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Design optimization of heat exchangers in topside systems for offshore oil and gas processing

Mayukh Bandopadhyay

Natural Gas Technology

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Supervisor:	Jostein Pettersen, EPT
Co-supervisor:	Henrik Hem Orskaug, Aker Solutions Einar Landa, Aker Solutions

Norwegian University of Science and Technology
Department of Energy and Process Engineering

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MASTER THESIS

for

Student Mayukh Bandopadhyay

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Design optimization of heat exchangers in topside systems for offshore oil and gas processing

Optimalisering av varmevekslere i system for offshore prosessering av olje og gass

Background and objective

Mechanical equipment units are integral parts of any process plant. On a typical oil and gas platform, heat exchangers, scrubbers, separators, rotating equipment etc. are critical for the proper operation of the process systems. These equipment units are needed for maintaining the correct process parameters of the fluids be it crude oil, natural gas or any other process stream.

Process systems consists of individual equipment units which are mapped together along with all relevant process and operational parameters like inlet and outlet temperatures and pressure of the fluids, flow rates, composition and liquid/vapour content. Changing the process parameters of any single unit will have an impact on other process and operation parameters, as well as on utility systems (power, heating, cooling). Too much change of process design may lead to off-spec products and avoiding this is a key constraint. For a typical oil and gas platform, heat exchangers and other mechanical equipment units are generally designed based on process datasheets provided by process designers to the equipment engineers. This sometimes leads to a very non ideal or non-economical design of heat exchangers (mainly) with respect to the inlet and outlet temperatures and the heat duty.

The main focus of this Master's thesis is to manipulate the process parameters of the process and the heat exchangers to achieve a more favourable equipment design and then evaluate the impact on other equipment units and on the process streams and products to check for off-spec conditions. Basis for the work in terms of typical process flow diagram with heat and material balances, as well as relevant heat exchanger designs, will be provided by Aker Solutions.

The main objective of the thesis will be to explore the possibilities for more favourable heat exchanger designs within the given constraints for the process.

The following tasks are to be considered:

1. Study relevant literature that describes production processes for oil & gas processing with emphasis on the mechanical equipment units especially considering heat exchangers.
2. Develop a model of the main production (separation and compression) process in HYSYS. The model should contain the necessary mechanical equipment units with relevant process parameters.
3. An analysis of the model by manipulating process parameters of the heat exchanger units and studying the impact on this change on the other mechanical equipment units and process parameters. The analysis needs to consider constraints like off-spec products caused by changes in process parameters of the heat exchangers. Changes in utilities also need to be considered.
4. Based on the process parameters of the heat exchanger units, thermal design calculations shall be conducted for relevant heat exchangers, using design software (HTRI/HTFS).
5. Develop generic understanding of how the process design and the thermal calculations for the heat exchangers influence the selection of type and the mechanical design of the heat exchangers. Mechanical design of exchanger units will be decided based on time available during the thesis period.
6. Conclusions, with recommendations for further work.

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Within 14 days of receiving the written text on the master thesis, the candidate shall submit a research plan for his project to the department.

When the thesis is evaluated, emphasis is put on processing of the results, and that they are presented in tabular and/or graphic form in a clear manner, and that they are analyzed carefully.

The thesis should be formulated as a research report with summary both in English and Norwegian, conclusion, literature references, table of contents etc. During the preparation of the text, the candidate should make an effort to produce a well-structured and easily readable report. In order to ease the evaluation of the thesis, it is important that the cross-references are correct. In the making of the report, strong emphasis should be placed on both a thorough discussion of the results and an orderly presentation.

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☐ Work to be done in lab (Water power lab, Fluids engineering lab, Thermal engineering lab)
☐ Field work

Department of Energy and Process Engineering, 14 January 2014

Olav Boll

Olav Bolland
Department Head

Jostein Petter

Jostein Pettersen
Academic Supervisor

Research Advisors/Industry contacts:

Henrik Hem Orskaug, Department Head – Mechanical, Aker Solutions
Einar Landa, Aker Solutions

Abstract

On a typical oil and gas platform, mechanical equipment units are integral parts of the topside processing system. Heat exchangers, separators, scrubbers, compressors and other equipment units are critical for the proper operation of the processing plant. The hydrocarbon stream received at the first production separator is a mixed stream comprising oil, water and gas phase. This mixed stream is processed in order to separate the oil dominated, water dominated and gas phase.

The processing systems for hydrocarbon separation consists of individual equipment units which are mapped together to form a network along with all the necessary process and operational parameters like inlet and outlet pressure and temperature, flow rates, compositional data and vapour fraction details. Modifying the process parameters on an individual equipment unit, impacts the process and operational parameters of subsequent downstream equipment units. Changing heat exchanger parameters has visible impacts on the operation of downstream equipments and also on the product specifications. Insufficient cooling of the gas stream reduces compressor efficiency, insufficient heating results in lesser quantities of gas bubbling out in the 3 phase separators and also insufficient cooling causes lesser condensate extraction from scrubber units, upstream of the compressor units.

For the varied heating and cooling applications on an oil and gas topside system, shell and tube exchangers, plate frame heat exchangers and printed circuit heat exchangers are the common configurations used in the industry. Shell and tube exchangers have a robust design and can handle most kinds of process fluids across a large pressure and temperature range. Plate frame exchangers are the preferred choice for topside applications compared to shell and tube exchangers considering the cost benefit owing to weight the footprint savings. However, the operating pressure and temperature are a limiting factor for plate frame exchanger applications. Process fluids only within the range of 35 barg and 200^{o}C can be processed in this type of exchanger. Printed circuit heat exchangers are specially designed compact heat exchangers that have a very high heat transfer effective surface area which allows this type of exchanger to handle large heating duty demands. The compact design of printed circuit exchangers gives them a low weight and footprint factor.

While doing thermal design calculations for shell and tube heat exchangers, factors like L/D ratio, RhoV2 factor, vibration factor, shell side and tube side fluid velocity, effective surface area per shell, allowable and actual pressure drop values, heat duty and LMTD need to be analyzed in order to achieve an optimum design of the heat exchanger.

Keywords: hydrocarbon separation, process parameters, heat exchangers, shell & tube, plate frame, printed circuit heat exchangers, thermal design,

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I would also like to appreciate the support I received from Odd Nesje and Thomas Kompalla at the Process Department in Aker Solutions regarding the development of the HYSYS simulation model for this thesis work.

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Nomenclature

bara	bar absolute
^{o}C	Celcius
TEG	Tri – Ethylene Glycol
BS&W	Basic Sediments and Water
GOR	Gas Oil Ratio
IOR	Increased Oil Recovery
LP	Low Pressure
HP	High Pressure
TVP	True Vapour Pressure
HC	Hydrocarbon
STHE	Shell & Tube Heat Exchanger
CHE	Compact Heat Exchanger
PFHE	Plate & Frame Heat Exchanger
PCHE	Printed Circuit Heat Exchanger
LMTD	Logarithmic Mean Temperature Difference
Sm3/d	Standard cubic meter per day
Sm3/hr	Standard cubic meter per hour
kg/s	Kilograms per second
D	Shell Inner Diameter
L	Tube Length
L/D	Ratio of Tube length to Shell Inner Diameter
TEMA	Tubular Exchanger Manufacturers Association
EDR	Exchanger Design and Rating software
RhoV2	Fluid density (Rho) multiplied by square of Velocity (V^2)

1.0 Introduction

1.1 Background and Objectives

In the offshore oil and gas industry, mechanical equipment units are integral components of all process plants on topside systems. On a typical oil and gas platform, heat exchangers, separators, compressors, pumps, scrubbers etc. are critical components for the proper operation of any hydrocarbon separation process plant. These equipment units are necessary for maintaining the correct process parameters of the different fluid streams flowing through the process system be it crude oil, natural gas, water or any other process stream.

Hydrocarbon separation process systems consist of individual equipment units that are mapped together to form a network alongwith all relevant process and operational parameters like inlet and outlet temperatures of the process streams, inlet pressures of the process streams, pressure drop across the equipments, flow rates, composition and liquid/vapour content of all the process streams. Modifying the process parameters of any particular equipment unit will have any impact on other process and operational parameters downstream of that equipment as well as on the utility systems (power, cooling medium system and heating medium system). Changing the process design by too large an extent can lead to the production of off-spec product. Avoiding the situation wherein we produce off-spec product at the outlet is a major constraint.

For a typical oil and gas platform, heat exchangers, separators and other mechanical equipment units are generally designed based on the process datasheets. These process datasheets are provided by the process designers to the equipment engineers who design these equipment units for the specified process and operatability range. The required process and operation range sometimes leads to a very non-ideal and non-economical design of heat exchangers mainly with respect to inlet and outlet temperatures, heat duty, weight and footprint factor. Eventually non-optimum design leads to increased cost factors.

The main objective of this thesis work is to explore the possibilities for more favourable design of heat exchangers within the specified constraints on the process parameters.

1.2 Scope of Work

The main focus of this Master's thesis is to manipulate the process parameters of the process and the heat exchangers and then evaluate the impact in order to achieve a more favourable equipment design. Basis for the work in terms of typical process flow diagram with heat and material balances, as well as relevant heat exchanger specifications was provided by Aker Solutions. The following tasks were considered as part of this thesis work:

1. Relevant background information on production processes for oil and gas processing was studied with emphasis on the mechanical equipments especially heat exchangers.
2. Develop a model of the main production process (separation and compression) in HYSYS. The model will contain all the necessary mechanical equipment units with relevant process parameters.

3. An analysis of the model by manipulating the process parameters of the heat exchanger units and then studying the impact of this change on other mechanical equipment units and process parameters. The analysis needs to consider the constraints like off-spec products caused by changes in the process parameters of the heat exchangers.
4. Based on the process parameters of the heat exchanger units, thermal design calculations shall be conducted for the relevant heat exchanger using the design software – Aspen Exchanger Design and Rating (ASPEN – EDR). The thermal design calculations of the relevant heat exchangers with the modified process parameters shall also be conducted using Aspen – EDR.
5. Develop a generic understanding of how the process design and the thermal calculations for the heat exchangers influence the selection of the type and the mechanical design of the heat exchangers.
6. Conclusions, with recommendations for further work.

1.3 Structure of Report

This report begins with an introduction to hydrocarbon separation providing information about the separation process of a mixed stream containing the oil, water and gas phase. This chapter also provides an overview of the major equipments that are part of the process design of a topside hydrocarbon separation system in the offshore oil and gas industry with a special emphasis on the heat exchangers that are part of the processing system.

Chapter 3 contains the Process Flow Diagram alongwith a detailed description of each of sections in the process design – Inlet Arrangement train; Oil Separation, Stabilization and Export train; Gas Recompression train; Gas Dehydration train and the Gas Compression and Injection train. This chapter also contains a detailed list of all the major equipments in the hydrocarbon separation process design which includes the equipment tag numbers, equipment title and the type of equipment. The oil and gas product specifications are also provided in this chapter.

Chapter 4 provides the basis for the analysis that is conducted as part of this thesis work. The wellstream composition that is used in the Hysys simulation model is given in this chapter. The details of the heating medium and cooling medium systems which are critical the heat exchangers in the process design are also included in this chapter.

In Chapter 5, the development of the Hysys simulation model is explained in detail providing information about the design basis, pseudo components, binary interaction parameters and the standard specifications for all major equipments. In this chapter, the development of the Hysys model of each process train (inlet arrangement, oil separation, gas recompression, gas dehydration and gas compression and injection) is discussed in detail.

Chapter 6 covers the simulation results of the base case design giving details of the oil and gas product specifications. The 3 case studies that are conducted as part of this thesis work are explained in detail in this chapter also.

Chapter 7 contains the thermal design calculations of the relevant exchangers in the base case scenario followed by the thermal calculations of the exchangers that are redesigned owing to changes in the process parameters. In this chapter, as part of the thermal design, the TEMA specification sheet of exchanger alongwith the setting plan and tube layout is provided. The remaining details of the thermal design are given in the Appendix section of this report.

2.0 Background on Hydrocarbon Separation and Equipments used

2.1 Fundamentals of Hydrocarbon Separation

The hydrocarbon stream received at the inlet manifold of most topside oil and gas processing systems comprise oil, gas, water and contaminants that need to be separated and processed (Devold 2006). The hydrocarbon stream received at the first production separator is given a certain retention time for the gas phase to bubble out, the heavier aqueous phase to settle at the bottom of the equipment unit and for the oil dominated phase to stabilize in the middle between the aqueous and gas phase. Certain amount of carry-over occurs during the separation process wherein traces of the other phases are mixed in main oil, water and gas phase.

The oil stream is heated and sent downstream to the subsequent separator units for further separation and stabilization. The heating of this stream is done in order to vapourize the lighter hydrocarbon which are then extracted in the subsequent separators and routed to the gas processing train. The heating up is also done to achieve the required vapour pressure specifications of the product stream at the outlet of the final separator. The oil stream is also routed through filter units and electrostatic coalescers in order to remove the solid and liquid contaminants and to meet the necessary specifications. The final oil product stream after pressurization and cooling to ‘export oil specifications’ can either be loaded onto tankers or transported through subsea pipelines to terminals or refinery sites onshore.

The main objective of processing the gas stream on a topside system is to make the fluid meet the export or injection specifications. The typical gas processing includes modifying the hydrocarbon dew point, removal of acid gas, dehydration and finally export compression. The only way to modify the hydrocarbon dewpoint of the gas is to either add or remove the heavier hydrocarbon components from the mixture. In the ‘Compression-Cooling-Separation’ technique, the compressed gas is cooled and the heavier components which have condensed are extracted in scrubber units while the gas stream is routed downstream for further compression. This is repeated till the required dewpoint specification is achieved. The dehydration process is done to meet the water dewpoint specification to ensure that no water condenses out during transportation. Typically a glycol solution like Tri-Ethylene Glycol is used to absorb the water content and then the TEG solution is regenerated to obtain the original purity. The content of acid gas (CO_2 and H_2S) needs to be reduced to the acceptable level since these gases have no heating value and can also be dangerous for the end consumer. An amine based solution in a contactor unit is generally used to control the acid gas content.

The water separated at the first production separator, is routed to the produced water system and depending on the stringency on the produced water specifications, the water is either processed to meet the specifications or else the return flow is routed back to the sea.

2.2 Mechanical equipments required in hydrocarbon separation

A typical offshore oil and gas separation and processing system comprises 3-phase separators, heat exchangers, scrubbers, pumps, compressors, turbines, storage tanks, flare units and a variety of other mechanical equipment units. The quantum of equipment units depend upon the extent of processing that the oil and gas streams need to be subjected to.

The hydrocarbon streams are generally received at the production separators for the initial processing. These three phase separators are typically gravity type wherein the separation process is based on the density of each phase (Devold 2006). The main objective is to achieve maximum liquid recovery alongwith stabilized oil and gas and to separate out the water. Such separator units have a typical retention time of 5 minutes during which the gas phase bubbles out of the hydrocarbon stream, the aqueous phase being heaviest settles at the bottom and oil phase is extracted from the middle section. Certain internals are fitted inside the separator unit which are typically proprietary design and are fitted to ensure maximum phase separation. A large pressure drop across one separator unit is avoided in order to ensure that flash vaporization does not occur.

Downstream of the separator, the oil and gas streams are generally heated or cooled in heat exchangers depending on the process design of the topside system. These heat exchangers can be shell and tube type, plate type or printed circuit type with the first 2 types being most common. In shell and tube exchangers, the process fluid and the heating/cooling medium passes through tubes or around the tubes inside a cylindrical shell. While in plate and frame exchangers, the process fluid and heating/cooling medium flows in opposite directions between alternating plates. The heat exchangers heat or cool down the process fluid either by direct or by indirect heat transfer. In indirect heat transfer the process fluid is heated or cooled against a heating or cooling medium which in turn is heated or cooled in subsequent heat exchangers against hot flue gas or sea water respectively. In direct heat transfer, the process fluid is directly heated or cooled against hot flue gas or sea water respectively. Indirect cooling is preferred in low temperature ambient conditions in order to prevent freeze out.

The cooled down gas may contain traces of mist and other liquid particles. Before being routed to the compressor unit, the condensed liquid needs to be extracted in order to avoid erosion of the rotary compressor blades. The separation of the liquid and gas phases from the 2-phase process fluid is done in a scrubber unit. The scrubber unit has specially designed trays installed inside the equipment which increases the surface contact of the process fluid with the trays. Large number of gas traps cause the gas to bubble up through the liquid and flow to the top of the vessel while the heavier liquid droplets coalesce and flow downwards. This equipment helps in extracting the heavier hydrocarbons in liquid phase while the gas phase routed downstream comprises lighter hydrocarbons.

The reservoir stream received at the inlet separator has a pressure level depending on the downhole pressure of the reservoir. As the oil dominated phase flows downstream, pressure loss occurs across every equipment unit as well as in the pipelines. After some point in the process flow, the pressure needs to be boosted for the oil stream to continue flowing through the process train. Centrifugal and screw pumps are used for boosting the pressure of the oil stream upto the required levels so that the hydrocarbon stream can either flow through the remaining process train or the stabilized oil stream can be transported through pipeline to shore.

The gas stream after undergoing multiple processing stages for CO_2 and H_2S removal, dehydration, meeting cricondenbar specifications can either be transported to shore through pipeline or be re-injected into the reservoir for maintaining downhole pressure. In both these cases the gas needs to be pressurized upto a certain point which is done using turbine or motor driven compressors. Depending on the flowrate of either export gas or injection gas and the required pressure levels, reciprocating compressors, screw compressor or centrifugal compressors can be chosen for the necessary application.

2.3 Fundamentals of Heat Exchanger Selection

For handling the variety of process fluids, shell and tube heat exchangers, plate frame heat exchangers and printed circuit heat exchangers are the common configurations that find application on a typical oil and gas processing topside system.

Shell and tube exchangers are the most commonly used configuration in the process industry. These exchangers have a highly robust design and can handle most kinds of process fluids. Also shell and tube exchangers can operate in the wide pressure and temperature range (Ludwig 1997). However, for meeting the required heat duty demand, the designed exchanger can sometimes have extreme dimensions resulting in high weight and footprint values which are not preferable for offshore process plants. These exchangers are designed according to the TEMA specifications.

Considering the limitation of weight and footprint on topside systems, plate frame exchangers are definitely the preferred choice provided the operating pressure and temperature range permits. Plate frame exchangers can be designed for pressure ranges upto 35 barg and the temperature limit for these exchangers is 200^{o}C. Even though plate and frame exchangers are more expensive than the conventional shell and tube exchangers, the cost benefit from weight and footprint savings is quite substantial and therefore makes these exchangers the preferred choice.

Printed circuit heat exchangers (PCHE’s) are specialized heat exchangers which are chosen when plate frame exchangers are not a feasible option owing to the pressure and temperature constraint and the design of the shell and tube exchangers is non-optimum. These exchangers have a specialized circuit design wherein the effective surface area is very high which accounts for very high heat transfer with a compact equipment design. Even though the cost benefit from weight and footprint saving is substantially high if a shell and tube exchanger is replaced with a printed circuits exchanger, these exchangers are very expensive owing to proprietary design. Each compact unit can handle a high heat transfer between the hot and cold side streams.

3.0 Process Description and Equipment Details

3.1 Process Description

This chapter describes in detail the process design for the hydrocarbon separation. The total process design description is split into sub-sections each explaining one process train.

3.1.1 Inlet Arrangement

The feed flow from Field 1 is received from four flow lines and mixed in the Field 1 manifold before being routed downstream through the Field 1 Inlet Heater (20-HA-002).

The feed flow from Field 2 is received from two flow lines and mixed in the Field 2 manifold before being routed downstream through the Field 2 Inlet Heater (20-HA-001).

3.1.2 Oil Stabilization and Export

The well fluid from the multiple reservoirs received at the Field 1 and Field 2 manifolds is heated in dedicated heaters upstream of the Inlet Separator (20-VA-001). The hydrocarbon from Field 1 and Field 2 is heated in the Field 1 Inlet Heater (20-HA-002) and Field 2 Inlet Heater (20-HA-001) respectively. The fluid from the individual fields are not mixed before heating because the temperature of one wellstream may be lower than the other which may result in lowering the wax appearance temperature of the mixed fluid. Both the inlet heaters heat the hydrocarbon streams to achieve an outlet temperature of 55^{o}C. This outlet temperature is decided based on the wax disappearance temperatures for the hydrocarbon stream.

The data received from Aker Solutions mentions that the presence of wax is observed in the range of 3.7% – 7.9%. The wax appearance temperature is estimated within the range of 25^{o}C and 38^{o}C while wax disappearance temperature is estimated within the range of 48.5^{o}C and 54.7^{o}C. The hydrocarbon stream also flows through 6 to 8 kms of flowlines in a cold water environment of 4^{o}C – 8^{o}C at sea bottom. The low ambient temperature tends to lower the wellstream temperature thereby bringing it closer to the wax appearance temperature. This emphasizes the need for the inlet heaters. The required heating of the well fluid would ensure that the dissolved wax does not hamper the hydrocarbon separation process.

The well fluid is therefore heated to 55^{o}C to avoid any precipitation of wax in the Inlet Separator. The Inlet Separator is a 3-phase separator which is operated at a pressure of 15 bara and a temperature range of 45^{o}C to 55^{o}C. It is specified to have a heavy liquid in light liquid of 5 vol-%. In the HYSYS model, the separator is designed to have a carry-over setup on the product basis of 5 vol% water in oil to meet the required specification. From the inlet separator, the oil is routed downstream for stabilization, the water is directed to the produced water system and the gas is routed to the dehydration and injection compression train.

Downstream of the inlet separator, the oil is directed to the 2nd Stage Separator (20-VA-002) passing through 2 heaters – Stabilization Separator Cross Heat Exchanger (20-HB-004) and Stabilization Separator Heater (20-HA-003).

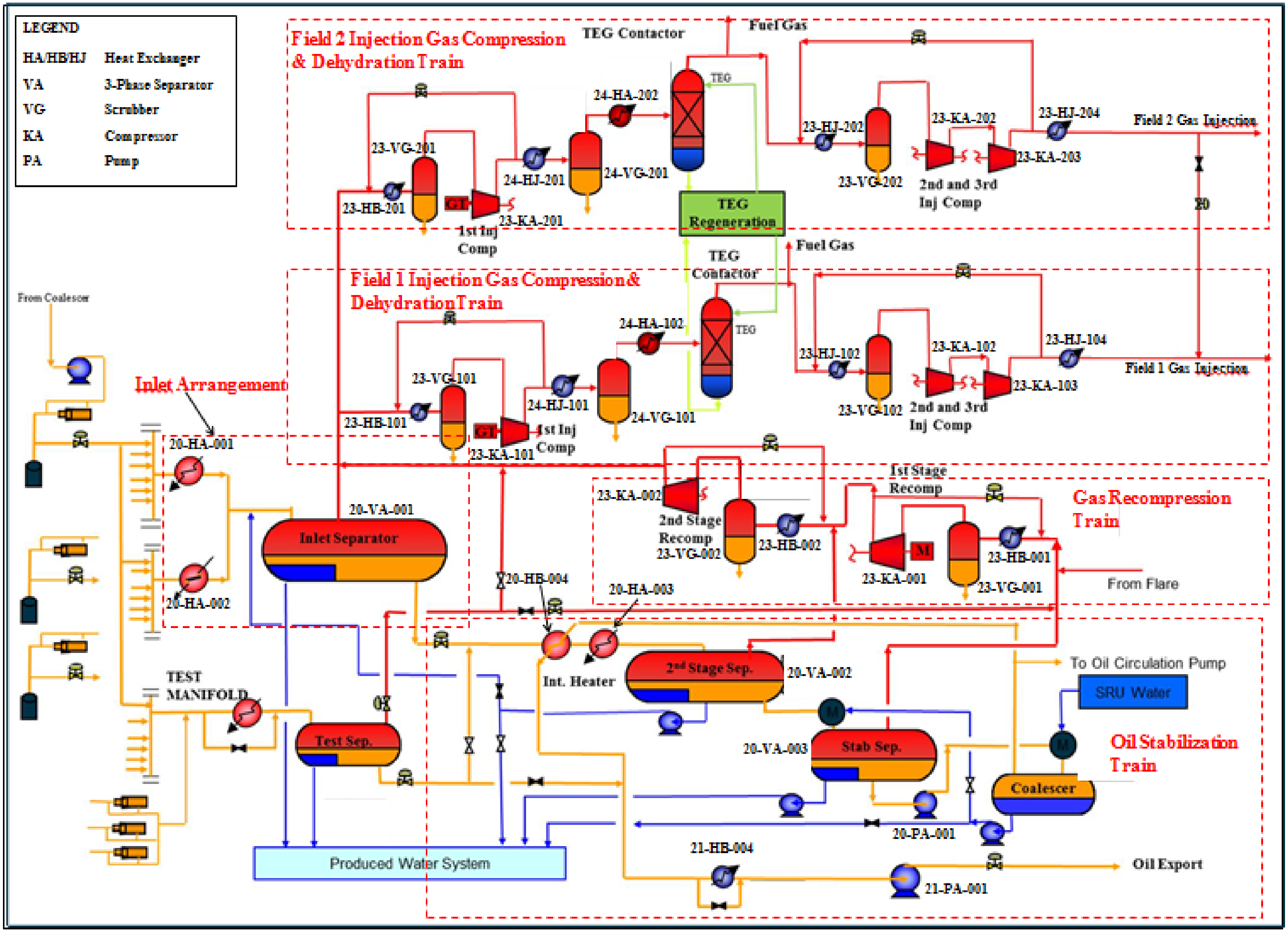


Figure 3.1 : Process Flow Diagram

In the Cross Exchanger, the heat from the stabilized oil is integrated into the stabilization process by heating the oil from the inlet separator against the high temperature stabilized oil. Downstream the cross exchanger, the outlet temperature of the oil from the Stabilization Heater is adjusted to obtain the vapour pressure of the final oil product. Out of the Stabilization Heater, the oil is routed to the 2nd Stage Separator, a 3-phase separator which is operated at an intermediate pressure of 7 bara and at a temperature between 75°C and 80°C to obtain the required vapour pressure. This separator is specified to have a heavy liquid in light liquid of 5 vol-%. Also for this separator, In the HYSYS model, the separator is designed to have a carry-over setup on the product basis of 5 vol% water in oil to meet the required specification. From this separator, the water is again routed to the produced water system while the gas directed towards the recompression train.

Downstream of the 2nd Stage Separator, the pressure of the hydrocarbon is reduced and directed to the Stabilization Separator (20-VA-003). This separator is also a 3-phase separator which is operated at a low pressure of 2 bara. The pressure of this separator is kept as low as possible whilst still maintaining sufficient pressure to route the gas to the inlet of the recompression train. The temperature of this separator is determined by the temperature of liquid hydrocarbon exiting the 2nd stage separator. This separator is specified to have a heavy liquid in light liquid of 2 vol-%. In the HYSYS model, the separator is designed to have a carry-over setup on the product basis of 2 vol% water in oil to meet the required specification. The required vapour pressure specification of the final oil product is reached in the Stabilization Separator. The water from the stabilization separator is also routed to the produced water system. The gas from this separator enters the first compression stage of the recompression train.

The high temperature stabilized oil is pumped from the outlet of the stabilization separator to an Electrostatic Coalescer where the final water removal is done to meet the oil product specifications. This equipment though a part of the process flow diagram, is not included in the simulation model since it does not affect the process parameters for the heat exchangers or the total heat and mass transfer of the entire system. Downstream of the coalescer, the stabilized oil is routed through the cross exchanger for heating the oil stream from the inlet separator. After the cross exchanger, the stabilized oil stream enters the Crude Oil Cooler (21-HB-001) where it is cooled to a temperature in the range of 55°C to 60°C. Downstream of the crude oil cooler, the final oil product is pumped by the Export Oil Pumps (21-PA-001A/B/C) to the export pressure of 187 bara. The outlet temperature of the Crude Oil Cooler is adjusted so as to achieve an Export Oil temperature of 60°C.

3.1.3 Gas Recompression

The gas that is extracted from the stabilization system (2nd Stage Separator and Stabilization Separator) is routed to the gas recompression train for recompression to 15 bara through 2 stages before it is merged with the gas from the Inlet Separator.

The gas from the Stabilization Separator enters the recompression train at the pressure and temperature of that separator. It is cooled in the 1st Stage Recompression Suction Cooler (23-HB-001) to 28°C before being scrubbed in the 1st Stage Recompression Suction Scrubber (23-VG-001). The gas is routed to the 1st Stage Recompressor (23-KA-001) where it is compressed to an intermediate pressure of 6 bara. The compressed gas is mixed with the gas extracted from the 2nd Stage Separator and then routed to the 2nd Stage Recompression Suction Cooler (23-HB-002). The mixed gas is cooled down to 28°C before being scrubbed in the 2nd Stage Recompression Scrubber (23-VG-002). The gas from the scrubber is sent downstream to the 2nd Stage Recompressor (23-KA-002) where it is compressed to 15 bara and then mixed with the gas from the inlet separator.

The liquid from the 1st and 2nd Stage Recompression Scrubbers are routed to the Stabilization Separator to integrate the extracted heavy hydrocarbons back into the process.

3.1.4 Gas Dehydration

The gas from Field 1 & 2 is dehydrated using Tri-Ethylene Glycol (TEG) by the Absorption process. Field 1 and Field 2 gas compression trains have individual dehydration towers (TEG contactors) but a common TEG Regeneration unit. The dehydration section of both trains is located in between the 1st and 2nd gas compression stages.

The compressed gas from the Field 1 1st Stage Injection Compressor (23-KA-101) is cooled to 25°C in the Field 1 Dehydration Inlet Cooler (24-HJ-101). Any condensed liquid is removed in the Field 1 Dehydration Scrubber (24-VG-101) downstream of the cooler. The gas extracted from the scrubber is superheated by 3°C in the Field 1 Dehydrator Inlet Superheater (24-HA-102) before routing it to the Field 1 TEG Contactor.

The compressed gas from the Field 2 1st Stage Injection Compressor (23-KA-201) is cooled to 25°C in the Field 2 Dehydration Inlet Cooler (24-HJ-201). Any condensed liquid is removed in the Field 2 Dehydration Scrubber (24-VG-201) downstream of the cooler. The gas extracted from the scrubber is superheated by 3°C in the Field 2 Dehydrator Inlet Superheater (24-HA-202) before routing it to the Field 2 TEG Contactor.

The superheating is done to avoid the gas being at dew point condition at the inlet of the contactor which could result in some condensation of hydrocarbon inside the contactor. The contactor is operated in the temperature range of approximately 30°C – 33°C since the efficiency of the absorption process is quite high at that temperature range.

Liquid extracted from the scrubbers in the dehydration section of both the trains is routed to the inlet separator.

3.1.5 Gas Compression for Injection

The gas extracted from the well fluid in the Inlet Separator alongwith the gas extracted from the oil stabilization train is compressed in two compression trains before being injected back into the field reservoir. Gas compression for both the fields consists of three compression stages with suction cooling, scrubbing and after-cooling in each train. The 2nd and 3rd stage injection compressors are configured into a back-to-back arrangement on a single shaft assembly in the same casing.

The gas from the Inlet Separator entering the Field 1 compression train is cooled to 28°C in the Field 1 1st Stage Injection Suction Cooler (23-HB-101). The condensed liquid is removed in the 1st Stage Injection Scrubber (23-VG-101) and the gas is sent downstream to the Field 1 1st Stage Injection Compressor (23-KA-101) to be compressed to 50.3 bara. The gas is then routed to the dehydration section for water removal depending on the product specifications for the injection gas. Downstream of the dehydration section, the gas exiting the TEG contactor is cooled in the Field 1 2nd Stage Gas Injection Suction Cooler (23-HJ-102) to 25°C. The condensed liquids are extracted in the Field 1 2nd Stage Injection Scrubber (23-VG-102) and the gas is routed to the Field 1 2nd Stage Injection Compressor (23-KA-102). The discharge pressure of 23-KA-102 is set to 83 bara and the gas is then routed to the Field 1 3rd Stage Injection Compressor (23-KA-103) where it is compressed to the gas injection pressure of 161 bara. Downstream the 3rd stage compressor, the gas is cooled in the Field 1 3rd Stage Gas Injection After Cooler (23-HJ-104) to the gas injection temperature of 60°C.

The gas from the Inlet Separator entering the Field 2 compression train is cooled to 28°C in the Field 2 1st Stage Injection Suction Cooler (23-HB-201). The condensed liquid is removed in the 1st Stage Injection Scrubber (23-VG-201) and the gas is sent downstream to the Field 2 1st Stage Injection Compressor (23-KA-201) to be compressed to 52.3 bara. The gas is then routed to the dehydration section for water removal depending on the product specifications for the injection gas. Downstream of the dehydration section, the gas exiting the TEG contactor is cooled in the Field 2 2nd Stage Gas Injection Suction Cooler (23-HJ-202) to 25°C. The condensed liquids are extracted in the Field 2 2nd Stage Injection Scrubber (23-VG-202) and the gas is routed to the Field 2 2nd Stage Injection Compressor (23-KA-202). The discharge pressure of 23-KA-202 is set to 94 bara and the gas is then routed to the Field 2 3rd Stage Injection Compressor (23-KA-203) where it is compressed to the gas injection pressure of 207 bara. Downstream the 3rd stage compressor, the gas is cooled in the Field 2 3rd Stage Gas Injection After Cooler (23-HJ-204) to the gas injection temperature of 60°C.

3.2 Details of Major Equipments

This section gives a detailed list of all major equipments in the process design including tag numbers, equipment names and type of each equipment. The process flow diagram given in the previous section is divided into 4 main trains depending on the process occurring in each train. The equipment tag numbers are listed based on the type of equipments in each process train.

3.2.1 Inlet Arrangement and Oil Stabilization Train

Equipment details for the inlet arrangement and oil stabilization and separation train is given in Table 3.1.

Table 3.1 : Equipment Details – Inlet Arrangement and Oil Stabilization Train

Sl. No.	Tag Number	Equipment Name	Equipment Type
1	20-HA-001	Field 2 Inlet Heater	Shell & Tube Exchanger
2	20-HA-002	Field 1 Inlet Heater	Shell & Tube Exchanger
3	20-HA-003	Stabilization Separator Heater	Shell & Tube Exchanger
4	20-HB-004	Stabilization Separator Cross Heat Exchanger	Shell & Tube Exchanger
5	21-HB-001	Crude Oil Cooler	Shell & Tube Exchanger
6	20-PA-001	Oil Booster Pump	Screw Pump
7	21-PA-001	Oil Export Pump	Screw Pump
8	20-VA-001	Inlet Separator	3-Phase Separator
9	20-VA-002	2nd Stage Separator	3-Phase Separator
10	20-VA-003	Stabilization Separator	3-Phase Separator

3.2.2 Gas Recompression Train

Equipment details for the gas recompression train is given in Table 3.2.

Table 3.2 : Equipment Details – Gas Recompression Train

Sl. No.	Tag Number	Equipment Name	Equipment Type
1	23-HB-001	1st Stage Recompressor Inlet Cooler	Shell & Tube Exchanger
2	23-HB-002	2nd Stage Recompressor Inlet Cooler	Shell & Tube Exchanger
3	23-KA-001	1st Stage Recompressor	Centrifugal Compressor
4	23-KA-002	2nd Stage Recompressor	Centrifugal Compressor
5	23-VG-001	1st Stage Recompressor Scrubber	Scrubber
6	23-VG-002	2nd Stage Recompressor Scrubber	Scrubber

3.2.3 Field 1 Gas Compression and Dehydration Train

Equipment details for the Field 1 Gas Compression and Dehydration train is given in Table 3.3.

Table 3.3 : Equipment Details – Field 1 Gas Compression and Dehydration Train

Sl. No.	Tag Number	Equipment Name	Equipment Type
1	23-HB-101	Field 1 1st Stage Injection Suction Cooler	Compact Heat Exchanger
2	24-HJ-101	Field 1 Dehydration Inlet Cooler	Compact Heat Exchanger
3	24-HA-102	Field 1 Dehydrator Inlet Superheater	Shell & Tube Exchanger
4	24-HJ-102	Field 1 2nd Stage Gas Injection Suction Cooler	Compact Heat Exchanger
5	23-HJ-104	Field 1 3rd Stage Gas Injection After Cooler	Compact Heat Exchanger
6	23-KA-101	Field 1 1st Stage Injection Compressor	Centrifugal Compressor
7	23-KA-102	Field 1 2nd Stage Injection Compressor	Centrifugal Compressor
8	23-KA-103	Field 1 3rd Stage Injection Compressor	Centrifugal Compressor
9	23-VG-101	Field 1 1st Stage Injection Scrubber	Scrubber
10	24-VG-101	Field 1 Dehydration Scrubber	Scrubber
11	23-VG-102	Field 1 2nd Stage Injection Scrubber	Scrubber

3.2.4 Field 2 Gas Compression and Dehydration Train

Equipment details for the Field 2 Gas Compression and Dehydration train is given in Table 3.4.

Table 3.4 : Equipment Details – Field 2 Gas Compression and Dehydration Train

Sl. No.	Tag Number	Equipment Name	Equipment Type
1	23-HB-201	Field 2 1st Stage Injection Suction Cooler	Compact Heat Exchanger
2	24-HJ-201	Field 2 Dehydration Inlet Cooler	Compact Heat Exchanger
3	24-HA-202	Field 2 Dehydrator Inlet Superheater	Shell & Tube Exchanger
4	24-HJ-202	Field 2 2nd Stage Gas Injection Suction Cooler	Compact Heat Exchanger
5	23-HJ-204	Field 2 3rd Stage Gas Injection After Cooler	Compact Heat Exchanger
6	23-KA-201	Field 2 1st Stage Injection Compressor	Centrifugal Compressor
7	23-KA-202	Field 2 2nd Stage Injection Compressor	Centrifugal Compressor
8	23-KA-203	Field 2 3rd Stage Injection Compressor	Centrifugal Compressor
9	23-VG-201	Field 2 1st Stage Injection Scrubber	Scrubber
10	24-VG-201	Field 2 Dehydration Scrubber	Scrubber
11	23-VG-202	Field 2 2nd Stage Injection Scrubber	Scrubber

3.3 Product Specifications

The product specifications for both the oil product and the gas product are listed in this section.

3.3.1 Oil Product Specifications

Oil product specifications are given in Table 3.5.

Table 3.5 : Oil Product Specifications

Specification	Unit	
Field 1 Oil Production	Sm^3/d	15000
Field 2 Oil Production	Sm^3/d	17000
Export Oil Pressure	bara	187.5
Export Oil Temperature	^oC	60.0
True Vapour Pressure (TVP) @ 30 ^oC	Bara	0.965
Basic Sediment and Water (BS&W)	%	< 0.5

3.3.2 Gas Product Specifications

Gas product specifications are given in Table 3.6.

Table 3.6 : Gas Product Specifications

Specification	Unit	
Field 1 Injection Gas Production	kg/hr	956500
Field 1 Gas Injection Pressure	bara	160
Field 1 Gas Injection Temperature	^oC	60
Field 2 Injection Gas Production	kg/hr	1084000
Field 2 Gas Injection Pressure	bara	206
Field 2 Gas Injection Temperature	^oC	60

Since the gas is only meant for re-injection into the Field 1 and Field 2 reservoirs, there is no cricondenbar specification for the gas product.

4.0 Basis for Analysis

This chapter gives details of the wellstream composition that has been used as the basis for developing the Hysys simulation model. It also contains information on the heating medium and the cooling medium systems that is critical for the designing of the heat exchanger units on the topside system.

4.1 Well Stream Composition

This section gives the composition of the well fluid entering the inlet separator from both the fields. The well stream compositions received from Aker Solutions vide email dated 11-Feb-2014 is given in Table 4.1.

Table 4.1 : Wellstream composition for both Field 1 and Field 2 in mole fraction

Component	**FIELD 1**	**FIELD 2**
	Mole Fraction	Mole Fraction
H_20	**0.8633**	**0.8291**
Nitrogen	**0.0016**	**0.0019**
Carbon Dioxide (CO_2)	**0.0020**	**0.0027**
Methane	**0.1102**	**0.1380**
Ethane	**0.0091**	**0.0117**
Propane	**0.0046**	**0.0059**
i-Butane	**0.0007**	**0.0010**
n-Butane	**0.0013**	**0.0018**
i-Pentane	**0.0004**	**0.0005**
n-Pentane	**0.0004**	**0.0005**
n-Hexane	**0.0003**	**0.0004**
C7*	**0.0003**	**0.0005**
C8*	**0.0003**	**0.0007**
C9*	**0.0002**	**0.0005**
C10 – C20*	**0.0034**	**0.0032**
C21 – C28*	**0.0010**	**0.0009**
C29*+	**0.0009**	**0.0009**
Total Mole Fraction	**1.0000**	**1.0000**

4.2 Cooling Medium System

The cooling medium system is designed to provide cooling duty by supplying low temperature cooling medium to all the process coolers. The cooling medium used for the designed system is a mixture of 45% TEG and 55% Water with the intention of avoiding any freezing of the cooling medium at the minimum ambient temperature of -16^{o}C.

The cooling medium system is a closed loop system wherein the low temperature cooling medium is circulated to the process coolers at a temperature of 15^{o}C. The cooling medium is circulated by three Cooling Medium Circulation Pumps (40-PA-001 A/B/C). The pumps operate in a 2+1 configuration where 2 pumps are working pumps and 1 pump is a stand-by pump.

The warm cooling medium from all the process coolers returns at about 60^{o}C. This return flow is cooled down in two stages.

- In the first stage, part heat from the cooling medium is extracted in the Winterization Heaters. This heat is used for heating purposes on a typical oil and gas platform.
- In the second stage, the remaining heat is extracted in the Cooling Medium Coolers (40-HB-001 A/B/C/D) where sea water is used to cool down the cooling medium to the temperature of 15^{o}C to be recirculated to the process coolers.

The system also includes a Cooling medium Expansion Tank (40-VL-001) which allows for the changes in the volume of the cooling medium. This is required to account for the liquid expansion and contraction resulting for the changes in temperature of the cooling medium.

The Cooling Medium Circulation Pumps, Winterization Heaters and Cooling Medium Coolers are not mentioned in the equipment list since the cooling medium system is not included in the simulation model.

4.2.1 Mitigation of Hydrate Formation

Hydrates are ice like structures which are formed when free water exists and the wellstream condition are within the hydrate formation area (TEP 4185, 2012). Owing to drop in the wellstream temperature, water tends to condense out from the gas and this free water phase causes the hydrates to form.

In both the gas compression and dehydration trains, since we have wet gas in the process stream it is important to check that we are above the hydrate formation temperature at all the wet gas locations. In the Dehydration Inlet Coolers (24-HJ101 & 24-HJ-201) the hydrate formation temperature is noted to be close to 18^{o}C. For all the other exchangers in the compression and dehydration trains where wet gas is a process fluid, the hydrate formation temperature is lower than inlet temperature of the cooling medium (15^{o}C).

To ensure hydrate mitigation, the inlet temperature of the cooling medium to the dehydration coolers is set to 20^{o}C. This is achieved by blending the cooling medium inlet to the dehydrators with a certain proportion of the warm cooling medium from the return line. The mixing operation is controlled based on the feedback from the temperature indicators on the cooling medium inlet line upstream the dehydrators.

4.3 Heating Medium System

Similar to the cooling medium system, the heating medium system is designed to provide heating duty by supplying high temperature heating medium to all the process heaters. The heating medium used for the designed system is a mixture of 45% TEG and 55% Water with the intention of avoiding any freezing of the cooling medium at the minimum ambient temperature of -16^{o}C.

The heating medium system is a closed loop system wherein the high temperature heating medium is circulated to the process heaters at a temperature of 150^{o}C. The heating medium is circulated by three Heating Medium Circulation Pumps (41-PA-001 A/B/C). The pumps operate in a 2+1 configuration where 2 pumps are working pumps and 1 pump is a stand-by pump.

The cold heating medium from all the process coolers returns at about 100^{o}C. This return flow is heated up in two stages.

- In the first stage, the return flow is heated in the Waste Heat Recovery Units on the Power Generator Turbine Exhaust
- In the second stage, the remaining heating up process is done in the Waste Heat Recovery Units of the Field 1 and Field 2 Gas Injection Compressor Turbine Exhausts (41-HW-101 & 41-HW-201) where the temperature of the heating medium is increased to 150^{o}C before being recirculated to the process heaters.

The system also includes a Heating Medium Expansion Tank (41-VL-001) which allows for the changes in the volume of the heating medium. This is required to account for the liquid expansion and contraction resulting for the changes in temperature of the heating medium.

The Heating Medium Circulation Pump and Waste Heat recovery Units are not mentioned in the equipment list since the heating medium system is not included in the simulation model.

5.0 Development of HYSYS Simulation Model

The Hysys simulation model of the process is developed based on the process description given in Section 3.1. The simulation model also comprises four main sections – oil stabilization, gas compression, gas dehydration and finally injection gas compression. This chapter gives in detail the design basis and the development of the simulation model.

5.1 Design Basis for Hysys Simulation

The simulation model for the process is developed as a ‘steady state’ simulation model using Hysys version 8.3.

The fluid package used for the simulation model is the Soave – Redlich – Kwong (SRK) equation of state alongwith a ‘Costald’ density option.

5.2 Pseudo Components

Certain pseudo components are created based on the compositional data of the well fluid from both Field 1 and Field 2. The characterization of these pseudo components has been done using PVTsim and the properties of the pseudo components are given in Table 5.1.

Table 5.1 : Properties of Field 1 and Field 2 Pseudo components

Component Name	Normal Boiling Point (NBP)	Molecular Weight (MW)	Liquid Density	Critical Temperature (Tc)	Critical Pressure (Pc)	Ac Factor
	°C		Kg/m^3	°C	bar	
C7*	91,95	96,00	738,0	262,18	31,95	0,4679
C8*	116,75	107,00	765,0	271,27	31,39	0,4999
C9*	142,25	121,00	781,0	293,30	29,89	0,5399
C10 – C12*	187,12	146,49	802,8	330,78	26,64	0,6130
C13 – C15*	246,36	189,37	829,6	382,38	22,23	0,7272
C16 – C17*	291,23	229,15	848,0	422,16	19,37	0,8255
C18 – C20*	324,78	262,25	863,4	449,21	17,64	0,9035
C21 – C24*	367,86	309,70	881,9	483,73	15,83	1,0069
C25 – C28*	412,38	364,82	900,0	518,59	14,36	1,1124
C29 – C34*	456,91	433,20	918,7	556,98	13,11	1,2206
C35 – C43*	510,80	533,39	941,5	605,55	11,90	1,3267
C44 – C80*	606,40	738,25	977,9	691,06	10,79	1,2841

5.3 Binary Interaction Parameters

In the various equations of state (EOS), the Binary Interaction Parameter (BIP) is used to analyze the extent of non-ideality in a binary mixture (Jaubert and Privat 2010).

The BIP values of Nitrogen and CO_2 towards the pseudo components are not the standard Hysys values and are given in Table 5.2. All remaining BIP's used for the simulation are the standard Hysys values. For all HC – HC binary mixtures, the BIP values are assumed to be zero.

Table 5.2 : Binary Interaction Parameters between components of the wellstream fluid

	H_20	**Nitrogen**	**CO_2**	**H_2S**
H_20	–	-0,4907	0,0392	0,0829
Nitrogen	-0,4907	–	0,0171	0,1588
Carbon Dioxide (CO_2)	0,0392	-0,0171	–	0,115
H_2S	0,0829	0,1588	0,115	–
Methane	0,5	0,03119	0,0956	0,08879
Ethane	0,5	0,03119	0,1401	0,08619
Propane	0,4819	0,0886	0,1368	0,0925
i-Butane	0,518	0,1315	0,1368	0,056
n-Butane	0,518	0,0597	0,1412	0,0626
i-Pentane	0,5	0,093	0,1297	0,06499
n-Pentane	0,5	0,09359	0,1347	0,0709
n-Hexane	0,5109	0,165	0,142	0,057
C7*	0,5	0,08	0,1	0,045
C8*	0,5	0,08	0,1	0,045
C9*	0,5	0,08	0,1	0,045
C10 – C12*	0,5	0,08	0,1	0,045
C13 – C15*	0,5	0,08	0,1	0,045
C16 – C17*	0,5	0,08	0,1	0,045
C18 – C20*	0,5	0,08	0,1	0,045
C21 – C24*	0,5	0,08	0,1	0,045
C25 – C28*	0,5	0,08	0,1	0,045
C29 – C34*	0,5	0,08	0,1	0,045
C35 – C43*	0,5	0,08	0,1	0,045
C44 – C80*	0,5	0,08	0,1	0,045

5.4 Standard Equipment Specifications

Pressure drops across various equipments and efficiencies of pumps are compressors have a considerable impact on the process flow. This section gives the pressure drops over various equipments and the efficiencies that are used in the Hysys simulations. No additional pressures drops across vessels and piping are included in the simulation model. It is assumed that the pressure drops given in Table 5.3 are sufficient to account for pressure drop across equipments and piping.

5.4.1 Pressure Drop

Table 5.3 : Equipment pressure drop used in simulations

Description	Tag No	Pressure Drop (bara)
Field 2 Inlet Separator	20-HA-001	1.0
Field 1 Inlet Separator	20-HA-002	1.0
Stabilization Separator Heater	20-HA-003	1.0
Stabilization Separator Cross Heat Exchanger	20-HB-004	1.0
Export Oil Cooler	21-HB-001	1.0
1st Stage Recompressor Suction Cooler	23-HB-001	0.5
2nd Stage Recompressor Suction Cooler	23-HB-002	0.5
Dehydration Suction Coolers		1.0
Dehydration Suction Superheaters		1.0
Injection Compressor Suction Coolers		1.0
Injection Compressor After Coolers		1.0

5.4.2 Pump Efficiencies

All pumps used in the simulation model are designed with an adiabatic efficiency of 75%.

5.4.3 Compressor Efficiencies

Table 5.4 gives the polytropic efficiencies of the each of the compressor units used in the Hysys simulation model.

Table 5.4 : Compressor Efficiencies

Description	**Tag No**	**Polytropic Efficiency (%)**
1st Stage Recompressor	23-KA-001	75.00
2nd Stage Recompressor	23-KA-002	75.00
Field 1 1st Stage Injection Compressor	23-KA-101	83.00
Field 1 2nd Stage Injection Compressor	23-KA-102	83.84
Field 1 3rd Stage Injection Compressor	23-KA-103	83.84
Field 2 1st Stage Injection Compressor	23-KA-202	84.00
Field 2 2nd Stage Injection Compressor	23-KA-202	78.95
Field 2 3rd Stage Injection Compressor	23-KA-203	78.95

5.5 Methodology of building Hysys Simulation Model

This section describes the methodology behind the development of the hysys model based on the process description given in Section 3.1. It also contains figures of each section of the hysys simulation model. The pictorial view of the Hysys simulation can be seen in Figure 5.1.

5.5.1 Inlet Arrangement

The well streams from the Field 1 and Field 2 wells are mixed and routed to the Field 1 and Field 2 manifold respectively. The pressure of the wellstream at both the manifolds is 16.5 bar. After a 0.5 bar pressure drop downstream the Field 1 and Field 2 manifolds, the wellstream from both the fields enters the respective inlet heaters at 16 bar. The pressure drop in both the heaters is set as 1 bar for the hot and cold stream.

The Field 1 Inlet Heater (20-HA-002) receives the hydrocarbon stream from the Field 1 manifold at a temperature of 28°C and heats it to 55°C. In the simulation, 20-HA-002 is modelled as a shell and tube heat exchanger (STHE) with the high pressure well stream as the tube side fluid (cold stream) and the heating medium as the shell side fluid (hot stream). The inlet/outlet temperatures and the heating duty for 20-HA-002 can be seen in Figure 5.2.

The Field 2 Inlet Heater (20-HA-001) receives the hydrocarbon stream from the Field 2 manifold at a temperature of 45°C and heats it to 55°C. In the simulation, 20-HA-001 is modelled similar to 20-HA-002, as a shell and tube heat exchanger with the high pressure well stream as the tube side fluid (cold stream) and the heating medium as the shell side fluid (hot stream). The inlet/outlet temperatures and the heating duty for 20-HA-001 can be seen in Figure 5.2.

The hydrocarbon streams from both the inlet heaters are mixed and routed downstream to the Inlet Separator (20-VA-001). 20-VA-001 is modelled as a 3-phase separator with the 5 vol% water dominant phase in hydrocarbon dominant phase. In Hysys, this specification is met by setting the heavy liquid in light liquid as 0.05 under carry-over setup. The oil is routed downstream to the Secondary Separator (-20-VA-002) shown as stream Oil (Inlet Separator) in the figure below, the water routed to the produced water system and the gas directed to the gas compression and injection train (Stream 43).

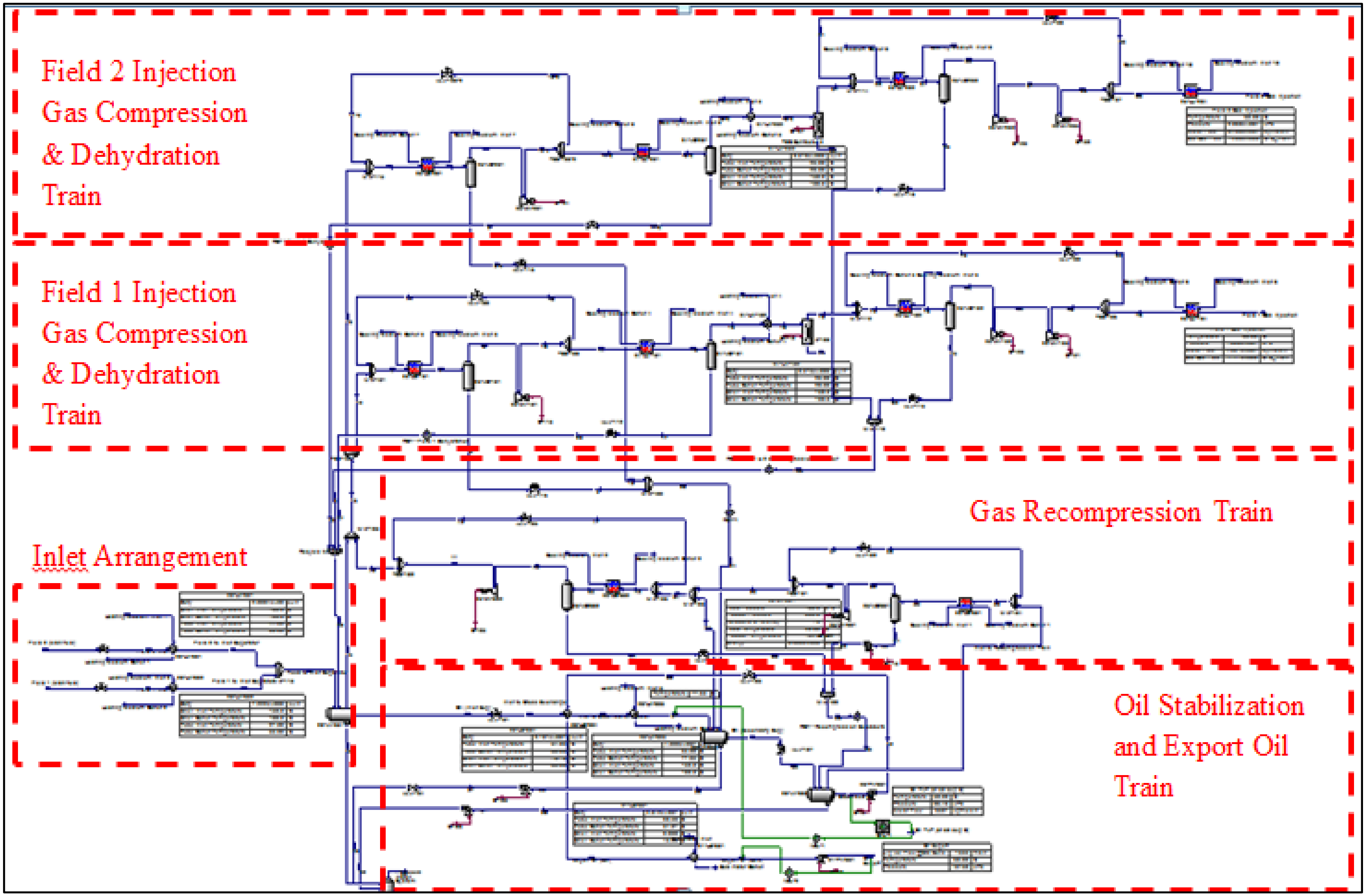
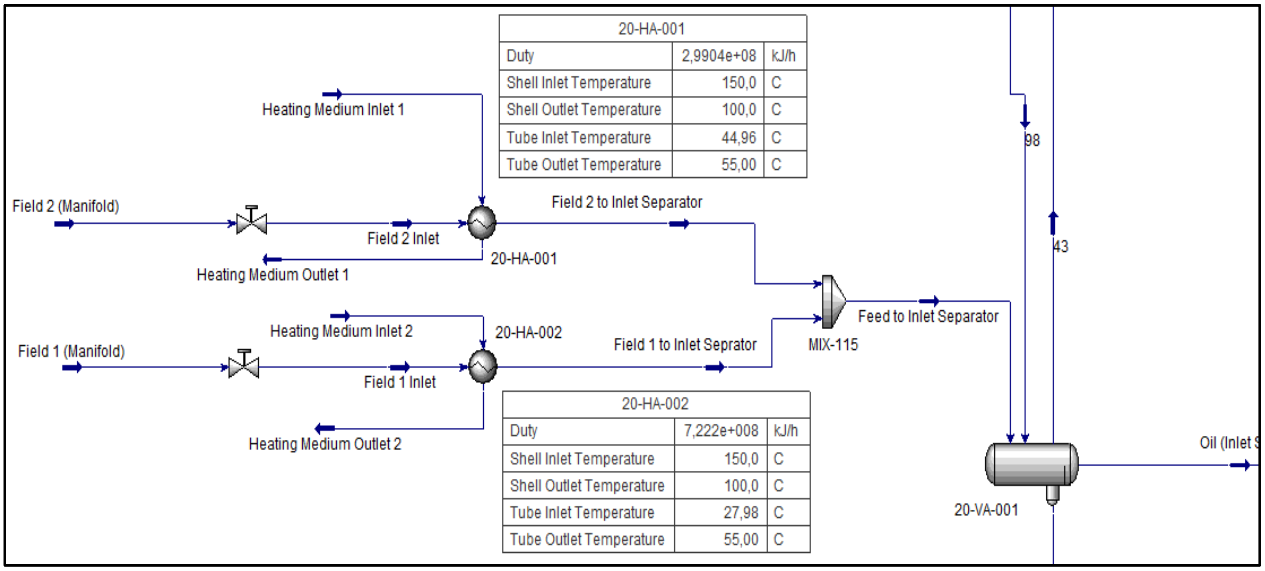


Figure 5.1 : HYSYS Simulation Model (Base Case Simulation)



20-HA-001		
Duty	2,9904e+08	kJ/h
Shell Inlet Temperature	150,0	C
Shell Outlet Temperature	100,0	C
Tube Inlet Temperature	44,96	C
Tube Outlet Temperature	55,00	C

20-HA-002		
Duty	7,222e+008	kJ/h
Shell Inlet Temperature	150,0	C
Shell Outlet Temperature	100,0	C
Tube Inlet Temperature	27,98	C
Tube Outlet Temperature	55,00	C

Figure 5.2 : Inlet Arrangement (Well stream to Inlet Separator) – HYSYS model

5.5.2 Oil Stabilization & Export Oil Train

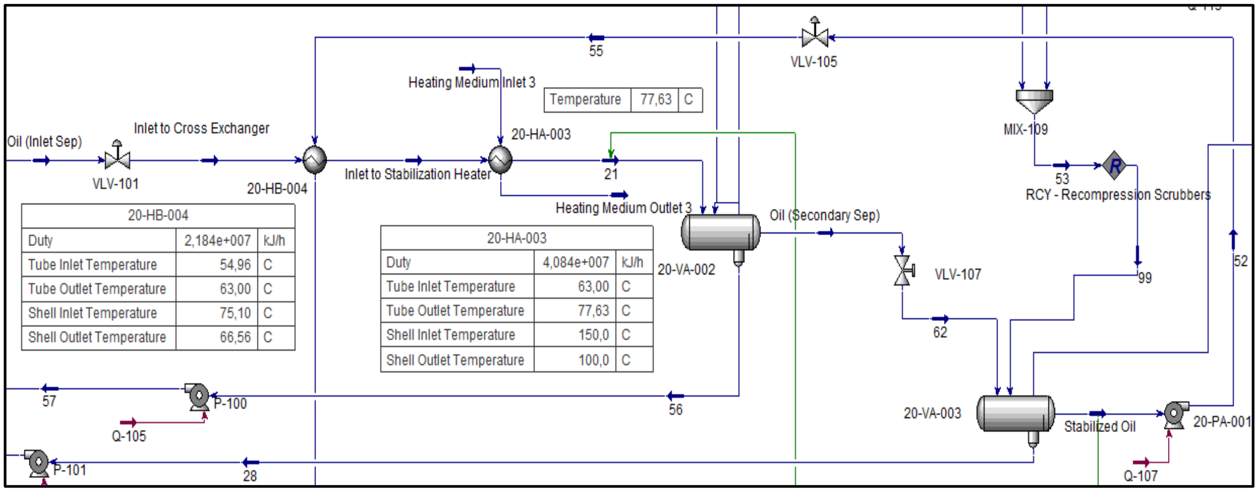
The oil stream out of the 20-VA-001 is routed to the Secondary Separator (20-VA-002) through two heat exchangers – Stabilization Separator Cross Exchanger (20-HB-004) and Stabilization Separator Heater (20-HA-003). The Cross Exchanger integrates the heat from the stabilized oil into the process. The oil being routed from the inlet separator to the secondary separator is heated against the high temperature stabilized oil from the Stabilization Separator (20-VA-003). This pre-heating of the oil stream helps in conserving the energy balance of the system and reduces the heating duty of 20-HA-003. The pressure of the oil stream from the inlet separator is taken down from 15 bar to 9 bar across a valve before it enters the 20-HB-004.

The Cross Exchanger receives the oil stream at about 9 bar and 54^{o}C and heats it to about 63^{o}C against the high temperature stabilized oil which enters at around 75^{o}C. In the simulation, 20-HB-004 is modelled as a shell and tube heat exchanger with the high pressure oil stream as the tube side fluid (cold stream) and the stabilized oil as the shell side fluid (hot stream). The inlet/outlet temperatures and the heating duty for 20-HB-004 can be seen in Figure 5.3.

The Stabilization Separator Heater (20-HA-003) receives the pre-heated oil at about 63^{o}C. The outlet temperature of 20-HA-003 is regulated in order to obtain the oil product specifications – True Vapour Pressure of 0.965 bar at 30^{o}C. 20-HA-003 is modelled as a shell and tube exchanger with the oil stream as the tube side fluid (cold stream) and the heating medium as the shell side fluid (hot stream). The inlet/outlet temperatures and the heating duty for the exchanger can be seen in Figure 5.3.

The heated oil stream is routed downstream to the separator 20-VA-002. This separator is operated at an intermediate pressure of 7 bar due to the 1 bar pressure drop each in both the upstream exchangers. 20-VA-002 is modelled as a 3-phase separator with the 5 vol% water dominant phase in hydrocarbon dominant phase. In Hysys, this specification is met by setting the heavy liquid in light liquid as 0.05 under carry-over setup. From 20-VA-002, the oil dominant stream represented as stream ‘Oil (Secondary Sep)’ in Figure 5.3 is routed downstream to the Stabilization Separator (20-VA-003), the water is routed to the produced water system and the gas directed to the gas recompression train.

Downstream of 20-VA-002, the pressure of the oil stream is taken down by 5 bar before the hydrocarbon stream reaches 20-VA-003. This separator is operated at a pressure as low as possible (2 bar) while still maintaining sufficient pressure for the gas stream to be routed to the inlet of the recompression train. 20-VA-003 is modelled as a 3-phase separator with the 2 vol% water dominant phase in hydrocarbon dominant phase. In Hysys, this specification is met by setting the heavy liquid in light liquid as 0.02 under carry-over setup.



20-HB-004		
Duty	2,184e+007	kJ/h
Tube Inlet Temperature	54,96	C
Tube Outlet Temperature	63,00	C
Shell Inlet Temperature	75,10	C
Shell Outlet Temperature	66,56	C

20-HA-003		
Duty	4,084e+007	kJ/h
Tube Inlet Temperature	63,00	C
Tube Outlet Temperature	77,63	C
Shell Inlet Temperature	150,0	C
Shell Outlet Temperature	100,0	C

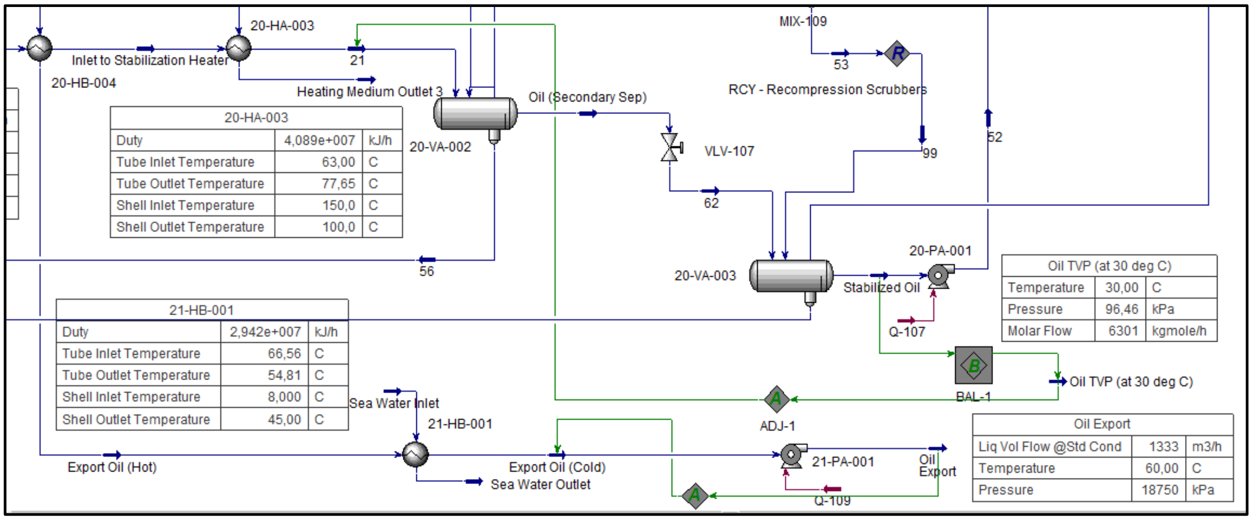
Figure 5.3 : Oil Stabilization Train – HYSYS model

The Stabilized Oil stream from 20-VA-003 is required to have the product specification of – True Vapour Pressure of 0.965 bar at 30^{o}C. In Hysys, this requirement is modelled by connecting an ‘Adjuster’ (ADJ-1) between the Oil TVP stream and outlet stream from 20-HA-003 as seen in Figure 5.4. The adjuster regulates the outlet temperature of the oil stream from 20-HA-003 in order to get the required TVP in the Stabilized Oil stream.

The Oil TVP (at 30^{o}C) stream is a material stream identical to the Stabilized Oil stream from 20-VA-003. It is specified to have the same component mole flow but at a temperature of 30^{o}C instead of 75^{o}C which is the outlet temperature of the stabilized oil. A ‘Balance’ function in Hysys is used to link the 2 streams since the production requirements are specified at 30^{o}C. The oil product specifications from the Hysys simulation can be seen in the Oil TVP table in Figure 5.4. These specifications are in line with the product specifications give in Section 3.4.1.

The stabilized oil is pressurized by the Oil Booster Pumps (20-PA-001A/B/C) to 9 bar and routed to the cross exchanger for the pre-heating of the oil stream from 20-VA-001. In Hysys, these pumps are modelled with the required pressure ratio and having a 75% adiabatic efficiency. These pumps operate in a 2+1 configuration where 2 pumps are working pumps and 1 pump is a stand-by pump. In the process of heat integration, the stabilized oil is cooled from 75^{o}C to 66^{o}C across 20-HB-003. The cooled down stabilized oil is routed downstream to the Crude Oil Cooler (21-HB-001) for further cooling to meet the export specifications given in Section 3.4.1. In the simulation, 21-HB-001 is modelled as a shell and tube heat exchanger with the high temperature stabilized oil stream as the tube side fluid (hot stream) and the low temperature sea water as the shell side fluid (cold stream). The inlet/outlet temperatures and heat duty of this exchanger can be seen in Figure 5.4.

Downstream of 21-HB-001, the crude oil is pressurized in the Export Oil Pumps (21-PA-001A/B/C) to the export oil pressure of 187 bar. Since the increase in pressure results in an increase of temperature, the outlet temperature from 21-HB-001 needs to be regulated such that the final temperature of the oil after pressurization is at the Export Oil temperature specification of 60^{o}C. In Hysys, this is done by connecting a ‘Adjuster’ (ADJ-2) between the Oil Export stream and the outlet stream from the Crude Oil Cooler. The adjuster regulates the outlet temperature from 21-HB-001 such that after pressurization, the temperature of the oil export stream reaches 60^{o}C. The flowrate, temperature and pressure of the Oil Export stream can be seen in the Oil Export table in Figure 5.4. These specifications are in line with the product specifications give in Section 3.4.1.



20-HA-003		
Duty	4,089e+007	kJ/h
Tube Inlet Temperature	63,00	C
Tube Outlet Temperature	77,65	C
Shell Inlet Temperature	150,0	C
Shell Outlet Temperature	100,0	C

21-HB-001		
Duty	2,942e+007	kJ/h
Tube Inlet Temperature	66,56	C
Tube Outlet Temperature	54,81	C
Shell Inlet Temperature	8,000	C
Shell Outlet Temperature	45,00	C

Oil TVP (at 30 deg C)		
Temperature	30,00	C
Pressure	96,46	kPa
Molar Flow	6301	kgmole/h

Oil Export		
Liq Vol Flow @Std Cond	1333	m3/h
Temperature	60,00	C
Pressure	18750	kPa

Figure 5.4 : Export Oil Train – HYSYS model

5.5.3 Gas Compression Train

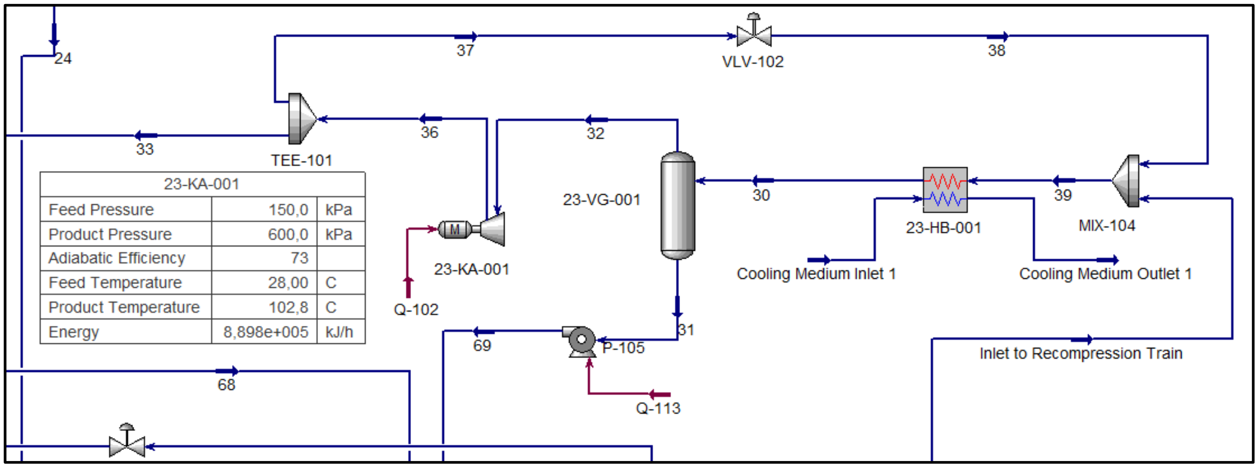
The gas from 20-VA-003 is routed to the inlet of the recompression train vide the stream Inlet to Recompression Train as seen in Figure 5.5. The gas stream is at the minimum pressure of 2 bar and a temperature of 75^{o}C. In the Hysys model, the inlet stream is mixed with the compressor recycle stream in order to simulate the compressor recycle loop. The gas stream is routed downstream to the 1st Stage Recompressor Inlet Cooler (23-HB-001) to cool down the gas to 28^{o}C.

The gas stream enters 23-HB-001 at 75^{o}C and is cooled down to 28^{o}C against the cooling medium entering at 15^{o}C and getting heated to 45^{o}C. Based on the temperature profile of the process fluids, this exchanger is designed a Compact Heat Exchanger (CHE) such as Plate & Frame Heat Exchanger (PFHE) or a Printed Circuit Heat Exchanger (PCHE). For the Hysys model, 23-HB-001 could not be designed as a shell & tube heat exchanger since hysys does not permit a shell & tube heat exchanger to be modelled with a temperature cross. Also plate and frame heat exchanger or printed circuit heat exchanger options do not feature in Hysys.

Based on a discussion with my supervisor, Prof. Jostein Pettersen, we agreed that in Hysys I would model all the compact heat exchangers in the simulation as LNG heat exchangers. LNG heat exchangers can operate with just 2 streams, one hot and one cold. The design of an LNG exchanger is similar to a compact heat exchanger and is therefore used for the simulation model. Thus 23-HB-001 is modelled as a counter-current LNG exchanger with the gas as the hot stream and the cooling medium as the cold stream. The exchanger is modelled to have an LMTD of 23^{o}C.

The cooled down gas is routed to the 1st Stage Recompression Scrubber (23-VG-001) to separate out the liquid that has condensed during the cooling process. In the Hysys simulation, the scrubber 23-VG-001 is modelled as a 2-phase separator wherein the gas stream is routed downstream to the compressor and the liquid stream containing the heavy hydrocarbons is pressurized and then routed to the Stabilization Separator.

The gas stream is routed to the 1st Stage Recompressor (23-KA-001) to be pressurized from 1.5 bar to 6 bar. In the Hysys simulation, 23-KA-001 is modelled as a centrifugal compressor with 73% adiabatic efficiency. The performance table for 23-KA-001 can be seen in the Figure 5.5 below.



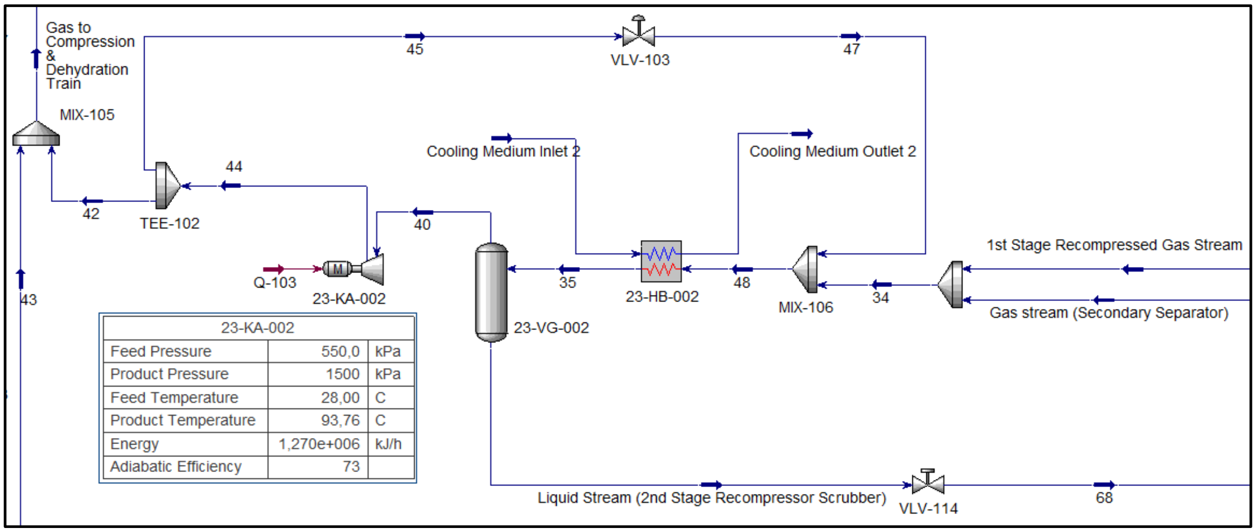
23-KA-001		
Feed Pressure	150,0	kPa
Product Pressure	600,0	kPa
Adiabatic Efficiency	73	
Feed Temperature	28,00	C
Product Temperature	102,8	C
Energy	8,898e+005	kJ/h

Figure 5.5 : Gas Recompression Train (Stage 1) - HYSYS model

Downstream of the 1st stage compression, the gas stream from the 1st stage compressor is mixed with the gas stream from the Secondary Separator as is seen in Figure 5.6. The mixed gas stream in the Hysys model is then linked to the compressor recycle stream in order to simulate the compressor recycle loop. The temperature of the mixed gas stream is quite high since the high temperature of the 1st stage compressed gas stream is the dominant factor.

The high temperature gas stream is routed downstream to the 2nd Stage Recompressor Cooler (23-HB-002) to be cooled down to 28°C. 23-HB-002 is also designed as a counter-current LNG exchanger with the gas as the hot stream and the cooling medium as the cold stream. The cooled down gas is routed to the 2nd Stage Recompression Scrubber (23-VG-002) to separate out the liquid that has condensed during the cooling process. In the Hysys simulation, the scrubber 23-VG-002 is modelled as a 2-phase separator wherein the gas stream is routed downstream to the compressor and the liquid stream containing the heavy hydrocarbons routed to the Stabilization Separator.

The gas stream is then routed to the 2nd Stage Recompressor (23-KA-002) to be pressurized from 6 bar to 15 bar to match the pressure of the gas stream from the inlet separator. In the Hysys simulation, 23-KA-002 is modelled as a centrifugal compressor with 73% adiabatic efficiency. The performance table for 23-KA-002 can be seen in the Figure 5.6 below.



23-KA-002		
Feed Pressure	550,0	kPa
Product Pressure	1500	kPa
Feed Temperature	28,00	C
Product Temperature	93,76	C
Energy	1,270e+006	kJ/h
Adiabatic Efficiency	73	

Figure 5.6 : Gas Recompression Train (Stage 2) – HYSYS model

Downstream the compressor, the recompressed gas is mixed with the main gas stream from 20-VA-001 and the total gas flow is routed to the compression and dehydration trains as seen in Figure 5.6.

5.5.4 Field 1 Injection Gas Compression and Dehydration Train

The total gas flow from the inlet separator and the recompression train are split into parts based on the capacity split between Field 1 and 2. In the Hysys model, a splitter is used to divide the gas flow between the 2 trains – 47% to the Field 1 injection compression train and 53% to the Field 2 injection compression train.

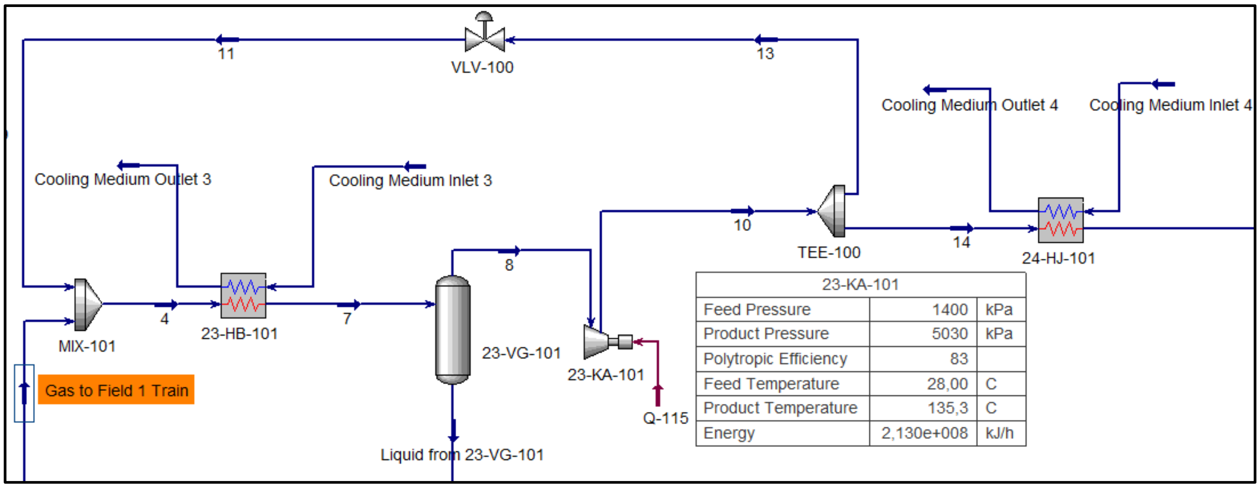
The gas feed to Field 1 injection compression train enters as the stream ‘Gas to Field 1 train’ as seen in Figure 5.7. In the Hysys model, the feed gas stream is mixed with the compressor recycle stream in order to simulate the compressor recycle loop. The gas is first cooled in Field 1 1st

Stage Injection Suction Cooler (23-HB-101) from the gas inlet temperature of 55°C to 28°C. 23-HB-101 is modelled as a counter-current LNG exchanger with the gas as the hot stream and the cooling medium as the cold stream as seen in Figure 5.7 below.

The cooled down gas is routed to the Field 1 1st Stage Injection Scrubber (23-VG-101) to separate out the liquid that has condensed during the cooling process. In the Hysys simulation, the scrubber 23-VG-101 is modelled as a 2-phase separator wherein the gas stream is routed downstream to the compressor and the liquid stream containing the heavy hydrocarbons is de-pressurized and then routed to the Secondary Separator.

The gas stream is then routed to the Field 1 1st Stage Injection Compressor (23-KA-101) to be pressurized from 14 bar to 50.3 bar. In the Hysys simulation, 23-KA-101 is modelled as a centrifugal compressor with 83% polytropic efficiency. The performance table for 23-KA-101 can be seen in the Figure 5.7.

Downstream the 1st stage compression, the hot gas needs to be cooled down before the dehydration process. The high temperature gas is cooled down to 25°C in the Field 1 Dehydration Suction Cooler (24-HJ-101). 24-HJ-101 is modelled as a counter-current LNG exchanger with the gas stream as the hot side and the cooling medium on the cold side.



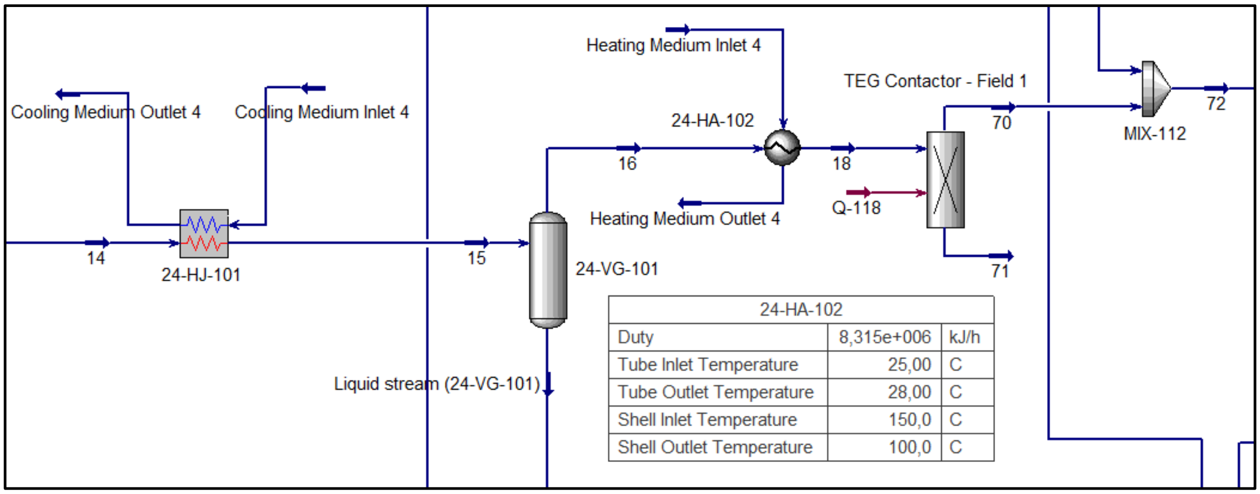
23-KA-101		
Feed Pressure	1400	kPa
Product Pressure	5030	kPa
Polytropic Efficiency	83	
Feed Temperature	28,00	C
Product Temperature	135,3	C
Energy	2,130e+008	kJ/h

Figure 5.7 : Field 1 1st Stage Compression – HYSYS model

The gas that is cooled down in 24-HJ-101 is routed to the Field 1 Dehydration Scrubber (24-VG-101) in order to separate out the liquid that has condensed during the cooling process. This is necessary since we need to avoid any liquid phase entering the TEG contactors. In the Hysys simulation, 24-HJ-101 is modelled as a 2-phase separator wherein the gas stream is routed to the superheater and the liquid stream containing the heavy hydrocarbons is de-pressurized and then recycled to the Inlet Separator.

The gas stream is then superheated by 3°C in the Field 1 Dehydration Superheater (24-HA-102) to 28°C. This superheating is done to ensure that the gas stays above the hydrocarbon dew point during the dehydration process in the TEG contactor. In the Hysys simulation, 24-HA-102 is modelled as a shell and tube exchanger with the gas stream as the tube side fluid (cold stream) and the heating medium as the shell side fluid (hot stream). The inlet/outlet temperatures and the heating duty for the exchanger can be seen in Figure 5.8.

In the Hysys simulation, the Field 1 TEG Contactor is modelled as a splitter with the specification that all hydrocarbons and 0.0405 molar of feed fraction of water is routed downstream as the vapour phase product.



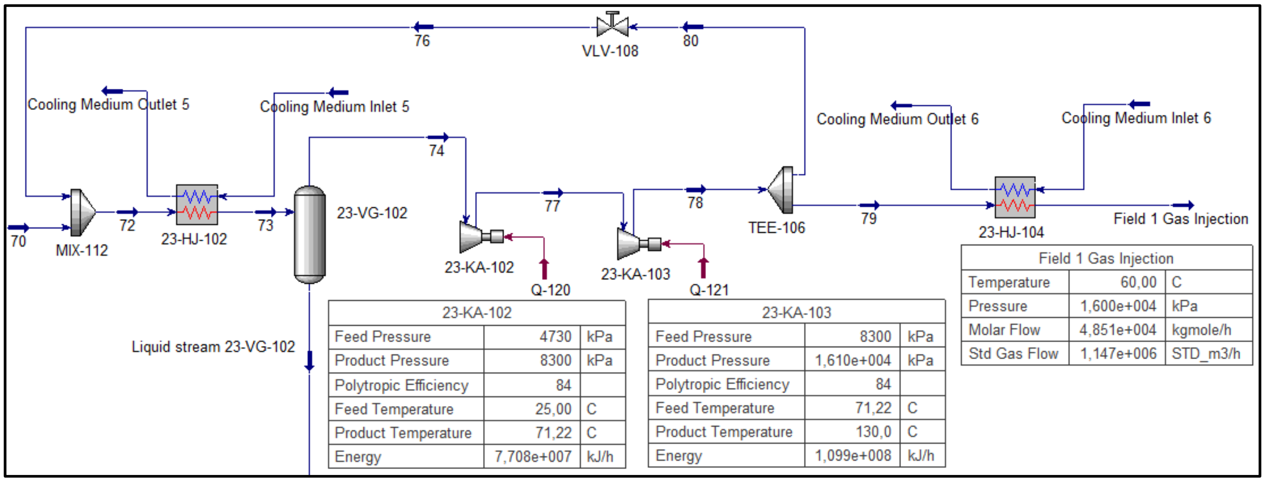
24-HA-102		
Duty	8,315e+006	kJ/h
Tube Inlet Temperature	25,00	C
Tube Outlet Temperature	28,00	C
Shell Inlet Temperature	150,0	C
Shell Outlet Temperature	100,0	C

Figure 5.8 : Field 1 Dehydration Train – HYSYS model

The gas stream after removal of the required water content is cooled down again to 25°C in the Field 1 2nd Stage Gas Injection Suction Cooler (24-HJ-102). Based on the temperature profile of the heat exchanger, 24-HJ-102 is modelled as a counter-current LNG exchanger with the gas stream as the hot side and the cooling medium on the cold side. The cooled down gas is routed downstream to the Field 1 2nd Stage Injection Scrubber (23-VG-102) to separate out the liquid that has condensed during the cooling process before the gas enters the compressors. In the Hysys simulation, the scrubber 23-VG-102 is modelled as a 2-phase separator wherein the gas stream is routed downstream to the compressors and the liquid stream containing the heavy hydrocarbons is de-pressurized and then routed to the Inlet Separator.

The intermediate pressure dehydrated gas stream is then routed to the Field 1 1st and 2nd Stage Injection Compressors (23-KA-102 & 23-KA-103 respectively). The gas stream is pressurized from 47.3 bar to 83.0 bar in 23-KA-102 and then from 83.0 bar to 161.0 bar in 23-KA-103. In the Hysys simulation, 23-KA-102 and 23-KA-103 are modelled as centrifugal compressors with 84% polytropic efficiency. The performance tables for 23-KA-102 and 23-KA-103 can be seen in the Figure 5.9. No intercooling followed by liquid removal is required between the 2nd and 3rd stage compression.

Downstream the compression process, the injection gas is cooled by the Field 1 3rd Stage Gas Injection After Cooler (23-HJ-104) to the injection gas temperature of 60°C. 23-HJ-104 is also modelled as a counter-current LNG exchanger with the gas stream as the hot side and the cooling medium on the cold side. The specification table of the Field 1 Injection Gas seen in Figure 5.9 is as per gas product specifications given in in Section 3.4.2.



23-KA-102		
Feed Pressure	4730	kPa
Product Pressure	8300	kPa
Polytropic Efficiency	84	
Feed Temperature	25,00	C
Product Temperature	71,22	C
Energy	7,708e+007	kJ/h

23-KA-103		
Feed Pressure	8300	kPa
Product Pressure	1,610e+004	kPa
Polytropic Efficiency	84	
Feed Temperature	71,22	C
Product Temperature	130,0	C
Energy	1,099e+008	kJ/h

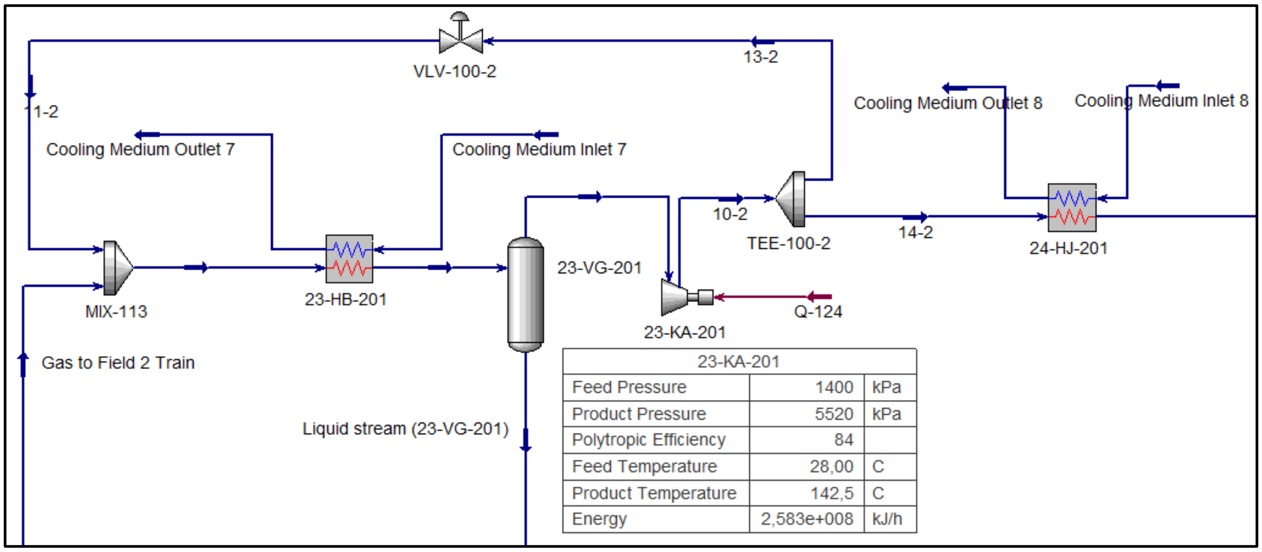
Field 1 Gas Injection		
Temperature	60,00	C
Pressure	1,600e+004	kPa
Molar Flow	4,851e+004	kgmole/h
Std Gas Flow	1,147e+006	STD_m3/h

Figure 5.9 : Field 1 2nd & 3rd Stage Injection Gas Compression – HYSYS model

5.5.5 Field 2 Injection Gas Compression and Dehydration Train

53% to the total gas flow from the inlet separator and the recompression train is routed to the Field 2 injection compression train as the stream 'Gas to Field 2 Train' seen in Figure 5.10. In the Hysys model, the feed gas stream is mixed with the compressor recycle stream in order to simulate the compressor recycle loop.

The gas is first cooled in the Field 2 1st Stage Injection Suction Cooler (23-HB-201) from the gas inlet temperature of 55°C to 28°C. 23-HB-201 is modelled as a counter-current LNG exchanger with the gas as the hot stream and the cooling medium as the cold stream as seen in Figure 5.10.



23-KA-201		
Feed Pressure	1400	kPa
Product Pressure	5520	kPa
Polytropic Efficiency	84	
Feed Temperature	28,00	C
Product Temperature	142,5	C
Energy	2,583e+008	kJ/h

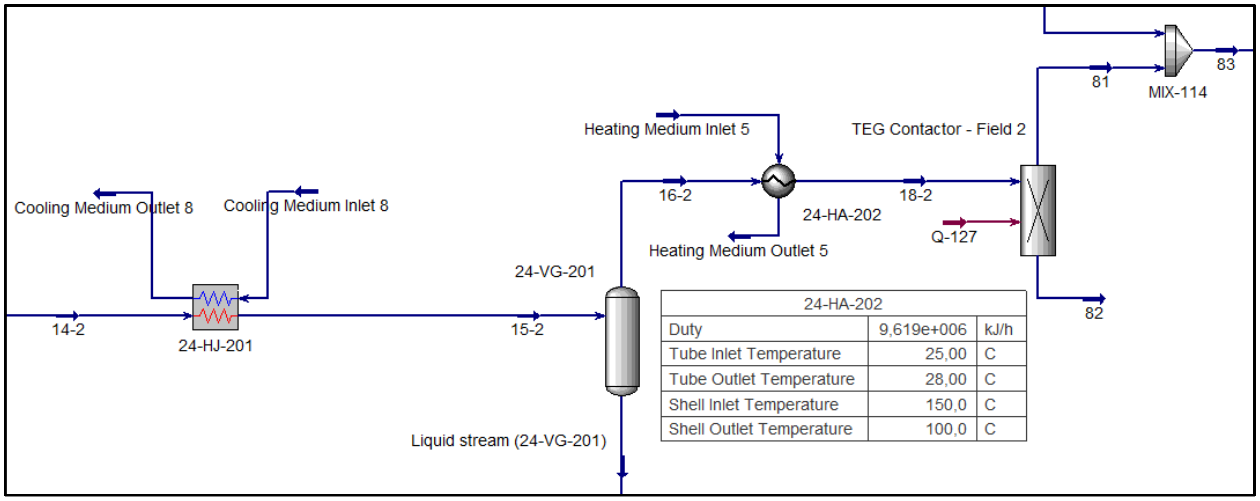
Figure 5.10 : Field 2 1st Stage Compression - HYSYS model

The cooled down gas is routed to the Field 2 1st Stage Injection Scrubber (23-VG-201) to separate out the liquid that has condensed during the cooling process. In the Hysys simulation, the scrubber 23-VG-201 is modelled as a 2-phase separator wherein the gas stream is routed downstream to the compressor and the liquid stream containing the heavy hydrocarbons is de-pressurized and then routed to the Secondary Separator.

The gas stream is then routed to the Field 2 1st Stage Injection Compressor (23-KA-201) to be pressurized from 14 bar to 55.2 bar. In the Hysys simulation, 23-KA-201 is modelled as a centrifugal compressor with 84% polytropic efficiency. The performance table for 23-KA-101 can be seen in the Figure 5.10.

Downstream the 1st stage compression, the hot gas needs to be cooled down before the dehydration process. The high temperature gas is cooled down to 25°C in the Field 2 Dehydration Suction Cooler (24-HJ-201) as seen in Figure 5.11. 24-HJ-201 is modelled as a counter-current LNG exchanger with the gas stream as the hot side and the cooling medium on the cold side.

The gas that is cooled down in 24-HJ-201 is routed to the Field 2 Dehydration Scrubber (24-VG-201) in order to separate out the liquid that has condensed during the cooling process. This is necessary since we need to avoid any liquid phase entering the TEG contactors. In the Hysys simulation, 24-VG-201 is modelled as a 2-phase separator wherein the gas stream is routed to the superheater and the liquid stream containing the heavy hydrocarbons is de-pressurized and then recycled to the Inlet Separator.

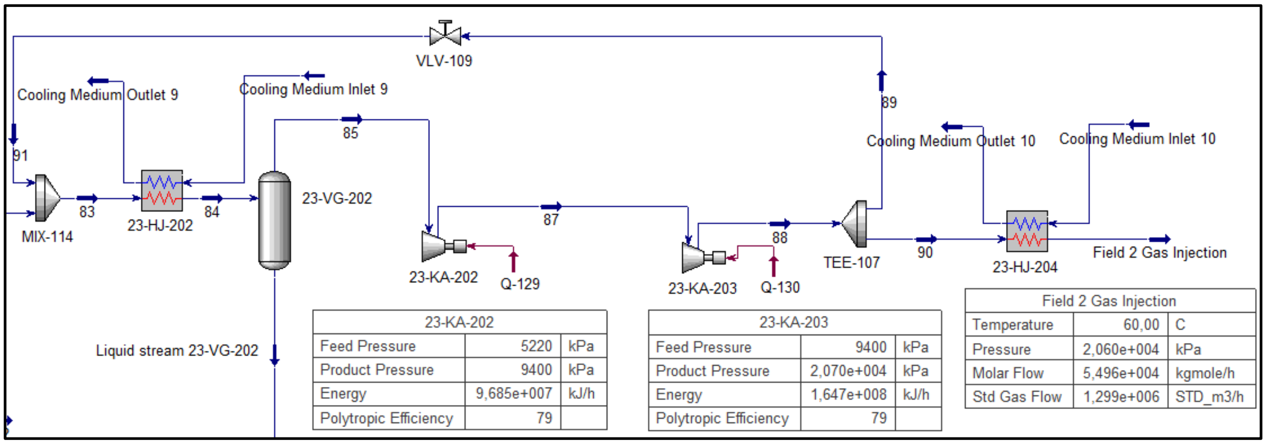


24-HA-202		
Duty	9,619e+006	kJ/h
Tube Inlet Temperature	25,00	C
Tube Outlet Temperature	28,00	C
Shell Inlet Temperature	150,0	C
Shell Outlet Temperature	100,0	C

Figure 5.11 : Field 2 Dehydration Train – HYSYS model

The gas stream is then superheated by 3°C in the Field 2 Dehydration Superheater (24-HA-202) to 28°C. This superheating is done to ensure that the gas stays above the hydrocarbon dew point during the dehydration process in the TEG contactor. In the Hysys simulation, 24-HA-202 is modelled as a shell and tube exchanger with the gas stream as the tube side fluid (cold stream) and the heating medium as the shell side fluid (hot stream). The inlet/outlet temperatures and the heating duty for the exchanger can be seen in Figure 5.11.

In the Hysys simulation, the Field 2 TEG Contactor is modelled as a splitter with the specification that all hydrocarbons and 0.0405 molar of feed fraction of water is routed downstream as the vapour phase product.



23-KA-202		
Feed Pressure	5220	kPa
Product Pressure	9400	kPa
Energy	9,685e+007	kJ/h
Polytropic Efficiency	79	

23-KA-203		
Feed Pressure	9400	kPa
Product Pressure	2,070e+004	kPa
Energy	1,647e+008	kJ/h
Polytropic Efficiency	79	

Field 2 Gas Injection		
Temperature	60,00	C
Pressure	2,060e+004	kPa
Molar Flow	5,496e+004	kgmole/h
Std Gas Flow	1,299e+006	STD_m3/h

Figure 5.12 : Field 2 2nd & 3rd Stage Injection Gas Compression – HYSYS model

The gas stream after removal of the required water content is cooled down again to 25°C in the Field 2 2nd Stage Gas Injection Suction Cooler (24-HJ-202). Based on the temperature profile of the heat exchanger, 24-HJ-202 is modelled as a counter-current LNG exchanger with the gas stream as the hot side and the cooling medium on the cold side. The cooled down gas is routed downstream to the Field 2 2nd Stage Injection Scrubber (23-VG-202) as seen in Figure 5.12 to separate out the liquid that has condensed during the cooling process before the gas enters the compressors. In the Hysys simulation, the scrubber 23-VG-202 is modelled as a 2-phase separator wherein the gas stream is routed downstream to the compressors and the liquid stream containing the heavy hydrocarbons is de-pressurized and then routed to the Inlet Separator.

The intermediate pressure dehydrated gas stream is then routed to the Field 2 1st and 2nd Stage Injection Compressors (23-KA-202 & 23-KA-203 respectively). The gas stream is pressurized from 52.2 bar to 94.0 bar in 23-KA-202 and then from 94.0 bar to 207.0 bar in 23-KA-103. In the Hysys simulation, 23-KA-202 and 23-KA-203 are modelled as centrifugal compressors with 79% polytropic efficiency. The performance tables for 23-KA-202 and 23-KA-203 can be seen in the Figure 5.12. No intercooling followed by liquid removal is required between the 2nd and 3rd stage compression.

Downstream the compression process, the injection gas is cooled by the Field 2 3rd Stage Gas Injection After Cooler (23-HJ-2104) to the injection gas temperature of 60°C. 23-HJ-204 is also modelled as a counter-current LNG exchanger with the gas stream as the hot side and the cooling medium on the cold side. The specification table of the Field 2 Injection Gas seen in Figure 5.12 is as per gas product specifications given in in Section 3.4.2.

5.5.6 Deviation from Process Description

During development of the Hysys simulation model, certain deviations were made from the original process description. These deviations were done in order to simplify the simulation model and also to remove certain sections of the process design which were not relevant for this thesis work.

The deviations made in the simulation model developed for this thesis work are mentioned below:

1. No Test Manifold, Test Separator and Test Oil Separation train was modelled as part of the simulation model for this thesis work. This section was not included since the equipments in the test train would not be in operation at all times and will not have any major impact on the design of the heat exchangers.
2. The Electrostatic Coalescer downstream the Stabilization Separation was not modelled in the simulation since this equipment did not impact the heat duty of the overall system and would not affect the thermal design of the heat exchangers neither in the base case nor in the case studies.

5.5.7 Determination of Flowrate for Field 1 & Field 2

For obtaining the required oil production from both Field 1 and Field 2, it is critical that the inlet flowrate for each of these fields is fed into the Hysys simulation model correctly. As per the oil product specifications given in Section 3.4.2, the oil production from Field 1 and Field 2 is required to be 15000 Sm3/d (625 Sm3/hr) and 17000 Sm3/d (708,3 Sm3/hr) respectively.

Determination of Field 1 Flowrate

The stream Field 2 to Inlet Separator is disconnected from the Hysys simulation model as seen in Figure 5.13. As a result the total oil product generated downstream the Stabilization Separator is produced only from the Field 1 inlet. An adjuster is connected between the stream – Field 1 (Manifold) and Stabilized Oil. The flowrate of 'Field 1 (Manifold)'is set as the adjusted variable and the flowrate of the 'Stabilized Oil' stream is assigned as the target variable. The value of the target variable is set as 625 Sm3/hr with a 2% tolerance. Based on the composition and the liquid and vapour content of the Field 1 hydrocarbon stream, the inlet flowrate of Field 1 is calculated to be 7645Sm3/hr.

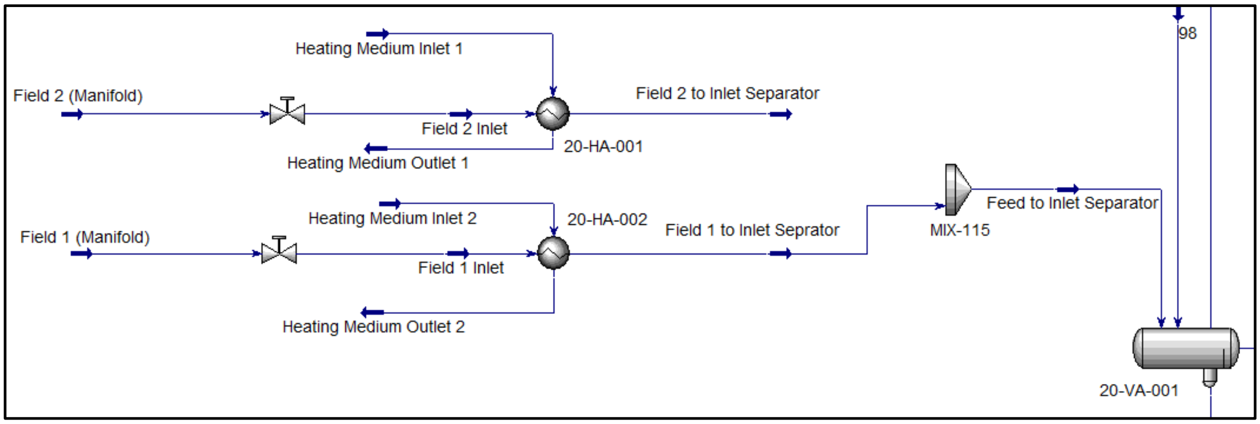


Figure 5.13 : Determination of Field 1 Flowrate

Determination of Field 2 Flowrate

The stream Field 1 to Inlet Separator is disconnected from the Hysys simulation model as seen in Figure 5.14. The similar procedure of connecting an adjuster between the stream Field 2 (Manifold) and the Stabilized Oil stream is followed as explained above. The flowrate of ‘Field 2 (Manifold)’is set as the adjusted variable and the flowrate of the ‘Stabilized Oil’ stream is assigned as the target variable. The value of the target variable is set as 708,3 Sm3/hr with a 2% tolerance. Based on the composition and the liquid and vapour content of the Field 2 hydrocarbon stream, the inlet flowrate of Field 2 is calculated to be 8814 Sm3/hr.

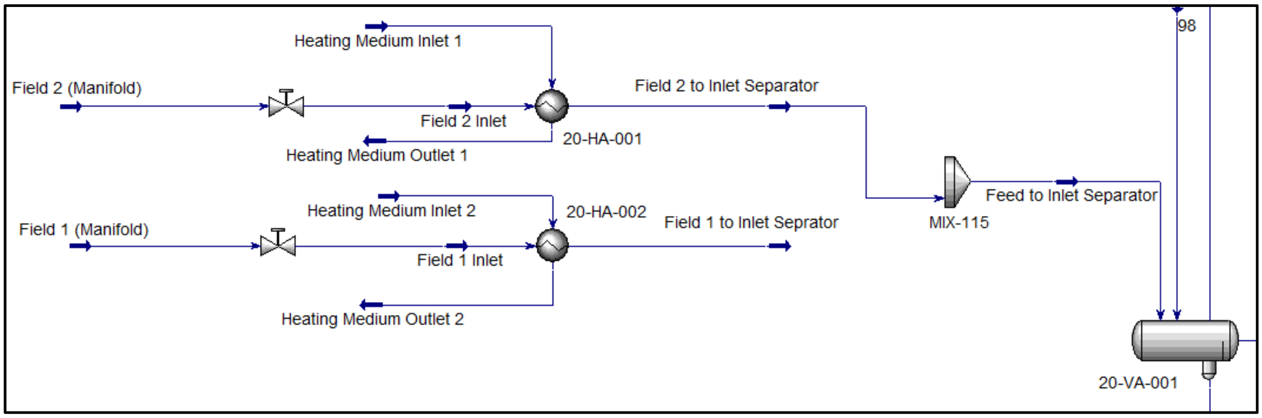


Figure 5.14 : Determination of Field 2 Flowrate

6.0 Base Case Simulation Results & Case Studies

6.1 Introduction

This chapter includes the results of the base case simulation and explains in detail each of the case studies that have been conducted on the base case simulation. The case studies are conducted in order to evaluate the impact on the heat exchanger design by changing the process parameters of the hot side and cold side streams. The three case studies done as part of this thesis work are:

- Case Study I – Removal of Stabilization Separator Cross Exchanger (20-HB-004)
- Case Study II – Feeding Low Temperature Heating Medium to Injection train Superheaters (24-HA-102 & 24-HA-202)
- Case Study III – Removal of Superheater and Scrubber unit prior to Gas Dehydration

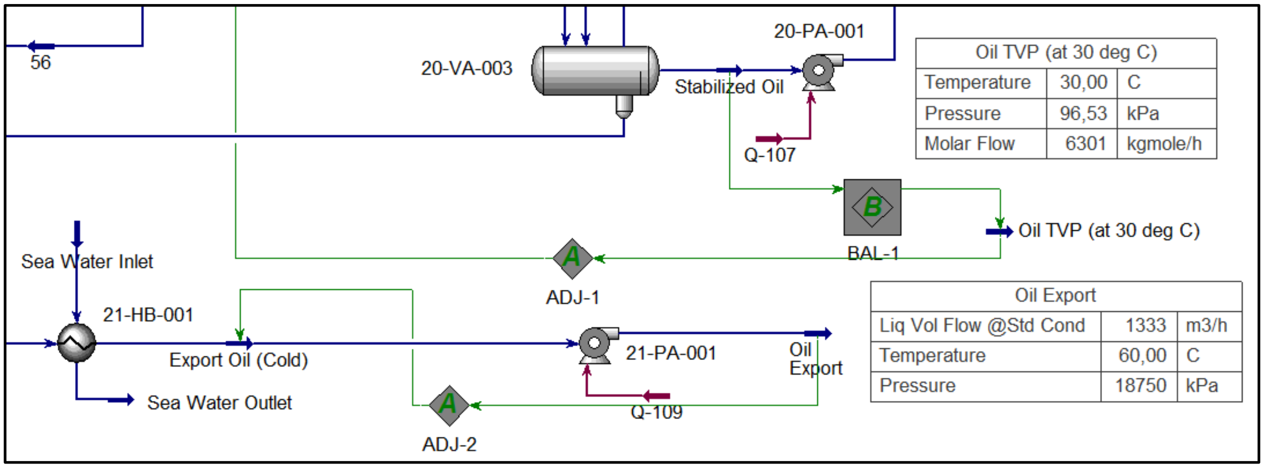
6.2 Base Case Simulation Results

This section gives the specifications and compositions of the oil product and gas product that has been extracted from the Hysys Simulation model.

6.2.1 Modelled Oil Product Specifications

Based on the simulation model (Base Case Simulation) that was developed as part of this thesis work, the specifications of the export oil stream can be seen in Figure 6.1. The adjuster (ADJ-1) seen in the figure below controls the temperature of the hydrocarbon stream out of the Stabilization Separator Heater such that the True Vapour Pressure of the stabilized oil out of the Stabilization Separator is achieved to be 0.96 bar at 30^{o}C as per the requirements given in Section 3.4.1. This can be seen in the Oil TVP table in Figure 6.1.

The total flowrate of export oil as seen in Figure 6.1 is calculated to be 1333 Sm3/hr which accounts to approximately 32000 Sm3/day as per the requirement given in Section 3.4.1.



Oil TVP (at 30 deg C)		
Temperature	30,00	C
Pressure	96,53	kPa
Molar Flow	6301	kgmole/h

Oil Export		
Liq Vol Flow @Std Cond	1333	m3/h
Temperature	60,00	C
Pressure	18750	kPa

Figure 6.1 : Oil Product Specifications from Hysys model

Table 6.1 gives the oil product composition extracted from the Hysys simulation model.

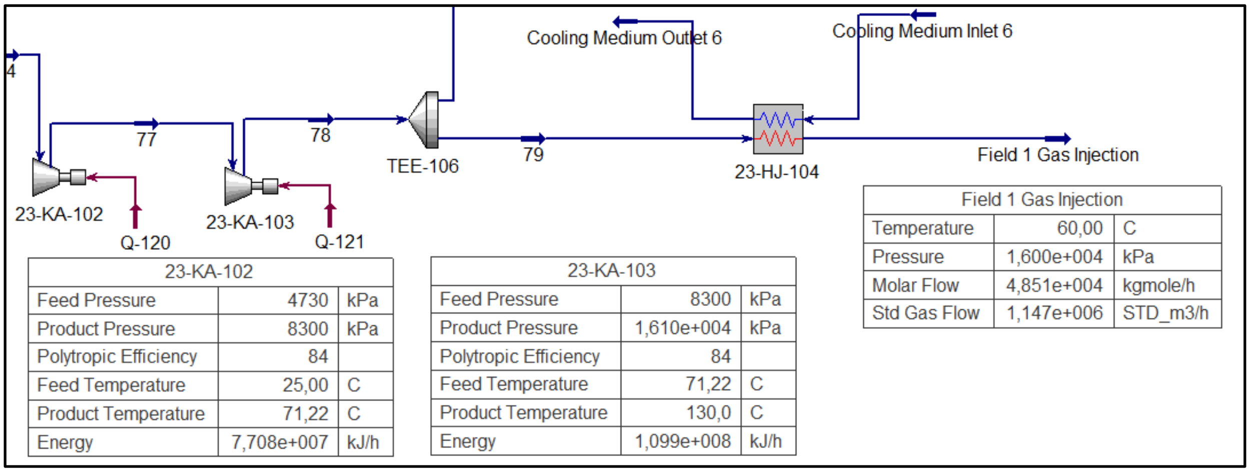
Table 6.1 : Oil Product Composition from Hysys model

	Mole Fraction	Liquid Phase	Aqueous Phase
Methane	0,0012	0,0015	0,0000
Ethane	0,0026	0,0034	0,0000
Propane	0,0085	0,0112	0,0000
i-Butane	0,0041	0,0054	0,0000
n-Butane	0,0111	0,0146	0,0000
i-Pentane	0,0079	0,0104	0,0000
n-Pentane	0,0097	0,0128	0,0000
n-Hexane	0,0172	0,0227	0,0000
H2O	0,2428	0,0020	1,0000
C7*	0,0358	0,0472	0,0000
Nitrogen	0,0000	0,0000	0,0000
C8*	0,0495	0,0653	0,0000
C9*	0,0384	0,0506	0,0000
C10-C12*	0,1384	0,1825	0,0000
C13-C15*	0,1052	0,1387	0,0000
C16-C17*	0,0555	0,0732	0,0000
C18-C20*	0,0666	0,0878	0,0000
C21-C24*	0,0608	0,0802	0,0000
C25-C28*	0,0444	0,0585	0,0000
C29-C34*	0,0444	0,0585	0,0000
C35-C43*	0,0333	0,0439	0,0000
C44-C80*	0,0222	0,0293	0,0000
CO2	0,0002	0,0003	0,0000

6.2.2 Modelled Injection Gas Specifications

Based on simulation model (Base Case Simulation) that was developed as part of this thesis work, the specifications of the injection gas from both Field 1 and Field 2 can be seen in Figures 6.2 & 6.3.

The total injection gas produced from the Field 1 gas injection train is 27.5 MSm3/day. The compressed gas exits the train at the injection pressure of 160 bara and at the injection temperature of 60^{o}C as per the requirements given in Section 3.4.2. Details can be seen in the Field 1 Gas Injection table in Figure 6.2.



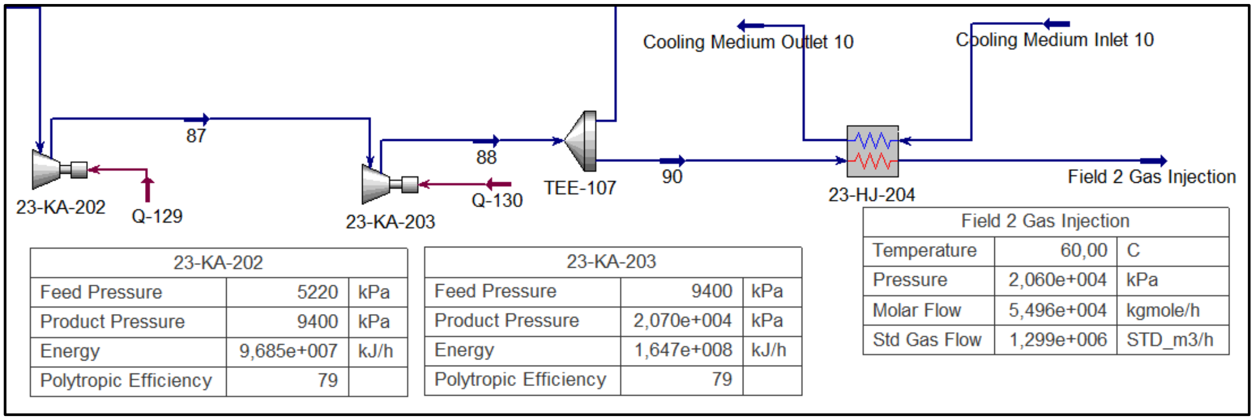
23-KA-102		
Feed Pressure	4730	kPa
Product Pressure	8300	kPa
Polytropic Efficiency	84	
Feed Temperature	25,00	C
Product Temperature	71,22	C
Energy	7,708e+007	kJ/h

23-KA-103		
Feed Pressure	8300	kPa
Product Pressure	1,610e+004	kPa
Polytropic Efficiency	84	
Feed Temperature	71,22	C
Product Temperature	130,0	C
Energy	1,099e+008	kJ/h

Field 1 Gas Injection		
Temperature	60,00	C
Pressure	1,600e+004	kPa
Molar Flow	4,851e+004	kgmole/h
Std Gas Flow	1,147e+006	STD_m3/h

Figure 6.2 : Field 1 Gas Product Specifications from Hysys model

The total injection gas produced from the Field 2 gas injection train accounts to 31.2 MSm3/day. The compressed gas exits the train at the injection pressure of 206 bara and at the injection temperature of 60°C as per the requirements given in Section 3.4.2. Details can be seen in the Field 2 Gas Injection table in Figure 6.3.



23-KA-202		
Feed Pressure	5220	kPa
Product Pressure	9400	kPa
Energy	9,685e+007	kJ/h
Polytropic Efficiency	79	

23-KA-203		
Feed Pressure	9400	kPa
Product Pressure	2,070e+004	kPa
Energy	1,647e+008	kJ/h
Polytropic Efficiency	79	

Field 2 Gas Injection		
Temperature	60,00	C
Pressure	2,060e+004	kPa
Molar Flow	5,496e+004	kgmole/h
Std Gas Flow	1,299e+006	STD_m3/h

Figure 6.3 : Field 2 Gas Product Specifications from Hysys model

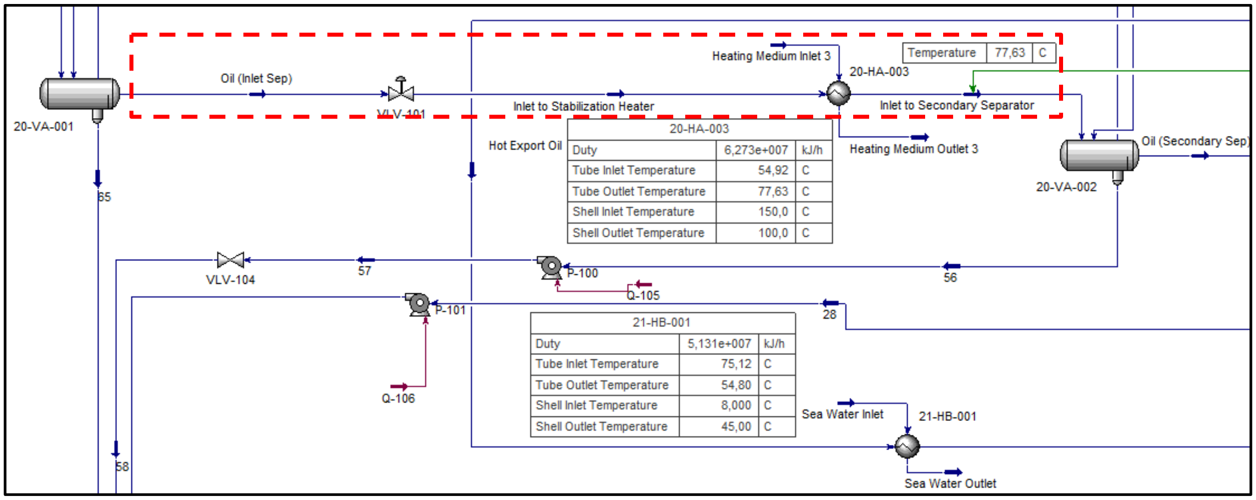
6.3 Case Study I – Removal of Stabilization Separator Cross Exchanger (20-HB-004)

In Case Study I, the Stabilization Separator Cross Exchanger (20-HB-004) between 20-VA-001 and 20-HA-003 is removed from the process design as seen in Figure 6.4. This exchanger was the first heat exchanger between the inlet and the secondary separators. The main application of this equipment was to integrate the heat from the high temperature stabilized oil into the hydrocarbon stream going to the secondary separator.

This case study is conducted in order to evaluate the possibility of removing one heat exchanger from the process flow and analyze the impact on the downstream equipments specially the heat exchangers that are linked to it. The intention is to simplify the process flow and reduce the number of equipments and the quantity of piping and then understand whether the connected heat exchangers can be redesigned to handle the additional heating and cooling duty and still produce the product within the required specifications.

The exchanger being studied (20-HB-004) has a two way application – First, it heats up the hydrocarbon stream from the inlet separator to about 63°C and this pre-heated hydrocarbon stream is heated further in the Stabilization Separator Heater (20-HA-003) to the required temperature of 77.6°C. However, owing to the pre-heating of the hydrocarbon stream, the required heating duty of 20-HA-003 is less resulting in a smaller exchanger being sufficient for the final heating application. This pre-heating is done against the stabilized oil stream. Secondly, 20-HB-004 cools downs the stabilized oil stream from the Stabilization Separator to about 66°C. This oil stream is pre-cooled in 20-HB-004 and then further cooled down in the Crude Oil Cooler (21-HB-001), downstream of 20-HB-004 to meet the export oil specifications. This pre-cooling results in a lower cooling duty for 21-HB-001 thereby making a smaller exchanger sufficient for the final cool down application.

Therefore to account for the heat integration into the process an additional exchanger (20-HB-004) is needed in order to reduce the heating and cooling duty demand of the mainstream exchangers (20-HA-003 & 21-HB-001).



20-HA-003		
Duty	6,273e+007	kJ/h
Tube Inlet Temperature	54,92	C
Tube Outlet Temperature	77,63	C
Shell Inlet Temperature	150,0	C
Shell Outlet Temperature	100,0	C

21-HB-001		
Duty	5,131e+007	kJ/h
Tube Inlet Temperature	75,12	C
Tube Outlet Temperature	54,80	C
Shell Inlet Temperature	8,000	C
Shell Outlet Temperature	45,00	C

Figure 6.4 : Case Study I – Hysys model

In this Case Study, a low temperature hydrocarbon stream (around 54°C) from the inlet separator enters 20-HA-003 and needs to be heated up to the temperature of 77.6°C to attain the required vapour pressure specifications downstream of 20-VA-003. This causes the revised exchanger design to have a much higher heat duty than the heat duty demand in the base case wherein the hydrocarbon stream is pre heated before entering 20-HA-003. The thermal design of 20-HA-003 in the base case scenario with the pre-heated hydrocarbon stream is given in Section 7.3.1 while the thermal design of the exchanger with the revised process parameters of the hydrocarbon stream is given in Section 7.3.2.

The changes in the main process parameters and exchanger design specifications between the base case and case study can be seen in Table 6.2. Owing to the removal of exchanger 20-HB-004, the temperature of the inlet stream into 20-HA-003 is lowered by 8°C. Since the outlet temperature of the hydrocarbon stream remains the same, an additional 53% of heating medium (mass flow) is required to meet the heating duty. Since the heating medium is the shell side fluid, a 26% increase in shell diameter is needed to accommodate the additional mass flowrate. The removal of 20-HB-004 results in a 40% increase in the heating duty of 20-HA-003 in order to meet the required outlet temperature of 77°C.

Table 6.2 : Comparison of exchanger design between Base case & Case study I (20-HA-003)

Sl No.	Process Parameter / Exchanger Specification	Unit	Base Case	Case Study I	Change
1	Flowrate of hydrocarbon Stream	kg/s	329	329	--
2	Inlet temperature of hydrocarbon stream	°C	63	55	-8
3	Outlet temperature of hydrocarbon stream	°C	77	77	--
4	Required flowrate of heating medium	kg/s	72	110	+53%
5	Total heat duty	KW	6352	8634	+40%
6	Shell – Inner Diameter (D)	mm	775	975	+26%
7	Tube length (L)	mm	6500	6500	--
8	Effective Surface Area per unit	m^2	611	986	+61%
9	Number of shells per unit		2	2	--
10	Number of shells in series		1	1	--
11	Number of shells in parallel		2	2	--
12	L/D Ratio (Ratio of tube length to shell ID)		8.4	6.7	--
13	Footprint	m^2	6.5	8.5	+31%
14	Weight/Shell	kg	5804	8848	+52%

Also as seen in the table above, an additional 61% of effective surface area is required to ensure that the necessary heating duty is met. In both the cases, the number of shells per unit stays the same with 2 shells in parallel and 1 shell in series. Considering the increase in dimensions, the footprint of each shell increases by 31% alongwith a 52% increase in the weight per shell. The L/D ratio also in both cases is within the range of 5 to 10 which is the standard range for optimum exchanger design.

The Crude Oil Cooler (21-HB-001), which cools the stabilized oil stream, is also impacted by the removal of 20-HB-004 from the process flow. It results in a very high temperature stabilized oil stream (around 75^{o}C) from the Stabilization Separator being routed downstream to 21-HB-001 to be cooled down to 54^{o}C to meet the export oil temperature specification. 21-HB-001 designed for this scenario requires a much higher cooling duty than the exchanger designed for the base case wherein the hot oil stream is pre-cooled in 20-HB-004. The base case thermal design of 21-HB-004 is given in Section 7.4.1 while the thermal design of the case study exchanger with the high temperature oil stream feed is given in Section 7.4.2.

The changes in the main process parameters and exchanger design specifications between the base case and case study can be seen in Table 6.3. Owing to the removal of exchanger 20-HB-004, the temperature of the inlet stream into 21-HB-001 is raised by 8^{o}C. Since the outlet temperature of the hydrocarbon stream after cooling remains the same, an additional 74% of cooling medium (mass flow) is required to meet the cooling duty. Since the cooling medium is the shell side fluid, a 5% increase in shell diameter is needed to accommodate the additional mass flowrate. Also a 7% increase in tube length is needed for the sufficient heat transfer. The removal of 20-HB-004 results in a 73% increase in the cooling duty of 21-HB-001 in order to meet the required outlet temperature of 54^{o}C.

Also an additional 19% of effective surface area is required to ensure that the necessary cooling duty is met. In both the cases, the number of shells per unit stays the same with 1 shell in parallel and 1 shell in series. Considering the increase in dimensions, the footprint of each shell increases by 11% alongwith a 21% increase in the weight per shell. The L/D ratio also in both cases is within the range of 5 to 10 which is the standard range for optimum exchanger design.

Table 6.3 : Comparison of exchanger design between Base case & Case study I (21-HB-001)

Sl No.	Process Parameter / Exchanger Specification	Unit	Base Case	Case Study I	Change
1	Flowrate of hydrocarbon Stream	kg/s	316	316	--
2	Inlet temperature of hydrocarbon stream	^{o}C	67	75	+8
3	Outlet temperature of hydrocarbon stream	^{o}C	54	54	--
4	Required flowrate of heating medium	kg/s	50	87	+74%
5	Total heat duty	KW	8175	14162	+73%
6	Shell – Inner Diameter (D)	mm	1050	1100	+5%

Sl No.	Process Parameter / Exchanger Specification	Unit	Base Case	Case Study I	Change
7	Tube length (L)	mm	6500	7000	+7%
8	Effective Surface Area per unit	m^2	562	668	+19%
9	Number of shells per unit		1	1	--
10	Number of shells in series		1	1	--
11	Number of shells in parallel		1	1	--
12	L/D Ratio (Ratio of tube length to shell ID)		6.2	6.4	--
13	Footprint	m^2	9.1	10.1	+11%
14	Weight/Shell	kg	9495	11453	+21%

Table 6.4 gives a comparison between the process parameters and dimensional details of the redesigned exchangers 20-HA-003 and 21-HB-001 and the base case exchanger 20-HB-004. The columns 20-HA-003 (added) and 21-HB-001 (added) show the quantum of the parameter that has been added by redesigning these exchangers while the column 20-HB-004 (removed) shows the quantum of that specific parameter has been saved by removing the exchanger 20-HB-004 from the process design.

This case study shows that removal of the exchanger 20-HB-004 will require the linked exchangers 20-HA-003 and 21-HB-001 to be redesigned. Table 6.2 and 6.3 show that the redesigned exchangers can handle the additional heating and cooling demand required to meet the product specifications. Table 6.4 shows that removal of 20-HB-004 and redesigning of 20-HA-003 and 21-HB-001 gives us a weight saving of 4032 kgs alongwith a footprint savings of 6.6m^2 which accounts for cost saving considering the cost impact of weight and footprint in topside systems. The sufficient heating duty available from the Waste Heat Recovery units can handle the additional 2208 KW of heating demand with minor changes to the heating medium system.

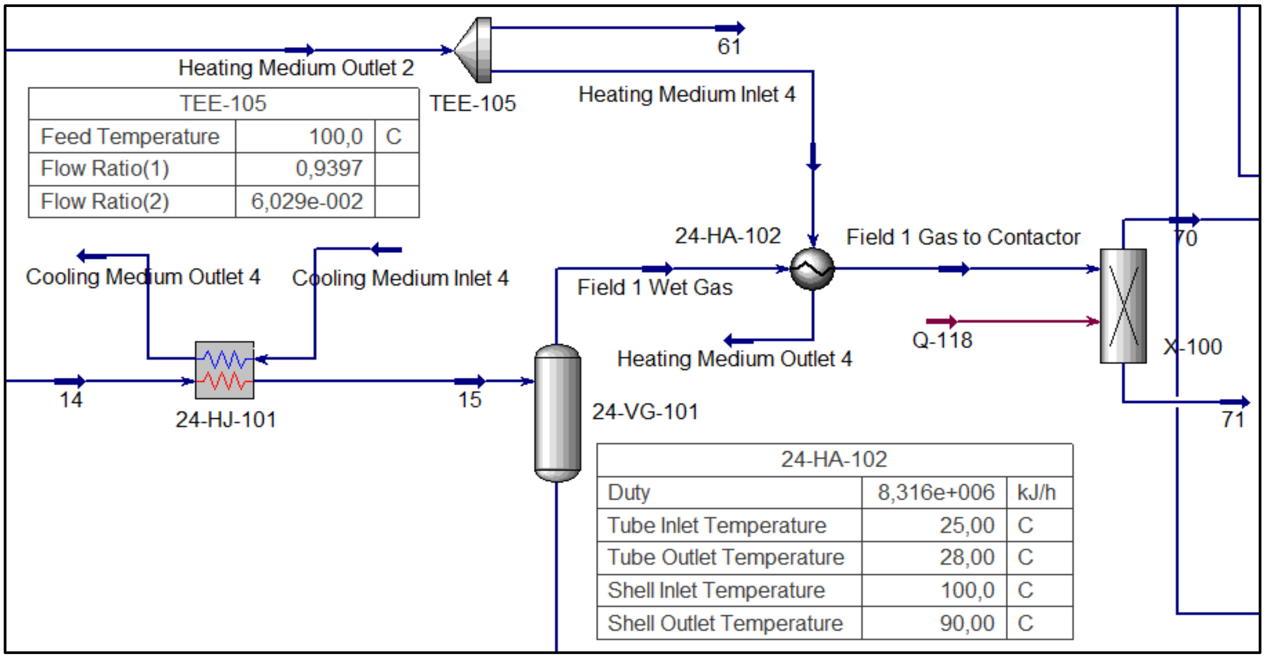
Table 6.4 : Comparison table for 20-HA-003, 21-HB-001 and 20-HB-004 – Case Study I

Sl No.	Process Parameter / Exchanger Specification	Unit	20-HA-003 Case Study I (Added)	21-HB-001 Case Study I (Added)	20-HB-004 Base Case (Removed)	Net Savings
1	Number of shells		0	0	2	+2
2	Weight	kg	3044	1958	9034	+4032
3	Footprint	m^2	2.0	1.0	9.6	+6.6
4	Total Heat Duty	KW	2282	5987	6061	-2208
5	Effective Surface Area per unit	m^2	375	106	405	-76

6.4 Case Study II – Feeding Low Temperature Heating Medium to Injection train Superheaters (24-HA-102 & 24-HA-202)

In the base case simulation, the process parameters of the gas flow through the Field 1 & 2 Dehydration Inlet Superheaters (24-HA-102 and 24-HA-202 respectively) are such that the heat exchangers designed for that application have a very non-optimum design. The 1st stage compressed gas from the Dehydration Scrubbers (24-VG-101 & 24-VG-201) needs to be heated up by 3°C while the heating medium has a temperature reduction of 50°C based on the specifications of the heating medium system. The pressure and temperature parameters make plate and frame exchangers an unviable option. The resulting shell and tube exchanger design has a very low L/D ratio (approximately 2) and also the low LMTD and the high viscosity make it difficult to obtain turbulent flow resulting in a non-optimum design of these heat exchangers.

In Case Study II, the non-optimum design of 24-HA-102 and 24-HA-202 is analyzed and probable options of improving the design are studied. Reducing the required outlet temperature of the hydrocarbon stream has a limited effect on improving the thermal design. However, reducing the inlet temperature of the heating medium as can be seen in Figure 6.5 and 6.6, has a substantial impact on improving the heat transfer and overall design of the heat exchanger.



TEE-105		
Feed Temperature	100,0	C
Flow Ratio(1)	0,9397	
Flow Ratio(2)	6,029e-002	

24-HA-102		
Duty	8,316e+006	kJ/h
Tube Inlet Temperature	25,00	C
Tube Outlet Temperature	28,00	C
Shell Inlet Temperature	100,0	C
Shell Outlet Temperature	90,00	C

Figure 6.5 : Case Study II – Low Temperature Heating Medium to 24-HA-102 – Hysys model

Since a lower temperature heating medium helps in achieving a more favourable design, the cold heating medium at 100°C exiting the Field 1 and Field 2 Inlet Heaters (20-HA-001 & 20-HA-002) is routed to 24-HA-202 and 24-HA-102 respectively. Since the heating medium needs to return to the Waste Heat Recovery Unit around 100°C, it is assumed that the outlet temperature of the heating medium from 24-HA-102 and 24-HA-202 be set at 90°C so there is not much deviation from the specifications of the heating medium system. Also the difference in dimension and heating duty between the inlet heaters and the wet gas superheaters requires that the flow of heating medium from the inlet heaters be spilt and part of it is sent to the superheaters while the remaining part of the heating medium is routed to the heating medium system.

As is seen in Figure 6.5, the heating medium outlet at 100^{o}C from 20-HA-002 is routed to a flow splitter and one part is sent downstream to 24-HA-102. Since the inlet and outlet temperatures values of 100^{o}C and 90^{o}C are fed into the Hysys model, the required flowrate is automatically calculated and the split in flow is derived accordingly. In the case of 24-HA-102, 6% of the total heating medium outlet from 20-HA-002 is routed to 24-HA-102 and the remaining flow is routed to the heating medium system. The 6% flow is sufficient for superheating the Field 1 wet gas by 3^{o}C. The base case thermal design of 24-HA-102 where normal heating medium with 150^{o}C was used is given in Section 7.2.1 while the thermal calculations of the redesigned heat exchanger with the lower temperature heating medium is given in Section 7.2.2

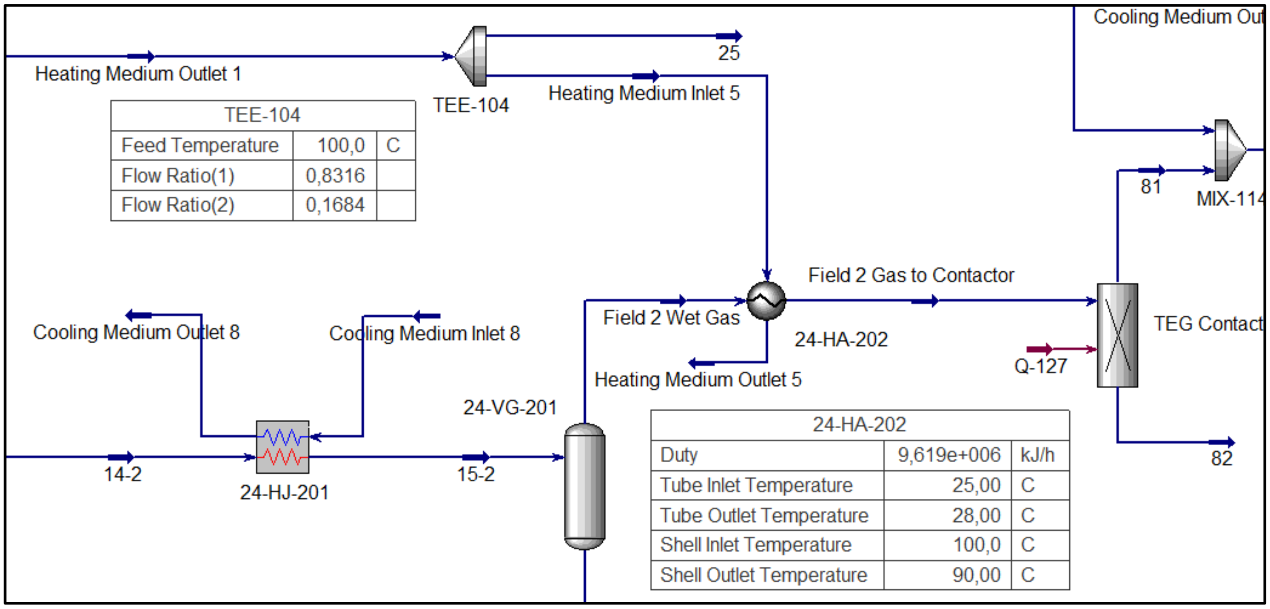
The changes in the main process parameters and exchanger design specifications between the base case and case study can be seen in Table 6.5. The high temperature of the heating medium in the base case design results in a non-optimum exchanger design with extreme dimensions (L/D ratio = 2) since the heating medium flowrate requirement is very less. However, on reducing the inlet temperature of the heating medium stream, the required flowrate increases by 4.5 times which in turn improves the dimensions of the revised exchanger.

Table 6.5 : Comparison of exchanger design between Base case & Case study II (24-HA-102)

Sl No.	Process Parameter / Exchanger Specification	Unit	Base Case	Case Study II	Change
1	Flowrate of hydrocarbon Stream	kg/s	266	266	--
2	Inlet temperature of heating medium	^{o}C	150	100	-50
3	Outlet temperature of heating medium	^{o}C	100	90	--
4	Required flowrate of heating medium	kg/s	15	77	+413%
5	Total heat duty	KW	1950	2100	+7%
6	Shell – Inner Diameter (D)	mm	875	975	+11%
7	Tube length (L)	mm	1750	5000	+185%
8	Effective Surface Area per unit	m^{2}	73	261	257%
9	Number of shells per unit		1	1	--
10	Number of shells in series		1	1	--
11	Number of shells in parallel		1	1	--
12	L/D Ratio (Ratio of tube length to shell ID)		2,00	5,13	--
13	Footprint	m^{2}	3,24	6,90	+113%
14	Weight/Shell	kg	7045	14997	+113%

The lower temperature of the heating medium results in longer tube lengths (increase of around 200%) with a slight increase in shell diameter (around 11%). The increased tube length gives a L/D ratio within the range of 5 and 10 which is one of the important criteria for an optimum heat exchanger design. The heat duty of the redesigned exchanger remains quite similar to that of the original design and so does the number of shells per unit. Only 1 shell per unit is sufficient to handle the required heating duty both in the base case design and in the case study. The revised dimensions of the case study heat exchanger cause a 113% increase in the footprint of the equipment which is also the reason for the weight of the equipment to increase from 7045 kgs to 14997kgs. Therefore, a major concern with the redesigned exchanger is the increase in the weight per unit.

A similar kind of arrangement as is explained above has been done for the superheater on the Field 2 gas injection train – 24-HA-202, seen in Figure 6.6. The heating medium outlet at 100^{o}C from 20-HA-001 is routed to a flow splitter and one part is sent downstream to 24-HA-202. Since the inlet and outlet temperatures values of 100^{o}C and 90^{o}C are fed into the Hysys model, the required flowrate is automatically calculated and the split in flow is derived accordingly. In the case of 24-HA-202, 17% of the total heating medium outlet from 20-HA-001 is routed to 24-HA-202 and the remaining flow is routed to the heating medium system. The 17% flow is sufficient for superheating the Field 2 wet gas by 3^{o}C. The base case thermal design of 24-HA-202 where normal heating medium with 150^{o}C was used is given in Section 7.2.1 while the thermal calculations of the redesigned heat exchanger is given in Section 7.2.2



TEE-104		
Feed Temperature	100,0	C
Flow Ratio(1)	0,8316	
Flow Ratio(2)	0,1684	

24-HA-202		
Duty	9,619e+006	kJ/h
Tube Inlet Temperature	25,00	C
Tube Outlet Temperature	28,00	C
Shell Inlet Temperature	100,0	C
Shell Outlet Temperature	90,00	C

Figure 6.6 : Case Study II – Low Temperature Heating Medium to 24-HA-202 – Hysys model

The changes in the main process parameters and exchanger design specifications between the base case and case study can be seen in Table 6.6. Similar to the discussion above, the high temperature of the heating medium in the base case design results in a non-optimum exchanger design with extreme dimensions (L/D ratio = 2) since the heating medium flowrate requirement is very less. However, on reducing the inlet temperature of the heating medium stream, the dimensions of the redesigned exchanger are improved owing to a drastic increase in the flowrate requirement of the heating medium. To allow for the necessary heat transfer to occur with the lower temperature of the heating medium, the tube length is increased (increase of around 270%) with a slight increase in shell diameter (around 14%). The increased tube length gives a L/D ratio within the range of 5 and 10 which is one of the important criteria for an optimum heat exchanger design.

Table 6.6 : Comparison of exchanger design between Base case & Case study II (24-HA-102)

Sl No.	Process Parameter / Exchanger Specification	Unit	Base Case	Case Study II	Change
1	Flowrate of hydrocarbon Stream	kg/s	301	301	--
2	Inlet temperature of heating medium	^oC	150	100	-50
3	Outlet temperature of heating medium	^oC	100	90	--
4	Required flowrate of heating medium	kg/s	17	89	+423%
5	Total heat duty	KW	2350	2175	
6	Shell – Inner Diameter (D)	mm	875	1000	+14%
7	Tube length (L)	mm	1750	6500	+271%
8	Effective Surface Area per unit	m^2	73	368	+400%
9	Number of shells per unit		1	1	--
10	Number of shells in series		1	1	--
11	Number of shells in parallel		1	1	--
12	L/D Ratio (Ratio of tube length to shell ID)		2,00	6,50	--
13	Footprint	m^2	3,24	8,62	+166%
14	Weight/Shell	kg	7045	17402	+147%

The heat duty of the redesigned exchanger remains quite similar to that of the original design and so does the number of shells per unit. Only 1 shell per unit is sufficient to handle the required heating duty both in the base case design and in the case study. The revised dimensions of the case study heat exchanger cause a 166% increase in the footprint of the equipment which is also the reason for the weight of the equipment to increase from 7045 kgs to 17402 kgs. Therefore, a major concern with the redesigned exchanger is the increase in the weight per unit.

In the offshore oil and gas industry, considering the importance of weight and footprint of equipments in topside systems, the cost and other benefits of optimizing the exchanger design will have to be evaluated against the additional cost due to weight increase and then a decision will have to be made based on the evaluation.

6.5 Case Study III – Removal of Superheater and Scrubber unit prior to Gas Dehydration

In the base case process design, the wet gas in the Field 1 and Field 2 gas injection trains is cooled down in the dehydration inlet coolers (24-HJ-101 and 24-HJ-201) downstream of the Field 1 and Field 2 1st Stage Injection Compressors (23-KA-101 and 23-KA-201). After cooling the liquid phase is extracted in the dehydration inlet scrubbers in both the trains (24-VG-101 and 24-VG-201) and the gas phase is superheated by 3°C in the dehydration inlet superheaters (24-HA-102 and 24-HA-202). The superheated gas at around 28°C to 30°C is then routed downstream to the Field 1 and Field 2 TEG Contactors for dehydration.

In this case study, the dehydration inlet scrubbers and the wet gas superheaters in both the trains are removed from the process design. As a result, the wet gas needs to be cooled less since there is no extraction of the liquid phase. The outlet temperature of the wet gas from 24-HJ-101 and 24-HJ-201 is set in order to avoid any chance of condensation in the TEG Contactors. This case study is also conducted in order to simplify the process design by reducing certain equipments in the Field 1 and Field 2 gas injection trains and then analyze the impact on the heat exchangers upstream of the equipments that have been removed.

As is seen in Figure 6.7, the wet gas downstream of 23-KA-101 is cooled down to 51°C in 24-HJ-101 before being routed to the Field 1 TEG contactor for dehydration. The outlet temperature of the wet gas stream from 24-HJ-101 is decided based the hydrocarbon phase envelope in order to ensure that the temperature of the wet gas stream entering the TEG Contactor is above the hydrocarbon dew point. The base case thermal design of 24-HJ-101 is given in Section 7.5.1 while the thermal calculations of the redesigned heat exchanger with a much lower cooling duty demand is given in Section 7.5.2.

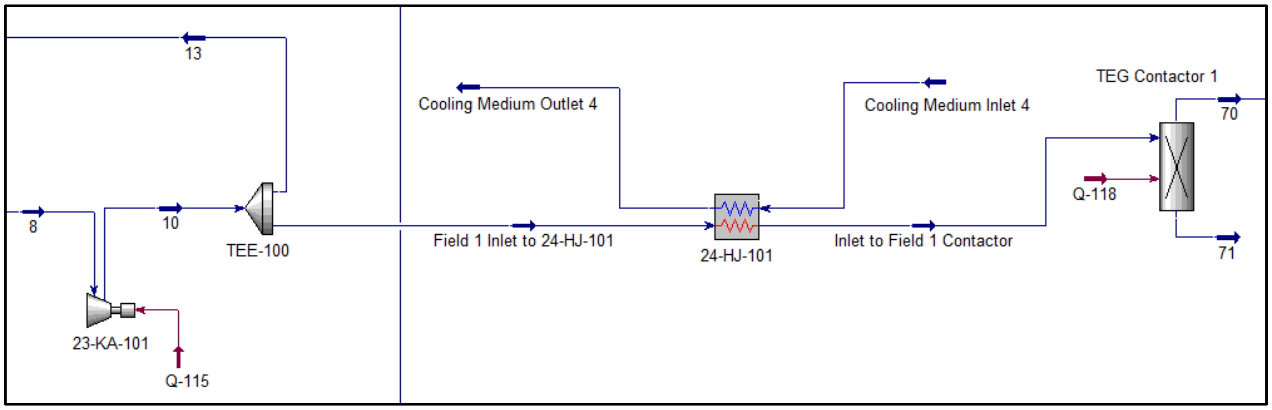


Figure 6.7 : Case Study III – Removal of Scrubber and Superheater unit before TEG Contactor 1 – Hysys model

The inlet and outlet temperatures of the cooling medium stream (20°C and 80°C respectively) are kept the same in the base case design and the case study. The changes in the main process parameters and exchanger design specifications between the base case and case study can be seen in Table 6.7.

Table 6.7 : Comparison of exchanger design between Base Case & Case study III (24-HJ-101)

Sl No.	Process Parameter / Exchanger Specification	Unit	Base Case	Case Study III	Change
1	Flowrate of hydrocarbon Stream	kg/s	268	268	--
2	Inlet temperature of wet gas stream	^{o}C	135	135	--
3	Outlet temperature of wet gas stream	^{o}C	25	51	+26
4	Required flowrate of cooling medium	kg/s	446	342	-23%
5	Total Cooling Duty	KW	74541	57144	-24%
6	Shell – Inner Diameter (D)	mm	2000	1550	-23%
7	Tube length (L)	mm	7500	9000	+20%
8	Effective Surface Area per unit	m^2	3512	2589	-26%
9	Number of shells per unit		2	2	--
10	Number of shells in series		1	1	--
11	Number of shells in parallel		2	2	--
12	L/D Ratio (Ratio of tube length to shell ID)		3,75	5,81	
13	Footprint	m^2	14.4	7,5	-48%
14	Weight/Shell	kg	76914	46586	-40%

The weight, footprint and dimensions of the base case exchanger shows that the equipment is of a very non-optimum design. Even the L/D ratio of this exchanger is outside the range for optimum design. In the case of the redesigned exchanger, the higher outlet temperature results in a lower cooling duty which causes a reduction in the scale of the exchanger. The revised dimensions of the case study exchanger give a 40% reduction in the weight per shell alongwith a 48% reduction in footprint. The L/D ratio also increases to 5.81 which is within the range required for optimum design. The process parameters in the base case design result in a very high effective surface area requirement which remains still high even in the case study redesigned exchanger. The weight of this equipment, both in the base case scenario and in the case study will account for a huge cost factor and it is advisable to substitute this shell and tube exchanger with a compact heat exchanger.

Since the pressure of the hot stream is higher than 35 bar, plate and frame exchanger is not a viable option. However, a Printed Circuit Heat Exchanger (PCHE) can be designed for this application. A PCHE can operate within this pressure range, handle the required scale of heat transfer and at the same time the exchanger design will be much more compact with a drastically lower weight and footprint factor. The cost benefit owing to weight and footprint savings will definitely favour the selection of a compact heat exchanger for this application.

The arrangement for the Field 2 injection train is similar to that as explained above for the Field 1 injection train. As seen in Figure 6.8, the Field 2 wet gas in compressed in 23-KA-201 and then routed downstream to the Field 2 Dehydration Inlet Cooler (24-HJ-201). In this case study, 24-HJ-201 cools downs the gas from 135^{o}C to 53^{o}C before it is routed downstream to the Field 2 TEG Contactor. The outlet temperature of the wet gas from 24-HJ-201 is determined from the hydrocarbon phase envelope of the gas phase such that the gas entering the TEG contactor is above its hydrocarbon dew point. This is done to ensure that no condensation occurs inside the TEG contactor. The base case thermal design of 24-HJ-201 is given in Section 7.5.1 while the thermal calculations of the redesigned heat exchanger with a much lower cooling duty demand is given in Section 7.5.2.

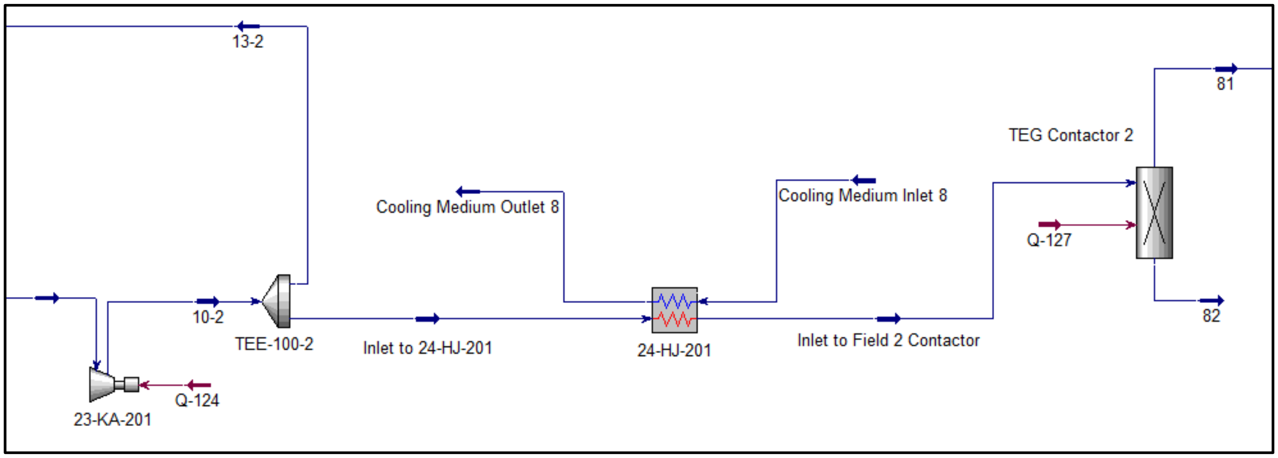


Figure 6.8 : Case Study III – Removal of Scrubber and Superheater unit before TEG Contactor 2 – Hysys model

The changes in the main process parameters and exchanger design specifications between the base case and case study can be seen in Table 6.8. Even in the case of this exchanger, the weight, footprint and dimensions of the base case design shows that the equipment is of a very non-optimum design. Even the L/D ratio of this exchanger is outside the range for optimum design. In the case of the redesigned exchanger, the higher outlet temperature results in a lower cooling duty which causes a reduction in the scale of the exchanger. The revised dimensions of the case study exchanger give a 26% reduction in the weight per shell alongwith a 15% reduction in footprint. The L/D ratio also increases to 5.29 which is within the range required for optimum design. The process parameters in the base case design result in a very high effective surface area requirement which remains still high even in the case study redesigned exchanger. The weight of this equipment, both in the base case scenario and in the case study will account for a huge cost factor and it is advisable to substitute this shell and tube exchanger with a compact heat exchanger too.

Since the pressure of the hot stream is higher than 35 bar, plate and frame exchanger is not a viable option. However, a Printed Circuit Heat Exchanger (PCHE) can be designed for this application also. A PCHE can operate within this pressure range, handle the required scale of heat transfer and at the same time the exchanger design will be much more compact with a drastically lower weight and footprint factor. The cost benefit owing to weight and footprint savings will definitely favour the selection of a compact heat exchanger for this application.

Table 6.8 : Comparison of exchanger design between Base Case & Case study III (24-HJ-201)

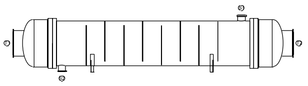
Sl No.	Process Parameter / Exchanger Specification	Unit	Base Case	Case Study III	Change
1	Flowrate of hydrocarbon Stream	kg/s	304	304	--
2	Inlet temperature of wet gas stream	^oC	142	142	--
3	Outlet temperature of wet gas stream	^oC	25	53	+28
4	Required flowrate of cooling medium	kg/s	546	418	-24%
5	Total Cooling Duty	KW	90985	69726	-24%
6	Shell – Inner Diameter (D)	mm	2000	1700	-15%
7	Tube length (L)	mm	8500	9000	+6%
8	Effective Surface Area per unit	m^2	3999	3096	-23%
9	Number of shells per unit		2	2	--
10	Number of shells in series		1	1	--
11	Number of shells in parallel		2	2	--
12	L/D Ratio (Ratio of tube length to shell ID)		4,25	5,29	--
13	Footprint	m^2	24,5	20,9	-15%
14	Weight/Shell	kg	81906	60439	-26%

7.0 Thermal Calculations of Heat Exchangers

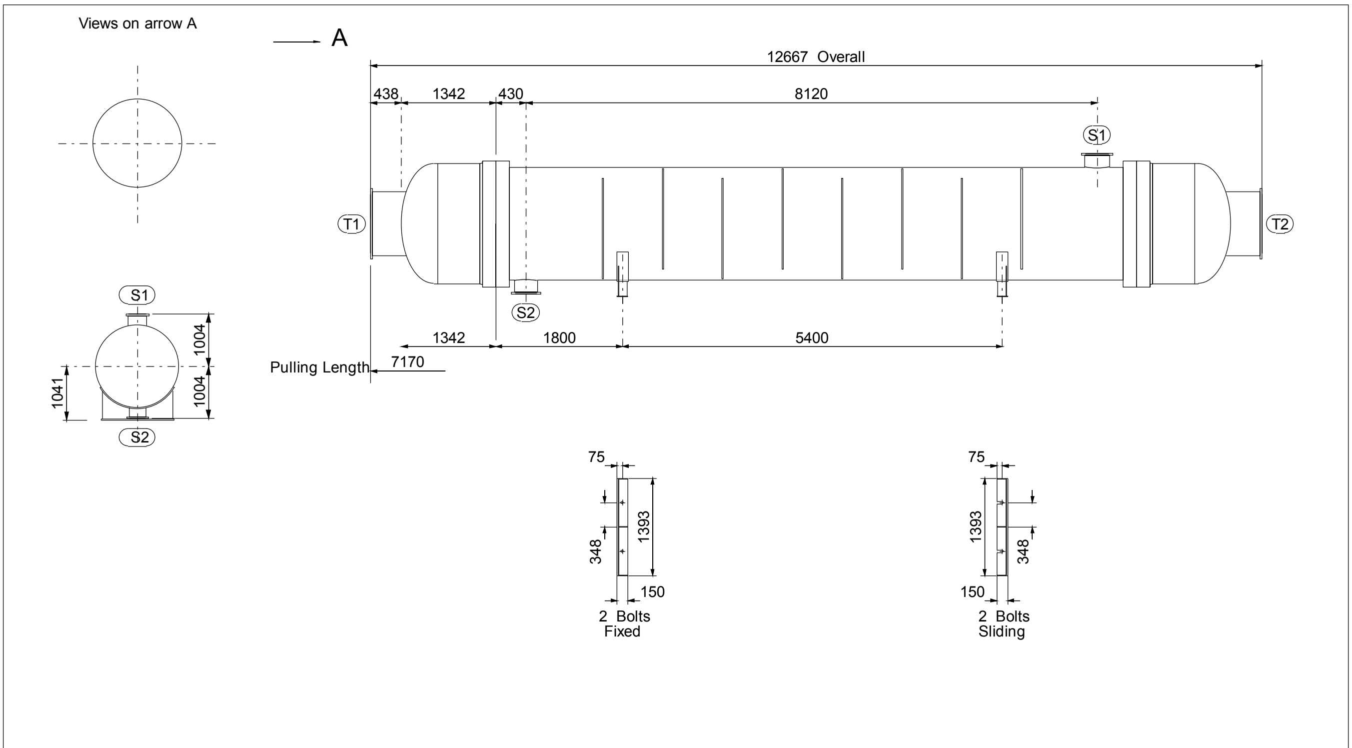
This chapter includes the thermal calculations of the heat exchangers in the base case simulation followed by the thermal calculations of the heat exchangers in the different case studies wherein the process parameters are modified and the exchanger has been redesigned.

7.1 Thermal calculations for Inlet Heaters (20-HA-001 & 20-HA-002) – Base Case Design

Heat Exchanger Specification Sheet

1	Field 2 Inlet Heater							
2	20-HA-001							
3	Base Case Simulation							
4	2 X 50% configuration							
5								
6	Size	1575--9000	mm	Type BEM	Hor	Connected in	2 parallel	1 series
7	Surf/unit(eff.)	2028	m^2	Shells/unit 2		Surf/shell (eff.)	1014	m^2
8	**PERFORMANCE OF ONE UNIT**							
9	Fluid allocation			Shell Side		Tube Side		
10	Fluid name			Heating Medium Inlet 1		Field 2 Inlet		
11	Fluid quantity, Total		kg/s	262,9586		1007,116		
12	Vapor (In/Out)		kg/s	0	0	104,3228	171,2098	
13	Liquid		kg/s	262,9586	262,9586	902,7936	835,9066	
14	Noncondensable		kg/s	0	0	0	0	
15								
16	Temperature (In/Out)		°C	150	110,9	46	55,67	
17	Dew / Bubble point		°C					
18	Density	Vapor/Liquid	kg/m^3	/ 1003	/ 1054	12,62 / 819,54	12,16 / 816	
19	Viscosity		mPa s	/ 1,15	/ 1,2046	0,1106 / 4,1438	0,1034 / 4,1145	
20	Molecular wt, Vap					20,94	20,85	
21	Molecular wt, NC							
22	Specific heat		kJ/(kg K)	/ 3,29	/ 3,273	2,19 / 2,074	2,19 / 2,077	
23	Thermal conductivity		W/(m K)	/ 0,231	/ 0,2309	0,0351 / 0,1123	0,0352 / 0,1123	
24	Latent heat		kJ/kg			18,6	18,6	
25	Pressure (abs)		bar	11	10,86387	16	15,51067	
26	Velocity		m/s	1,29		10,75		
27	Pressure drop, allow./calc.		bar	1	0,13613	0,5	0,48933	
28	Fouling resist. (min)		m^2 K/W	0		0	0 Ao based	
29	Heat exchanged	41528	kW			MTD corrected	102,09	°C
30	Transfer rate, Service	12,9		Dirty 616,2		Clean 616,2		W/(m^2 K)
31	**CONSTRUCTION OF ONE SHELL**					**Sketch**		
32				Shell Side	Tube Side			
33	Design/vac/test pressure:g		bar	20/ /	120/ /			
34	Design temperature		°C	180	180			
35	Number passes per shell			1	1			
36	Corrosion allowance		mm	3,18	0			
37	Connections	In	mm	1 350/ -	1 900/ -			
38	Size/rating	Out		1 300/ -	1 900/ -			
39	Nominal	Intermediate		/ -	/ -			
40	Tube No. 1180	OD 31,75	Tks-Avg 2,11	mm	Length 9000	mm	Pitch 40	mm
41	Tube type Plain		#/m	Material 22Cr,5Ni,3Mo steel		Tube pattern 30		
42	Shell Carbon Steel	ID 1575	OD 1609	mm	Shell cover	-		
43	Channel or bonnet	22Cr,5Ni,3Mo steel			Channel cover	-		
44	Tubesheet-stationary	22Cr,5Ni,3Mo steel	-		Tubesheet-floating	-		
45	Floating head cover	-			Impingement protection	None		
46	Baffle-crossing SS 316L	Type Single segmental		Cut(%d) 10	H	Spacing: c/c	850	mm
47	Baffle-long	-	Seal type		Inlet	1332,48	mm	
48	Supports-tube	U-bend		Type				
49	Bypass seal		Tube-tubesheet joint	Exp.				
50	Expansion joint	-	Type	None				
51	RhoV2-Inlet nozzle	2203	Bundle entrance 188		Bundle exit 187		kg/(m s^2)	
52	Gaskets - Shell side	-	Tube Side		Flat Metal Jacket Fibe			
53	Floating head	-						
54	Code requirements	EN13445			TEMA class	R - refinery service		
55	Weight/Shell	64287,7	Filled with water 88508,4		Bundle	25340,6	kg	
56	Remarks							
57								
58								

Setting Plan



Nozzle Data				
Ref	OD	Wall	Standard	Notes
S1	356 mm	10, mm	150 ANSI Slip on	
S2	324 mm	10, mm	150 ANSI Slip on	
T1	914 mm	36, mm	150 ANSI Slip on	
T2	914 mm	36, mm	150 ANSI Slip on	

Design Data	Units	Shell	Channel
Design Pressure	bar	20,	120,
Design Temperature	C	180,	180,
Full Vacuum			
Corrosion Allowance	mm	3,175	0,
Test Pressure	bar		
Number of Passes		1	1
Radiography			
PWHT			
Internal Volume	m³	16,8516	4,9833

Weight Summary		
Empty	Flooded	Bundle
64288 kg	88508 kg	25341 kg

Field 2 Inlet Heater
20-HA-001
Base Case Simulation
2 X 50% configuration

Design Codes
EN13445
TEMA R

Customer Specifications

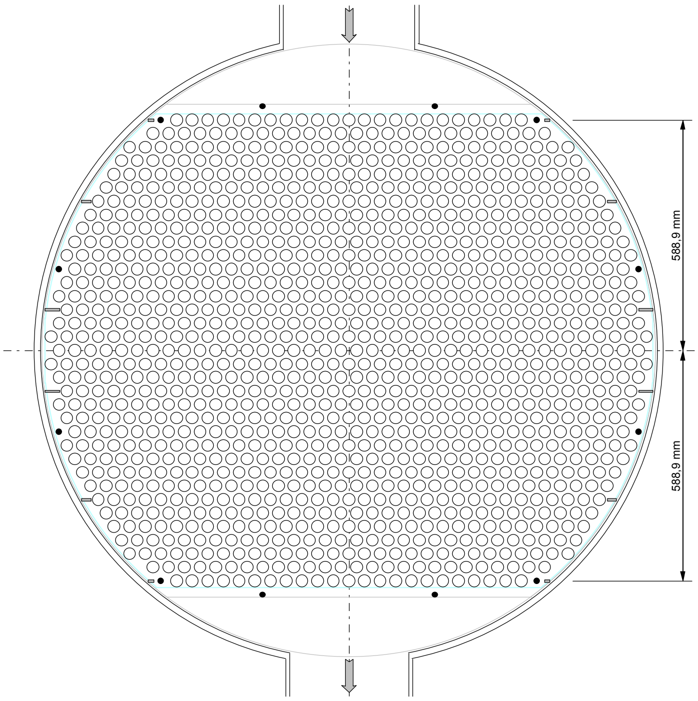
Aspen Shell & Tube Exchanger

Setting Plan
BEM 1575 - 9000

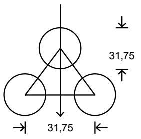
Drawing Number

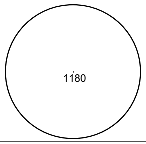
Revision	Date	Dwg.	Chk.	App.
	4.6.2014			

Tube Layout



Shell inside diameter	mm	1575,
Front head inside diameter	mm	1575,
Outer tube limit	mm	1560,712
Tube number (calcs.)		1180
Tube number (layout)		1180
Tube O.D.	mm	31,75
Tube pitch	mm	40,
Tube pattern		30
Tube passes		1
Tie rod number		12
Tie rod diameter	mm	15,875
Sealing strips (pairs)		6
Baffle type		Single segmental
Impingement protection		None
Tube length	mm	9000,
Shell Side Inlet Nozzle Inside Diameter	mm	335,6
Shell Side Outlet Nozzle Inside Diameter	mm	303,9





Field 2 Inlet Heater
20-HA-001
Base Case Simulation
2 X 50% configuration

Design Codes
EN13445
TEMA R - refinery service

Customer Specifications

Aspen Shell & Tube

Tube Layout

Drawing Number

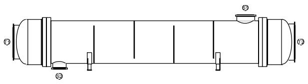
Revision	Date	Dwg.	App.
	4.6.2014		

Heat Exchanger Specification Sheet

1	Field 1 Inlet Heater							
2	20-HA-002							
3	Base Case Simulation							
4	2 X 50% Configuration							
5								
6	Size	1150--7400	mm	Type BEM	Hor	Connected in	2 parallel	1 series
7	Surf/unit(eff.)	824,2	m^2	Shells/unit 2		Surf/shell (eff.)	412,1	m^2

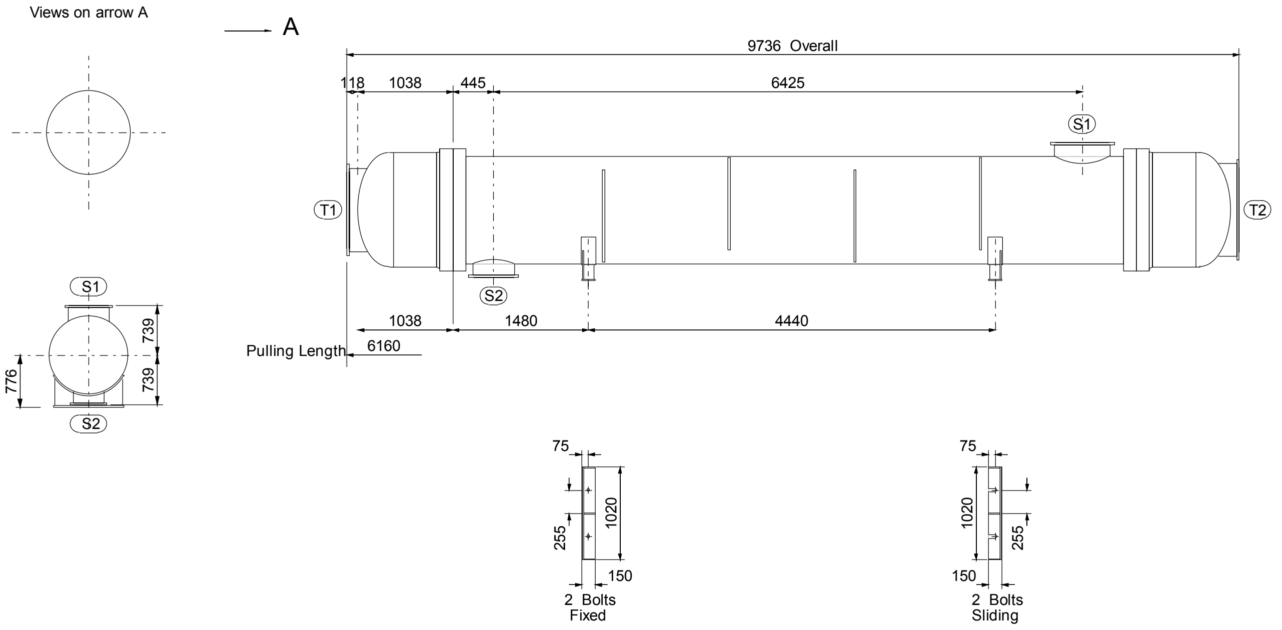
8	**PERFORMANCE OF ONE UNIT**					
9	Fluid allocation		Shell Side		Tube Side	
10	Fluid name		Heating Medium Inlet 2		Field 1 Inlet	
11	Fluid quantity, Total	**kg/s**	635,072		910,7961	
12	Vapor (In/Out)	**kg/s**	0	0	117,4927	129,1628
13	Liquid	**kg/s**	635,072	635,072	793,3034	781,6333
14	Noncondensable	**kg/s**	0	0	0	0
15						
16	Temperature (In/Out)	**°C**	150	116,12	29,81	54,71
17	Dew / Bubble point	**°C**				
18	Density Vapor/Liquid	**kg/m^3**	/ 1003	/ 1054	12,75 / 834,23	11,88 / 828,21
19	Viscosity	**mPa s**	/ 1,15	/ 2,438	0,0118 / 6,4215	0,0122 / 5,4174
20	Molecular wt, Vap				20,08	20,07
21	Molecular wt, NC					
22	Specific heat	**kJ/(kg K)**	/ 3,29	/ 3,02	2,173 / 2,006	2,191 / 2,057
23	Thermal conductivity	**W/(m K)**	/ 0,231	/ 0,2295	0,0333 / 0,1144	0,0351 / 0,1139
24	Latent heat	**kJ/kg**			25,7	27,4
25	Pressure (abs)	**bar**	11	10,39471	16	15,0095
26	Velocity	**m/s**	3,93		17,09	
27	Pressure drop, allow./calc.	**bar**	1	0,60529	1	0,9905
28	Fouling resist. (min)	**m^2 K/W**	0		0	0 Ao based

29	Heat exchanged	50244,1	**kW**		MTD corrected	101,68	**°C**
30	Transfer rate, Service	599,5	Dirty 668,8	Clean 668,8			**W/(m^2 K)**

31	**CONSTRUCTION OF ONE SHELL**					**Sketch**
32				Shell Side	Tube Side	
33	Design/vac/test pressure:g		**bar**	21/ /	120/ /	
34	Design temperature		**°C**	180	180	
35	Number passes per shell			1	1	
36	Corrosion allowance		**mm**	3	0	
37	Connections	In	**mm**	1 600/ -	1 900/ -	
38	Size/rating	Out		1 450/ -	1 1000/ -	
39	Nominal	Intermediate		/ -	/ -	

40	Tube No. 581	OD 31,75	Tks-Avg 2,11	**mm**	Length 7400	**mm**	Pitch 39,69		**mm**
41	Tube type Plain		**#/m**	Material 22Cr,5Ni,3Mo steel		Tube pattern 30			
42	Shell Carbon Steel	ID 1150	OD 1178	**mm**	Shell cover	-			
43	Channel or bonnet	22Cr,5Ni,3Mo steel			Channel cover	-			
44	Tubesheet-stationary	22Cr,5Ni,3Mo steel	-		Tubesheet-floating	-			
45	Floating head cover	-			Impingement protection	None			
46	Baffle-crossing SS 316L	Type Single segmental	Cut(%d) 12,99	H	Spacing: c/c	1370			**mm**
47	Baffle-long	-	Seal type		Inlet	1500,48			**mm**
48	Supports-tube	U-bend			Type				
49	Bypass seal		Tube-tubesheet joint		Exp.				
50	Expansion joint	-	Type	None					
51	RhoV2-Inlet nozzle	1345	Bundle entrance 941		Bundle exit 911				**kg/(m s^2)**
52	Gaskets - Shell side	-	Tube Side		Flat Metal Jacket Fibe				
53	Floating head	-							
54	Code requirements	EN13445			TEMA class	R - refinery service			
55	Weight/Shell	31523,9	Filled with water 43393,5		Bundle	10455,6			**kg**
56	Remarks								
57									
58									

Setting Plan



Nozzle Data				
Ref	OD	Wall	Standard	Notes
S1	610 mm	10, mm	150 ANSI Slip on	
S2	457 mm	10, mm	150 ANSI Slip on	
T1	914 mm	36, mm	150 ANSI Slip on	
T2	1016 mm	40, mm	150 ANSI Slip on	

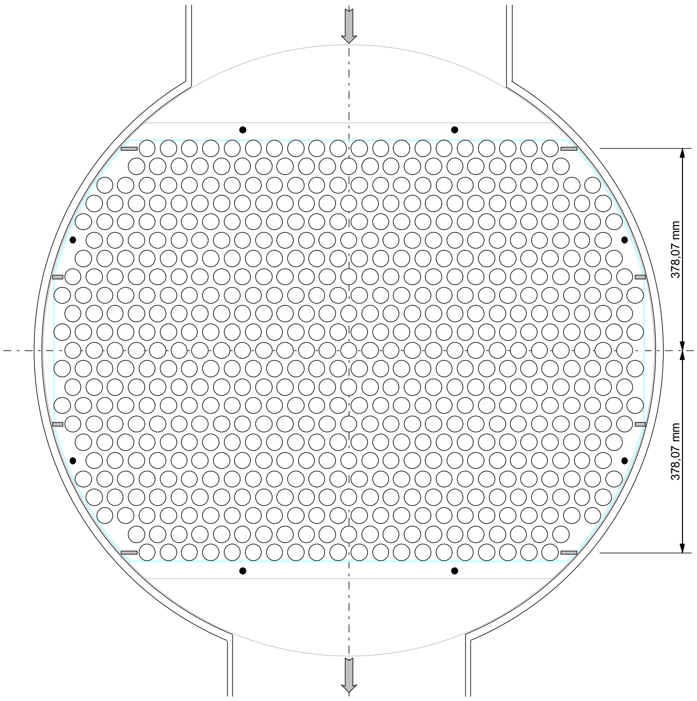
Design Data	Units	Shell	Channel
Design Pressure	bar	21,	120,
Design Temperature	C	180,	180,
Full Vacuum			
Corrosion Allowance	mm	3,	0,
Test Pressure	bar		
Number of Passes		1	1
Radiography			
PWHT			
Internal Volume	m³	7,4821	2,0972

Weight Summary		
Empty	Flooded	Bundle
31524 kg	43394 kg	10456 kg

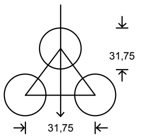
Field 1 Inlet Heater
20-HA-002
Base Case Simulation
2 X 50% Configuration
Design Codes
EN13445
TEMA R
Customer Specifications

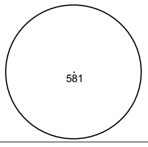
Aspen Shell & Tube Exchanger				
Setting Plan BEM 1150 - 7400				
Drawing Number				
Revision	Date	Dwg.	Chk.	App.
	5.6.2014			

Tube Layout



Shell inside diameter	mm	1150,
Front head inside diameter	mm	1150,
Outer tube limit	mm	1137,3
Tube number (calcs.)		581
Tube number (layout)		581
Tube O.D.	mm	31,75
Tube pitch	mm	39,6875
Tube pattern		30
Tube passes		1
Tie rod number		8
Tie rod diameter	mm	12,7
Sealing strips (pairs)		4
Baffle type		Single segmental
Impingement protection		None
Tube length	mm	7400,
Shell Side Inlet Nozzle Inside Diameter	mm	590,
Shell Side Outlet Nozzle Inside Diameter	mm	437,





Field 1 Inlet Heater
20-HA-002
Base Case Simulation
2 X 50% Configuration

Design Codes
EN13445
TEMA R - refinery service

Customer Specifications

Aspen Shell & Tube

Tube Layout

Drawing Number

Revision	Date	Dwg.	App.
	5.6.2014		

7.2 Thermal Calculations of Superheaters in the Gas Compression Train

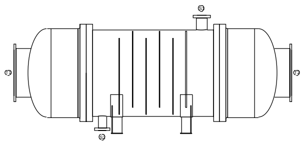
This section contains the thermal design calculations of the relevant heat exchangers in Case Study II.

7.2.1 Thermal Calculations of 24-HA-102 & 24-HA-202 – Base Case Design

Heat Exchanger Specification Sheet

1	Field 1 Dehydrator Inlet Superheater							
2	24-HA-102							
3	Base Case Simulation							
4	1 X 100% Configuration							
5								
6	Size	875--1750	mm	Type BEM	Hor	Connected in	1 parallel	1 series
7	Surf/unit(eff.)	72,8	m²	Shells/unit 1		Surf/shell (eff.)	72,8	m²

8	**PERFORMANCE OF ONE UNIT**					
9	Fluid allocation		Shell Side		Tube Side	
10	Fluid name		Heating Medium Inlet 4		Field 1 Wet Gas	
11	Fluid quantity, Total	**kg/s**	14,6247		265,9028	
12	Vapor (In/Out)	**kg/s**	0	0	265,9028	265,9028
13	Liquid	**kg/s**	14,6247	14,6247	0	0
14	Noncondensable	**kg/s**	0	0	0	0
15						
16	Temperature (In/Out)	**°C**	150	107,5	25	29,64
17	Dew / Bubble point	**°C**				
18	Density Vapor/Liquid	**kg/m³**	/ 1003	/ 1004,88	44,78 /	43,4 /
19	Viscosity	**mPa s**	/ 1,15	/ 1,1976	0,0126 /	0,0127 /
20	Molecular wt, Vap				19,72	19,72
21	Molecular wt, NC					
22	Specific heat	**kJ/(kg K)**	/ 3,29	/ 3,28	2,48 /	2,469 /
23	Thermal conductivity	**W/(m K)**	/ 0,231	/ 0,2309	0,0356 /	0,0357 /
24	Latent heat	**kJ/kg**				
25	Pressure (abs)	**bar**	11	10,96306	49,3	48,74384
26	Velocity	**m/s**	0,54		27,68	
27	Pressure drop, allow./calc.	**bar**	1	0,03694	1	0,55616
28	Fouling resist. (min)	**m² K/W**	0		0	0 Ao based
29	Heat exchanged 1950	**kW**			MTD corrected 100,44	**°C**
30	Transfer rate, Service 266,7		Dirty 736,5	Clean 736,5		**W/(m² K)**

31	**CONSTRUCTION OF ONE SHELL**					**Sketch**
32				Shell Side	Tube Side	
33	Design/vac/test pressure:g		**bar**	21/ /	80/ /	
34	Design temperature		**°C**	180	180	
35	Number passes per shell			1	1	
36	Corrosion allowance		**mm**	3,18	0	
37	Connections	In	**mm**	1 125/ -	1 500/ -	
38	Size/rating	Out		1 100/ -	1 500/ -	
39	Nominal	Intermediate		/ -	/ -	

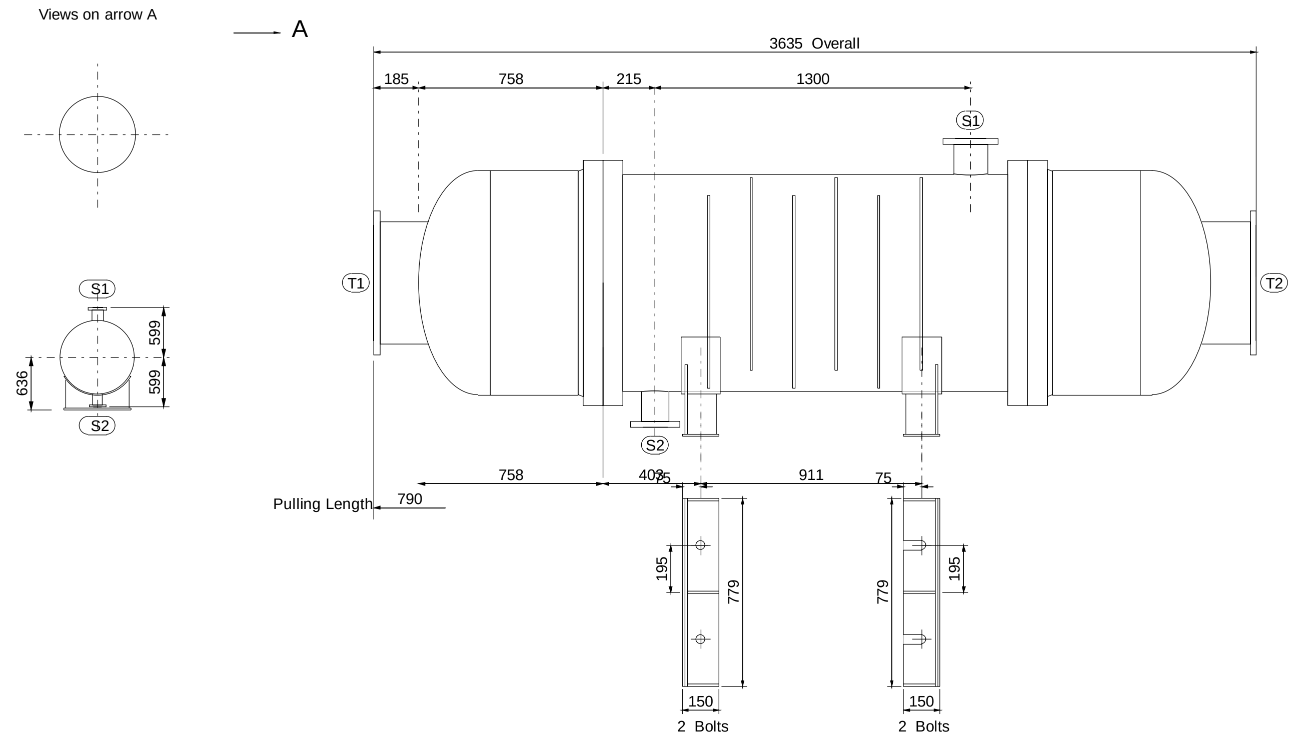
40	Tube No. 577	OD 25,4	Tks-Avg 1,65	**mm**	Length 1750	**mm**	Pitch 31,75	**mm**
41	Tube type Plain		**#/m**	Material 22Cr,5Ni,3Mo steel		Tube pattern 30		
42	Shell Carbon Steel	ID 875	OD 899	**mm**	Shell cover	-		
43	Channel or bonnet 22Cr,5Ni,3Mo steel				Channel cover	-		
44	Tubesheet-stationary 22Cr,5Ni,3Mo steel	-			Tubesheet-floating	-		
45	Floating head cover -				Impingement protection	None		
46	Baffle-crossing SS 316L	Type Single segmental	Cut(%d) 10	H	Spacing: c/c	175		**mm**
47	Baffle-long -		Seal type		Inlet	352,98		**mm**
48	Supports-tube	U-bend		Type				
49	Bypass seal		Tube-tubesheet joint	Exp.				
50	Expansion joint	-	Type	None				
51	RhoV2-Inlet nozzle	1394	Bundle entrance	116	Bundle exit	112		**kg/(m s²)**
52	Gaskets - Shell side	-	Tube Side		Flat Metal Jacket Fibe			
53	Floating head	-						
54	Code requirements	EN13445			TEMA class	R - refinery service		
55	Weight/Shell	7045,4	Filled with water	9571,7	Bundle	2055,7		**kg**
56	Remarks							
57								
58								

1	Size	875	x	1750	mm	Type	BEM	Hor	Connected in	1	parallel	1	series
2	Surf/Unit (gross/eff/finned)	80,6	/	72,8	/		m²		Shells/unit	1			
3	Surf/Shell (gross/eff/finned)	80,6	/	72,8	/		m²						
4													

5	Design			PERFORMANCE OF ONE UNIT						
6			Shell Side		Tube Side		**Heat Transfer Parameters**			
7	**Process Data**		**In**	**Out**	**In**	**Out**	Total heat load	kW	1950	
8	Total flow	kg/s	14,6247		265,9028		Eff. MTD/ 1 pass MTD	°C	100,44 / 100,27	
9	Vapor	kg/s	0	0	265,9028	265,9028	Actual/Reqd area ratio - fouled/clean		2,76 / 2,76	
10	Liquid	kg/s	14,6247	14,6247	0	0				
11	Noncondensable	kg/s	0		0		**Coef./Resist.**	W/(m² K)	m² K/W	%
12	Cond./Evap.		0		0		Overall fouled	736,5	0,00136	
13	Temperature	°C	150	107,5	25	29,64	Overall clean	736,5	0,00136	
14	Dew / Bubble point	°C					Tube side film	3025,3	0,00033	24,34
15	Quality		0	0	1	1	Tube side fouling		0	0
16	Pressure (abs)	bar	11	10,96306	49,3	48,74384	Tube wall	8893,7	0,00011	8,28
17	Delta P allow/calc	bar	1	0,03694	1	0,55616	Outside fouling		0	0
18	Velocity	m/s	0,54	0,52	26,83	27,68	Outside film	1093	0,00091	67,38
19										
20	**Liquid Properties**						**Shell Side Pressure Drop**		bar	%
21	Density	kg/m³	1003	1004,88			Inlet nozzle		0,00752	20,35
22	Viscosity	mPa s	1,15	1,1976			Inlet space Xflow		0,00275	7,44
23	Specific heat	kJ/(kg K)	3,29	3,28			Baffle Xflow		0,00999	27,05
24	Therm. cond.	W/(m K)	0,231	0,2309			Baffle window		0,00204	5,53
25	Surface tension	N/m					Outlet space Xflow		0,00276	7,47
26	Molecular weight						Outlet nozzle		0,01188	32,16
27	**Vapor Properties**						Intermediate nozzle			
28	Density	kg/m³			44,78	43,4	**Tube Side Pressure Drop**		bar	%
29	Viscosity	mPa s			0,0126	0,0127	Inlet nozzle		0,11839	21,47
30	Specific heat	kJ/(kg K)			2,48	2,469	Entering tubes		0,07818	14,18
31	Therm. cond.	W/(m K)			0,0356	0,0357	Inside tubes		0,13392	24,29
32	Molecular weight				19,72	19,72	Exiting tubes		0,10732	19,47
33	**Two-Phase Properties**						Outlet nozzle		0,11354	20,59
34	Latent heat	kJ/kg					Intermediate nozzle			
35										
36	**Heat Transfer Parameters**						**Velocity / Rho*V2**		m/s	kg/(m s²)
37	Reynolds No. vapor				2107147	2097887	Shell nozzle inlet		1,18	1394
38	Reynolds No. liquid		12048,66	11569,93			Shell bundle Xflow	0,54	0,52	
39	Prandtl No. vapor				0,88	0,87	Shell baffle window	0,46	0,44	
40	Prandtl No. liquid		16,38	17,01			Shell nozzle outlet		1,79	3225
41	**Heat Load**		kW		kW		Shell nozzle interm			
42	Vapor only		0		1950				m/s	kg/(m s²)
43	2-Phase vapor		0		0		Tube nozzle inlet		32,87	48380
44	Latent heat		0		0		Tubes	26,83	27,68	
45	2-Phase liquid		0		0		Tube nozzle outlet		33,92	49921
46	Liquid only		-1950		0		Tube nozzle interm			
47										

48	**Tubes**			**Baffles**			**Nozzles: (No./OD)**			
49	Type		Plain	Type		Single segmental			**Shell Side**	**Tube Side**
50	ID/OD	mm	22,1 / 25,4	Number		6	Inlet	mm	1 / 139,7	1 / 508
51	Length act/eff	mm	1750 / 1581	Cut(%d)	10		Outlet		1 / 114,3	1 / 508
52	Tube passes		1	Cut orientation		H	Other		/	/
53	Tube No.		577	Spacing: c/c	mm	175	Impingement protection			None
54	Tube pattern		30	Spacing at inlet	mm	352,98				
55	Tube pitch	mm	31,75	Spacing at outlet	mm	352,98				
56	Insert		None							
57	Vibration problem		No / No			RhoV2 violation				No

Setting Plan



Nozzle Data				
Ref	OD	Wall	Standard	Notes
S1	140 mm	7,1 mm	150 ANSI Slip on	
S2	114 mm	6,3 mm	150 ANSI Slip on	
T1	508 mm	14,2 mm	150 ANSI Slip on	
T2	508 mm	14,2 mm	150 ANSI Slip on	

Design Data	Units	Shell	Channel
Design Pressure	bar	21,	80,
Design Temperature	C	180,	180,
Full Vacuum			
Corrosion Allowance	mm	3,18	0,
Test Pressure	bar		
Number of Passes		1	1
Radiography			
PWHT			
Internal Volume	m³	0,935	0,8646

Weight Summary		
Empty	Flooded	Bundle
7045 kg	9572 kg	2056 kg

Field 1 Dehydrator Inlet Superheater
24-HA-102
Base Case Simulation
1 X 100% Configuration

Design Codes
EN13445
TEMA R

Customer Specifications

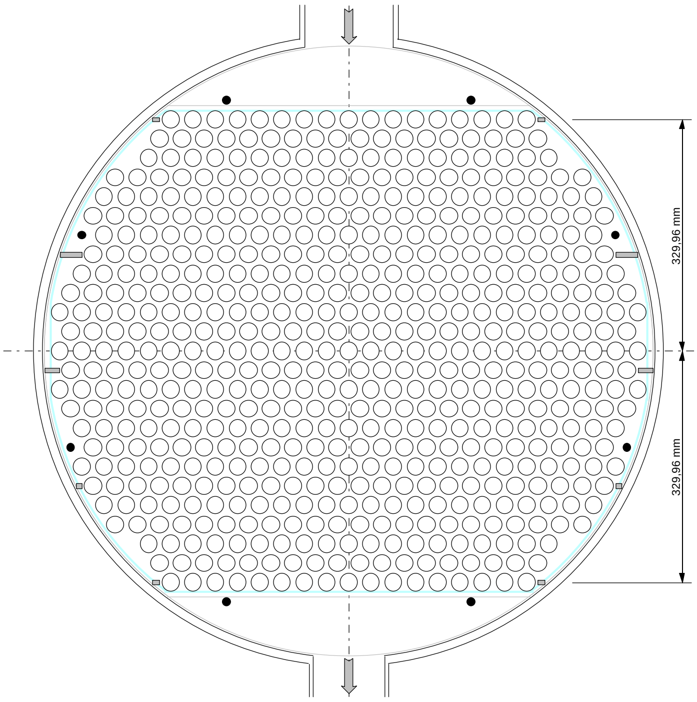
Aspen Shell & Tube Exchanger

Setting Plan
BEM 875 - 1750

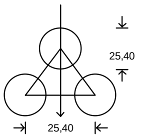
Drawing Number

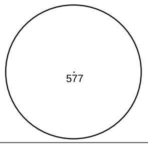
Revision	Date	Dwg.	Chk.	App.
	7.6.2014			

Tube Layout



Shell inside diameter	mm	875,
Front head inside diameter	mm	875,
Outer tube limit	mm	862,3
Tube number (calcs.)		577
Tube number (layout)		577
Tube O.D.	mm	25,4
Tube pitch	mm	31,75
Tube pattern		30
Tube passes		1
Tie rod number		8
Tie rod diameter	mm	12,7
Sealing strips (pairs)		5
Baffle type		Single segmental
Impingement protection		None
Tube length	mm	1750,
Shell Side Inlet Nozzle Inside Diameter	mm	125,5
Shell Side Outlet Nozzle Inside Diameter	mm	101,7





Field 1 Dehydrator Inlet Superheater
24-HA-102
Base Case Simulation
1 X 100% Configuration

Design Codes
EN13445
TEMA R - refinery service

Customer Specifications

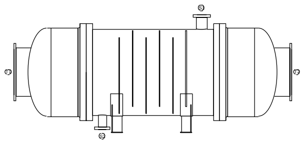
Aspen Shell & Tube

Tube Layout

Drawing Number

Revision	Date	Dwg.	App.
	7.6.2014		

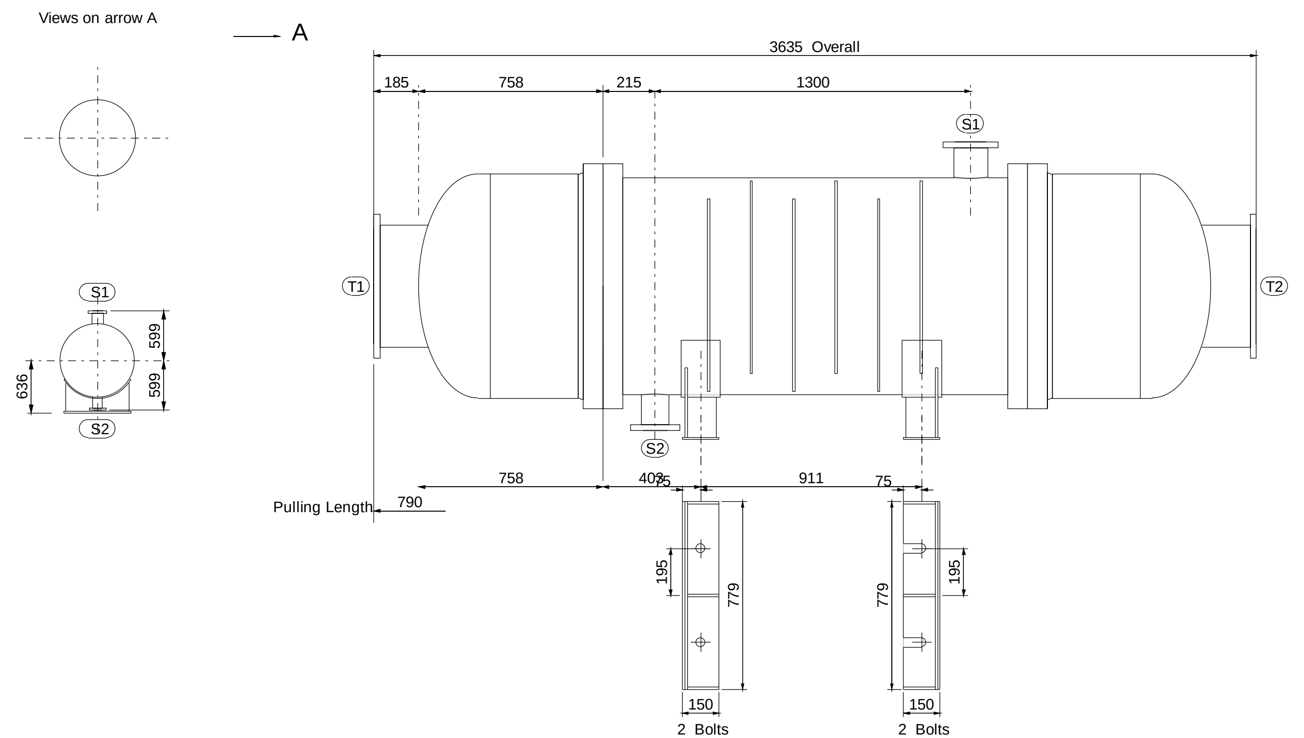
Heat Exchanger Specification Sheet

1	Field 2 Dehydrator Inlet Superheater							
2	24-HA-202							
3	Base Case Simulation							
4	1 X 100% Configuration							
5								
6	Size	875 - - 1750	**mm**	Type BEM	Hor	Connected in	1 parallel	1 series
7	Surf/unit(eff.)	72,8	**m²**	Shells/unit 1	Surf/shell (eff.)	72,8	**m²**	
8	**PERFORMANCE OF ONE UNIT**							
9	Fluid allocation		Shell Side		Tube Side			
10	Fluid name		Heating Medium Inlet 5		Field 2 Wet Gas			
11	Fluid quantity, Total	**kg/s**	16,9167		301,2883			
12	Vapor (In/Out)	**kg/s**	0	0	301,2883	301,2883		
13	Liquid	**kg/s**	16,9167	16,9167	0	0		
14	Noncondensable	**kg/s**	0	0	0	0		
15								
16	Temperature (In/Out)	**°C**	150	108,35	25	29,77		
17	Dew / Bubble point	**°C**						
18	Density Vapor/Liquid	**kg/m³**	/ 1003	/ 1005,46	49,89 /	48,25 /		
19	Viscosity	**mPa s**	/ 1,15	/ 1,2122	0,0128 /	0,0128 /		
20	Molecular wt, Vap				19,72	19,72		
21	Molecular wt, NC							
22	Specific heat	**kJ/(kg K)**	/ 3,29	/ 3,277	2,54 /	2,527 /		
23	Thermal conductivity	**W/(m K)**	/ 0,231	/ 0,2309	0,0362 /	0,0363 /		
24	Latent heat	**kJ/kg**						
25	Pressure (abs)	**bar**	11	10,95169	54,2	53,56083		
26	Velocity	**m/s**	0,63		28,21			
27	Pressure drop, allow./calc.	**bar**	1	0,04831	1	0,63918		
28	Fouling resist. (min)	**m² K/W**	0		0	0 Ao based		
29	Heat exchanged	2175	**kW**	MTD corrected	100,93	**°C**		
30	Transfer rate, Service	296	Dirty 801,2	Clean 801,2	**W/(m² K)**			
31	**CONSTRUCTION OF ONE SHELL**						**Sketch**	
32				Shell Side		Tube Side		
33	Design/vac/test pressure:g		**bar**	21/ /		80/ /		
34	Design temperature		**°C**	180		180		
35	Number passes per shell			1		1		
36	Corrosion allowance		**mm**	3,18		0		
37	Connections	In	**mm**	1	125/ -	1	500/ -	
38	Size/rating	Out		1	100/ -	1	500/ -	
39	Nominal	Intermediate			/ -		/ -	
40	Tube No. 577	OD 25,4	Tks-Avg 1,65	**mm**	Length 1750	**mm**	Pitch 31,75	**mm**
41	Tube type Plain	**#/m**	Material 22Cr,5Ni,3Mo steel	Tube pattern 30				
42	Shell Carbon Steel	ID 875	OD 899	**mm**	Shell cover	-		
43	Channel or bonnet	22Cr,5Ni,3Mo steel			Channel cover	-		
44	Tubesheet-stationary	22Cr,5Ni,3Mo steel	-		Tubesheet-floating	-		
45	Floating head cover	-			Impingement protection	None		
46	Baffle-crossing	SS 316L	Type	Single segmental	Cut(%d) 10	H	Spacing: c/c 175	**mm**
47	Baffle-long	-	Seal type		Inlet	352,98	**mm**	
48	Supports-tube	U-bend	Type					
49	Bypass seal	Tube-tubesheet joint	Exp.					
50	Expansion joint	-	Type	None				
51	RhoV2-Inlet nozzle	1865	Bundle entrance	156	Bundle exit	149	**kg/(m s²)**	
52	Gaskets - Shell side	-	Tube Side	Flat Metal Jacket Fibe				
53	Floating head	-						
54	Code requirements	EN13445	TEMA class	R - refinery service				
55	Weight/Shell	7045,4	Filled with water	9571,7	Bundle	2055,7	**kg**	
56	Remarks							
57								
58								

Heat Exchanger Thermal Design Shell&Tube V7.3.1 CP1

1	Size	875 x 1750 mm	Type	BEM	Hor		Connected in	1 parallel	1 series	
2	Surf/Unit (gross/eff/finned)		80,6 /	72,8 /		m²	Shells/unit	1		
3	Surf/Shell (gross/eff/finned)		80,6 /	72,8 /		m²				
4										
5	Design			PERFORMANCE OF ONE UNIT						
6			**Shell Side**		**Tube Side**		**Heat Transfer Parameters**			
7	**Process Data**		**In**	**Out**	**In**	**Out**	Total heat load	kW	2175	
8	Total flow	kg/s	16,9167		301,2883		Eff. MTD/ 1 pass MTD	°C	100,93 / 100,69	
9	Vapor	kg/s	0	0	301,2883	301,2883	Actual/Reqd area ratio - fouled/clean		2,71 / 2,71	
10	Liquid	kg/s	16,9167	16,9167	0	0				
11	Noncondensable	kg/s	0		0		**Coef./Resist.**	W/(m² K)	m² K/W	**%**
12	Cond./Evap.		0		0		Overall fouled	801,2	0,00125	
13	Temperature	°C	150	108,35	25	29,77	Overall clean	801,2	0,00125	
14	Dew / Bubble point	°C					Tube side film	3397	0,00029	23,59
15	Quality		0	0	1	1	Tube side fouling		0	0
16	Pressure (abs)	bar	11	10,95169	54,2	53,56083	Tube wall	8893	0,00011	9,01
17	Delta P allow/calc	bar	1	0,04831	1	0,63918	Outside fouling		0	0
18	Velocity	m/s	0,63	0,6	27,28	28,21	Outside film	1188,6	0,00084	67,41
19										
20	**Liquid Properties**						**Shell Side Pressure Drop**		bar	**%**
21	Density	kg/m³	1003	1005,46			Inlet nozzle		0,01006	20,82
22	Viscosity	mPa s	1,15	1,2122			Inlet space Xflow		0,00353	7,3
23	Specific heat	kJ/(kg K)	3,29	3,277			Baffle Xflow		0,01263	26,14
24	Therm. cond.	W/(m K)	0,231	0,2309			Baffle window		0,00266	5,51
25	Surface tension	N/m					Outlet space Xflow		0,00354	7,34
26	Molecular weight						Outlet nozzle		0,01589	32,88
27	**Vapor Properties**						Intermediate nozzle			
28	Density	kg/m³			49,89	48,25	**Tube Side Pressure Drop**		bar	**%**
29	Viscosity	mPa s			0,0128	0,0128	Inlet nozzle		0,13642	21,53
30	Specific heat	kJ/(kg K)			2,54	2,527	Entering tubes		0,09018	14,23
31	Therm. cond.	W/(m K)			0,0362	0,0363	Inside tubes		0,15205	24
32	Molecular weight				19,72	19,72	Exiting tubes		0,1238	19,54
33	**Two-Phase Properties**						Outlet nozzle		0,13111	20,69
34	Latent heat	kJ/kg					Intermediate nozzle			
35										
36	**Heat Transfer Parameters**						**Velocity / Rho*V2**		m/s	kg/(m s²)
37	Reynolds No. vapor				2346587	2343083	Shell nozzle inlet		1,36	1865
38	Reynolds No. liquid		13936,89	13221,5			Shell bundle Xflow	0,63	0,6	
39	Prandtl No. vapor				0,9	0,89	Shell baffle window	0,54	0,51	
40	Prandtl No. liquid		16,38	17,2			Shell nozzle outlet		2,07	4313
41	**Heat Load**		kW		kW		Shell nozzle interm			
42	Vapor only		0		2175				m/s	kg/(m s²)
43	2-Phase vapor		0		0		Tube nozzle inlet		33,43	55751
44	Latent heat		0		0		Tubes	27,28	28,21	
45	2-Phase liquid		0		0		Tube nozzle outlet		34,57	57649
46	Liquid only		-2175		0		Tube nozzle interm			
47										
48	**Tubes**				**Baffles**			**Nozzles: (No./OD)**		
49	Type			Plain	Type		Single segmental		**Shell Side**	**Tube Side**
50	ID/OD	mm	22,1 /	25,4	Number		6	Inlet mm	1 / 139,7	1 / 508
51	Length act/eff	mm	1750 /	1581	Cut(%d)	10		Outlet	1 / 114,3	1 / 508
52	Tube passes			1	Cut orientation		H	Other	/	/
53	Tube No.			577	Spacing: c/c	mm	175	Impingement protection		None
54	Tube pattern			30	Spacing at inlet	mm	352,98			
55	Tube pitch	mm		31,75	Spacing at outlet	mm	352,98			
56	Insert			None						
57	Vibration problem			No / No			RhoV2 violation			No

Setting Plan



Nozzle Data				
Ref	OD	Wall	Standard	Notes
S1	140 mm	7,1 mm	150 ANSI Slip on	
S2	114 mm	6,3 mm	150 ANSI Slip on	
T1	508 mm	14,2 mm	150 ANSI Slip on	
T2	508 mm	14,2 mm	150 ANSI Slip on	

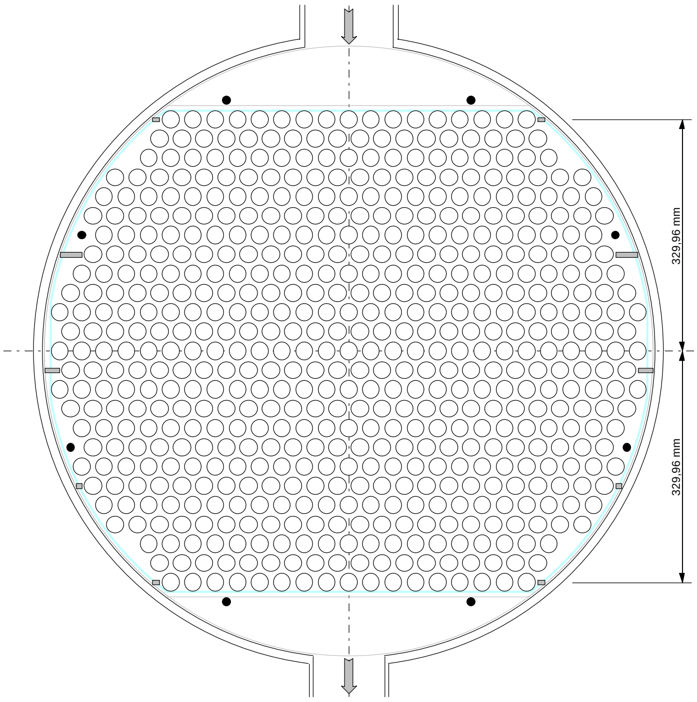
Design Data	Units	Shell	Channel
Design Pressure	bar	21,	80,
Design Temperature	C	180,	180,
Full Vacuum			
Corrosion Allowance	mm	3,175	0,
Test Pressure	bar		
Number of Passes		1	1
Radiography			
PWHT			
Internal Volume	m³	0,935	0,8646

Weight Summary		
Empty	Flooded	Bundle
7045 kg	9572 kg	2056 kg

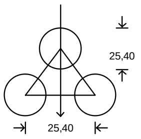
Field 2 Dehydrator Inlet Superheater
24-HA-202
Base Case Simulation
1 X 100% Configuration
Design Codes
EN13445
TEMA R
Customer Specifications

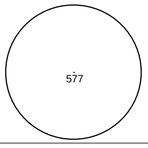
Aspen Shell & Tube Exchanger				
Setting Plan BEM 875 - 1750				
Drawing Number				
Revision	Date	Dwg.	Chk.	App.
	7.6.2014			

Tube Layout



Shell inside diameter	mm	875,
Front head inside diameter	mm	875,
Outer tube limit	mm	862,3
Tube number (calcs.)		577
Tube number (layout)		577
Tube O.D.	mm	25,4
Tube pitch	mm	31,75
Tube pattern		30
Tube passes		1
Tie rod number		8
Tie rod diameter	mm	12,7
Sealing strips (pairs)		5
Baffle type		Single segmental
Impingement protection		None
Tube length	mm	1750,
Shell Side Inlet Nozzle Inside Diameter	mm	125,5
Shell Side Outlet Nozzle Inside Diameter	mm	101,7





Field 2 Dehydrator Inlet Superheater
24-HA-202
Base Case Simulation
1 X 100% Configuration

Design Codes
EN13445
TEMA R - refinery service

Customer Specifications

Aspen Shell & Tube

Tube Layout

Drawing Number

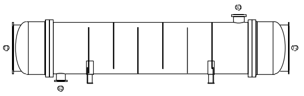
Revision	Date	Dwg.	App.
	7.6.2014		

7.2.2 Thermal Calculations of 24-HA-102 & 24-HA-202 – Case Study II

Heat Exchanger Specification Sheet

1	Field 1 Dehydrator Inlet Superheater							
2	24-HA-102							
3	Case Study 2							
4	1 X 100% Configuration							
5								
6	Size	975--5000	**mm**	Type BEM	Hor	Connected in	1 parallel	1 series
7	Surf/unit(eff.)	261,7	**m^2**	Shells/unit 1		Surf/shell (eff.)	261,7	**m^2**

8	**PERFORMANCE OF ONE UNIT**					
9	Fluid allocation		Shell Side		Tube Side	
10	Fluid name		Heating Medium Inlet 4		Field 1 Wet Gas	
11	Fluid quantity, Total	**kg/s**	76,5775		265,9025	
12	Vapor (In/Out)	**kg/s**	0	0	265,9025	265,9025
13	Liquid	**kg/s**	76,5775	76,5775	0	0
14	Noncondensable	**kg/s**	0	0	0	0
15						
16	Temperature (In/Out)	**°C**	100	89,28	25	29,65
17	Dew / Bubble point	**°C**				
18	Density Vapor/Liquid	**kg/m^3**	/ 1054	/ 1055,5	44,78 /	43,49 /
19	Viscosity	**mPa s**	/ 2,438	/ 2,529	0,0126 /	0,0126 /
20	Molecular wt, Vap				19,72	19,72
21	Molecular wt, NC					
22	Specific heat	**kJ/(kg K)**	/ 3,03	/ 3,028	2,48 /	2,47 /
23	Thermal conductivity	**W/(m K)**	/ 0,2295	/ 0,2293	0,0356 /	0,0357 /
24	Latent heat	**kJ/kg**				
25	Pressure (abs)	**bar**	11	10,83342	49,3	48,81579
26	Velocity	**m/s**	1,87		24,47	
27	Pressure drop, allow./calc.	**bar**	1	0,16658	1	0,48421
28	Fouling resist. (min)	**$m^2 K/W$**	0		0	0 Ao based
29	Heat exchanged 2100 **kW**				MTD corrected 67,38	**°C**
30	Transfer rate, Service 119,1		Dirty 850,1	Clean 850,1		**$W/(m^2 K)$**

31	**CONSTRUCTION OF ONE SHELL**					**Sketch**
32				Shell Side	Tube Side	
33	Design/vac/test pressure:g		**bar**	21/ /	80/ /	
34	Design temperature		**°C**	180	180	
35	Number passes per shell			1	1	
36	Corrosion allowance		**mm**	3,18	0	
37	Connections	In	**mm**	1 250/ -	1 900/ -	
38	Size/rating	Out		1 200/ -	1 900/ -	
39	Nominal	Intermediate		/ -	/ -	

40	Tube No. 708	OD 24,5	Tks-Avg 1,65	**mm**	Length 5000	**mm**	Pitch 31,75	**mm**
41	Tube type Plain		**#/m**	Material 22Cr,5Ni,3Mo steel		Tube pattern 30		
42	Shell Carbon Steel	ID 975	OD 1001	**mm**	Shell cover	-		
43	Channel or bonnet	22Cr,5Ni,3Mo steel			Channel cover	-		
44	Tubesheet-stationary	22Cr,5Ni,3Mo steel	-		Tubesheet-floating	-		
45	Floating head cover	-			Impingement protection	None		
46	Baffle-crossing SS 316L	Type Single segmental	Cut(%d) 10	H	Spacing: c/c	610	**mm**	
47	Baffle-long	-	Seal type		Inlet	876,48	**mm**	
48	Supports-tube	U-bend		Type				
49	Bypass seal		Tube-tubesheet joint	Exp.				
50	Expansion joint	-	Type	None				
51	RhoV2-Inlet nozzle	2201	Bundle entrance	227	Bundle exit	225	**$kg/(m s^2)$**	
52	Gaskets - Shell side	-	Tube Side		Flat Metal Jacket Fibe			
53	Floating head	-						
54	Code requirements	EN13445			TEMA class	R - refinery service		
55	Weight/Shell	14997,1	Filled with water	21564,7	Bundle	5018,7	**kg**	
56	Remarks							
57								
58								

1	Size	975	x	5000	mm	Type	BEM	Hor	Connected in	1	parallel	1	series
2	Surf/Unit (gross/eff/finned)	272,5	/	261,7	/		m²		Shells/unit	1			
3	Surf/Shell (gross/eff/finned)	272,5	/	261,7	/		m²						
4													

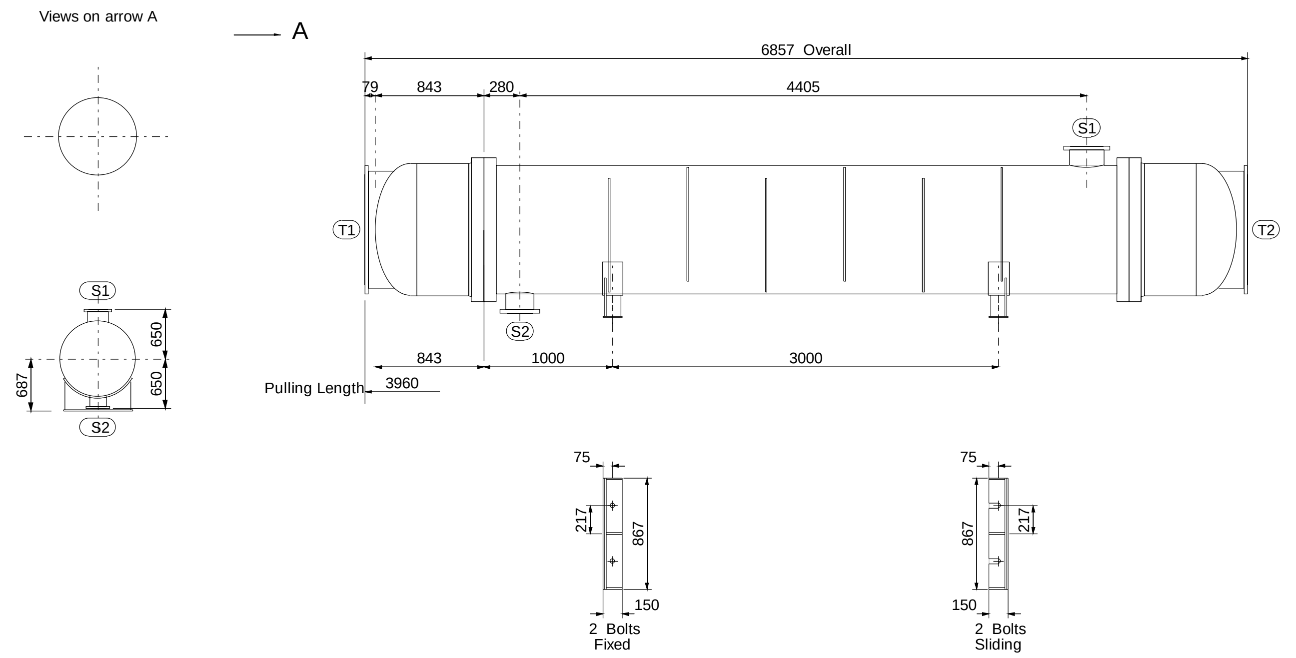
5	Design				PERFORMANCE OF ONE UNIT						
6			Shell Side		Tube Side		**Heat Transfer Parameters**				
7	**Process Data**		**In**	**Out**	**In**	**Out**	Total heat load	kW	2100		
8	Total flow	kg/s	76,5775		265,9025		Eff. MTD/ 1 pass MTD	°C	67,38 / 67,27		
9	Vapor	kg/s	0	0	265,9025	265,9025	Actual/Reqd area ratio - fouled/clean		7,14 / 7,14		
10	Liquid	kg/s	76,5775	76,5775	0	0					
11	Noncondensable	kg/s	0		0		**Coef./Resist.**	W/(m² K)	m² K/W	%	
12	Cond./Evap.		0		0		Overall fouled	850,1	0,00118		
13	Temperature	°C	100	89,28	25	29,65	Overall clean	850,1	0,00118		
14	Dew / Bubble point	°C					Tube side film	2771	0,00036	30,68	
15	Quality		0	0	1	1	Tube side fouling		0	0	
16	Pressure (abs)	bar	11	10,83342	49,3	48,81579	Tube wall	8871,2	0,00011	9,58	
17	Delta P allow/calc	bar	1	0,16658	1	0,48421	Outside fouling		0	0	
18	Velocity	m/s	0,6	0,59	23,76	24,47	Outside film	1422,9	0,0007	59,74	
19											

20	**Liquid Properties**						**Shell Side Pressure Drop**	bar	%
21	Density	kg/m³	1054	1055,5			Inlet nozzle	0,01338	8,03
22	Viscosity	mPa s	2,438	2,529			Inlet space Xflow	0,01761	10,57
23	Specific heat	kJ/(kg K)	3,03	3,028			Baffle Xflow	0,05002	30,03
24	Therm. cond.	W/(m K)	0,2295	0,2293			Baffle window	0,04676	28,07
25	Surface tension	N/m					Outlet space Xflow	0,0177	10,63
26	Molecular weight						Outlet nozzle	0,0211	12,67
27	**Vapor Properties**						Intermediate nozzle		
28	Density	kg/m³			44,78	43,49	**Tube Side Pressure Drop**	bar	%
29	Viscosity	mPa s			0,0126	0,0126	Inlet nozzle	0,00106	0,22
30	Specific heat	kJ/(kg K)			2,48	2,47	Entering tubes	0,06167	12,89
31	Therm. cond.	W/(m K)			0,0356	0,0357	Inside tubes	0,32026	66,96
32	Molecular weight				19,72	19,72	Exiting tubes	0,09075	18,97
33	**Two-Phase Properties**						Outlet nozzle	0,00454	0,95
34	Latent heat	kJ/kg					Intermediate nozzle		
35									

36	**Heat Transfer Parameters**					**Velocity / Rho*V2**	m/s		kg/(m s²)
37	Reynolds No. vapor			1790166	1783313	Shell nozzle inlet	1,45		2201
38	Reynolds No. liquid	6344,78	6116,59			Shell bundle Xflow	0,6	0,59	
39	Prandtl No. vapor			0,88	0,88	Shell baffle window	1,87	1,86	
40	Prandtl No. liquid	32,19	33,39			Shell nozzle outlet	2,24		5293
41	**Heat Load**	kW		kW		Shell nozzle interm			
42	Vapor only	0		2100			m/s		kg/(m s²)
43	2-Phase vapor	0		0		Tube nozzle inlet	10,13		4593
44	Latent heat	0		0		Tubes	23,76	24,47	
45	2-Phase liquid	0		0		Tube nozzle outlet	10,43		4732
46	Liquid only	-2100		0		Tube nozzle interm			
47									

48	**Tubes**			**Baffles**			**Nozzles: (No./OD)**			
49	Type		Plain	Type		Single segmental			**Shell Side**	**Tube Side**
50	ID/OD	mm	21,2 / 24,5	Number		6	Inlet	mm	1 / 273	1 / 914
51	Length act/eff	mm	5000 / 4803	Cut(%d)		10	Outlet		1 / 219,1	1 / 914
52	Tube passes		1	Cut orientation		H	Other		/	/
53	Tube No.		708	Spacing: c/c	mm	610	Impingement protection			None
54	Tube pattern		30	Spacing at inlet	mm	876,48				
55	Tube pitch	mm	31,75	Spacing at outlet	mm	876,48				
56	Insert		None							
57	Vibration problem		No / No				RhoV2 violation			No

Setting Plan



Nozzle Data				
Ref	OD	Wall	Standard	Notes
S1	273 mm	10, mm	150 ANSI Slip on	
S2	219 mm	8, mm	150 ANSI Slip on	
T1	914 mm	25, mm	150 ANSI Slip on	
T2	914 mm	25, mm	150 ANSI Slip on	

Design Data	Units	Shell	Channel
Design Pressure	bar	21,	80,
Design Temperature	C	180,	180,
Full Vacuum			
Corrosion Allowance	mm	3,18	0,
Test Pressure	bar		
Number of Passes		1	1
Radiography			
PWHT			
Internal Volume	m³	3,572	1,3283

Weight Summary		
Empty	Flooded	Bundle
14997 kg	21565 kg	5019 kg

Field 1 Dehydrator Inlet Superheater
24-HA-102
Case Study 2
1 X 100% Configuration

Design Codes
EN13445
TEMA R

Customer Specifications

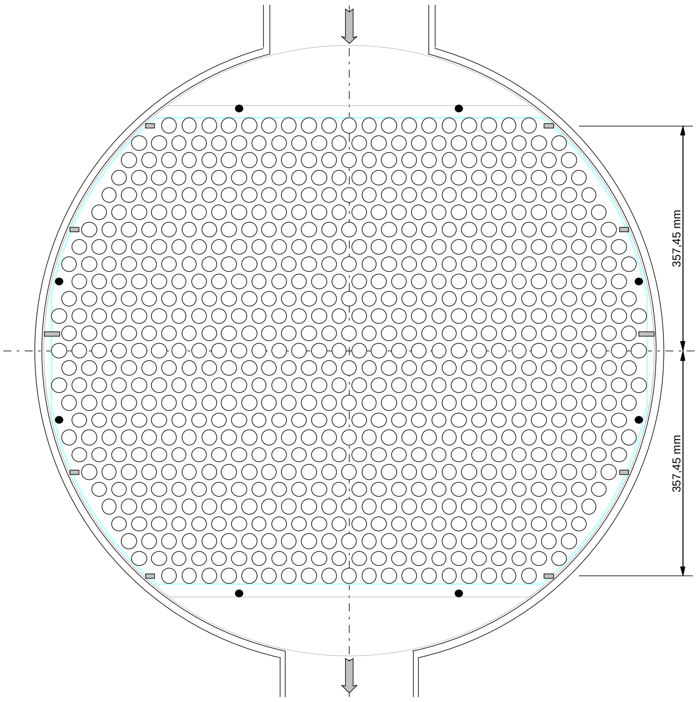
Aspen Shell & Tube Exchanger

Setting Plan
BEM 975 - 5000

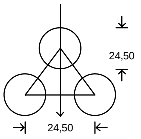
Drawing Number

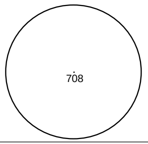
Revision	Date	Dwg.	Chk.	App.
	9.6.2014			

Tube Layout



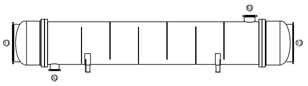
Shell inside diameter	mm	975,
Front head inside diameter	mm	975,
Outer tube limit	mm	962,3
Tube number (calcs.)		708
Tube number (layout)		708
Tube O.D.	mm	24,5
Tube pitch	mm	31,75
Tube pattern		30
Tube passes		1
Tie rod number		8
Tie rod diameter	mm	12,7
Sealing strips (pairs)		5
Baffle type		Single segmental
Impingement protection		None
Tube length	mm	5000,
Shell Side Inlet Nozzle Inside Diameter	mm	253,
Shell Side Outlet Nozzle Inside Diameter	mm	203,1





Field 1 Dehydrator Inlet Superheater	Aspen Shell & Tube			
24-HA-102				
Case Study 2				
1 X 100% Configuration	Tube Layout			
Design Codes				
EN13445				
TEMA R - refinery service	Drawing Number			
Customer Specifications				
	Revision	Date	Dwg.	App.
		9.6.2014		

Heat Exchanger Specification Sheet

1	Field 2 Dehydrator Inlet Superheater						
2	24-HA-202						
3	Case Study 2						
4	1 X 100% Configuration						
5							
6	Size	1000--6500	mm	Type BEM Hor	Connected in	1 parallel	1 series
7	Surf/unit(eff.)	367,2	m²	Shells/unit 1	Surf/shell (eff.)	367,2	m²
8	**PERFORMANCE OF ONE UNIT**						
9	Fluid allocation		Shell Side		Tube Side		
10	Fluid name		Heating Medium Inlet 5		Field 2 Wet Gas		
11	Fluid quantity, Total	**kg/s**	88,58		301,2119		
12	Vapor (In/Out)	**kg/s**	0	0	301,2119	301,2119	
13	Liquid	**kg/s**	88,58	88,58	0	0	
14	Noncondensable	**kg/s**	0	0	0	0	
15							
16	Temperature (In/Out)	**°C**	100	89,88	25	29,61	
17	Dew / Bubble point	**°C**					
18	Density Vapor/Liquid	**kg/m³**	/ 1054	/ 1055,22	49,89 /	48,45 /	
19	Viscosity	**mPa s**	/ 2,436	/ 2,5105	0,0128 /	0,0129 /	
20	Molecular wt, Vap				19,72	19,72	
21	Molecular wt, NC						
22	Specific heat	**kJ/(kg K)**	/ 3,03	/ 3,029	2,54 /	2,53 /	
23	Thermal conductivity	**W/(m K)**	/ 0,2295	/ 0,2294	0,0362 /	0,0363 /	
24	Latent heat	**kJ/kg**					
25	Pressure (abs)	**bar**	10	9,86414	54,2	53,69001	
26	Velocity	**m/s**	1,44		22,17		
27	Pressure drop, allow./calc.	**bar**	1	0,13586	1	0,50999	
28	Fouling resist. (min)	**m² K/W**	0		0	0 Ao based	
29	Heat exchanged	2350	**kW**		MTD corrected	67,67	**°C**
30	Transfer rate, Service	94,6	Dirty 855,8		Clean 855,8		**W/(m² K)**
31	**CONSTRUCTION OF ONE SHELL**					**Sketch**	
32				Shell Side	Tube Side		
33	Design/vac/test pressure:g		**bar**	21/ /	80/ /		
34	Design temperature		**°C**	180	180		
35	Number passes per shell			1	1		
36	Corrosion allowance		**mm**	3,18	0		
37	Connections	In	**mm**	1 300/ -	1 900/ -		
38	Size/rating	Out		1 250/ -	1 900/ -		
39	Nominal	Intermediate		/ -	/ -		
40	Tube No. 731	OD 25,4	Tks-Avg 1,65	**mm**	Length 6500	**mm**	Pitch 31,75 **mm**
41	Tube type Plain		**#/m**	Material 22Cr,5Ni,3Mo steel		Tube pattern 30	
42	Shell Carbon Steel	ID 1000	OD 1026	**mm**	Shell cover	-	
43	Channel or bonnet	22Cr,5Ni,3Mo steel			Channel cover	-	
44	Tubesheet-stationary	22Cr,5Ni,3Mo steel	-		Tubesheet-floating	-	
45	Floating head cover	-			Impingement protection	None	
46	Baffle-crossing SS 316L	Type Single segmental	Cut(%d) 12,75	H	Spacing: c/c 855		**mm**
47	Baffle-long -		Seal type		Inlet	1009,98	**mm**
48	Supports-tube		U-bend		Type		
49	Bypass seal		Tube-tubesheet joint		Exp.		
50	Expansion joint	-	Type None				
51	RhoV2-Inlet nozzle	1415	Bundle entrance 242		Bundle exit 240		**kg/(m s²)**
52	Gaskets - Shell side	-	Tube Side		Flat Metal Jacket Fibe		
53	Floating head	-					
54	Code requirements	EN13445			TEMA class	R - refinery service	
55	Weight/Shell	17402,6	Filled with water 25342,1		Bundle	6462,9	**kg**
56	Remarks						
57							
58							

Size 1000 x 6500 mm	Type BEM Hor	Connected in	1 parallel	1 series
Surf/Unit (gross/eff/finned)	379,2 / 367,2 / m²	Shells/unit	1	
Surf/Shell (gross/eff/finned)	379,2 / 367,2 / m²			

Design **PERFORMANCE OF ONE UNIT**

		Shell Side		**Tube Side**	
Process Data		**In**	**Out**	**In**	**Out**
Total flow	kg/s	88,58		301,2119	
Vapor	kg/s	0	0	301,2119	301,2119
Liquid	kg/s	88,58	88,58	0	0
Noncondensable	kg/s	0		0	
Cond./Evap.		0		0	
Temperature	°C	100	89,88	25	29,61
Dew / Bubble point	°C				
Quality		0	0	1	1
Pressure (abs)	bar	10	9,86414	54,2	53,69001
Delta P allow/calc	bar	1	0,13586	1	0,50999
Velocity	m/s	0,54	0,53	21,53	22,17

Heat Transfer Parameters			
Total heat load	kW	2350	
Eff. MTD/ 1 pass MTD	°C	67,67 / 67,6	
Actual/Reqd area ratio - fouled/clean		9,05 / 9,05	
Coef./Resist.	W/(m² K)	m² K/W	**%**
Overall fouled	855,8	0,00117	
Overall clean	855,8	0,00117	
Tube side film	2828,4	0,00035	30,26
Tube side fouling		0	0
Tube wall	8894,4	0,00011	9,62
Outside fouling		0	0
Outside film	1423,4	0,0007	60,12

Liquid Properties					
Density	kg/m³	1054	1055,22		
Viscosity	mPa s	2,436	2,5105		
Specific heat	kJ/(kg K)	3,03	3,029		
Therm. cond.	W/(m K)	0,2295	0,2294		
Surface tension	N/m				
Molecular weight					
Vapor Properties					
Density	kg/m³			49,89	48,45
Viscosity	mPa s			0,0128	0,0129
Specific heat	kJ/(kg K)			2,54	2,53
Therm. cond.	W/(m K)			0,0362	0,0363
Molecular weight				19,72	19,72
Two-Phase Properties					
Latent heat	kJ/kg				

Shell Side Pressure Drop	bar	**%**
Inlet nozzle	0,00899	6,62
Inlet space Xflow	0,01676	12,34
Baffle Xflow	0,0492	36,23
Baffle window	0,03183	23,44
Outlet space Xflow	0,0168	12,38
Outlet nozzle	0,0122	8,99
Intermediate nozzle		
Tube Side Pressure Drop	bar	**%**
Inlet nozzle	0,0017	0,34
Entering tubes	0,0558	11,06
Inside tubes	0,36352	72,08
Exiting tubes	0,07731	15,33
Outlet nozzle	0,00603	1,2
Intermediate nozzle		

Heat Transfer Parameters				
Reynolds No. vapor			1854655	1847295
Reynolds No. liquid	5922,75	5747,1		
Prandtl No. vapor			0,9	0,9
Prandtl No. liquid	32,16	33,15		
Heat Load	kW		kW	
Vapor only	0		2350	
2-Phase vapor	0		0	
Latent heat	0		0	
2-Phase liquid	0		0	
Liquid only	-2350		0	

Velocity / Rho*V2	m/s		kg/(m s²)
Shell nozzle inlet	1,16		1415
Shell bundle Xflow	0,54	0,53	
Shell baffle window	1,44	1,43	
Shell nozzle outlet	1,67		2942
Shell nozzle interm			
	m/s		kg/(m s²)
Tube nozzle inlet	10,3		5291
Tubes	21,53	22,17	
Tube nozzle outlet	10,61		5450
Tube nozzle interm			

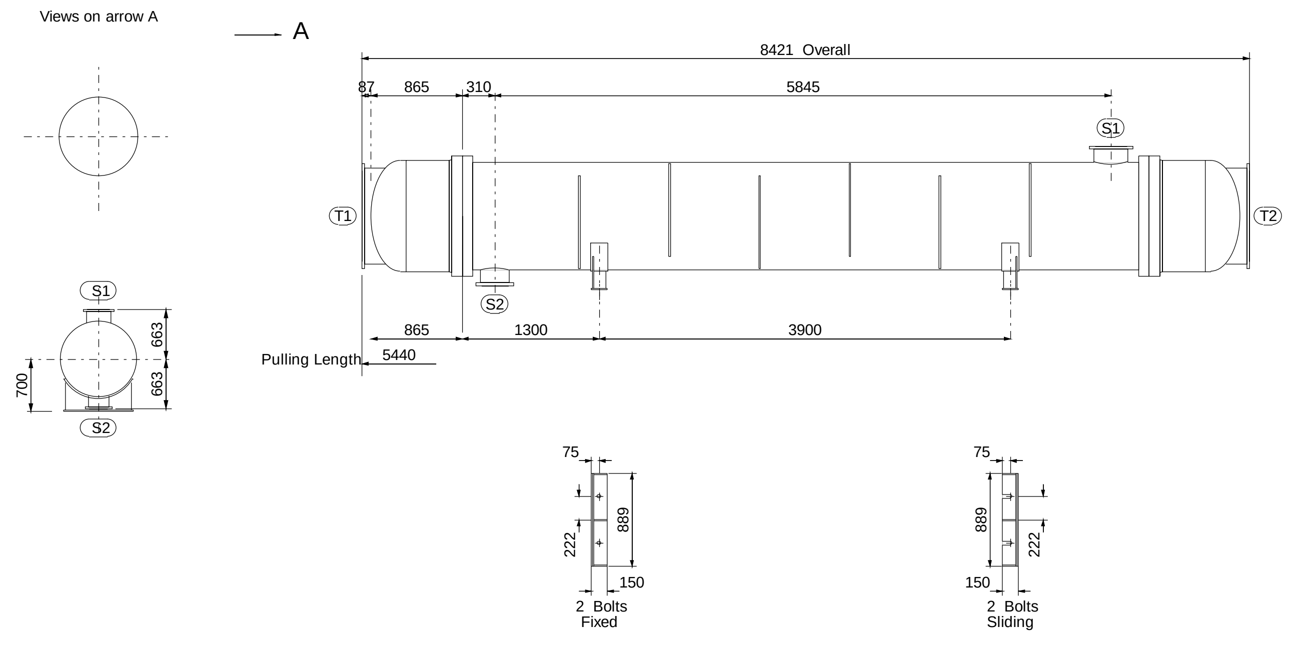
Tubes		
Type		Plain
ID/OD	mm	22,1 / 25,4
Length act/eff	mm	6500 / 6295
Tube passes		1
Tube No.		731
Tube pattern		30
Tube pitch	mm	31,75
Insert		None
Vibration problem		No / No

Baffles		
Type		Single segmental
Number		6
Cut(%d)		12,75
Cut orientation		H
Spacing: c/c	mm	855
Spacing at inlet	mm	1009,98
Spacing at outlet	mm	1009,98

Nozzles: (No./OD)		**Shell Side**	**Tube Side**
Inlet	mm	1 / 323,9	1 / 914
Outlet		1 / 273	1 / 914
Other		/	/
Impingement protection			None

RhoV2 violation No

Setting Plan



Nozzle Data				
Ref	OD	Wall	Standard	Notes
S1	324 mm	10, mm	150 ANSI Slip on	
S2	273 mm	10, mm	150 ANSI Slip on	
T1	914 mm	25, mm	150 ANSI Slip on	
T2	914 mm	25, mm	150 ANSI Slip on	

Design Data	Units	Shell	Channel
Design Pressure	bar	21,	80,
Design Temperature	C	180,	180,
Full Vacuum			
Corrosion Allowance	mm	3,175	0,
Test Pressure	bar		
Number of Passes		1	1
Radiography			
PWHT			
Internal Volume	m³	4,9399	1,4152

Weight Summary		
Empty	Flooded	Bundle
17403 kg	25342 kg	6463 kg

Field 2 Dehydrator Inlet Superheater
24-HA-202
Case Study 2
1 X 100% Configuration
Design Codes
EN13445
TEMA R
Customer Specifications

Aspen Shell & Tube Exchanger

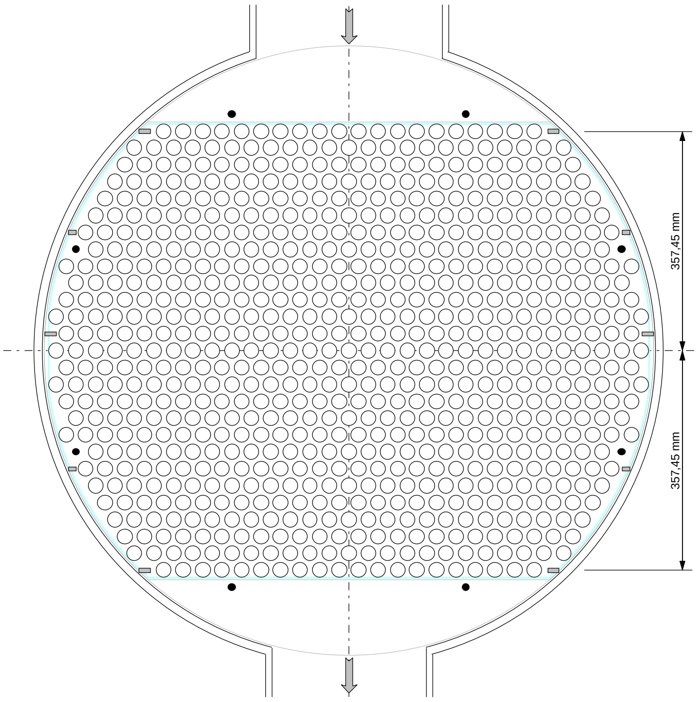
Setting Plan

BEM 1000 - 6500

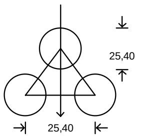
Drawing Number

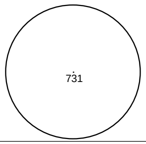
Revision	Date	Dwg.	Chk.	App.
	9.6.2014			

Tube Layout



Shell inside diameter	mm	1000,
Front head inside diameter	mm	1000,
Outer tube limit	mm	987,3
Tube number (calcs.)		731
Tube number (layout)		731
Tube O.D.	mm	25,4
Tube pitch	mm	31,75
Tube pattern		30
Tube passes		1
Tie rod number		8
Tie rod diameter	mm	12,7
Sealing strips (pairs)		5
Baffle type		Single segmental
Impingement protection		None
Tube length	mm	6500,
Shell Side Inlet Nozzle Inside Diameter	mm	303,9
Shell Side Outlet Nozzle Inside Diameter	mm	253,





Field 2 Dehydrator Inlet Superheater	Aspen Shell & Tube
24-HA-202	
Case Study 2	
1 X 100% Configuration	Tube Layout
Design Codes	
EN13445	
TEMA R - refinery service	
	Drawing Number
Customer Specifications	

Revision	Date	Dwg.	App.
	9.6.2014		

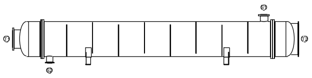
7.3 Thermal Calculations of Stabilization Separator Heater (20-HA-003)

This section contains the thermal design calculations of the relevant heat exchangers in Case Study I.

7.3.1 Thermal Calculation of 20-HA-003 – Base Case Design

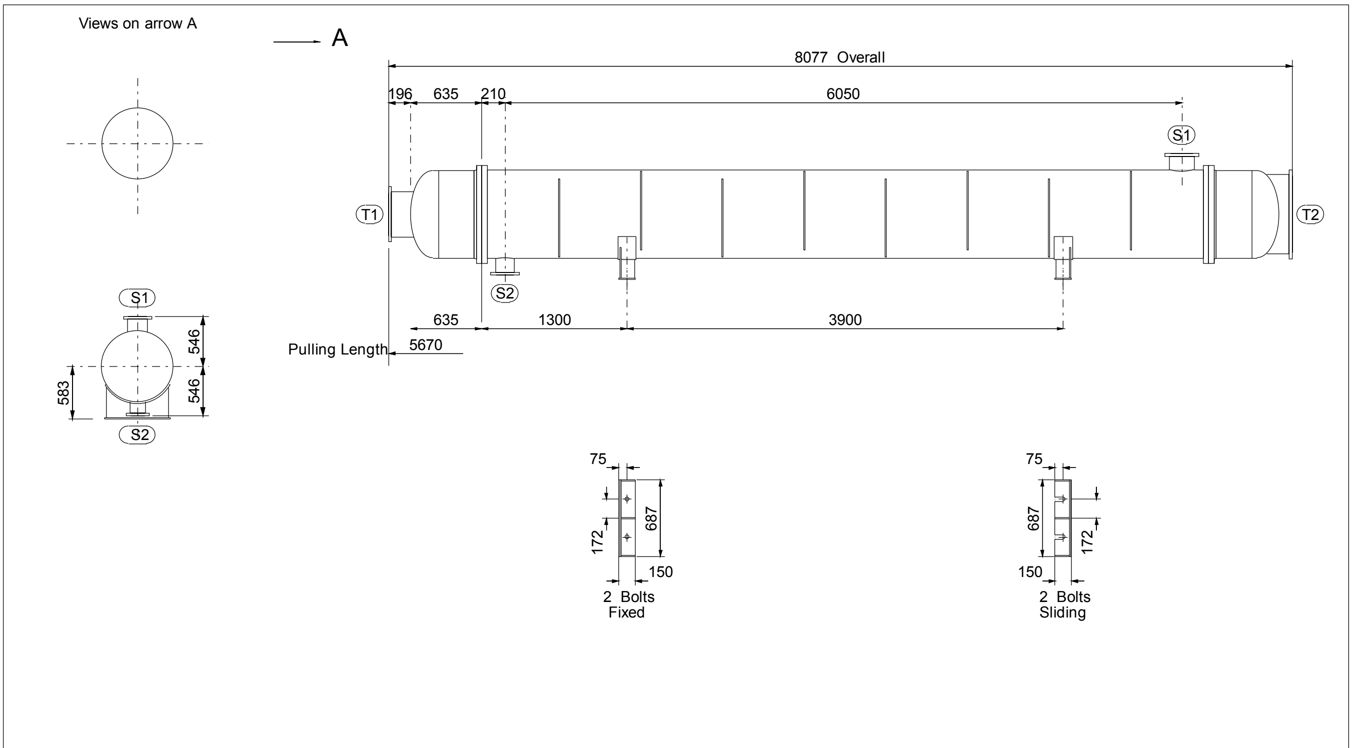
Heat Exchanger Specification Sheet

1	Stabilization Separator Heater					
2	20-HA-003					
3	Base Case Simulation					
4	1 X 100% Configuration					
5						
6	Size 775--6500	mm	Type BEM Hor	Connected in	2 parallel	1 series
7	Surf/unit(eff.) 611,2	m²	Shells/unit 2	Surf/shell (eff.)	305,6	m²
8	**PERFORMANCE OF ONE UNIT**					
9	Fluid allocation		Shell Side		Tube Side	
10	Fluid name		Heating Medium Inlet 3		Inlet to Stabilization Heater	
11	Fluid quantity, Total	**kg/s**	71,7853		329,1525	
12	Vapor (In/Out)	**kg/s**	0	0	5,3652	6,6309
13	Liquid	**kg/s**	71,7853	71,7853	323,7873	322,5216
14	Noncondensable	**kg/s**	0	0	0	0
15						
16	Temperature (In/Out)	**°C**	150	118,42	63,13	77,94
17	Dew / Bubble point	**°C**				
18	Density Vapor/Liquid	**kg/m³**	/ 1003	/ 1007,58	6,63 / 812,9	6,13 / 802,28
19	Viscosity	**mPa s**	/ 1,15	/ 1,2656	0,012 / 3,5025	0,0126 / 3,0153
20	Molecular wt, Vap				23,16	23,1
21	Molecular wt, NC					
22	Specific heat	**kJ/(kg K)**	/ 3,29	/ 3,266	2,11 / 2,14	2,116 / 2,173
23	Thermal conductivity	**W/(m K)**	/ 0,231	/ 0,2309	0,034 / 0,1115	0,034 / 0,1075
24	Latent heat	**kJ/kg**			20,9	17,8
25	Pressure (abs)	**bar**	11	10,91026	8	7,04681
26	Velocity	**m/s**	1,45		31,32	
27	Pressure drop, allow./calc.	**bar**	1	0,08974	1	0,95319
28	Fouling resist. (min)	**m² K/W**	0		0	0 Ao based
29	Heat exchanged 6352,2	**kW**		MTD corrected	66,61	**°C**
30	Transfer rate, Service 156		Dirty 616,6	Clean 616,6		**W/(m² K)**

31	**CONSTRUCTION OF ONE SHELL**					**Sketch**
32				Shell Side	Tube Side	
33	Design/vac/test pressure:g		**bar**	21/ /	24/ /	
34	Design temperature		**°C**	180	180	
35	Number passes per shell			1	1	
36	Corrosion allowance		**mm**	3	0	
37	Connections	In	**mm**	1 200/ -	1 400/ -	
38	Size/rating	Out		1 150/ -	1 700/ -	
39	Nominal	Intermediate		/ -	/ -	

40	Tube No. 798	OD 19,05	Tks-Avg 1,25	**mm**	Length 6500	**mm**	Pitch 23,81	**mm**
41	Tube type Plain	**#/m**	Material 22Cr,5Ni,3Mo steel		Tube pattern 30			
42	Shell Carbon Steel	ID 775	OD 793	**mm**	Shell cover	-		
43	Channel or bonnet 22Cr,5Ni,3Mo steel				Channel cover	-		
44	Tubesheet-stationary 22Cr,5Ni,3Mo steel	-			Tubesheet-floating	-		
45	Floating head cover -				Impingement protection	None		
46	Baffle-crossing SS 316L	Type Single segmental	Cut(%d) 10	H	Spacing: c/c 730			**mm**
47	Baffle-long -	Seal type			Inlet 644,48			**mm**
48	Supports-tube	U-bend			Type			
49	Bypass seal	Tube-tubesheet joint	Exp.					
50	Expansion joint	-	Type None					
51	RhoV2-Inlet nozzle 1224	Bundle entrance 219			Bundle exit 210			**kg/(m s²)**
52	Gaskets - Shell side	-	Tube Side		Flat Metal Jacket Fibe			
53	Floating head	-						
54	Code requirements	EN13445			TEMA class	R - refinery service		
55	Weight/Shell	5804,1	Filled with water 9627,9		Bundle	3416,3		**kg**
56	Remarks							
57								
58								

Setting Plan



Nozzle Data				
Ref	OD	Wall	Standard	Notes
S1	219 mm	8, mm	150 ANSI Slip on	
S2	168 mm	7,1 mm	150 ANSI Slip on	
T1	406 mm	10, mm	150 ANSI Slip on	
T2	711 mm	10, mm	150 ANSI Slip on	

Design Data	Units	Shell	Channel
Design Pressure	bar	21,	24,
Design Temperature	C	180,	180,
Full Vacuum			
Corrosion Allowance	mm	3,	0,
Test Pressure	bar		
Number of Passes		1	1
Radiography			
PWHT			
Internal Volume	m³	3,0003	0,6298

Weight Summary		
Empty	Flooded	Bundle
5804 kg	9628 kg	3416 kg

Stabilization Separator Heater
20-HA-003
Base Case Simulation
1 X 100% Configuration

Design Codes
EN13445
TEMA R

Customer Specifications

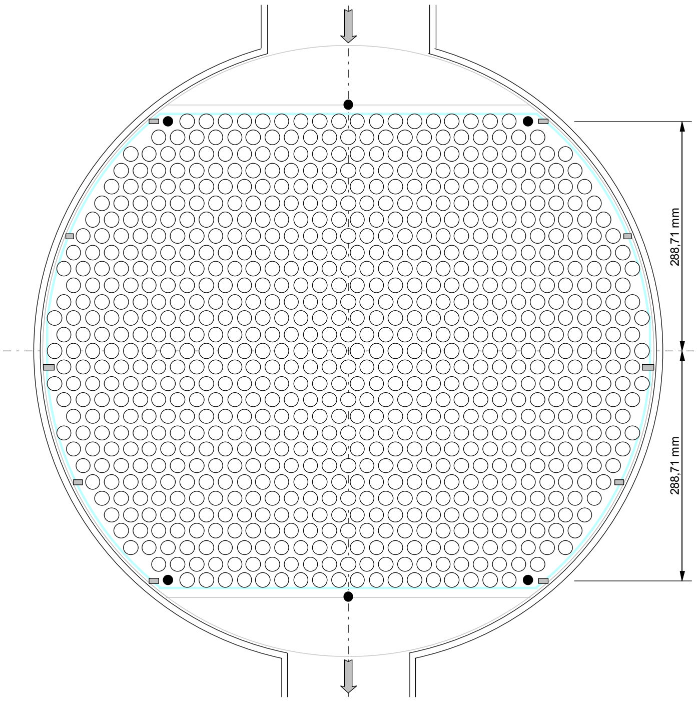
Aspen Shell & Tube Exchanger

Setting Plan
BEM 775 - 6500

Drawing Number

Revision	Date	Dwg.	Chk.	App.
	6.6.2014			

Tube Layout



Shell inside diameter	mm	775,
Front head inside diameter	mm	775,
Outer tube limit	mm	762,3
Tube number (calcs.)		798
Tube number (layout)		798
Tube O.D.	mm	19,05
Tube pitch	mm	23,8125
Tube pattern		30
Tube passes		1
Tie rod number		6
Tie rod diameter	mm	12,7
Sealing strips (pairs)		5
Baffle type		Single segmental
Impingement protection		None
Tube length	mm	6500,
Shell Side Inlet Nozzle Inside Diameter	mm	203,1
Shell Side Outlet Nozzle Inside Diameter	mm	154,1

Stabilization Separator Heater
20-HA-003
Base Case Simulation
1 X 100% Configuration

Design Codes
EN13445
TEMA R - refinery service

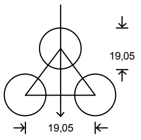
Customer Specifications

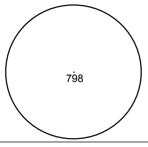
Aspen Shell & Tube

Tube Layout

Drawing Number

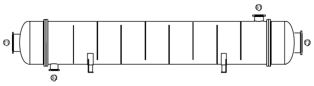
Revision	Date	Dwg.	App.
	6.6.2014		



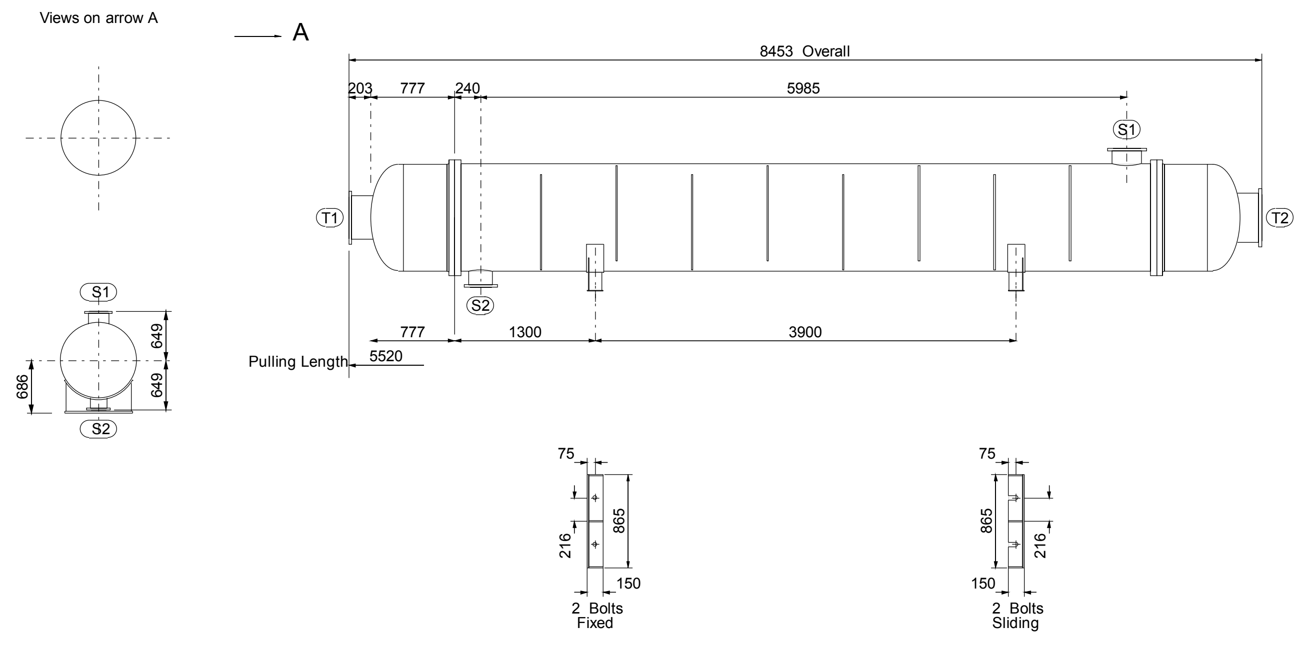


7.3.2 Thermal Calculation of 20-HA-003 – Case Study I

Heat Exchanger Specification Sheet

1	Stabilization Separator Heater						
2	20-HA-003						
3	Case Study 1						
4	1 X 100% Configuration						
5							
6	Size 975--6500	mm	Type BEM	Hor	Connected in	2 parallel	1 series
7	Surf/unit(eff.) 985,9	m²	Shells/unit 2		Surf/shell (eff.)	492,9	m²
8	**PERFORMANCE OF ONE UNIT**						
9	Fluid allocation		Shell Side		Tube Side		
10	Fluid name		Heating Medium Inlet 3		Inlet to Stabilization Separator		
11	Fluid quantity, Total	**kg/s**	110,3256		329,1558		
12	Vapor (In/Out)	**kg/s**	0	0	4,8715	6,5505	
13	Liquid	**kg/s**	110,3256	110,3256	324,2843	322,6053	
14	Noncondensable	**kg/s**	0	0	0	0	
15							
16	Temperature (In/Out)	**°C**	150	125,86	55,07	76,49	
17	Dew / Bubble point	**°C**					
18	Density Vapor/Liquid	**kg/m³**	/ 1003	/ 1008,09	6,55 / 820,76	6,36 / 811,04	
19	Viscosity	**mPa s**	/ 1,15	/ 1,2786	0,0122 / 4,1764	0,0124 / 3,4016	
20	Molecular wt, Vap				22,33	22,35	
21	Molecular wt, NC						
22	Specific heat	**kJ/(kg K)**	/ 3,29	/ 3,263	2,1 / 2,101	2,095 / 2,151	
23	Thermal conductivity	**W/(m K)**	/ 0,231	/ 0,2309	0,0337 / 0,1141	0,0339 / 0,113	
24	Latent heat	**kJ/kg**			19,4	18,8	
25	Pressure (abs)	**bar**	11	10,90013	8	7,14517	
26	Velocity	**m/s**	1,41		16,43		
27	Pressure drop, allow./calc.	**bar**	1	0,09987	1	0,85483	
28	Fouling resist. (min)	**m² K/W**	0		0	0 Ao based	
29	Heat exchanged 8634	**kW**			MTD corrected	77,05	**°C**
30	Transfer rate, Service 113,7		Dirty 628,2		Clean 628,2		**W/(m² K)**
31	**CONSTRUCTION OF ONE SHELL**				**Sketch**		
32			Shell Side	Tube Side			
33	Design/vac/test pressure:g	**bar**	21/ /	24/ /			
34	Design temperature	**°C**	180	180			
35	Number passes per shell		1	1			
36	Corrosion allowance	**mm**	3	0			
37	Connections In	**mm**	1 250/ -	1 400/ -			
38	Size/rating Out		1 200/ -	1 450/ -			
39	Nominal Intermediate		/ -	/ -			
40	Tube No. 1290	OD 19,05	Tks-Avg 1,2 **mm**	Length 6500 **mm**	Pitch 23,81	**mm**	
41	Tube type Plain	**#/m**	Material 22Cr,5Ni,3Mo steel		Tube pattern 30		
42	Shell Carbon Steel	ID 975	OD 999 **mm**	Shell cover	-		
43	Channel or bonnet	22Cr,5Ni,3Mo steel		Channel cover	-		
44	Tubesheet-stationary	22Cr,5Ni,3Mo steel	-	Tubesheet-floating	-		
45	Floating head cover	-		Impingement protection	None		
46	Baffle-crossing SS 316L	Type Single segmental	Cut(%d) 10	H	Spacing: c/c 700	**mm**	
47	Baffle-long -	Seal type		Inlet	742,48	**mm**	
48	Supports-tube	U-bend		Type			
49	Bypass seal		Tube-tubesheet joint	Exp.			
50	Expansion joint	-	Type	None			
51	RhoV2-Inlet nozzle	1200	Bundle entrance 224		Bundle exit 215	**kg/(m s²)**	
52	Gaskets - Shell side	-	Tube Side		Flat Metal Jacket Fibe		
53	Floating head	-					
54	Code requirements	EN13445			TEMA class	R - refinery service	
55	Weight/Shell	8848,2	Filled with water 14522,6		Bundle	5395	**kg**
56	Remarks						
57							
58							

Setting Plan



Nozzle Data				
Ref	OD	Wall	Standard	Notes
S1	273 mm	10, mm	150 ANSI Slip on	
S2	219 mm	8, mm	150 ANSI Slip on	
T1	406 mm	10, mm	150 ANSI Slip on	
T2	457 mm	10, mm	150 ANSI Slip on	

Design Data	Units	Shell	Channel
Design Pressure	bar	21,	24,
Design Temperature	C	180,	180,
Full Vacuum			
Corrosion Allowance	mm	3,	0,
Test Pressure	bar		
Number of Passes		1	1
Radiography			
PWHT			
Internal Volume	m³	4,73	1,0786

Weight Summary		
Empty	Flooded	Bundle
8848 kg	14523 kg	5395 kg

Stabilization Separator Heater
20-HA-003
Case Study 1
1 X 100% Configuration

Design Codes
EN13445
TEMA R

Customer Specifications

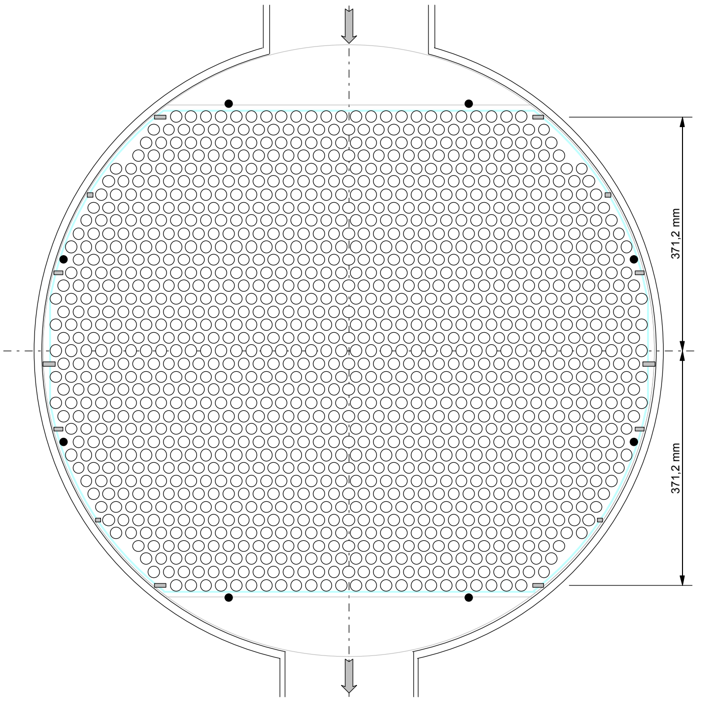
Aspen Shell & Tube Exchanger

Setting Plan
BEM 975 - 6500

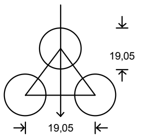
Drawing Number

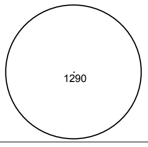
Revision	Date	Dwg.	Chk.	App.
	11.6.2014			

Tube Layout



Shell inside diameter	mm	975,
Front head inside diameter	mm	975,
Outer tube limit	mm	962,3
Tube number (calcs.)		1290
Tube number (layout)		1290
Tube O.D.	mm	19,05
Tube pitch	mm	23,8125
Tube pattern		30
Tube passes		1
Tie rod number		8
Tie rod diameter	mm	12,7
Sealing strips (pairs)		7
Baffle type		Single segmental
Impingement protection		None
Tube length	mm	6500,
Shell Side Inlet Nozzle Inside Diameter	mm	253,
Shell Side Outlet Nozzle Inside Diameter	mm	203,1





Stabilization Separator Heater	Aspen Shell & Tube
20-HA-003	
Case Study 1	
1 X 100% Configuration	Tube Layout
Design Codes	
EN13445	
TEMA R - refinery service	
	Drawing Number
Customer Specifications	

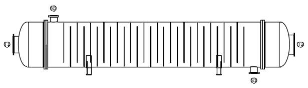
Revision	Date	Dwg.	App.
	11.6.2014		

7.4 Thermal Calculations of Crude Oil Cooler (21-HB-001)

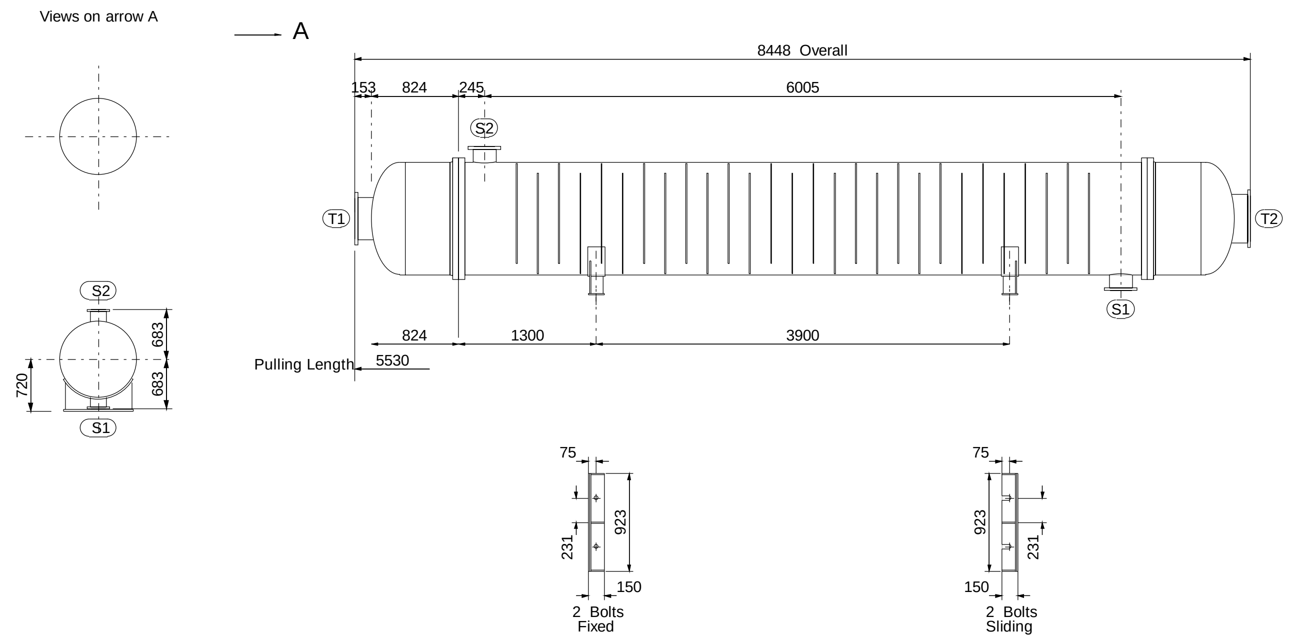
This section contains the thermal design calculations of the relevant heat exchangers in Case Study I.

7.4.1 Thermal Calculations of 21-HB-001 – Base Case Design

Heat Exchanger Specification Sheet

1	Export Oil Cooler							
2	21-HB-001							
3	Base Case Simulation							
4	1 X 100% Configuration							
5								
6	Size	1050--6500	mm	Type BEM	Hor	Connected in	1 parallel	1 series
7	Surf/unit(eff.)	562,2	m²	Shells/unit 1	Surf/shell (eff.)	562,2	m²	
8	**PERFORMANCE OF ONE UNIT**							
9	Fluid allocation		Shell Side		Tube Side			
10	Fluid name		Sea Water		Export Oil			
11	Fluid quantity, Total	**kg/s**	49,8656		316,2761			
12	Vapor (In/Out)	**kg/s**	0	0	0	0		
13	Liquid	**kg/s**	49,8656	49,8656	316,2761	316,2761		
14	Noncondensable	**kg/s**	0	0	0	0		
15								
16	Temperature (In/Out)	**°C**	8	47,64	66,5	54,73		
17	Dew / Bubble point	**°C**						
18	Density Vapor/Liquid	**kg/m³**	/ 1020	/ 1012,4	/ 817,5	/ 818,99		
19	Viscosity	**mPa s**	/ 1,375	/ 1,1631	/ 3,696	/ 3,8612		
20	Molecular wt, Vap							
21	Molecular wt, NC							
22	Specific heat	**kJ/(kg K)**	/ 4,44	/ 4,437	/ 2,2	/ 2,193		
23	Thermal conductivity	**W/(m K)**	/ 0,5834	/ 0,5981	/ 0,1182	/ 0,1184		
24	Latent heat	**kJ/kg**						
25	Pressure (abs)	**bar**	10	9,7287	6,5	6,35436		
26	Velocity	**m/s**	1,35		1,21			
27	Pressure drop, allow./calc.	**bar**	1	0,2713	1	0,14564		
28	Fouling resist. (min)	**m² K/W**	0		0	0 Ao based		
29	Heat exchanged	8174,5	**kW**	MTD corrected	30,93	**°C**		
30	Transfer rate, Service	470,2	Dirty 464,8	Clean 464,8	**W/(m² K)**			
31	**CONSTRUCTION OF ONE SHELL**					**Sketch**		
32				Shell Side	Tube Side			
33	Design/vac/test pressure:g		**bar**	21/ /	21/ /			
34	Design temperature		**°C**	180	180			
35	Number passes per shell			1	1			
36	Corrosion allowance		**mm**	0	0			
37	Connections	In	**mm**	1 200/ -	1 400/ -			
38	Size/rating	Out		1 200/ -	1 450/ -			
39	Nominal	Intermediate		/ -	/ -			
40	Tube No. 1473	OD 19,05	Tks-Avg 1,2	**mm**	Length 6500	**mm**	Pitch 23,81	**mm**
41	Tube type Plain	**#/m**	Material 22Cr,5Ni,3Mo steel	Tube pattern 30				
42	Shell 22Cr,5Ni,3Mo steel	ID 1050	OD 1066	**mm**	Shell cover	-		
43	Channel or bonnet	22Cr,5Ni,3Mo steel			Channel cover	-		
44	Tubesheet-stationary	22Cr,5Ni,3Mo steel	-		Tubesheet-floating	-		
45	Floating head cover	-			Impingement protection	None		
46	Baffle-crossing SS 316L	Type Single segmental	Cut(%d) 10	H	Spacing: c/c	200	**mm**	
47	Baffle-long	-	Seal type	Inlet	488,48	**mm**		
48	Supports-tube	U-bend	Type					
49	Bypass seal	Tube-tubesheet joint	Exp.					
50	Expansion joint	-	Type	None				
51	RhoV2-Inlet nozzle	2323	Bundle entrance	464	Bundle exit	475	**kg/(m s²)**	
52	Gaskets - Shell side	-	Tube Side	Flat Metal Jacket Fibe				
53	Floating head	-						
54	Code requirements	EN13445	TEMA class	R - refinery service				
55	Weight/Shell	9495,1	Filled with water	16003,1	Bundle	6535,7	**kg**	
56	Remarks							
57								
58								

Setting Plan



Nozzle Data				
Ref	OD	Wall	Standard	Notes
S1	219 mm	8, mm	150 ANSI Slip on	
S2	219 mm	8, mm	150 ANSI Slip on	
T1	406 mm	10, mm	150 ANSI Slip on	
T2	457 mm	10, mm	150 ANSI Slip on	

Design Data	Units	Shell	Channel
Design Pressure	bar	21,	21,
Design Temperature	C	180,	180,
Full Vacuum			
Corrosion Allowance	mm	0,	0,
Test Pressure	bar		
Number of Passes		1	1
Radiography			
PWHT			
Internal Volume	m³	5,3905	1,3019

Weight Summary		
Empty	Flooded	Bundle
9495 kg	16003 kg	6536 kg

Export Oil Cooler
21-HB-001
Base Case Simulation
1 X 100% Configuration
Design Codes
EN13445
TEMA R
Customer Specifications

Aspen Shell & Tube Exchanger

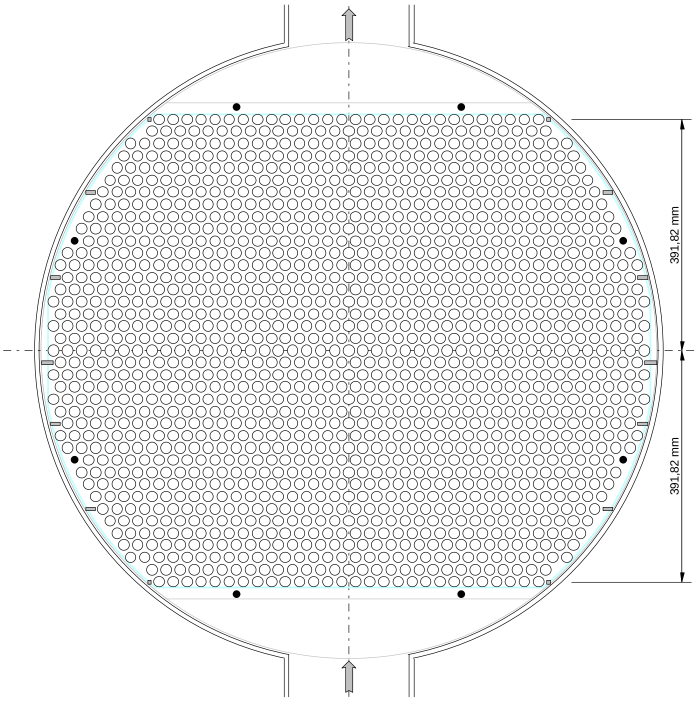
Setting Plan

BEM 1050 - 6500

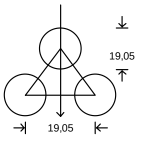
Drawing Number

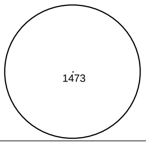
Revision	Date	Dwg.	Chk.	App.
	7.6.2014			

Tube Layout



Shell inside diameter	mm	1050,
Front head inside diameter	mm	1050,
Outer tube limit	mm	1037,3
Tube number (calcs.)		1473
Tube number (layout)		1473
Tube O.D.	mm	19,05
Tube pitch	mm	23,8125
Tube pattern		30
Tube passes		1
Tie rod number		8
Tie rod diameter	mm	12,7
Sealing strips (pairs)		7
Baffle type		Single segmental
Impingement protection		None
Tube length	mm	6500,
Shell Side Inlet Nozzle Inside Diameter	mm	203,1
Shell Side Outlet Nozzle Inside Diameter	mm	203,1

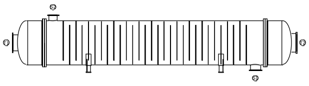




Export Oil Cooler	Aspen Shell & Tube			
21-HB-001				
Base Case Simulation				
1 X 100% Configuration	Tube Layout			
Design Codes				
EN13445				
TEMA R - refinery service	Drawing Number			
Customer Specifications				
	Revision	Date	Dwg.	App.
		7.6.2014		

7.4.2 Thermal Calculations of 21-HB-001 – Case Study I

Heat Exchanger Specification Sheet

1	Export Oil Cooler												
2	21-HB-001												
3	Case Study 1												
4	1 X 100% Configuration												
5													
6	Size	1100--7000	mm	Type	BEM	Hor	Connected in	1	parallel	1	series		
7	Surf/unit(eff.)	668	m^2	Shells/unit	1	Surf/shell (eff.)	668	m^2					
8	**PERFORMANCE OF ONE UNIT**												
9	Fluid allocation		Shell Side		Tube Side								
10	Fluid name		Sea Water		Export Oil								
11	Fluid quantity, Total	kg/s	86,8636		316,2758								
12	Vapor (In/Out)	kg/s	0	0	0	0							
13	Liquid	kg/s	86,8636	86,8636	316,2758	316,2758							
14	Noncondensable	kg/s	0	0	0	0							
15													
16	Temperature (In/Out)	°C	8	45,34	75,1	54,9							
17	Dew / Bubble point	°C											
18	Density Vapor/Liquid	kg/m^3	/ 1020	/ 1002,29	/ 810,1	/ 812,5							
19	Viscosity	mPa s	/ 1,375	/ 0,881	/ 3,092	/ 3,3291							
20	Molecular wt, Vap												
21	Molecular wt, NC												
22	Specific heat	kJ/(kg K)	/ 4,45	/ 4,437	/ 2,23	/ 2,219							
23	Thermal conductivity	W/(m K)	/ 0,5834	/ 0,6177	/ 0,1171	/ 0,1174							
24	Latent heat	kJ/kg											
25	Pressure (abs)	bar	10	9,36757	7,5	7,36364							
26	Velocity	m/s	2,24		1,12								
27	Pressure drop, allow./calc.	bar	1	0,63243	1	0,13636							
28	Fouling resist. (min)	m^2 K/W	0		0	0 Ao based							
29	Heat exchanged	14161,9	kW	MTD corrected	37,73	°C							
30	Transfer rate, Service	561,9	Dirty	495,1	Clean	495,1	$W/(m^2 K)$						
31	**CONSTRUCTION OF ONE SHELL**				**Sketch**								
32			Shell Side	Tube Side									
33	Design/vac/test pressure:g		bar	21/ /	21/ /								
34	Design temperature		°C	180	180								
35	Number passes per shell			1	1								
36	Corrosion allowance		mm	0	0								
37	Connections	In	mm	1 304,8/ -	1 406,4/ -								
38	Size/rating	Out		1 254/ -	1 457,2/ -								
39	Nominal	Intermediate		/ -	/ -								
40	Tube No.	1624	OD	19,05	Tks-Avg	1,24	mm	Length	7000	mm	Pitch	23,81	mm
41	Tube type	Plain	#/m	Material	22Cr,5Ni,3Mo steel	Tube pattern	30						
42	Shell	22Cr,5Ni,3Mo steel	ID	1100	OD	1118	mm	Shell cover	-				
43	Channel or bonnet	22Cr,5Ni,3Mo steel	Channel cover	-									
44	Tubesheet-stationary	22Cr,5Ni,3Mo steel	-	Tubesheet-floating	-								
45	Floating head cover	-	Impingement protection	None									
46	Baffle-crossing	SS 316L	Type	Single segmental	Cut(%d)	10	H	Spacing: c/c	200	mm			
47	Baffle-long	-	Seal type		Inlet	536,48	mm						
48	Supports-tube		U-bend		Type								
49	Bypass seal		Tube-tubesheet joint	Exp.									
50	Expansion joint	-	Type	None									
51	RhoV2-Inlet nozzle	1389	Bundle entrance	821	Bundle exit	841	$kg/(m s^2)$						
52	Gaskets - Shell side	-	Tube Side	Flat Metal Jacket Fibe									
53	Floating head	-											
54	Code requirements	EN13445	TEMA class	R - refinery service									
55	Weight/Shell	11453	Filled with water	18982,8	Bundle	7912,5	kg						
56	Remarks												
57													
58													

Size	1100	x	7000	mm	Type	BEM	Hor	Connected in	1	parallel	1	series
Surf/Unit (gross/eff/finned)	680,3	/	668	/		m²		Shells/unit	1			
Surf/Shell (gross/eff/finned)	680,3	/	668	/		m²						

Design **PERFORMANCE OF ONE UNIT**

		Shell Side		**Tube Side**	
Process Data		**In**	**Out**	**In**	**Out**
Total flow	kg/s	86,8636		316,2758	
Vapor	kg/s	0	0	0	0
Liquid	kg/s	86,8636	86,8636	316,2758	316,2758
Noncondensable	kg/s	0		0	
Cond./Evap.		0		0	
Temperature	°C	8	45,34	75,1	54,9
Dew / Bubble point	°C				
Quality		0	0	0	0
Pressure (abs)	bar	10	9,36757	7,5	7,36364
Delta P allow/calc	bar	1	0,63243	1	0,13636
Velocity	m/s	2,19	2,24	1,12	1,11
Liquid Properties					
Density	kg/m³	1020	1002,29	810,1	812,5
Viscosity	mPa s	1,375	0,881	3,092	3,3291
Specific heat	kJ/(kg K)	4,45	4,437	2,23	2,219
Therm. cond.	W/(m K)	0,5834	0,6177	0,1171	0,1174
Surface tension	N/m				
Molecular weight					
Vapor Properties					
Density	kg/m³				
Viscosity	mPa s				
Specific heat	kJ/(kg K)				
Therm. cond.	W/(m K)				
Molecular weight					
Two-Phase Properties					
Latent heat	kJ/kg				
Heat Transfer Parameters					
Reynolds No. vapor					
Reynolds No. liquid		30893,27	48215,32	4842,5	4497,58
Prandtl No. vapor					
Prandtl No. liquid		10,49	6,33	58,88	62,91
Heat Load		kW		kW	
Vapor only		0		0	
2-Phase vapor		0		0	
Latent heat		0		0	
2-Phase liquid		0		0	
Liquid only		14161,9		-14161,9	

Heat Transfer Parameters			
Total heat load	kW	14161,9	
Eff. MTD/ 1 pass MTD	°C	37,73 / 37,71	
Actual/Reqd area ratio - fouled/clean		0,88 / 0,88	

Coef./Resist.	W/(m² K)	m² K/W	%
Overall fouled	495,1	0,00202	
Overall clean	495,1	0,00202	
Tube side film	581	0,00172	85,21
Tube side fouling		0	0
Tube wall	12128,5	0,00008	4,08
Outside fouling		0	0
Outside film	4622,9	0,00022	10,71

Shell Side Pressure Drop	bar	%
Inlet nozzle	0,00895	1,42
Inlet space Xflow	0,02613	4,13
Baffle Xflow	0,47971	75,88
Baffle window	0,08006	12,66
Outlet space Xflow	0,02514	3,98
Outlet nozzle	0,0122	1,93
Intermediate nozzle		
Tube Side Pressure Drop	bar	%
Inlet nozzle	0,03412	25,02
Entering tubes	0,00243	1,78
Inside tubes	0,08335	61,12
Exiting tubes	0,00328	2,41
Outlet nozzle	0,0132	9,68
Intermediate nozzle		

Velocity / Rho*V2		m/s		kg/(m s²)
Shell nozzle inlet		1,17		1389
Shell bundle Xflow	2,19		2,24	
Shell baffle window	1,73		1,77	
Shell nozzle outlet		1,7		2909
Shell nozzle interm				
		m/s		kg/(m s²)
Tube nozzle inlet		3,31		8892
Tubes	1,12		1,11	
Tube nozzle outlet		2,58		5415
Tube nozzle interm				

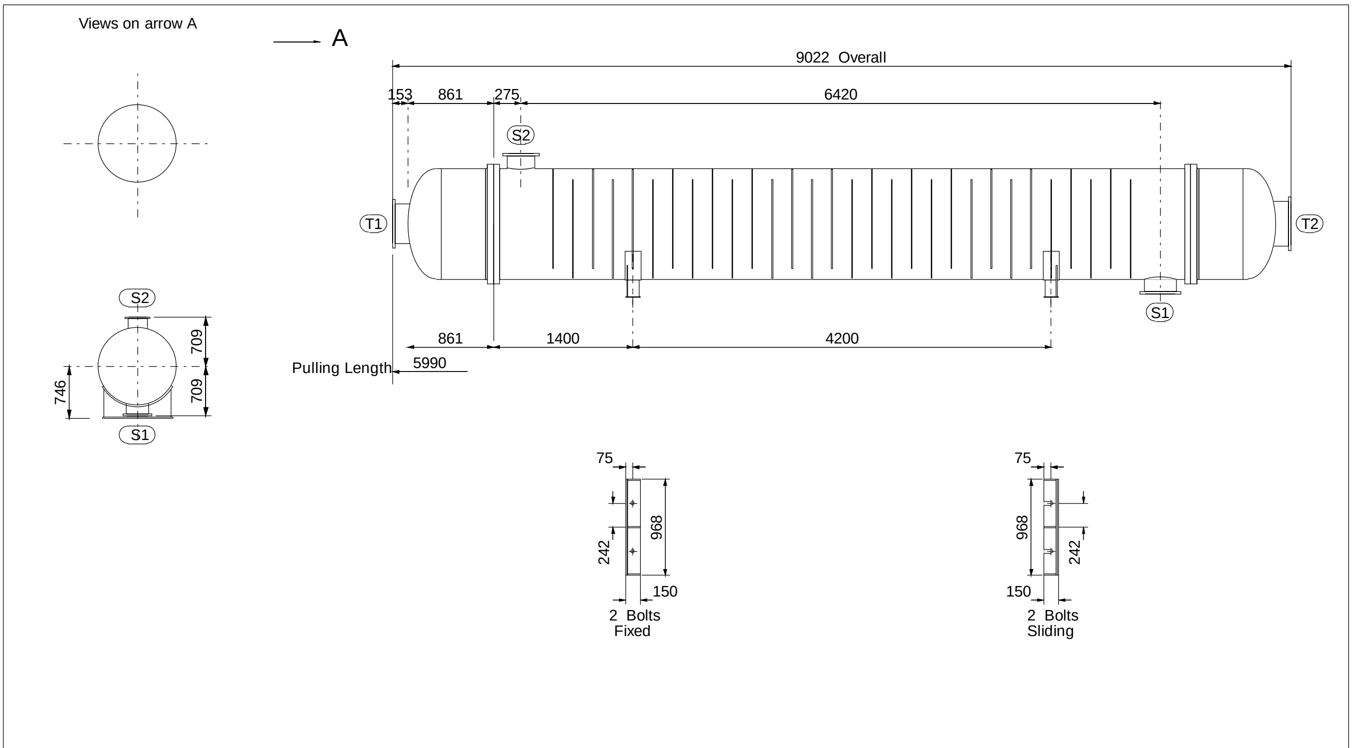
Tubes			
Type			Plain
ID/OD	mm	16,56 /	19,05
Length act/eff	mm	7000 /	6873
Tube passes			1
Tube No.			1624
Tube pattern			30
Tube pitch	mm		23,81
Insert			None
Vibration problem			No / No

Baffles		
Type		Single segmental
Number		30
Cut(%d)		10
Cut orientation		H
Spacing: c/c	mm	200
Spacing at inlet	mm	536,48
Spacing at outlet	mm	536,48

Nozzles: (No./OD)		**Shell Side**	**Tube Side**
Inlet	mm	1 / 323,85	1 / 406,4
Outlet		1 / 273,05	1 / 457,2
Other		/	/
Impingement protection			None

RhoV2 violation No

Setting Plan



Nozzle Data				
Ref	OD	Wall	Standard	Notes
S1	324 mm	9,5 mm	150 ANSI Slip on	
S2	273 mm	9,3 mm	150 ANSI Slip on	
T1	406 mm	9,5 mm	150 ANSI Slip on	
T2	457 mm	9,5 mm	150 ANSI Slip on	

Design Data	Units	Shell	Channel
Design Pressure	bar	21,	21,
Design Temperature	C	180,	180,
Full Vacuum			
Corrosion Allowance	mm	0,	0,
Test Pressure	bar		
Number of Passes		1	1
Radiography			
PWHT			
Internal Volume	m³	6,385	1,4846

Weight Summary		
Empty	Flooded	Bundle
11453 kg	18983 kg	7913 kg

Export Oil Cooler
21-HB-001
Case Study 1
1 X 100% Configuration

Design Codes
EN13445
TEMA R

Customer Specifications

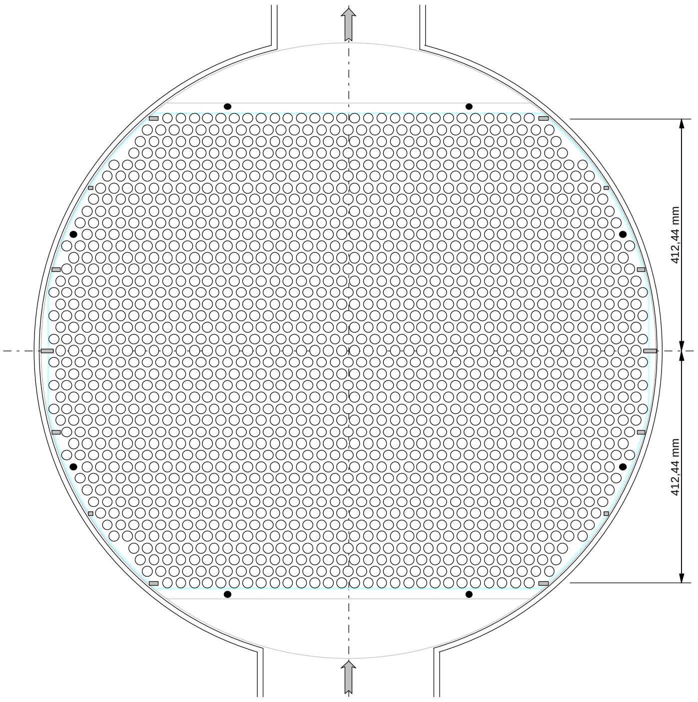
Aspen Shell & Tube Exchanger

Setting Plan
BEM 1100 - 7000

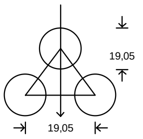
Drawing Number

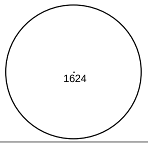
Revision	Date	Dwg.	Chk.	App.
	9.6.2014			

Tube Layout



Shell inside diameter	mm	1100,
Front head inside diameter	mm	1100,
Outer tube limit	mm	1087,3
Tube number (calcs.)		1624
Tube number (layout)		1624
Tube O.D.	mm	19,05
Tube pitch	mm	23,8125
Tube pattern		30
Tube passes		1
Tie rod number		8
Tie rod diameter	mm	12,7
Sealing strips (pairs)		7
Baffle type		Single segmental
Impingement protection		None
Tube length	mm	7000,
Shell Side Inlet Nozzle Inside Diameter	mm	304,8
Shell Side Outlet Nozzle Inside Diameter	mm	254,508





Export Oil Cooler
21-HB-001
Case Study 1
1 X 100% Configuration

Design Codes
EN13445
TEMA R - refinery service

Customer Specifications

Aspen Shell & Tube

Tube Layout

Drawing Number

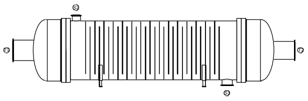
Revision	Date	Dwg.	App.
	9.6.2014		

7.5 Thermal Calculations of Field 1 & 2 Dehydration Inlet Coolers (24-HJ-101 & 24-HJ-201)

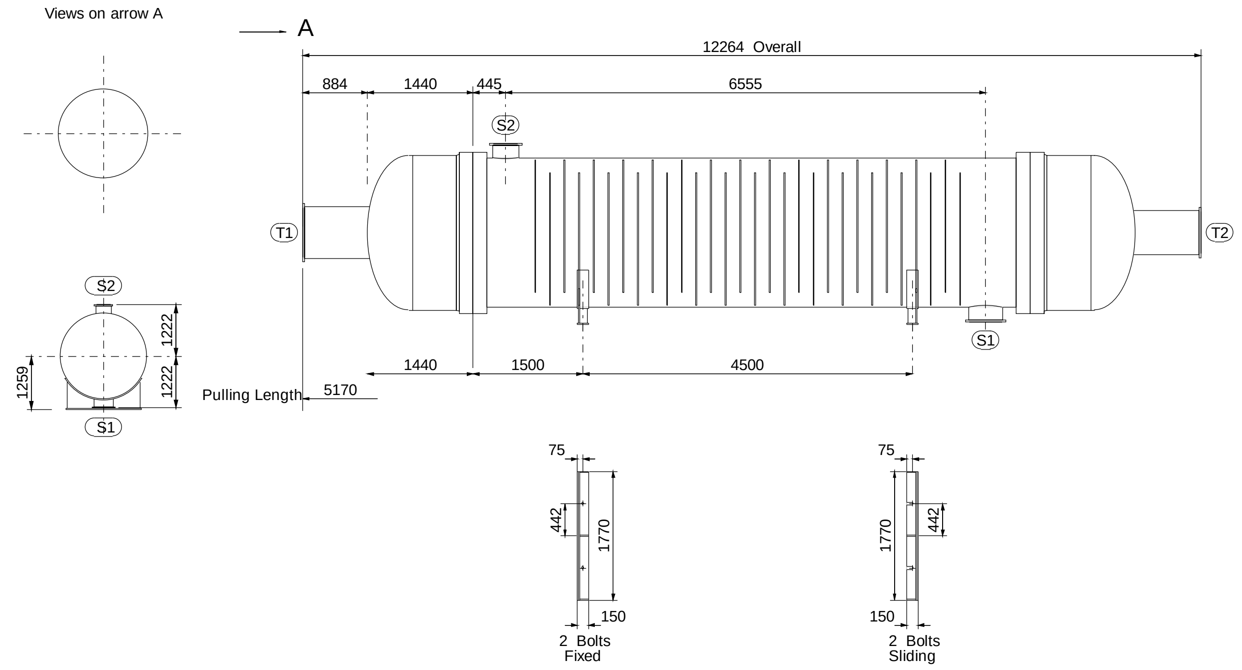
This section contains the thermal design calculations of the relevant heat exchangers in Case Study III.

7.5.1 Thermal Calculations of the 24-HJ-101 & 24-HJ-201 – Base Case Design

Heat Exchanger Specification Sheet

1	Field 1 Dehydration Inlet Cooler					
2	24-HJ-101					
3	Base Case Simulation					
4	1 X 100% Configuration					
5						
6	Size 2000 - - 7500	mm	Type BEM Hor	Connected in	2 parallel	1 series
7	Surf/unit(eff.) 3512,1	m²	Shells/unit 2	Surf/shell (eff.)	1756	m²
8	**PERFORMANCE OF ONE UNIT**					
9	Fluid allocation		Shell Side		Tube Side	
10	Fluid name		Cooling Medium Inlet 4		Inlet to 24-HJ-101	
11	Fluid quantity, Total	**kg/s**	446,1111		268,2778	
12	Vapor (In/Out)	**kg/s**	0	0	268,2778	268,2778
13	Liquid	**kg/s**	446,1111	446,1111	0	0
14	Noncondensable	**kg/s**	0	0	0	0
15						
16	Temperature (In/Out)	**°C**	20	80	135	25,81
17	Dew / Bubble point	**°C**				
18	Density Vapor/Liquid	**kg/m³**	/ 1127	/ 1072	30,19 /	41,38 /
19	Viscosity	**mPa s**	/ 17,13	/ 3,715	0,0157 /	0,0156 /
20	Molecular wt, Vap				20,37	20,37
21	Molecular wt, NC					
22	Specific heat	**kJ/(kg K)**	/ 2,65	/ 2,93	2,55 /	2,547 /
23	Thermal conductivity	**W/(m K)**	/ 0,2165	/ 0,2274	0,0501 /	0,0494 /
24	Latent heat	**kJ/kg**				
25	Pressure (abs)	**bar**	10	9	50,3	50,25467
26	Velocity	**m/s**	3,02		3,74	
27	Pressure drop, allow./calc.	**bar**	1	1,70701	1	0,04533
28	Fouling resist. (min)	**m² K/W**	0		0	0 Ao based
29	Heat exchanged 74540,9	**kW**			MTD corrected 21,93	**°C**
30	Transfer rate, Service 967,6		Dirty 349,3		Clean 349,3	**W/(m² K)**
31	**CONSTRUCTION OF ONE SHELL**				**Sketch**	
32			Shell Side	Tube Side		
33	Design/vac/test pressure:g	**bar**	21/ /	85/ /		
34	Design temperature	**°C**	180	180		
35	Number passes per shell		1	1		
36	Corrosion allowance	**mm**	3,18	0		
37	Connections	In **mm**	1 450/ -	1 700/ -		
38	Size/rating	Out	1 350/ -	1 600/ -		
39	Nominal	Intermediate	/ -	/ -		
40	Tube No. 3093	OD 25,4	Tks-Avg 1,65 **mm**	Length 7500 **mm**	Pitch 31,75	**mm**
41	Tube type Plain	**#/m**	Material 22Cr,5Ni,3Mo steel		Tube pattern 30	
42	Shell Carbon Steel	ID 2000	OD 2044 **mm**	Shell cover	-	
43	Channel or bonnet 22Cr,5Ni,3Mo steel			Channel cover	-	
44	Tubesheet-stationary 22Cr,5Ni,3Mo steel	-		Tubesheet-floating	-	
45	Floating head cover -			Impingement protection	None	
46	Baffle-crossing SS 316L	Type Single segmental	Cut(%d) 10	H	Spacing: c/c 200	**mm**
47	Baffle-long -		Seal type		Inlet 657,48	**mm**
48	Supports-tube	U-bend		Type		
49	Bypass seal		Tube-tubesheet joint	Exp.		
50	Expansion joint -		Type None			
51	RhoV2-Inlet nozzle 1962		Bundle entrance 1501		Bundle exit 1566	**kg/(m s²)**
52	Gaskets - Shell side -		Tube Side		Flat Metal Jacket Fibe	
53	Floating head -					
54	Code requirements EN13445				TEMA class R - refinery service	
55	Weight/Shell 76914,4		Filled with water 107549,6		Bundle 36377	**kg**
56	Remarks					
57						
58						

Setting Plan



Nozzle Data				
Ref	OD	Wall	Standard	Notes
S1	457 mm	10, mm	150 ANSI Slip on	
S2	356 mm	10, mm	150 ANSI Slip on	
T1	711 mm	20, mm	150 ANSI Slip on	
T2	610 mm	17,5 mm	150 ANSI Slip on	

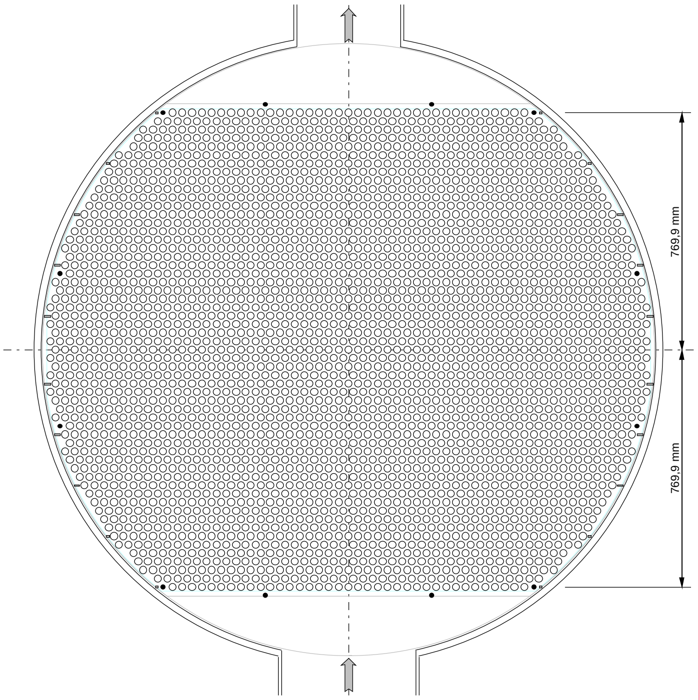
Design Data	Units	Shell	Channel
Design Pressure	bar	21,	85,
Design Temperature	C	180,	180,
Full Vacuum			
Corrosion Allowance	mm	3,175	0,
Test Pressure	bar		
Number of Passes		1	1
Radiography			
PWHT			
Internal Volume	m³	21,9114	8,1575

Weight Summary		
Empty	Flooded	Bundle
76914 kg	107550 kg	36377 kg

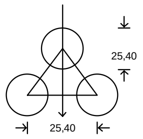
Field 1 Dehydration Inlet Cooler
24-HJ-101
Base Case Simulation
1 X 100% Configuration
Design Codes
EN13445
TEMA R
Customer Specifications

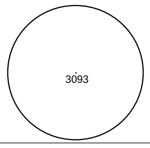
Aspen Shell & Tube Exchanger				
Setting Plan BEM 2000 - 7500				
Drawing Number				
Revision	Date	Dwg.	Chk.	App.
	12.6.2014			

Tube Layout



Shell inside diameter	mm	2000,
Front head inside diameter	mm	2000,
Outer tube limit	mm	1984,125
Tube number (calcs.)		3093
Tube number (layout)		3093
Tube O.D.	mm	25,4
Tube pitch	mm	31,75
Tube pattern		30
Tube passes		1
Tie rod number		12
Tie rod diameter	mm	15,875
Sealing strips (pairs)		10
Baffle type		Single segmental
Impingement protection		None
Tube length	mm	7500,
Shell Side Inlet Nozzle Inside Diameter	mm	437,
Shell Side Outlet Nozzle Inside Diameter	mm	335,6



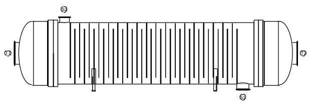


Field 1 Dehydration Inlet Cooler	Aspen Shell & Tube			
24-HJ-101				
Base Case Simulation				
1 X 100% Configuration	Tube Layout			
Design Codes				
EN13445				
TEMA R - refinery service	Drawing Number			
Customer Specifications				
	Revision	Date	Dwg.	App.
		12.6.2014		

Heat Exchanger Specification Sheet

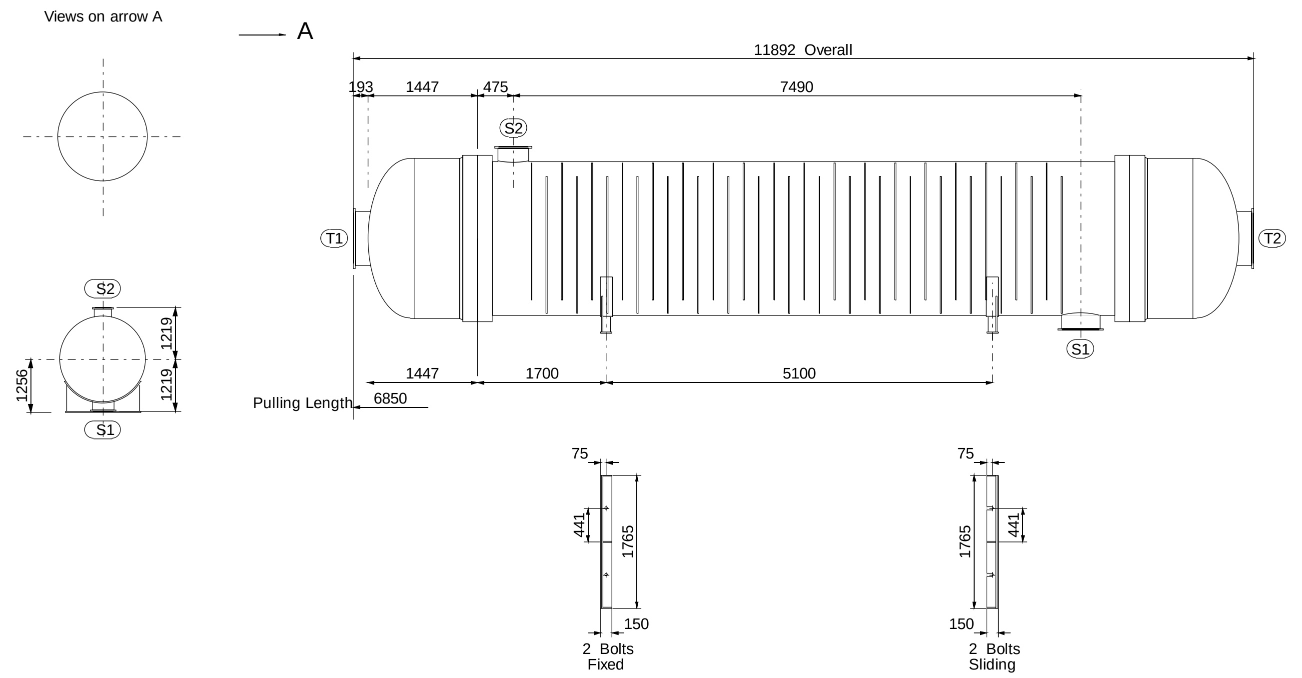
1	Field 2 Dehydration Inlet Cooler							
2	24-HJ-201							
3	Base Case Simulation							
4	1 X 100% Configuration							
5								
6	Size	2000--8500	**mm**	Type BEM	Hor	Connected in	2 parallel	1 series
7	Surf/unit(eff.)	3998,8	**m^2**	Shells/unit 2		Surf/shell (eff.)	1999,4	**m^2**

8	**PERFORMANCE OF ONE UNIT**					
9	Fluid allocation		Shell Side		Tube Side	
10	Fluid name		Cooling Medium Inlet 8		Inlet to 24-HJ-201	
11	Fluid quantity, Total	**kg/s**	545,5555		303,8889	
12	Vapor (In/Out)	**kg/s**	0	0	303,8889	303,8889
13	Liquid	**kg/s**	545,5555	545,5555	0	0
14	Noncondensable	**kg/s**	0	0	0	0
15						
16	Temperature (In/Out)	**°C**	20	80	142	25,98
17	Dew / Bubble point	**°C**				
18	Density Vapor/Liquid	**kg/m^3**	/ 1127	/ 1072	32,51 /	45,35 /
19	Viscosity	**mPa s**	/ 17,13	/ 3,715	0,016 /	0,0159 /
20	Molecular wt, Vap				20,33	20,33
21	Molecular wt, NC					
22	Specific heat	**kJ/(kg K)**	/ 2,65	/ 2,92	2,58 /	2,578 /
23	Thermal conductivity	**W/(m K)**	/ 0,2165	/ 0,2274	0,0515 /	0,0508 /
24	Latent heat	**kJ/kg**				
25	Pressure (abs)	**bar**	10	9	55,2	55,15403
26	Velocity	**m/s**	3,7		3,94	
27	Pressure drop, allow./calc.	**bar**	1	2,71438	1	0,04598
28	Fouling resist. (min)	**m^2 K/W**	0		0	0 Ao based
29	Heat exchanged	90985,3 **kW**			MTD corrected	24,03 **°C**
30	Transfer rate, Service	947	Dirty 389,6	Clean 389,6		**W/(m^2 K)**

31	**CONSTRUCTION OF ONE SHELL**					**Sketch**
32				Shell Side	Tube Side	
33	Design/vac/test pressure:g		**bar**	21/ /	85/ /	
34	Design temperature		**°C**	180	180	
35	Number passes per shell			1	1	
36	Corrosion allowance		**mm**	0	0	
37	Connections	In	**mm**	1 500/ -	1 700/ -	
38	Size/rating	Out		1 400/ -	1 700/ -	
39	Nominal	Intermediate		/ -	/ -	

40	Tube No. 3093	OD 25,4	Tks-Avg 1,65	**mm**	Length 8500	**mm**	Pitch 31,75	**mm**
41	Tube type Plain	**#/m**	Material 22Cr,5Ni,3Mo steel		Tube pattern 30			
42	Shell Carbon Steel	ID 2000	OD 2038	**mm**	Shell cover	-		
43	Channel or bonnet	22Cr,5Ni,3Mo steel			Channel cover	-		
44	Tubesheet-stationary	22Cr,5Ni,3Mo steel	-		Tubesheet-floating	-		
45	Floating head cover	-			Impingement protection	None		
46	Baffle-crossing SS 316L	Type Single segmental	Cut(%d) 10	H	Spacing: c/c 200	**mm**		
47	Baffle-long -	Seal type			Inlet 585,2	**mm**		
48	Supports-tube	U-bend	Type					
49	Bypass seal	Tube-tubesheet joint	Exp.					
50	Expansion joint	-	Type None					
51	RhoV2-Inlet nozzle	1887	Bundle entrance 2834		Bundle exit 3807	**kg/(m s^2)**		
52	Gaskets - Shell side	-	Tube Side		Flat Metal Jacket Fibe			
53	Floating head	-						
54	Code requirements	EN13445			TEMA class	R - refinery service		
55	Weight/Shell	81905,9	Filled with water 115930,2		Bundle	40528,1	**kg**	
56	Remarks							
57								
58								

Setting Plan



Nozzle Data				
Ref	OD	Wall	Standard	Notes
S1	508 mm	10, mm	150 ANSI Slip on	
S2	406 mm	10, mm	150 ANSI Slip on	
T1	711 mm	20, mm	150 ANSI Slip on	
T2	711 mm	20, mm	150 ANSI Slip on	

Design Data	Units	Shell	Channel
Design Pressure	bar	21,	85,
Design Temperature	C	180,	180,
Full Vacuum			
Corrosion Allowance	mm	0,	0,
Test Pressure	bar		
Number of Passes		1	1
Radiography			
PWHT			
Internal Volume	m³	24,8703	7,7965

Weight Summary		
Empty	Flooded	Bundle
81906 kg	115930 kg	40528 kg

Field 2 Dehydration Inlet Cooler
24-HJ-201
Base Case Simulation
1 X 100% Configuration

Design Codes
EN13445
TEMA R

Customer Specifications

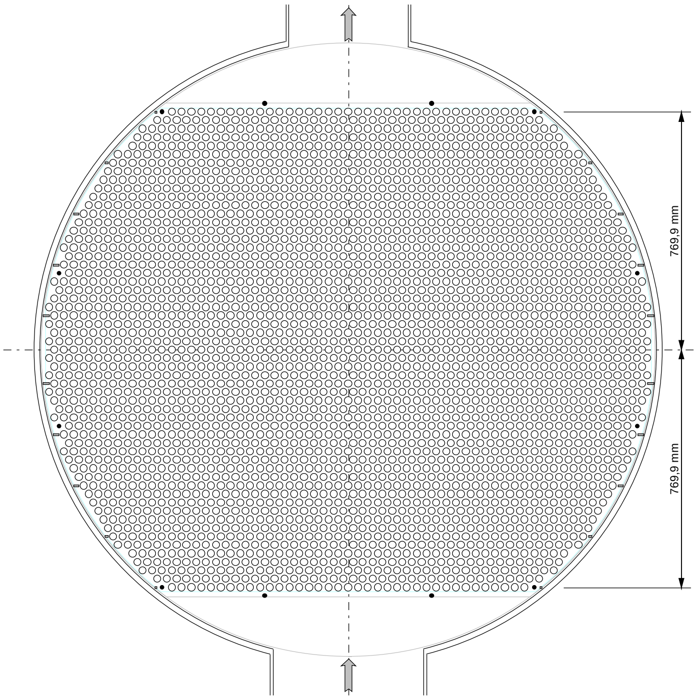
Aspen Shell & Tube Exchanger

Setting Plan
BEM 2000 - 8500

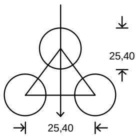
Drawing Number

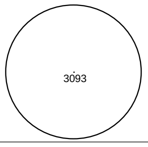
Revision	Date	Dwg.	Chk.	App.
	12.6.2014			

Tube Layout



Shell inside diameter	mm	2000,
Front head inside diameter	mm	2000,
Outer tube limit	mm	1984,125
Tube number (calcs.)		3093
Tube number (layout)		3093
Tube O.D.	mm	25,4
Tube pitch	mm	31,75
Tube pattern		30
Tube passes		1
Tie rod number		12
Tie rod diameter	mm	15,875
Sealing strips (pairs)		10
Baffle type		Single segmental
Impingement protection		None
Tube length	mm	8500,
Shell Side Inlet Nozzle Inside Diameter	mm	488,
Shell Side Outlet Nozzle Inside Diameter	mm	386,4

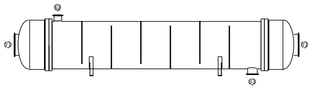




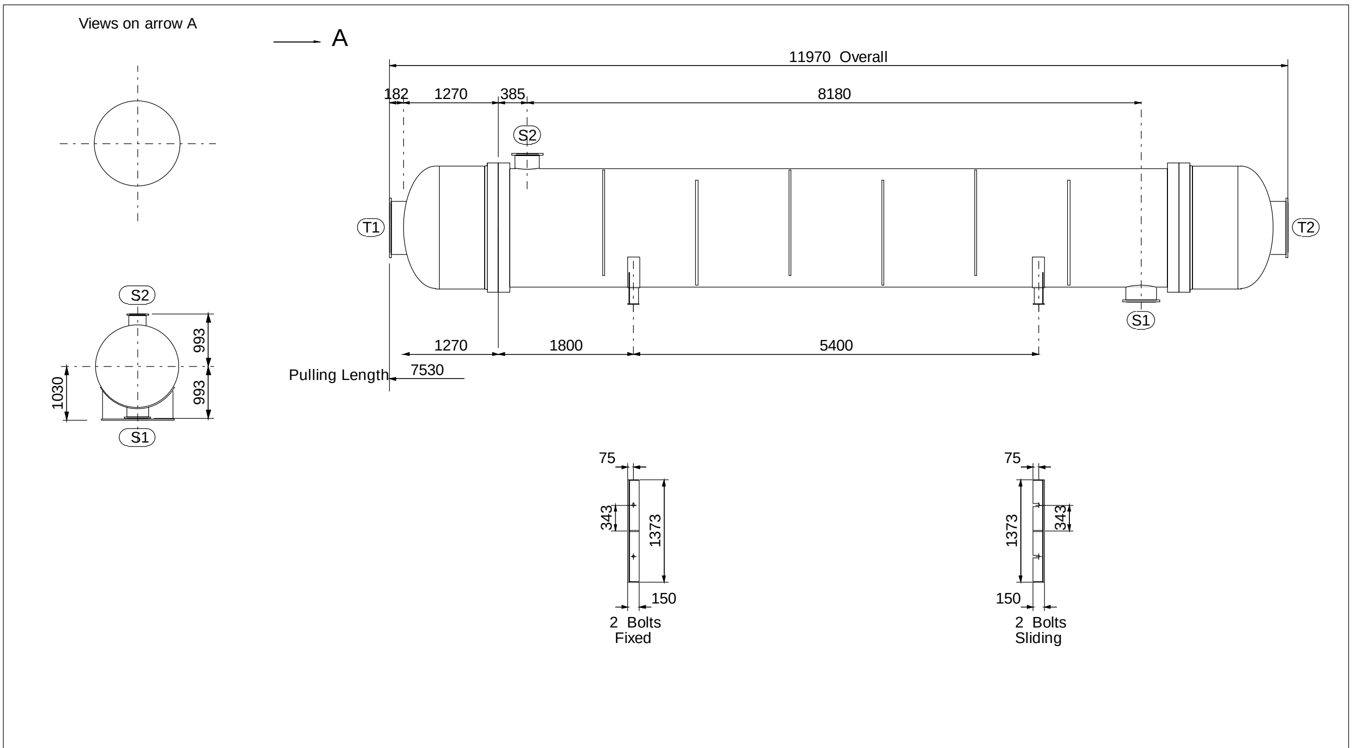
Field 2 Dehydration Inlet Cooler	Aspen Shell & Tube			
24-HJ-201				
Base Case Simulation				
1 X 100% Configuration	Tube Layout			
Design Codes				
EN13445				
TEMA R - refinery service	Drawing Number			
Customer Specifications				
	Revision	Date	Dwg.	App.
		12.6.2014		

7.5.2 Thermal Calculations of the 24-HJ-101 & 24-HJ-201 – Case Study III

Heat Exchanger Specification Sheet

1	Field 1 Dehydration Inlet Cooler						
2	24-HJ-101						
3	Case Study 3						
4	1 X 100% Configuration						
5							
6	Size 1550 - - 9000	mm	Type BEM Hor	Connected in	2 parallel	1 series	
7	Surf/unit(eff.) 2588,6	m^2	Shells/unit 2	Surf/shell (eff.)	1294,3	m^2	
8	**PERFORMANCE OF ONE UNIT**						
9	Fluid allocation		Shell Side		Tube Side		
10	Fluid name		Cooling Medium Inlet 4		Inlet to 24-HJ-101		
11	Fluid quantity, Total	**kg/s**	342,2222		268,25		
12	Vapor (In/Out)	**kg/s**	0	0	268,25	268,25	
13	Liquid	**kg/s**	342,2222	342,2222	0	0	
14	Noncondensable	**kg/s**	0	0	0	0	
15							
16	Temperature (In/Out)	**°C**	20	80,67	135	51,12	
17	Dew / Bubble point	**°C**					
18	Density Vapor/Liquid	**kg/m^3**	/ 1127	/ 1109,12	30,19 /	38,11 /	
19	Viscosity	**mPa s**	/ 17,13	/ 12,7686	0,0157 /	0,0156 /	
20	Molecular wt, Vap				20,37	20,37	
21	Molecular wt, NC						
22	Specific heat	**kJ/(kg K)**	/ 2,65	/ 2,738	2,55 /	2,543 /	
23	Thermal conductivity	**W/(m K)**	/ 0,2165	/ 0,22	0,0501 /	0,0494 /	
24	Latent heat	**kJ/kg**					
25	Pressure (abs)	**bar**	10	9,67489	50,3	50,24069	
26	Velocity	**m/s**	1,62		6,21		
27	Pressure drop, allow./calc.	**bar**	1	0,32511	1	0,05932	
28	Fouling resist. (min)	**m^2 K/W**	0		0	0 Ao based	
29	Heat exchanged 57144,2	**kW**		MTD corrected	41,52	**°C**	
30	Transfer rate, Service 531,7		Dirty 392,3	Clean 392,3		**W/(m^2 K)**	
31	**CONSTRUCTION OF ONE SHELL**						**Sketch**
32				Shell Side	Tube Side		
33	Design/vac/test pressure:g		**bar**	21/ /	80/ /		
34	Design temperature		**°C**	180	180		
35	Number passes per shell			1	1		
36	Corrosion allowance		**mm**	3,18	0		
37	Connections	In	**mm**	1 400/ -	1 700/ -		
38	Size/rating	Out		1 300/ -	1 700/ -		
39	Nominal	Intermediate		/ -	/ -		
40	Tube No. 1865	OD 25,4	Tks-Avg 1,65	**mm**	Length 9000	**mm**	Pitch 31,75 **mm**
41	Tube type Plain		**#/m**	Material 22Cr,5Ni,3Mo steel		Tube pattern	30
42	Shell Carbon Steel	ID 1550	OD 1586	**mm**	Shell cover	-	
43	Channel or bonnet	22Cr,5Ni,3Mo steel			Channel cover	-	
44	Tubesheet-stationary	22Cr,5Ni,3Mo steel	-		Tubesheet-floating	-	
45	Floating head cover	-			Impingement protection	None	
46	Baffle-crossing SS 316L	Type Single segmental	Cut(%d) 10	H	Spacing: c/c	1240	**mm**
47	Baffle-long	-	Seal type		Inlet	1248,47	**mm**
48	Supports-tube	U-bend		Type			
49	Bypass seal		Tube-tubesheet joint	Exp.			
50	Expansion joint	-	Type	None			
51	RhoV2-Inlet nozzle	1889	Bundle entrance	390	Bundle exit	407	**kg/(m s^2)**
52	Gaskets - Shell side	-	Tube Side		Flat Metal Jacket Fibe		
53	Floating head	-					
54	Code requirements	EN13445			TEMA class	R - refinery service	
55	Weight/Shell	46586,1	Filled with water	68074,3	Bundle	22341,7	**kg**
56	Remarks						
57							
58							

Setting Plan



Nozzle Data				
Ref	OD	Wall	Standard	Notes
S1	406 mm	10, mm	150 ANSI Slip on	
S2	324 mm	10, mm	150 ANSI Slip on	
T1	711 mm	20, mm	150 ANSI Slip on	
T2	711 mm	20, mm	150 ANSI Slip on	

Design Data	Units	Shell	Channel
Design Pressure	bar	21,	80,
Design Temperature	C	180,	180,
Full Vacuum			
Corrosion Allowance	mm	3,175	0,
Test Pressure	bar		
Number of Passes		1	1
Radiography			
PWHT			
Internal Volume	m³	16,3821	4,2713

Weight Summary		
Empty	Flooded	Bundle
46586 kg	68074 kg	22342 kg

Field 1 Dehydration Inlet Cooler
24-HJ-101
Case Study 3
1 X 100% Configuration
Design Codes
EN13445
TEMA R
Customer Specifications

Aspen Shell & Tube Exchanger

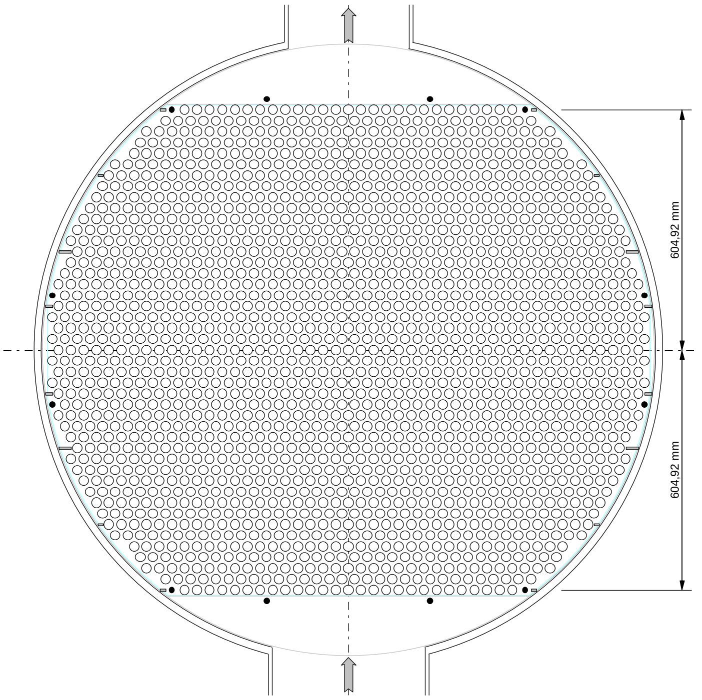
Setting Plan

BEM 1550 - 9000

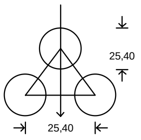
Drawing Number

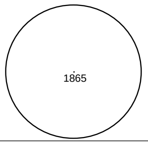
Revision	Date	Dwg.	Chk.	App.
	12.6.2014			

Tube Layout



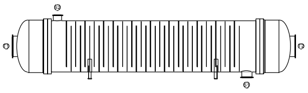
Shell inside diameter	mm	1550,
Front head inside diameter	mm	1550,
Outer tube limit	mm	1535,712
Tube number (calcs.)		1865
Tube number (layout)		1865
Tube O.D.	mm	25,4
Tube pitch	mm	31,75
Tube pattern		30
Tube passes		1
Tie rod number		12
Tie rod diameter	mm	15,875
Sealing strips (pairs)		8
Baffle type		Single segmental
Impingement protection		None
Tube length	mm	9000,
Shell Side Inlet Nozzle Inside Diameter	mm	386,4
Shell Side Outlet Nozzle Inside Diameter	mm	303,9



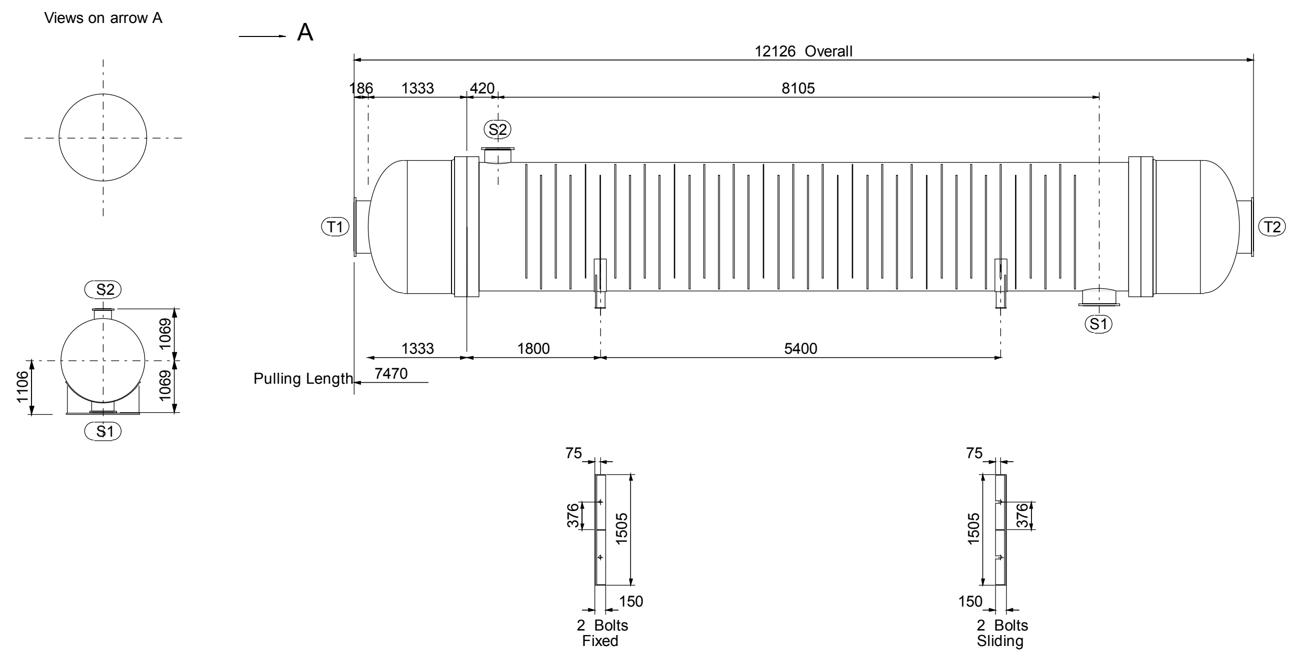


Field 1 Dehydration Inlet Cooler	Aspen Shell & Tube			
24-HJ-101				
Case Study 3				
1 X 100% Configuration	Tube Layout			
Design Codes				
EN13445				
TEMA R - refinery service	Drawing Number			
Customer Specifications				
	Revision	Date	Dwg.	App.
		12.6.2014		

Heat Exchanger Specification Sheet

1	Field 2 Dehydration Inlet Cooler								
2	24-HJ-201								
3	Case Study 3								
4	1 X 100% Configuration								
5									
6	Size	1700 - - 9000	mm	Type	BEM	Hor	Connected in	2 parallel	1 series
7	Surf/unit(eff.)	3096,2	m²	Shells/unit 2		Surf/shell (eff.)	1548,1	m²	
8	**PERFORMANCE OF ONE UNIT**								
9	Fluid allocation		Shell Side		Tube Side				
10	Fluid name		Cooling Medium Inlet 8		Inlet to 24-HJ-201				
11	Fluid quantity, Total	**kg/s**	418,3333		303,8889				
12	Vapor (In/Out)	**kg/s**	0	0	303,8889	303,8889			
13	Liquid	**kg/s**	418,3333	418,3333	0	0			
14	Noncondensable	**kg/s**	0	0	0	0			
15									
16	Temperature (In/Out)	**°C**	20	80	142	52,85			
17	Dew / Bubble point	**°C**							
18	Density Vapor/Liquid	**kg/m³**	/ 1127	/ 1072	32,51 /	41,55 /			
19	Viscosity	**mPa s**	/ 17,13	/ 3,715	0,016 /	0,0159 /			
20	Molecular wt, Vap				20,33	20,33			
21	Molecular wt, NC								
22	Specific heat	**kJ/(kg K)**	/ 2,65	/ 2,95	2,58 /	2,574 /			
23	Thermal conductivity	**W/(m K)**	/ 0,2165	/ 0,2274	0,0515 /	0,0507 /			
24	Latent heat	**kJ/kg**							
25	Pressure (abs)	**bar**	10	9,07171	55,2	55,14039			
26	Velocity	**m/s**	3,34		5,44				
27	Pressure drop, allow./calc.	**bar**	1	0,92829	1	0,05961			
28	Fouling resist. (min)	**m² K/W**	0		0	0 Ao based			
29	Heat exchanged	69726,1	**kW**		MTD corrected	45,83	**°C**		
30	Transfer rate, Service	491,3	Dirty	465,2	Clean	465,2	**W/(m² K)**		
31	**CONSTRUCTION OF ONE SHELL**				**Sketch**				
32			Shell Side	Tube Side					
33	Design/vac/test pressure:g	**bar**	21/ /	85/ /					
34	Design temperature	**°C**	180	180					
35	Number passes per shell		1	1					
36	Corrosion allowance	**mm**	3,18	0					
37	Connections In	**mm**	1 450/ -	1 700/ -					
38	Size/rating Out		1 350/ -	1 700/ -					
39	Nominal Intermediate		/ -	/ -					
40	Tube No. 2240	OD 25,4	Tks-Avg 1,65	**mm**	Length 9000	**mm**	Pitch 31,75	**mm**	
41	Tube type Plain	**#/m**	Material 22Cr,5Ni,3Mo steel		Tube pattern 30				
42	Shell Carbon Steel	ID 1700	OD 1738	**mm**	Shell cover	-			
43	Channel or bonnet	22Cr,5Ni,3Mo steel			Channel cover	-			
44	Tubesheet-stationary	22Cr,5Ni,3Mo steel	-		Tubesheet-floating	-			
45	Floating head cover	-			Impingement protection	None			
46	Baffle-crossing SS 316L	Type Single segmental	Cut(%d) 10	H	Spacing: c/c	200	**mm**		
47	Baffle-long	-	Seal type		Inlet	630,48	**mm**		
48	Supports-tube	U-bend		Type					
49	Bypass seal		Tube-tubesheet joint	Exp.					
50	Expansion joint	-	Type	None					
51	RhoV2-Inlet nozzle	1726	Bundle entrance	1787	Bundle exit	1864	**kg/(m s²)**		
52	Gaskets - Shell side	-	Tube Side		Flat Metal Jacket Fibe				
53	Floating head	-							
54	Code requirements	EN13445			TEMA class	R - refinery service			
55	Weight/Shell	60438,2	Filled with water	86093,1	Bundle	29781,3	**kg**		
56	Remarks								
57									
58									

Setting Plan



Nozzle Data				
Ref	OD	Wall	Standard	Notes
S1	457 mm	10, mm	150 ANSI Slip on	
S2	356 mm	10, mm	150 ANSI Slip on	
T1	711 mm	20, mm	150 ANSI Slip on	
T2	711 mm	20, mm	150 ANSI Slip on	

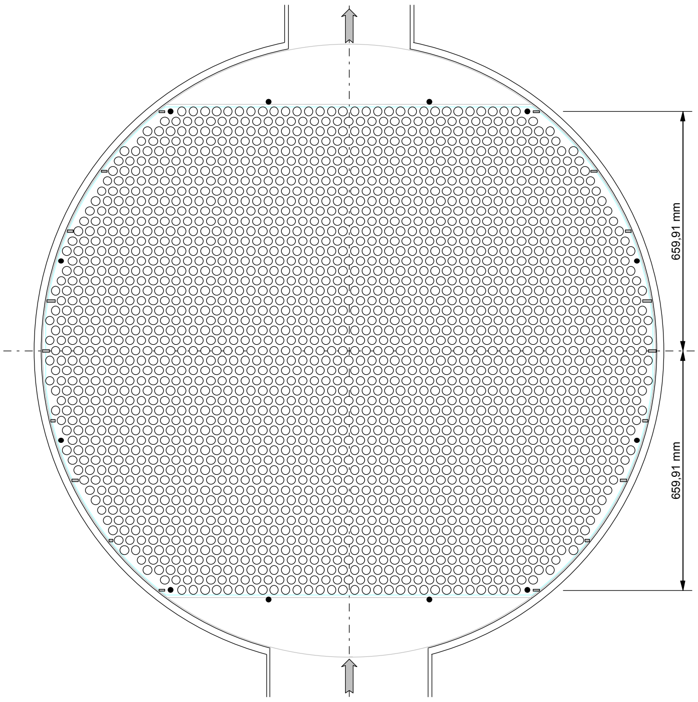
Design Data	Units	Shell	Channel
Design Pressure	bar	21,	85,
Design Temperature	C	180,	180,
Full Vacuum			
Corrosion Allowance	mm	3,175	0,
Test Pressure	bar		
Number of Passes		1	1
Radiography			
PWHT			
Internal Volume	m³	19,1443	5,309

Weight Summary		
Empty	Flooded	Bundle
60438 kg	86093 kg	29781 kg

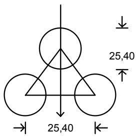
Field 2 Dehydration Inlet Cooler
24-HJ-201
Case Study 3
1 X 100% Configuration
Design Codes
EN13445
TEMA R
Customer Specifications

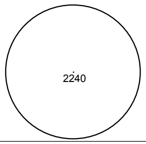
Aspen Shell & Tube Exchanger				
Setting Plan BEM 1700 - 9000				
Drawing Number				
Revision	Date	Dwg.	Chk.	App.
	12.6.2014			

Tube Layout



Shell inside diameter	mm	1700,
Front head inside diameter	mm	1700,
Outer tube limit	mm	1685,712
Tube number (calcs.)		2240
Tube number (layout)		2240
Tube O.D.	mm	25,4
Tube pitch	mm	31,75
Tube pattern		30
Tube passes		1
Tie rod number		12
Tie rod diameter	mm	15,875
Sealing strips (pairs)		9
Baffle type		Single segmental
Impingement protection		None
Tube length	mm	9000,
Shell Side Inlet Nozzle Inside Diameter	mm	437,
Shell Side Outlet Nozzle Inside Diameter	mm	335,6





Field 2 Dehydration Inlet Cooler
24-HJ-201
Case Study 3
1 X 100% Configuration

Design Codes
EN13445
TEMA R - refinery service

Customer Specifications

Aspen Shell & Tube

Tube Layout

Drawing Number

Revision	Date	Dwg.	App.
	12.6.2014		

8.0 Discussion and Conclusions

8.1 Discussion on optimum design of heat exchangers

Optimum design of heat exchangers followed by their efficient operation is critical for the proper functioning of the entire process system. The process fluid be it either liquid or gas phase, after being heated or cooled in the heat exchangers is sent downstream to equipment units like compressors, separators or scrubbers. The outlet temperature of the process stream has a direct impact on the operation and functioning of the subsequent equipment unit. If the downstream equipment is a compressor unit and the temperature of the inlet feed gas is too high, higher energy would be required to compress the gas giving us a lower compressor efficiency value. If the downstream equipment is a 3-phase separator and the inlet stream is not heated to the right temperature, the required split between oil dominated phase, water dominated phase the gas phase will not happen. Similarly, if the inlet stream to a scrubber unit is not cooled down to the required temperature, a lesser quantity of liquid phase would be condensing out in scrubber unit. This implies that the gas phase would have a higher content of heavier hydrocarbons than specified which might result in off-spec product at the outlet of the process train.

The different scenarios explained above emphasize the fact that, for the proper operation of any oil and gas processing unit in the offshore industry, optimum design of all major equipment units especially heat exchangers is a critical factor. While optimizing the thermal design of individual heat exchanger units and also of multiple units in a heat exchanger network, L/D ratio, weight and footprint factor, effective surface area per shell and the number of shells per unit are all critical factors which need to be taken into account. Plate heat exchangers are generally the preferred choice provided the operating pressure and temperature permit the design of this type of exchanger. These exchangers provide huge savings in weight and footprint but are more expensive compared to the conventional shell and tube exchangers.

Shell and tube exchangers are comparatively cheaper than compact heat exchangers and can handle most process fluids. However the process parameters and the required heating or cooling duty can result in extreme dimensions mainly because of the low LMTD and high viscosity makes it difficult to obtain turbulent flow. In the eventuality that the designed shell and tube heat exchanger has very large dimensional features alongwith extremely high heat duty requirement and the operating parameters are beyond the range of plate exchangers, printed circuit heat exchangers would have to be preferred choice. As seen in the 3rd case study, the extreme dimensions would result in loss of available footprint which is very critical on an oil and gas platform. The PCHE’s are comparatively more expensive than shell and tube exchangers but the savings due to reduced weight cost and footprint cost would compensate for the additional expense. Also changing the process parameters of the heating or cooling medium alters the heat duty requirement of the exchanger which can result in the modified exchanger having a more optimum design than the base case scenario.

8.2 Conclusions

The work done as part of this thesis involves doing the thermal design calculations of the heat exchangers based on the process parameters from the base case process design and also the thermal design calculations of the relevant heat exchangers with the modified process parameters from the case studies. The main conclusions to this thesis work regarding the optimum design of heat exchangers are as follows:

1. For optimum design of a shell and tube heat exchanger unit, the ratio of tube length to shell inner diameter (L/D ratio) should be in the range of 5 to 10.
2. If the process conditions include high design pressure, high design temperature and phase change, shell and tube exchangers is the preferred choice for such operating conditions.
3. When operating pressure and temperature permit, then plate frame exchangers must be the preferred choice considering the savings on weight and footprint.
4. When the water cut in the reservoir stream is high, like the Field 1 and Field 2 wellstream composition used as part of this thesis work, avoiding excessive surface temperature on the tube side needs to be focused on, in order to reduce the risk of scaling.
5. Vibration on the tube side needs to be avoided. If higher pressure drop than the allowable limit is required in order to prevent vibration then the additional pressure drop should be accepted into the process design.
6. As seen in Case Study I, simplifying the process design by removing an exchanger unit (20-HB-004), results in scaling up the exchanger design of 20-HA-003 and 21-HB001 in order to compensate for the additional heating and cooling duty. Since the weight saving and footprint saving is quite considerable, this options can be further analyzed in detail to be implemented into the process design.
7. As seen in Case Study II, increasing or decreasing the outlet temperature of the gas stream has little effect on improving the dimensions of the exchanger. Therefore for optimizing the design of the exchanger, reduction in the heating medium inlet temperature is required.
8. As seen in Case Study III, when the design of the shell and tube exchanger results in extreme dimensions causing very high weight and footprint factors, it is preferable to switch to printed circuit heat exchanger as the choice for that application.

9.0 References

Devold, H. (2006). "Oil and gas production handbook." ABB ATPA Oil and Gas.

Jaubert, J.-N. and R. Privat (2010). "Relationship between the binary interaction parameters (< i> k</i>< sub> ij</sub>) of the Peng–Robinson and those of the Soave–Redlich–Kwong equations of state: Application to the definition of the PR2SRK model." Fluid Phase Equilibria **295**(1): 26-37.

Ludwig, E. E. (1997). Applied Process Design for Chemical and Petrochemical Plants: Volume 3, Gulf Professional Publishing.

TEP 4185 (2012). Compendium of the Natural Gas Technology course (TEP 4185) at Norwegian University of Science and Technology. Gas Processing – Section 6.

Appendix A – Process Datasheets for Heat Exchangers in Base Case Simulation

Heat Exchanger: 20-HA-001

CONDITIONS

Name		Field 2 Inlet	Heating Medium Inlet 1	Field 2 to Inlet Separator	Heating Medium Outlet 1
Vapour		0.1643	0.0000	0.1655	0.0000
Temperature	(C)	44.9640	150.0000	55.0000	100.0000
Pressure	(kPa)	1600.0000	1100.0000	1500.0000	1000.0000
Molar Flow	(kgmole/h)	366548.4143	24434.6310	366548.4143	24434.6310
Mass Flow	(kg/h)	7251237.8039	1893301.6974	7251237.8039	1893301.6974
Std Ideal Liq Vol Flow	(m3/h)	9657.7878	1705.8369	9657.7878	1705.8369
Molar Enthalpy	(kJ/kgmole)	-2.528e+005	-4.912e+005	-2.520e+005	-5.035e+005
Molar Entropy	(kJ/kgmole-C)	79.11	172.4	81.73	141.7
Heat Flow	(kJ/h)	-9.2679e+10	-1.2003e+10	-9.2380e+10	-1.2302e+10

PROPERTIES

Name		Field 2 Inlet	Heating Medium Inlet 1	Field 2 to Inlet Separator	Heating Medium Outlet 1
Molecular Weight		19.78	77.48	19.78	77.48
Molar Density	(kgmole/m3)	3.575	12.94	3.227	13.60
Mass Density	(kg/m3)	70.72	1003	63.84	1054
Act. Volume Flow	(m3/h)	1.025e+005	1888	1.136e+005	1797
Mass Enthalpy	(kJ/kg)	-1.278e+004	-6340	-1.274e+004	-6498
Mass Entropy	(kJ/kg-C)	3.999	2.224	4.131	1.828
Heat Capacity	(kJ/kgmole-C)	76.57	255.2	76.69	234.3
Mass Heat Capacity	(kJ/kg-C)	3.871	3.294	3.877	3.024
LHV Molar Basis (Std)	(kJ/kgmole)	---	1.462e+006	---	1.462e+006
HHV Molar Basis (Std)	(kJ/kgmole)	---	1.614e+006	---	1.614e+006
HHV Mass Basis (Std)	(kJ/kg)	---	2.083e+004	---	2.083e+004
CO2 Loading		---	---	---	---
CO2 Apparent Mole Conc.	(kgmole/m3)	---	0.0000	---	0.0000
CO2 Apparent Wt. Conc.	(kgmol/kg)	---	0.0000	---	0.0000
LHV Mass Basis (Std)	(kJ/kg)	---	1.887e+004	---	1.887e+004
Phase Fraction [Vol. Basis]		0.3599	0.0000	0.3625	0.0000
Phase Fraction [Mass Basis]		0.1640	0.0000	0.1664	0.0000
Phase Fraction [Act. Vol. Basis]		0.9392	0.0000	0.9449	0.0000
Mass Exergy	(kJ/kg)	60.70	65.58	62.49	25.75
Partial Pressure of CO2	(kPa)	25.59	0.0000	23.94	0.0000
Cost Based on Flow	(Cost/s)	0.0000	0.0000	0.0000	0.0000
Act. Gas Flow	(ACT_m3/h)	9.630e+004	---	1.073e+005	---
Avg. Liq. Density	(kgmole/m3)	37.95	14.32	37.95	14.32
Specific Heat	(kJ/kgmole-C)	76.57	255.2	76.69	234.3
Std. Gas Flow	(STD_m3/h)	8.667e+006	5.777e+005	8.667e+006	5.777e+005
Std. Ideal Liq. Mass Density	(kg/m3)	750.8	1110	750.8	1110
Act. Liq. Flow	(m3/s)	1.731	0.5245	1.739	0.4992
Z Factor		---	2.416e-002	---	2.371e-002
Watson K		15.46	8.816	15.46	8.816
User Property		---	---	---	---
Partial Pressure of H2S	(kPa)	0.0000	0.0000	0.0000	0.0000
Cp/(Cp - R)		1.122	1.034	1.122	1.037
Cp/Cv		1.023	1.064	1.022	1.062
Heat of Vap.	(kJ/kgmole)	6.094e+004	7.244e+004	6.105e+004	7.313e+004
Kinematic Viscosity	(cSt)	---	1.147	---	2.315
Liq. Mass Density (Std. Cond)	(kg/m3)	822.7	1130	822.7	1130
Liq. Vol. Flow (Std. Cond)	(m3/h)	8814	1676	8814	1676
Liquid Fraction		0.8357	1.000	0.8345	1.000
Molar Volume	(m3/kgmole)	0.2797	7.728e-002	0.3099	7.355e-002
Mass Heat of Vap.	(kJ/kg)	3080	934.9	3086	943.9
Phase Fraction [Molar Basis]		0.1643	0.0000	0.1655	0.0000
Surface Tension	(dyne/cm)	---	35.73	---	40.78
Thermal Conductivity	(W/m-K)	---	0.2310	---	0.2295
Viscosity	(cP)	---	1.150	---	2.438
Cv (Semi-Ideal)	(kJ/kgmole-C)	68.25	246.9	68.38	226.0

Heat Exchanger: 20-HA-001 (continued)

PROPERTIES

Name		Field 2 Inlet	Heating Medium Inlet 1	Field 2 to Inlet Separator	Heating Medium Outlet 1	
Mass Cv (Semi-Ideal)	(kJ/kg-C)	3.450	3.187	3.456	2.916	
Cv	(kJ/kgmole-C)	74.88	240.0	75.03	220.5	
Mass Cv	(kJ/kg-C)	3.785	3.097	3.793	2.846	
Cv (Ent. Method)	(kJ/kgmole-C)	---	205.9	---	195.1	
Mass Cv (Ent. Method)	(kJ/kg-C)	---	2.657	---	2.517	
Cp/Cv (Ent. Method)		---	1.240	---	1.201	
Reid VP at 37.8 C	(kPa)	---	9.847e-004	---	9.847e-004	
True VP at 37.8 C	(kPa)	---	3.420	---	3.420	
Liq. Vol. Flow - Sum(Std. Cond)	(m3/h)	1.425e+006	1676	1.436e+006	1676	
Viscosity Index		-10.86	5.070	-14.22	12.83	

DETAILS

Overall/Detailed Performance

Duty:	2.990e+08 kJ/h	UA Curv. Error:	0.00e-01 kJ/C-h
Heat Leak:	0.000e-01 kJ/h	Hot Pinch Temp:	100.0 C
Heat Loss:	0.000e-01 kJ/h	Cold Pinch Temp:	44.96 C
UA:	4.151e+06 kJ/C-h	Ft Factor:	---
Min. Approach:	55.04 C	Uncorrected Lmtd:	73.21 C
Lmtd:	72.03 C		

Case Name: BASE CASE SIMULATION

Unit Set: SI

Date/Time:

Heat Exchanger: 20-HA-002

CONDITIONS

Name		Field 1 Inlet	Heating Medium Inlet 2	Field 1 to Inlet Seprator	Heating Medium Outlet 2
Vapour		0.1293	0.0000	0.1313	0.0000
Temperature	(C)	27.9805	150.0000	55.0000	100.0000
Pressure	(kPa)	1600.0000	1100.0000	1500.0000	1000.0000
Molar Flow	(kgmole/h)	333234.4142	59012.1474	333234.4142	59012.1474
Mass Flow	(kg/h)	6557731.8745	4572518.3652	6557731.8745	4572518.3652
Std Ideal Liq Vol Flow	(m3/h)	8307.8856	4119.7715	8307.8856	4119.7715
Molar Enthalpy	(kJ/kgmole)	-2.611e+005	-4.912e+005	-2.589e+005	-5.035e+005
Molar Entropy	(kJ/kgmole-C)	71.06	172.4	78.03	141.7
Heat Flow	(kJ/h)	-8.6999e+10	-2.8989e+10	-8.6277e+10	-2.9712e+10

PROPERTIES

Name		Field 1 Inlet	Heating Medium Inlet 2	Field 1 to Inlet Seprator	Heating Medium Outlet 2
Molecular Weight		19.68	77.48	19.68	77.48
Molar Density	(kgmole/m3)	4.717	12.94	3.999	13.60
Mass Density	(kg/m3)	92.83	1003	78.69	1054
Act. Volume Flow	(m3/h)	7.064e+004	4561	8.333e+004	4340
Mass Enthalpy	(kJ/kg)	-1.327e+004	-6340	-1.316e+004	-6498
Mass Entropy	(kJ/kg-C)	3.611	2.224	3.965	1.828
Heat Capacity	(kJ/kgmole-C)	77.61	255.2	77.88	234.3
Mass Heat Capacity	(kJ/kg-C)	3.944	3.294	3.957	3.024
LHV Molar Basis (Std)	(kJ/kgmole)	---	1.462e+006	---	1.462e+006
HHV Molar Basis (Std)	(kJ/kgmole)	---	1.614e+006	---	1.614e+006
HHV Mass Basis (Std)	(kJ/kg)	---	2.083e+004	---	2.083e+004
CO2 Loading		---	---	---	---
CO2 Apparent Mole Conc.	(kgmole/m3)	---	0.0000	---	0.0000
CO2 Apparent Wt. Conc.	(kgmol/kg)	---	0.0000	---	0.0000
LHV Mass Basis (Std)	(kJ/kg)	---	1.887e+004	---	1.887e+004
Phase Fraction [Vol. Basis]		0.2980	0.0000	0.3024	0.0000
Phase Fraction [Mass Basis]		0.1273	0.0000	0.1311	0.0000
Phase Fraction [Act. Vol. Basis]		0.9179	0.0000	0.9293	0.0000
Mass Exergy	(kJ/kg)	46.84	65.58	51.44	25.75
Partial Pressure of CO2	(kPa)	23.64	0.0000	22.24	0.0000
Cost Based on Flow	(Cost/s)	0.0000	0.0000	0.0000	0.0000
Act. Gas Flow	(ACT_m3/h)	6.484e+004	---	7.744e+004	---
Avg. Liq. Density	(kgmole/m3)	40.11	14.32	40.11	14.32
Specific Heat	(kJ/kgmole-C)	77.61	255.2	77.88	234.3
Std. Gas Flow	(STD_m3/h)	7.879e+006	1.395e+006	7.879e+006	1.395e+006
Std. Ideal Liq. Mass Density	(kg/m3)	789.3	1110	789.3	1110
Act. Liq. Flow	(m3/s)	1.611	1.267	1.636	1.206
Z Factor		---	2.416e-002	---	2.371e-002
Watson K		15.11	8.816	15.11	8.816
User Property		---	---	---	---
Partial Pressure of H2S	(kPa)	0.0000	0.0000	0.0000	0.0000
Cp/(Cp - R)		1.120	1.034	1.120	1.037
Cp/Cv		1.018	1.064	1.017	1.062
Heat of Vap.	(kJ/kgmole)	6.222e+004	7.244e+004	6.233e+004	7.313e+004
Kinematic Viscosity	(cSt)	---	1.147	---	2.315
Liq. Mass Density (Std. Cond)	(kg/m3)	857.7	1130	857.7	1130
Liq. Vol. Flow (Std. Cond)	(m3/h)	7645	4047	7645	4047
Liquid Fraction		0.8707	1.000	0.8687	1.000
Molar Volume	(m3/kgmole)	0.2120	7.728e-002	0.2501	7.355e-002
Mass Heat of Vap.	(kJ/kg)	3162	934.9	3167	943.9
Phase Fraction [Molar Basis]		0.1293	0.0000	0.1313	0.0000
Surface Tension	(dyne/cm)	---	35.73	---	40.78
Thermal Conductivity	(W/m-K)	---	0.2310	---	0.2295
Viscosity	(cP)	---	1.150	---	2.438
Cv (Semi-Ideal)	(kJ/kgmole-C)	69.30	246.9	69.56	226.0

Heat Exchanger: 20-HA-002 (continued)

PROPERTIES

Name	Field 1 Inlet	Heating Medium Inlet 2	Field 1 to Inlet Seprator	Heating Medium Outlet 2	
Mass Cv (Semi-Ideal) (kJ/kg-C)	3.521	3.187	3.535	2.916	
Cv (kJ/kgmole-C)	76.25	240.0	76.55	220.5	
Mass Cv (kJ/kg-C)	3.875	3.097	3.890	2.846	
Cv (Ent. Method) (kJ/kgmole-C)	---	205.9	---	195.1	
Mass Cv (Ent. Method) (kJ/kg-C)	---	2.657	---	2.517	
Cp/Cv (Ent. Method)	---	1.240	---	1.201	
Reid VP at 37.8 C (kPa)	---	9.847e-004	---	9.847e-004	
True VP at 37.8 C (kPa)	---	3.420	---	3.420	
Liq. Vol. Flow - Sum(Std. Cond) (m3/h)	1.022e+006	4047	1.037e+006	4047	
Viscosity Index	-3.676	5.070	-11.75	12.83	

DETAILS

Overall/Detailed Performance

Duty:	7.222e+08 kJ/h	UA Curv. Error:	0.00e-01 kJ/C-h
Heat Leak:	0.000e-01 kJ/h	Hot Pinch Temp:	100.0 C
Heat Loss:	0.000e-01 kJ/h	Cold Pinch Temp:	27.98 C
UA:	9.007e+06 kJ/C-h	Ft Factor:	---
Min. Approach:	72.02 C	Uncorrected Lmtd:	82.98 C
Lmtd:	80.18 C		

Case Name:	BASE CASE SIMULATION MODEL.HSC
Unit Set:	SI
Date/Time:	Wed Jun 04 19:32:50 2014

Heat Exchanger: 20-HA-003

CONDITIONS

Name		let to Stabilization Heater	Heating Medium Inlet 3	21	Heating Medium Outlet 3
Vapour		0.0163	0.0000	0.0227	0.0000
Temperature	(C)	63.0000 *	150.0000 *	77.6224 *	100.0000 *
Pressure	(kPa)	800.0000 *	1100.0000 *	700.0000 *	1000.0000 *
Molar Flow	(kgmole/h)	8980.8379	3335.2211	8980.8379	3335.2211
Mass Flow	(kg/h)	1184949.0545	258427.4678	1184949.0545	258427.4678
Std Ideal Liq Vol Flow	(m3/h)	1376.3692	232.8393	1376.3692	232.8393
Molar Enthalpy	(kJ/kgmole)	-3.843e+005	-4.912e+005	-3.797e+005	-5.035e+005
Molar Entropy	(kJ/kgmole-C)	294.1	172.4	307.4	141.7
Heat Flow	(kJ/h)	-3.4509e+09	-1.6384e+09	-3.4101e+09	-1.6792e+09

PROPERTIES

Name		let to Stabilization Heate	Heating Medium Inlet 3	21	Heating Medium Outlet 3
Molecular Weight		131.9	77.48	131.9	77.48
Molar Density	(kgmole/m3)	4.629	12.94	3.918	13.60
Mass Density	(kg/m3)	610.8	1003	516.9	1054
Act. Volume Flow	(m3/h)	1940	257.8	2292	245.3
Mass Enthalpy	(kJ/kg)	-2912	-6340	-2878	-6498
Mass Entropy	(kJ/kg-C)	2.229	2.224	2.330	1.828
Heat Capacity	(kJ/kgmole-C)	299.7	255.2	307.0	234.3
Mass Heat Capacity	(kJ/kg-C)	2.272	3.294	2.327	3.024
LHV Molar Basis (Std)	(kJ/kgmole)	---	1.462e+006	---	1.462e+006
HHV Molar Basis (Std)	(kJ/kgmole)	---	1.614e+006	---	1.614e+006
HHV Mass Basis (Std)	(kJ/kg)	---	2.083e+004	---	2.083e+004
CO2 Loading		---	---	---	---
CO2 Apparent Mole Conc.	(kgmole/m3)	---	0.0000	---	0.0000
CO2 Apparent Wt. Conc.	(kgmol/kg)	---	0.0000	---	0.0000
LHV Mass Basis (Std)	(kJ/kg)	---	1.887e+004	---	1.887e+004
Phase Fraction [Vol. Basis]		6.474e-003	0.0000	9.250e-003	0.0000
Phase Fraction [Mass Basis]		2.810e-003	0.0000	4.327e-003	0.0000
Phase Fraction [Act. Vol. Basis]		0.2590	0.0000	0.3646	0.0000
Mass Exergy	(kJ/kg)	6.796	65.58	11.19	25.75
Partial Pressure of CO2	(kPa)	17.55	0.0000	16.10	0.0000
Cost Based on Flow	(Cost/s)	0.0000	0.0000	0.0000	0.0000
Act. Gas Flow	(ACT_m3/h)	502.5	---	835.7	---
Avg. Liq. Density	(kgmole/m3)	6.525	14.32	6.525	14.32
Specific Heat	(kJ/kgmole-C)	299.7	255.2	307.0	234.3
Std. Gas Flow	(STD_m3/h)	2.123e+005	7.886e+004	2.123e+005	7.886e+004
Std. Ideal Liq. Mass Density	(kg/m3)	860.9	1110	860.9	1110
Act. Liq. Flow	(m3/s)	0.3993	7.160e-002	0.4046	6.814e-002
Z Factor		---	2.416e-002	---	2.371e-002
Watson K		11.63	8.816	11.63	8.816
User Property		---	---	---	---
Partial Pressure of H2S	(kPa)	0.0000	0.0000	0.0000	0.0000
Cp/(Cp - R)		1.029	1.034	1.028	1.037
Cp/Cv		1.002	1.064	1.002	1.062
Heat of Vap.	(kJ/kgmole)	2.001e+005	7.244e+004	2.014e+005	7.313e+004
Kinematic Viscosity	(cSt)	---	1.147	---	2.315
Liq. Mass Density (Std. Cond)	(kg/m3)	859.9	1130	859.9	1130
Liq. Vol. Flow (Std. Cond)	(m3/h)	1378	228.7	1378	228.7
Liquid Fraction		0.9837	1.000	0.9773	1.000
Molar Volume	(m3/kgmole)	0.2160	7.728e-002	0.2552	7.355e-002
Mass Heat of Vap.	(kJ/kg)	1517	934.9	1526	943.9
Phase Fraction [Molar Basis]		0.0163	0.0000	0.0227	0.0000
Surface Tension	(dyne/cm)	---	35.73	---	40.78
Thermal Conductivity	(W/m-K)	---	0.2310	---	0.2295
Viscosity	(cP)	---	1.150	---	2.438
Cv (Semi-Ideal)	(kJ/kgmole-C)	291.4	246.9	298.7	226.0

* Specified by user.

Heat Exchanger: 20-HA-003 (continued)

PROPERTIES

Name		let to Stabilization Heate	Heating Medium Inlet 3	21	Heating Medium Outlet 3	
Mass Cv (Semi-Ideal)	(kJ/kg-C)	2.209	3.187	2.264	2.916	
Cv	(kJ/kgmole-C)	299.1	240.0	306.4	220.5	
Mass Cv	(kJ/kg-C)	2.267	3.097	2.322	2.846	
Cv (Ent. Method)	(kJ/kgmole-C)	---	205.9	---	195.1	
Mass Cv (Ent. Method)	(kJ/kg-C)	---	2.657	---	2.517	
Cp/Cv (Ent. Method)		---	1.240	---	1.201	
Reid VP at 37.8 C	(kPa)	153.0	9.847e-004	153.0	9.847e-004	
True VP at 37.8 C	(kPa)	1363	3.420	1363	3.420	
Liq. Vol. Flow - Sum(Std. Cond)	(m3/h)	4822	228.7	6172	228.7	
Viscosity Index		16.05	5.070	13.91	12.83	

DETAILS

Overall/Detailed Performance

Duty:	4.082e+07 kJ/h	UA Curv. Error:	0.00e-01 kJ/C-h
Heat Leak:	0.000e-01 kJ/h	Hot Pinch Temp:	100.0 C
Heat Loss:	0.000e-01 kJ/h	Cold Pinch Temp:	63.00 C
UA:	8.120e+05 kJ/C-h	Ft Factor:	---
Min. Approach:	37.00 C	Uncorrected Lmtd:	52.73 C
Lmtd:	50.27 C		

NORWEGIAN UNIV OF
Burlington, MA
USA

Case Name:	BASE CASE SIMULATION MODEL.HSC
Unit Set:	SI
Date/Time:	Wed Jun 04 19:34:14 2014

Heat Exchanger: 20-HB-004

CONDITIONS

Name	Inlet to Cross Exchanger	55	nlet to Stabilization Heater	Export Oil (Hot)
Vapour	0.0124	0.0000	0.0163	0.0000
Temperature (C)	54.9743	75.0989	63.0000 *	66.5758
Pressure (kPa)	900.0000	750.0000	800.0000 *	650.0000 *
Molar Flow (kgmole/h)	8980.8379	6300.4220	8980.8379	6300.4220
Mass Flow (kg/h)	1184949.0545	1138594.4706	1184949.0545	1138594.4706
Std Ideal Liq Vol Flow (m3/h)	1376.3692	1318.0673	1376.3692	1318.0673
Molar Enthalpy (kJ/kgmole)	-3.867e+005	-4.320e+005	-3.843e+005	-4.354e+005
Molar Entropy (kJ/kgmole-C)	286.7	402.2	294.1	392.2
Heat Flow (kJ/h)	-3.4727e+09	-2.7215e+09	-3.4509e+09	-2.7433e+09

PROPERTIES

Name	Inlet to Cross Exchanger	55	nlet to Stabilization Heate	Export Oil (Hot)	
Molecular Weight	131.9	180.7	131.9	180.7	
Molar Density (kgmole/m3)	5.106	4.483	4.629	4.524	
Mass Density (kg/m3)	673.7	810.2	610.8	817.5	
Act. Volume Flow (m3/h)	1759	1405	1940	1393	
Mass Enthalpy (kJ/kg)	-2931	-2390	-2912	-2409	
Mass Entropy (kJ/kg-C)	2.173	2.225	2.229	2.170	
Heat Capacity (kJ/kgmole-C)	295.7	403.8	299.7	397.7	
Mass Heat Capacity (kJ/kg-C)	2.241	2.234	2.272	2.200	
LHV Molar Basis (Std) (kJ/kgmole)	---	---	---	---	
HHV Molar Basis (Std) (kJ/kgmole)	---	---	---	---	
HHV Mass Basis (Std) (kJ/kg)	---	---	---	---	
CO2 Loading	---	---	---	---	
CO2 Apparent Mole Conc. (kgmole/m3)	---	1.120e-003	---	1.131e-003	
CO2 Apparent Wt. Conc. (kgmol/kg)	---	1.383e-006	---	1.383e-006	
LHV Mass Basis (Std) (kJ/kg)	---	---	---	---	
Phase Fraction [Vol. Basis]	4.836e-003	0.0000	6.474e-003	0.0000	
Phase Fraction [Mass Basis]	2.020e-003	0.0000	2.810e-003	0.0000	
Phase Fraction [Act. Vol. Basis]	0.1884	0.0000	0.2590	0.0000	
Mass Exergy (kJ/kg)	5.054	9.019	6.796	6.364	
Partial Pressure of CO2 (kPa)	18.24	0.0000	17.55	0.0000	
Cost Based on Flow (Cost/s)	0.0000	0.0000	0.0000	0.0000	
Act. Gas Flow (ACT_m3/h)	331.4	---	502.5	---	
Avg. Liq. Density (kgmole/m3)	6.525	4.780	6.525	4.780	
Specific Heat (kJ/kgmole-C)	295.7	403.8	299.7	397.7	
Std. Gas Flow (STD_m3/h)	2.123e+005	1.490e+005	2.123e+005	1.490e+005	
Std. Ideal Liq. Mass Density (kg/m3)	860.9	863.8	860.9	863.8	
Act. Liq. Flow (m3/s)	0.3965	0.3904	0.3993	0.3869	
Z Factor	---	---	---	---	
Watson K	11.63	11.65	11.63	11.65	
User Property	---	---	---	---	
Partial Pressure of H2S (kPa)	0.0000	0.0000	0.0000	0.0000	
Cp/(Cp - R)	1.029	1.021	1.029	1.021	
Cp/Cv	1.002	1.264	1.002	1.265	
Heat of Vap. (kJ/kgmole)	1.986e+005	1.985e+005	2.001e+005	1.992e+005	
Kinematic Viscosity (cSt)	---	3.818	---	4.521	
Liq. Mass Density (Std. Cond) (kg/m3)	859.9	854.3	859.9	854.3	
Liq. Vol. Flow (Std. Cond) (m3/h)	1378	1333	1378	1333	
Liquid Fraction	0.9876	1.000	0.9837	1.000	
Molar Volume (m3/kgmole)	0.1959	0.2231	0.2160	0.2211	
Mass Heat of Vap. (kJ/kg)	1505	1098	1517	1102	
Phase Fraction [Molar Basis]	0.0124	0.0000	0.0163	0.0000	
Surface Tension (dyne/cm)	---	---	---	---	
Thermal Conductivity (W/m-K)	---	0.1172	---	0.1182	
Viscosity (cP)	---	3.093	---	3.696	
Cv (Semi-Ideal) (kJ/kgmole-C)	287.4	395.4	291.4	389.4	

* Specified by user.

Heat Exchanger: 20-HB-004 (continued)

PROPERTIES

Name		Inlet to Cross Exchanger	55	let to Stabilization Heate	Export Oil (Hot)	
Mass Cv (Semi-Ideal)	(kJ/kg-C)	2.178	2.188	2.209	2.154	
Cv	(kJ/kgmole-C)	295.1	319.3	299.1	314.3	
Mass Cv	(kJ/kg-C)	2.236	1.767	2.267	1.739	
Cv (Ent. Method)	(kJ/kgmole-C)	---	---	---	---	
Mass Cv (Ent. Method)	(kJ/kg-C)	---	---	---	---	
Cp/Cv (Ent. Method)		---	---	---	---	
Reid VP at 37.8 C	(kPa)	153.0	34.24	153.0	34.24	
True VP at 37.8 C	(kPa)	1363	108.6	1363	108.6	
Liq. Vol. Flow - Sum(Std. Cond)	(m3/h)	4000	1322	4822	1322	
Viscosity Index		17.24	15.90	16.05	17.18	

DETAILS

Overall/Detailed Performance

Duty:	2.179e+07 kJ/h	UA Curv. Error:	0.00e-01 kJ/C-h
Heat Leak:	0.000e-01 kJ/h	Hot Pinch Temp:	66.58 C
Heat Loss:	0.000e-01 kJ/h	Cold Pinch Temp:	54.97 C
UA:	2.015e+06 kJ/C-h	Ft Factor:	---
Min. Approach:	11.60 C	Uncorrected Lmtd:	11.85 C
Lmtd:	10.81 C		

NORWEGIAN UNIV OF
Burlington, MA
USA

Case Name:	BASE CASE SIMULATION MODEL.HSC
Unit Set:	SI
Date/Time:	Wed Jun 04 19:34:50 2014

Heat Exchanger: 21-HB-001

CONDITIONS

Name		Export Oil (Hot)	Sea Water Inlet	Export Oil (Cold)	Sea Water Outlet
Vapour		0.0000	0.0000	0.0000	0.0000
Temperature	(C)	66.5758	8.0000 *	54.8057 *	45.0000 *
Pressure	(kPa)	650.0000 *	1000.0000 *	550.0000 *	900.0000 *
Molar Flow	(kgmole/h)	6300.4220	9964.7750	6300.4220	9964.7750
Mass Flow	(kg/h)	1138594.4706	179516.4228	1138594.4706	179516.4228
Std Ideal Liq Vol Flow	(m3/h)	1318.0673	179.8787	1318.0673	179.8787
Molar Enthalpy	(kJ/kgmole)	-4.354e+005	-2.877e+005	-4.401e+005	-2.847e+005
Molar Entropy	(kJ/kgmole-C)	392.2	48.59	378.2	58.47
Heat Flow	(kJ/h)	-2.7433e+09	-2.8669e+09	-2.7727e+09	-2.8374e+09

PROPERTIES

Name		Export Oil (Hot)	Sea Water Inlet	Export Oil (Cold)	Sea Water Outlet	
Molecular Weight		180.7	18.02	180.7	18.02	
Molar Density	(kgmole/m3)	4.524	56.63	4.580	55.09	
Mass Density	(kg/m3)	817.5	1020	827.7	992.4	
Act. Volume Flow	(m3/h)	1393	176.0	1376	180.9	
Mass Enthalpy	(kJ/kg)	-2409	-1.597e+004	-2435	-1.581e+004	
Mass Entropy	(kJ/kg-C)	2.170	2.697	2.093	3.246	
Heat Capacity	(kJ/kgmole-C)	397.7	80.12	389.2	79.88	
Mass Heat Capacity	(kJ/kg-C)	2.200	4.447	2.154	4.434	
LHV Molar Basis (Std)	(kJ/kgmole)	---	0.0000	---	0.0000	
HHV Molar Basis (Std)	(kJ/kgmole)	---	4.101e+004	---	4.101e+004	
HHV Mass Basis (Std)	(kJ/kg)	---	2276	---	2276	
CO2 Loading		---	---	---	---	
CO2 Apparent Mole Conc.	(kgmole/m3)	1.131e-003	0.0000	1.145e-003	0.0000	
CO2 Apparent Wt. Conc.	(kgmol/kg)	1.383e-006	0.0000	1.383e-006	0.0000	
LHV Mass Basis (Std)	(kJ/kg)	---	---	---	---	
Phase Fraction [Vol. Basis]		0.0000	0.0000	0.0000	0.0000	
Phase Fraction [Mass Basis]		0.0000	0.0000	0.0000	0.0000	
Phase Fraction [Act. Vol. Basis]		0.0000	0.0000	0.0000	0.0000	
Mass Exergy	(kJ/kg)	6.364	3.429	3.493	3.905	
Partial Pressure of CO2	(kPa)	0.0000	0.0000	0.0000	0.0000	
Cost Based on Flow	(Cost/s)	0.0000	0.0000	0.0000	0.0000	
Act. Gas Flow	(ACT_m3/h)	---	---	---	---	
Avg. Liq. Density	(kgmole/m3)	4.780	55.40	4.780	55.40	
Specific Heat	(kJ/kgmole-C)	397.7	80.12	389.2	79.88	
Std. Gas Flow	(STD_m3/h)	1.490e+005	2.356e+005	1.490e+005	2.356e+005	
Std. Ideal Liq. Mass Density	(kg/m3)	863.8	998.0	863.8	998.0	
Act. Liq. Flow	(m3/s)	0.3869	4.888e-002	0.3821	5.025e-002	
Z Factor		---	7.554e-003	---	6.177e-003	
Watson K		11.65	---	11.65	---	
User Property		---	---	---	---	
Partial Pressure of H2S	(kPa)	0.0000	0.0000	0.0000	0.0000	
Cp/(Cp - R)		1.021	1.116	1.022	1.116	
Cp/Cv		1.265	1.130	1.265	1.153	
Heat of Vap.	(kJ/kgmole)	1.992e+005	3.659e+004	1.999e+005	3.688e+004	
Kinematic Viscosity	(cSt)	4.521	1.348	5.835	0.5984	
Liq. Mass Density (Std. Cond)	(kg/m3)	854.3	1015	854.3	1015	
Liq. Vol. Flow (Std. Cond)	(m3/h)	1333	176.9	1333	176.9	
Liquid Fraction		1.000	1.000	1.000	1.000	
Molar Volume	(m3/kgmole)	0.2211	1.766e-002	0.2183	1.815e-002	
Mass Heat of Vap.	(kJ/kg)	1102	2031	1106	2047	
Phase Fraction [Molar Basis]		0.0000	0.0000	0.0000	0.0000	
Surface Tension	(dyne/cm)	---	75.03	---	68.62	
Thermal Conductivity	(W/m-K)	0.1182	0.5834	0.1196	0.6376	
Viscosity	(cP)	3.696	1.375	4.830	0.5939	
Cv (Semi-Ideal)	(kJ/kgmole-C)	389.4	71.81	380.9	71.57	

* Specified by user.

Heat Exchanger: 21-HB-001 (continued)

PROPERTIES

Name		Export Oil (Hot)	Sea Water Inlet	Export Oil (Cold)	Sea Water Outlet	
Mass Cv (Semi-Ideal)	(kJ/kg-C)	2.154	3.986	2.108	3.973	
Cv	(kJ/kgmole-C)	314.3	70.88	307.8	69.28	
Mass Cv	(kJ/kg-C)	1.739	3.935	1.703	3.846	
Cv (Ent. Method)	(kJ/kgmole-C)	---	---	---	---	
Mass Cv (Ent. Method)	(kJ/kg-C)	---	---	---	---	
Cp/Cv (Ent. Method)		---	---	---	---	
Reid VP at 37.8 C	(kPa)	34.24	6.442	34.24	6.442	
True VP at 37.8 C	(kPa)	108.6	6.442	108.6	6.442	
Liq. Vol. Flow - Sum(Std. Cond)	(m3/h)	1322	176.9	1322	176.9	
Viscosity Index		17.18	7.070	18.97	-4.906	

DETAILS

Overall/Detailed Performance

Duty:	2.945e+07 kJ/h	UA Curv. Error:	0.00e-01 kJ/C-h
Heat Leak:	0.000e-01 kJ/h	Hot Pinch Temp:	66.58 C
Heat Loss:	0.000e-01 kJ/h	Cold Pinch Temp:	45.00 C
UA:	9.774e+05 kJ/C-h	Ft Factor:	---
Min. Approach:	21.58 C	Uncorrected Lmtd:	32.58 C
Lmtd:	30.13 C		

* Specified by user.

Heat Exchanger: 24-HA-102

CONDITIONS

Name		Field 1 Wet Gas	Heating Medium Inlet 4	Field 1 Gas to Contactor	Heating Medium Outlet 4
Vapour		1.0000	0.0000	1.0000	0.0000
Temperature	(C)	25.0000	150.0000 *	28.0000 *	100.0000 *
Pressure	(kPa)	4930.0000	1100.0000 *	4830.0000 *	1000.0000 *
Molar Flow	(kgmole/h)	48543.5903	679.5104	48543.5903	679.5104
Mass Flow	(kg/h)	957250.5369	52651.4266	957250.5369	52651.4266
Std Ideal Liq Vol Flow	(m3/h)	2811.6979	47.4382	2811.6979	47.4382
Molar Enthalpy	(kJ/kgmole)	-8.352e+004	-4.912e+005	-8.335e+004	-5.035e+005
Molar Entropy	(kJ/kgmole-C)	152.6	172.4	153.3	141.7
Heat Flow	(kJ/h)	-4.0544e+09	-3.3381e+08	-4.0461e+09	-3.4212e+08

PROPERTIES

Name		Field 1 Wet Gas	Heating Medium Inlet 4	Field 1 Gas to Contactor	Heating Medium Outlet 4
Molecular Weight		19.72	77.48	19.72	77.48
Molar Density	(kgmole/m3)	2.271	12.94	2.184	13.60
Mass Density	(kg/m3)	44.78	1003	43.08	1054
Act. Volume Flow	(m3/h)	2.138e+004	52.51	2.222e+004	49.98
Mass Enthalpy	(kJ/kg)	-4235	-6340	-4227	-6498
Mass Entropy	(kJ/kg-C)	7.739	2.224	7.776	1.828
Heat Capacity	(kJ/kgmole-C)	48.89	255.2	48.50	234.3
Mass Heat Capacity	(kJ/kg-C)	2.479	3.294	2.460	3.024
LHV Molar Basis (Std)	(kJ/kgmole)	---	1.462e+006	---	1.462e+006
HHV Molar Basis (Std)	(kJ/kgmole)	---	1.614e+006	---	1.614e+006
HHV Mass Basis (Std)	(kJ/kg)	---	2.083e+004	---	2.083e+004
CO2 Loading		---	---	---	---
CO2 Apparent Mole Conc.	(kgmole/m3)	---	0.0000	---	0.0000
CO2 Apparent Wt. Conc.	(kgmol/kg)	---	0.0000	---	0.0000
LHV Mass Basis (Std)	(kJ/kg)	---	1.887e+004	---	1.887e+004
Phase Fraction [Vol. Basis]		1.000	0.0000	1.000	0.0000
Phase Fraction [Mass Basis]		1.000	0.0000	1.000	0.0000
Phase Fraction [Act. Vol. Basis]		1.000	0.0000	1.000	0.0000
Mass Exergy	(kJ/kg)	472.8	65.58	470.6	25.75
Partial Pressure of CO2	(kPa)	77.39	0.0000	75.82	0.0000
Cost Based on Flow	(Cost/s)	0.0000	0.0000	0.0000	0.0000
Act. Gas Flow	(ACT_m3/h)	2.138e+004	---	2.222e+004	---
Avg. Liq. Density	(kgmole/m3)	17.26	14.32	17.26	14.32
Specific Heat	(kJ/kgmole-C)	48.89	255.2	48.50	234.3
Std. Gas Flow	(STD_m3/h)	1.148e+006	1.607e+004	1.148e+006	1.607e+004
Std. Ideal Liq. Mass Density	(kg/m3)	340.5	1110	340.5	1110
Act. Liq. Flow	(m3/s)	0.0000	1.459e-002	---	1.388e-002
Z Factor		---	2.416e-002	0.8831	2.371e-002
Watson K		17.97	8.816	17.97	8.816
User Property		---	---	---	---
Partial Pressure of H2S	(kPa)	0.0000	0.0000	0.0000	0.0000
Cp/(Cp - R)		1.205	1.034	1.207	1.037
Cp/Cv		1.489	1.064	1.472	1.062
Heat of Vap.	(kJ/kgmole)	9666	7.244e+004	9771	7.313e+004
Kinematic Viscosity	(cSt)	0.2819	1.147	0.2939	2.315
Liq. Mass Density (Std. Cond)	(kg/m3)	0.8365	1130	0.8365	1130
Liq. Vol. Flow (Std. Cond)	(m3/h)	1.144e+006	46.60	1.144e+006	46.60
Liquid Fraction		0.0000	1.000	0.0000	1.000
Molar Volume	(m3/kgmole)	0.4404	7.728e-002	0.4578	7.355e-002
Mass Heat of Vap.	(kJ/kg)	490.2	934.9	495.5	943.9
Phase Fraction [Molar Basis]		1.0000	0.0000	1.0000	0.0000
Surface Tension	(dyne/cm)	---	35.73	---	40.78
Thermal Conductivity	(W/m-K)	3.558e-002	0.2310	3.580e-002	0.2295
Viscosity	(cP)	1.262e-002	1.150	1.266e-002	2.438
Cv (Semi-Ideal)	(kJ/kgmole-C)	40.57	246.9	40.19	226.0

* Specified by user.

Heat Exchanger: 24-HA-102 (continued)

PROPERTIES

Name		Field 1 Wet Gas	Heating Medium Inlet 4	Field 1 Gas to Contactor	Heating Medium Outlet 4	
Mass Cv (Semi-Ideal)	(kJ/kg-C)	2.057	3.187	2.038	2.916	
Cv	(kJ/kgmole-C)	32.82	240.0	32.94	220.5	
Mass Cv	(kJ/kg-C)	1.665	3.097	1.671	2.846	
Cv (Ent. Method)	(kJ/kgmole-C)	---	205.9	---	195.1	
Mass Cv (Ent. Method)	(kJ/kg-C)	---	2.657	---	2.517	
Cp/Cv (Ent. Method)		---	1.240	---	1.201	
Reid VP at 37.8 C	(kPa)	---	9.847e-004	---	9.847e-004	
True VP at 37.8 C	(kPa)	---	3.420	---	3.420	
Liq. Vol. Flow - Sum(Std. Cond)	(m3/h)	1.144e+006	46.60	1.144e+006	46.60	
Viscosity Index		---	5.070	---	12.83	

DETAILS

Overall/Detailed Performance

Duty:	8.316e+06 kJ/h	UA Curv. Error:	0.00e-01 kJ/C-h
Heat Leak:	0.000e-01 kJ/h	Hot Pinch Temp:	100.0 C
Heat Loss:	0.000e-01 kJ/h	Cold Pinch Temp:	25.00 C
UA:	8.632e+04 kJ/C-h	Ft Factor:	---
Min. Approach:	75.00 C	Uncorrected Lmtd:	96.60 C
Lmtd:	96.34 C		

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USA

Case Name:	BASE CASE SIMULATION MODEL.HSC
Unit Set:	SI
Date/Time:	Sun Jun 08 19:49:31 2014

Heat Exchanger: 24-HA-202

CONDITIONS

Name		Field 2 Wet Gas	Heating Medium Inlet 5	2 Gas to TEG Contactor	Heating Medium Outlet 5
Vapour		1.0000	0.0000	1.0000	0.0000
Temperature	(C)	25.0000	150.0000 *	28.0000 *	100.0000 *
Pressure	(kPa)	5420.0000	1100.0000 *	5320.0000 *	1000.0000 *
Molar Flow	(kgmole/h)	54998.7620	786.0151	54998.7620	786.0151
Mass Flow	(kg/h)	1084637.5850	60903.8778	1084637.5850	60903.8778
Std Ideal Liq Vol Flow	(m3/h)	3185.7806	54.8735	3185.7806	54.8735
Molar Enthalpy	(kJ/kgmole)	-8.364e+004	-4.912e+005	-8.347e+004	-5.035e+005
Molar Entropy	(kJ/kgmole-C)	151.5	172.4	152.2	141.7
Heat Flow	(kJ/h)	-4.6001e+09	-3.8613e+08	-4.5905e+09	-3.9575e+08

PROPERTIES

Name		Field 2 Wet Gas	Heating Medium Inlet 5	ld 2 Gas to TEG Contac	Heating Medium Outlet 5	
Molecular Weight		19.72	77.48	19.72	77.48	
Molar Density	(kgmole/m3)	2.530	12.94	2.437	13.60	
Mass Density	(kg/m3)	49.89	1003	48.05	1054	
Act. Volume Flow	(m3/h)	2.174e+004	60.74	2.257e+004	57.81	
Mass Enthalpy	(kJ/kg)	-4241	-6340	-4232	-6498	
Mass Entropy	(kJ/kg-C)	7.682	2.224	7.719	1.828	
Heat Capacity	(kJ/kgmole-C)	50.06	255.2	49.61	234.3	
Mass Heat Capacity	(kJ/kg-C)	2.539	3.294	2.515	3.024	
LHV Molar Basis (Std)	(kJ/kgmole)	---	1.462e+006	---	1.462e+006	
HHV Molar Basis (Std)	(kJ/kgmole)	---	1.614e+006	---	1.614e+006	
HHV Mass Basis (Std)	(kJ/kg)	---	2.083e+004	---	2.083e+004	
CO2 Loading		---	---	---	---	
CO2 Apparent Mole Conc.	(kgmole/m3)	---	0.0000	---	0.0000	
CO2 Apparent Wt. Conc.	(kgmol/kg)	---	0.0000	---	0.0000	
LHV Mass Basis (Std)	(kJ/kg)	---	1.887e+004	---	1.887e+004	
Phase Fraction [Vol. Basis]		1.000	0.0000	1.000	0.0000	
Phase Fraction [Mass Basis]		1.000	0.0000	1.000	0.0000	
Phase Fraction [Act. Vol. Basis]		1.000	0.0000	1.000	0.0000	
Mass Exergy	(kJ/kg)	483.1	65.58	481.1	25.75	
Partial Pressure of CO2	(kPa)	85.08	0.0000	83.51	0.0000	
Cost Based on Flow	(Cost/s)	0.0000	0.0000	0.0000	0.0000	
Act. Gas Flow	(ACT_m3/h)	2.174e+004	---	2.257e+004	---	
Avg. Liq. Density	(kgmole/m3)	17.26	14.32	17.26	14.32	
Specific Heat	(kJ/kgmole-C)	50.06	255.2	49.61	234.3	
Std. Gas Flow	(STD_m3/h)	1.300e+006	1.858e+004	1.300e+006	1.858e+004	
Std. Ideal Liq. Mass Density	(kg/m3)	340.5	1110	340.5	1110	
Act. Liq. Flow	(m3/s)	0.0000	1.687e-002	---	1.606e-002	
Z Factor		---	2.416e-002	0.8720	2.371e-002	
Watson K		17.97	8.816	17.97	8.816	
User Property		---	---	---	---	
Partial Pressure of H2S	(kPa)	0.0000	0.0000	0.0000	0.0000	
Cp/(Cp - R)		1.199	1.034	1.201	1.037	
Cp/Cv		1.520	1.064	1.501	1.062	
Heat of Vap.	(kJ/kgmole)	9171	7.244e+004	9278	7.313e+004	
Kinematic Viscosity	(cSt)	0.2570	1.147	0.2675	2.315	
Liq. Mass Density (Std. Cond)	(kg/m3)	0.8365	1130	0.8365	1130	
Liq. Vol. Flow (Std. Cond)	(m3/h)	1.297e+006	53.90	1.297e+006	53.90	
Liquid Fraction		0.0000	1.000	0.0000	1.000	
Molar Volume	(m3/kgmole)	0.3953	7.728e-002	0.4104	7.355e-002	
Mass Heat of Vap.	(kJ/kg)	465.1	934.9	470.4	943.9	
Phase Fraction [Molar Basis]		1.0000	0.0000	1.0000	0.0000	
Surface Tension	(dyne/cm)	---	35.73	---	40.78	
Thermal Conductivity	(W/m-K)	3.617e-002	0.2310	3.637e-002	0.2295	
Viscosity	(cP)	1.282e-002	1.150	1.285e-002	2.438	
Cv (Semi-Ideal)	(kJ/kgmole-C)	41.75	246.9	41.29	226.0	

* Specified by user.

Heat Exchanger: 24-HA-202 (continued)

PROPERTIES

Name	Field 2 Wet Gas	Heating Medium Inlet 5	ld 2 Gas to TEG Contac	Heating Medium Outlet 5	
Mass Cv (Semi-Ideal) (kJ/kg-C)	2.117	3.187	2.094	2.916	
Cv (kJ/kgmole-C)	32.94	240.0	33.06	220.5	
Mass Cv (kJ/kg-C)	1.670	3.097	1.676	2.846	
Cv (Ent. Method) (kJ/kgmole-C)	---	205.9	---	195.1	
Mass Cv (Ent. Method) (kJ/kg-C)	---	2.657	---	2.517	
Cp/Cv (Ent. Method)	---	1.240	---	1.201	
Reid VP at 37.8 C (kPa)	---	9.847e-004	---	9.847e-004	
True VP at 37.8 C (kPa)	---	3.420	---	3.420	
Liq. Vol. Flow - Sum(Std. Cond) (m3/h)	1.297e+006	53.90	1.297e+006	53.90	
Viscosity Index	---	5.070	---	12.83	

DETAILS

Overall/Detailed Performance

Duty:	9.619e+06 kJ/h	UA Curv. Error:	0.00e-01 kJ/C-h
Heat Leak:	0.000e-01 kJ/h	Hot Pinch Temp:	100.0 C
Heat Loss:	0.000e-01 kJ/h	Cold Pinch Temp:	25.00 C
UA:	9.985e+04 kJ/C-h	Ft Factor:	---
Min. Approach:	75.00 C	Uncorrected Lmtd:	96.60 C
Lmtd:	96.34 C		

Case Name:	BASE CASE SIMULATION MODEL.HSC
Unit Set:	SI
Date/Time:	Mon Jun 09 12:54:39 2014

LNG: 24-HJ-101

CONDITIONS

Name	Inlet to 24-HJ-101	Cooling Medium Inlet 4	Outlet from 24-HJ-101	Cooling Medium Outlet 4
Vapour	1.0000	0.0000	0.9959	0.0000
Temperature (C)	135.2802	20.0000 *	25.0000 *	80.0000 *
Pressure (kPa)	5030.0000	1000.0000 *	4930.0000 *	900.0000 *
Molar Flow (kgmole/h)	4.874e+004	2.073e+004	4.874e+004	2.073e+004
Mass Flow (kg/h)	9.658e+005	1.606e+006	9.658e+005	1.606e+006
Std Ideal Liq Vol Flow (m3/h)	2824	1447	2824	1447
Molar Enthalpy (kJ/kgmole)	-7.860e+004	-5.210e+005	-8.411e+004	-5.081e+005
Molar Entropy (kJ/kgmole-C)	167.9	88.84	152.3	129.0
Heat Flow (kJ/h)	-3.831e+009	-1.080e+010	-4.100e+009	-1.053e+010

PROPERTIES

Name	Inlet to 24-HJ-101	Cooling Medium Inlet 4	Outlet from 24-HJ-101	Cooling Medium Outlet 4
Molecular Weight	19.81	77.48	19.81	77.48
Molar Density (kgmole/m3)	1.524	14.54	2.279	13.84
Mass Density (kg/m3)	30.19	1127	45.15	1072
Act. Volume Flow (m3/h)	3.199e+004	1426	2.139e+004	1498
Mass Enthalpy (kJ/kg)	-3967	-6725	-4245	-6558
Mass Entropy (kJ/kg-C)	8.475	1.147	7.688	1.665
Heat Capacity (kJ/kgmole-C)	50.43	205.6	49.17	226.6
Mass Heat Capacity (kJ/kg-C)	2.545	2.654	2.482	2.925
LHV Molar Basis (Std) (kJ/kgmole)	---	1.462e+006	---	1.462e+006
HHV Molar Basis (Std) (kJ/kgmole)	---	1.614e+006	---	1.614e+006
HHV Mass Basis (Std) (kJ/kg)	---	2.083e+004	---	2.083e+004
CO2 Loading	---	---	---	---
CO2 Apparent Mole Conc. (kgmole/m3)	---	0.0000	---	0.0000
CO2 Apparent Wt. Conc. (kgmol/kg)	---	0.0000	---	0.0000
LHV Mass Basis (Std) (kJ/kg)	---	1.887e+004	---	1.887e+004
Phase Fraction [Vol. Basis]	1.000	0.0000	0.9956	0.0000
Phase Fraction [Mass Basis]	1.000	0.0000	0.9911	0.0000
Phase Fraction [Act. Vol. Basis]	1.000	0.0000	0.9994	0.0000
Mass Exergy (kJ/kg)	513.4	2.394	470.1	14.86
Partial Pressure of CO2 (kPa)	78.72	0.0000	77.39	0.0000
Cost Based on Flow (Cost/s)	0.0000	0.0000	0.0000	0.0000
Act. Gas Flow (ACT_m3/h)	3.199e+004	---	2.138e+004	---
Avg. Liq. Density (kgmole/m3)	17.26	14.32	17.26	14.32
Specific Heat (kJ/kgmole-C)	50.43	205.6	49.17	226.6
Std. Gas Flow (STD_m3/h)	1.153e+006	4.902e+005	1.153e+006	4.902e+005
Std. Ideal Liq. Mass Density (kg/m3)	342.0	1110	342.0	1110
Act. Liq. Flow (m3/s)	---	0.3961	3.492e-003	0.4161
Z Factor	0.9722	2.822e-002	---	2.215e-002
Watson K	17.93	8.816	17.93	8.816
User Property	---	---	---	---
Partial Pressure of H2S (kPa)	0.0000	0.0000	0.0000	0.0000
Cp/(Cp - R)	1.197	1.042	1.203	1.038
Cp/Cv	1.282	1.059	1.483	1.062
Heat of Vap. (kJ/kgmole)	1.090e+004	7.313e+004	1.098e+004	7.380e+004
Kinematic Viscosity (cSt)	0.5187	15.21	---	3.464
Liq. Mass Density (Std. Cond) (kg/m3)	0.8405	1130	0.8405	1130
Liq. Vol. Flow (Std. Cond) (m3/h)	1.149e+006	1422	1.149e+006	1422
Liquid Fraction	0.0000	1.000	4.093e-003	1.000
Molar Volume (m3/kgmole)	0.6563	6.877e-002	0.4388	7.225e-002
Mass Heat of Vap. (kJ/kg)	550.2	943.9	554.2	952.5
Phase Fraction [Molar Basis]	1.0000	0.0000	0.9959	0.0000
Surface Tension (dyne/cm)	---	48.40	---	42.74
Thermal Conductivity (W/m-K)	5.008e-002	0.2165	---	0.2274
Viscosity (cP)	1.566e-002	17.13	---	3.715
Cv (Semi-Ideal) (kJ/kgmole-C)	42.11	197.3	40.86	218.3

* Specified by user.

LNG: 24-HJ-101 (continued)

PROPERTIES

Name		Inlet to 24-HJ-101	Cooling Medium Inlet 4	Outlet from 24-HJ-101	Cooling Medium Outlet 4	
Mass Cv (Semi-Ideal)	(kJ/kg-C)	2.125	2.547	2.062	2.818	
Cv	(kJ/kgmole-C)	39.33	194.1	33.17	213.3	
Mass Cv	(kJ/kg-C)	1.985	2.506	1.674	2.753	
Cv (Ent. Method)	(kJ/kgmole-C)	---	179.3	---	190.6	
Mass Cv (Ent. Method)	(kJ/kg-C)	---	2.314	---	2.460	
Cp/Cv (Ent. Method)		---	1.147	---	1.189	
Reid VP at 37.8 C	(kPa)	---	9.847e-004	---	9.847e-004	
True VP at 37.8 C	(kPa)	---	3.420	---	3.420	
Liq. Vol. Flow - Sum(Std. Cond)	(m3/h)	1.149e+006	1422	1.144e+006	1422	
Viscosity Index		-34.28	25.80	---	16.38	

Case Name:	BASE CASE SIMULATION MODEL.HSC
Unit Set:	SI
Date/Time:	Mon Jun 09 12:53:25 2014

LNG: 24-HJ-201

CONDITIONS

Name		Inlet to 24-HJ-201	Cooling Medium Inlet 8	Outlet from 24-HJ-201	Cooling Medium Outlet 8
Vapour		1.0000	0.0000	0.9958	0.0000
Temperature	(C)	142.4725	20.0000 *	25.0000 *	80.0000 *
Pressure	(kPa)	5520.0000	1000.0000 *	5420.0000 *	900.0000 *
Molar Flow	(kgmole/h)	5.523e+004	2.535e+004	5.523e+004	2.535e+004
Mass Flow	(kg/h)	1.094e+006	1.964e+006	1.094e+006	1.964e+006
Std Ideal Liq Vol Flow	(m3/h)	3200	1770	3200	1770
Molar Enthalpy	(kJ/kgmole)	-7.830e+004	-5.210e+005	-8.423e+004	-5.081e+005
Molar Entropy	(kJ/kgmole-C)	167.9	88.84	151.2	129.0
Heat Flow	(kJ/h)	-4.324e+009	-1.321e+010	-4.652e+009	-1.288e+010

PROPERTIES

Name		Inlet to 24-HJ-201	Cooling Medium Inlet 8	Outlet from 24-HJ-201	Cooling Medium Outlet 8
Molecular Weight		19.81	77.48	19.81	77.48
Molar Density	(kgmole/m3)	1.641	14.54	2.539	13.84
Mass Density	(kg/m3)	32.51	1127	50.30	1072
Act. Volume Flow	(m3/h)	3.366e+004	1743	2.175e+004	1831
Mass Enthalpy	(kJ/kg)	-3952	-6725	-4251	-6558
Mass Entropy	(kJ/kg-C)	8.474	1.147	7.632	1.665
Heat Capacity	(kJ/kgmole-C)	51.08	205.6	50.34	226.6
Mass Heat Capacity	(kJ/kg-C)	2.578	2.654	2.541	2.925
LHV Molar Basis (Std)	(kJ/kgmole)	---	1.462e+006	---	1.462e+006
HHV Molar Basis (Std)	(kJ/kgmole)	---	1.614e+006	---	1.614e+006
HHV Mass Basis (Std)	(kJ/kg)	---	2.083e+004	---	2.083e+004
CO2 Loading		---	---	---	---
CO2 Apparent Mole Conc.	(kgmole/m3)	---	0.0000	---	0.0000
CO2 Apparent Wt. Conc.	(kgmol/kg)	---	0.0000	---	0.0000
LHV Mass Basis (Std)	(kJ/kg)	---	1.887e+004	---	1.887e+004
Phase Fraction [Vol. Basis]		1.000	0.0000	0.9955	0.0000
Phase Fraction [Mass Basis]		1.000	0.0000	0.9911	0.0000
Phase Fraction [Act. Vol. Basis]		1.000	0.0000	0.9993	0.0000
Mass Exergy	(kJ/kg)	529.0	2.394	480.4	14.86
Partial Pressure of CO2	(kPa)	86.39	0.0000	85.08	0.0000
Cost Based on Flow	(Cost/s)	0.0000	0.0000	0.0000	0.0000
Act. Gas Flow	(ACT_m3/h)	3.366e+004	---	2.174e+004	---
Avg. Liq. Density	(kgmole/m3)	17.26	14.32	17.26	14.32
Specific Heat	(kJ/kgmole-C)	51.08	205.6	50.34	226.6
Std. Gas Flow	(STD_m3/h)	1.306e+006	5.993e+005	1.306e+006	5.993e+005
Std. Ideal Liq. Mass Density	(kg/m3)	342.0	1110	342.0	1110
Act. Liq. Flow	(m3/s)	---	0.4842	4.010e-003	0.5087
Z Factor		0.9735	2.822e-002	---	2.215e-002
Watson K		17.93	8.816	17.93	8.816
User Property		---	---	---	---
Partial Pressure of H2S	(kPa)	0.0000	0.0000	0.0000	0.0000
Cp/(Cp - R)		1.194	1.042	1.198	1.038
Cp/Cv		1.282	1.059	1.513	1.062
Heat of Vap.	(kJ/kgmole)	1.052e+004	7.313e+004	1.059e+004	7.380e+004
Kinematic Viscosity	(cSt)	0.4907	15.21	---	3.464
Liq. Mass Density (Std. Cond)	(kg/m3)	0.8405	1130	0.8405	1130
Liq. Vol. Flow (Std. Cond)	(m3/h)	1.302e+006	1738	1.302e+006	1738
Liquid Fraction		0.0000	1.000	4.206e-003	1.000
Molar Volume	(m3/kgmole)	0.6094	6.877e-002	0.3939	7.225e-002
Mass Heat of Vap.	(kJ/kg)	530.7	943.9	534.7	952.5
Phase Fraction [Molar Basis]		1.0000	0.0000	0.9958	0.0000
Surface Tension	(dyne/cm)	---	48.40	---	42.74
Thermal Conductivity	(W/m-K)	5.146e-002	0.2165	---	0.2274
Viscosity	(cP)	1.595e-002	17.13	---	3.715
Cv (Semi-Ideal)	(kJ/kgmole-C)	42.76	197.3	42.03	218.3

* Specified by user.

LNG: 24-HJ-201 (continued)

PROPERTIES

Name		Inlet to 24-HJ-201	Cooling Medium Inlet 8	Outlet from 24-HJ-201	Cooling Medium Outlet 8
Mass Cv (Semi-Ideal)	(kJ/kg-C)	2.158	2.547	2.121	2.818
Cv	(kJ/kgmole-C)	39.85	194.1	33.28	213.3
Mass Cv	(kJ/kg-C)	2.011	2.506	1.680	2.753
Cv (Ent. Method)	(kJ/kgmole-C)	---	179.3	---	190.6
Mass Cv (Ent. Method)	(kJ/kg-C)	---	2.314	---	2.460
Cp/Cv (Ent. Method)		---	1.147	---	1.189
Reid VP at 37.8 C	(kPa)	---	9.847e-004	---	9.847e-004
True VP at 37.8 C	(kPa)	---	3.420	---	3.420
Liq. Vol. Flow - Sum(Std. Cond)	(m3/h)	1.302e+006	1738	1.297e+006	1738
Viscosity Index		-35.39	25.80	---	16.38

Appendix B – Process Datasheets for Heat Exchangers in Case Study I

Case Name:	CASE STUDY 1.HSC
Unit Set:	SI
Date/Time:	Mon Jun 09 01:34:49 2014

Heat Exchanger: 20-HA-003

CONDITIONS

Name		let to Stabilization Heater	Heating Medium Inlet 3	t to Secondary Separator	Heating Medium Outlet 3
Vapour		0.0148	0.0000	0.0228	0.0000
Temperature	(C)	54.9165	150.0000 *	77.6271 *	100.0000 *
Pressure	(kPa)	800.0000	1100.0000 *	700.0000 *	1000.0000 *
Molar Flow	(kgmole/h)	8980.9947	5125.8344	8980.9947	5125.8344
Mass Flow	(kg/h)	1184961.0373	397171.9902	1184961.0373	397171.9902
Std Ideal Liq Vol Flow	(m3/h)	1376.3849	357.8461	1376.3849	357.8461
Molar Enthalpy	(kJ/kgmole)	-3.867e+005	-4.912e+005	-3.797e+005	-5.035e+005
Molar Entropy	(kJ/kgmole-C)	286.7	172.4	307.4	141.7
Heat Flow	(kJ/h)	-3.4728e+09	-2.5180e+09	-3.4101e+09	-2.5808e+09

PROPERTIES

Name		let to Stabilization Heate	Heating Medium Inlet 3	et to Secondary Separa	Heating Medium Outlet 3
Molecular Weight		131.9	77.48	131.9	77.48
Molar Density	(kgmole/m3)	4.801	12.94	3.918	13.60
Mass Density	(kg/m3)	633.4	1003	516.9	1054
Act. Volume Flow	(m3/h)	1871	396.1	2292	377.0
Mass Enthalpy	(kJ/kg)	-2931	-6340	-2878	-6498
Mass Entropy	(kJ/kg-C)	2.173	2.224	2.330	1.828
Heat Capacity	(kJ/kgmole-C)	295.6	255.2	307.0	234.3
Mass Heat Capacity	(kJ/kg-C)	2.241	3.294	2.327	3.024
LHV Molar Basis (Std)	(kJ/kgmole)	---	1.462e+006	---	1.462e+006
HHV Molar Basis (Std)	(kJ/kgmole)	---	1.614e+006	---	1.614e+006
HHV Mass Basis (Std)	(kJ/kg)	---	2.083e+004	---	2.083e+004
CO2 Loading		---	---	---	---
CO2 Apparent Mole Conc.	(kgmole/m3)	---	0.0000	---	0.0000
CO2 Apparent Wt. Conc.	(kgmol/kg)	---	0.0000	---	0.0000
LHV Mass Basis (Std)	(kJ/kg)	---	1.887e+004	---	1.887e+004
Phase Fraction [Vol. Basis]		5.810e-003	0.0000	9.251e-003	0.0000
Phase Fraction [Mass Basis]		2.457e-003	0.0000	4.328e-003	0.0000
Phase Fraction [Act. Vol. Basis]		0.2376	0.0000	0.3646	0.0000
Mass Exergy	(kJ/kg)	4.907	65.58	11.19	25.75
Partial Pressure of CO2	(kPa)	17.00	0.0000	16.10	0.0000
Cost Based on Flow	(Cost/s)	0.0000	0.0000	0.0000	0.0000
Act. Gas Flow	(ACT_m3/h)	444.5	---	835.8	---
Avg. Liq. Density	(kgmole/m3)	6.525	14.32	6.525	14.32
Specific Heat	(kJ/kgmole-C)	295.6	255.2	307.0	234.3
Std. Gas Flow	(STD_m3/h)	2.124e+005	1.212e+005	2.124e+005	1.212e+005
Std. Ideal Liq. Mass Density	(kg/m3)	860.9	1110	860.9	1110
Act. Liq. Flow	(m3/s)	0.3962	0.1100	0.4046	0.1047
Z Factor		---	2.416e-002	---	2.371e-002
Watson K		11.63	8.816	11.63	8.816
User Property		---	---	---	---
Partial Pressure of H2S	(kPa)	0.0000	0.0000	0.0000	0.0000
Cp/(Cp - R)		1.029	1.034	1.028	1.037
Cp/Cv		1.002	1.064	1.002	1.062
Heat of Vap.	(kJ/kgmole)	2.001e+005	7.244e+004	2.014e+005	7.313e+004
Kinematic Viscosity	(cSt)	---	1.147	---	2.315
Liq. Mass Density (Std. Cond)	(kg/m3)	859.9	1130	859.9	1130
Liq. Vol. Flow (Std. Cond)	(m3/h)	1378	351.5	1378	351.5
Liquid Fraction		0.9852	1.000	0.9772	1.000
Molar Volume	(m3/kgmole)	0.2083	7.728e-002	0.2552	7.355e-002
Mass Heat of Vap.	(kJ/kg)	1517	934.9	1526	943.9
Phase Fraction [Molar Basis]		0.0148	0.0000	0.0228	0.0000
Surface Tension	(dyne/cm)	---	35.73	---	40.78
Thermal Conductivity	(W/m-K)	---	0.2310	---	0.2295
Viscosity	(cP)	---	1.150	---	2.438
Cv (Semi-Ideal)	(kJ/kgmole-C)	287.3	246.9	298.7	226.0

* Specified by user.

Heat Exchanger: 20-HA-003 (continued)

PROPERTIES

Name	let to Stabilization Heate	Heating Medium Inlet 3	et to Secondary Separa	Heating Medium Outlet 3	
Mass Cv (Semi-Ideal) (kJ/kg-C)	2.178	3.187	2.264	2.916	
Cv (kJ/kgmole-C)	295.1	240.0	306.4	220.5	
Mass Cv (kJ/kg-C)	2.236	3.097	2.322	2.846	
Cv (Ent. Method) (kJ/kgmole-C)	---	205.9	---	195.1	
Mass Cv (Ent. Method) (kJ/kg-C)	---	2.657	---	2.517	
Cp/Cv (Ent. Method)	---	1.240	---	1.201	
Reid VP at 37.8 C (kPa)	153.0	9.847e-004	153.0	9.847e-004	
True VP at 37.8 C (kPa)	1363	3.420	1363	3.420	
Liq. Vol. Flow - Sum(Std. Cond) (m3/h)	4500	351.5	6172	351.5	
Viscosity Index	17.24	5.070	13.91	12.83	

DETAILS

Overall/Detailed Performance

Duty:	6.273e+07 kJ/h	UA Curv. Error:	0.00e-01 kJ/C-h
Heat Leak:	0.000e-01 kJ/h	Hot Pinch Temp:	100.0 C
Heat Loss:	0.000e-01 kJ/h	Cold Pinch Temp:	54.92 C
UA:	1.158e+06 kJ/C-h	Ft Factor:	---
Min. Approach:	45.08 C	Uncorrected Lmtd:	57.66 C
Lmtd:	54.17 C		

Heat Exchanger: 21-HB-001

CONDITIONS

Name		Hot Export Oil	Sea Water Inlet	Low Temp Export Oil	Sea Water Outlet
Vapour		0.0000	0.0000	0.0000	0.0000
Temperature	(C)	75.1186	8.0000 *	54.7998 *	45.0000 *
Pressure	(kPa)	750.0000	1000.0000 *	550.0000 *	900.0000 *
Molar Flow	(kgmole/h)	6300.3826	17358.1373	6300.3826	17358.1373
Mass Flow	(kg/h)	1138593.4197	312708.5873	1138593.4197	312708.5873
Std Ideal Liq Vol Flow	(m3/h)	1318.0638	313.3396	1318.0638	313.3396
Molar Enthalpy	(kJ/kgmole)	-4.319e+005	-2.877e+005	-4.401e+005	-2.847e+005
Molar Entropy	(kJ/kgmole-C)	402.2	48.59	378.2	58.47
Heat Flow	(kJ/h)	-2.7214e+09	-4.9939e+09	-2.7727e+09	-4.9426e+09

PROPERTIES

Name		Hot Export Oil	Sea Water Inlet	Low Temp Export Oil	Sea Water Outlet
Molecular Weight		180.7	18.02	180.7	18.02
Molar Density	(kgmole/m3)	4.483	56.63	4.580	55.09
Mass Density	(kg/m3)	810.1	1020	827.7	992.4
Act. Volume Flow	(m3/h)	1405	306.5	1376	315.1
Mass Enthalpy	(kJ/kg)	-2390	-1.597e+004	-2435	-1.581e+004
Mass Entropy	(kJ/kg-C)	2.225	2.697	2.093	3.246
Heat Capacity	(kJ/kgmole-C)	403.8	80.12	389.2	79.88
Mass Heat Capacity	(kJ/kg-C)	2.234	4.447	2.154	4.434
LHV Molar Basis (Std)	(kJ/kgmole)	---	0.0000	---	0.0000
HHV Molar Basis (Std)	(kJ/kgmole)	---	4.101e+004	---	4.101e+004
HHV Mass Basis (Std)	(kJ/kg)	---	2276	---	2276
CO2 Loading		---	---	---	---
CO2 Apparent Mole Conc.	(kgmole/m3)	1.120e-003	0.0000	1.144e-003	0.0000
CO2 Apparent Wt. Conc.	(kgmol/kg)	1.383e-006	0.0000	1.383e-006	0.0000
LHV Mass Basis (Std)	(kJ/kg)	---	---	---	---
Phase Fraction [Vol. Basis]		0.0000	0.0000	0.0000	0.0000
Phase Fraction [Mass Basis]		0.0000	0.0000	0.0000	0.0000
Phase Fraction [Act. Vol. Basis]		0.0000	0.0000	0.0000	0.0000
Mass Exergy	(kJ/kg)	9.025	3.429	3.491	3.905
Partial Pressure of CO2	(kPa)	0.0000	0.0000	0.0000	0.0000
Cost Based on Flow	(Cost/s)	0.0000	0.0000	0.0000	0.0000
Act. Gas Flow	(ACT_m3/h)	---	---	---	---
Avg. Liq. Density	(kgmole/m3)	4.780	55.40	4.780	55.40
Specific Heat	(kJ/kgmole-C)	403.8	80.12	389.2	79.88
Std. Gas Flow	(STD_m3/h)	1.490e+005	4.104e+005	1.490e+005	4.104e+005
Std. Ideal Liq. Mass Density	(kg/m3)	863.8	998.0	863.8	998.0
Act. Liq. Flow	(m3/s)	0.3904	8.514e-002	0.3821	8.753e-002
Z Factor		---	7.554e-003	---	6.177e-003
Watson K		11.65	---	11.65	---
User Property		---	---	---	---
Partial Pressure of H2S	(kPa)	0.0000	0.0000	0.0000	0.0000
Cp/(Cp - R)		1.021	1.116	1.022	1.116
Cp/Cv		1.264	1.130	1.265	1.153
Heat of Vap.	(kJ/kgmole)	1.985e+005	3.659e+004	1.999e+005	3.688e+004
Kinematic Viscosity	(cSt)	3.817	1.348	5.836	0.5984
Liq. Mass Density (Std. Cond)	(kg/m3)	854.3	1015	854.3	1015
Liq. Vol. Flow (Std. Cond)	(m3/h)	1333	308.1	1333	308.1
Liquid Fraction		1.000	1.000	1.000	1.000
Molar Volume	(m3/kgmole)	0.2231	1.766e-002	0.2183	1.815e-002
Mass Heat of Vap.	(kJ/kg)	1098	2031	1106	2047
Phase Fraction [Molar Basis]		0.0000	0.0000	0.0000	0.0000
Surface Tension	(dyne/cm)	---	75.03	---	68.62
Thermal Conductivity	(W/m-K)	0.1171	0.5834	0.1196	0.6376
Viscosity	(cP)	3.092	1.375	4.831	0.5939
Cv (Semi-Ideal)	(kJ/kgmole-C)	395.5	71.81	380.9	71.57

* Specified by user.

Heat Exchanger: 21-HB-001 (continued)

PROPERTIES

Name		Hot Export Oil	Sea Water Inlet	Low Temp Export Oil	Sea Water Outlet	
Mass Cv (Semi-Ideal)	(kJ/kg-C)	2.188	3.986	2.108	3.973	
Cv	(kJ/kgmole-C)	319.3	70.88	307.8	69.28	
Mass Cv	(kJ/kg-C)	1.767	3.935	1.703	3.846	
Cv (Ent. Method)	(kJ/kgmole-C)	---	---	---	---	
Mass Cv (Ent. Method)	(kJ/kg-C)	---	---	---	---	
Cp/Cv (Ent. Method)		---	---	---	---	
Reid VP at 37.8 C	(kPa)	34.23	6.442	34.23	6.442	
True VP at 37.8 C	(kPa)	108.5	6.442	108.5	6.442	
Liq. Vol. Flow - Sum(Std. Cond)	(m3/h)	1322	308.1	1322	308.1	
Viscosity Index		15.90	7.070	18.97	-4.906	

DETAILS

Overall/Detailed Performance

Duty:	5.131e+07 kJ/h	UA Curv. Error:	0.00e-01 kJ/C-h
Heat Leak:	0.000e-01 kJ/h	Hot Pinch Temp:	75.12 C
Heat Loss:	0.000e-01 kJ/h	Cold Pinch Temp:	45.00 C
UA:	1.499e+06 kJ/C-h	Ft Factor:	---
Min. Approach:	30.12 C	Uncorrected Lmtd:	37.85 C
Lmtd:	34.23 C		

Appendix C – Process Datasheets for Heat Exchangers in Case Study II

Case Name:	CASE STUDY 2.HSC
Unit Set:	SI
Date/Time:	Mon Jun 09 13:33:25 2014

Heat Exchanger: 24-HA-102

CONDITIONS

Name		Field 1 Wet Gas	Heating Medium Inlet 4	Field 1 Gas to Contactor	Heating Medium Outlet 4
Vapour		1.0000	0.0000	1.0000	0.0000
Temperature	(C)	25.0000	100.0000	28.0000 *	90.0000 *
Pressure	(kPa)	4930.0000	1000.0000	4830.0000 *	900.0000 *
Molar Flow	(kgmole/h)	48543.5493	3557.8692	48543.5493	3557.8692
Mass Flow	(kg/h)	957248.8623	275679.2127	957248.8623	275679.2127
Std Ideal Liq Vol Flow	(m3/h)	2811.6945	248.3829	2811.6945	248.3829
Molar Enthalpy	(kJ/kgmole)	-8.352e+004	-5.035e+005	-8.335e+004	-5.058e+005
Molar Entropy	(kJ/kgmole-C)	152.6	141.7	153.3	135.4
Heat Flow	(kJ/h)	-4.0544e+09	-1.7913e+09	-4.0461e+09	-1.7996e+09

PROPERTIES

Name		Field 1 Wet Gas	Heating Medium Inlet 4	Field 1 Gas to Contactor	Heating Medium Outlet 4
Molecular Weight		19.72	77.48	19.72	77.48
Molar Density	(kgmole/m3)	2.271	13.60	2.184	13.72
Mass Density	(kg/m3)	44.78	1054	43.08	1063
Act. Volume Flow	(m3/h)	2.138e+004	261.7	2.222e+004	259.3
Mass Enthalpy	(kJ/kg)	-4235	-6498	-4227	-6528
Mass Entropy	(kJ/kg-C)	7.739	1.828	7.776	1.747
Heat Capacity	(kJ/kgmole-C)	48.89	234.3	48.50	230.4
Mass Heat Capacity	(kJ/kg-C)	2.479	3.024	2.460	2.974
LHV Molar Basis (Std)	(kJ/kgmole)	---	1.462e+006	---	1.462e+006
HHV Molar Basis (Std)	(kJ/kgmole)	---	1.614e+006	---	1.614e+006
HHV Mass Basis (Std)	(kJ/kg)	---	2.083e+004	---	2.083e+004
CO2 Loading		---	---	---	---
CO2 Apparent Mole Conc.	(kgmole/m3)	---	0.0000	---	0.0000
CO2 Apparent Wt. Conc.	(kgmol/kg)	---	0.0000	---	0.0000
LHV Mass Basis (Std)	(kJ/kg)	---	1.887e+004	---	1.887e+004
Phase Fraction [Vol. Basis]		1.000	0.0000	1.000	0.0000
Phase Fraction [Mass Basis]		1.000	0.0000	1.000	0.0000
Phase Fraction [Act. Vol. Basis]		1.000	0.0000	1.000	0.0000
Mass Exergy	(kJ/kg)	472.8	25.75	470.6	19.80
Partial Pressure of CO2	(kPa)	77.39	0.0000	75.82	0.0000
Cost Based on Flow	(Cost/s)	0.0000	0.0000	0.0000	0.0000
Act. Gas Flow	(ACT_m3/h)	2.138e+004	---	2.222e+004	---
Avg. Liq. Density	(kgmole/m3)	17.26	14.32	17.26	14.32
Specific Heat	(kJ/kgmole-C)	48.89	234.3	48.50	230.4
Std. Gas Flow	(STD_m3/h)	1.148e+006	8.412e+004	1.148e+006	8.412e+004
Std. Ideal Liq. Mass Density	(kg/m3)	340.5	1110	340.5	1110
Act. Liq. Flow	(m3/s)	0.0000	7.269e-002	---	7.204e-002
Z Factor		---	2.371e-002	0.8831	2.173e-002
Watson K		17.97	8.816	17.97	8.816
User Property		---	---	---	---
Partial Pressure of H2S	(kPa)	0.0000	0.0000	0.0000	0.0000
Cp/(Cp - R)		1.205	1.037	1.207	1.037
Cp/Cv		1.489	1.062	1.472	1.062
Heat of Vap.	(kJ/kgmole)	9666	7.313e+004	9771	7.380e+004
Kinematic Viscosity	(cSt)	0.2819	2.315	0.2939	2.807
Liq. Mass Density (Std. Cond)	(kg/m3)	0.8365	1130	0.8365	1130
Liq. Vol. Flow (Std. Cond)	(m3/h)	1.144e+006	244.0	1.144e+006	244.0
Liquid Fraction		0.0000	1.000	0.0000	1.000
Molar Volume	(m3/kgmole)	0.4404	7.355e-002	0.4578	7.289e-002
Mass Heat of Vap.	(kJ/kg)	490.2	943.9	495.5	952.5
Phase Fraction [Molar Basis]		1.0000	0.0000	1.0000	0.0000
Surface Tension	(dyne/cm)	---	40.78	---	41.76
Thermal Conductivity	(W/m-K)	3.558e-002	0.2295	3.580e-002	0.2285
Viscosity	(cP)	1.262e-002	2.438	1.266e-002	2.984
Cv (Semi-Ideal)	(kJ/kgmole-C)	40.57	226.0	40.19	222.1

* Specified by user.

Heat Exchanger: 24-HA-102 (continued)

PROPERTIES

Name	Field 1 Wet Gas	Heating Medium Inlet 4	Field 1 Gas to Contactor	Heating Medium Outlet 4
Mass Cv (Semi-Ideal) (kJ/kg-C)	2.057	2.916	2.038	2.867
Cv (kJ/kgmole-C)	32.82	220.5	32.94	216.9
Mass Cv (kJ/kg-C)	1.665	2.846	1.671	2.799
Cv (Ent. Method) (kJ/kgmole-C)	---	195.1	---	192.7
Mass Cv (Ent. Method) (kJ/kg-C)	---	2.517	---	2.487
Cp/Cv (Ent. Method)	---	1.201	---	1.196
Reid VP at 37.8 C (kPa)	---	9.847e-004	---	9.847e-004
True VP at 37.8 C (kPa)	---	3.420	---	3.420
Liq. Vol. Flow - Sum(Std. Cond) (m3/h)	1.144e+006	244.0	1.144e+006	244.0
Viscosity Index	---	12.83	---	14.60

DETAILS

Overall/Detailed Performance

Duty:	8.316e+06 kJ/h	UA Curv. Error:	0.00e-01 kJ/C-h
Heat Leak:	0.000e-01 kJ/h	Hot Pinch Temp:	90.00 C
Heat Loss:	0.000e-01 kJ/h	Cold Pinch Temp:	25.00 C
UA:	1.216e+05 kJ/C-h	Ft Factor:	---
Min. Approach:	65.00 C	Uncorrected Lmtd:	68.44 C
Lmtd:	68.37 C		

NORWEGIAN UNIV OF
Burlington, MA
USA

Case Name:	CASE STUDY 2.HSC
Unit Set:	SI
Date/Time:	Mon Jun 09 13:36:00 2014

Heat Exchanger: 24-HA-202

CONDITIONS

Name		Field 2 Wet Gas	Heating Medium Inlet 5	Field 2 Gas to Contactor	Heating Medium Outlet 5
Vapour		1.0000	0.0000	1.0000	0.0000
Temperature	(C)	25.0000	100.0000 *	28.0000 *	90.0000 *
Pressure	(kPa)	5420.0000	1000.0000 *	5320.0000 *	900.0000 *
Molar Flow	(kgmole/h)	54998.7165	4115.5191	54998.7165	4115.5191
Mass Flow	(kg/h)	1084635.7174	318888.3536	1084635.7174	318888.3536
Std Ideal Liq Vol Flow	(m3/h)	3185.7768	287.3137	3185.7768	287.3137
Molar Enthalpy	(kJ/kgmole)	-8.364e+004	-5.035e+005	-8.347e+004	-5.058e+005
Molar Entropy	(kJ/kgmole-C)	151.5	141.7	152.2	135.4
Heat Flow	(kJ/h)	-4.6001e+09	-2.0721e+09	-4.5905e+09	-2.0817e+09

PROPERTIES

Name		Field 2 Wet Gas	Heating Medium Inlet 5	Field 2 Gas to Contactor	Heating Medium Outlet 5
Molecular Weight		19.72	77.48	19.72	77.48
Molar Density	(kgmole/m3)	2.530	13.60	2.437	13.72
Mass Density	(kg/m3)	49.89	1054	48.05	1063
Act. Volume Flow	(m3/h)	2.174e+004	302.7	2.257e+004	300.0
Mass Enthalpy	(kJ/kg)	-4241	-6498	-4232	-6528
Mass Entropy	(kJ/kg-C)	7.682	1.828	7.719	1.747
Heat Capacity	(kJ/kgmole-C)	50.06	234.3	49.61	230.4
Mass Heat Capacity	(kJ/kg-C)	2.539	3.024	2.515	2.974
LHV Molar Basis (Std)	(kJ/kgmole)	---	1.462e+006	---	1.462e+006
HHV Molar Basis (Std)	(kJ/kgmole)	---	1.614e+006	---	1.614e+006
HHV Mass Basis (Std)	(kJ/kg)	---	2.083e+004	---	2.083e+004
CO2 Loading		---	---	---	---
CO2 Apparent Mole Conc.	(kgmole/m3)	---	0.0000	---	0.0000
CO2 Apparent Wt. Conc.	(kgmol/kg)	---	0.0000	---	0.0000
LHV Mass Basis (Std)	(kJ/kg)	---	1.887e+004	---	1.887e+004
Phase Fraction [Vol. Basis]		1.000	0.0000	1.000	0.0000
Phase Fraction [Mass Basis]		1.000	0.0000	1.000	0.0000
Phase Fraction [Act. Vol. Basis]		1.000	0.0000	1.000	0.0000
Mass Exergy	(kJ/kg)	483.1	25.75	481.1	19.80
Partial Pressure of CO2	(kPa)	85.08	0.0000	83.51	0.0000
Cost Based on Flow	(Cost/s)	0.0000	0.0000	0.0000	0.0000
Act. Gas Flow	(ACT_m3/h)	2.174e+004	---	2.257e+004	---
Avg. Liq. Density	(kgmole/m3)	17.26	14.32	17.26	14.32
Specific Heat	(kJ/kgmole-C)	50.06	234.3	49.61	230.4
Std. Gas Flow	(STD_m3/h)	1.300e+006	9.731e+004	1.300e+006	9.731e+004
Std. Ideal Liq. Mass Density	(kg/m3)	340.5	1110	340.5	1110
Act. Liq. Flow	(m3/s)	0.0000	8.408e-002	---	8.333e-002
Z Factor		---	2.371e-002	0.8720	2.173e-002
Watson K		17.97	8.816	17.97	8.816
User Property		---	---	---	---
Partial Pressure of H2S	(kPa)	0.0000	0.0000	0.0000	0.0000
Cp/(Cp - R)		1.199	1.037	1.201	1.037
Cp/Cv		1.520	1.062	1.501	1.062
Heat of Vap.	(kJ/kgmole)	9171	7.313e+004	9278	7.380e+004
Kinematic Viscosity	(cSt)	0.2570	2.315	0.2675	2.807
Liq. Mass Density (Std. Cond)	(kg/m3)	0.8365	1130	0.8365	1130
Liq. Vol. Flow (Std. Cond)	(m3/h)	1.297e+006	282.2	1.297e+006	282.2
Liquid Fraction		0.0000	1.000	0.0000	1.000
Molar Volume	(m3/kgmole)	0.3953	7.355e-002	0.4104	7.289e-002
Mass Heat of Vap.	(kJ/kg)	465.1	943.9	470.4	952.5
Phase Fraction [Molar Basis]		1.0000	0.0000	1.0000	0.0000
Surface Tension	(dyne/cm)	---	40.78	---	41.76
Thermal Conductivity	(W/m-K)	3.617e-002	0.2295	3.637e-002	0.2285
Viscosity	(cP)	1.282e-002	2.438	1.285e-002	2.984
Cv (Semi-Ideal)	(kJ/kgmole-C)	41.75	226.0	41.29	222.1

* Specified by user.

Heat Exchanger: 24-HA-202 (continued)

PROPERTIES

Name		Field 2 Wet Gas	Heating Medium Inlet 5	Field 2 Gas to Contactor	Heating Medium Outlet 5	
Mass Cv (Semi-Ideal)	(kJ/kg-C)	2.117	2.916	2.094	2.867	
Cv	(kJ/kgmole-C)	32.94	220.5	33.06	216.9	
Mass Cv	(kJ/kg-C)	1.670	2.846	1.676	2.799	
Cv (Ent. Method)	(kJ/kgmole-C)	---	195.1	---	192.7	
Mass Cv (Ent. Method)	(kJ/kg-C)	---	2.517	---	2.487	
Cp/Cv (Ent. Method)		---	1.201	---	1.196	
Reid VP at 37.8 C	(kPa)	---	9.847e-004	---	9.847e-004	
True VP at 37.8 C	(kPa)	---	3.420	---	3.420	
Liq. Vol. Flow - Sum(Std. Cond)	(m3/h)	1.297e+006	282.2	1.297e+006	282.2	
Viscosity Index		---	12.83	---	14.60	

DETAILS

Overall/Detailed Performance

Duty:	9.619e+06 kJ/h	UA Curv. Error:	0.00e-01 kJ/C-h
Heat Leak:	0.000e-01 kJ/h	Hot Pinch Temp:	90.00 C
Heat Loss:	0.000e-01 kJ/h	Cold Pinch Temp:	25.00 C
UA:	1.407e+05 kJ/C-h	Ft Factor:	---
Min. Approach:	65.00 C	Uncorrected Lmtd:	68.44 C
Lmtd:	68.37 C		

Appendix D – Process Datasheets for Heat Exchangers in Case Study III

LNG: 24-HJ-101

CONDITIONS

Name		Field 1 Inlet to 24-HJ-101	Cooling Medium Inlet 4	Inlet to Field 1 Contactor	Cooling Medium Outlet 4
Vapour		1.0000	0.0000	1.0000 *	0.0000
Temperature	(C)	135.2823	20.0000 *	48.8340	80.0000 *
Pressure	(kPa)	5030.0000	1000.0000 *	4930.0000 *	900.0000 *
Molar Flow	(kgmole/h)	4.874e+004	1.589e+004	4.874e+004	1.589e+004
Mass Flow	(kg/h)	9.657e+005	1.232e+006	9.657e+005	1.232e+006
Std Ideal Liq Vol Flow	(m3/h)	2824	1110	2824	1110
Molar Enthalpy	(kJ/kgmole)	-7.860e+004	-5.210e+005	-8.282e+004	-5.081e+005
Molar Entropy	(kJ/kgmole-C)	167.9	88.84	156.5	129.0
Heat Flow	(kJ/h)	-3.831e+009	-8.282e+009	-4.037e+009	-8.076e+009

PROPERTIES

Name		ield 1 Inlet to 24-HJ-101	Cooling Medium Inlet 4	Inlet to Field 1 Contactor	Cooling Medium Outlet 4
Molecular Weight		19.81	77.48	19.81	77.48
Molar Density	(kgmole/m3)	1.524	14.54	2.026	13.84
Mass Density	(kg/m3)	30.19	1127	40.15	1072
Act. Volume Flow	(m3/h)	3.199e+004	1093	2.405e+004	1148
Mass Enthalpy	(kJ/kg)	-3967	-6725	-4180	-6558
Mass Entropy	(kJ/kg-C)	8.475	1.147	7.898	1.665
Heat Capacity	(kJ/kgmole-C)	50.43	205.6	48.32	226.6
Mass Heat Capacity	(kJ/kg-C)	2.545	2.654	2.439	2.925
LHV Molar Basis (Std)	(kJ/kgmole)	---	1.462e+006	---	1.462e+006
HHV Molar Basis (Std)	(kJ/kgmole)	---	1.614e+006	---	1.614e+006
HHV Mass Basis (Std)	(kJ/kg)	---	2.083e+004	---	2.083e+004
CO2 Loading		---	---	---	---
CO2 Apparent Mole Conc.	(kgmole/m3)	---	0.0000	---	0.0000
CO2 Apparent Wt. Conc.	(kgmol/kg)	---	0.0000	---	0.0000
LHV Mass Basis (Std)	(kJ/kg)	---	1.887e+004	---	1.887e+004
Phase Fraction [Vol. Basis]		1.000	0.0000	1.000	0.0000
Phase Fraction [Mass Basis]		1.000	0.0000	1.000	0.0000
Phase Fraction [Act. Vol. Basis]		1.000	0.0000	1.000	0.0000
Mass Exergy	(kJ/kg)	513.4	2.394	472.6	14.86
Partial Pressure of CO2	(kPa)	78.72	0.0000	77.15	0.0000
Cost Based on Flow	(Cost/s)	0.0000	0.0000	0.0000	0.0000
Act. Gas Flow	(ACT_m3/h)	3.199e+004	---	2.405e+004	---
Avg. Liq. Density	(kgmole/m3)	17.26	14.32	17.26	14.32
Specific Heat	(kJ/kgmole-C)	50.43	205.6	48.32	226.6
Std. Gas Flow	(STD_m3/h)	1.152e+006	3.758e+005	1.152e+006	3.758e+005
Std. Ideal Liq. Mass Density	(kg/m3)	342.0	1110	342.0	1110
Act. Liq. Flow	(m3/s)	---	0.3036	0.0000	0.3190
Z Factor		0.9722	2.822e-002	---	2.215e-002
Watson K		17.93	8.816	17.93	8.816
User Property		---	---	---	---
Partial Pressure of H2S	(kPa)	0.0000	0.0000	0.0000	0.0000
Cp/(Cp - R)		1.197	1.042	1.208	1.038
Cp/Cv		1.282	1.059	1.415	1.062
Heat of Vap.	(kJ/kgmole)	1.090e+004	7.313e+004	1.098e+004	7.380e+004
Kinematic Viscosity	(cSt)	0.5187	15.21	0.3304	3.464
Liq. Mass Density (Std. Cond)	(kg/m3)	0.8405	1130	0.8405	1130
Liq. Vol. Flow (Std. Cond)	(m3/h)	1.149e+006	1090	1.149e+006	1090
Liquid Fraction		0.0000	1.000	0.0000	1.000
Molar Volume	(m3/kgmole)	0.6563	6.877e-002	0.4935	7.225e-002
Mass Heat of Vap.	(kJ/kg)	550.2	943.9	554.2	952.5
Phase Fraction [Molar Basis]		1.0000	0.0000	1.0000	0.0000
Surface Tension	(dyne/cm)	---	48.40	---	42.74
Thermal Conductivity	(W/m-K)	5.008e-002	0.2165	3.831e-002	0.2274
Viscosity	(cP)	1.566e-002	17.13	1.327e-002	3.715
Cv (Semi-Ideal)	(kJ/kgmole-C)	42.11	197.3	40.01	218.3

* Specified by user.

LNG: 24-HJ-101 (continued)

PROPERTIES

Name	Field 1 Inlet to 24-HJ-101	Cooling Medium Inlet 4	Inlet to Field 1 Contactor	Cooling Medium Outlet 4	
Mass Cv (Semi-Ideal) (kJ/kg-C)	2.125	2.547	2.019	2.818	
Cv (kJ/kgmole-C)	39.33	194.1	34.16	213.3	
Mass Cv (kJ/kg-C)	1.985	2.506	1.724	2.753	
Cv (Ent. Method) (kJ/kgmole-C)	---	179.3	---	190.6	
Mass Cv (Ent. Method) (kJ/kg-C)	---	2.314	---	2.460	
Cp/Cv (Ent. Method)	---	1.147	---	1.189	
Reid VP at 37.8 C (kPa)	---	9.847e-004	---	9.847e-004	
True VP at 37.8 C (kPa)	---	3.420	---	3.420	
Liq. Vol. Flow - Sum(Std. Cond) (m3/h)	1.149e+006	1090	1.149e+006	1090	
Viscosity Index	-34.28	25.80	---	16.38	

NORWEGIAN UNIV OF
Burlington, MA
USA

Case Name: CASE STUDY 3.HSC
Unit Set: SI
Date/Time: Wed Jun 11 17:55:09 2014

LNG: 24-HJ-201

CONDITIONS

Name	Inlet to 24-HJ-201	Cooling Medium Inlet 8	Inlet to Field 2 Contactor	Cooling Medium Outlet 8
Vapour	1.0000	0.0000	1.0000 *	0.0000
Temperature (C)	142.4748	20.0000 *	50.4076	80.0000 *
Pressure (kPa)	5520.0000	1000.0000 *	5420.0000 *	900.0000 *
Molar Flow (kgmole/h)	5.523e+004	1.944e+004	5.523e+004	1.944e+004
Mass Flow (kg/h)	1.094e+006	1.506e+006	1.094e+006	1.506e+006
Std Ideal Liq Vol Flow (m3/h)	3200	1357	3200	1357
Molar Enthalpy (kJ/kgmole)	-7.830e+004	-5.210e+005	-8.285e+004	-5.081e+005
Molar Entropy (kJ/kgmole-C)	167.9	88.84	155.7	129.0
Heat Flow (kJ/h)	-4.324e+009	-1.013e+010	-4.576e+009	-9.875e+009

PROPERTIES

Name	Inlet to 24-HJ-201	Cooling Medium Inlet 8	Inlet to Field 2 Contactor	Cooling Medium Outlet 8
Molecular Weight	19.81	77.48	19.81	77.48
Molar Density (kgmole/m3)	1.641	14.54	2.232	13.84
Mass Density (kg/m3)	32.51	1127	44.22	1072
Act. Volume Flow (m3/h)	3.366e+004	1337	2.475e+004	1404
Mass Enthalpy (kJ/kg)	-3952	-6725	-4181	-6558
Mass Entropy (kJ/kg-C)	8.474	1.147	7.857	1.665
Heat Capacity (kJ/kgmole-C)	51.08	205.6	49.10	226.6
Mass Heat Capacity (kJ/kg-C)	2.578	2.654	2.478	2.925
LHV Molar Basis (Std) (kJ/kgmole)	---	1.462e+006	---	1.462e+006
HHV Molar Basis (Std) (kJ/kgmole)	---	1.614e+006	---	1.614e+006
HHV Mass Basis (Std) (kJ/kg)	---	2.083e+004	---	2.083e+004
CO2 Loading	---	---	---	---
CO2 Apparent Mole Conc. (kgmole/m3)	---	0.0000	---	0.0000
CO2 Apparent Wt. Conc. (kgmol/kg)	---	0.0000	---	0.0000
LHV Mass Basis (Std) (kJ/kg)	---	1.887e+004	---	1.887e+004
Phase Fraction [Vol. Basis]	1.000	0.0000	1.000	0.0000
Phase Fraction [Mass Basis]	1.000	0.0000	1.000	0.0000
Phase Fraction [Act. Vol. Basis]	1.000	0.0000	1.000	0.0000
Mass Exergy (kJ/kg)	529.0	2.394	483.2	14.86
Partial Pressure of CO2 (kPa)	86.39	0.0000	84.82	0.0000
Cost Based on Flow (Cost/s)	0.0000	0.0000	0.0000	0.0000
Act. Gas Flow (ACT_m3/h)	3.366e+004	---	2.475e+004	---
Avg. Liq. Density (kgmole/m3)	17.26	14.32	17.26	14.32
Specific Heat (kJ/kgmole-C)	51.08	205.6	49.10	226.6
Std. Gas Flow (STD_m3/h)	1.306e+006	4.595e+005	1.306e+006	4.595e+005
Std. Ideal Liq. Mass Density (kg/m3)	342.0	1110	342.0	1110
Act. Liq. Flow (m3/s)	---	0.3713	0.0000	0.3901
Z Factor	0.9735	2.822e-002	---	2.215e-002
Watson K	17.93	8.816	17.93	8.816
User Property	---	---	---	---
Partial Pressure of H2S (kPa)	0.0000	0.0000	0.0000	0.0000
Cp/(Cp - R)	1.194	1.042	1.204	1.038
Cp/Cv	1.282	1.059	1.430	1.062
Heat of Vap. (kJ/kgmole)	1.051e+004	7.313e+004	1.059e+004	7.380e+004
Kinematic Viscosity (cSt)	0.4907	15.21	0.3047	3.464
Liq. Mass Density (Std. Cond) (kg/m3)	0.8405	1130	0.8405	1130
Liq. Vol. Flow (Std. Cond) (m3/h)	1.302e+006	1333	1.302e+006	1333
Liquid Fraction	0.0000	1.000	0.0000	1.000
Molar Volume (m3/kgmole)	0.6094	6.877e-002	0.4481	7.225e-002
Mass Heat of Vap. (kJ/kg)	530.7	943.9	534.7	952.5
Phase Fraction [Molar Basis]	1.0000	0.0000	1.0000	0.0000
Surface Tension (dyne/cm)	---	48.40	---	42.74
Thermal Conductivity (W/m-K)	5.146e-002	0.2165	3.899e-002	0.2274
Viscosity (cP)	1.595e-002	17.13	1.347e-002	3.715
Cv (Semi-Ideal) (kJ/kgmole-C)	42.76	197.3	40.79	218.3

* Specified by user.

LNG: 24-HJ-201 (continued)

PROPERTIES

Name	Inlet to 24-HJ-201	Cooling Medium Inlet 8	Inlet to Field 2 Contactor	Cooling Medium Outlet 8
Mass Cv (Semi-Ideal) (kJ/kg-C)	2.158	2.547	2.058	2.818
Cv (kJ/kgmole-C)	39.85	194.1	34.33	213.3
Mass Cv (kJ/kg-C)	2.011	2.506	1.733	2.753
Cv (Ent. Method) (kJ/kgmole-C)	---	179.3	---	190.6
Mass Cv (Ent. Method) (kJ/kg-C)	---	2.314	---	2.460
Cp/Cv (Ent. Method)	---	1.147	---	1.189
Reid VP at 37.8 C (kPa)	---	9.847e-004	---	9.847e-004
True VP at 37.8 C (kPa)	---	3.420	---	3.420
Liq. Vol. Flow - Sum(Std. Cond) (m3/h)	1.302e+006	1333	1.302e+006	1333
Viscosity Index	-35.39	25.80	---	16.38

Appendix E – Thermal Calculations for Heat Exchangers in Base Case Design

Basic Geometry

Unit Configuration

Exchanger Type		BEM	Tube number (calcs.)		1180
Position		Hor	Tube length actual	**mm**	9000
Arrangement		2 par 1 ser	Tube passes		1
Baffle type		Single segmental	Tube type		Plain
Baffle number		8	Tube O.D.	**mm**	31,75
Spacing (center-center)	**mm**	850	Tube pitch	**mm**	40
Spacing at inlet	**mm**	1332,48	Tube pattern		30

		Shell	**Kettle**	**Front head**	**Rear head**
Outside diameter	**mm**	1609		1715	1715
Inside Diameter	**mm**	1575		1575	1575

		Shell Side			**Tube Side**	
Nozzle type		Inlet	Outlet		Inlet	Outlet
Number of nozzles		1	1		1	1
Actual outside diameter	**mm**	355,6	323,9		914	914
Inside diameter	**mm**	335,6	303,9		842	842
Height under nozzle	**mm**	182,73	182,73			
Dome inside diameter	**mm**					
Vapor belt inside diameter	**mm**					
Vapor belt inside width	**mm**					
Vapor belt slot area	**mm²**					
Impingement protection		No impingement	No impingement	No impingement		
Distance to tubesheet	**mm**	8550	430			

20-HA-001 : Base Case Design Date: 4.6.2014 Time: 18:31:58

Tubes

Tubes

Type		Plain	Total number		1180
Outside diameter	**mm**	31,75	Number of tubes plugged		0
Inside diameter	**mm**	27,53	Tube length actual	**mm**	9000
Wall thickness	**mm**	2,11	Tube length effective	**mm**	8615
Area ratio Ao/Ai		1,15	Tubesheet thickness	**mm**	189,52
Pitch	**mm**	40	Material		22Cr,5Ni,3Mo steel
Pattern		30	Thermal conductivity	**W/(m K)**	16,0027
External enhancement			Internal enhancement		

Low circumferential fins			**Low longitudinal fins**		
Fin density	**#/m**		Fin number		0
Fin height	**mm**		Fin thickness	**mm**	
Fin thickness	**mm**		Fin height	**mm**	
Tube root diameter	**mm**		Fin spacing	**mm**	
Tube wall thickness under fin	**mm**		Cut and twist length	**mm**	
Tube inside diameter under fins	**mm**				

Baffles

Baffles

Type		Single segmental	Baffle cut: inner / outer / interm			
Tubes in window		No	Actual (% diameter)			/ 10 /
Number		8	Nominal (% diameter)			/ 10 /
Spacing (center-center)	**mm**	850	Actual (% area)			/ 5,2 /
Spacing at inlet	**mm**	1332,48	Cut orientation			H
Spacing at outlet	**mm**	1332,48	Thickness		**mm**	12,7
Spacing at central in/out for G,H,I,J shells	**mm**		Tube rows in baffle overlap			34
Spacing at center of H shell	**mm**		Tube rows in baffle window			0,5
End length at front head	**mm**	1525	Baffle hole - tube od diam clearance		**mm**	0,79
End length at rear head	**mm**	1525	Shell id - baffle od diam clearance		**mm**	7,94

VariableBaffles

Baffle spacing	**mm**
Baffle cut percent, outer	
Baffle cut percent, inner	
Number of baffle spaces	
Baffle region length	**mm**
Baffle cut area percent, outer	
Baffle cut area percent, inner	

Supports Misc. Baffles

Supports-tube

Supports in endspace at front head	0
Supports in endspace at rear head	0
Supports between baffles	0
Support blanking baffle	No
Supports at U-bend	0
Supports at each G,H,J shell inlet and I shell outlet	0
Supports at center of H shell	0
Supports for K, X shells	0
Special support at inlet nozzle	No

Longitudinal Baffle

Thickness	**mm**	
Window length at front head	**mm**	
Window length at center	**mm**	
Window length at rear head	**mm**	

Bundle

Bundle

Shell ID to center 1st tube row	**mm**		Tube passes		1
From top		182,73	Tube pass layout		Ribbon (single band)
From bottom		182,73	Tube pass orientation		Standard (horizontal)
From right		11,62	U-bend orientation		Undefined
From Left		11,62	Horizontal pass lane width	**mm**	
Impingement protection		None	Vertical pass lane width	**mm**	
Impingement distance	**mm**		Interpass tube alignment		No
Impingement plate diameter	**mm**		Deviation in tubes/pass		0
Impingement plate width	**mm**		Outer tube limit	**mm**	1560,71
Impingement plate length	**mm**		Shell id - bundle otl diam clearance	**mm**	14,29
Impingement plate thickness	**mm**		Tie rod number		12
Gross surface area per shell	**m²**	1059,3	Tie rod diameter	**mm**	15,88
Effective surface area per shell	**m²**	1014	Sealing strips (pairs)		6
Bare tube area per shell	**m²**	1014	Tube to tubesheet joint		Exp.
Finned area per shell	**m²**	0	Tube projection from front tsht	**mm**	3
U-bend area per shell	**m²**	0	Tube projection from rear tsht	**mm**	3

20-HA-002 : Base Case Design

Basic Geometry

Unit Configuration

Exchanger Type		BEM	Tube number (calcs.)		581
Position		Hor	Tube length actual	**mm**	7400
Arrangement		2 par 1 ser	Tube passes		1
Baffle type		Single segmental	Tube type		Plain
Baffle number		4	Tube O.D.	**mm**	31,75
Spacing (center-center)	**mm**	1370	Tube pitch	**mm**	39,69
Spacing at inlet	**mm**	1500,48	Tube pattern		30

		Shell	**Kettle**	**Front head**	**Rear head**
Outside diameter	**mm**	1178		1254	1254
Inside Diameter	**mm**	1150		1150	1150

		Shell Side			**Tube Side**	
Nozzle type		Inlet	Outlet		Inlet	Outlet
Number of nozzles		1	1		1	1
Actual outside diameter	**mm**	610	457		914	1016
Inside diameter	**mm**	590	437		842	936
Height under nozzle	**mm**	181,05	181,05			
Dome inside diameter	**mm**					
Vapor belt inside diameter	**mm**					
Vapor belt inside width	**mm**					
Vapor belt slot area	**mm²**					
Impingement protection		No impingement	No impingement	No impingement		
Distance to tubesheet	**mm**	6870	445			

20-HA-002 : Base Case Design

Tubes

Tubes					
Type		Plain	Total number		581
Outside diameter	**mm**	31,75	Number of tubes plugged		0
Inside diameter	**mm**	27,53	Tube length actual	**mm**	7400
Wall thickness	**mm**	2,11	Tube length effective	**mm**	7111
Area ratio Ao/Ai		1,15	Tubesheet thickness	**mm**	141,52
Pitch	**mm**	39,69	Material		22Cr,5Ni,3Mo steel
Pattern		30	Thermal conductivity	**W/(m K)**	15,9016
External enhancement			Internal enhancement		
Low circumferential fins			**Low longitudinal fins**		
Fin density	**#/m**		Fin number		0
Fin height	**mm**		Fin thickness	**mm**	
Fin thickness	**mm**		Fin height	**mm**	
Tube root diameter	**mm**		Fin spacing	**mm**	
Tube wall thickness under fin	**mm**		Cut and twist length	**mm**	
Tube inside diameter under fins	**mm**				

20-HA-002 : Base Case Design

Baffles

Baffles

Type		Single segmental	Baffle cut: inner / outer / interm		
Tubes in window		No	Actual (% diameter)		/ 12,99 /
Number		4	Nominal (% diameter)		/ 12,99 /
Spacing (center-center)	mm	1370	Actual (% area)		/ 7,63 /
Spacing at inlet	mm	1500,48	Cut orientation		H
Spacing at outlet	mm	1500,48	Thickness	mm	15,88
Spacing at central in/out for G,H,I,J shells	mm		Tube rows in baffle overlap		22
Spacing at center of H shell	mm		Tube rows in baffle window		0,5
End length at front head	mm	1645	Baffle hole - tube od diam clearance	mm	0,4
End length at rear head	mm	1645	Shell id - baffle od diam clearance	mm	6,35

VariableBaffles

Baffle spacing	**mm**
Baffle cut percent, outer	
Baffle cut percent, inner	
Number of baffle spaces	
Baffle region length	**mm**
Baffle cut area percent, outer	
Baffle cut area percent, inner	

Supports Misc. Baffles

Supports-tube		**Longitudinal Baffle**	
Supports in endspace at front head	0	Thickness	mm
Supports in endspace at rear head	0	Window length at front head	mm
Supports between baffles	0	Window length at center	mm
Support blanking baffle	No	Window length at rear head	mm
Supports at U-bend	0		
Supports at each G,H,J shell inlet and I shell outlet	0		
Supports at center of H shell	0		
Supports for K, X shells	0		
Special support at inlet nozzle	No		

20-HA-002 : Base Case Design

Bundle

Bundle					
Shell ID to center 1st tube row	**mm**		Tube passes		1
From top		181,05	Tube pass layout		Ribbon (single band)
From bottom		181,05	Tube pass orientation		Standard (horizontal)
From right		23,34	U-bend orientation		Undefined
From Left		23,34	Horizontal pass lane width	**mm**	
Impingement protection		None	Vertical pass lane width	**mm**	
Impingement distance	**mm**		Interpass tube alignment		No
Impingement plate diameter	**mm**		Deviation in tubes/pass		0
Impingement plate width	**mm**		Outer tube limit	**mm**	1137,3
Impingement plate length	**mm**		Shell id - bundle otl diam clearance	**mm**	12,7
Impingement plate thickness	**mm**		Tie rod number		8
Gross surface area per shell	**m²**	428,8	Tie rod diameter	**mm**	12,7
Effective surface area per shell	**m²**	412,1	Sealing strips (pairs)		4
Bare tube area per shell	**m²**	412,1	Tube to tubesheet joint		Exp.
Finned area per shell	**m²**	0	Tube projection from front tsht	**mm**	3
U-bend area per shell	**m²**	0	Tube projection from rear tsht	**mm**	3

20-HA-003 : Base Case Design

Basic Geometry

Unit Configuration

Exchanger Type		BEM	Tube number (calcs.)		798
Position		Hor	Tube length actual	**mm**	6500
Arrangement		2 par 1 ser	Tube passes		1
Baffle type		Single segmental	Tube type		Plain
Baffle number		8	Tube O.D.	**mm**	19,05
Spacing (center-center)	**mm**	730	Tube pitch	**mm**	23,81
Spacing at inlet	**mm**	644,48	Tube pattern		30

		Shell	**Kettle**	**Front head**	**Rear head**
Outside diameter	**mm**	793		789	789
Inside Diameter	**mm**	775		775	775

		Shell Side			**Tube Side**	
Nozzle type		Inlet	Outlet		Inlet	Outlet
Number of nozzles		1	1		1	1
Actual outside diameter	**mm**	219,1	168,3		406,4	711
Inside diameter	**mm**	203,1	154,1		386,4	691
Height under nozzle	**mm**	89,26	89,26			
Dome inside diameter	**mm**					
Vapor belt inside diameter	**mm**					
Vapor belt inside width	**mm**					
Vapor belt slot area	**mm²**					
Impingement protection		No impingement	No impingement	No impingement		
Distance to tubesheet	**mm**	6260	210			

20-HA-003 : Base Case Design

Tubes

Tubes					
Type		Plain	Total number		798
Outside diameter	**mm**	19,05	Number of tubes plugged		0
Inside diameter	**mm**	16,55	Tube length actual	**mm**	6500
Wall thickness	**mm**	1,25	Tube length effective	**mm**	6399
Area ratio Ao/Ai		1,15	Tubesheet thickness	**mm**	47,52
Pitch	**mm**	23,81	Material		22Cr,5Ni,3Mo steel
Pattern		30	Thermal conductivity	**W/(m K)**	16,2011
External enhancement			Internal enhancement		
Low circumferential fins			**Low longitudinal fins**		
Fin density	**#/m**		Fin number		0
Fin height	**mm**		Fin thickness	**mm**	
Fin thickness	**mm**		Fin height	**mm**	
Tube root diameter	**mm**		Fin spacing	**mm**	
Tube wall thickness under fin	**mm**		Cut and twist length	**mm**	
Tube inside diameter under fins	**mm**				

20-HA-003 : Base Case Design

Baffles

Baffles

Type		Single segmental	Baffle cut: inner / outer / interm		
Tubes in window		No	Actual (% diameter)		/ 10 /
Number		8	Nominal (% diameter)		/ 10 /
Spacing (center-center)	**mm**	730	Actual (% area)		/ 5,2 /
Spacing at inlet	**mm**	644,48	Cut orientation		H
Spacing at outlet	**mm**	644,48	Thickness	**mm**	7,94
Spacing at central in/out for G,H,I,J shells	**mm**		Tube rows in baffle overlap		28
Spacing at center of H shell	**mm**		Tube rows in baffle window		0,5
End length at front head	**mm**	695	Baffle hole - tube od diam clearance	**mm**	0,79
End length at rear head	**mm**	695	Shell id - baffle od diam clearance	**mm**	4,76

VariableBaffles

Baffle spacing	**mm**
Baffle cut percent, outer	
Baffle cut percent, inner	
Number of baffle spaces	
Baffle region length	**mm**
Baffle cut area percent, outer	
Baffle cut area percent, inner	

Supports Misc. Baffles

Supports-tube		**Longitudinal Baffle**	
Supports in endspace at front head	0	Thickness	**mm**
Supports in endspace at rear head	0	Window length at front head	**mm**
Supports between baffles	0	Window length at center	**mm**
Support blanking baffle	No	Window length at rear head	**mm**
Supports at U-bend	0		
Supports at each G,H,J shell inlet and I shell outlet	0		
Supports at center of H shell	0		
Supports for K, X shells	0		
Special support at inlet nozzle	No		

20-HA-003 : Base Case Design

Bundle

Bundle					
Shell ID to center 1st tube row	**mm**		Tube passes		1
From top		89,26	Tube pass layout		Ribbon (single band)
From bottom		89,26	Tube pass orientation		Standard (horizontal)
From right		8,88	U-bend orientation		Undefined
From Left		8,88	Horizontal pass lane width	**mm**	
Impingement protection		None	Vertical pass lane width	**mm**	
Impingement distance	**mm**		Interpass tube alignment		No
Impingement plate diameter	**mm**		Deviation in tubes/pass		0
Impingement plate width	**mm**		Outer tube limit	**mm**	762,3
Impingement plate length	**mm**		Shell id - bundle otl diam clearance	**mm**	12,7
Impingement plate thickness	**mm**		Tie rod number		6
Gross surface area per shell	**m²**	310,4	Tie rod diameter	**mm**	12,7
Effective surface area per shell	**m²**	305,6	Sealing strips (pairs)		5
Bare tube area per shell	**m²**	305,6	Tube to tubesheet joint		Exp.
Finned area per shell	**m²**	0	Tube projection from front tsht	**mm**	3
U-bend area per shell	**m²**	0	Tube projection from rear tsht	**mm**	3

21-HB-001 : Base Case Design

Basic Geometry

Unit Configuration

Exchanger Type		BEM	Tube number (calcs.)		1473
Position		Hor	Tube length actual	**mm**	6500
Arrangement		1 par 1 ser	Tube passes		1
Baffle type		Single segmental	Tube type		Plain
Baffle number		28	Tube O.D.	**mm**	19,05
Spacing (center-center)	**mm**	200	Tube pitch	**mm**	23,81
Spacing at inlet	**mm**	488,48	Tube pattern		30

		Shell	**Kettle**	**Front head**	**Rear head**
Outside diameter	**mm**	1066		1066	1066
Inside Diameter	**mm**	1050		1050	1050

		Shell Side		**Tube Side**	
Nozzle type		Inlet	Outlet	Inlet	Outlet
Number of nozzles		1	1	1	1
Actual outside diameter	**mm**	219,1	219,1	406,4	457
Inside diameter	**mm**	203,1	203,1	386,4	437
Height under nozzle	**mm**	123,65	123,65		
Dome inside diameter	**mm**				
Vapor belt inside diameter	**mm**				
Vapor belt inside width	**mm**				
Vapor belt slot area	**mm²**				
Impingement protection		No impingement	No impingement		
Distance to tubesheet	**mm**	6250	245		

21-HB-001 : Base Case Design

Tubes

Tubes					
Type		Plain	Total number		1473
Outside diameter	**mm**	19,05	Number of tubes plugged		0
Inside diameter	**mm**	16,65	Tube length actual	**mm**	6500
Wall thickness	**mm**	1,2	Tube length effective	**mm**	6377
Area ratio Ao/Ai		1,14	Tubesheet thickness	**mm**	58,52
Pitch	**mm**	23,81	Material		22Cr,5Ni,3Mo steel
Pattern		30	Thermal conductivity	**W/(m K)**	16,1365
External enhancement			Internal enhancement		
Low circumferential fins			**Low longitudinal fins**		
Fin density	**#/m**		Fin number		0
Fin height	**mm**		Fin thickness	**mm**	
Fin thickness	**mm**		Fin height	**mm**	
Tube root diameter	**mm**		Fin spacing	**mm**	
Tube wall thickness under fin	**mm**		Cut and twist length	**mm**	
Tube inside diameter under fins	**mm**				

Baffles

Baffles

Type		Single segmental	Baffle cut: inner / outer / interm		
Tubes in window		No	Actual (% diameter)		/ 10 /
Number		28	Nominal (% diameter)		/ 10 /
Spacing (center-center)	**mm**	200	Actual (% area)		/ 5,2 /
Spacing at inlet	**mm**	488,48	Cut orientation		H
Spacing at outlet	**mm**	488,48	Thickness	**mm**	6,35
Spacing at central in/out for G,H,I,J shells	**mm**		Tube rows in baffle overlap		38
Spacing at center of H shell	**mm**		Tube rows in baffle window		0,5
End length at front head	**mm**	550	Baffle hole - tube od diam clearance	**mm**	0,79
End length at rear head	**mm**	550	Shell id - baffle od diam clearance	**mm**	6,35

VariableBaffles

Baffle spacing	**mm**
Baffle cut percent, outer	
Baffle cut percent, inner	
Number of baffle spaces	
Baffle region length	**mm**
Baffle cut area percent, outer	
Baffle cut area percent, inner	

Supports Misc. Baffles

Supports-tube

Supports in endspace at front head	0
Supports in endspace at rear head	0
Supports between baffles	0
Support blanking baffle	No
Supports at U-bend	0
Supports at each G,H,J shell inlet and I shell outlet	0
Supports at center of H shell	0
Supports for K, X shells	0
Special support at inlet nozzle	No

Longitudinal Baffle

Thickness	**mm**	
Window length at front head	**mm**	
Window length at center	**mm**	
Window length at rear head	**mm**	

21-HB-001 : Base Case Design

Bundle

Bundle					
Shell ID to center 1st tube row	**mm**		Tube passes		1
From top		123,65	Tube pass layout		Ribbon (single band)
From bottom		123,65	Tube pass orientation		Standard (horizontal)
From right		15,41	U-bend orientation		Undefined
From Left		15,41	Horizontal pass lane width	**mm**	
Impingement protection		None	Vertical pass lane width	**mm**	
Impingement distance	**mm**		Interpass tube alignment		No
Impingement plate diameter	**mm**		Deviation in tubes/pass		0
Impingement plate width	**mm**		Outer tube limit	**mm**	1037,3
Impingement plate length	**mm**		Shell id - bundle otl diam clearance	**mm**	12,7
Impingement plate thickness	**mm**		Tie rod number		8
Gross surface area per shell	**m²**	573	Tie rod diameter	**mm**	12,7
Effective surface area per shell	**m²**	562,2	Sealing strips (pairs)		7
Bare tube area per shell	**m²**	562,2	Tube to tubesheet joint		Exp.
Finned area per shell	**m²**	0	Tube projection from front tsht	**mm**	3
U-bend area per shell	**m²**	0	Tube projection from rear tsht	**mm**	3

24-HA-102 : Base Case Design

Basic Geometry

Unit Configuration

Exchanger Type		BEM	Tube number (calcs.)		577
Position		Hor	Tube length actual	**mm**	1750
Arrangement		1 par 1 ser	Tube passes		1
Baffle type		Single segmental	Tube type		Plain
Baffle number		6	Tube O.D.	**mm**	25,4
Spacing (center-center)	**mm**	175	Tube pitch	**mm**	31,75
Spacing at inlet	**mm**	352,98	Tube pattern		30

		Shell	**Kettle**	**Front head**	**Rear head**
Outside diameter	**mm**	899		927	927
Inside Diameter	**mm**	875		875	875

		Shell Side			**Tube Side**	
Nozzle type		Inlet	Outlet		Inlet	Outlet
Number of nozzles		1	1		1	1
Actual outside diameter	**mm**	139,7	114,3		508	508
Inside diameter	**mm**	125,5	101,7		479,6	479,6
Height under nozzle	**mm**	94,84	94,84			
Dome inside diameter	**mm**					
Vapor belt inside diameter	**mm**					
Vapor belt inside width	**mm**					
Vapor belt slot area	**mm²**					
Impingement protection		No impingement	No impingement	No impingement		
Distance to tubesheet	**mm**	1515	215			

24-HA-102 : Base Case Design

Tubes

Tubes					
Type		Plain	Total number		577
Outside diameter	**mm**	25,4	Number of tubes plugged		0
Inside diameter	**mm**	22,1	Tube length actual	**mm**	1750
Wall thickness	**mm**	1,65	Tube length effective	**mm**	1581
Area ratio Ao/Ai		1,15	Tubesheet thickness	**mm**	81,53
Pitch	**mm**	31,75	Material		22Cr,5Ni,3Mo steel
Pattern		30	Thermal conductivity	**W/(m K)**	15,7194
External enhancement			Internal enhancement		

Low circumferential fins			**Low longitudinal fins**		
Fin density	**#/m**		Fin number		0
Fin height	**mm**		Fin thickness	**mm**	
Fin thickness	**mm**		Fin height	**mm**	
Tube root diameter	**mm**		Fin spacing	**mm**	
Tube wall thickness under fin	**mm**		Cut and twist length	**mm**	
Tube inside diameter under fins	**mm**				

24-HA-102 : Base Case Design

Baffles

Baffles

Type		Single segmental	Baffle cut: inner / outer / interm		
Tubes in window		No	Actual (% diameter)		/ 10 /
Number		6	Nominal (% diameter)		/ 10 /
Spacing (center-center)	**mm**	175	Actual (% area)		/ 5,2 /
Spacing at inlet	**mm**	352,98	Cut orientation		H
Spacing at outlet	**mm**	352,98	Thickness	**mm**	6,35
Spacing at central in/out for G,H,I,J shells	**mm**		Tube rows in baffle overlap		24
Spacing at center of H shell	**mm**		Tube rows in baffle window		0,5
End length at front head	**mm**	437,5	Baffle hole - tube od diam clearance	**mm**	0,79
End length at rear head	**mm**	437,5	Shell id - baffle od diam clearance	**mm**	4,76

VariableBaffles

Baffle spacing	**mm**
Baffle cut percent, outer	
Baffle cut percent, inner	
Number of baffle spaces	
Baffle region length	**mm**
Baffle cut area percent, outer	
Baffle cut area percent, inner	

Supports Misc. Baffles

Supports-tube		**Longitudinal Baffle**		
Supports in endspace at front head	0	Thickness	**mm**	
Supports in endspace at rear head	0	Window length at front head	**mm**	
Supports between baffles	0	Window length at center	**mm**	
Support blanking baffle	No	Window length at rear head	**mm**	
Supports at U-bend	0			
Supports at each G,H,J shell inlet and I shell outlet	0			
Supports at center of H shell	0			
Supports for K, X shells	0			
Special support at inlet nozzle	No			

24-HA-102 : Base Case Design

Bundle

Bundle

Shell ID to center 1st tube row	**mm**		Tube passes		1
From top		94,84	Tube pass layout		Ribbon (single band)
From bottom		94,84	Tube pass orientation		Standard (horizontal)
From right		12,05	U-bend orientation		Undefined
From Left		12,05	Horizontal pass lane width	**mm**	
Impingement protection		None	Vertical pass lane width	**mm**	
Impingement distance	**mm**		Interpass tube alignment		No
Impingement plate diameter	**mm**		Deviation in tubes/pass		0
Impingement plate width	**mm**		Outer tube limit	**mm**	862,3
Impingement plate length	**mm**		Shell id - bundle otl diam clearance	**mm**	12,7
Impingement plate thickness	**mm**		Tie rod number		8
Gross surface area per shell	**m^2**	80,6	Tie rod diameter	**mm**	12,7
Effective surface area per shell	**m^2**	72,8	Sealing strips (pairs)		5
Bare tube area per shell	**m^2**	72,8	Tube to tubesheet joint		Exp.
Finned area per shell	**m^2**	0	Tube projection from front tsht	**mm**	3
U-bend area per shell	**m^2**	0	Tube projection from rear tsht	**mm**	3

24-HA-202 : Base Case Design

Basic Geometry

Unit Configuration

Exchanger Type		BEM	Tube number (calcs.)		577
Position		Hor	Tube length actual	**mm**	1750
Arrangement		1 par 1 ser	Tube passes		1
Baffle type		Single segmental	Tube type		Plain
Baffle number		6	Tube O.D.	**mm**	25,4
Spacing (center-center)	**mm**	175	Tube pitch	**mm**	31,75
Spacing at inlet	**mm**	352,98	Tube pattern		30

		Shell	**Kettle**	**Front head**	**Rear head**
Outside diameter	**mm**	899		927	927
Inside Diameter	**mm**	875		875	875

		Shell Side		**Tube Side**	
Nozzle type		Inlet	Outlet	Inlet	Outlet
Number of nozzles		1	1	1	1
Actual outside diameter	**mm**	139,7	114,3	508	508
Inside diameter	**mm**	125,5	101,7	479,6	479,6
Height under nozzle	**mm**	94,84	94,84		
Dome inside diameter	**mm**				
Vapor belt inside diameter	**mm**				
Vapor belt inside width	**mm**				
Vapor belt slot area	**mm²**				
Impingement protection		No impingement	No impingement		
Distance to tubesheet	**mm**	1515	215		

24-HA-202 : Base Case Design

Tubes

Tubes					
Type		Plain	Total number		577
Outside diameter	**mm**	25,4	Number of tubes plugged		0
Inside diameter	**mm**	22,1	Tube length actual	**mm**	1750
Wall thickness	**mm**	1,65	Tube length effective	**mm**	1581
Area ratio Ao/Ai		1,15	Tubesheet thickness	**mm**	81,53
Pitch	**mm**	31,75	Material		22Cr,5Ni,3Mo steel
Pattern		30	Thermal conductivity	**W/(m K)**	15,7182
External enhancement			Internal enhancement		
Low circumferential fins			**Low longitudinal fins**		
Fin density	**#/m**		Fin number		0
Fin height	**mm**		Fin thickness	**mm**	
Fin thickness	**mm**		Fin height	**mm**	
Tube root diameter	**mm**		Fin spacing	**mm**	
Tube wall thickness under fin	**mm**		Cut and twist length	**mm**	
Tube inside diameter under fins	**mm**				

24-HA-202 : Base Case Design

Baffles

Baffles

Type		Single segmental	Baffle cut: inner / outer / interm			
Tubes in window		No	Actual (% diameter)		/	10 /
Number		6	Nominal (% diameter)		/	10 /
Spacing (center-center)	**mm**	175	Actual (% area)		/	5,2 /
Spacing at inlet	**mm**	352,98	Cut orientation			H
Spacing at outlet	**mm**	352,98	Thickness	**mm**		6,35
Spacing at central in/out for G,H,I,J shells	**mm**		Tube rows in baffle overlap			24
Spacing at center of H shell	**mm**		Tube rows in baffle window			0,5
End length at front head	**mm**	437,5	Baffle hole - tube od diam clearance	**mm**		0,79
End length at rear head	**mm**	437,5	Shell id - baffle od diam clearance	**mm**		4,76

VariableBaffles

Baffle spacing	**mm**
Baffle cut percent, outer	
Baffle cut percent, inner	
Number of baffle spaces	
Baffle region length	**mm**
Baffle cut area percent, outer	
Baffle cut area percent, inner	

Supports Misc. Baffles

Supports-tube		**Longitudinal Baffle**	
Supports in endspace at front head	0	Thickness	**mm**
Supports in endspace at rear head	0	Window length at front head	**mm**
Supports between baffles	0	Window length at center	**mm**
Support blanking baffle	No	Window length at rear head	**mm**
Supports at U-bend	0		
Supports at each G,H,J shell inlet and I shell outlet	0		
Supports at center of H shell	0		
Supports for K, X shells	0		
Special support at inlet nozzle	No		

24-HA-202 : Base Case Design

Bundle

Bundle					
Shell ID to center 1st tube row	**mm**		Tube passes		1
From top		94,84	Tube pass layout		Ribbon (single band)
From bottom		94,84	Tube pass orientation		Standard (horizontal)
From right		12,05	U-bend orientation		Undefined
From Left		12,05	Horizontal pass lane width	**mm**	
Impingement protection		None	Vertical pass lane width	**mm**	
Impingement distance	**mm**		Interpass tube alignment		No
Impingement plate diameter	**mm**		Deviation in tubes/pass		0
Impingement plate width	**mm**		Outer tube limit	**mm**	862,3
Impingement plate length	**mm**		Shell id - bundle otl diam clearance	**mm**	12,7
Impingement plate thickness	**mm**		Tie rod number		8
Gross surface area per shell	**m²**	80,6	Tie rod diameter	**mm**	12,7
Effective surface area per shell	**m²**	72,8	Sealing strips (pairs)		5
Bare tube area per shell	**m²**	72,8	Tube to tubesheet joint		Exp.
Finned area per shell	**m²**	0	Tube projection from front tsht	**mm**	3
U-bend area per shell	**m²**	0	Tube projection from rear tsht	**mm**	3

24-HJ-101 : Base Case Design

Basic Geometry

Unit Configuration

Exchanger Type		BEM	Tube number (calcs.)		3093
Position		Hor	Tube length actual	**mm**	7500
Arrangement		2 par 1 ser	Tube passes		1
Baffle type		Single segmental	Tube type		Plain
Baffle number		30	Tube O.D.	**mm**	25,4
Spacing (center-center)	**mm**	200	Tube pitch	**mm**	31,75
Spacing at inlet	**mm**	657,48	Tube pattern		30

		Shell	**Kettle**	**Front head**	**Rear head**
Outside diameter	**mm**	2044		2124	2124
Inside Diameter	**mm**	2000		2000	2000

		Shell Side		**Tube Side**	
Nozzle type		Inlet	Outlet	Inlet	Outlet
Number of nozzles		1	1	1	1
Actual outside diameter	**mm**	457	355,6	711	610
Inside diameter	**mm**	437	335,6	671	575
Height under nozzle	**mm**	217,4	217,4		
Dome inside diameter	**mm**				
Vapor belt inside diameter	**mm**				
Vapor belt inside width	**mm**				
Vapor belt slot area	**mm²**				
Impingement protection		No impingement	No impingement		
Distance to tubesheet	**mm**	7000	445		

24-HJ-101 : Base Case Design

Tubes

Tubes					
Type		Plain	Total number		3093
Outside diameter	**mm**	25,4	Number of tubes plugged		0
Inside diameter	**mm**	22,1	Tube length actual	**mm**	7500
Wall thickness	**mm**	1,65	Tube length effective	**mm**	7115
Area ratio Ao/Ai		1,15	Tubesheet thickness	**mm**	189,52
Pitch	**mm**	31,75	Material		22Cr,5Ni,3Mo steel
Pattern		30	Thermal conductivity	**W/(m K)**	16,3173
External enhancement			Internal enhancement		
Low circumferential fins			**Low longitudinal fins**		
Fin density	**#/m**		Fin number		0
Fin height	**mm**		Fin thickness	**mm**	
Fin thickness	**mm**		Fin height	**mm**	
Tube root diameter	**mm**		Fin spacing	**mm**	
Tube wall thickness under fin	**mm**		Cut and twist length	**mm**	
Tube inside diameter under fins	**mm**				

Baffles

Baffles

Type		Single segmental
Tubes in window		No
Number		30
Spacing (center-center)	**mm**	200
Spacing at inlet	**mm**	657,48
Spacing at outlet	**mm**	657,48
Spacing at central in/out for G,H,I,J shells	**mm**	
Spacing at center of H shell	**mm**	
End length at front head	**mm**	850
End length at rear head	**mm**	850

Baffle cut: inner / outer / interm				
Actual (% diameter)		/	10 /	
Nominal (% diameter)		/	10 /	
Actual (% area)		/	5,2 /	
Cut orientation				H
Thickness	**mm**			9,52
Tube rows in baffle overlap				56
Tube rows in baffle window				0,5
Baffle hole - tube od diam clearance	**mm**			0,79
Shell id - baffle od diam clearance	**mm**			9,52

VariableBaffles

Baffle spacing	**mm**
Baffle cut percent, outer	
Baffle cut percent, inner	
Number of baffle spaces	
Baffle region length	**mm**
Baffle cut area percent, outer	
Baffle cut area percent, inner	

Supports Misc. Baffles

Supports-tube

Supports in endspace at front head	0
Supports in endspace at rear head	0
Supports between baffles	0
Support blanking baffle	No
Supports at U-bend	0
Supports at each G,H,J shell inlet and I shell outlet	0
Supports at center of H shell	0
Supports for K, X shells	0
Special support at inlet nozzle	No

Longitudinal Baffle

Thickness	**mm**	
Window length at front head	**mm**	
Window length at center	**mm**	
Window length at rear head	**mm**	

24-HJ-101 : Base Case Design

Bundle

Bundle

Shell ID to center 1st tube row	**mm**		Tube passes		1
From top		217,4	Tube pass layout		Ribbon (single band)
From bottom		217,4	Tube pass orientation		Standard (horizontal)
From right		18,92	U-bend orientation		Undefined
From Left		18,92	Horizontal pass lane width	**mm**	
Impingement protection		None	Vertical pass lane width	**mm**	
Impingement distance	**mm**		Interpass tube alignment		No
Impingement plate diameter	**mm**		Deviation in tubes/pass		0
Impingement plate width	**mm**		Outer tube limit	**mm**	1984,12
Impingement plate length	**mm**		Shell id - bundle otl diam clearance	**mm**	15,88
Impingement plate thickness	**mm**		Tie rod number		12
Gross surface area per shell	**m^2**	1851,1	Tie rod diameter	**mm**	15,88
Effective surface area per shell	**m^2**	1756	Sealing strips (pairs)		10
Bare tube area per shell	**m^2**	1756	Tube to tubesheet joint		Exp.
Finned area per shell	**m^2**	0	Tube projection from front tsht	**mm**	3
U-bend area per shell	**m^2**	0	Tube projection from rear tsht	**mm**	3

24-HJ-201 : Base Case Design

Basic Geometry

Unit Configuration

Exchanger Type		BEM	Tube number (calcs.)		3093
Position		Hor	Tube length actual	**mm**	8500
Arrangement		2 par 1 ser	Tube passes		1
Baffle type		Single segmental	Tube type		Plain
Baffle number		36	Tube O.D.	**mm**	25,4
Spacing (center-center)	**mm**	200	Tube pitch	**mm**	31,75
Spacing at inlet	**mm**	585,2	Tube pattern		30

		Shell	**Kettle**	**Front head**	**Rear head**
Outside diameter	**mm**	2038		2124	2124
Inside Diameter	**mm**	2000		2000	2000

		Shell Side		**Tube Side**	
Nozzle type		Inlet	Outlet	Inlet	Outlet
Number of nozzles		1	1	1	1
Actual outside diameter	**mm**	508	406,4	711	711
Inside diameter	**mm**	488	386,4	671	671
Height under nozzle	**mm**	217,4	217,4		
Dome inside diameter	**mm**				
Vapor belt inside diameter	**mm**				
Vapor belt inside width	**mm**				
Vapor belt slot area	**mm²**				
Impingement protection		No impingement	No impingement		
Distance to tubesheet	**mm**	7965	475		

24-HJ-201 : Base Case Design

Tubes

Tubes					
Type		Plain	Total number		3093
Outside diameter	**mm**	25,4	Number of tubes plugged		0
Inside diameter	**mm**	22,1	Tube length actual	**mm**	8500
Wall thickness	**mm**	1,65	Tube length effective	**mm**	8101
Area ratio Ao/Ai		1,15	Tubesheet thickness	**mm**	196,52
Pitch	**mm**	31,75	Material		22Cr,5Ni,3Mo steel
Pattern		30	Thermal conductivity	**W/(m K)**	16,35
External enhancement			Internal enhancement		
Low circumferential fins			**Low longitudinal fins**		
Fin density	**#/m**		Fin number		0
Fin height	**mm**		Fin thickness	**mm**	
Fin thickness	**mm**		Fin height	**mm**	
Tube root diameter	**mm**		Fin spacing	**mm**	
Tube wall thickness under fin	**mm**		Cut and twist length	**mm**	
Tube inside diameter under fins	**mm**				

24-HJ-201 : Base Case Design

Baffles

Baffles

Type		Single segmental	Baffle cut: inner / outer / interm			
Tubes in window		No	Actual (% diameter)		/ 10 /	
Number		36	Nominal (% diameter)		/ 10 /	
Spacing (center-center)	**mm**	200	Actual (% area)		/ 5,2 /	
Spacing at inlet	**mm**	585,2	Cut orientation			H
Spacing at outlet	**mm**	515,75	Thickness	**mm**		9,52
Spacing at central in/out for G,H,I,J shells	**mm**		Tube rows in baffle overlap			56
Spacing at center of H shell	**mm**		Tube rows in baffle window			0,5
End length at front head	**mm**	715,28	Baffle hole - tube od diam clearance	**mm**		0,79
End length at rear head	**mm**	784,72	Shell id - baffle od diam clearance	**mm**		9,52

VariableBaffles

Baffle spacing	**mm**
Baffle cut percent, outer	
Baffle cut percent, inner	
Number of baffle spaces	
Baffle region length	**mm**
Baffle cut area percent, outer	
Baffle cut area percent, inner	

Supports Misc. Baffles

Supports-tube

Supports in endspace at front head	0
Supports in endspace at rear head	0
Supports between baffles	0
Support blanking baffle	No
Supports at U-bend	0
Supports at each G,H,J shell inlet and I shell outlet	0
Supports at center of H shell	0
Supports for K, X shells	0
Special support at inlet nozzle	No

Longitudinal Baffle

Thickness	**mm**
Window length at front head	**mm**
Window length at center	**mm**
Window length at rear head	**mm**

24-HJ-201 : Base Case Design

Bundle

Bundle					
Shell ID to center 1st tube row	**mm**		Tube passes		1
From top		217,4	Tube pass layout		Ribbon (single band)
From bottom		217,4	Tube pass orientation		Standard (horizontal)
From right		18,92	U-bend orientation		Undefined
From Left		18,92	Horizontal pass lane width	**mm**	
Impingement protection		None	Vertical pass lane width	**mm**	
Impingement distance	**mm**		Interpass tube alignment		No
Impingement plate diameter	**mm**		Deviation in tubes/pass		0
Impingement plate width	**mm**		Outer tube limit	**mm**	1984,12
Impingement plate length	**mm**		Shell id - bundle otl diam clearance	**mm**	15,88
Impingement plate thickness	**mm**		Tie rod number		12
Gross surface area per shell	**m²**	2097,9	Tie rod diameter	**mm**	15,88
Effective surface area per shell	**m²**	1999,4	Sealing strips (pairs)		10
Bare tube area per shell	**m²**	1999,4	Tube to tubesheet joint		Exp.
Finned area per shell	**m²**	0	Tube projection from front tsht	**mm**	3
U-bend area per shell	**m²**	0	Tube projection from rear tsht	**mm**	3

Appendix F – Thermal Calculations for Heat Exchangers in Case Study I

20-HA-003 : Case Study I

Basic Geometry

Unit Configuration

Exchanger Type		BEM	Tube number (calcs.)		1290
Position		Hor	Tube length actual	**mm**	6500
Arrangement		2 par 1 ser	Tube passes		1
Baffle type		Single segmental	Tube type		Plain
Baffle number		8	Tube O.D.	**mm**	19,05
Spacing (center-center)	**mm**	700	Tube pitch	**mm**	23,81
Spacing at inlet	**mm**	742,48	Tube pattern		30

		Shell	**Kettle**	**Front head**	**Rear head**
Outside diameter	**mm**	999		993	993
Inside Diameter	**mm**	975		975	975

		Shell Side		**Tube Side**	
Nozzle type		Inlet	Outlet	Inlet	Outlet
Number of nozzles		1	1	1	1
Actual outside diameter	**mm**	273	219,1	406,4	457
Inside diameter	**mm**	253	203,1	386,4	437
Height under nozzle	**mm**	106,78	106,78		
Dome inside diameter	**mm**				
Vapor belt inside diameter	**mm**				
Vapor belt inside width	**mm**				
Vapor belt slot area	**mm²**				
Impingement protection		No impingement	No impingement		
Distance to tubesheet	**mm**	6225	240		

20-HA-003 : Case Study I

Tubes

Tubes					
Type		Plain	Total number		1290
Outside diameter	**mm**	19,05	Number of tubes plugged		0
Inside diameter	**mm**	16,65	Tube length actual	**mm**	6500
Wall thickness	**mm**	1,2	Tube length effective	**mm**	6385
Area ratio Ao/Ai		1,14	Tubesheet thickness	**mm**	54,52
Pitch	**mm**	23,81	Material		22Cr,5Ni,3Mo steel
Pattern		30	Thermal conductivity	**W/(m K)**	16,138
External enhancement			Internal enhancement		
Low circumferential fins			**Low longitudinal fins**		
Fin density	**#/m**		Fin number		0
Fin height	**mm**		Fin thickness	**mm**	
Fin thickness	**mm**		Fin height	**mm**	
Tube root diameter	**mm**		Fin spacing	**mm**	
Tube wall thickness under fin	**mm**		Cut and twist length	**mm**	
Tube inside diameter under fins	**mm**				

Baffles

Baffles

Type		Single segmental	Baffle cut: inner / outer / interm		
Tubes in window		No	Actual (% diameter)		/ 10 /
Number		8	Nominal (% diameter)		/ 10 /
Spacing (center-center)	**mm**	700	Actual (% area)		/ 5,2 /
Spacing at inlet	**mm**	742,48	Cut orientation		H
Spacing at outlet	**mm**	742,48	Thickness	**mm**	9,52
Spacing at central in/out for G,H,I,J shells	**mm**		Tube rows in baffle overlap		36
Spacing at center of H shell	**mm**		Tube rows in baffle window		0,5
End length at front head	**mm**	800	Baffle hole - tube od diam clearance	**mm**	0,79
End length at rear head	**mm**	800	Shell id - baffle od diam clearance	**mm**	4,76

VariableBaffles

Baffle spacing	**mm**
Baffle cut percent, outer	
Baffle cut percent, inner	
Number of baffle spaces	
Baffle region length	**mm**
Baffle cut area percent, outer	
Baffle cut area percent, inner	

Supports Misc. Baffles

Supports-tube		**Longitudinal Baffle**		
Supports in endspace at front head	0	Thickness	**mm**	
Supports in endspace at rear head	0	Window length at front head	**mm**	
Supports between baffles	0	Window length at center	**mm**	
Support blanking baffle	No	Window length at rear head	**mm**	
Supports at U-bend	0			
Supports at each G,H,J shell inlet and I shell outlet	0			
Supports at center of H shell	0			
Supports for K, X shells	0			
Special support at inlet nozzle	No			

20-HA-003 : Case Study I

Bundle

Bundle

Shell ID to center 1st tube row	**mm**		Tube passes		1
From top		106,78	Tube pass layout		Ribbon (single band)
From bottom		106,78	Tube pass orientation		Standard (horizontal)
From right		13,63	U-bend orientation		Undefined
From Left		13,63	Horizontal pass lane width	**mm**	
Impingement protection		None	Vertical pass lane width	**mm**	
Impingement distance	**mm**		Interpass tube alignment		No
Impingement plate diameter	**mm**		Deviation in tubes/pass		0
Impingement plate width	**mm**		Outer tube limit	**mm**	962,3
Impingement plate length	**mm**		Shell id - bundle otl diam clearance	**mm**	12,7
Impingement plate thickness	**mm**		Tie rod number		8
Gross surface area per shell	**m²**	501,8	Tie rod diameter	**mm**	12,7
Effective surface area per shell	**m²**	492,9	Sealing strips (pairs)		7
Bare tube area per shell	**m²**	492,9	Tube to tubesheet joint		Exp.
Finned area per shell	**m²**	0	Tube projection from front tsht	**mm**	3
U-bend area per shell	**m²**	0	Tube projection from rear tsht	**mm**	3

21-HB-001 : Case Study I

Basic Geometry

Unit Configuration

Exchanger Type		BEM	Tube number (calcs.)		1624
Position		Hor	Tube length actual	**mm**	7000
Arrangement		1 par 1 ser	Tube passes		1
Baffle type		Single segmental	Tube type		Plain
Baffle number		30	Tube O.D.	**mm**	19,05
Spacing (center-center)	**mm**	200	Tube pitch	**mm**	23,81
Spacing at inlet	**mm**	536,48	Tube pattern		30

		Shell	**Kettle**	**Front head**	**Rear head**
Outside diameter	**mm**	1118		1118	1118
Inside Diameter	**mm**	1100		1100	1100

		Shell Side		**Tube Side**	
Nozzle type		Inlet	Outlet	Inlet	Outlet
Number of nozzles		1	1	1	1
Actual outside diameter	**mm**	323,85	273,05	406,4	457,2
Inside diameter	**mm**	304,8	254,51	387,35	438,15
Height under nozzle	**mm**	128,03	128,03		
Dome inside diameter	**mm**				
Vapor belt inside diameter	**mm**				
Vapor belt inside width	**mm**				
Vapor belt slot area	**mm²**				
Impingement protection		No impingement	No impingement		
Distance to tubesheet	**mm**	6695	275		

21-HB-001 : Case Study I

Tubes

Tubes

Type		Plain	Total number		1624
Outside diameter	**mm**	19,05	Number of tubes plugged		0
Inside diameter	**mm**	16,56	Tube length actual	**mm**	7000
Wall thickness	**mm**	1,24	Tube length effective	**mm**	6873
Area ratio Ao/Ai		1,15	Tubesheet thickness	**mm**	60,52
Pitch	**mm**	23,81	Material		22Cr,5Ni,3Mo steel
Pattern		30	Thermal conductivity	**W/(m K)**	16,1767
External enhancement			Internal enhancement		

Low circumferential fins			**Low longitudinal fins**		
Fin density	**#/m**		Fin number		0
Fin height	**mm**		Fin thickness	**mm**	
Fin thickness	**mm**		Fin height	**mm**	
Tube root diameter	**mm**		Fin spacing	**mm**	
Tube wall thickness under fin	**mm**		Cut and twist length	**mm**	
Tube inside diameter under fins	**mm**				

21-HB-001 : Case Study I

Baffles

Baffles

Type		Single segmental	Baffle cut: inner / outer / interm		
Tubes in window		No	Actual (% diameter)		/ 10 /
Number		30	Nominal (% diameter)		/ 10 /
Spacing (center-center)	**mm**	200	Actual (% area)		/ 5,2 /
Spacing at inlet	**mm**	536,48	Cut orientation		H
Spacing at outlet	**mm**	536,48	Thickness	**mm**	6,35
Spacing at central in/out for G,H,I,J shells	**mm**		Tube rows in baffle overlap		40
Spacing at center of H shell	**mm**		Tube rows in baffle window		0,5
End length at front head	**mm**	600	Baffle hole - tube od diam clearance	**mm**	0,79
End length at rear head	**mm**	600	Shell id - baffle od diam clearance	**mm**	6,35

VariableBaffles

Baffle spacing	**mm**
Baffle cut percent, outer	
Baffle cut percent, inner	
Number of baffle spaces	
Baffle region length	**mm**
Baffle cut area percent, outer	
Baffle cut area percent, inner	

Supports Misc. Baffles

Supports-tube		**Longitudinal Baffle**	
Supports in endspace at front head	0	Thickness	**mm**
Supports in endspace at rear head	0	Window length at front head	**mm**
Supports between baffles	0	Window length at center	**mm**
Support blanking baffle	No	Window length at rear head	**mm**
Supports at U-bend	0		
Supports at each G,H,J shell inlet and I shell outlet	0		
Supports at center of H shell	0		
Supports for K, X shells	0		
Special support at inlet nozzle	No		

21-HB-001 : Case Study I

Bundle

Bundle

Shell ID to center 1st tube row	**mm**		Tube passes		1
From top		128,03	Tube pass layout		Ribbon (single band)
From bottom		128,03	Tube pass orientation		Standard (horizontal)
From right		16,6	U-bend orientation		Undefined
From Left		16,6	Horizontal pass lane width	**mm**	
Impingement protection		None	Vertical pass lane width	**mm**	
Impingement distance	**mm**		Interpass tube alignment		No
Impingement plate diameter	**mm**		Deviation in tubes/pass		0
Impingement plate width	**mm**		Outer tube limit	**mm**	1087,3
Impingement plate length	**mm**		Shell id - bundle otl diam clearance	**mm**	12,7
Impingement plate thickness	**mm**		Tie rod number		8
Gross surface area per shell	**m²**	680,3	Tie rod diameter	**mm**	12,7
Effective surface area per shell	**m²**	668	Sealing strips (pairs)		7
Bare tube area per shell	**m²**	668	Tube to tubesheet joint		Exp.
Finned area per shell	**m²**	0	Tube projection from front tsht	**mm**	3
U-bend area per shell	**m²**	0	Tube projection from rear tsht	**mm**	3

Appendix G – Thermal Calculations for Heat Exchangers in Case Study II

24-HA-102 : Case Study II

Basic Geometry

Unit Configuration

Exchanger Type		BEM	Tube number (calcs.)		708
Position		Hor	Tube length actual	**mm**	5000
Arrangement		1 par 1 ser	Tube passes		1
Baffle type		Single segmental	Tube type		Plain
Baffle number		6	Tube O.D.	**mm**	24,5
Spacing (center-center)	**mm**	610	Tube pitch	**mm**	31,75
Spacing at inlet	**mm**	876,48	Tube pattern		30

		Shell	**Kettle**	**Front head**	**Rear head**
Outside diameter	**mm**	1001		1033	1033
Inside Diameter	**mm**	975		975	975

		Shell Side		**Tube Side**	
Nozzle type		Inlet	Outlet	Inlet	Outlet
Number of nozzles		1	1	1	1
Actual outside diameter	**mm**	273	219,1	914	914
Inside diameter	**mm**	253	203,1	864	864
Height under nozzle	**mm**	117,8	117,8		
Dome inside diameter	**mm**				
Vapor belt inside diameter	**mm**				
Vapor belt inside width	**mm**				
Vapor belt slot area	**mm²**				
Impingement protection		No impingement	No impingement		
Distance to tubesheet	**mm**	4685	280		

24-HA-102 : Case Study II

Tubes

Tubes					
Type		Plain	Total number		708
Outside diameter	**mm**	24,5	Number of tubes plugged		0
Inside diameter	**mm**	21,2	Tube length actual	**mm**	5000
Wall thickness	**mm**	1,65	Tube length effective	**mm**	4803
Area ratio Ao/Ai		1,16	Tubesheet thickness	**mm**	95,52
Pitch	**mm**	31,75	Material		22Cr,5Ni,3Mo steel
Pattern		30	Thermal conductivity	**W/(m K)**	15,7218
External enhancement			Internal enhancement		
Low circumferential fins			**Low longitudinal fins**		
Fin density	**#/m**		Fin number		0
Fin height	**mm**		Fin thickness	**mm**	
Fin thickness	**mm**		Fin height	**mm**	
Tube root diameter	**mm**		Fin spacing	**mm**	
Tube wall thickness under fin	**mm**		Cut and twist length	**mm**	
Tube inside diameter under fins	**mm**				

Baffles

Baffles

Type		Single segmental	Baffle cut: inner / outer / interm		
Tubes in window		No	Actual (% diameter)		/ 10 /
Number		6	Nominal (% diameter)		/ 10 /
Spacing (center-center)	**mm**	610	Actual (% area)		/ 5,2 /
Spacing at inlet	**mm**	876,48	Cut orientation		H
Spacing at outlet	**mm**	876,48	Thickness	**mm**	9,52
Spacing at central in/out for G,H,I,J shells	**mm**		Tube rows in baffle overlap		26
Spacing at center of H shell	**mm**		Tube rows in baffle window		0,5
End length at front head	**mm**	975	Baffle hole - tube od diam clearance	**mm**	0,79
End length at rear head	**mm**	975	Shell id - baffle od diam clearance	**mm**	4,76

VariableBaffles

Baffle spacing	**mm**
Baffle cut percent, outer	
Baffle cut percent, inner	
Number of baffle spaces	
Baffle region length	**mm**
Baffle cut area percent, outer	
Baffle cut area percent, inner	

Supports Misc. Baffles

Supports-tube		Longitudinal Baffle	
Supports in endspace at front head	0	Thickness	**mm**
Supports in endspace at rear head	0	Window length at front head	**mm**
Supports between baffles	0	Window length at center	**mm**
Support blanking baffle	No	Window length at rear head	**mm**
Supports at U-bend	0		
Supports at each G,H,J shell inlet and I shell outlet	0		
Supports at center of H shell	0		
Supports for K, X shells	0		
Special support at inlet nozzle	No		

24-HA-102 : Case Study II

Bundle

Bundle					
Shell ID to center 1st tube row	**mm**		Tube passes		1
From top		117,8	Tube pass layout		Ribbon (single band)
From bottom		117,8	Tube pass orientation		Standard (horizontal)
From right		14,88	U-bend orientation		Undefined
From Left		14,88	Horizontal pass lane width	**mm**	
Impingement protection		None	Vertical pass lane width	**mm**	
Impingement distance	**mm**		Interpass tube alignment		No
Impingement plate diameter	**mm**		Deviation in tubes/pass		0
Impingement plate width	**mm**		Outer tube limit	**mm**	962,3
Impingement plate length	**mm**		Shell id - bundle otl diam clearance	**mm**	12,7
Impingement plate thickness	**mm**		Tie rod number		8
Gross surface area per shell	**m²**	272,5	Tie rod diameter	**mm**	12,7
Effective surface area per shell	**m²**	261,7	Sealing strips (pairs)		5
Bare tube area per shell	**m²**	261,7	Tube to tubesheet joint		Exp.
Finned area per shell	**m²**	0	Tube projection from front tsht	**mm**	3
U-bend area per shell	**m²**	0	Tube projection from rear tsht	**mm**	3

24-HA-202 : Case Study II

Basic Geometry

Unit Configuration

Exchanger Type		BEM	Tube number (calcs.)		731
Position		Hor	Tube length actual	**mm**	6500
Arrangement		1 par 1 ser	Tube passes		1
Baffle type		Single segmental	Tube type		Plain
Baffle number		6	Tube O.D.	**mm**	25,4
Spacing (center-center)	**mm**	855	Tube pitch	**mm**	31,75
Spacing at inlet	**mm**	1009,98	Tube pattern		30

		Shell	**Kettle**	**Front head**	**Rear head**
Outside diameter	**mm**	1026		1060	1060
Inside Diameter	**mm**	1000		1000	1000

		Shell Side		**Tube Side**	
Nozzle type		Inlet	Outlet	Inlet	Outlet
Number of nozzles		1	1	1	1
Actual outside diameter	**mm**	323,9	273	914	914
Inside diameter	**mm**	303,9	253	864	864
Height under nozzle	**mm**	129,85	129,85		
Dome inside diameter	**mm**				
Vapor belt inside diameter	**mm**				
Vapor belt inside width	**mm**				
Vapor belt slot area	**mm²**				
Impingement protection		No impingement	No impingement		
Distance to tubesheet	**mm**	6155	310		

Tubes

Tubes

Type		Plain	Total number		731
Outside diameter	**mm**	25,4	Number of tubes plugged		0
Inside diameter	**mm**	22,1	Tube length actual	**mm**	6500
Wall thickness	**mm**	1,65	Tube length effective	**mm**	6295
Area ratio Ao/Ai		1,15	Tubesheet thickness	**mm**	99,52
Pitch	**mm**	31,75	Material		22Cr,5Ni,3Mo steel
Pattern		30	Thermal conductivity	**W/(m K)**	15,7206
External enhancement			Internal enhancement		

Low circumferential fins			**Low longitudinal fins**		
Fin density	**#/m**		Fin number		0
Fin height	**mm**		Fin thickness	**mm**	
Fin thickness	**mm**		Fin height	**mm**	
Tube root diameter	**mm**		Fin spacing	**mm**	
Tube wall thickness under fin	**mm**		Cut and twist length	**mm**	
Tube inside diameter under fins	**mm**				

Baffles

Baffles

Type		Single segmental	Baffle cut: inner / outer / interm		
Tubes in window		No	Actual (% diameter)		/ 12,75 /
Number		6	Nominal (% diameter)		/ 12,75 /
Spacing (center-center)	**mm**	855	Actual (% area)		/ 7,43 /
Spacing at inlet	**mm**	1009,98	Cut orientation		H
Spacing at outlet	**mm**	1009,98	Thickness	**mm**	9,52
Spacing at central in/out for G,H,I,J shells	**mm**		Tube rows in baffle overlap		26
Spacing at center of H shell	**mm**		Tube rows in baffle window		0,5
End length at front head	**mm**	1112,5	Baffle hole - tube od diam clearance	**mm**	0,79
End length at rear head	**mm**	1112,5	Shell id - baffle od diam clearance	**mm**	6,35

VariableBaffles

Baffle spacing	**mm**
Baffle cut percent, outer	
Baffle cut percent, inner	
Number of baffle spaces	
Baffle region length	**mm**
Baffle cut area percent, outer	
Baffle cut area percent, inner	

Supports Misc. Baffles

Supports-tube		**Longitudinal Baffle**	
Supports in endspace at front head	0	Thickness	**mm**
Supports in endspace at rear head	0	Window length at front head	**mm**
Supports between baffles	0	Window length at center	**mm**
Support blanking baffle	No	Window length at rear head	**mm**
Supports at U-bend	0		
Supports at each G,H,J shell inlet and I shell outlet	0		
Supports at center of H shell	0		
Supports for K, X shells	0		
Special support at inlet nozzle	No		

24-HA-202 : Case Study II

Bundle

Bundle					
Shell ID to center 1st tube row	**mm**		Tube passes		1
From top		129,85	Tube pass layout		Ribbon (single band)
From bottom		129,85	Tube pass orientation		Standard (horizontal)
From right		11,05	U-bend orientation		Undefined
From Left		11,05	Horizontal pass lane width	**mm**	
Impingement protection		None	Vertical pass lane width	**mm**	
Impingement distance	**mm**		Interpass tube alignment		No
Impingement plate diameter	**mm**		Deviation in tubes/pass		0
Impingement plate width	**mm**		Outer tube limit	**mm**	987,3
Impingement plate length	**mm**		Shell id - bundle otl diam clearance	**mm**	12,7
Impingement plate thickness	**mm**		Tie rod number		8
Gross surface area per shell	**m²**	379,2	Tie rod diameter	**mm**	12,7
Effective surface area per shell	**m²**	367,2	Sealing strips (pairs)		5
Bare tube area per shell	**m²**	367,2	Tube to tubesheet joint		Exp.
Finned area per shell	**m²**	0	Tube projection from front tsht	**mm**	3
U-bend area per shell	**m²**	0	Tube projection from rear tsht	**mm**	3

Appendix H – Thermal Calculations for Heat Exchangers in Case Study III

24-HJ-101 : Case Study III

Basic Geometry

Unit Configuration

Exchanger Type		BEM	Tube number (calcs.)		1865
Position		Hor	Tube length actual	**mm**	9000
Arrangement		2 par 1 ser	Tube passes		1
Baffle type		Single segmental	Tube type		Plain
Baffle number		6	Tube O.D.	**mm**	25,4
Spacing (center-center)	**mm**	1240	Tube pitch	**mm**	31,75
Spacing at inlet	**mm**	1248,47	Tube pattern		30

		Shell	**Kettle**	**Front head**	**Rear head**
Outside diameter	**mm**	1586		1642	1642
Inside Diameter	**mm**	1550		1550	1550

		Shell Side		**Tube Side**	
Nozzle type		Inlet	Outlet	Inlet	Outlet
Number of nozzles		1	1	1	1
Actual outside diameter	**mm**	406,4	323,9	711	711
Inside diameter	**mm**	386,4	303,9	671	671
Height under nozzle	**mm**	157,38	157,38		
Dome inside diameter	**mm**				
Vapor belt inside diameter	**mm**				
Vapor belt inside width	**mm**				
Vapor belt slot area	**mm²**				
Impingement protection		No impingement	No impingement		
Distance to tubesheet	**mm**	8565	385		

24-HJ-101 : Case Study III

Tubes

Tubes

Type		Plain	Total number		1865
Outside diameter	**mm**	25,4	Number of tubes plugged		0
Inside diameter	**mm**	22,1	Tube length actual	**mm**	9000
Wall thickness	**mm**	1,65	Tube length effective	**mm**	8697
Area ratio Ao/Ai		1,15	Tubesheet thickness	**mm**	148,52
Pitch	**mm**	31,75	Material		22Cr,5Ni,3Mo steel
Pattern		30	Thermal conductivity	**W/(m K)**	16,4295
External enhancement			Internal enhancement		

Low circumferential fins			**Low longitudinal fins**		
Fin density	**#/m**		Fin number		0
Fin height	**mm**		Fin thickness	**mm**	
Fin thickness	**mm**		Fin height	**mm**	
Tube root diameter	**mm**		Fin spacing	**mm**	
Tube wall thickness under fin	**mm**		Cut and twist length	**mm**	
Tube inside diameter under fins	**mm**				

24-HJ-101 : Case Study III

Baffles

Baffles

Type		Single segmental	Baffle cut: inner / outer / interm			
Tubes in window		No	Actual (% diameter)		/	10 /
Number		6	Nominal (% diameter)		/	10 /
Spacing (center-center)	**mm**	1240	Actual (% area)		/	5,2 /
Spacing at inlet	**mm**	1248,47	Cut orientation			H
Spacing at outlet	**mm**	1248,47	Thickness	**mm**		19,05
Spacing at central in/out for G,H,I,J shells	**mm**		Tube rows in baffle overlap			44
Spacing at center of H shell	**mm**		Tube rows in baffle window			0,5
End length at front head	**mm**	1400	Baffle hole - tube od diam clearance	**mm**		0,4
End length at rear head	**mm**	1400	Shell id - baffle od diam clearance	**mm**		7,94

VariableBaffles

Baffle spacing	**mm**
Baffle cut percent, outer	
Baffle cut percent, inner	
Number of baffle spaces	
Baffle region length	**mm**
Baffle cut area percent, outer	
Baffle cut area percent, inner	

Supports Misc. Baffles

Supports-tube

Supports in endspace at front head	0
Supports in endspace at rear head	0
Supports between baffles	0
Support blanking baffle	No
Supports at U-bend	0
Supports at each G,H,J shell inlet and I shell outlet	0
Supports at center of H shell	0
Supports for K, X shells	0
Special support at inlet nozzle	No

Longitudinal Baffle

Thickness	**mm**	
Window length at front head	**mm**	
Window length at center	**mm**	
Window length at rear head	**mm**	

24-HJ-101 : Case Study III

Bundle

Bundle					
Shell ID to center 1st tube row	**mm**		Tube passes		1
From top		157,38	Tube pass layout		Ribbon (single band)
From bottom		157,38	Tube pass orientation		Standard (horizontal)
From right		16,18	U-bend orientation		Undefined
From Left		16,18	Horizontal pass lane width	**mm**	
Impingement protection		None	Vertical pass lane width	**mm**	
Impingement distance	**mm**		Interpass tube alignment		No
Impingement plate diameter	**mm**		Deviation in tubes/pass		0
Impingement plate width	**mm**		Outer tube limit	**mm**	1535,71
Impingement plate length	**mm**		Shell id - bundle otl diam clearance	**mm**	14,29
Impingement plate thickness	**mm**		Tie rod number		12
Gross surface area per shell	**m²**	1339,4	Tie rod diameter	**mm**	15,88
Effective surface area per shell	**m²**	1294,3	Sealing strips (pairs)		8
Bare tube area per shell	**m²**	1294,3	Tube to tubesheet joint		Exp.
Finned area per shell	**m²**	0	Tube projection from front tsht	**mm**	3
U-bend area per shell	**m²**	0	Tube projection from rear tsht	**mm**	3

24-HJ-201 : Case Study III

Basic Geometry

Unit Configuration

Exchanger Type		BEM	Tube number (calcs.)		2240
Position		Hor	Tube length actual	**mm**	9000
Arrangement		2 par 1 ser	Tube passes		1
Baffle type		Single segmental	Tube type		Plain
Baffle number		38	Tube O.D.	**mm**	25,4
Spacing (center-center)	**mm**	200	Tube pitch	**mm**	31,75
Spacing at inlet	**mm**	630,48	Tube pattern		30

		Shell	**Kettle**	**Front head**	**Rear head**
Outside diameter	**mm**	1738		1806	1806
Inside Diameter	**mm**	1700		1700	1700

		Shell Side		**Tube Side**	
Nozzle type		Inlet	Outlet	Inlet	Outlet
Number of nozzles		1	1	1	1
Actual outside diameter	**mm**	457	355,6	711	711
Inside diameter	**mm**	437	335,6	671	671
Height under nozzle	**mm**	177,39	177,39		
Dome inside diameter	**mm**				
Vapor belt inside diameter	**mm**				
Vapor belt inside width	**mm**				
Vapor belt slot area	**mm²**				
Impingement protection		No impingement	No impingement		
Distance to tubesheet	**mm**	8525	420		

24-HJ-201 : Case Study III

Tubes

Tubes					
Type		Plain	Total number		2240
Outside diameter	**mm**	25,4	Number of tubes plugged		0
Inside diameter	**mm**	22,1	Tube length actual	**mm**	9000
Wall thickness	**mm**	1,65	Tube length effective	**mm**	8661
Area ratio Ao/Ai		1,15	Tubesheet thickness	**mm**	166,52
Pitch	**mm**	31,75	Material		22Cr,5Ni,3Mo steel
Pattern		30	Thermal conductivity	**W/(m K)**	16,4586
External enhancement			Internal enhancement		
Low circumferential fins			**Low longitudinal fins**		
Fin density	**#/m**		Fin number		0
Fin height	**mm**		Fin thickness	**mm**	
Fin thickness	**mm**		Fin height	**mm**	
Tube root diameter	**mm**		Fin spacing	**mm**	
Tube wall thickness under fin	**mm**		Cut and twist length	**mm**	
Tube inside diameter under fins	**mm**				

24-HJ-201 : Case Study III

Baffles

Baffles

Type		Single segmental	Baffle cut: inner / outer / interm			
Tubes in window		No	Actual (% diameter)		/ 10 /	
Number		38	Nominal (% diameter)		/ 10 /	
Spacing (center-center)	**mm**	200	Actual (% area)		/ 5,2 /	
Spacing at inlet	**mm**	630,48	Cut orientation			H
Spacing at outlet	**mm**	630,48	Thickness	**mm**		9,52
Spacing at central in/out for G,H,I,J shells	**mm**		Tube rows in baffle overlap			48
Spacing at center of H shell	**mm**		Tube rows in baffle window			0,5
End length at front head	**mm**	800	Baffle hole - tube od diam clearance	**mm**		0,79
End length at rear head	**mm**	800	Shell id - baffle od diam clearance	**mm**		7,94

VariableBaffles

Baffle spacing	**mm**
Baffle cut percent, outer	
Baffle cut percent, inner	
Number of baffle spaces	
Baffle region length	**mm**
Baffle cut area percent, outer	
Baffle cut area percent, inner	

Supports Misc. Baffles

Supports-tube		**Longitudinal Baffle**	
Supports in endspace at front head	0	Thickness	**mm**
Supports in endspace at rear head	0	Window length at front head	**mm**
Supports between baffles	0	Window length at center	**mm**
Support blanking baffle	No	Window length at rear head	**mm**
Supports at U-bend	0		
Supports at each G,H,J shell inlet and I shell outlet	0		
Supports at center of H shell	0		
Supports for K, X shells	0		
Special support at inlet nozzle	No		

24-HJ-201 : Case Study III

Bundle

Bundle

Shell ID to center 1st tube row	**mm**		Tube passes		1
From top		177,39	Tube pass layout		Ribbon (single band)
From bottom		177,39	Tube pass orientation		Standard (horizontal)
From right		11,8	U-bend orientation		Undefined
From Left		11,8	Horizontal pass lane width	**mm**	
Impingement protection		None	Vertical pass lane width	**mm**	
Impingement distance	**mm**		Interpass tube alignment		No
Impingement plate diameter	**mm**		Deviation in tubes/pass		0
Impingement plate width	**mm**		Outer tube limit	**mm**	1685,71
Impingement plate length	**mm**		Shell id - bundle otl diam clearance	**mm**	14,29
Impingement plate thickness	**mm**		Tie rod number		12
Gross surface area per shell	**m^2**	1608,7	Tie rod diameter	**mm**	15,88
Effective surface area per shell	**m^2**	1548,1	Sealing strips (pairs)		9
Bare tube area per shell	**m^2**	1548,1	Tube to tubesheet joint		Exp.
Finned area per shell	**m^2**	0	Tube projection from front tsht	**mm**	3
U-bend area per shell	**m^2**	0	Tube projection from rear tsht	**mm**	3