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Modeling alternatives for multiphase boosters, for field performance studies

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Submission date: June 2017
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Abstract

The concept selection for the development of a petroleum field critically depends upon the uncertainties involved in the field performance analysis, and any deviation in the actual field production from the originally estimated production rates may change the risk to the investment. Predicting the throughput of the fields is related with the performance of the equipment selected in the field architecture. Low energy or depleting fields require artificial pressure boosting for throughput sustenance. In comparison with conventional single-phase boosters, a multiphase booster may alleviate the need of extensive subsea processing equipment but its uncertain performance and inadequate performance prediction models becomes the major source of uncertainty, when predicting the boosted production profile. In commercial production simulator, the user typically must choose a specific booster model from the database; but the correction methods and the validity range of the model are not fully disclosed. In consequence, the computed production profile may still have a high uncertainty associated.

This thesis explores alternative approaches to model the performance of a multiphase boosters, suitable for the field design phase when computing the production profiles; and presents a framework for automated selection of an optimum booster by honouring all constraints of the field. Two test cases were employed: The Snøhvit field and the Draugen field. In the Snøhvit field's case, as no booster is yet installed, a simplified booster model of a wet gas compressor was developed that requires minimum user input. In the Draugen field, the actual booster model (a helicoaxial booster available in PIPESIM) was employed for the study. In the case of helicoaxial booster, the sensitivity of the boosters' performance was checked against varying water-cut and GVF. The approach includes a unique procedure to develop an empirical equation, that generates iso-speed performance map of the booster by processing the data obtained from PIPESIM. For automated booster selection, an Ms Excel utility was prepared that takes field data as an input, and yields the best possible booster along with the feasible operational configuration. Such utility can reduce the booster selection time consumed during manual checking the applicability of the different boosters available in the commercial simulators.

The procedure followed to obtain the coefficients of the equation to generate iso-speed maps can further be analysed to investigate the relation between coefficients' value with the fluid's intrinsic properties; as any further success can lead to the development of a numerical model for multiphase boosting process.

Preface

This Master's thesis was performed at the Department of Geoscience and Petroleum (IGP) between January 15, 2017 till June 11, 2017 at the Norwegian University of Science and Technology, Trondheim. The thesis was completed in supervision of Milan Stanko and Jesus De Andrade; and assisted by Gilberto Nunez.

The author wishes to express his sincere appreciation and gratitude for the consultation, guidance, motivation and precious time that was provided by all above throughout the thesis. The author beliefs that the challenges involved in the thesis provided an opportunity to learn and enhance the technical skills, which will certainly assist in resolving professional challenges in the future endeavour.

The author also wishes his gratitude to the Professor Michael Golan for his persisting motivation and encouragement throughout the studies.

June 11, 2017

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Nomenclature

Abbreviations

SMUBS	Shell Multiphase Underwater Boosting Station
GVF	GVF
WC	Water-cut
cP	Centi-Poise
WGC	Wet Gas Compressor
MMSCF/d	Million Standard Cubic Feet per Day
PLEM	Pipeline End Manifold
STB	Stock Tank Barrel
PFD	Process Flow Diagram
DIA	Direct Integration Approach
VBA	Visual Basic Applications
Ms	Microsoft
Hx	Helicoaxial
Petex	Petroleum Experts

Basic Symbols

ρ	Density
ʆ	Correction factor
λ	Flux fraction
μ	Viscosity
ϕ	Two-phase flow function
φ	Flow coefficient
Ψ	Head coefficient
α	Volume factor
β	Mass factor
v	Velocity
N	Speed of the booster
D	Diameter of the impeller
p	Pressure

P	Power
dp	Pressure difference
η	Efficiency
n	Polytropic exponent
k	Isentropic exponent

Subscripts

G	Gas phase
L	Liquid phase
W	Water phase
S	Superficial
TP	Two-phase
MP	Multiphase
SP	Single-phase
H	Head

CHAPTER 1 INTRODUCTION

1.1 Field Performance Studies

Financial study of a petroleum field depends upon original hydrocarbon reserves in the reservoir and the potential of the reservoir to move the fluid from the bottom hole to the platform or the processing facility. In nodal analysis, generally a separator is considered as end-node in the production system, and the potential of the reservoir to move the fluid to the end-node is analysed to determine natural flowing potential of the field. During the flow of the fluid from reservoir to the production system, pressure of the fluid is reduced due to gravitational, frictional and acceleration losses[1, 2]. At the beginning of the field's life, natural flowing potential of the field remains high. However, scheduled constant fields production rate is generally kept lower than natural flowing potential to improve the economic feasibility of the field. To maintain the equilibrium within production system, the rate is typically controlled by wellhead chokes. During the life of the field, reservoir pressure depletes and causes imbalance at the key node, thus require opening of the choke valve to balance the available and required pressure keeping constant production rates. Duration of such constant production is called a plateau period. Once the plateau period ends, then the production rate reduces in accordance with the natural flowing potential of the field.

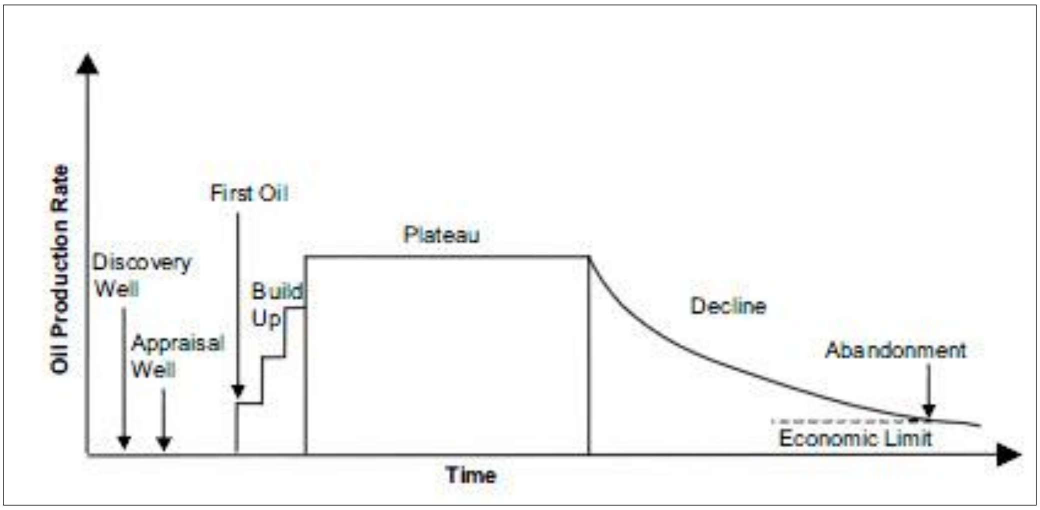


Figure 1. 1 Typical Oil Field's Production Profile[3]

For extension in either plateau period or the production rate beyond natural flowing potential requires artificial pressure boosting to balance the required and available pressure for the revised production rate. There are several industrially applicable pressures boosting options are available. Following are few of the available pressure boosting options for increasing flowing potential of the petroleum field[4],

- Downhole pumping
- Water injection
- Gas Injection
- Multiphase pressure boosting
- Jet pump
- Gas lift

Among other viable options for pressure boosting, multiphase boosters can operate under a wide range of GVF and water-cut in contrast with more sensitive boosters such as ESPs that tolerate little amount of gas. Furthermore, it can be stationed anywhere at the surface production network, and can boost comparatively high flow rates with wide range of GVF[5]. Additionally, flexibility in placement of the multiphase booster also reduces the maintenance cost. All such significance of multiphase booster priorities it from other pressure boosting options.

In contrast to single phase boosters, multiphase boosters are relatively new in the industry, thus uncertainties associated in performance prediction of multiphase boosting process are yet to be fully resolved[6]. Several researches in this domain have already been conducted, and several performance prediction models have been proposed. But, every performance prediction model has its own indigenous constraints and none of the model is fully robust to precisely predict the output of simultaneous boosting of liquid and gaseous phase. Uncertain prediction may result in significant deviation between the on-field test results and the predictive performance.

In concept selection phase for a petroleum field development, prediction of multiphase booster's performance is subject to the predictive model chosen for its performance evaluation. Unlike single phase booster, typical commercial network simulators such as GAP (Petex) and PIPESIM (Schlumberger) do not contain sufficient information about their performance prediction model. Furthermore, these simulators contain only booster models of Framo Engineering (Framo 2000/H-series and Framo 2009/Hx-series). All such shortcomings challenge performance evaluation of any multiphase booster model that is not available in commercial network simulators, as the evaluated performance can neither be validated against simulators' output nor against field/experimental data.

1.2 Objective of The Thesis

Subject thesis is designed to address the difficulties involved in performance evaluation of multiphase boosters in field development studies. Such difficulties are related with unavailability of a generalised multiphase booster model in commercial network simulators, and uncertainties involved in adopted method to evaluate performance of the booster. Limited information about the performance of the multiphase boosters also makes it difficult to evaluate applicability of any new booster model. Since the performance envelop of a booster depends upon the fluid properties at booster inlet like inlet pressure, inlet temperature, water-cut, GVF etc. So, the proper prediction demands to evaluate the booster's performance for every change in the fluid property. As the phase fractions of a petroleum field varies throughout the production network as well as throughout the life of the field, therefore, it is important to evaluate performance of the booster at variant fluid phases and properties.

In addition to above, selecting a booster for the specific field often results in parallel/series operational configuration. All such operational configurations demand to validate the operability of the selected booster for each configuration. Parallel operation of the booster does not incur much difficulty in selecting the booster, as fluid's properties remains constant for all the boosters. On the other hand, selection of boosters for series operation is much more challenging as the fluid's properties varies for the later staged boosters. Such manual selection may lead to the in-efficient selection of the booster which may increase the risk in the investments.

1.3 Scope of The Thesis

Aiming to address the above issues, and to suggest an alternative approach to predict performance evaluation method for a multiphase booster in the field development studies, scope of the subject thesis is categorially devised. Following are the specific objective of subject Master's thesis,

i. To provide an alternative modelling approach for performance evaluation of a multiphase boosters in field performance studies. Development of a framework to represent a multiphase boosting equipment for early screening field life studies,
    a. Case 1: Using Excel spreadsheet for Snøhvit and Draugen field, find operational constraints that define an operational map of the proposed multiphase booster.
    b. Case 2: Using GAP, development of a script for a generic booster using programmable Inline (general) Element.

c. Impact of boosting model accuracy in performance evaluation of the production system.

ii. Develop an Ms Excel utility that utilize data of multiphase boosters available in PIPESIM/GAP, and select an optimum booster model, in terms of power and efficiency, for a specified performance.

iii. Propose a methodology to select a multiphase booster model for variant field specifications such as water-cut, gas/oil ratio and suction pressure. For given field specification, propose a methodology to select parallel/serial installation configuration of the booster.

1.4 General Approach to Cover the Thesis' Scope

As the scope of the thesis is diversified, and it deals with two different petroleum fields that are entirely distinctive in characteristics, so, the performance evaluation for each field is also conducted separately. For Snøhvit field, detailed network modelling is possible as sufficient field data is available, so the execution of task 1 regarding the development of a generic multiphase booster model using programmable Inline (general) Element, will be conducted. As the adequate field data for Draugen field is unavailable, so, the performance evaluation of the proposed booster for Draugen field's SMUBS-II will be carried out using Ms Excel spreadsheet. To develop an Excel utility for task 2, data available in PIPESIM for multiphase booster models will be used, and a generic methodology will be developed that may further be updated with the data of other multiphase booster models as well. For task 3, a generic spreadsheet will be developed that will take input of any petroleum field, and will propose a best possible booster model along with the optimum operational configuration.

1.5 Structure of The Report

The report is organised to separately address all the issues mentioned in the scope of thesis, by dealing each petroleum field separately. To fulfil the scope, subject report has been structured into following chapters,

Chapter#01: Discusses the concept of field development studies, concept of boosting, significance of multiphase boosting, challenges in application, objective and scope of the thesis.

Chapter#02: Contains the theoretical basis to deal with multiphase flow, modelling approaches for multiphase boosters and previously developed models.

Chapter#03: Discuss the development of an Excel utility and a procedure for the optimum selection of a multiphase booster. Also includes the relative change in performance envelop of a booster, and the methodology to populate a database for automatic performance map generation.

Chapter#04: Detailed analysis of the Snøhvit field's wet gas compression project, development of generic multiphase booster model using GAP's programmable Inline Element, comparison of output of developed model with field development studies.

Chapter#05: Analysis for pressure boosting required for Draugen field's SMUBS-II, developed an Excel utility to check operability of proposed multiphase booster at various stages of field.

Chapter#06: Concludes all the analyses and the results for each task, and give recommendation for further research.

Appendix A: Contains information about Snøhvit field.

Appendix B: Contains information about Draugen field.

Appendix C: Contains VBA scripts for the automated booster selection

CHAPTER 2 MULTIPHASE BOOSTERS

Conventional boosters are primarily designed to deal with single flow regime. Liquid boosters or pumps are preferred for liquid dominated flow regimes, whereas, dry gas compressors are preferred for gas dominated flow regime. Implementation of boosting equipment in upstream pressure boosting mechanism must be able to handle the phase change. Phase transformation depends upon reservoir fluid composition and variation in fluid properties during transportation. Change in phase of the fluid also depends upon varying field properties such as water-cut, GOR etc. which may also contribute in developing multiple flow regime within production system. Appropriate concept selection of production system and the selection of a multiphase booster requires adequate knowledge about behaviour of the reservoir's fluid with change in pressure/temperature, and anticipation for water conning/water break through during later stage of the field life. Therefore, in subject chapter, theoretical basis appertain multiphase boosters is linked with physical behaviour of multiphase flow, and the reservoir fluid's property that implicates change in flow regime.

2.1 Multiphase Flow

Fluid phases are primarily classified as solid, liquid or gas. Definition of the fluid phase depends upon its physical properties. In general, reservoir fluid transforms either into liquid or gas phase within production tubing and transportation lines due to change in pressure/temperature, while reduction in temperature can also introduce a solid phase such as gas hydrates. Each phase has its own junction/interphase that separates it from other phases. But, change in one phase's particle size introduces new phase whose properties are partly define by one phase and partly by other like emulsions (between two immiscible liquid phases, froth/foam (between liquid and gas phases) and slurries (between solid and liquid phases)[7]

Within certain multiphase flow section, flow may transform into different regimes that directly affects energy loss during transportation. Classification of different fluid regimes depends upon physical quantity of any phase within multiphase flow. To classify phase distribution within horizontal and vertical flow lines, following definition of fluid properties will be used[7],

(a) Volume Fraction

Within multiphase flowlines, each phase occupies certain area of the line. Considering same length of the segment, area occupied by each phase corresponds to the volume of each phase. If occupied area/volume of each phase is normalized with total area/volume, then covered volume/area can be classified as fraction of volume/area covered by that phase. For multiphase flow, dealing with liquid and gas phase only, volume fractions for each phase is defined as,

$$Liquid\ volume\ fraction, \alpha_L = \frac{Volume\ of\ liquid}{Total\ volume} \qquad \text{Eq. 2.1}$$

$$Gas\ volume\ fraction (GVF), \alpha_G = \frac{Volume\ of\ gas}{Total\ volume} \qquad \text{Eq. 2.2}$$

It is important to understand that above volumes are at actual conditions of pressure and temperature. For liquid dominated flow, effect of pressure may not incur notable change in volume fraction, but for gas dominated flow, such change introduces notable change in volume fractions.

(b) Mass Fraction

Volume fractions of a phase is an extrinsic property that depends upon fluid composition and external conditions. To classify phase distribution intensively, mass of the phase is used instead of volume. Therefore, mass fraction of a phase within multiphase flow is define as,

$$Mass\ fraction\ of\ liquid\ phase, \beta_L = \frac{Mass\ of\ liquid}{Total\ mass} \qquad \text{Eq. 2.3}$$

$$Mass\ fraction\ of\ gas\ phase, \beta_G = \frac{Mass\ of\ gas}{Total\ mass} \qquad \text{Eq. 2.4}$$

(c) Holdup

Holdup is the terminology used to indicate the fraction of any phase present in the segment of the line. It is primarily used for liquid phase, as, change in liquid phase within production system incurs radical change in flow regime. Liquid holdup is also a volume fraction of liquid, but it is determined through volume fraction of gas like,

$$Liquid\ holdup, \alpha_L = 1 - \alpha_G \qquad \text{Eq. 2.5}$$

(d) Water-Cut

In petroleum industry, determination of water production is of vital importance as rise in water production may indicate water conning or early water breakthrough. Therefore, to express water production rate, the terminology ‘water-cut’ is used. Water-cut is basically a ratio between production rates of water within total liquid production rate.

Definition of water-cut does not include gas production rate. If total liquid contains water and oil only, then Water-Cut is defined as,

$$Water - cut, WC = \frac{Q_w}{Q_w + Q_o} \quad \text{Eq. 2.6}$$

(e) Superficial Velocity

Unlike single phase, instantaneous velocity of multiphase flow cannot be related with volumetric flow rate and area because volume fraction of each phase varies within segments of transportation line. However, for segment of the line, instead of instantaneous fluid velocity, if average instantaneous velocity is used then total volumetric flow rate of the phase may be expressed as a function of area fraction and volume fraction. Such average instantaneous velocity is called superficial velocity. Basis of the superficial velocity is an assumption that the average velocity the phase will possess if it occupies whole segment of the line. Such basis results in lower value of superficial velocity in comparison with actual average velocity. Therefore, for gas phase, superficial velocity is defined as,

$$Q_G = \alpha_G . A . v_G \quad \text{Eq. 2.7}$$

$$v_{SG} = \alpha_G . v_G = \left(\frac{Q_G}{A}\right) \quad \text{Eq. 2.8}$$

$$v_{SL} = \alpha_L . v_L = \left(\frac{Q_L}{A}\right) \quad \text{Eq. 2.9}$$

(f) Multiphase Fluid Velocity

In multiphase flow lines, average velocity of the fluid can be expressed as arithmetic sum of the product of volume fraction and average velocity of each phase,

$$v_{TP} = \sum_{k=1}^{N} \alpha_k . v_k \quad \text{Eq. 2.10}$$

(g) Multiphase Fluid Density

Like velocity, considering homogenous mixing of the fluids within a segment, multiphase fluid density can also be expressed as,

$$\rho_{TP} = \sum_{K=1}^{N} \alpha_K . \rho_K \qquad \text{Eq. 2.11}$$

$$\rho_{TP} = \alpha_G . \rho_G + (1 - \alpha_G) . \rho_L \qquad \text{Eq. 2.12}$$

(h) Flow Regimes

Depending on the relative velocities of liquid and gaseous phases within multiphase flow, flow may adopt different flow regimes within a transportation line. These regimes define behaviour of the multiphase flow and the transportation lines must be laid according to the elevation profile of the surface. For horizontal pipelines, multiphase flow can be classified into different regimes against superficial velocities of liquid and gaseous phase.

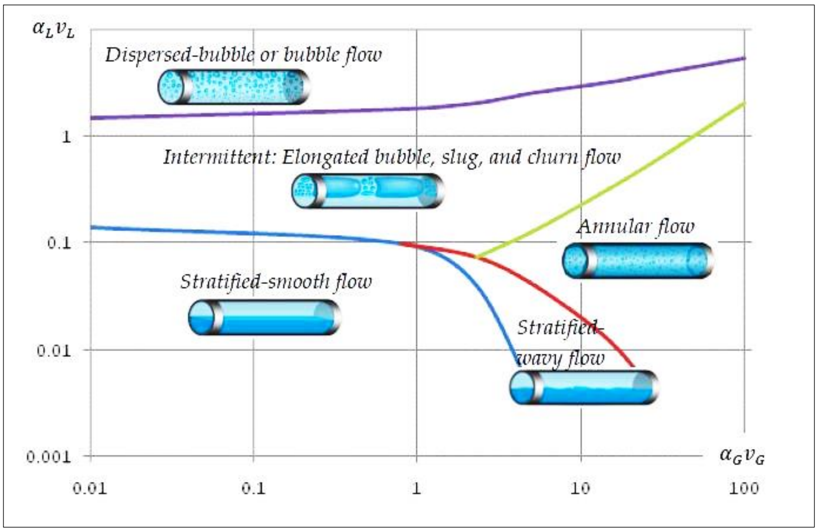


Figure 2. 1 Steady State Flow Regime Map, Horizontal Segment[7]

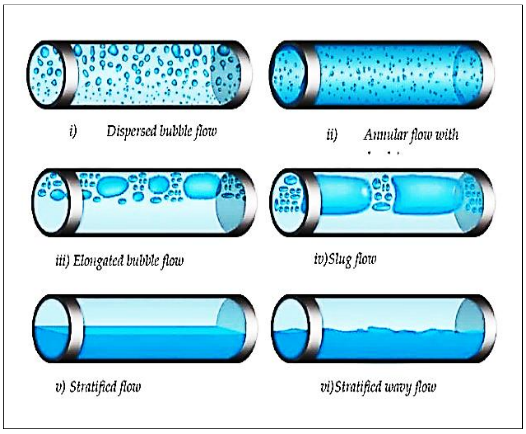


Figure 2. 2 Multiphase Flow Regime, Horizontal Segment[7]

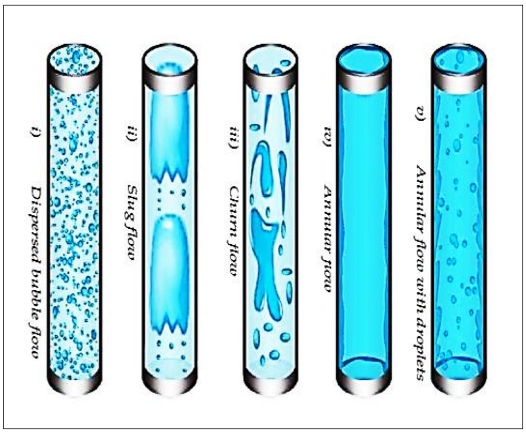


Figure 2. 3 Multiphase Flow Regime, Vertical Segment[7]

2.2 Classification of Petroleum Reservoirs

Properties of reservoir fluids are based on the depositional environment and the properties of the formation where fluid is produced. General classification of the reservoir bases on the composition and the position of the initial reservoir temperature and pressure with respect to cricondentherm and cricondenbar. A reservoir is classified as a dry gas reservoir if initial reservoir temperature is greater than cricondentherm as well as its position at surface/standard conditions is also outside of the two-phase envelope. If temperature of a reservoir is higher than cricondentherm but its position at surface conditions is within two-phase envelope then it will be classified as a wet gas reservoir. While a reservoir is classified as gas condensate if its initial temperature is less than cricondentherm but greater than mixture's critical temperature. Whereas, a reservoir is classified as volatile/black oil if its initial temperature is less than two-phase mixture's critical temperature[8]. Following Figure illustrates classification of a reservoir based on the location of its initial temperature and pressure,

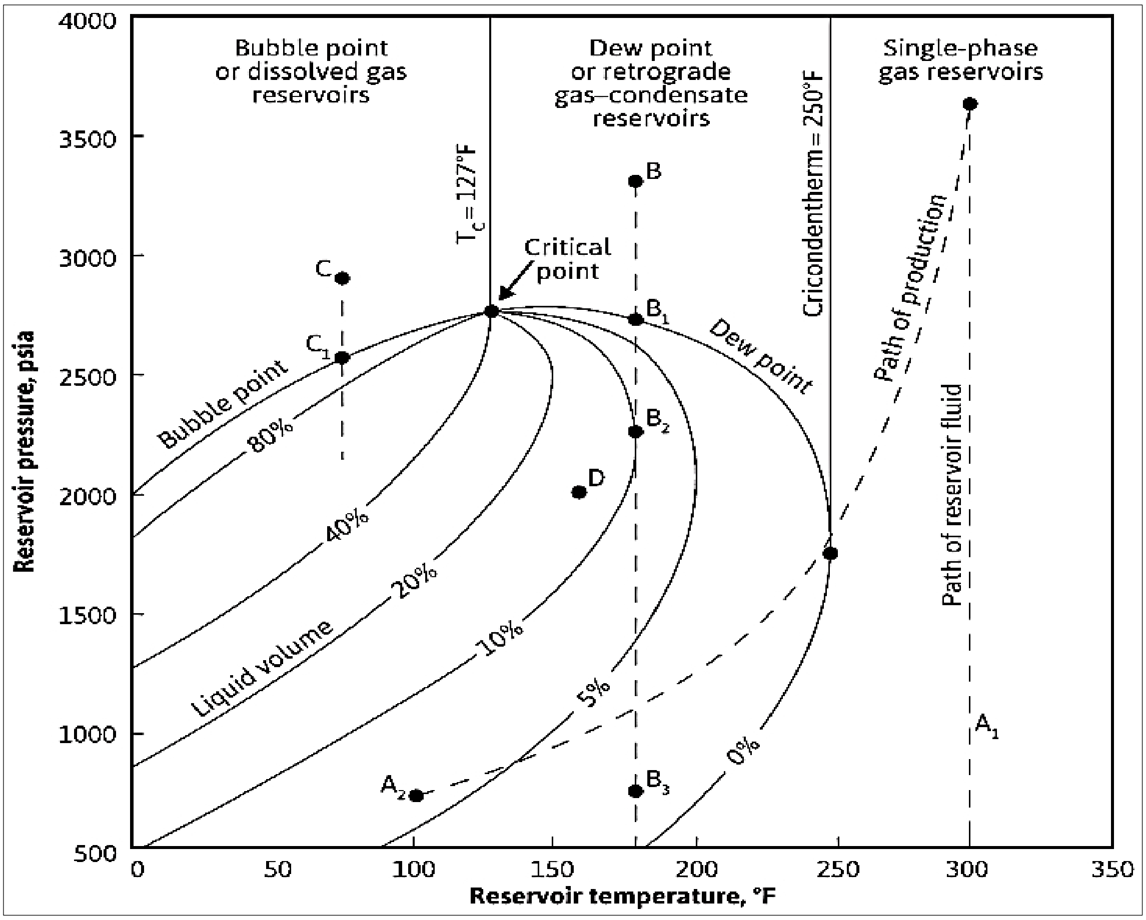


Figure 2. 4 P-T Envelope of Different Depletion Reservoirs[8]

2.3 Pressure Boosting for Multiphase Flow

Inability of reservoir's natural flowing potential to maintain certain production rate requires external pressure boosting. Conventional pressure boosting concepts in upstream oil and gas sector can be categorised as[5],

I. Gas lift
II. Downhole pressure boosters (ESPs)
III. Wellhead phase separation, followed by single phase boosting
IV. Multiphase boosting at the surface

Among all four categories, single unit multiphase boosting option covers broader range of gas volume fraction, as well as better maintenance options. In comparison with gas lift and single-phase boosting, multiphase boosters provides higher pressure boosting and do not require separation of liquid and gas streams at the surface, that mitigates requirement of surface safety equipment to deal with fire hazards[9].

Like single phase boosters, multiphase boosters may also be categorised according to various classifications. They can be classified in accordance to the design, capacity, quality of the fluid etc.

In general, multiphase boosters are normally classified according to the working principal, which can be illustrated as,

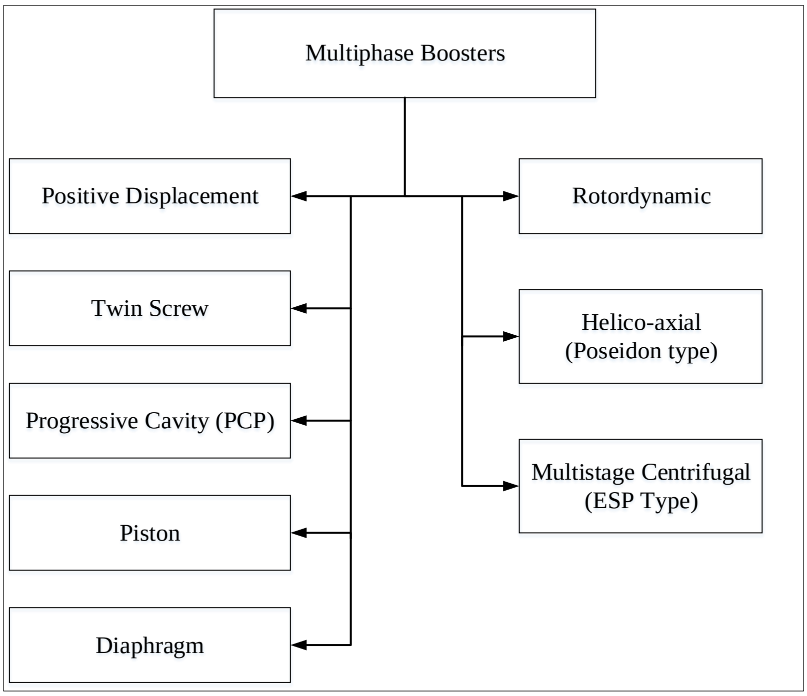


Figure 2. 5 Classification of Multiphase Boosters[10]

Like single phase liquid and gas boosters, positive displacement multiphase boosters are designed for high pressure requirement, but their applicability is limited to low GVF values. Among positive displacement boosters, twin screw boosters distinguish from others due to their capability of handling high GVF values, with rapid fluctuations[10]. Positive displacement boosters can only deal with low flow rates which reduces their application.

On the other hand, multiphase rotor dynamic boosters are like single phase rotor dynamic boosters in capabilities. They are capable of handling high flow rates with broader range of GVF. Rotor dynamic boosters having radial impellers are much close to the centrifugal single-phase boosters. Like positive displacement boosters, performance of rotor dynamic boosters also affects by increase in GVF. One of the reasons for the degradation in performance is the generation of gas pockets within impeller blades that changes angular momentum, which generates Coriolis forces. Increase in Coriolis force separates liquid and gas pockets during boosting process, which reduces head build-up per stage[6]. Electrical submersible pumps (ESPs) and hydraulic submersible boosters are based on radial impellers, therefore, their gas handling ability limits to 40 [%] [11, 12].

On the other hand, development of Coriolis forces is considerably low for semi-axial impeller. Reduction in Coriolis acceleration reduces inter-stage phase separation which enables semi-axial multiphase booster to handle high range of GVF.

Design of rotor dynamic boosters was modified in POSEIDON type booster. POSEIDON was a cooperation between French petroleum institute (IFP) and E&P companies (TOTAL S.A and STATOIL A.S.A). POSEIDON project developed a hybrid booster design by combining centrifugal and axial impellers. Such modification in design mitigated phase separation between stages. The design was based on helical impellers to increase pressure, while stationary diffusers ensures adequate mixing to ensure homogeneity of the two-phase mixture. Adequate phase mixing reduces loss of head due to phase separation and develops high pressure with relatively high efficiency[13].

2.4 Performance Predictive Models for Multiphase Boosters

Substantial research and development in the field of single phase boosting has been conducted, which has made it possible to efficiently predict the performance of the booster. Although, prediction of single phase boosting of gas phase has still some uncertainties, but flaws in calculations has been reduced to great deal by advancement in measuring technologies.

While for multiphase boosting, change in thermodynamic properties of the phases during the boosting introduces uncertainty in evaluation of the process. Several researches are based on phase homogeneity during the boosting, and thermal balance between the phases. But, such assumptions do not comply with full range of GVF[4]. Presently developed performance prediction models for multiphase boosters are based on set of assumptions, that only validates the model to certain range of gas and liquid fraction, none, of the model has been declared as robust to deal with full range of phase fractions. In below section, some of the performance prediction models for multiphase fluid boosting are present[6, 14, 15].

2.4.1 Performance Prediction Through Analytical Approach

Effect of the properties of multiphase fluid during boosting has been analysed by discretising the boosting process into segments. Each impeller of the booster is considered as a segment of the entire boosting process. Such approach has recently been employed for rotor dynamic boosters and wet gas compressors. Several experimental arrangements are under consideration to evaluate boosting performance of wet gas compressors[16]. During the experiments, various combinations of liquid and gas phase, having different volume fractions, were tested for pressure ratios, temperature ratios, phase equilibrium, ratio between power consumption etc. One constraint associated with such experiments is the dependence of the results on the geometry of the booster. To make generalised evaluations, all such measurements must be normalised with the booster design which will further increase uncertainty as the booster having different geometry may yield high errors if the model normalised for the experimental booster's geometry is used. During the measurement for multiphase fluid boosting using helicoaxial type impeller, Ramberg[4] considered change in hydrostatic head for multiphase fluid in comparison with hydrostatic head for single phase fluid; keeping inlet pressure, temperature, speed of the booster and design of the impeller as constant. Ramberg analysed change in the head with respect to the ratio of fluid's intrinsic properties like density/ viscosity against inlet parameters such as pressure and temperature. By experimental results, Ramberg expressed change in multiphase head with respect to single phase head in terms of head correction factor, and related the correction factor in terms of gas volume factor and density ratio. Assumptions for Ramberg's model is the homogeneity of the phases, and the density of two phases was related with gas volume factor, neglecting phase slip during the boosting process. Following equations represents the model that Ramberg presented in his research,

$$H_{MP} = H_{SP}.\left(\frac{\rho_{MP}}{\rho_{SP}}\right).(1 + \alpha_G) \quad \text{Eq. 2.13}$$

$$H_{MP} = \left(Correction\ factor, \mathfrak{f}_{TP,H}\right).H_{SP} \quad \text{Eq. 2.14}$$

$$\mathfrak{f}_{TP,H} = (1 + \alpha_G.\left(\frac{1}{\left(\frac{\rho_{MP}}{\rho_{SP}}\right) - 1}\right).(1 + \alpha_G) \quad \text{Eq. 2.15}$$

2.4.2 Performance Prediction Through Empirical Model

In empirical modelling of multiphase fluid boosting, analogy between single phase and multiphase fluid was tried to be developed through similarity laws. Since, similarity laws depend upon impeller's geometry, therefore, all such empirical models are limited to specific design of booster's impellers. Based on similarity laws, degradation in head for multiphase fluid was compared with single phase fluid and degradation factors for head, pressure and efficiency were presented as,

$$Head\ coefficient, \Psi = \left(\frac{H}{N^2.D^2}\right) \quad \text{Eq. 2.16}$$

$$Head\ degradation\ factor, \mathfrak{f}_{TP,Head} = \left(\frac{\Psi_{TP}}{\Psi_{SP}}\right) \quad \text{Eq. 2.17}$$

$$Pressure\ degradation\ factor, \mathfrak{f}_{TP,Pressure} = (\frac{p_{TP}}{p_{SP}}) \quad \text{Eq. 2.18}$$

$$Efficiency\ degradation\ factor, \mathfrak{f}_{TP,Efficiency} = \left(\frac{\eta_{TP}}{\eta_{SP}}\right) \quad \text{Eq. 2.19}$$

2.4.3 MIT Model for Performance Prediction

During research in Massachusetts Institute of Technology (MIT), dependence of head degradation due to multiphase in comparison with the head degradation due to single phase was reduced by normalizing the head. Head was normalized by considering difference in calculated and measured head for both of multiphase and single-phase fluid. Such modification substantially reduced the dependence of measurement over impeller's geometry. This model has been recognised as MIT model and was presented by J.E Korenchan[17]. Unlike Ramberg's model, MIT model considers phase slip ratio during boosting, as it is required to calculate fluid flow angle at the booster outlet, as well as to calculated two phase flow function. Following equations represents MIT model for multiphase fluid boosting,

$$Normalised\ head, H^* = \frac{\Psi_{TP,Theoretical} - \Psi_{TP,Measured}}{\Psi_{SP,Theoretical} - \Psi_{SP,Measured}} \qquad \text{Eq. 2.20}$$

$$Two\ phase\ head\ degradation\ factor, \Psi_{TP} = 1 - \left(\frac{f_{TP,flow}\Phi_{TP2}}{Tan\beta_2}\right) \qquad \text{Eq. 2.21}$$

2.4.4 Homogeneous Model for Multiphase Fluid Boosting

In homogeneous multiphase fluid model, phases are assumed to remain homogeneous throughout the boosting process. In such assumption, phase distribution for high gas volume ratio has been neglected. Phase separation can occur due to gas locking within impeller that violates assumption of uniform density of the phases. Homogenous model was tested for electrical submersible boosters and results were complying the homogenous fluid assumption[18]. Since electrical submersible boosters are designed for low GVFs i.e. 0-40 [%], so, it may be anticipated that fluid behave as homogeneous for either very low or very high value of GVF. Low GVF fluid behaves like single phase liquid (e.g. liquid boosters) while the high GVF fluids behave like single phase gas (e.g. wet gas compressors). Ramberg[4] also assumed homogenous properties of the fluid, and his model yielded satisfactory results for GVF from 0 - 60[%]. Therefore, homogenous fluid model may adapt for low gas contents, while phase separation should be considered for high gas contents. Following equations summarises homogeneous fluid model,

$$\rho_{MP} = \alpha_G.\rho_G + (1 - \alpha_G).\rho_L \qquad \text{Eq. 2.22}$$

$$Head, H_{MP} = \left(\frac{\Delta\, p}{g.\rho_{MP}}\right) \qquad \text{Eq. 2.23}$$

2.4.5 Direct Integration Approach (DIA)

Schultz J.M[19] predicted compression path of the gas on the basis of average specific volume. Such assumption results in significant difference from practical results with theoretical predictions, as neither thermodynamic properties remain consistent during the boosting process nor the specific volume. Huntington[15] improved the predictive method for polytropic gas compression path by distributing it into small segments, such that specific volume will remain constant within the segment. Then the evaluated polytropic head developed within each segment was integrated to find the total head.

$$Total\ Head, H = \int v_{AVG}.\Delta\, p \qquad \text{Eq. 2.24}$$

By discretizing the boosting path into segments, Huntington's approach resulted in better estimation of fluid's thermodynamic properties. Huntington named such approach as a reference or a direct integration approach. Hundseid[20] implemented direct integration approach to evaluate performance of multiphase fluid boosting and analysed the phase equilibrium during the boosting. In direct integration approach, phases are assumed to be in complete equilibrium which does not comply with test results for multiphase boosters[16].

Direct integration approach considers the phase transformation during the boosting. Impact of phase change on the head can be analysed by discretizing the boosting process into segments and analysing the net impact of boosting over the composition and thermodynamic properties of the phases. Commercial process simulators such as Aspen Hysys can be used to obtain thermodynamic properties. By using Aspen Hysys' results, a comparative analysis can be made by comparing the Hysys' output with the experimental results. Difference among the two may result in phase change correction factor, that may further improve the results of homogeneous fluid model for the GVF of 60 [%] and above.

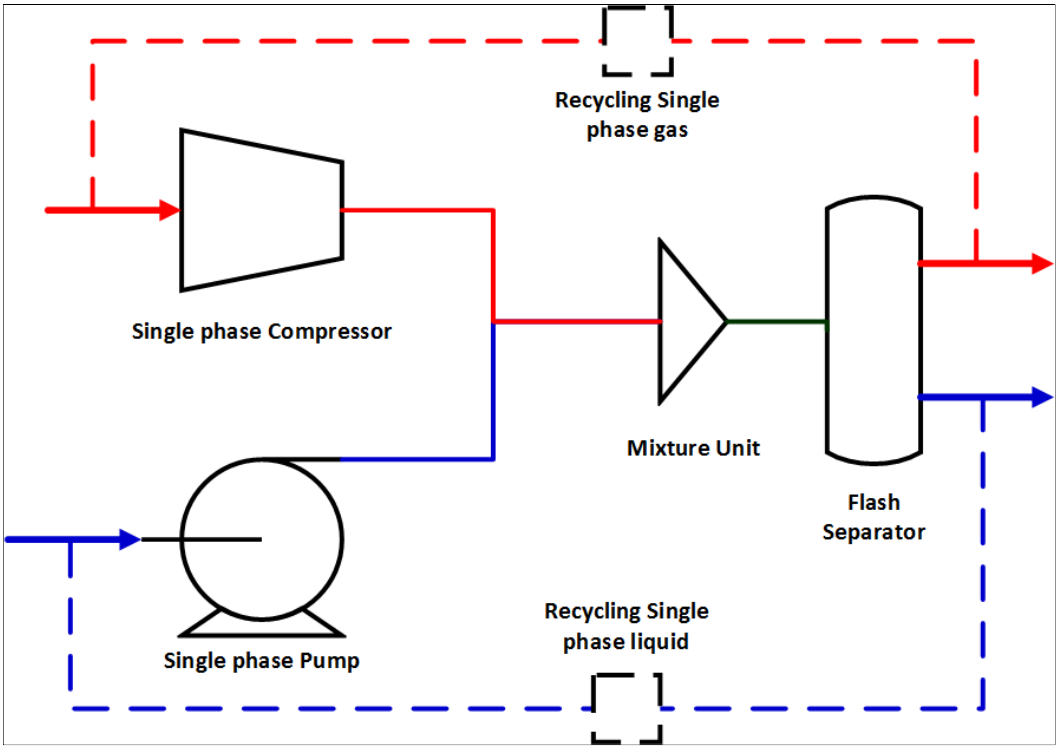


Figure 2. 6 Proposed Hysys Model for Direct Integration Approach(DIA)

2.4.6 Liquid Evaporation Model for Multiphase Fluid Boosting

Liquid evaporation model was tested for wet gas compressors, considering liquid to be in the droplet form. This model integrates thermal model of the liquid and compression model of the gas. During each boosting step, both temperature and pressure of the liquid droplet varies, that incurs change in its thermodynamic properties. By evaluating enthalpy of evaporation, such model predicts change in phase fraction during boosting[21]

2.5 Multiphase Boosting Head Calculations

Considering homogeneous fluid model, head developed during multiphase boosting can be defined on the basis of volume fractions or the mass fractions. Following are few definitions and equations that can be used to evaluate the multiphase boosting,

a) Isentropic Head

Isentropic head of the multiphase boosting can be evaluated using gas mass fraction (β)

$$H_{isentropic} = \frac{\beta . R . k . Z_{in} . T_{in}}{\gamma_g . MM_{air} . g . (k-1)} * \left(\left(\frac{p_{out}}{p_{in}} \right)^{\frac{k-1}{k}} - 1 \right) + \frac{(1-\beta) . dp}{\rho_l . g} \quad \text{Eq. 2.25}$$

b) Isothermal Head

Isothermal head of the multiphase boosting can be evaluated using gas mass fraction (β)

$$H_{isothermal} = \frac{\beta . R . Z_{avg} . T_{in}}{\gamma_g . MM_{air} . g} * \ln \left(\frac{p_{out}}{p_{in}} \right) + \frac{(1-\beta) . dp}{\rho_l . g} \quad \text{Eq. 2.26}$$

c) Polytropic Head

Isothermal head of the multiphase boosting can be evaluated using gas mass fraction (β)

$$H_{polytropic} = \frac{\beta . R . n . Z_{in} . T_{in}}{\gamma_g . MM_{air} . g . (n-1)} * \left(\left(\frac{p_{out}}{p_{in}} \right)^{\frac{n-1}{n}} - 1 \right) + \frac{(1-\beta) . dp}{\rho_l . g} \quad \text{Eq. 2.27}$$

2.6 Generic Performance Map of a Multiphase Booster

In literature, a typical performance map of a multiphase booster is different from the map of a single-phase booster. Single-phase boosters generally have parabolic curves for both of iso-speed and iso-power envelop. While in literature, slanted profile for both of iso-speed and iso-power curves are presented. In the commercial network, the performance maps for multiphase boosters depict straight line, with negative slopes, from the minimum flow line to the maximum flow point. In contrast to the single-phase booster’s map, maximum flow limit is not considered in the performance map obtained from the network simulators. Following map is obtained from PIPESIM for the booster model Hx-310_1100_120 of Framo 2009 multiphase boosters (Hx series).

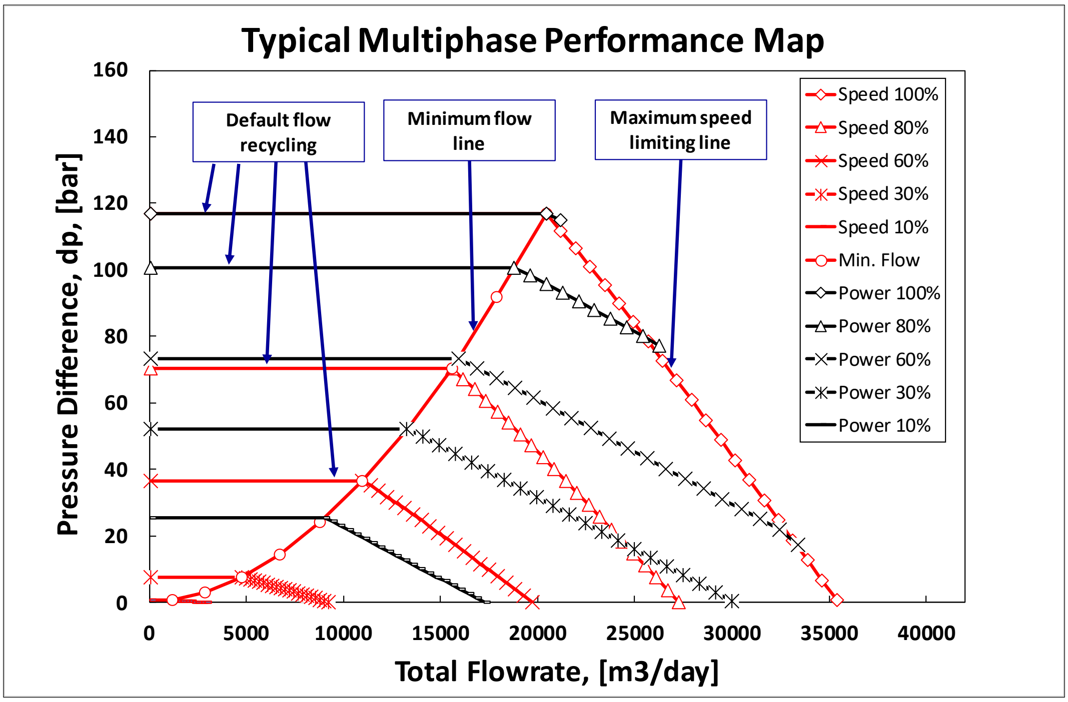


Figure 2. 7 Generic Multiphase Performance Map, Obtained from PIPESIM

As evident from Figure 2.7, the software automatically yields maximum pressure difference for the flow rate less than minimum flow value for each speed/power value. After minimum flow line, both the iso-power and iso-speed curves linearly declines towards the x-axis to indicate maximum flow handling ability for each speed/power curve. In the map, both the speeds and powers are mentioned in percentage of the respective maximum value. In the Figure 2.7, 100 [%] speed indicates the upper bound of the map, which is also the design limit of the booster. At 100 [%] speed, all the iso-speed and iso-power curves merge on the 100 [%] speed curve.

In the thesis, iso-power curves are not considered for any analysis, as all the curves merge to 100 [%] speed curve; and by using only iso-speed curves, the maximum range of the map can be obtained. Therefore, all the performance maps included in the later sections of the report contains only the iso-speed maps.

CHAPTER 3 SELECTION CRITERIA FOR MULTIPHASE BOOSTERS

Task (ii) and (iii) of the thesis combinedly demands to utilize data of the multiphase boosters available in the commercial network simulators, and to develop an Ms Excel utility that will take field data as an input and propose the best suited booster model along with the optimum serial/parallel operational configuration.

Being relatively new in the industry, multiphase booster's application lacks the availability of robust performance prediction models that limits the evaluation of the booster model during the varying field properties such as water-cut or GVF. Efficient field development study related to pressure boosting requires an optimized selection of the booster to cope-up with the all possible variation in the field's specifications during the life of the field. Commercial network simulators only contain helicoaxial design models of multiphase boosters of Framo Engineering. To select the optimum booster, it is either required to use the actual design equation being used by these software for all available booster models, or by evaluating the performance of the booster through automation. To fulfil the subject task, modelling of design equation was attempted, however, none of the hypothesis justified the results pertain to the relation between the phase fraction and the output of the booster.

Since the attempt to model a design equation was unsuccessful, so, direct use of the booster output data from the software was preferred for the subject task.

3.1 Uncertainty in GAP and PIPESIM Results

Unlike single phase booster models, methodology to evaluate the performance of the multiphase booster is unclear in GAP and PIPESIM. Upon test, it was observed that the GAP and the PIPESIM are following different methodology to evaluate the performance of the multiphase booster.

To compare the output of the PIPESIM and the GAP, Framo multiphase booster model Hx-310_1100_120 was tested with similar fluid properties and booster inlet conditions. For fluid property calculations, Black Oil (BO) fluid model was used in both software, and Standings correlation for GOR, and Beggs & Robinson correlation for the viscosity was used with similar calibration data.

At 100 [%] speed, both software yielded entirely different results. Comparison of results of the GAP and the PIPESIM is listed below,

Table 3. 1 Comparison Between GAP and PIPESIM Output

Property	Value		Units
	PIPESIM	GAP	
Density of oil	800	800	[kg/m^3]
Specific gravity of gas	0.56	0.56	[-]
Standard flow rate of oil	2000	2000	[Sm^3/day]
Standard flow rate of gas	20000	20000	[Sm^3/day]
Inlet pressure	10	10	[bara]
Inlet temperature	15.56	15.56	[°C]
Results from the Software			
Outlet pressure	105.34	120.11	[bara]
Outlet temperature	21.803	76.97	[°C]
GVF	50	32.69	[%]

Test results clearly indicates substantial variation in the results. PIPESIM is evaluating the booster performance at inlet conditions, whereas, GAP is considering GVF at the average conditions of booster inlet and outlet. Furthermore, approximately 6 [°C] temperature raised during boosting according to the results of PIPESIM, while, GAP yielded 61 [°C] temperature rise. Such inconsistency in the results introduces uncertainty in predicted output of the method as PIPESIM may be evaluating the multiphase booster output using isentropic model while GAP may be considering polytropic model to evaluate the performance of the same booster.

In addition to above, for the same multiphase booster model, GAP's database indicates maximum differential pressure higher than PIPESIM. Such as for the booster model of Hx-310_1100_120, maximum pressure difference of 174 [bara] is mentioned in GAP's database, whereas, the PIPESIM indicates maximum pressure difference of 120 [bar], which is similar to what indicated by the model number. Similarly, maximum limit for GVF was mentioned as 0.65 in the database of the GAP, while the PIPESIM does not indicate any such limitation.

Above uncertainties in the multiphase booster's output demands to choose either the GAP or the PIPESIM to obtain the necessary data as both software sre following significantly different methodologies. Due to relative ease in acquiring data, PIPESIM is selected to obtain all necessary information, that was further used to fulfil the objective of the task (ii) and (iii).

3.2 Investigation for Multiphase Booster Model

Appropriate approach to predict performance output of the booster requires to analyse the output of the booster at variant inputs. Then, obtained results should be analysed to develop a single relation to predict output of the multiphase booster.

To initiate the analysis, a simple PIPESIM model was developed, and output data of the booster was plotted to compare the results. Figure 3.1, represents the model developed in the PIPESIM,

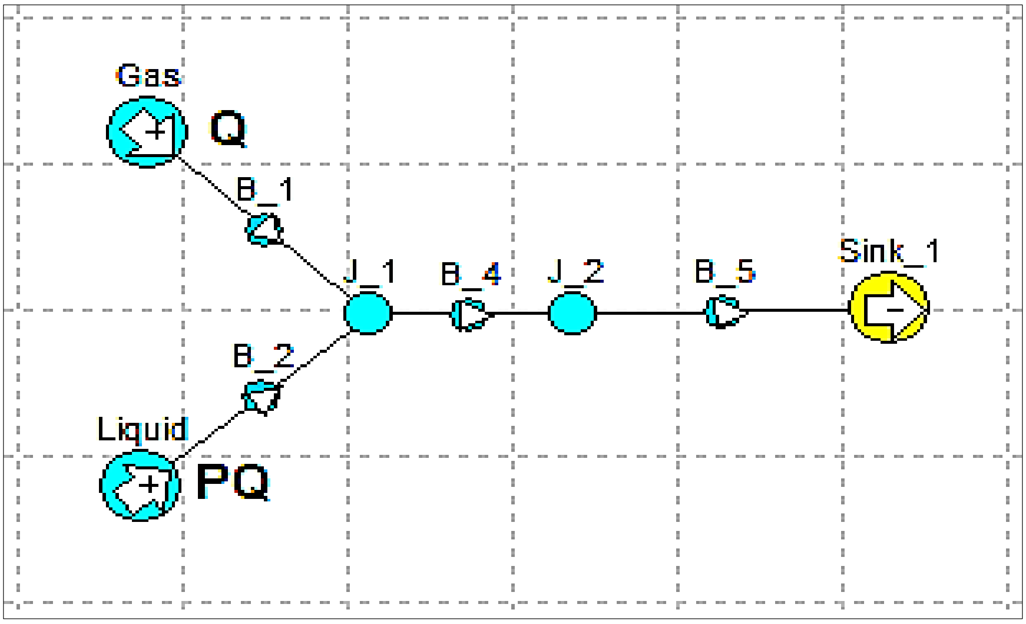


Figure 3. 1 PIPESIM Model to Obtain Multiphase Booster Data

To analyse the booster performance, multiphase booster model Hx-310_1100_120 was used with different combinations of oil/gas, water/gas and water/air having different densities of oil and gas, as well as water having different densities to mitigate the impact of viscosity correction. For the analysis, the performance map based on the speed [%] was used. As evident in the Figure 3.2, the outlet pressure at each speed remains constant for the flow rate lower than minimum flow value. Once the value of the flow rate reaches the minimum flowline, then the curve declines linearly until it reaches the maximum flow value. In PIPESIM, the flow rate lesser than minimum flow rate is considered as recycling flow, and it does not consider in calculating the head against the flow rate at given speed.

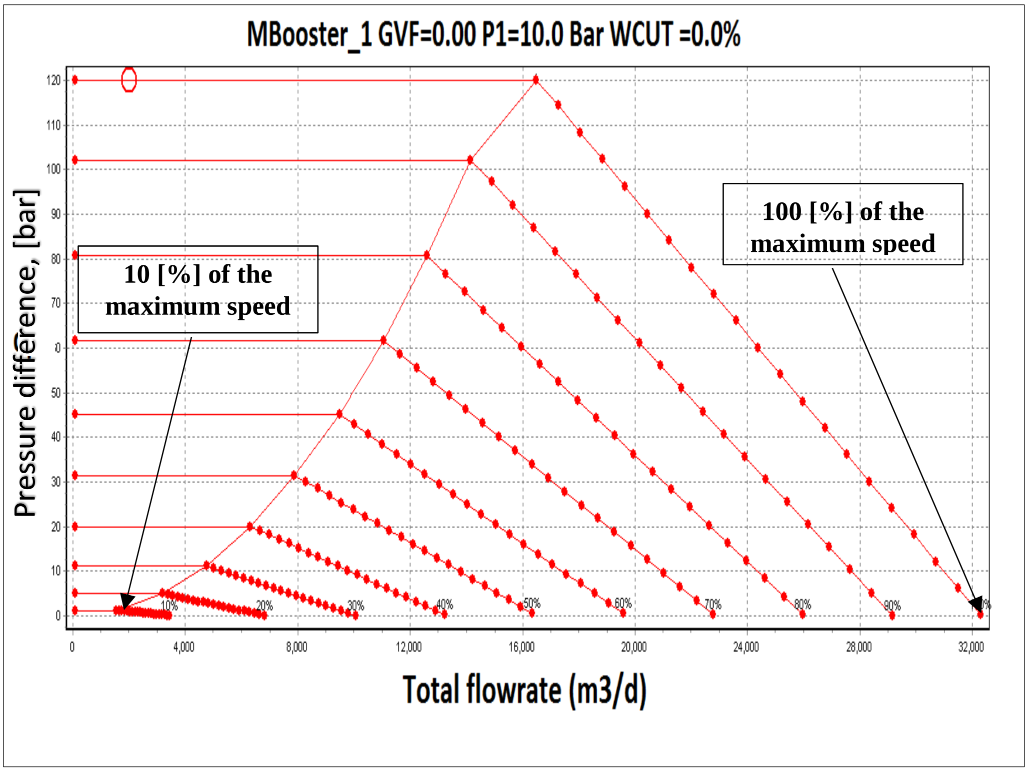


Figure 3. 2 Multiphase Booster's Iso-speed Performance Map

With rise in GVF, PIPESIM indicates change in performance curve towards right hand side, along with certain change in slope of minimum flow line. Such response was observed upon plotting minimum flow lines of two different fluid compositions at different GVFs.

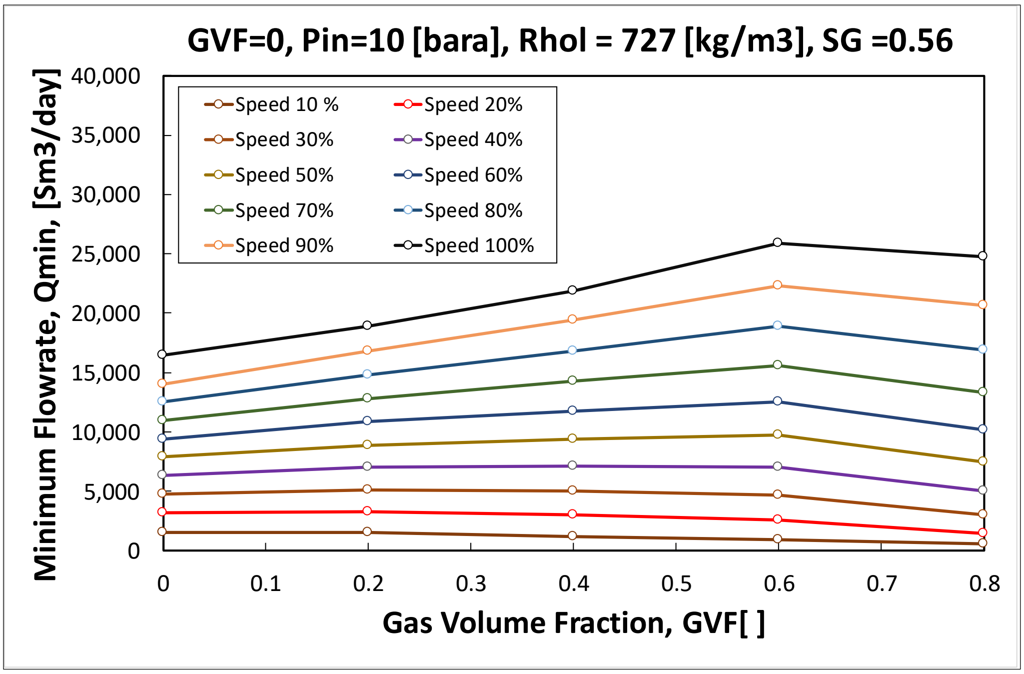


Figure 3. 3 Variation in Minimum Flow Line w.r.t GVF

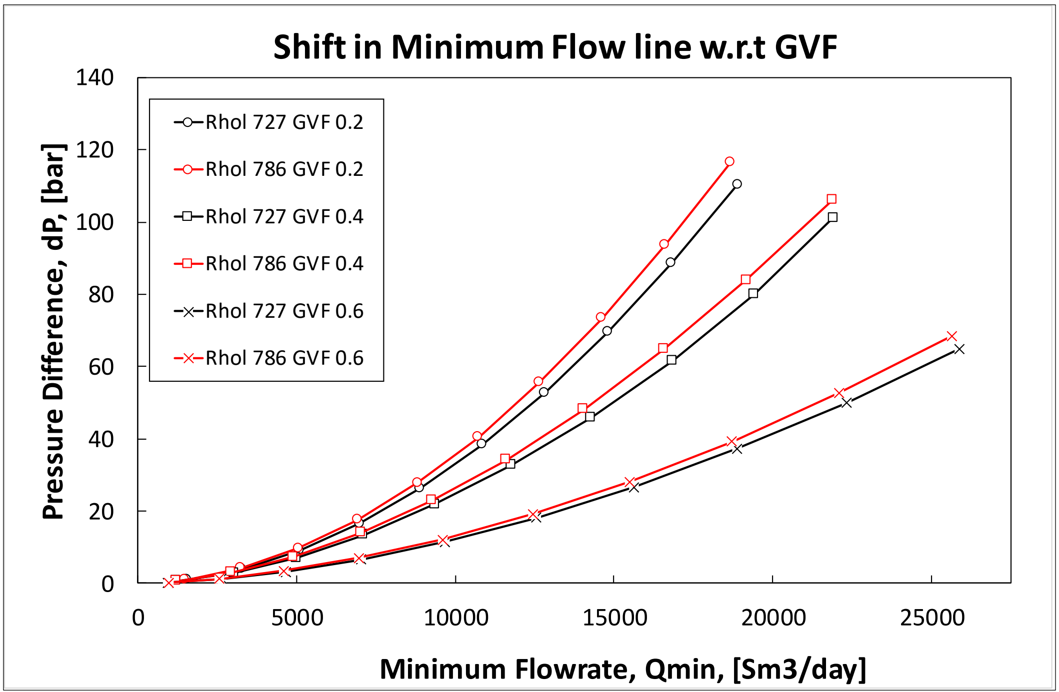


Figure 3. 4 Decline in Minimum Flow Line w.r.t Density

Figure 3.5 indicates definite change in minimum flow lines with rise in GVF. Response of both fluids for all three GVFs remain identical. Furthermore, definite decline in performance for low density fluid is evident for higher booster speeds, whereas, low booster speed's output does not indicate notable change. In addition to above, the definite change in performance map's trend can be witnessed for the GVF 80[%]. Such drastic change validates the limitation of GVF up to 65[%], as mentioned in the GAP's database.

PIPESIM clearly mentions correction for the viscosity in the user manual, if fluid's viscosity is other than 6 [cP], then the output will be corrected for the viscosity difference. Furthermore, evaluation of boosting for multiphase fluid was observed to be isothermal in accordance to PIPESIM results. Therefore, an analogy between multiphase boosting and single-phase boosting was tried to establish through generation of the performance map between total flow rate at actual conditions versus isothermal head of the fluid. As adiabatic head for single phase fluid remains constant at the given impeller size and frequency, so, it was presumed that isothermal head for multiphase fluid will also remain same. As investigation for the effect of viscosity is not considered in the thesis, so, the fluid model of water was altered, such that specific gravity of the gas phase was kept at 0.787, whereas, density of water was varied to 1000 [kg/m^3], 800 [kg/m^3] and 700 [kg/m^3], to mitigate the effect of viscosity in the calculations. Upon overlapping the performance map for different fluid combinations, following performance maps were obtained,

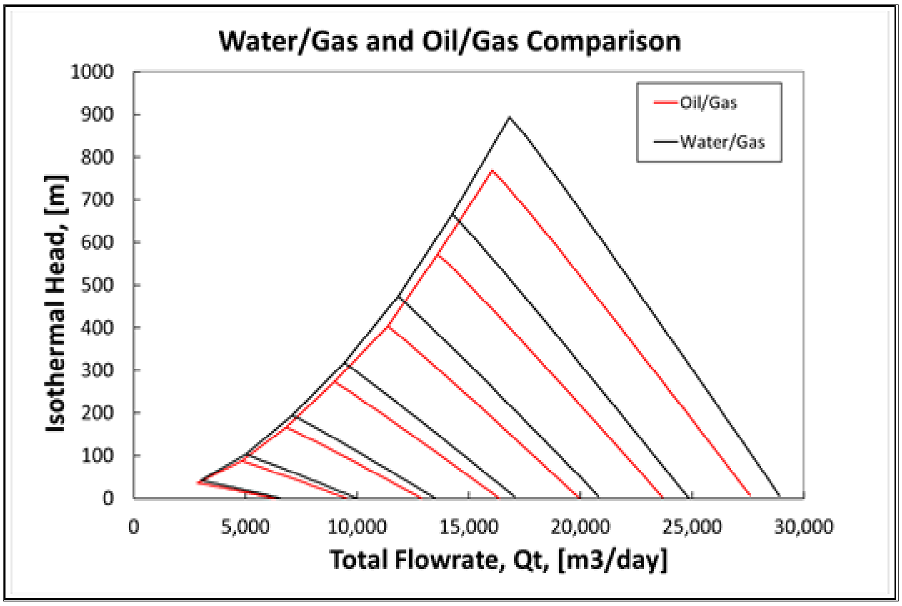


Figure 3. 5 Iso-speed Performance Map for Oil/Gas and Water/Gas, GVF=40[%]

Comparison between performance map of the fluid combinations of oil/gas and water/gas indicates profound difference. Such difference provides concrete evidence about change in isothermal head with respect to the change in the density of the fluid. Therefore, it may be declared that the application of similarity laws in the case of multiphase fluid boosting is not as simple as in the case of single phase fluid. Variation in isothermal head may either require a head correction factor, or a new definition of the multiphase booster head.

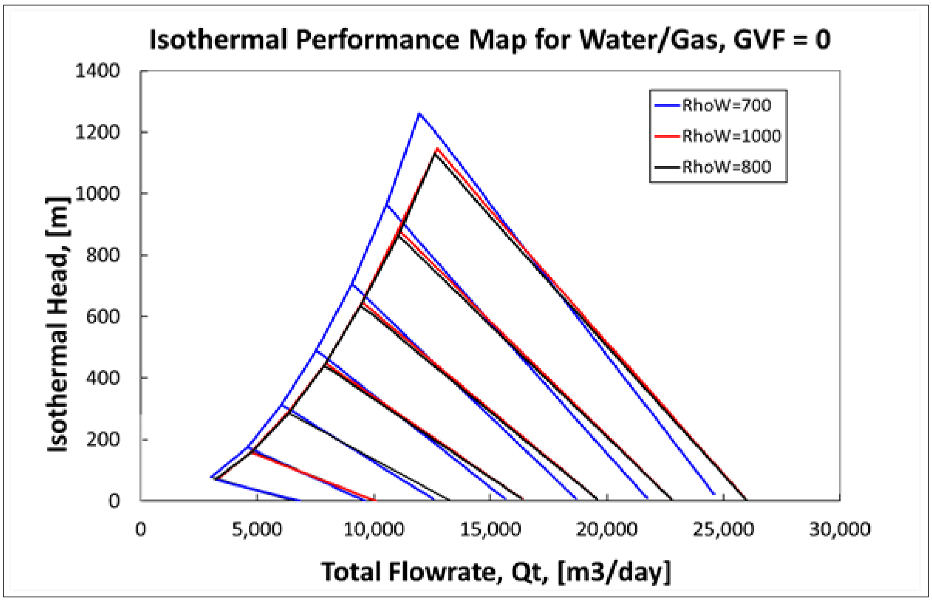


Figure 3. 6 Iso-speed Performance Map with Different Water Densities, GVF=0[%]

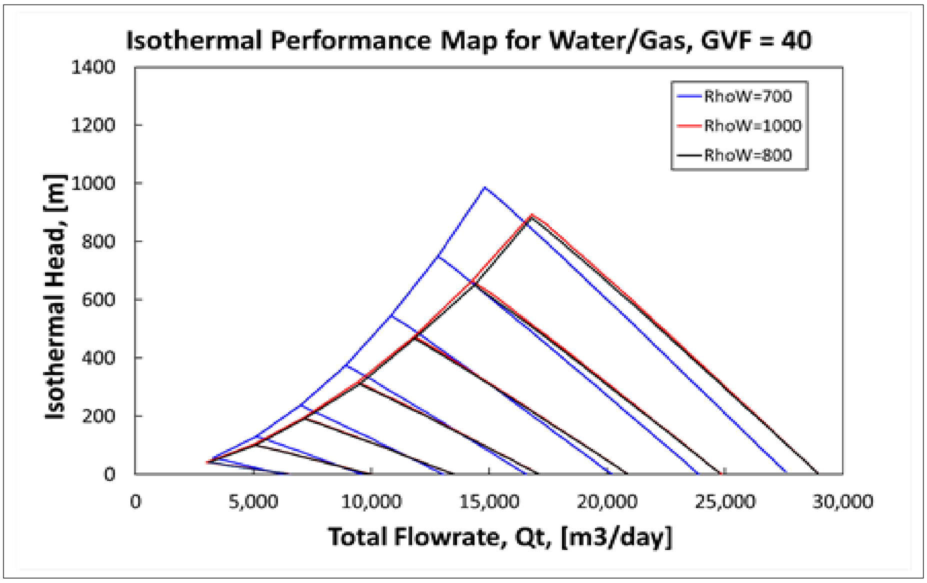


Figure 3. 7 Iso-speed Performance Map with Different Water Densities, GVF=0[%]

Figure 3.6 and 3.7 indicates that using with water with different densities does not mitigates the correction for the viscosity, as bot Figures contains completely non-overlapping maps.

Performance maps with the combination of the fluid having water having three different densities of water as liquid phase and gas having specific gravity 0.787, clearly indicates that the change in performance map is not only due to the correction for viscosity. As black oil model was used for fluid's property calculations, so, the change in density caused the change in the viscosity as well. Therefore, approach used to mitigate the effect of viscosity by changing the density was not aborted, as the results did not validate the hypothesis pertain to constant viscosity of water.

Such results indicate the requirement of head correction factor, as any simplistic hypothesis about the methodology to evaluate the multiphase boosting process, analogous to the methodology for single phase boosting, cannot be applied.

Therefore, development of a unique multiphase fluid boosting evaluation model was not considered to fulfil the subject task, and the adapted methodology was restricted to the empirical relation between the Data Obtained From PIPESIM.

3.3 Methodology for Optimum Booster Selection

The data obtained from PIPESIM for multiphase booster's iso-speed map was processed to develop an empirical relations that was further used to develop a full map similar to what produced by PIPESIM.

To organize the database, Framo 2009 multiphase booster models, available in the list of the multiphase booster category was categorised in accordance with the booster pressure rating. In total, thirteen boosters are available in the list which were categorised as following,

Table 3. 2 Classification of Framo 2009 Multiphase Boosters (Hx series)

Maximum pressure boosting, dp = 38 [bar] Booster Model#	Maximum pressure boosting, dp = 45 [bar] Booster Model#	Maximum pressure boosting, dp = 120 [bar] Booster Model#	Maximum pressure boosting, dp = 180 [bar] Booster Model#
360_1200_38	310_500_45	310_600_120	310_250_180
360_1500_38	310_700_45	310_800_120	310_400_180
360_1800_38	310_900_45	310_1100_120	310_500_180
	310_1100_45		

Shape of the performance maps obtained from PIPESIM can be categorised into two types. First type of the map is for the boosters having boosting pressure limit of 120 [bar] and 180 [bar], while the second type is for the boosters having pressure difference rating of 38 [bar] and 45 [bar]. Following Figures represents the performance maps obtained from PIPESIM for each category of the booster,

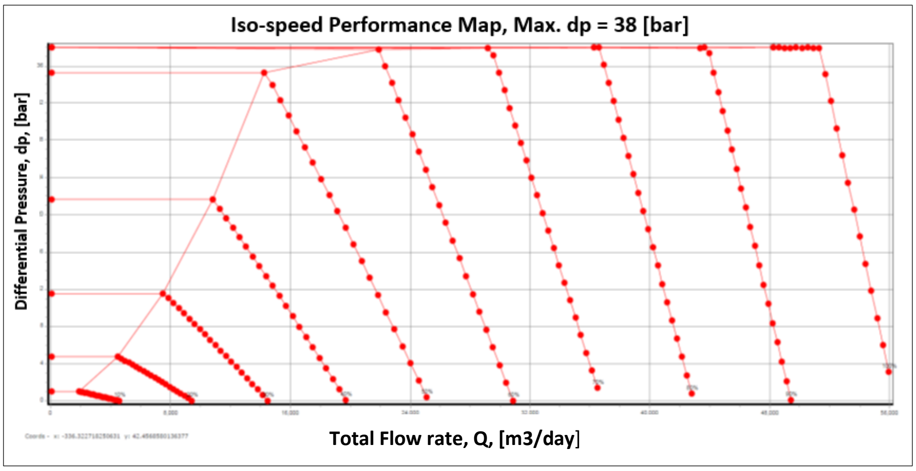


Figure 3. 8 Typical Iso-Speed Performance Map, Max. dp = 38 [bar], from PIPESIM

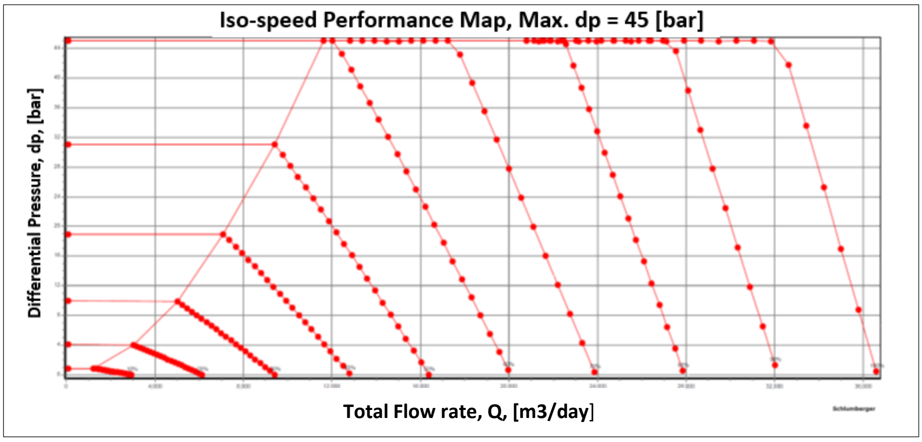


Figure 3. 9 Typical Iso-Speed Performance Map, Max. dp = 45 [bar], from PIPESIM

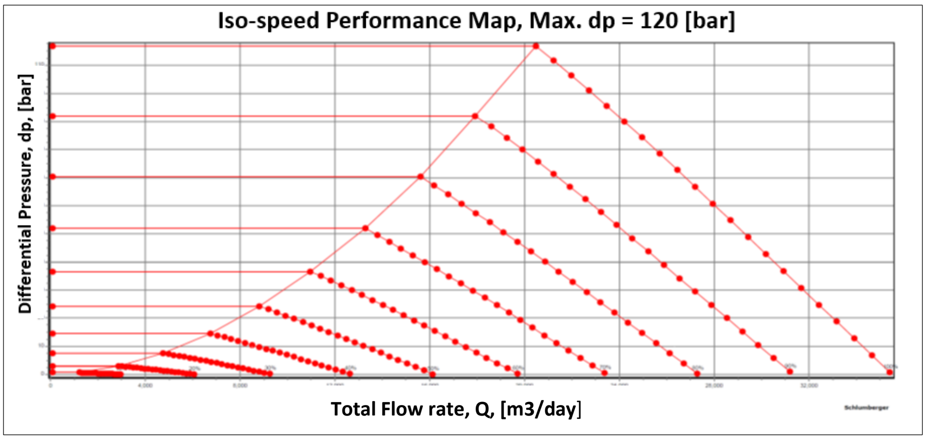


Figure 3. 10 Typical Iso-Speed Performance Map, Max. dp = 120 [bar], from PIPESIM

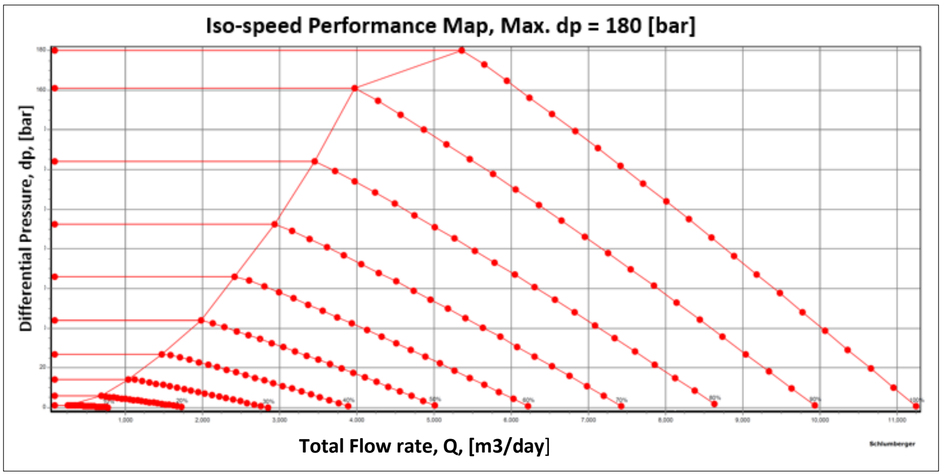


Figure 3. 11 Typical Iso-Speed Performance Map, Max. dp = 180 [bar], from PIPESIM

As evident from above maps, PIPESIM yields a regular map for the booster having maximum pressure boosting rating of 120 [bar] and 180 [bar]. While the performance maps of the boosters having maximum pressure difference rating of 38 [bar] and 45 [bar] indicates overlapping of speed curves over the speed of 50[%] and above.

To develop any empirical relation, it is necessary to have certain variation in one parameter with respect to the change in other. Considering performance of pressure boosting rating of 120 [bar] and 180 [bar], each speed curve has definite separation from the adjacent curves that can be easily processed to develop an empirical relation. To develop a relation for the booster output, Ms Excel's default polynomial regression procedure was used to develop a relation. Such methodology is expected to generate a polynomial relation with relatively better precision for the boosters with maximum pressure boosting rating of 120[bar] and 180[bar]. However, same methodology will lead to considerable error in the relation for low boosting ranged models, as speed curves overlaps.

As the main objective of the subject task is to devise a method that may indicate the best possible booster model and best operating configuration, so, it may be assumed that the error associated with low pressure boosting models will provide a marginal map that should only be used as an initial reference.

3.4 Procedure to Develop Empirical Relation

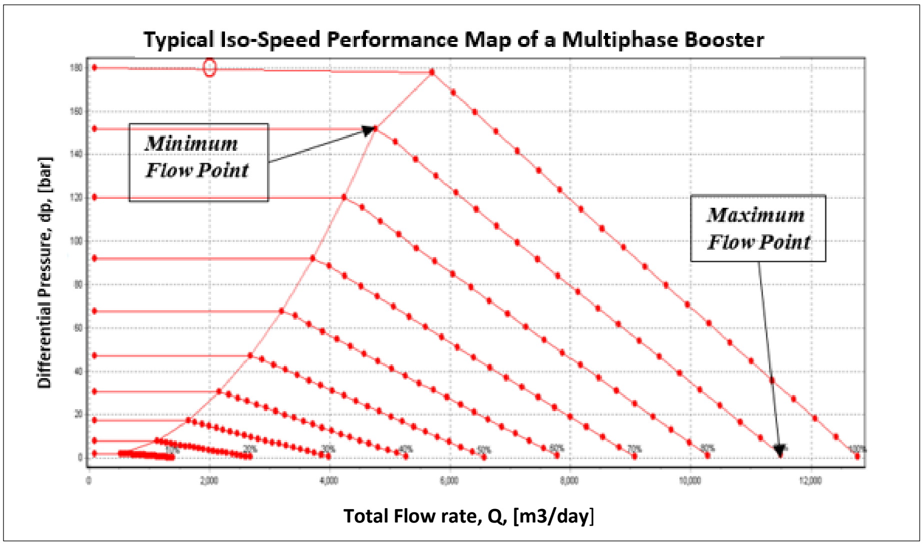


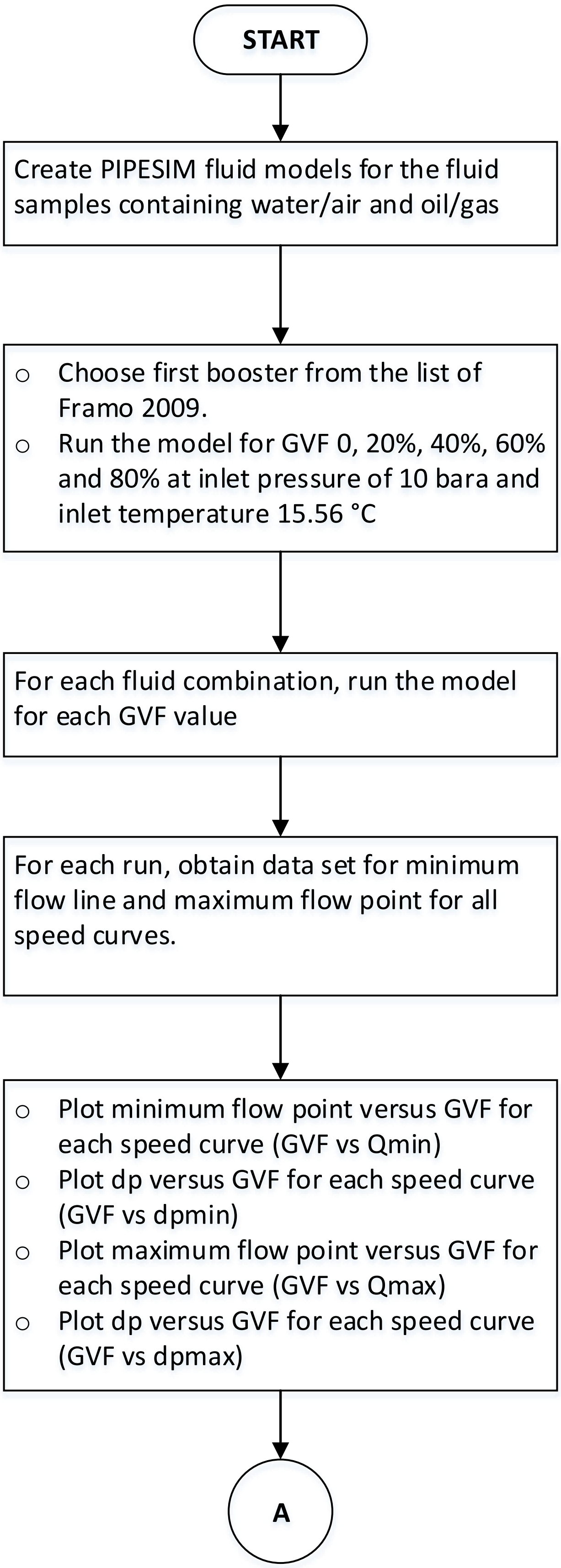
Figure 3. 12 Typical Iso-speed Performance Map of a Multiphase Booster, from PIPESIM

Figure 3.12 represents the iso-speed performance map for the multiphase booster model Hx-310_1100_120. The map shows a straight line between maximum flow rate and minimum flow rate points for each speed curve. While Figure 3.3 and 3.4 indicates the change in minimum flow line by changing GVF and the density of the fluid.

As shown in Figure 3.4 – 3.8, increase in GVF moves the minimum flow line towards right, which reduces the total area of the envelop. This response will remain consistent from GVF of 0-65[%]. However, GVF above 65[%] will involve certain error in the analysis. Similar behaviour has been observed for maximum flow points. Therefore, it is devised to develop a robust function of minimum flowline's points and maximum flow points for each speed, and against each GVF; then a straight line is drawn between these two points. By doing so, the iso-speed performance curves for all speeds can be generated.

As indicated in Figure 3.6, the performance map varies with respect to the change in fluid type/density and GVF. Since, impact of density of the fluid has not been precisely identified, therefore, the methodology will cover fluid combination of water/air and oil/gas (water density=1000 [kg/m^3], oil density = 800 [kg/m^3] and gas specific gravity of 0.787). Then density corrected data will be populated by linearly interpolating the flow points of both combinations of the fluid.

The methodology to develop a polynomial for minimum flow line and maximum flow points can be represented through following flow diagram,


START
Create PIPESIM fluid models for the fluid samples containing water/air and oil/gas
Choose first booster from the list of Framo 2009.
Run the model for GVF 0, 20%, 40%, 60% and 80% at inlet pressure of 10 bara and inlet temperature 15.56 °C
For each fluid combination, run the model for each GVF value
For each run, obtain data set for minimum flow line and maximum flow point for all speed curves.
Plot minimum flow point versus GVF for each speed curve (GVF vs Qmin)
Plot dp versus GVF for each speed curve (GVF vs dpmin)
Plot maximum flow point versus GVF for each speed curve (GVF vs Qmax)
Plot dp versus GVF for each speed curve (GVF vs dpmax)
A

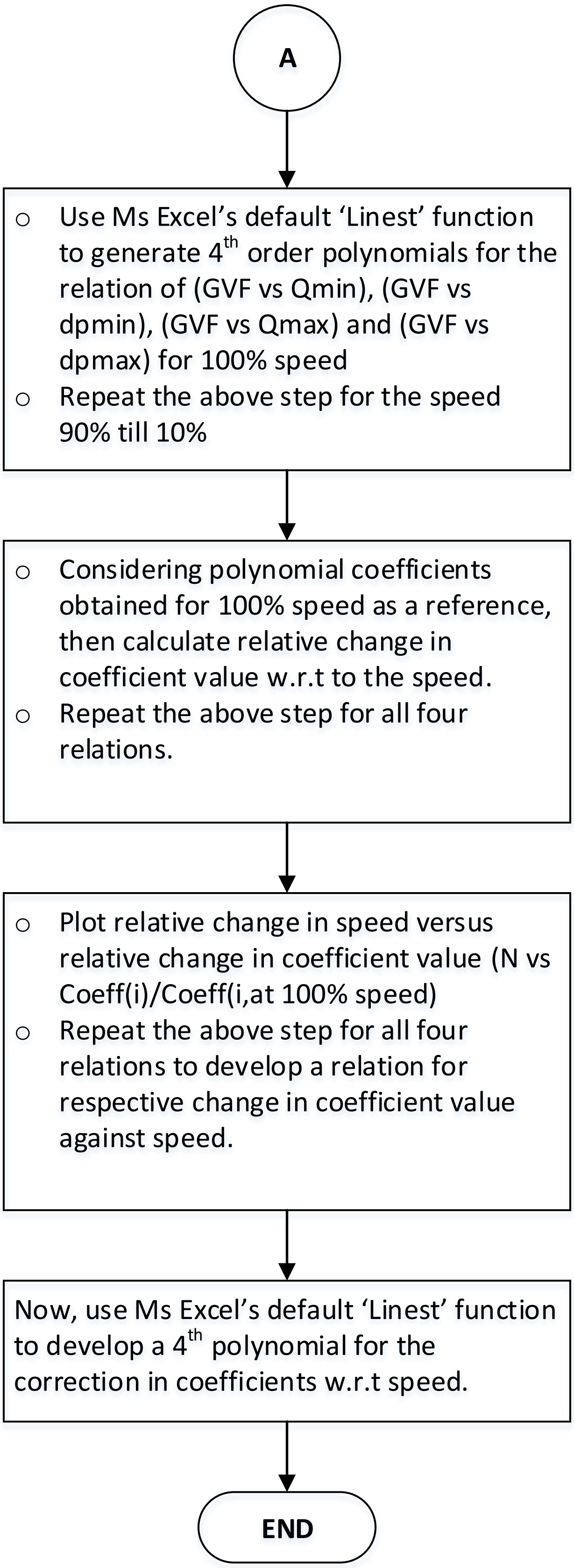


Figure 3. 13 PFD for Empirical Equation Development for Multiphase Booster's Map, as a Function of GVF and Speed [%]

Once the polynomials equations are developed for all the boosters, then Ms Excel VBA function was developed for the minimum flow point, minimum flow pressure difference point, maximum flow point and maximum flow pressure difference point for each booster. Developed VBA functions will take the GVF of the fluid (at booster's inlet) and speed as an input, and will yield minimum flow point, maximum flow point, and pressure difference value at maximum and minimum flow points. Execution of the script for any specific booster model is reflected through following flow diagram,

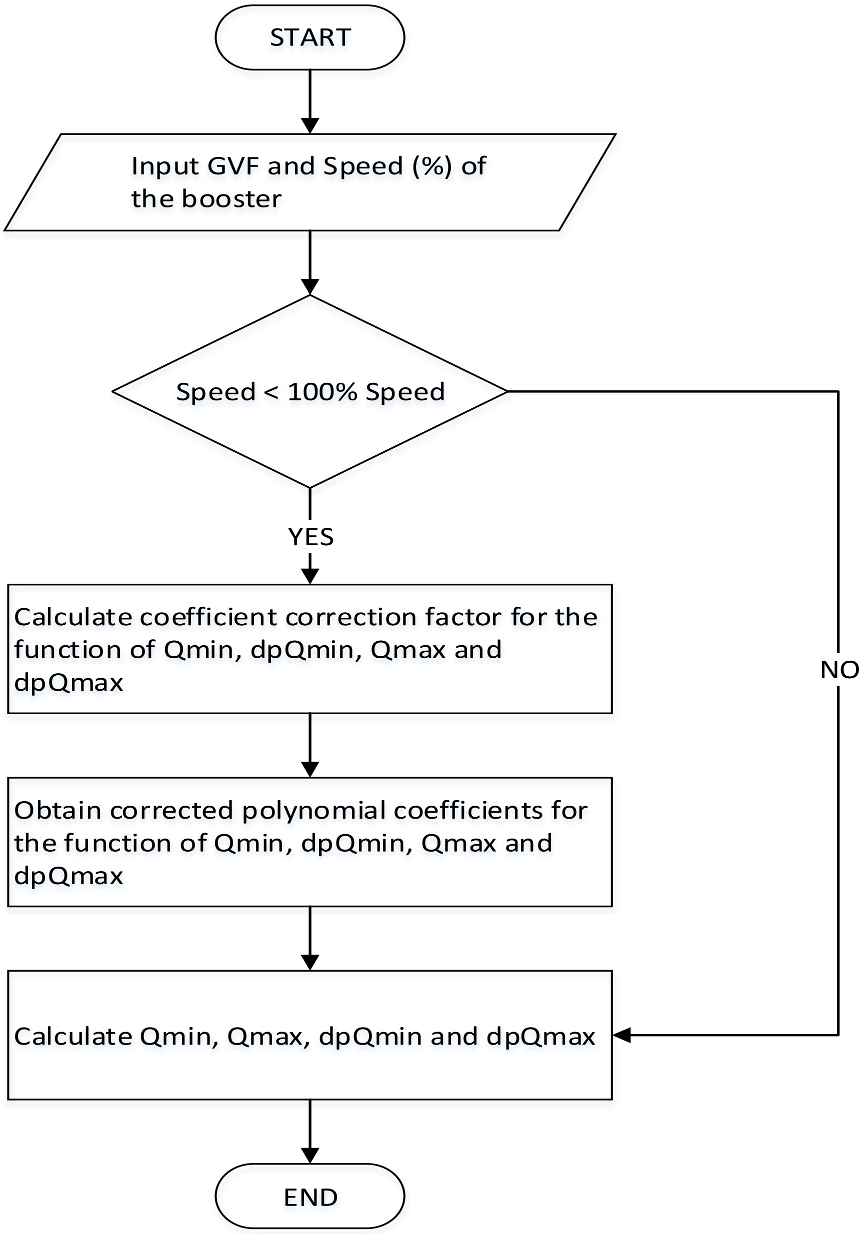


Figure 3. 14 Process Flow Diagram to Generate Iso-Speed Performance Map

3.5 Automated Booster Selection

After generating polynomials for all thirteen Framo 2009 multiphase boosters in the list, the next step is to organize the list of the booster in ascending order of the flow ratings, for each pressure boosting category, as mentioned in the able 3.2 represents the organized list of the boosters.

Then, first booster model for each boosting pressure category will be selected, and maximum achievable boosting pressure will be calculated by inputting give GVF and 100 [%] speed. This approach will screen out the booster's categories that may not meet the required pressure boosting. If the selected booster is under sized to handle the given flow rate, then, the script will look for parallel arrangement of such booster model. Generally, running a booster of high pressure boosting rating at lower outputs to manage the high flow rates incurs into booster operation at significantly low efficiency that may lead to significant power loss. Therefore, the algorithm to automatically select the booster is set to screen out all boosters that cannot meet required pressure boosting.

3.5.1 Operation at The Best Efficiency Point (BEP)

Scope of subject task demands to optimize the booster selection; such that selected booster will operate at its BEP. To evaluate the BEP on the map, it is required to calculate the hydraulic power against the given shaft power. Since the calculation of hydraulic power depends upon the definition of the boosting process for the gas phase, and the boosting process for gas phase within multiphase booster is still under research. Therefore, the devised algorithm for automatic selection of the booster does not optimize the booster selection on the basis of BEP, rather to ensure operating point within certain margin (i.e.10 [%]) of the maximum flow limit.

To ensure operation of the booster within performance envelop, algorithm was set such that if required flow rate is more than 90[%] of the maximum flow rate at the maximum speed curve, then the desired flow rate will be reduced to look for parallel configuration. Figure 3.16 reflects the efficient booster operation criteria,

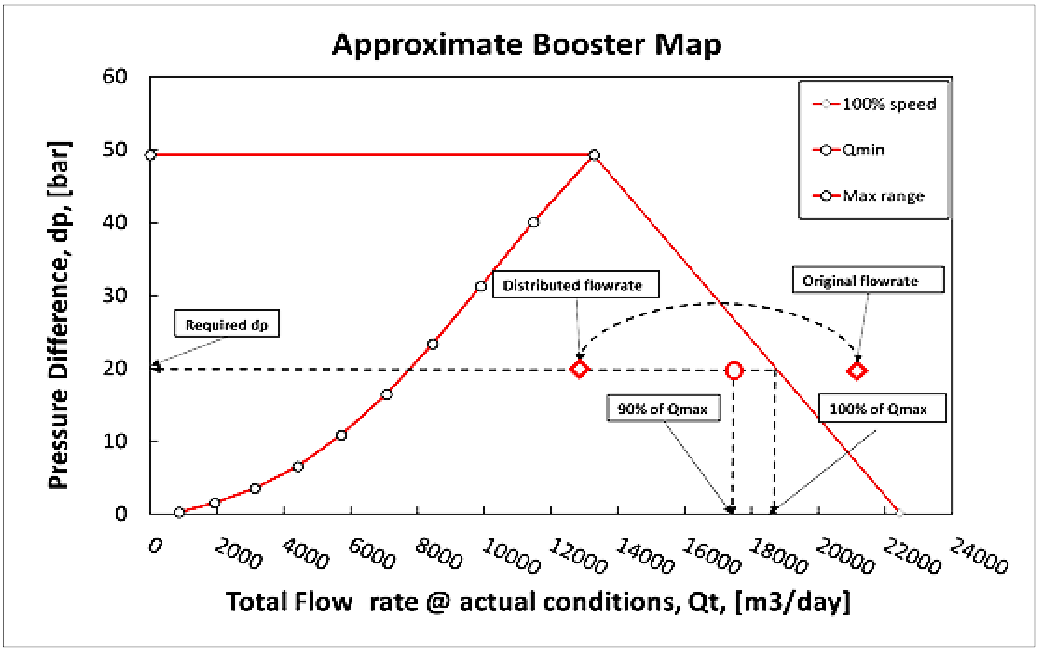
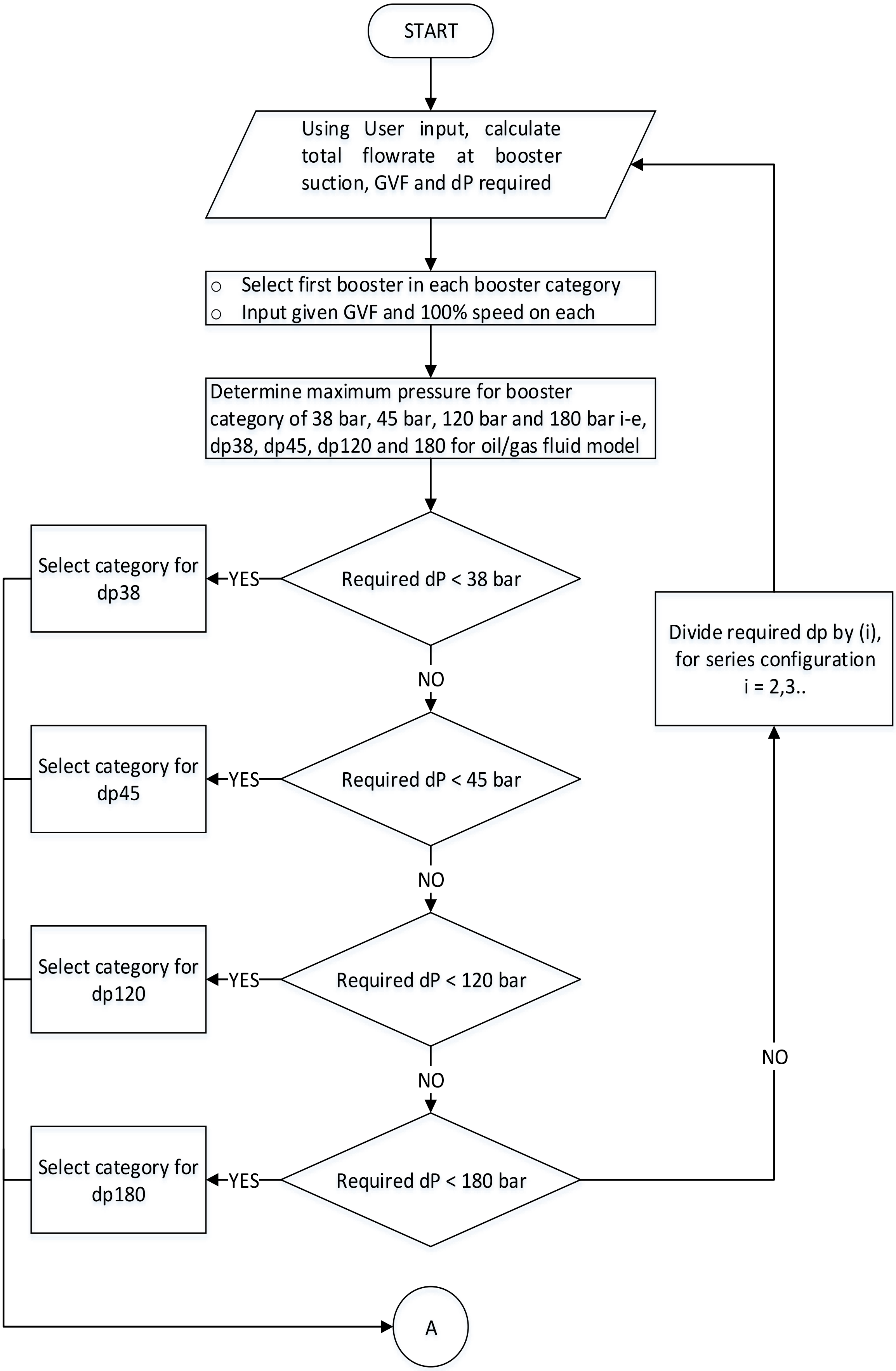


Figure 3. 15 Criteria for Parallel Configuration

To determine the series configuration, the algorithm was set such that if none of the booster is capable to meet the required pressure boosting, then required increase in pressure will be linearly distributed. The reason for linear pressure distribution is that if the required pressure increase is greater than the maximum available pressure, then the linear distribution will ensure that the same booster model will be selected for each stage.

Furthermore, to select the booster for boosting stages of two or above will require re-estimation of GVF, based on the output of the first stage booster. Although, such algorithm can be set, but it may incur selection of two entirely different booster models for each stage. In addition, it may also incur selection of different numbers of booster in parallel operation for each stage

Therefore, algorithm was set to only choose similar booster model for each stage, and it will be required to use control loops to optimize performance through anti-surge valves or suction throttle valves.



START
Using User input, calculate total flowrate at booster suction, GVF and dP required
Select first booster in each booster category
Input given GVF and 100% speed on each
Determine maximum pressure for booster category of 38 bar, 45 bar, 120 bar and 180 bar i-e, dp38, dp45, dp120 and 180 for oil/gas fluid model
Required dP < 38 bar
YES
Select category for dp38
NO
Required dP < 45 bar
YES
Select category for dp45
NO
Required dP < 120 bar
YES
Select category for dp120
NO
Required dP < 180 bar
YES
Select category for dp180
NO
Divide required dp by (i), for series configuration i = 2,3..
A

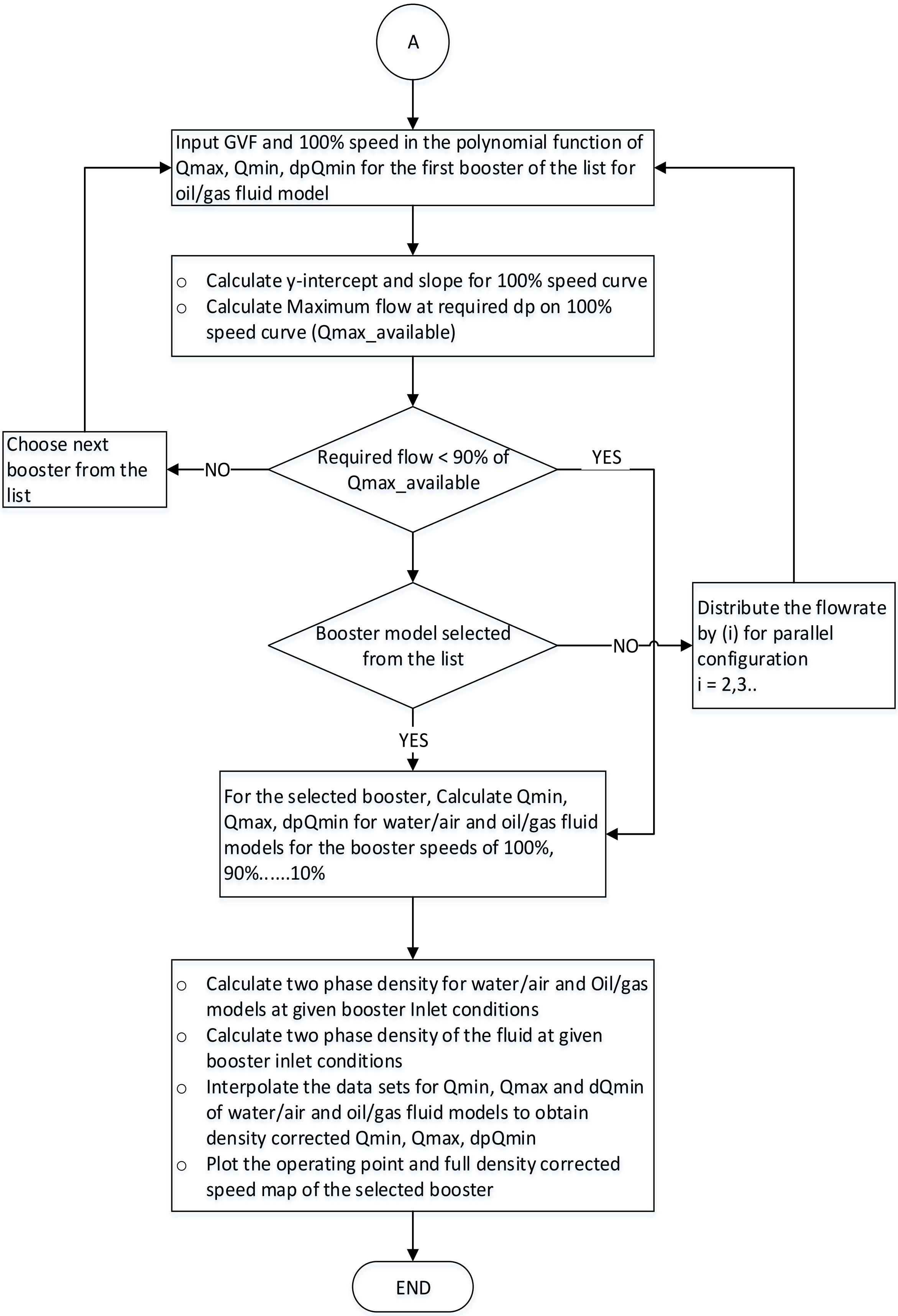


Figure 3. 16 Process Flow Diagram for The Booster Selection

3.5.2 Test Case for The Booster Selection Script

To test the developed algorithm for automated booster selection script, a set of data is required to be input by the user. Basically, execution of the code demands to provide total flow rate, required pressure boosting, two-phase fluid density and the GVF. The user may either provide this information directly, or it can be calculated by providing the production and reservoir data.

For direct data input, the user needs to input following information,

Table 3. 3 Data Required for Direct Data Input Approach

Property Name	Units
Total flow rate at booster inlet	[m^3/day]
GVF at booster inlet	[-]
Booster inlet pressure	[bara]
Booster outlet pressure	[bara]
Two-phase density	[kg/m^3]

While, for indirect data input, the user will input following information,

Table 3. 4 Data Required for Indirect Data Input Approach

Property Name	Units	Property Name	Units
Required oil rate	[Sm3/day]	Reservoir pressure	[bara]
Water-Cut	[-]	Reservoir temperature	[°C]
Booster inlet pressure	[bara]	Bubble point pressure	[bara]
Booster outlet pressure	[bara]	GOR at reservoir conditions	[Sm3/Sm3]
Temperature at booster inlet	[°C]		
Density of oil	[kg/m3]		
Specific gravity of gas	[-]		

For the indirect approach, the user also needs to tune the equation of state, which has been programmed to be automatically executed. Once the equation of state is tuned, then the solution gas oil ratio and formation volume factors for oil and gas will be calculated to obtain the amount of free gas, total oil flow rate and water flow rate. Detailed calculation steps have been incorporated in Appendix C.

Test Case 1 (Direct Approach):

Table 3. 5 Data Inputs for Test Case 1

Property Name	Value	Units
Total flow rate at booster inlet	20000	[m^3/day]
GVF at booster inlet	0.6	[-]
Booster inlet pressure	22	[bara]
Booster outlet pressure	75	[bara]
Two-phase density	332	[kg/m^3]

Test Case 2 (Direct Approach):

Table 3. 6 Data Inputs for Test Case 2

Property Name	Value	Units
Total flow rate at booster inlet	45000	[m^3/day]
GVF at booster inlet	0.45	[-]
Booster inlet pressure	22	[bara]
Booster outlet pressure	120	[bara]
Two-phase density	450	[kg/m^3]

Test Case 3 (Indirect Approach):

Table 3. 7 Date Input for Test Case 3

Property Name	Value	Units
Required oil rate	15000	[Sm^3/day]
Water-Cut	0.3	[-]
Booster inlet pressure	22	[bara]
Booster outlet pressure	180	[bara]
Temperature at booster inlet	15.56	[°C]
Density of oil	828	[kg/m^3]
Specific gravity of gas	0.787	[-]
Reservoir pressure	165	[bara]
Reservoir temperature	68	[°C]
Bubble point pressure	34	[bara]
GOR at reservoir conditions	55	[Sm^3/Sm^3]

Test Case 4 (Indirect Approach):

Table 3. 8 Data Input for Test Case 4

Property Name	Value	Units
Required oil rate	27000	[Sm3/day]
Water-Cut	0	[-]
Booster inlet pressure	22	[bara]
Booster outlet pressure	40	[bara]
Temperature at booster inlet	15.56	[°C]
Density of oil	828	[kg/m3]
Specific gravity of gas	0.787	[-]
Reservoir pressure	165	[bara]
Reservoir temperature	68	[°C]
Bubble point pressure	45	[bara]
GOR at reservoir conditions	55	[Sm3/Sm3]

Results for Test Case 1:

Table 3. 9 Results for Test Case 1

Best of possible booster	310-1100-120
No. of boosters in series	1
No. of boosters in parallel	1

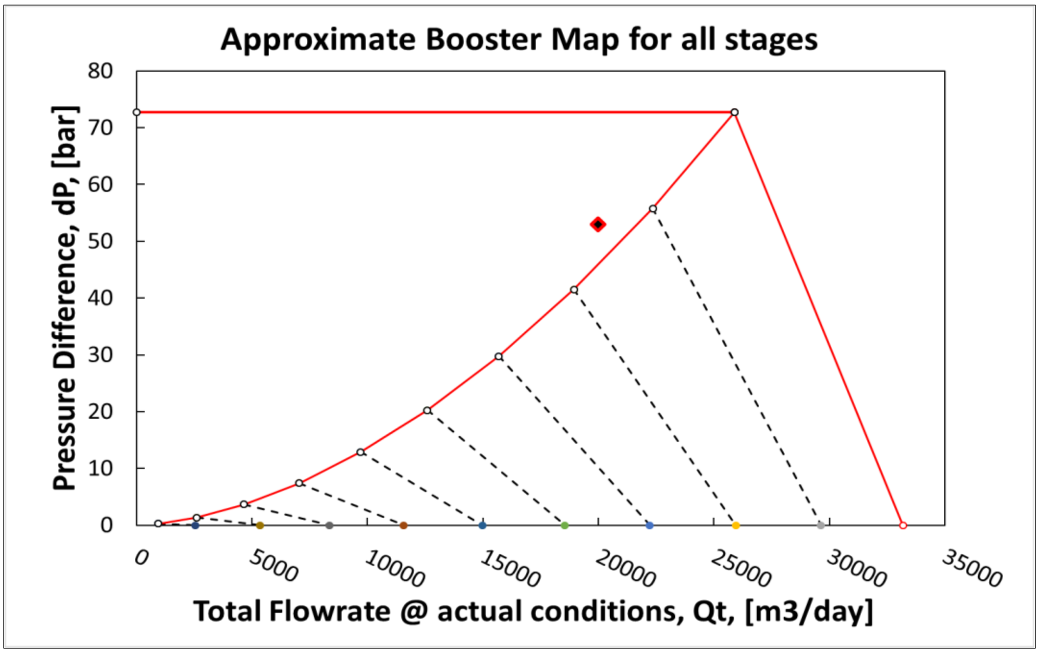


Figure 3. 17 Approximate Iso-speed Performance Map, Test Case 1

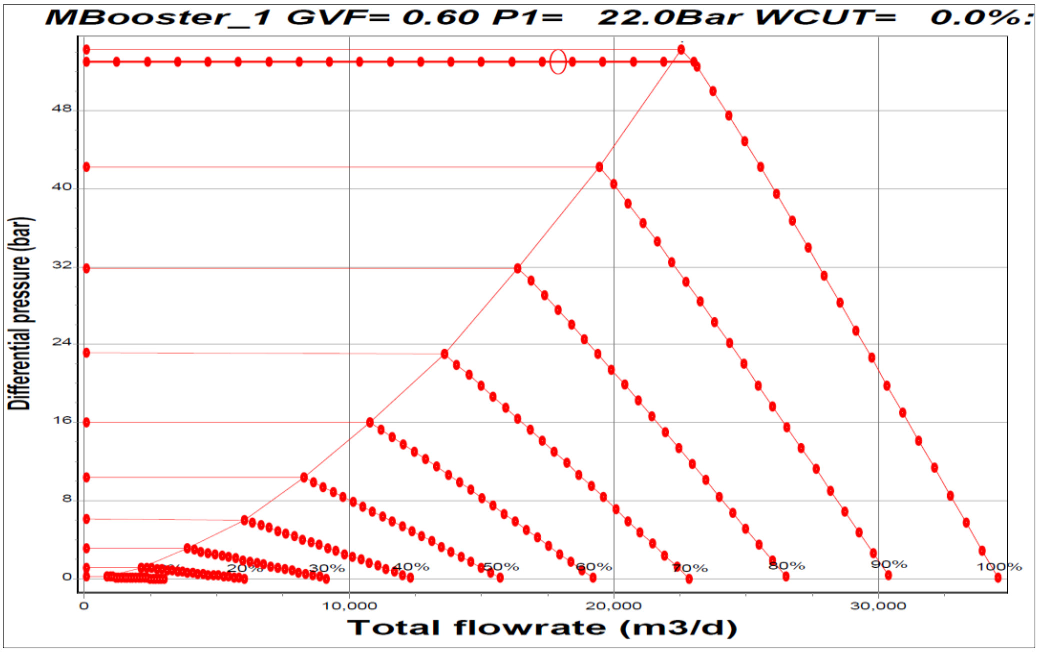


Figure 3. 18 PIPESIM Output, Iso-speed Performance Map, Test Case 1

Results for Test Case 2:

Table 3. 10 Results for Test Case 2

Best of possible booster	310-800-120
No. of boosters in series	1
No. of boosters in parallel	3

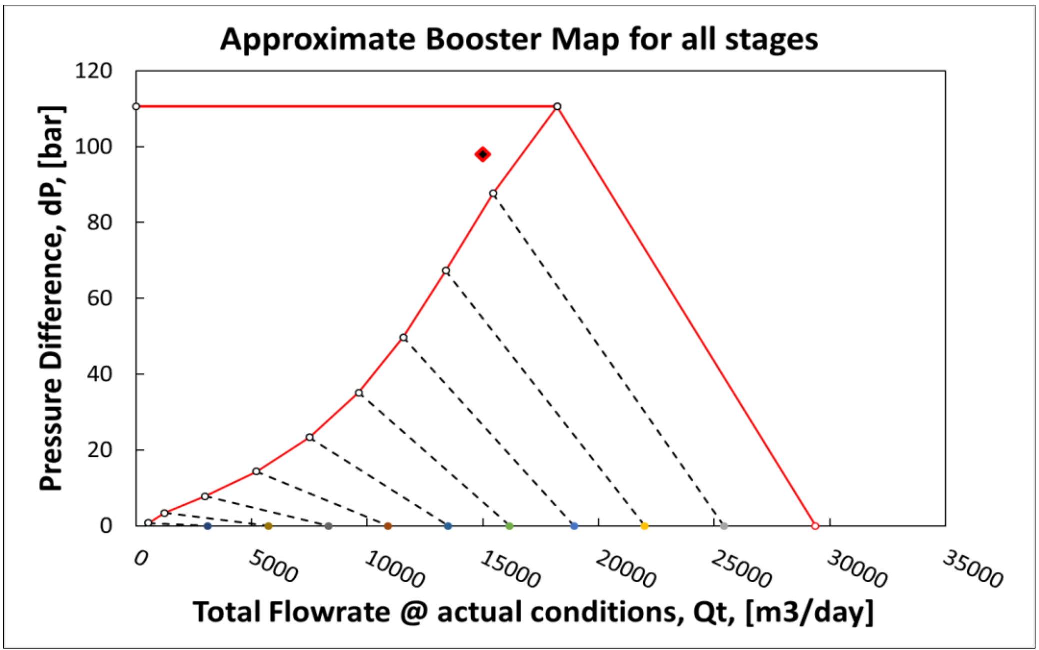


Figure 3. 19 Approximate Iso-speed Performance Map, Test Case 2

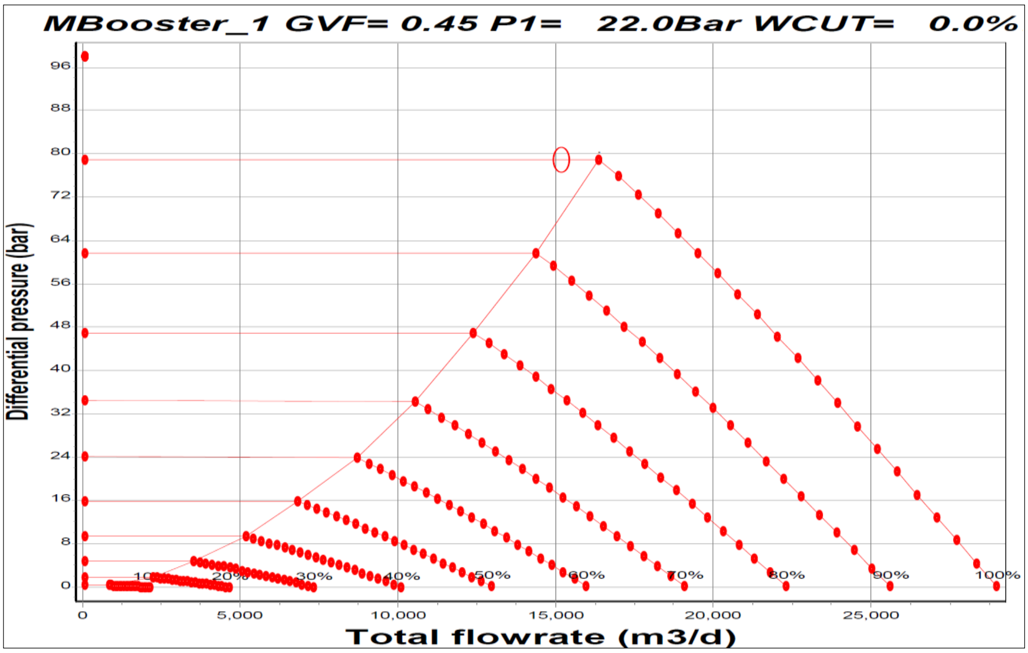


Figure 3. 20 PIPESIM Output, Iso-speed Performance Map, Test Case 2

Results for Test Case 3:

Table 3. 11 Results for Test Case 3

Best of possible booster	310-400-180
No. of boosters in series	1
No. of boosters in parallel	4
Calculated GVF	0.274

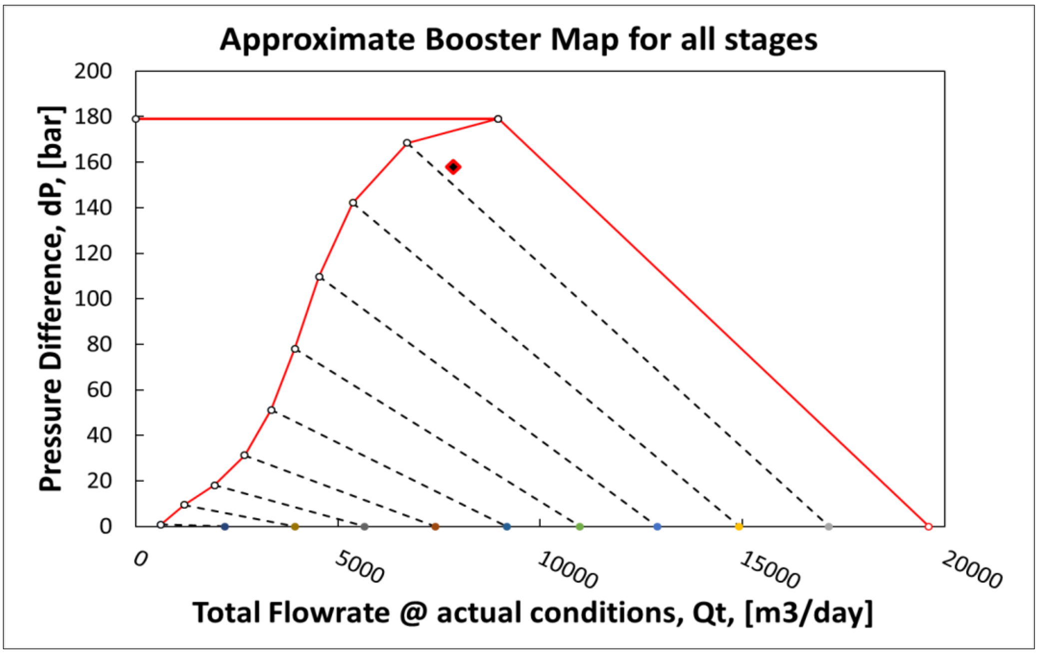


Figure 3. 21 Approximate Iso-speed Performance Map, Test Case 3

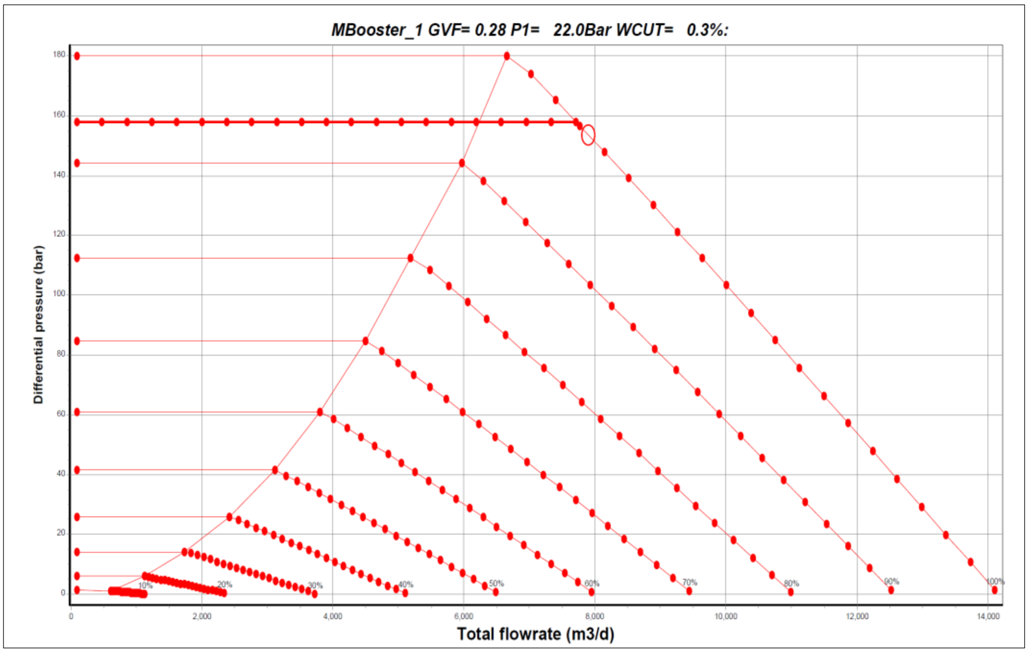


Figure 3. 22 PIPESIM Output, Iso-speed Performance Map, Test Case 3

Results for Test Case 4:

Table 3. 12 Results for Test Case 4

Best of possible booster	360-1800-38
No. of boosters in series	1
No. of boosters in parallel	1
Calculated GVF	0.344

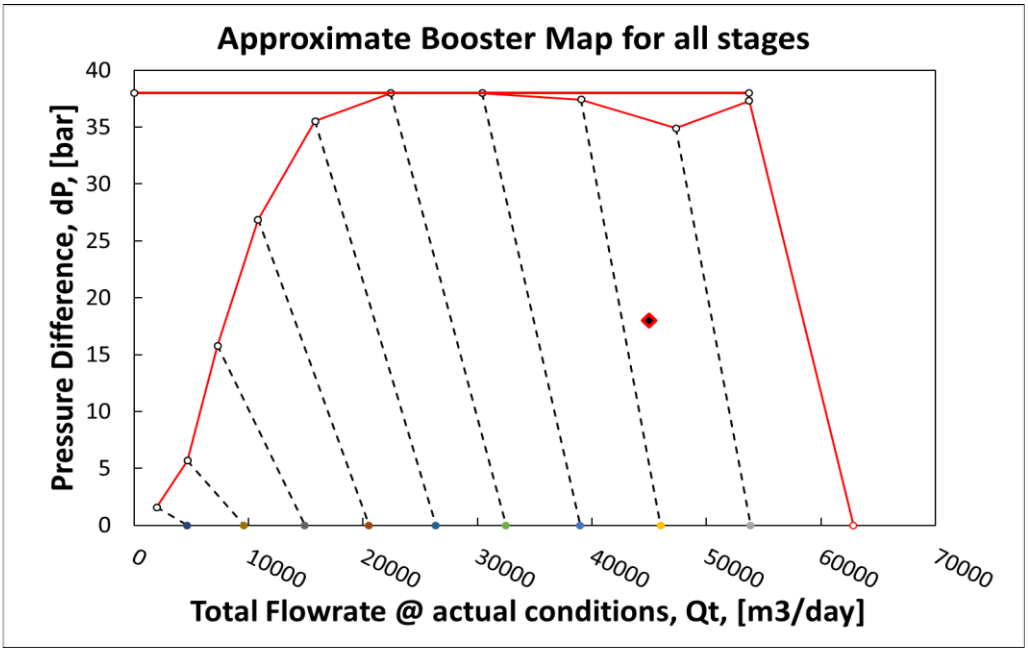


Figure 3. 23 Approximate Iso-speed Performance Map, Test Case 4

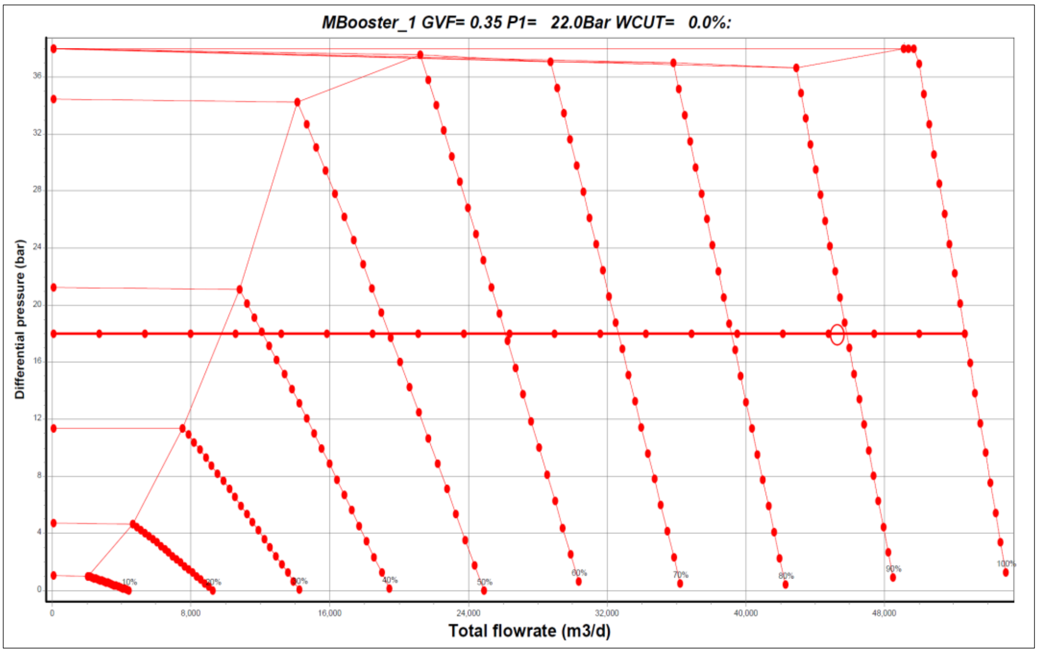


Figure 3. 24 PIPESIM Output, Iso-speed Performance Map, Test Case 4

3.6 Conclusion

As evident from the comparative maps for the test case 4, performance map obtained through constructed polynomial is not identical to the one obtained from PIPESIM. Reason for such inconsistent output is the irregular shape of the performance map of the booster model for low differential pressure rating. Apart from low pressure rating boosters, output of other boosters is very much identical to PIPESIM's generated performance map.

Considering the marginal error associated with low pressure rating boosters, it can be concluded that the results for adapted methodology will only provide an approximation about the booster selection.

CHAPTER 4 SNØHVIT FIELD SUBSEA MULTIPHASE BOOSTING

4.1 Objective for Snøhvit Field's Subsea Boosting Analysis

This chapter covers the task (i) of the thesis, that deals with the evaluation of the performance of the proposed wet gas compressor for boosting at Snøhvit field. The objective of the task (i) is to develop a methodology that may assist to evaluate performance of the wet gas compressors proposed for the Snøhvit field subsea boosting using a wet gas compressor.

Unavailability of wet gas compressor in commercial network simulators is the major obstacle in evaluation of any new unit, which is not available in network simulators. As varying field properties (water-cut, GOR, pressure, temperature etc.) incurs radical changes in fluid properties at the inlet of the booster. Therefore, to appropriately analyse the performance of any multiphase booster, it is necessary to include such variation in calculating the fluid properties at the booster inlet.

Therefore, the subject task aims to develop an alternative approach that may represent a multiphase booster unit in the network simulator to appropriately analyse the booster performance against varying properties throughout the life of the field.

The chapter is structured to briefly discuss the characteristics of Snøhvit field and the development strategy devised to produce the field. Later, the mechanism of boosting proposed and the methodology adapted to fulfil the task is discussed.

The analysis for Snøhvit field's wet gas compression using Ms Excel is incorporated in the Appendix A.

4.2 Development Study of Snøhvit Field

Snøhvit field is located at central part of Hammerfest basin in the Barents Sea. It was the first field developed in the Barents Sea. It was discovered in the year 1984; it is a part of Snøhvit unit as centrally located Snøhvit field, along with other satellite fields namely Albatross and Askeladd. Hydrocarbon fluid from entire Snøhvit unit is primarily based on gases, with insignificant fraction of natural gas liquids and gas condensates.

Development through Snøhvit unit was planned to setup entire production system at seabed, and to pipe-back the commingled production to onshore liquefied natural gas (LNG) processing facility located at Melkoya, near Hammerfest [22], using single transportation line. The onshore gas processing facility is designed to extract carbon dioxide out of the gas, and sent it back to offshore subsea facility for gas reinjection into the formation. Re-injection of produced carbon dioxide will minimize the emission of greenhouse gases.

The early field development plan for the Snøhvit field was based on phase wise development. Initial phase of development was based on production through centrally located Snøhvit field, which is at 143 [km] distanced from on-shore gas processing facility, and Albatross field which is located 11 [km] apart from Snøhvit field, whereas, Askeladd field is located at the distance of 34 [km]. First phase was based on 10 subsea wells altogether, consisting 9 production wells and one gas injection well to reinject carbon dioxide into the formation. Second phase was based on major production through Askeladd field with 8 production wells, and additional production well for Albatross field[23]. The general architecture and phase-wise development along with general network for Snøhvit unit is reflected through following Figure,

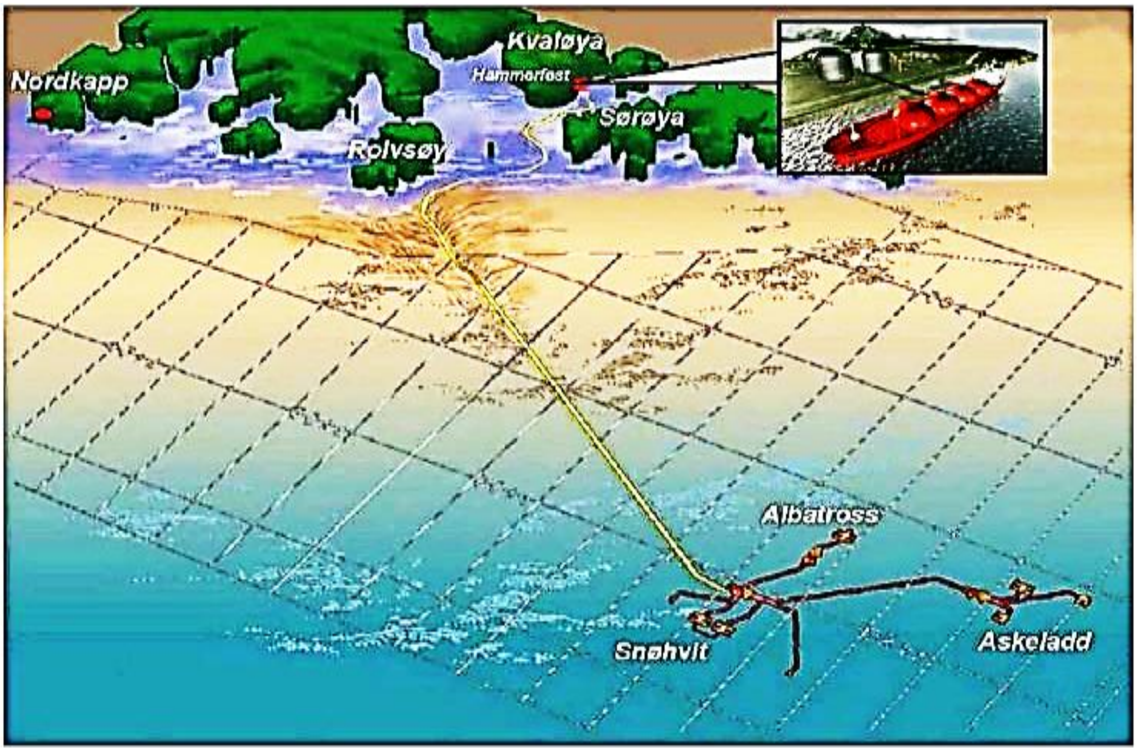


Figure 4. 1 Layout of Snøhvit Field[22]

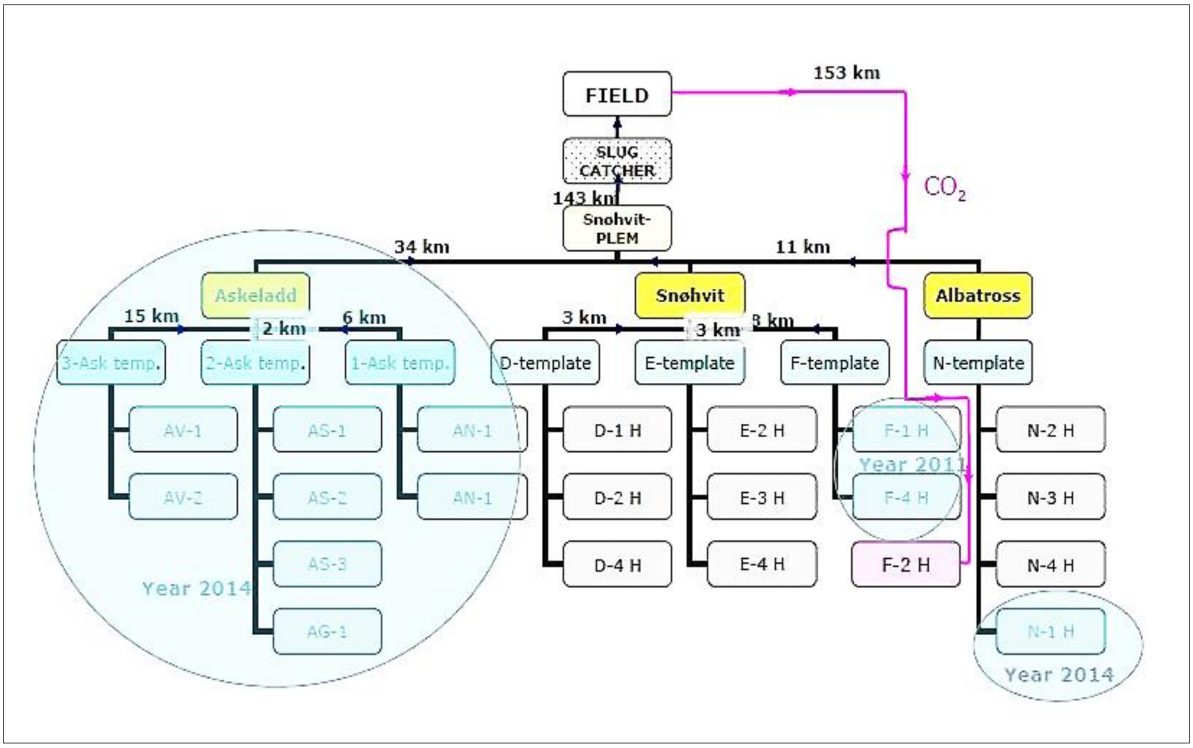


Figure 4. 2 Network Hierarchy of Snøhvit Unit [23]

4.3 Production Scheduling and Development Strategy

Production through entire Snøhvit unit, including centrally located Snøhvit field and two satellite fields i.e. Albatross and Askeladd, was scheduled to maintain plateau rate of 20.8 [MMSCM/d][23] from the year 2008 till the year 2032 . Initial studies depict maintenance of plateau production rate at natural flowing potential of all three fields till the year 2019. From the year 2020, natural flowing potential of Snøhvit unit will not be sufficient to maintain plateau production rate. To maintain Snøhvit unit's production rate of 20.8 [MMSCM/d] during scheduled plateau period, it was planned to either boost the pressure of the produced fluid at the PLEM through wet gas compressors or to install another trunk line in parallel to existing one, to meet 65 [bara] pressure at on-shore slug catcher. Anticipated production strategy is sensitive to the performance of a wet gas compressor over the entire field life. To meet the boosting requirement, wet gas compressor model number WGC-4000 of Framo Engineering was considered. Since the considered wet gas compressor can handle maximum flow of 4800 [Am^3/hr][24], therefore, it was planned to keep two compressors in parallel. In addition to flow, prediction of production rate is also constraint to the maximum shaft power, maximum outlet temperature and maximum differential pressure of the wet gas compressor. Such boosters' constraints are required to be honoured during estimation of production rate at the later stage of the field. Figure 4.3-4 depict change in natural flowing potential of entire unit over the years against scheduled production rates.

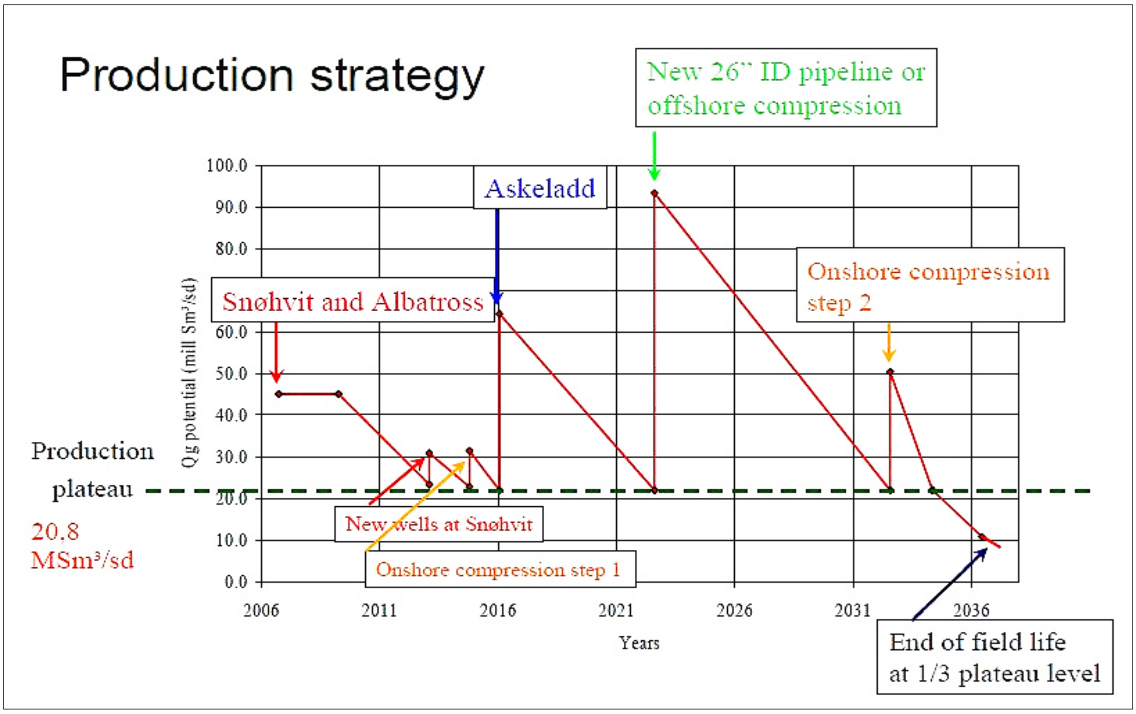


Figure 4. 3 Production Strategy of Snøhvit Unit[23]

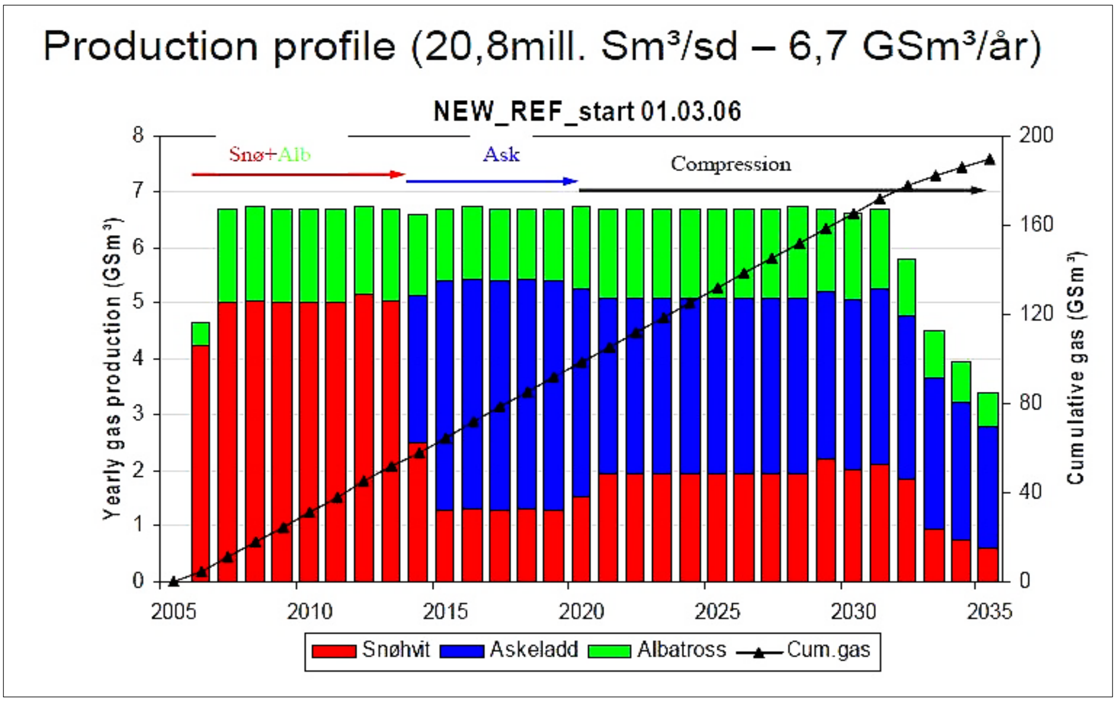


Figure 4. 4 Production Schedule for Snøhvit Field[23]

Due to the uncertainties involved in performance prediction of multiphase boosters, honouring design constraints of the wet gas compressor becomes challenging. Performance of a multiphase booster can be determined through various models, but all predictive models possess uncertainties and limitations that should be considered during performance evaluation. Such limitations make performance prediction of a wet gas compressor sensitive to the predictive model used, which may yield errors in the result.

4.4 Performance Prediction of WGC-4000 at Snøhvit Field

Multiphase boosting methodology for Snøhvit unit was devised to commingled production through Snøhvit and satellite fields at the PLEM, and boost it to meet required pressure at the inlet of trunk line. Pressure at the inlet of trunk line should be sufficient enough to meet the on-shore separator's set pressure of 65 [bara]. Since, all three fields have different reservoir characteristics, and their production schedules are also dissimilar; therefore, all reservoir will undergo pressure decline at different rates. Core reservoir characteristics and general production system data for all three reservoirs have been included in Appendix A.

By characteristics, reservoir fluid of all three reservoirs is primarily dry gas, with fraction of gas condensate. To determine producing gas oil ratio, combined production data since 2007 till 2016 was used. According to the production data, producing gas oil ratio was found as 3696 [Sm^3/Sm^3][25]

4.5 Reservoir Pressure Trend, in Comparison with Dry Gas Tank Model

For Snøhvit and associated satellite fields, adequate information is available appertain reservoir pressure profile over planned field life. Since initial reservoir pressure and temperature of all three reservoirs lie above cricondentherm temperature and cricondenbar pressure, therefore, all three fields are anticipated as dry gas reservoirs[8].

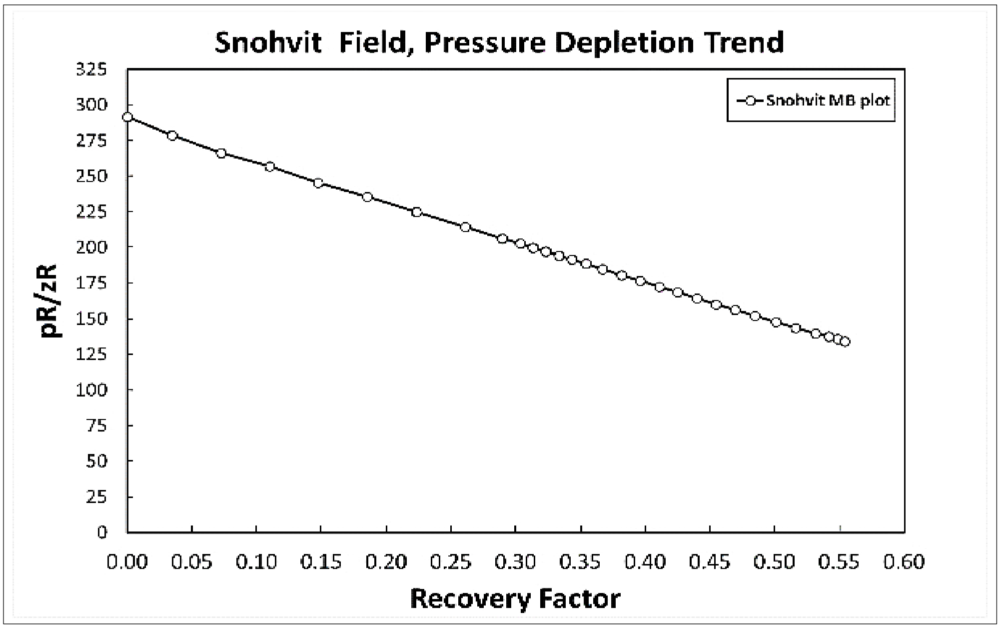


Figure 4. 5 Pressure Depletion Trend, Snøhvit Field[26]

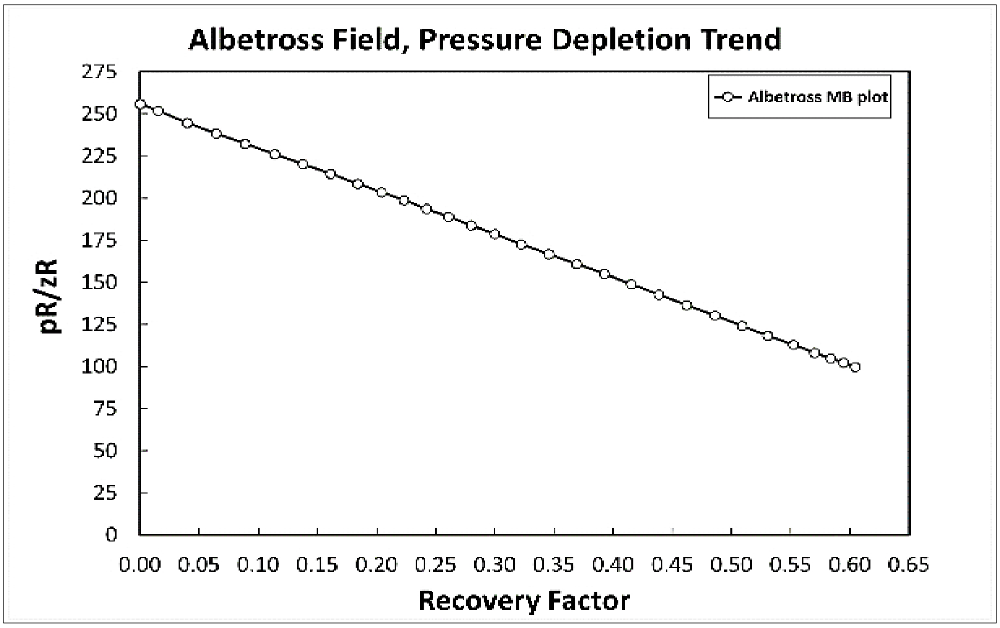


Figure 4. 6 Pressure Depletion Trend, Albatross Field[26]

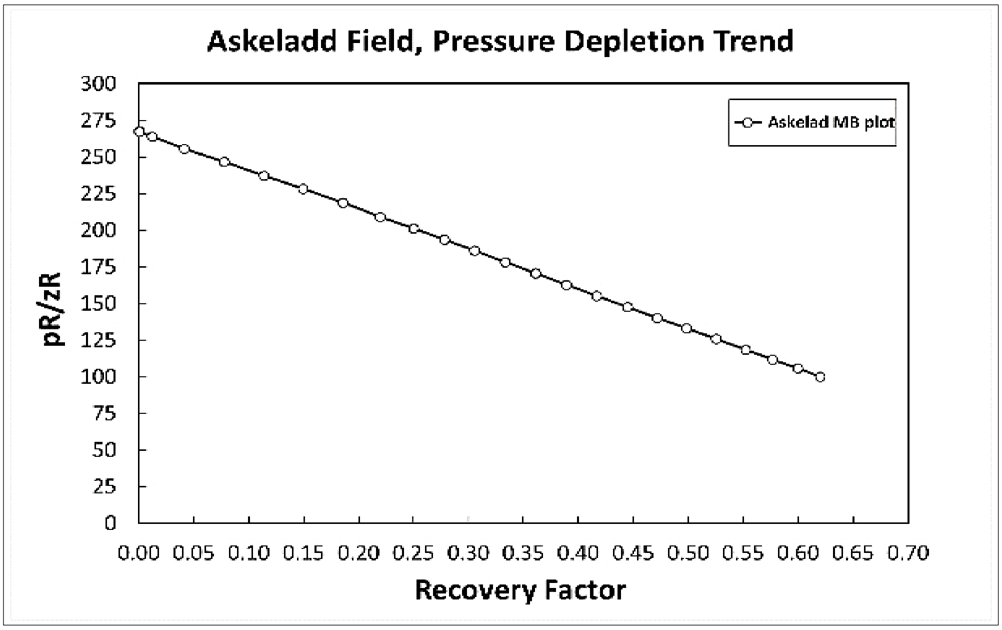


Figure 4. 7 Pressure Depletion Trend, Askeladd Field[26]

Since the depletion trends for all three reservoirs are almost linear, therefore, it was deemed that all fields are characteristically dry gas fields. According to the plan, separated carbon dioxide will be injected into the Tubaen formation[23], having impermeable layer of shale to inflict any impact on reservoir pressure maintenance. Therefore, any deviation of reservoir pressure from field data to the dry gas material balance will be deemed as an impact of either any active aquifer or communication with the satellite fields. Following trends indicates presence of active aquifers for deviation of field data from the trend of reservoir pressure calculated through dry gas material balance,

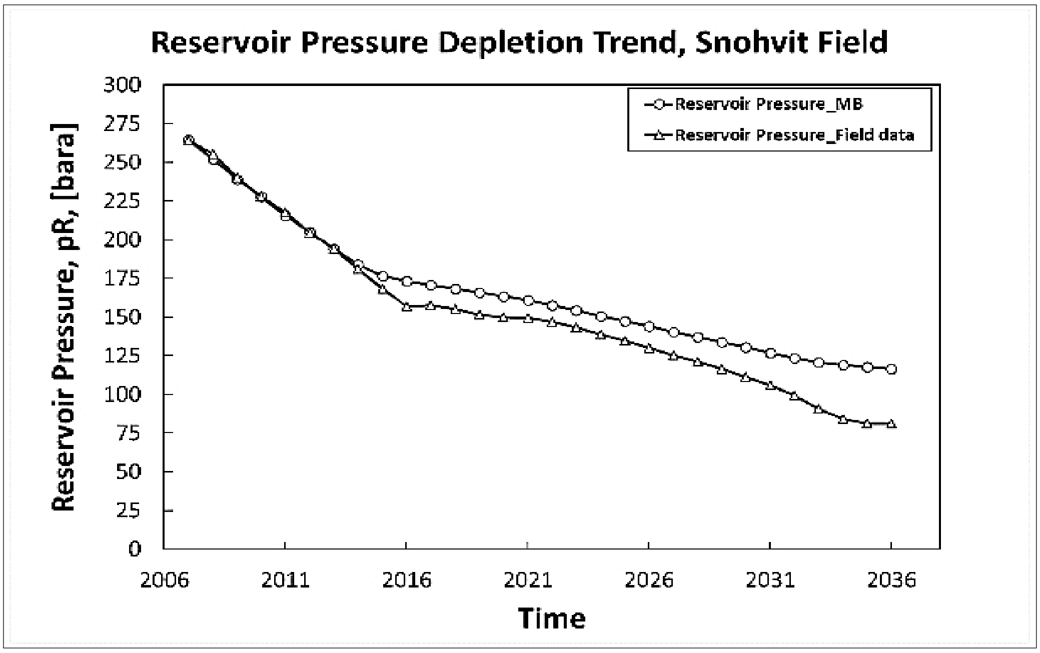


Figure 4. 8 Difference in Pressure Profiles, Snøhvit Field[26]

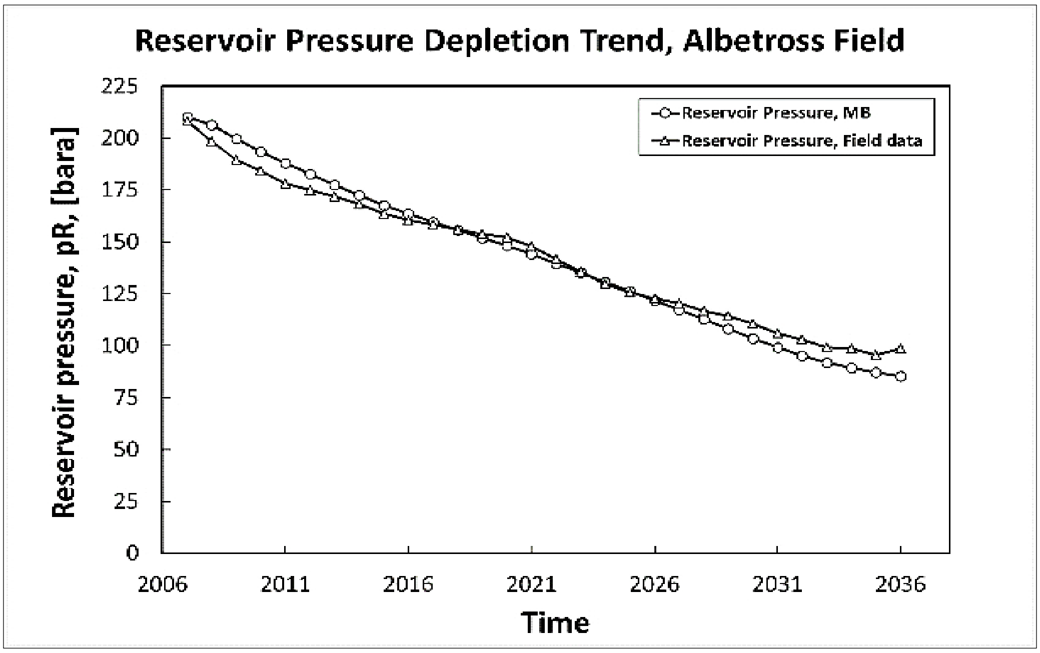


Figure 4. 9 Difference in Pressure Profiles, Albatross Field[26]

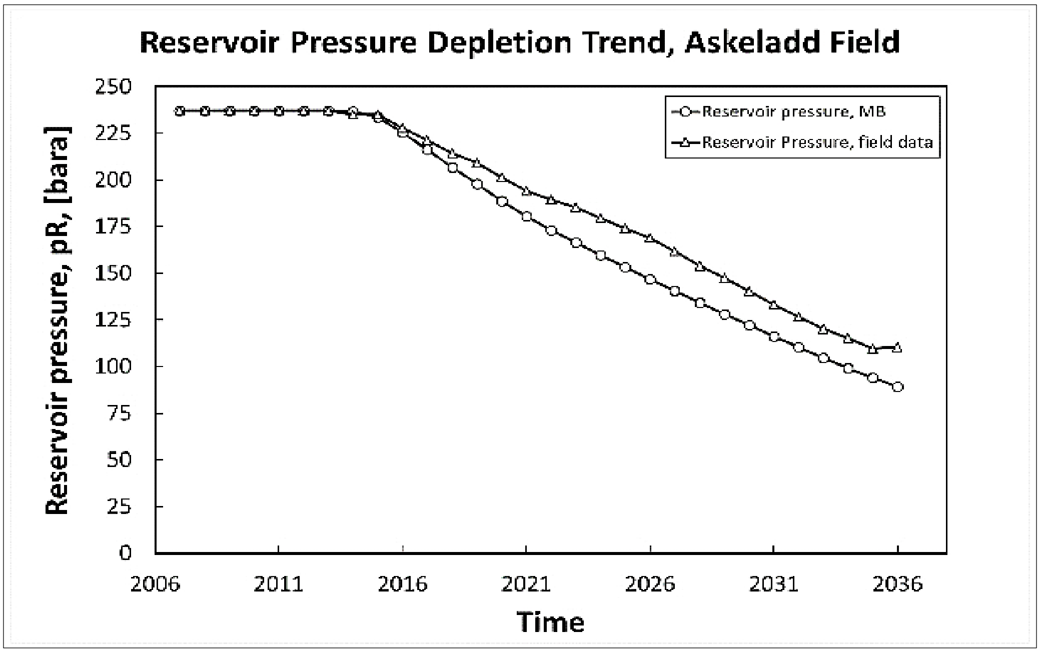


Figure 4. 10 Difference in Pressure Profiles, Askeladd Field[26]

In calculating reservoir pressure through dry gas material balance, it was assumed that the gas compressibility factor remains fix throughout the year that will incur marginal inconsistency in the result. Therefore, for all three reservoirs, reservoir pressure depletion trend through dry gas material balance will have slight difference as compared to field data. However, if we consider overall trends, then it may be deemed that for Albatross field, reservoir pressure obtained through dry gas material balance is complying with field data. Whereas, for Snøhvit and Askeladd fields, trend of reservoir pressure obtained through dry gas material balance is lower for Snøhvit and higher for Askeladd. Such deviation indicates communication of these reservoirs with other satellite fields.

Therefore, to develop a network model for entire Snøhvit unit, data obtained through field has been considered as authentic and used to develop well model using PROSPER (Petex).

4.6 Network Modelling of Snøhvit Field

To analyse applicability of the wet gas compressor during early field development studies, it is important to devise a network model that replicates actual field performance. Such model requires detailed specification of flowlines, trunk lines, environmental conditions, well auxiliaries and behaviour of reservoir fluid over life cycle of the field. Typical gas reservoir can be anticipated to primarily yield gas along with fractions of gas condensates at the surface, but such anticipation may not be valid at later stages as both condensate to gas ratio (CGR) and water-cut may increase at later stage of the field. Production history of Snøhvit field indicates producing condensate to gas ratio as around 19 [STB/MMSCF] which is slightly ahead of the CGR range for dry gas reservoir, but such low producing CGR may not incur any radical change in the properties of the gas[27]. Therefore, during modelling of Snøhvit field, dry gas reservoir model was used.

(a) Well Model

Deviation data for all producing wells are available in Norwegian petroleum directorate database[25] which was used to set well specifications in the PROSPER. Since, only cumulative production profile is available that may not be used to precisely model the production through each well, therefore, it was assumed that all wells are identical in dimensions, and production through each reservoir is equally distributed among all producing wells. In reservoir model selection, back pressure equation was selected with an assumption that fluid flow will obey Darcy law.

(b) Network Model

General well layout and lengths of flowlines were set in accordance with drilling and commissioning plan till the year 2014[23]. Dimensions of the flow lines, modelling constraints and other parameters set in the network models were included in Appendix A.

Elevation profile for all flowlines have been assumed as perfectly horizontal, as sufficient information appertain elevation profiles of the wells were not available. However, elevation profile for the trunk line was available[23] which was used to set elevation profile of the trunk line in the network model.

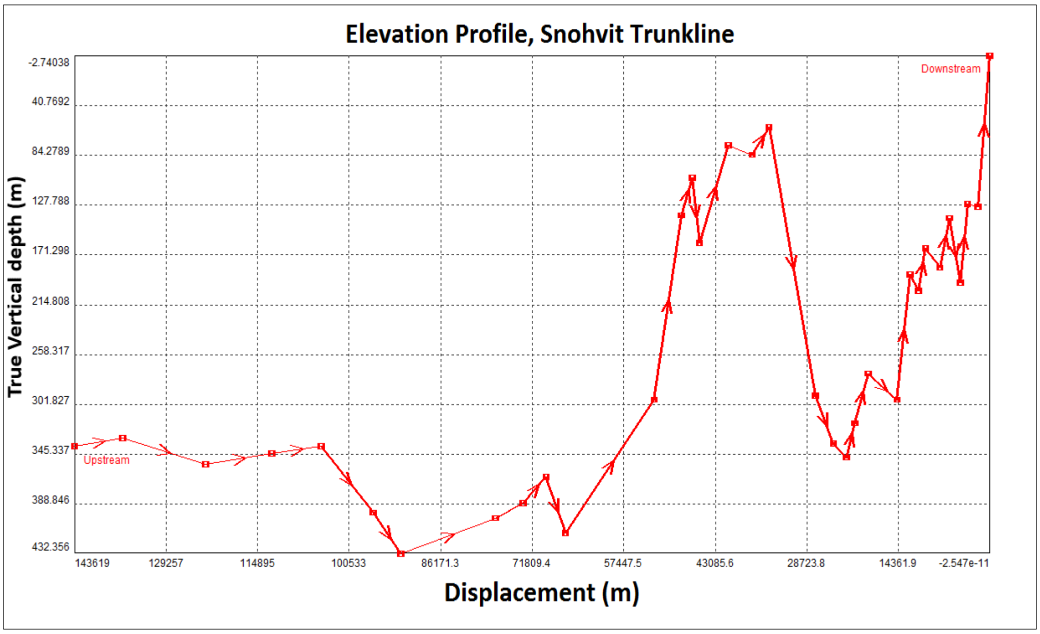


Figure 4. 11 Elevation Profile Of Trunk Line, Snøhvit Field[23], Set On GAP

(c) Production Maintenance During Plateau Period

According to early field development studies, production rate was maintained at 20.8 [MMSCM/d] through commingled production of all the fields[23]. Whereas, plateau production period was planned to exceed till the year 2032. Before the year 2022, natural flowing potential was gradually raised by including additional production wells into the network, as well as, production through Askeladd field was also commenced to enhance production life of Snøhvit and Albatross field, and to maintain the plateau production rate.

As evident in the Figure 4.3 and 4.4, natural flowing potential was sufficient to maintain the plateau production till the year 2022, therefore, applicability of wet gas compressor was tested through network simulation from the year 2023 till the year 2036.

Table 4. 1 Design Constraints of WGC 4000[24]

Property	Design Limits	Units
Maximum flow rate	4800	[m^3/ hr]
Maximum outlet temperature	120	[°C]
Maximum pressure difference	32	[bar]

Applicability of the wet gas compressor is subject to the designed constraints which may implicate decline in plateau production rate during later stage of the field. To set the criteria for the analysis, constraints mentioned in table 4.1 were considered for the wet gas compressor WGC-4000 of Framo Engineering.

(d) GAP Inline (general) Element

To precisely analyse the applicability of the wet gas compressor, it is required to have same or similar equipment in GAP, so that, the equipment may automatically honour all of its constraints during network simulation. Contrary, GAP does not have wet gas compressor models in the boosting equipment list which limits the precise analysis. To replicate the wet gas compressor, Inline (general) Element of GAP was used, and performance of the wet gas compressor was simulated through script, by honouring all design constraints of WGC-4000. Since actual flow handline ability of WGC-4000 is less than plateau production rate, therefore, performance model was scripted for two compressors, working in parallel to each other.

(e) Inline (general) Element's Script

Since reservoir fluid through all three reservoirs contains primarily gas contents with insignificant fraction of condensate. Such high gas content generates very high GVF at early field stages, while maximum anticipated GVF will also remain high enough (i.e. > 90[%]) to implicate any radical change in the flow regime. Therefore, homogenous fluid model was used to calculate hydrostatic head developed for each pressure rise value, which was further used to calculate the required shaft power[4, 24].

(f) Efficiency of WGC-4000

Calculation of shaft power requires overall efficiency of the booster. At present, determination of actual polytropic exponent is a challenge in hand, whereas, determination of mechanical efficiency also requires experimental data of the booster. Uncertainty involved in determining the efficiencies directly affects the outcome of shaft power. For time being, mechanical efficiency was assumed to be 95[%]. On the other hand, polytropic efficiency of the booster was estimated through the approximate relation between impeller geometry and flow co-efficient [28]. Based on design flow specs and maximum speed of WGC-4000 of Framo Engineering, regression was performed to calculate polynomial equation for the relation between flow coefficient and polytropic efficiency,

$$Flow\ coefficient, \varphi = (700.3) * \frac{Q_s}{N * D^3} \qquad \text{Eq. 4.1}$$

Where, Qs is in [ft^3/s], D is in [ft.] and N is in [RPM]

Based on maximum flow rate of WGC-4000, diameter of the impeller was determined as 2.09 [ft.].

Using Eq.4.1 for the range of flow coefficient between 0.3 till 1, following polynomial equation was obtained through polynomial regression,

$$Polytropic\ efficiency, \eta_p = (1.1774.10^{-19} * Q^4) - (3.9190.10^{-14} * Q^3) + (3.7236.10^{-09} * Q^2) - (5.7132.10^{-5} * Q) + 84.236 \qquad \text{Eq. 4.2}$$

Once polytropic efficiency is determined, then sequence of following equation is used to calculate the overall efficiency of the booster,

$$Isentropic\ exponent, k = 1.46 - 0.16\left(\gamma_g - 0.55\right)(1 - 0.0067\gamma_g - 0.000272T) \qquad \text{Eq. 4.3}$$

$$Polytropic\ exponent, n = \frac{1}{1 - \frac{\frac{k-1}{k}}{\eta_p}}$$ Eq. 4.4

$$Outlet\ temperaure, T_{out} = T_{in}\left(r_p^{\frac{n-1}{n}}\right)$$ Eq. 4.5

$$Adiabatic\ efficiency, \eta_a = \frac{Adiabatic\ work}{Actual\ Work}$$ Eq. 4.6

$$Addiabatic\ efficiency, \eta_a = \frac{r_p^{\frac{k-1}{k}} - 1}{\left(\frac{T_{out}}{T_{in}} - 1\right)}$$ Eq. 4.7

$$Overall\ efficiency, \eta \quad = \frac{Adiabatic\ work}{Adiabatic\ efficiency * \ Mechanical\ efficiency}$$ Eq. 4.8

Sequentially using Eq. 4.1 till Eq. 4.8, overall efficiency was obtained, which was further used in following equation to calculate shaft power,

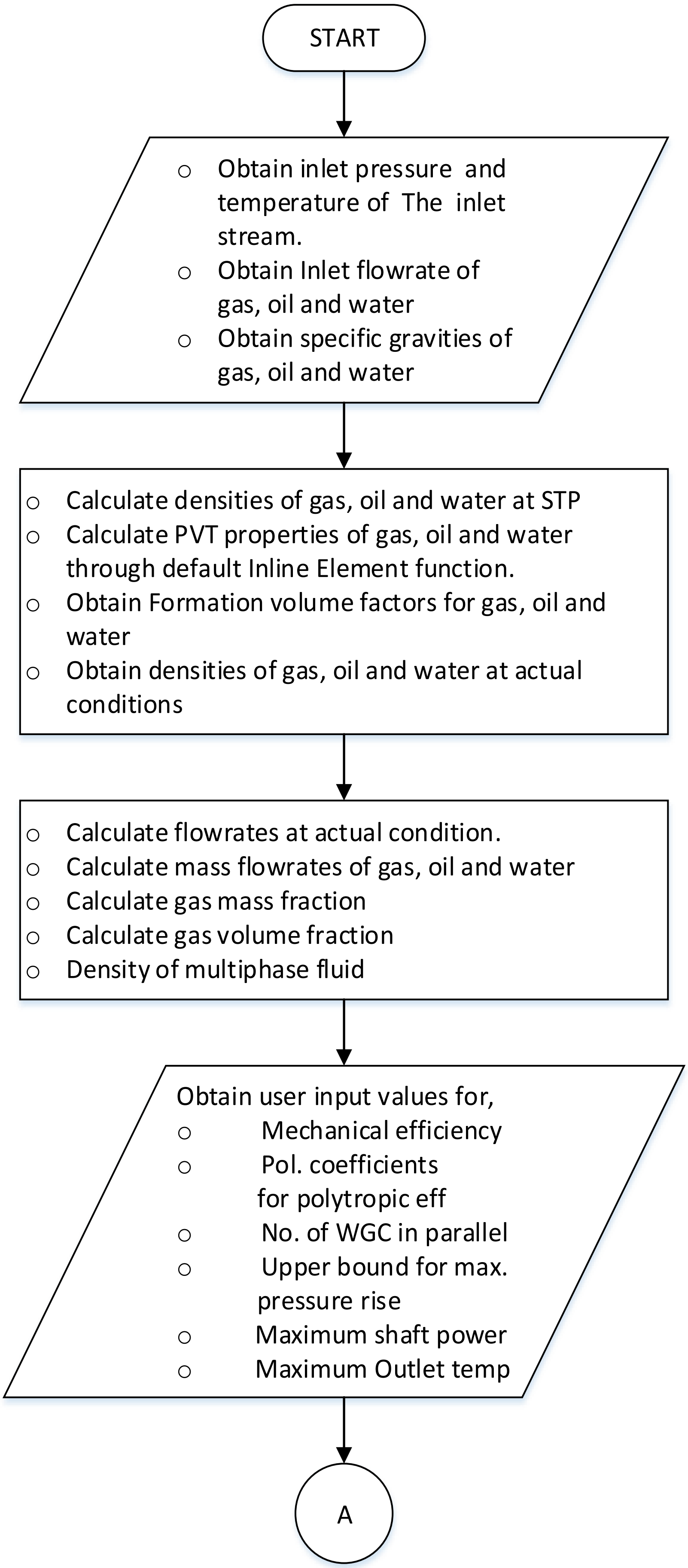
$$Gass\ mass\ fraction, \beta = \frac{Mass\ of\ gas}{Total\ mass}$$ Eq. 4.9

$$Adiabatic\ Head, H_{adiabatic} = \frac{\beta . R . Z_{in} . T_{in} . k . \left(r_p^{\frac{k-1}{k}} - 1\right)}{MM_{gas} . \rho_{gas} . g . (k-1)} + \frac{(1-\beta) . d_p}{\rho_{liquid} . g}$$ Eq. 4.10

$$Hydraulic\ Power, P_{hyd} = \frac{Q_{actual} . g . H_{adiabatic} . \rho_{TP}}{86400}$$ Eq. 4.11

$$Shaft\ Power, P_{shaft} = \frac{Hydraulic\ Power, P_{hyd}}{Overall\ efficiency, \eta}$$ Eq. 4.12

Using above equations, script of Inline (general) Element was prepared to replicate performance of the wet gas compressor. For each iteration within GAP's network solver, data flow within Inline (general) Element will obey following algorithm,


START
Obtain inlet pressure and temperature of The inlet stream.
Obtain Inlet flowrate of gas, oil and water
Obtain specific gravities of gas, oil and water
Calculate densities of gas, oil and water at STP
Calculate PVT properties of gas, oil and water through default Inline Element function.
Obtain Formation volume factors for gas, oil and water
Obtain densities of gas, oil and water at actual conditions
Calculate flowrates at actual condition.
Calculate mass flowrates of gas, oil and water
Calculate gas mass fraction
Calculate gas volume fraction
Density of multiphase fluid
Obtain user input values for,
Mechanical efficiency
Pol. coefficients for polytropic eff
No. of WGC in parallel
Upper bound for max. pressure rise
Maximum shaft power
Maximum Outlet temp
A

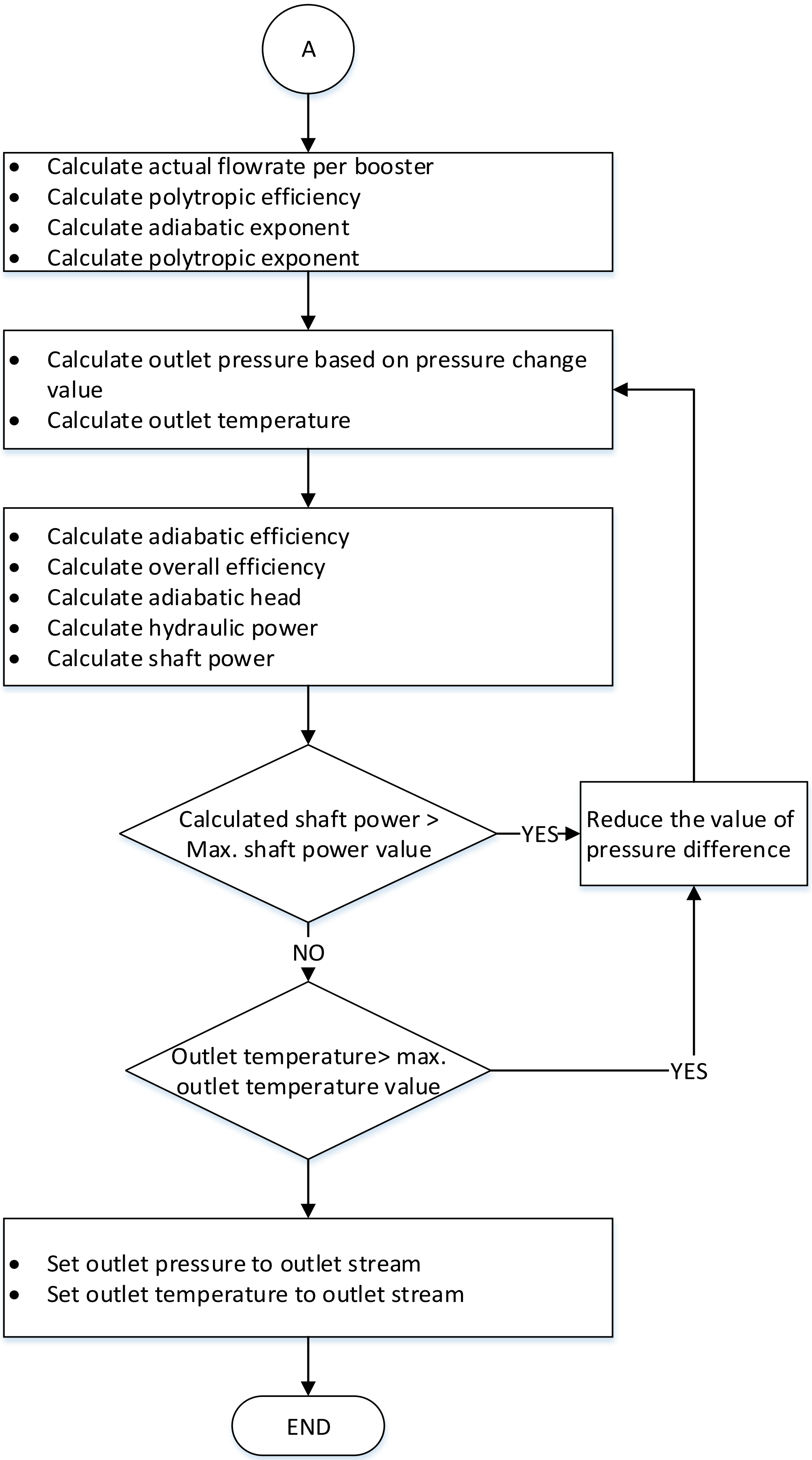


Figure 4. 12 Process Flow Diagram for GAP Inline Element, Snøhvit Field WGC-4000

4.7 Limitation in GAP Solver to Optimize Booster Outlet Pressure

Earlier, it has been tried to script the Inline Element code such that maximum differential pressure value will be set to the outlet of Inline Element, and simulation will be run. For each iteration, if simulated flow rate is greater than set flow constrain then value of pressure difference will be reduced. But, such approach was not allowing GAP's solver to get converged. Exact reason for such non-convergence is still unknown, however, it may be due to the pressure based solver methodology in GAP. Therefore, aforementioned approach was not implemented; instead maximum pressure difference value was manually adjusted to obtain equilibrium within the system.

4.8 GAP Network Modelling

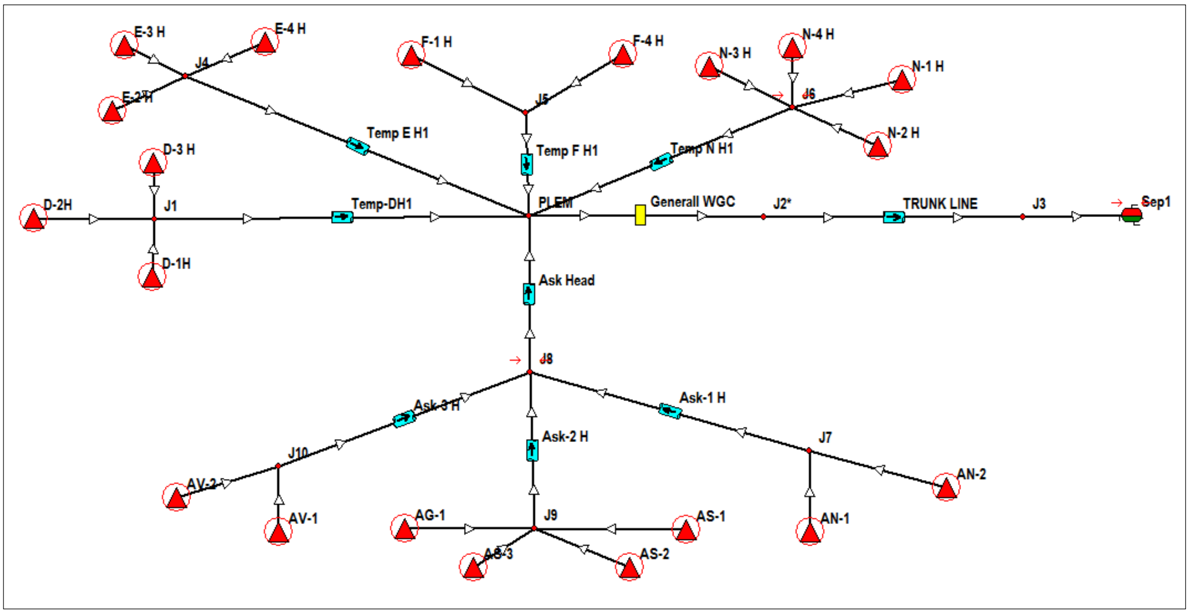


Figure 4. 13 Gap Network Simulation Model, Snøhvit Field

The network model represented by the Figure 4.15 reflects the network layout for the entire Snøhvit unit. Each flow line is set with the dimensions of the actual flowline of the field. The Inline Element, scripted as a wet gas compressor is represented in yellow coloured block. The detailed specification for the network and the script for the Inline Element are included in the Appendix A.

4.8.1 Sensitivity Analysis for The Performance of WGC-4000

The performance of any booster depends upon the fluid properties at the inlet of the booster. Likewise, performance of any multiphase booster also sensitive to the field's characteristics that changes fluid parameters.

For subject task, the criteria to test the sensitivity of the performance of the wet gas compressor is set as gas' water saturation. Such simplistic criteria are set to analyse the output of the wet gas compressor at varying booster inlet conditions. However, adapted methodology could also be tested against other field's sensitive parameters.

For the subject task, the wet gas compressor model developed through Inline (general) Element that was tested for the case of gas under saturated with water. Later, booster was tested for the case of gas saturated with water.

To approximate the amount of free water at booster inlet, network's pressure nodes are set as the bottom hole, well head/template and PLEM. Saturated water was estimated at each pressure node, and amount of free water was calculated.

Detailed water balance methodology has been included in the Appendix-A.

4.9 Results of The Analysis, Snøhvit Field

Sensitivity analysis of the proposed wet gas compressor model, developed through Inline (general) Element, depicts improve in performance of the booster at water saturated gas case. Such result indicates improvement in performance due to rise in density of fluid at the booster inlet. Because of simplistic calculation approach, rise in density of the fluid resulted in better output of the booster. Improvement in field productivity due to rise in density of the fluid can be evident in following Figures,

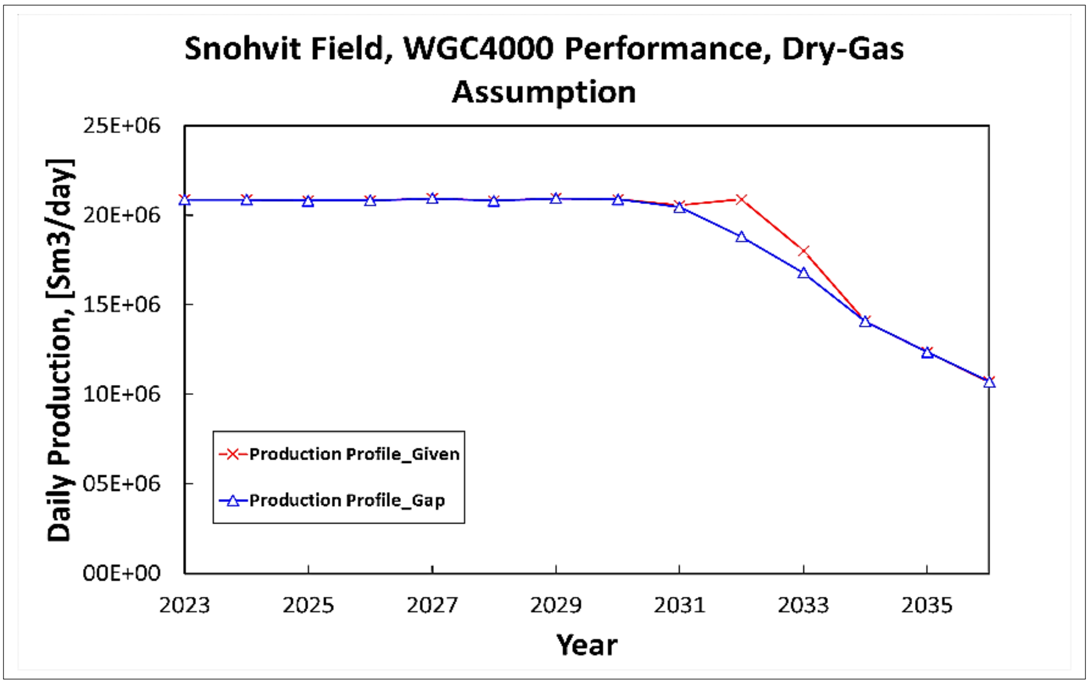


Figure 4. 14 WGC-4000 Performance, Snøhvit Field, Gas Under Saturated with Water[23]

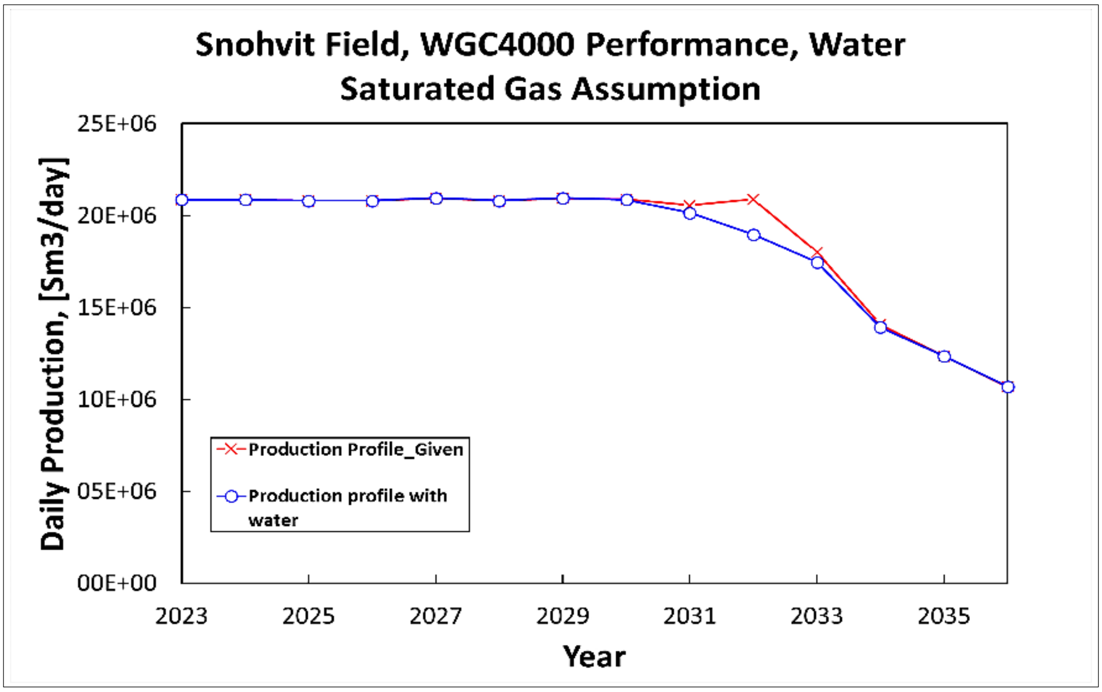


Figure 4. 15 WGC-4000 Performance, Snøhvit Field, Gas Saturated with Water[23]

As evident in the Figures 4.16 and 4.17, improvement in booster performance indicates overlapping of the given field's production profile and the production profile obtained through GAP simulation for the year 2033. If the actual boosters' mechanical and polytropic efficiency differs from the assumed values then the output of the booster will be different from the results presented in the Figure 4.14 and 4.15.

CHAPTER 5 DRAUGEN FIELD, SMUBS-II PROJECT

5.1 Objective of Booster's Performance Evaluation at Draugen Field

This chapter also deals with the objective of task (i) by proposing an alternative approach to evaluate the performance of the multiphase booster for Draugen field's SMUBS-II. The objective of the task is to approximate field's production profile in conjunction with the performance of the booster selected for the project.

To fulfil the task, this chapter is structured to describe the field's characteristics to depict the continual variation in fluid properties, proposal for artificial pressure boosting for production rate maintenance, hurdles in appropriate analysis and an alternative approach to propose the solution for the task.

5.2 Introduction to Draugen Field

Draugen field is situated near southern-end of Haltenbanken area. It was discovered in the year 1984, and production through the field commenced from the year 1993[29, 30]. Draugen is an offshore oil field, located at about 160 [km] from Trondheim, Norway. The average depth of the sea is around 280 [m]. The development plan of the field is based on gravity based fixed mono-column concrete (GBS) platform with topside integration. Draugen has both platform and subsea wells. Draugen field's main reservoir lie at about 1600 [m] depth, and mainly based on Rogn formation of late Jurassic formation. Western part of the field also produces through Garn formation of middle Jurassic age. Pressure maintenance of the field is assisted by water injection along with some support from aquifer expansion.

Main hydrocarbon production through Draugen field is oil, that is stored in the storage vessels installed on the bottom of the facility, and shipped through floating loading buoy[29]. Whereas, associated gas is transported to Karsto processing plant, located in Nord-Rogaland, Norway.

5.3 Draugen Field Description

Production facility at the Draugen field is consist of tie back lines through Rogn-South and Garn-West formation at the seabed. Commingled production through both formations is transported to topside integrated GBS platform. Production through Rogn-South formation is commingled at tee-manifold, which further commingles with the production of Garn-West formation at central manifold. Tie-back length from central manifold to topside integrated platform is about 4 [km].

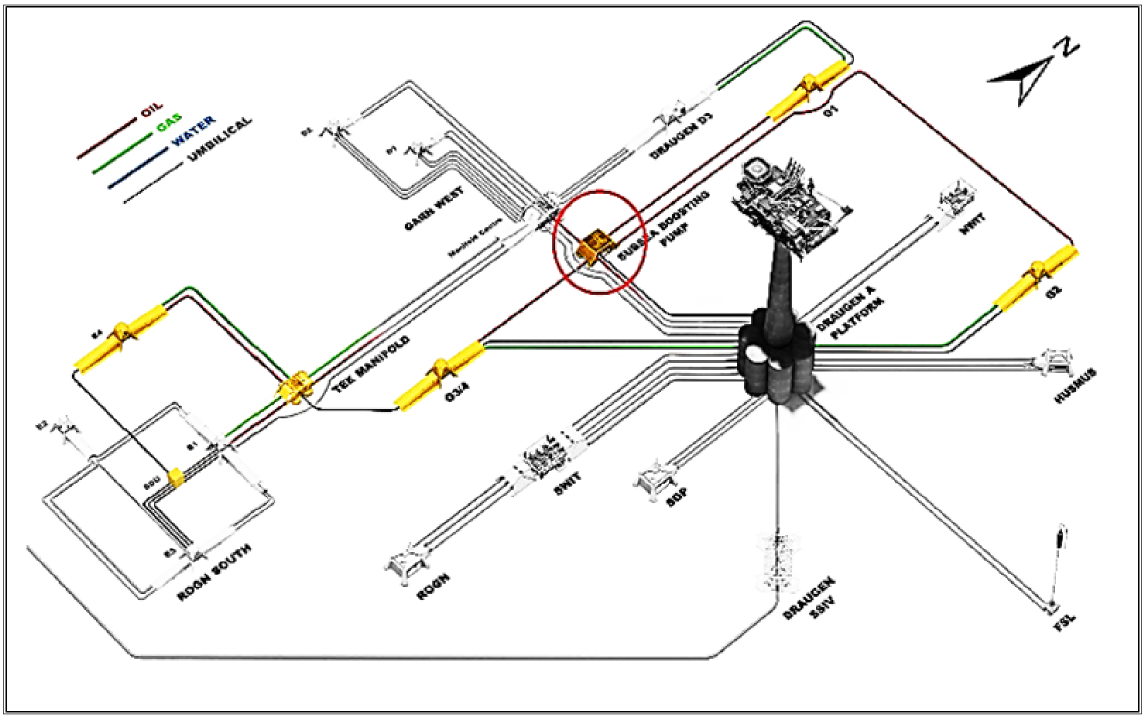


Figure 5. 1 Draugen Field Layout [31]

5.4 Field Characteristics and Production Profile

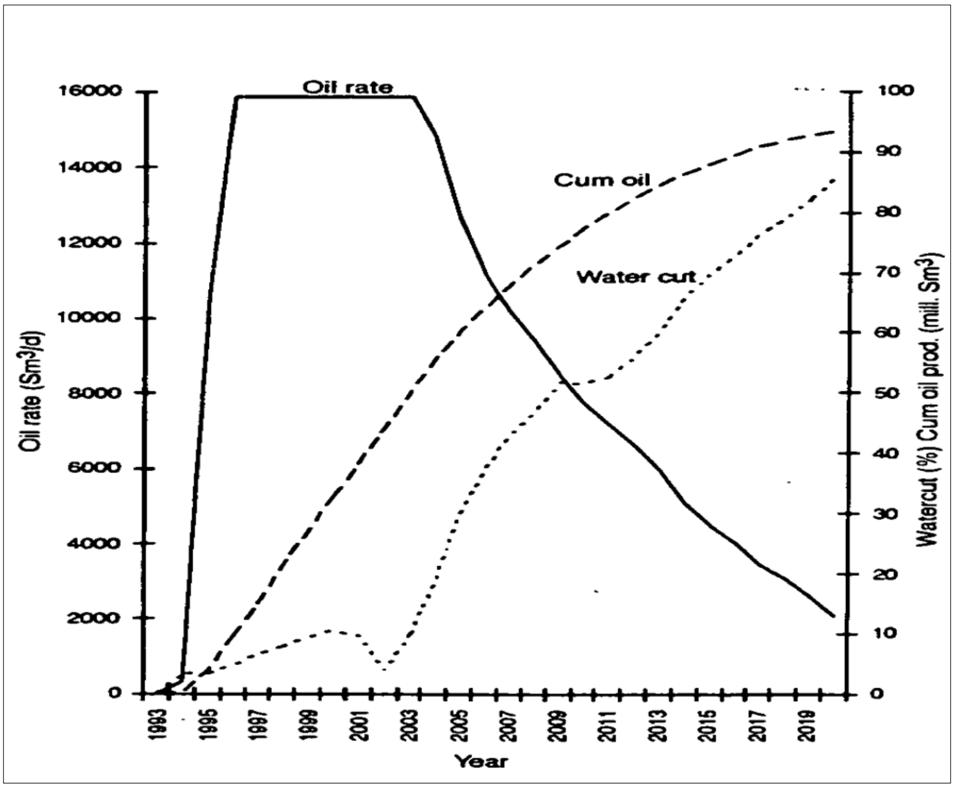


Figure 5. 2 Main Production Profile, Draugen Field[32]

Main hydrocarbon production through the field is non-volatile oil, along with associated gas and produced water. Pressure maintenance was planned through water injection, and continuous expansion of aquifer tends to continuously increase water-cut of the field. The production was remained water-free till the year 1999, while considerable water production started from the year 2000 [29]. Based on early estimation of the production rate, plateau oil production rate was around 16000 [Sm^3/day], while water-cut remained lower than 10 [%] till the year 2000. Figure 5.2 indicates the early estimated production profile of Draugen field.
According to Norwegian Petroleum Directorate (NPD)[29], peak production through Draugen field was increased to around 35000 [Sm^3/day] of oil, which is much more if compared with the earlier estimated rate. Considering the decline production profile of Draugen field, production rate will decline to 3756 [Sm^3/day] of oil by the year 2016. To sustain the production rate of oil above 4000 [Sm^3/day], an arrangement of artificial pressure boosting will be required to make up the deficiency in natural flowing potential. Artificial boosting will further increase the recovery factor of Draugen field beyond 70 [%], which is already highest in Norway. Earlier it was estimated to be 40 [%], but at present, extensive recovery has been achieved due to robust pressure maintenance activities.

Figure 5.3 represents the production profile of Draugen field since the commencement of the production, the profiles of water-cut and produced gas oil ratio are also incorporated in the following Figures.

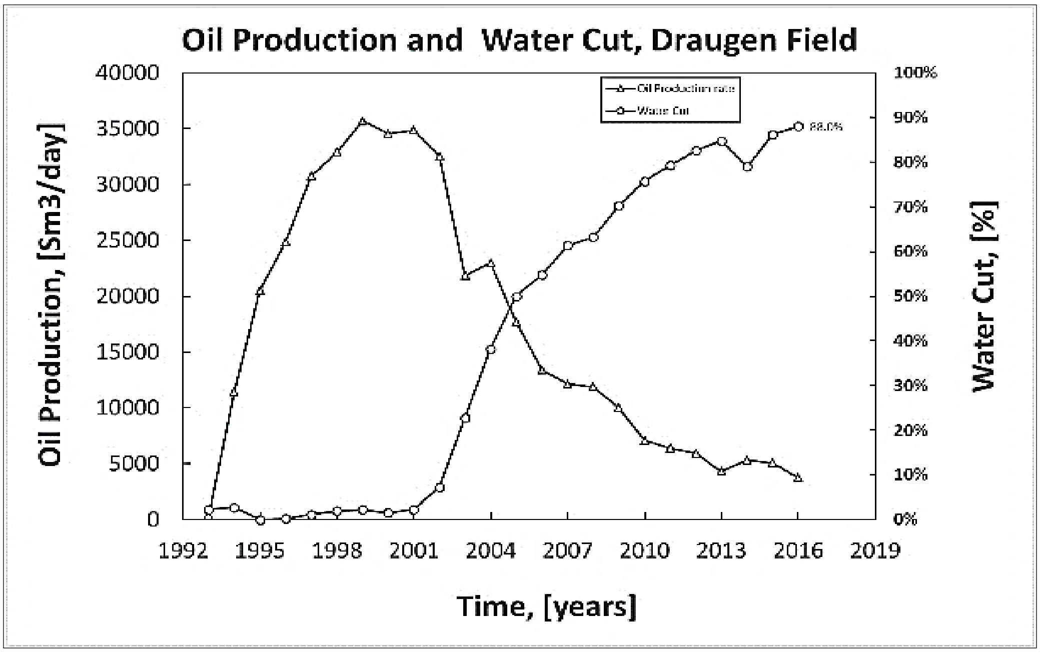


Figure 5. 3 Production Profile and Water-Cut, Draugen Field[29]

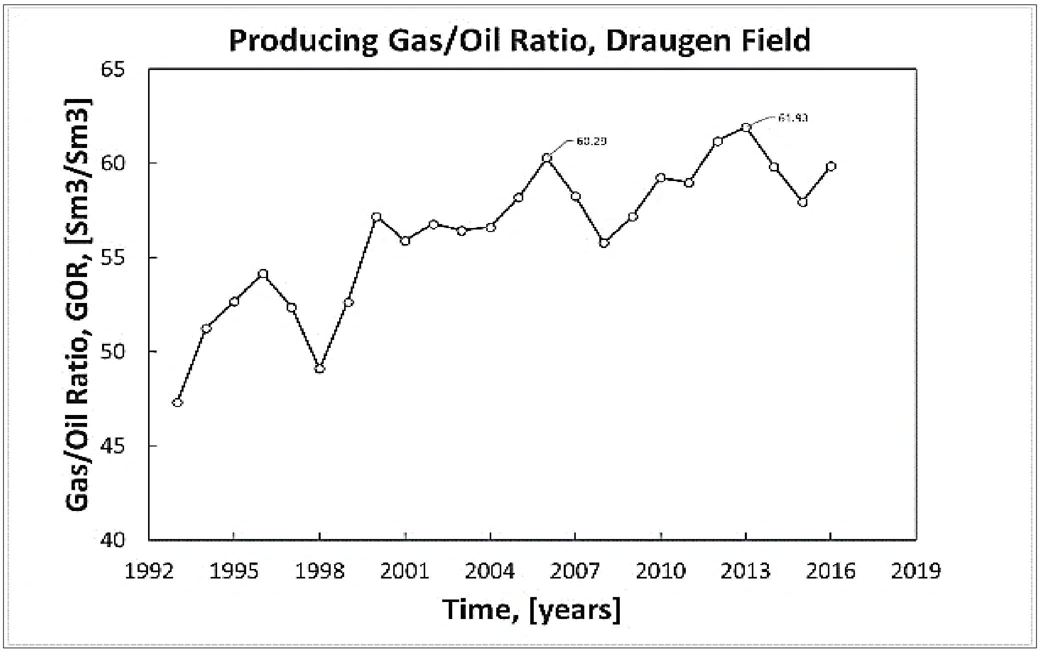


Figure 5. 4 Producing Gas/Oil Ratio, Draugen Field[29]

To meet the requirement of pressure increase, subsea boosting pump located near central manifold, was proposed. As per design concept, subsea boosting pump will intake fluid flow form central manifold, that contains commingled production through Garn-West and Rogn-South formations. For said purpose, Framo Engineering was granted a project to design subsea boosting pump, and helicoaxial type booster was proposed to meet the requirement. As per information, specifications of proposed booster will be,

Table 5. 1 Shell's Subsea Boosting Pump for Draugen SMUBS-I[31]

Specification	Value	Unit
Maximum differential pressure	50	[bar]
Pump suction pressure	21 – 29	[bara]
Pump suction GVF	10 – 32	[[%]]
Maximum shaft power	2300	[kW]
Flow rate	643 - 855	[m^3/h]
Flow rate	15432 - 20520	[m^3/day]
Pump Speed	1500 - 4200	[RPM]

To calculate the total flow rate at the booster inlet, following data pertain to commingled fluid’s properties has been considered,

Table 5. 2 Fluid characteristics of Draugen field [1-3]

Property	Value	Units
Fluid Type	Under saturated Oil	**[-]**
Oil API gravity @ STP	40.1	[API]
Specific gravity of gas	0.787	[-]
Initial reservoir pressure	165	[bara]
Initial reservoir temperature	68	[°C]
Initial Gas/Oil Ratio	51 - 67	[Sm3/Sm3]
Bubble point pressure	34 - 65	[bara]
Depth of the reservoir	1610	[m]

Reinholdtsen[32] stated variation in gas oil ratio from 67 [Sm^3/Sm^3] to 51 [Sm^3/Sm^3] from Southern to Northern zones respectively, with corresponding bubble point pressures of 65 [bara] to 34 [bara]. However, present producing gas oil ratio is around 60 [Sm^3/Sm^3]; at the beginning, it was around 50 [Sm^3/Sm^3] which has been gradually raised to the 60 [Sm^3/Sm^3] till the year 2016. Such trend of producing gas oil ratio indicates increase in production through Southern zones. Therefore, bubble point pressure of 34 [bara] was taken for the calculations appertain Draugen field SMUBS-I as a reference, as it validates the field's measured [33].Furthermore, producing gas oil ratio was taken as 51 [Sm3/Sm3] for SMUBS-I. Upon validation of the calculations, the equation of state [34] was accordingly tuned to yield solution gas oil ratio of 60 [Sm3/Sm3] for the present analysis.

5.5 The Appropriate Analytical Approach for Performance Prediction

To predict performance of proposed booster in Draugen field, it is necessary to develop a method that will generate approximate performance map of the booster at given conditions of pressure, temperature, water-cut, solution gas oil ratio (GOR) and GVF. Since, estimation of total flow rate depends upon certain value of water-cut, inlet pressure and temperature, and they will incur change in GVF and multiphase fluid's density as well, that will also re-define performance map of the booster. Therefore, at given values of inlet pressure, temperature and water-cut, an operating point can be calculated by calculating the required pressure at the booster outlet to maintain the desired oil production rate. Once, the operating point is calculated then it can be overlapped on the approximate performance map to analyse whether the desired oil production rate is achievable or the oil production rate is should be altered.

5.6 Limitation in The Appropriate Analysis for Draugen SMUBS-II

For precise evaluation of field's performance over the years, it is required to develop a precise network simulation model on commercial. Such simulation models can provide accurate values of pressure at the inlet of booster, by considering change in inflow performance relationship and tubing performance relationship. But, development of such model requires detailed information about the reservoir, production system, surface production architecture and environmental conditions.

Conversely, such detailed information is not available for Draugen field; thus, precise network modelling of Draugen field is not possible. Such limitation will not allow to repeat the methodology adapted for the Snøhvit field.

5.7 Methodology for Draugen SMUBS-II Evaluation

Unavailability of correct information about Draugen field does not allow to devise the methodology based on network simulation. Thus, for Draugen field, it is decided to create an Ms Excel spreadsheet that will take field data as an input, and calculate approximated performance map of the proposed booster model, and an operating point against given conditions. Plotting operating point on booster performance map will graphically indicate whether desired oil flow rate is feasible or not.

Skiftesvik[33] discussed test project of world's first subsea multiphase booster pump installed in Draugen field in the year 1994. Shell's multiphase underwater booster station (SMUBS-I) was implemented to raise the fluid production rate through Rogn-South formation which has around 9 [km] of distance from the test facility. Skiftesvik also mentioned field measured data for the Draugen SMUBS-I project, which was used to back calculate pressure loss during transportation of fluid.

To estimate maximum producible total flow rate against given suction pressure, field data was used to develop a polynomial equation, and spreadsheet is formulated such that if the desired total flow rate becomes greater than maximum possible total flow rate at given booster suction pressure, than maximum flow rate will become desired flow rate, otherwise, desired rate will be used for further calculation. The relation between booster inlet pressure and maximum possible flow rate is incorporated in the Appendix-B.

In measured data[33], temperature at the suction of the booster was mentioned as 50 – 60 [°C], that indicates thermal heat proofing of the flow lines as reservoir temperature, as the reservoir temperature is 68 [°C]. While the total temperature drops during transportation of fluid from 9 [km] distanced wellhead is about 8 – 18 [°C]. Therefore, to set the criteria for calculations, it was assumed that the fluid temperature at the suction of the booster will be constant as 50 [°C]. Furthermore, boosting has been assumed as isothermal, that means temperature at the outlet of the booster will also be fixed at 50 [°C].

5.8 Calculation for Required Pressure at the Booster Outlet

To calculate required pressure at the booster outlet, net standard flow rate is used as reference point, and required pressure is back calculated. To back calculate the pressure, entire trunk line's length of 4 [km] was discretised into small segments. Then segments of the trunk line and the riser's length of 280 [m] was used to calculate the required inlet pressure.

To simplify the estimation of viscosity of the fluid during transportation, both water and oil phases are combinedly assumed as liquid phase having net emulsion viscosity estimated through Brinkman's emulsion viscosity relation [35, 36]. Whereas, viscosity of oil was estimated from Standing correlation[8], while the gas viscosity was approximated through Lee Gonzalez correlation[8].

For the calculation of required pressure at the booster outlet, homogeneous flow model[2] is considered as applicable, multiphase fluid phase within trunk line is assumed as homogeneous single phase fluid, having properties corrected for all fluid phases within the trunk line. To further simplify the calculation, water and oil are combinedly assumed as single-phase liquid, having corrected fluid properties. So, simplified pressure drop calculations across trunk line will be followed as,

$$Superficial\ velocity\ of\ gas, V_{SG} = \frac{Q_{Gas}}{A} \quad \text{Eq. 5.1}$$

$$Superficial\ velocity\ of\ Liquid, V_{SL} = \frac{Q_{Water} + Q_{Oil}}{A} \quad \text{Eq. 5.2}$$

$$Mean\ Velocity, V_m = V_{SG} + V_{SL} \quad \text{Eq. 5.3}$$

$$Liquid\ Flux\ Fraction, \lambda_{Liquid} = \frac{V_{SL}}{V_m} \quad \text{Eq. 5.4}$$

$$Gas\ Fux\ Fraction, \lambda_{Gas} = \frac{V_{SG}}{V_m} \quad \text{Eq. 5.5}$$

$$Volume\ average\ liquid\ density, \rho_{Liquid} = \frac{Q_{Oil}.\rho_{Oil} + Q_{water}.\rho_{Water}}{Q_{Oil} + Q_{Water}} \quad \text{Eq. 5.6}$$

$$Mean\ Density\ , \rho_{Mean} = \rho_{Gas}.\lambda_{Gas} + \rho_{Liquid}.\lambda_{Liquid} \quad \text{Eq. 5.7}$$

$$Water - cut, WC = \frac{Q_{Water}}{Q_{Water} + Q_{Oil}} \quad \text{Eq. 5.8}$$

$$Liquid\ Phase\ Viscosity, \mu_{Liquid} = \mu_c.(1-\varphi)^{-2.5} \quad \text{Eq. 5.9}$$

$$Mean\ Viscosity, \mu_m = \mu_{Gas}.\lambda_{Gas} + \mu_{Liquid}.\lambda_{Liquid} \quad \text{Eq. 5.10}$$

Viscosity of the gas was estimated on the base of specific gravity of the gas[37].

$$Reynold\ Number, RN = \frac{\rho_m\ .V_m\ .d}{\mu_m} \quad \text{Eq. 5.11}$$

Source[1] $$Single\ phase\ friction\ factor, f^{\circ} = 0.16.(RN)^{-0.172} \quad \text{Eq. 5.12}$$

$$Friction\ correction\ factor, C_{Two\ phase} = \frac{\rho_{Gas}.y_{Liquid}.(1-\lambda_{Liquid})^2 + \rho_{Liquid}.(1-y_{Liquid}).\lambda_{Liquid}^2}{\rho_m.y_{liquid}.(1-y_{Liquid})} \quad \text{Eq. 5.13}$$

Since, the GVF during transportation is assumed to be low as the trunk line pressure is far above bubble point pressure at reservoir conditions, and entire trunk line is assumed as linear. Therefore, Eq.3.13 was simplified with an assumption that gas and liquid phase will have similar velocities. Such assumption equates liquid loading to liquid flux fraction.

$$Two\ phase\ friction\ factor, f_{TP} = C_{Two\ phase}\ .f^{\circ} \quad \text{Eq. 5.14}$$

$$Multiphase\ pressure\ gradient, dPG_{MP} = \frac{0.5.f_{TP}.\rho_m.V_m^2}{d} \quad \text{Eq. 5.15}$$

$$Multiphase\ pressure\ drop, dP_{MP} = (dPG_{MP} * Length) + (\rho_m.g.H_{Riser}) \quad \text{Eq. 5.16}$$

Although local gas oil ratio will result in gas liberation during transportation, but, such consideration is not expected to incur any radical change in pressure estimation. Criteria to set phase concentration and dispersion phase was based upon water-cut, such that oil phase will be considered as concentrated phase with water as dispersion phase for the water-cut between 0 – 50 [%]. When water-cut exceeds 50 [%], then concentrated phase will change from oil to water and dispersed phase will change from water to oil phase.

To set the separator conditions, Draugen field's SMUBS-I measured data was taken as a reference, and separator pressure was assumed as 35 [bara], which is greater than bubble point pressure. Then Ms Excel solver was used to estimate the possible separator temperature that complies with the separator pressure assumption of 35 [bara]. Approximated pressure and GVF profile against trunk line temperature profile of Draugen field, considering measured data of Draugen field's SMUBS-I, are illustrated below,

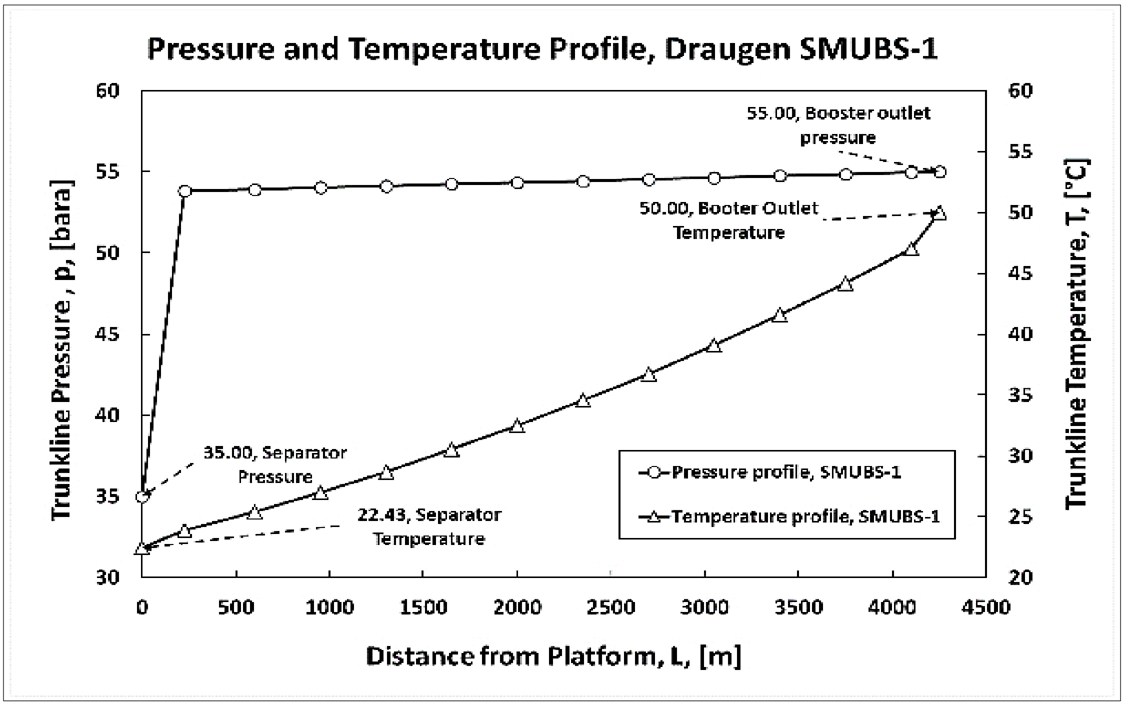


Figure 5. 5 GVF Profile, Draugen Smubs-I

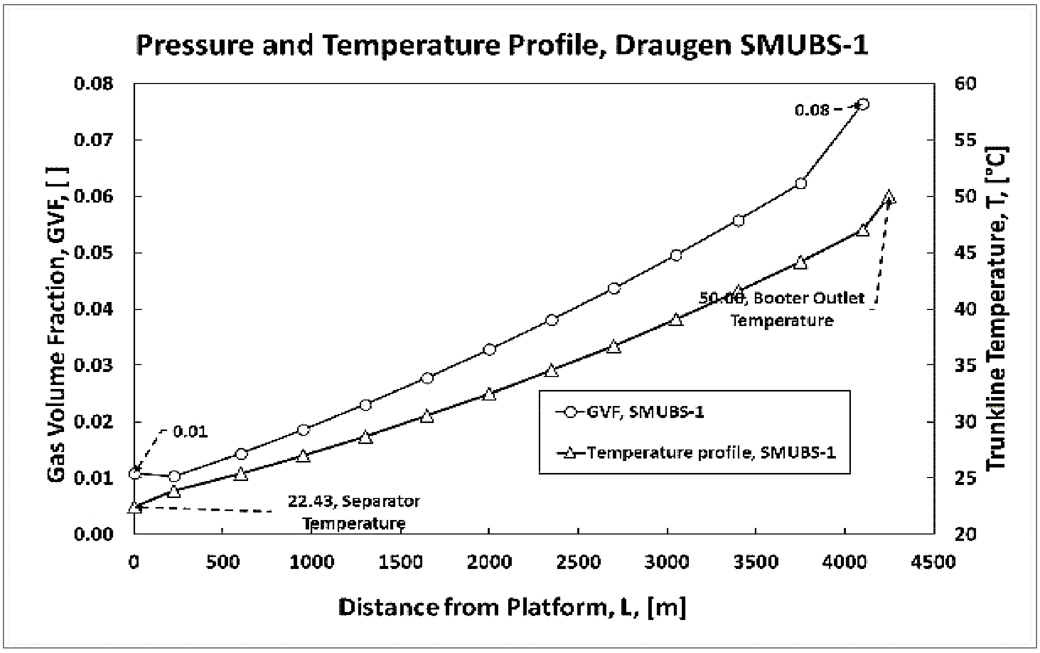


Figure 5. 6 Pressure and Temperature Profile, Draugen SMUBS-I

As illustrated above, at assumed separator pressure, temperature of the fluid at the separator is estimated as 22.43 [°C], whereas, GVF remains around 10 [%]. Although, precise calculation of pressure loss within trunk line requires dynamic calculation of liquid loading within segments, but for subject task, error associated with steady state multiphase flow pressure loss assumption will be accommodated in the total possible error in analysis. Upon validation of Draugen field's SMUBS-I measured data, same formulation is adapted for revised gas oil ratio of 60 [Sm^3/Sm^3] having accordingly tuned equation of state.

5.8.1 Uncertainty in Separator Pressure

The calculated separator pressure and the surface oil temperature may result the completely matched output of the multiphase booster used for SMUBS-I, however, the calculations were calibrated on the assumption of completely horizontal elevation profile of the trunk line, and a vertical profile of the riser. Such assumption may verify the homogeneous fluid assumption. Conversely, if the actual elevation profile differs from the assumed elevation profile, then the pressure drop within trunk line will drastically increase due to the occurrence of phase slip, and change in liquid loading within elevated segments. In that case, the actual separator pressure will be lesser than 35 [bara].

Therefore, to analyse the performance of the proposed booster for Draugen SMUBS-II, the separator pressures was considered as a sensitive parameter, and the results are included for the both separator pressures of 35 [bara] and 8[bara].

The methodology adapted for the Draugen SMUBS-II will only propose an alternative approach to analyse the performance of the multiphase booster. For accurate results, it is strongly recommended to provide the required pressure difference and booster inlet conditions as a user input, and the methodology should only be used to analyse the performance of the booster.

5.9 Calculation for Operating Point

To obtain operating point, following calculation steps are adapted,

i. Take desired oil rate, water-cut, booster inlet pressure as an input.
ii. Calculate solution gas oil ratio at booster inlet conditions, and calculate gas rate at free state.
iii. Calculate water rate using water-cut, gas and oil rate at local conditions.
iv. Calculate GVF at booster inlet.
v. Back-calculate pressure from separator conditions till the booster's outlet.
vi. Calculate pressure difference across booster, and total actual flow rate.

5.10 Calculation for Booster Performance Map

Selected model of multiphase booster is of Helicoaxial type by design, and can accommodate flow rate with GVF range from 0-75[%]. Since, exact booster performance map is unavailable, therefore, performance data of a multiphase booster of Helicoaxial design is obtained from a commercial network simulator PIPESIM (Schlumberger). From PIPESIM, multiphase booster model of Framo Hx-310/1100/120 was used to obtain booster performance map using Draugen field's fluid model.

To approximate performance map of the selected booster for Draugen field, following calculation steps are adapted,

i. Create fluid model in PIPESIM, using Draugen field's fluid properties.
ii. Run simulation for different gas and oil rates, at fixed water-cut of 50[%], keeping inlet pressure at 21 [bara] and inlet temperature of 50 [°C]
iii. Obtain booster performance map for random GVF values like 0, 0.14, 0.24, 0.44, 0.6
iv. Use minimum flow points for 100 [%] speed curves and GVF values of 0 - 60 [%].
v. Normalize all flow rates with maximum flow rate at GVF 0 and speed 100[%]
vi. Normalize all pressure differences (dp) with maximum dp at GVF0 and speed 100[%].
vii. Perform 4th order polynomial regression to develop an equation for change in minimum flow point (for both minimum flow and dp) with respect to change in GVF.

viii. Repeat step (iv) and (v) for the speed curves ranging from 100[%] till 10[%].

ix. Keep polynomial coefficients A, B, C, D and E as reference, calculate respective ratio of the change in each coefficient with respect to 100[%] polynomial coefficients like,

$$Relative\ change\ in\ coefficet\ (A) = \frac{Coefficient\ A_{Speed(i)}}{Coefficient\ A_{speed(100[\%])}}$$

x. Calculate relative change for the coefficients A, B, C, D and E.

xi. Perform 4th order polynomial regression (for both minimum flow and dp) for relative change in each coefficient with respect to the speeds of the booster.

xii. Develop a relation that take GVF, maximum flow rate and dp as an input and generate minimum flowline by following methodology,

    a. For given speed of the booster, calculate corrected polynomial coefficients A, B, C, D, and E using polynomial equation developed in step (xi).
    b. For given GVF, calculate minimum flow point using polynomial equation developed in step (vii)

xiii. Repeat steps (iv) till (xii) for maximum flow points

xiv. Using maximum dp = 50 [bar] and maximum flow rate = 20520 [m^3/day] and GVF of Draugen field's input data, generate data for minimum and maximum flow points for the speeds of 100[%] till 10[%].

xv. Plot minimum flow points, maximum flow points and the line joining the both to develop full map of the selected booster for Draugen field.

Since detailed network simulation is not available, and correct values of pressure and free gas volume are unavailable, therefore, uncertainty involved in generated performance map cannot be mitigated. The magnitude of free gas at booster inlet is itself a function of pressure and water-cut, which further implicates significant change in system performance curves. To elaborate the relative change in system performance curve with respect to the change in GVF, system performance curve and GVF were plotted for the water-cut of 0.5, 0.65 and 0.8.

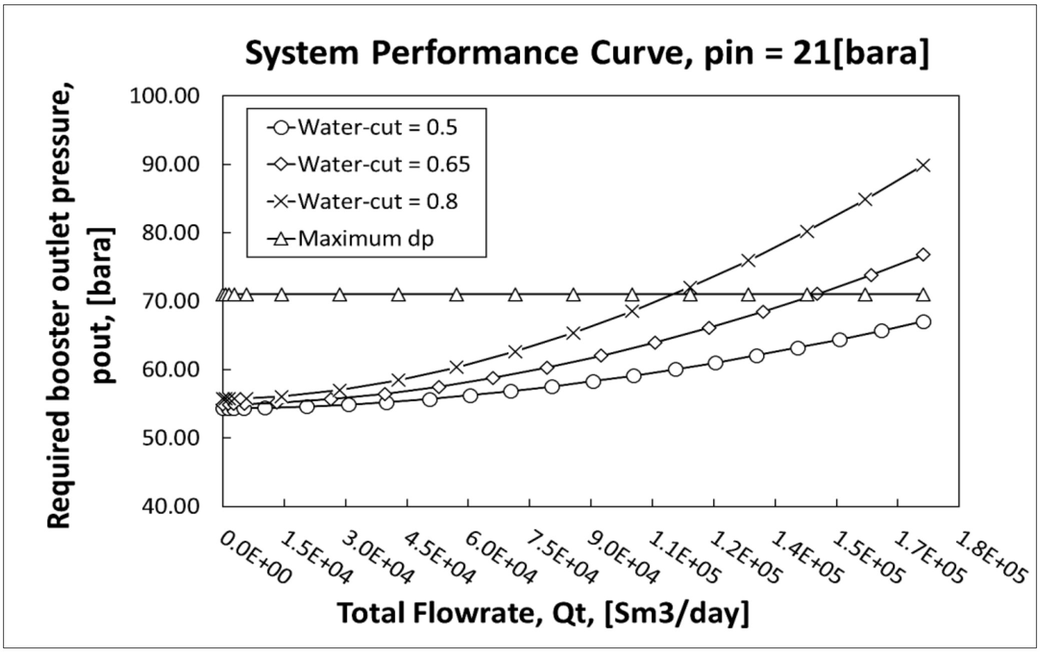


Figure 5. 7 System Performance Curves for Draugen Field

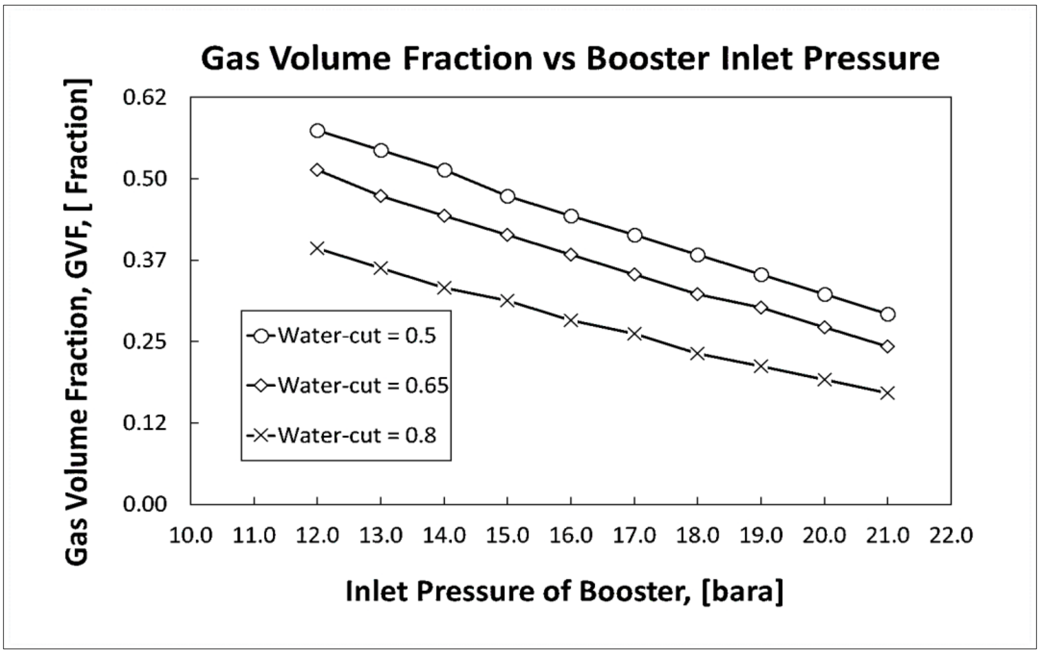


Figure 5. 8 Relation Between Booster Inlet Pressure And GVF

As evident from the Figure 5.7, GVF for each case of water-cut is related with the selection of booster's inlet pressure. Figure 5.6 indicates the relative decline in the value of flow rate, for each water-cut, at the maximum booster outlet pressure.

In addition to the maximum pressure boosting capability, another important constraint that limits the flow handling capability of any booster is the shaft power. Determining shaft power is subject to calculate overall efficiency of the booster including hydraulic efficiency, mechanical efficiency, drive's efficiency etc. Since evaluating precise efficiency is not achievable at presently available data. Therefore, at assumed global efficiency of 75 [%], the shaft power was calculated for the case of separator pressure of 35 [bara] and 8 [bara] and water-cut of 0.5, 0.65 and 0.8 for each case.

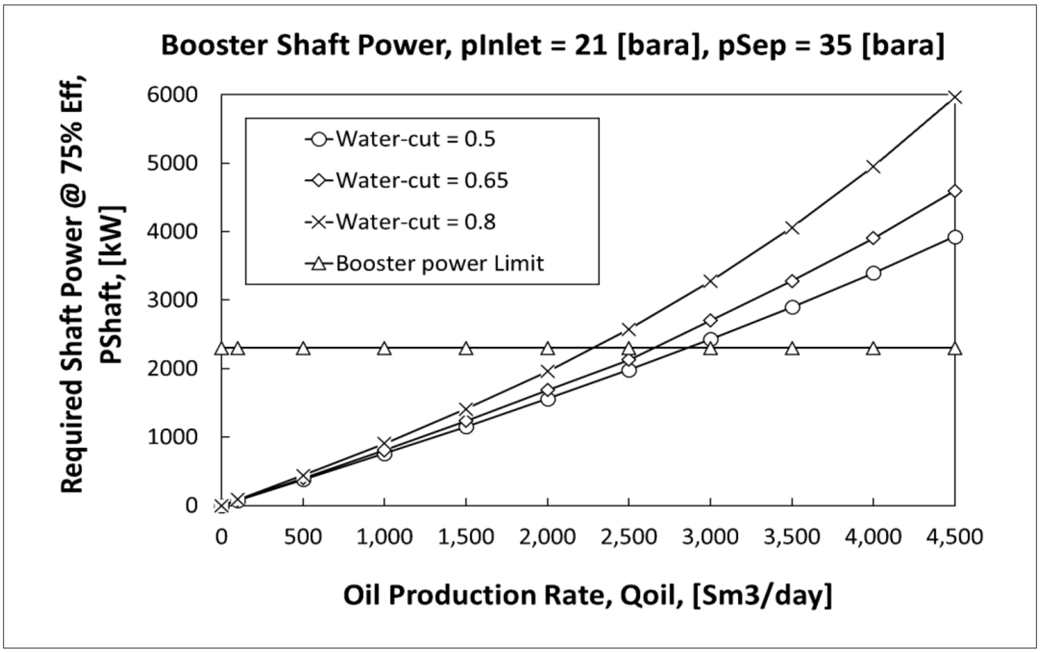


Figure 5. 9 Power Defined Oil Rates, Draugen Field, Sep. Pressure=35 [bara]

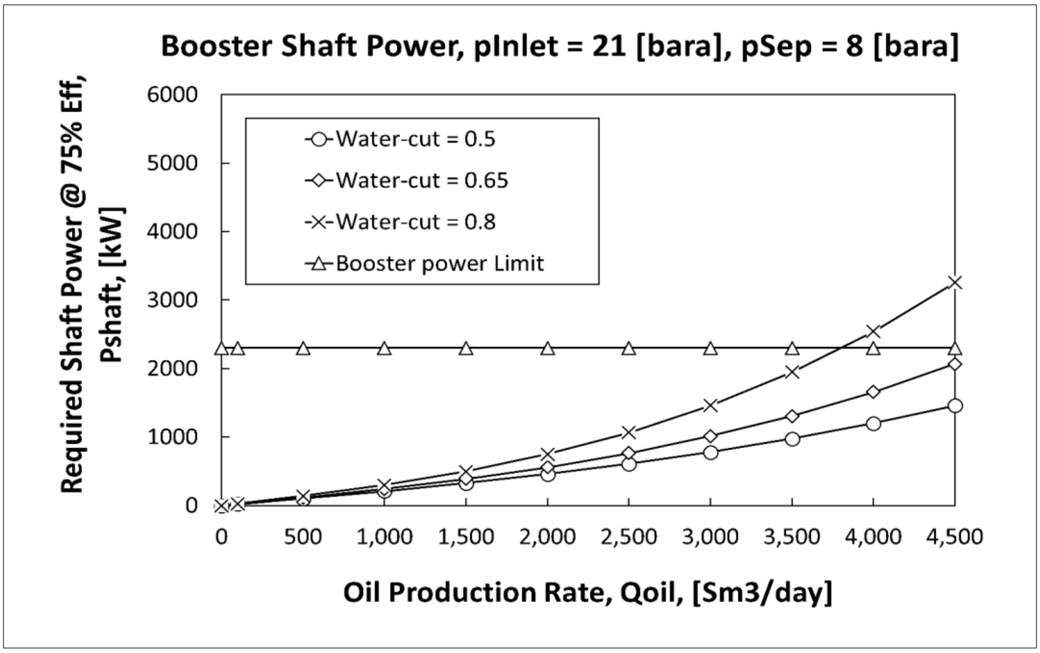


Figure 5. 10 Power Defined Oil Rates, Draugen Field, Sep. Pressure =8 [bara]

5.11 SMUBS-II, Booster's Performance Evaluation

Once full performance map and operating point have been created, then overlapping of operating point on booster map will indicate whether operating point is within operational map at given booster inlet conditions or not. For instance, if oil production rate of 4000 [Sm^3/day] is required at water-cut of 50[%] and booster inlet conditions of 21 [bara] and 50 [°C], then approximated performance map can be illustrated as following,

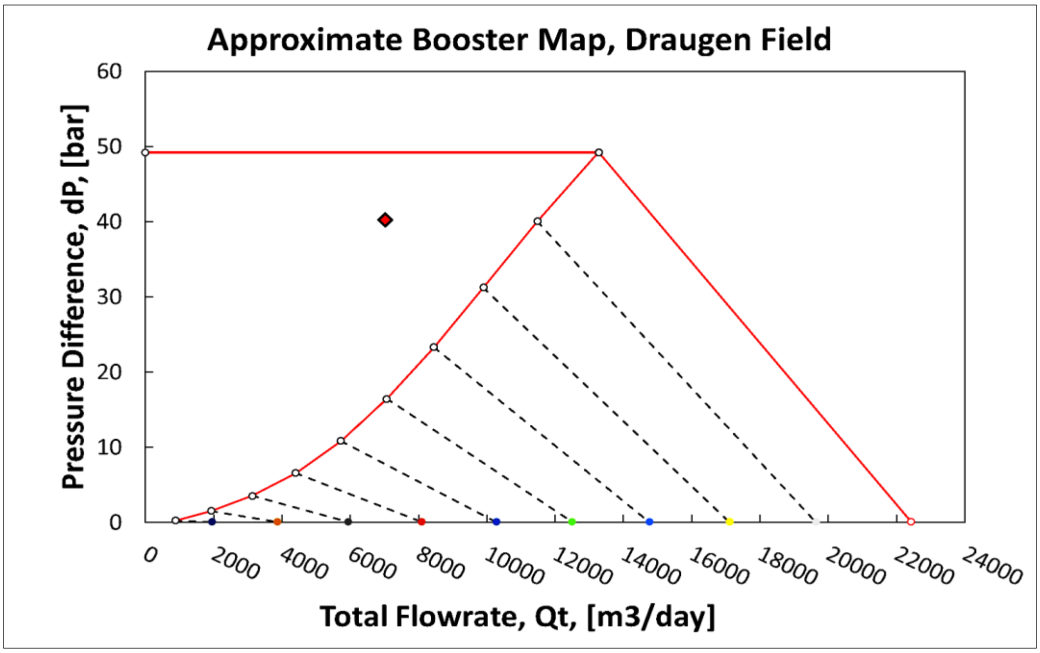


Figure 5. 11 Draugen Field, Generalised Iso-speed Performance Map

5.12 Limitation of The Analysis

Figure 5.1 illustrates continues rise in water-cut of the field, that will implicate continues change in density of the fluid over the corresponding stage of the field. Since the methodology adapted is entirely based upon the data obtained from the PIPESIM, and it requires specifying fluid properties prior to execute simulation. Therefore, to generalize fluid properties, fluid model in PIPESIM was set on the assumptions mentioned earlier. The PIPESIM fluid model was set at following fluid properties,

Table 5. 3 Draugen field, Fluid Model Properties in PIPESIM

Property	Value	Units
Booster Inlet Pressure	21	[bara]
Booster Inlet temperature	50	[°C]
Water-cut	50	[[%]]
Solution Gas/Oil Ratio (GOR)	60	[Sm^3/Sm^3]

On the other hand, spreadsheet was set with flexibility in the value of water-cut, inlet pressure of the booster and inlet temperature of the booster. If any such value differs from the fluid model set for PIPESIM, then density of the liquid fluid at inlet of the booster will change. Since performance data of the booster was obtained for certain value of the density of liquid at the inlet of the booster, so, any variation will not incur any change in booster performance map. However, difference in fluid properties from the one set in PIPESIM fluid model will change the position of operating point.

In subject approach, field's performance characteristics cannot be incorporated, which limits the evaluation of available pressure at booster's inlet. Such limitation does not allow to precisely estimate the maximum producible flow rate against pressure. However, field's measured data for the flow rate against the pressure at the point of booster's position is available, which was used to approximate maximum producible total flow rate against given inlet pressure. Such approach assists in limiting the desired flow rate, and analysis will only be conducted for producible total rates.

5.13 Analysis for Draugen Field SMUBS-II

Considering oil production rate and water-cut profile illustrated in the Figure 5.1, desired oil production rate can be assumed to be 4000 [Sm^3/day], but water-cut value has continues increasing trend. Such increasing trend will affect GVF and total flow rate at the suction of the booster. Such variation in water-cut and GVF has been set as a criterion for the sensitivity analysis for the performance prediction of the booster. To analyse operability of the selected booster, performance will be tested at the booster inlet pressure of 21 [bara] and water-cut values ranging from 30 [%] till 70 [%]. Following table shows the approximate GVF against water-cut, at oil production rate of 4000 [Sm^3/day] and booster inlet temperature and pressure of 50 [°C] and 21 [bara],

Table 5. 4 Calculated GVF for Different Water-Cut Values

Water-Cut [%]	GVF [-]
0.3	0.34
0.4	0.32
0.5	0.29
0.6	0.26
0.7	0.22
0.8	0.17

5.14 Results of The Analysis for Draugen SMUBS-II

In accordance with the values of water-cut mentioned in the table 5.4, the analysis was conducted for the separator pressure values of 35 [bara] and 8 [bara]. Since the correctness of the separator pressure is still not certain, and the results are indigenously depending upon the separator conditions, therefore, the results can be declared as a reference for initial approximation only.

Following Figures indicates the change in the operating points position and the change on the iso-speed performance map by varying the water-cut (or the GVF).

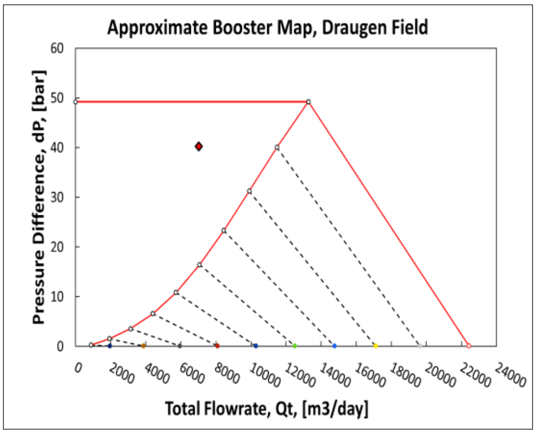


Figure 5. 12 Water-Cut 30 [%], GVF 34 [%], Sep. Pressure = 35 [bara]

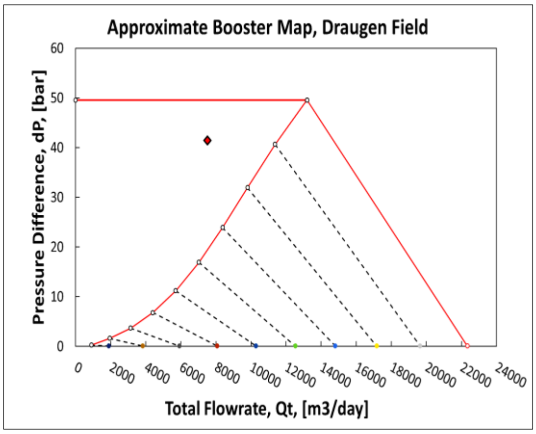


Figure 5. 13 Water-Cut 40 [%], GVF 32 [%], Sep. Pressure = 35 [bara]

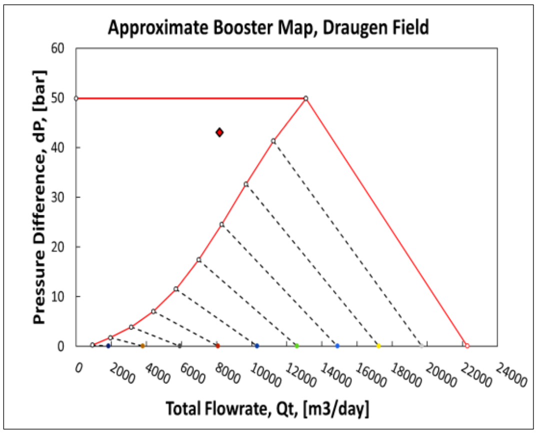


Figure 5. 14 Water-Cut 50 [%],
GVF 29 [%], Sep. Pressure = 35 [bara]

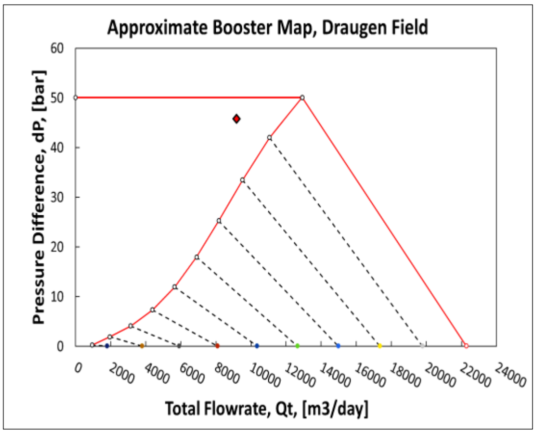


Figure 5. 15 Water-Cut 60 [%],
GVF 26 [%], Sep. Pressure = 35 [bara]

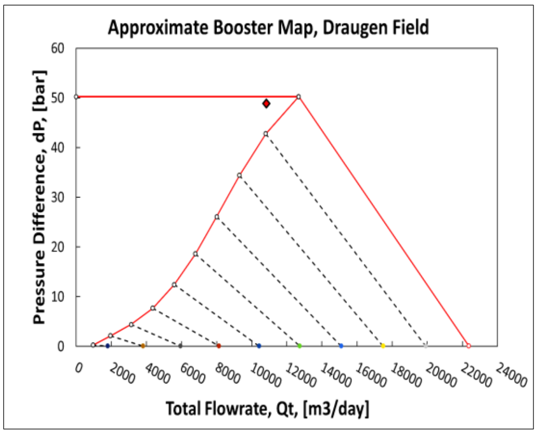


Figure 5. 16 Water-Cut 70 [%],
GVF 22 [%], Sep. Pressure = 35 [bara]

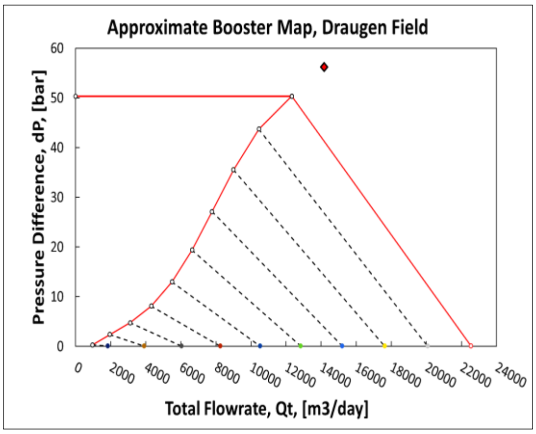


Figure 5. 17 Water-Cut 80 [%],
GVF 17 [%], Sep. Pressure = 35 [bara]

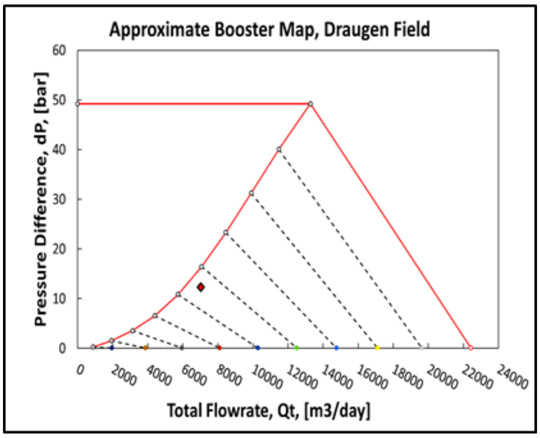


Figure 5. 18 Water-Cut 30 [%],
GVF 34 [%], Sep. Pressure = 8 [bara]

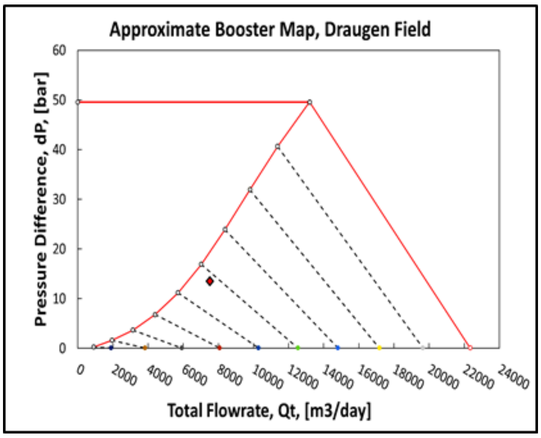


Figure 5. 19 Water-Cut 40 [%],
GVF 32 [%], Sep. Pressure = 8 [bara]

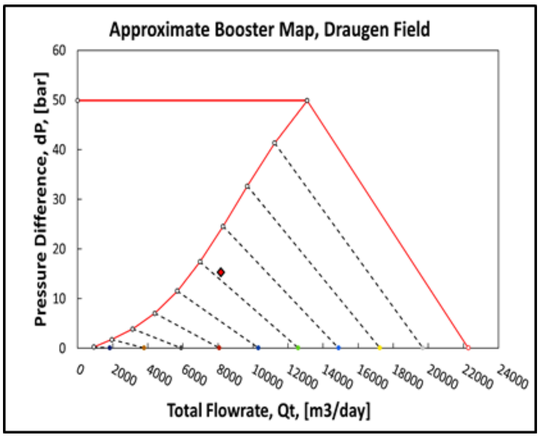


Figure 5. 20 Water-Cut 50 [%], GVF 29 [%], Sep. Pressure = 8 [bara]

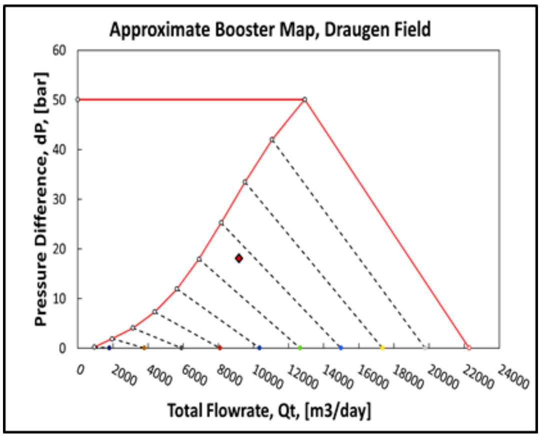


Figure 5. 21 Water-Cut 60 [%], GVF 26 [%], Sep. Pressure = 8 [bara]

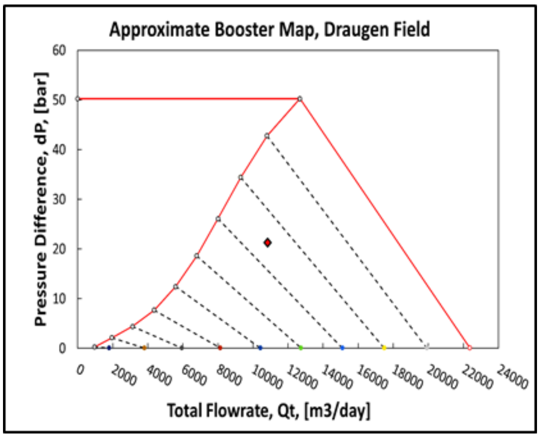


Figure 5. 22 Water-Cut 70 [%], GVF 22 [%], Sep. Pressure = 8 [bara]

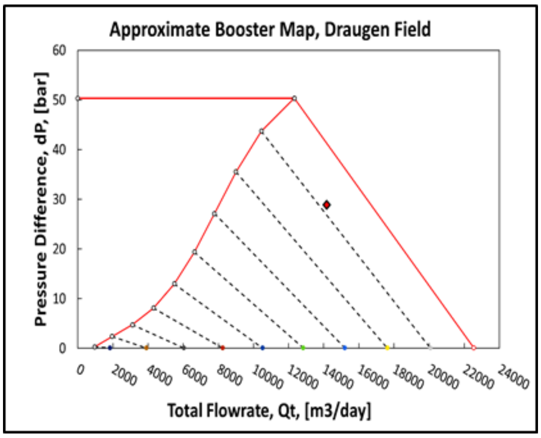


Figure 5. 23 Water-Cut 80 [%], GVF 17 [%], Sep. Pressure = 8 [bara]

As evident in approximate performance maps, operating point changes from left of surge line to the right of maximum flow limit line of the booster for the case of separator pressure of 35 [bara]. If operating point is at the left of surge limit line, the it can be moved towards operating zone of the map by flow recycling. However, for the operating point at the right side of stone-wall limit, oil production rate must be decreased to change the operating point within operating zone.

On the other hand, separator pressure of 8 [bara] reduces the required pressure at the booster outlet, and the operating point remained within booster envelop for all the values of water-cut.

Such variation in the output for the different values of the separator pressure establishes a course for the further work, as the analysis will remain uncertain without integration of the complete flow assurance calculations along with booster's performance.

CHAPTER 6 CONCLUSION AND RECOMMENDATIONS

The aim of the thesis has been to develop an alternative approach to evaluate the performance of a multiphase booster with the variation in core field parameters such as inlet pressure, temperature, WC, GOR etc. The major problem associated in selection of a booster is to predict its operability at the later stages of field life. Although, the scope of the thesis was distributed in three different tasks, the overall scope is still the same, i.e. to develop a framework that may be used to estimate the performance of any multiphase booster by varying field parameters. Since, all tasks were related to different fields, the outcome of the methodology and the results of all the tasks are concluded separately.

6.1 Alternative Modelling Approach for Multiphase Boosting

The objective of the subject task is to evaluate the proposed multiphase booster for Snøhvit and Draugen fields. For the case of Draugen field, the design rating of the multiphase booster is comparative to the boosters available in the PIPESIM and GAP. While, the proposed wet gas compressor unit for the Snøhvit field is not available in PIPESIM and GAP.

6.2 Snøhvit Field Multiphase Boosting

The unavailability of a wet gas compressor model in the production simulator does not allow to predict the output of the selected multiphase booster with the changes in Snøhvit field's pressure and flow rate. Thus, development of an Inline Element, modelled as a wet gas compressor, may provide an initial approximation for the performance of the selected booster. Since the performance of any booster is strongly affected by its efficiency. The estimation of the efficiency for multiphase fluid booster is still under research. So, the adapted method to estimate polytropic efficiency of the axial booster may not truly represent the output of the actual booster for Snøhvit field. However, availability of the detailed design specifications or the experimental data of the selected booster will provide a good approximation of efficiency at the given booster inlet conditions. In such case, the script of the Inline Element may be edit accordingly, such that the value of mechanical efficiency and polytropic efficiency may be replaced with the actual efficiency relation of the selected booster to yield more precise results.

Furthermore, boosting process has been assumed as polytropic in the script of Inline Element. Such assumption may yield a better result for the GVF of 90 [%] and above, as the modelled wet gas compressor is similar the dry gas axial compressor. With the substantial change in water production over the productive life of the field, such assumption may not represent the actual performance, as thermal equilibrium between the phases may violate the assumption of polytropic boosting. Such vulnerability in the result of the modelled booster will always introduce uncertainty in the results.

The proper implementation of the proposed methodology demands the GAP solver to optimize the power of the booster such that the script will rise the pressure up to the maximum and let the solver to yield the new value of the flow rate. If the new value of the flow rate becomes greater than the given value, the script should reduce the pressure rise value accordingly or vice versa. Such approach was not applicable, as the GAP solver failed to converge the system within defined tolerance. Tolerance was also relaxed to assist the solver to get converged, but, still it failed. That deficiency of the solver compelled to revise the methodology to manually input the boosting pressure value, and ask the solver to yield the possible flow. Such alteration made the script semi-automated, as the user must analyse the performance of the booster for every interval, and the network solver cannot be run with scheduled production rates for the entire field life.

6.3 Draugen Field, SMUBS-II

Unlike Snøhvit field, necessary information pertain to the reservoir and network production model was unavailable for the Draugen field. The shortage of data compelled to devise the totally different methodology for the Draugen field. The only available information for the analysis was the first subsurface boosting project SMUBS-I in the Draugen field, executed in the year 1994. The field measured data for the SMUBS-I was utilised to back calculate the pressure drop within the trunk line, and to adjust the surface parameters to match the measured data. Upon validation of the calculations, the methodology was set to approximate the performance map of the booster against the given booster inlet conditions, and the position of the operating point was calculated by obtaining required pressure at booster outlet at the given value of water-cut.

The validation of data is based on the assumption of homogeneous fluid model, horizontal trunk line elevation profile, absolute vertical profile of the riser, isothermal boosting process and linear temperature decline profile from the estimated surface oil temperature of 22.43 [°C] and booster inlet temperature of 50 [°C]. In the case of deviation of any above assumption with the actual conditions, the whole calculation will become uncertain. The difference between the actual scenario and the assumption will demand in depth flow assurance studies to determine the required pressure at the booster outlet.

Such methodology may only be applicable if the field’s measured pressure and temperature at the node, where second phase of boosting station is planned, is available. Generally, the pressure sensors within the flowlines are not recommended, and determination of the pressure and temperature at the inlet of the booster is difficult to find. But, the system can be analysed at the minimum operating conditions of the booster, that can be taken as an input for the network model.

6.4 Excel Utility to Optimize Booster Selection

The objective of the subject task demands to develop a methodology that may yield a best possible multiphase booster to meet the desired boosting scenario. The selection of a best possible booster requires the fluid’s conditions at the inlet of the booster. To populate the database of the boosters, the available multiphase boosters of helicoaxial design type are used, and the performance map data was processed to develop a list of polynomial equations.

Development of polynomial equations introduced marginal error in between the results of the polynomial and the actual performance map data obtained from the simulator’s database.

In the database of GAP pertain to the multiphase boosters (Hx-series), pre-defined series of polynomial coefficients are mentioned for each booster model. Although, actual calculations approach by the GAP is not disclosed, but, the use of polynomial equations establishes a similarity between the approach presented in the thesis and the approach followed in GAP.

At present, both PIPESIM and GAP contain only 13 models of the helicoaxial type multiphase boosters of Framo Engineering. However, any update in the list of the booster should be incorporated in the database populated for subject task.

Efficiency of the multiphase boosters is yet to be find, as substantial research and development in this domain is still in progress. Therefore, it was decided to restrain from the estimation of the efficiency of the booster, as the resulted efficiency may incur further error in the selection. So, the selection of the best possible booster was based on the envelop of the selected booster, and it was ensured that the operating point will remain within booster operational envelop.

The decision to keep constant pressure difference between all the boosters in serial configuration will require an integral control loop to maintain constant pressure difference in each booster. Since, operating different booster models in series is not advised, so, the algorithm was set to consider constant pressure difference among all the boosters operating in series. Same pressure difference among boosters in series may also be maintained by reducing number of impellers in the later stage's booster, or, by introducing flow recycling within the booster to reduce any excess pressure or by having different speed for each booster.

Although, the operational envelop of the booster is a function of booster inlet conditions and the GVF of the fluid, and it will change the performance map of the booster for the later stages. But, rise in pressure by the first stage booster will reduce the GVF of fluid for late stage, therefore, the operational envelop of the later stages will be much wider and better than the first stage booster. Upon ensuring the operability of the multiphase booster model for the first stage, it can be concluded that the speed for the later stage will always be lower than the first stage booster.

6.5 Recommendations

The theme of the subject thesis is to develop an alternative methodology that can be used to evaluate the performance of the multiphase booster in field development studies. All the tasks were designed to meet the main theme of the thesis while dealing with different petroleum fields. Since, the purpose of the subject thesis is to propose an alternative approach, so, the methodology developed for all the tasks require user input for essential parameters that may either be obtained from the field's measured data or by the specification of the multiphase booster. Because of the assumptions, results for each task contains certain level of errors due to uncertain assumptions. To further improve the results for each task, the level of uncertainties involved in the assumptions should be reduced. Therefore, the developed methodologies should be further analysed to reduce the margin of errors.

For further analysis, following recommendations should be considered for each task,

6.5.1 Draugen Field

(a) Requirement for Network Modelling

As mentioned in chapter 5, a good approach to evaluate the performance of the proposed booster for the Draugen SMUBS-II is to integrate a reservoir model with the network model, then test the booster for the varying field parameters. Such approach will ensure the more precise estimates of pressure, temperature, GVF, intrinsic fluid properties and the correct value of the required pressure at the booster inlet. The methodology adapted for the Draugen field case is just a simple alternative to this approach, having relatively high uncertainty due to the shortage of essential information about the separator conditions and network specifications.

Therefore, it is recommended to seek the essential information about the network and reservoir model, integrate the model and solve the network. Upon converging, the network model will yield the correct information at booster inlet, also the more accurate pressure value at the booster outlet can be achieved. Once the correct information about the booster inlet and outlet parameters is obtained, then the developed Ms Excel utility for the Draugen field's case can be used to evaluate the performance of the booster.

(b) Correct On-Platform Separator Pressure and Network Elevation Profile

In the chapter 5, the difference in the result due to uncertain on-platform separator set parameters and the unavailability of the network elevation profile are mentioned. The uncertainty in the results of the adapted methodology can be significantly reduced by replacing the assumed parameter with the correct field measured data.

Therefore, it is recommended to replace the assumed parameters with the actual field measured data. This revision may also assist to tune the calculations, and more accurate results can be achieved.

6.5.2 Automated Booster Selection Utility

The objective of the subject task was to devise a methodology to optimize the selection of a multiphase booster, along with best possible operational configuration, in field development studies. The execution of any proposed methodology for the selection of the booster may either require inputting the user defined data into the network simulator for each model of the booster and obtain the results. Acquiring the information from the simulator may also be done through automation using VBA scripting. The main issue associated with direct acquisition of the necessary information is the time taken by the simulator to simulate for each case. Since the selection of the booster requires multiple data entry for each booster, so, it was decided to adapt an alternative methodology to get the similar data. So, the performance maps for all available models were transformed into the polynomial equations and incorporated in the VBA modules of the Ms Excel utility.

As mentioned in the chapter 3, irregular booster maps for lower rating pressure boosters and the error in generation of the polynomials reduces the accuracy of the result. Additionally, the maps obtained from PIPESIM and GAP are also approximations to the performance of multiphase boosters when operating at different conditions. Therefore, it is recommended to consider following points to further improve the results.

(a) Numerical Model for Multiphase Booster

Designing a robust a numerical model for a multiphase booster was not the main objective of the thesis. Although it was attempted to develop a simplified relation using the output of the multiphase boosters available in the typical network simulator, but, the results were not validating any hypothesis. The validation of homogeneous fluid properties is still under consideration in many of the recent researches, but the phase separation phenomenon can be neglected for the fluids having high GVFs. Testing the hypothesis with any of non-homogenous fluid is constraint by the time for the subject thesis.

Therefore, it is recommended to test the hypothesis with different non-homogenous fluid models to find a model that may yield a more accurate result. The hypotheses adapted should also be tested for the experimental outputs, as it may further authenticate the result. Upon validation of the result, a numerical model should be developed that take fluid properties as an input and yield the full performance map.

Once an accurate numerical model develops, then the polynomial equations incorporated in the VBA database should be replaced with the equations yielded by the numerical model. This modification will substantially improve the results, as the developed performance map will be more realistic than the one generated through adapted methodology.

(b) Selection of The Most Efficient Booster

In general, the optimized selection of the booster should ensure that the selected booster is operating at its BEP. Since, the determination of a BEP is subject to the definition of the boosting process selected. The uncertainty involved in definition of the boosting process for a booster having high GVFs is already explained in the chapter#03. Because of uncertain definition of the booster efficiency, is was decided to ignore the BEP operation criteria in the selection of the booster. Instead of BEP, the algorithm was devised to ensure the operating point will remain under 90 [%] of the choke limit. Although, such methodology will ensure the operability of the booster, but the deviation from the best operating point may result in substantial power loss due to the operation of the booster at low efficiency.

Therefore, it is recommended to continue the research pertain to the efficiency of the multiphase booster. Upon development of any relation for the efficiency of the multiphase booster as a function of GVF and intrinsic fluid properties, the relations for each booster model should be incorporated in the VBA database. Once the database for each booster model updated with BEP relation, then the algorithm devised for the selection of the booster should be updated to select the booster that will operate at its BEP.

6.5.3 Snøhvit Field

(a) Efficiency of The Proposed Wet-Gas Compressor

Efficiency of a multiphase booster depends upon the boosting process. Determination of the boosting process for a multiphase fluid is still under study, as the properties of gas/liquid phase changes differently during the process. Approximation of the process for a fluid mixture having one dominant phase is comparatively easy as the homogenous fluid property models yields results with insignificant errors; whereas, homogenous fluid model yields significant error for the fluid without any dominant phase. Having very high GVF, the assumption of homogenous fluid model and isentropic boosting process might work for the case studies presented in the thesis, however, the same case should also be evaluated by considering non-homogeneous fluid models and polytropic compression process. If the results are significantly different than what yielded by the homogenous fluid model, then the difference in the result might define the course for the further research in this domain.

Furthermore, the method adapted in the thesis to approximate the polytropic efficiency of the booster for the case of Snøhvit field's wet gas compression might not reflect the actual efficiency of the booster. The reason for the difference in the efficiency is the difference in design of the impeller, as the adapted methodology was considering the design of a multistage axial impeller, while the booster for Snøhvit field is helicoaxial in design. This assumption might lead to relatively high values of the efficiencies as compared with the actual efficiency of the booster having Helicoaxial impellers. Replacing the adapted efficiency with more realistic values will improve the results of the approximation.

(b) Flow Optimizing Methodology for Network Solver

As mentioned earlier, the correct approach to incorporate the Inline Element, modelled as a wet gas compressor, is to allow the GAP solver to optimize the required differential pressure across the wet gas compressor in order to achieve the set value of the flow. Despite of trying with multiple possibilities, GAP's solver failed to converge the network by following the correct methodology. Therefore, the script was modified such that differential pressure was kept as a user input, and the correct pressure difference was manually obtained by hit and trial method.

Therefore, it is recommended to review the appended script for the Inline (general) Element and modify it accordingly, such that it make the solver to optimize the required differential pressure. Such modification will mitigate the requirement of user intervention, and will certainly reduce the simulation time for the field development studies for lengthy field life or having short intervals of time.

REFERENCES

1. Asheim, H., *MONA, An Accurate Two-Phase Well Flow Model Based on Phase Slippage.*
2. Kabir, C.S. and A.R. Hasan, *Performance of a two-phase gas/liquid flow model in vertical wells.* Journal of Petroleum Science and Engineering, 1990. **4**(3): p. 273-289.
3. *Oilfield Decline Rates*. [cited 2017 09/06/2017]; Available from: https://grandemotte.wordpress.com/oil-and-gas-5-production-decline-rates/.
4. Ramberg, R.M., *Multiphase pump performance modelling*. 2007: Norwegian University.
5. Torp, T.A., *Subsea Multiphase Boosting: Review and Future Applications*. Society of Underwater Technology.
6. Nunez, G., et al., *AVAILABLE TECHNOLOGIES AND PERFORMANCE PREDICTION MODELS FOR MULTIPHASE BOOSTING.*
7. Bratland, O., *Pipe Flow 2: Multi-phase Flow Assurance.* Ove Bratland, 2010.
8. Whitson, C.H. and M.R. Brulé, *Phase behavior*. 2000: Henry L. Doherty Memorial Fund of AIME, Society of Petroleum Engineers Richardson, TX.
9. Mueller-Link, D., A. Jaschke, and G. Schroder, *Multiphase Boosting in Oil and Gas Production*. International Petroleum Technology Conference.
10. Shippen, M. and S. Scott. *Multiphase pumping as an alternative to conventional separation, pumping and compression*. in *PSIG Annual Meeting*. 2002. Pipeline Simulation Interest Group.
11. Hua, G., et al., *Comparison of Multiphase Pumping Technologies for Subsea and Downhole Applications.*
12. Karamanoğlu, Y., *Investigation of flow through a semi axial centrifugal pump*. 2006, Citeseer.
13. Vangen, G., C. Carstensen, and L.E. Bakken, *Gullfaks Multiphase Booster Project*. Offshore Technology Conference.
14. Knudsen, H.R., *Multiphase performance validation.* 2013.
15. Huntington, R., *Evaluation of polytropic calculation methods for turbomachinery performance.* Journal of Engineering for gas Turbines and Power, 1985. **107**(10): p. 872-876.

16. Musgrove, G., et al. *Overview of Important Considerations in Wet Gas Compression Testing and Analysis*. in *43rd Turbomachinery & 30th Pump Users Symposia, Houston, TX*. 2014.
17. Korenchan, J.E., *Application of analytical centrifugal-pump performance models in two-phase flow*. 1984, Massachusetts Institute of Technology.
18. Pessoa, R. and M. Prado, *Two-phase flow performance for electrical submersible pump stages.* SPE production & facilities, 2003. **18**(01): p. 13-27.
19. Schultz, J.M., *Erratum:"The Polytropic Analysis of Centrifugal Compressors"(Journal of Engineering for Power, 1962, 84, pp. 69–82).* Journal of Engineering for Power, 1962. **84**(2): p. 222-222.
20. Hundseid, O.y., L.E. Bakken, and T. Helde. *A revised compressor polytropic performance analysis*. in *ASME Turbo Expo 2006: Power for Land, Sea, and Air*. 2006. American Society of Mechanical Engineers.
21. Abdelwahab, A. *An investigation of the use of wet compression in industrial centrifugal compressors*. in *ASME Turbo Expo 2006: Power for Land, Sea, and Air*. 2006. American Society of Mechanical Engineers.
22. Witting, F., *Snohvit and Beyond - Setting New Standards For Subsea to Shore Developments*. Society of Petroleum Engineers.
23. Pettersen, J., *Snøhvit field development.* TEP4520, Statoil, 2011.
24. Hjelmeland, M., A.B. Olsen, and R. Marjohan, *Advances in Subsea Wet Gas Compression Technologies*. International Petroleum Technology Conference.
25. Directorate, N.P., *SNØHVIT*.
26. Directorate, N.P. *NPD Fact Pages*. 2017 [cited 2017 09/03/2017]; Available from: http://factpages.npd.no/ReportServer?/FactPages/PageView/field&rs:Command=Render&rc:Toolbar=false&rc:Parameters=f&NpdId=2053062&IpAddress=129.241.134.140&CultureCode=nb-no.
27. McCain, W.D., *The properties of petroleum fluids*. 1990: PennWell Books.
28. Ehlers, G.A. *Selection of Turbomachinery–Centrifugal Compressors*. in *Proceedings of the Twenty-Third Turbomachinery Symposium, September 13-15*. 1994.
29. Field, N.D.
30. Provan, D.M.J., *Draugen oil field, Haltenbanken Province, offshore Norway*. Journal Name: AAPG Bulletin (American Association of Petroleum Geologists); (USA); Journal Volume: 74:9; Conference: Gulf Coast Association of Geological Societies and Gulf Coast Section of SEPM (Society of Economics, Paleontologists, and

Mineralogist) meeting, Lafayette, LA (USA), 17-19 Oct 1990. 1990: ; None. Medium: X; Size: Pages: 1520.

31. Richard Tong, T.C.S.S.P.E. *Draugen Subsea Boosting Pump*. 25 March, 2014 [cited 2017 07/06/2017]; Available from: http://www.ptil.no/getfile.php/1327510/PDF/Seminar%202014/Undervassanlegg/6%20Shell%20-%20Draugen%20Subsea%20Booster%20pump.pdf.
32. Reinholdtsen, B., *Draugen Field development; the role of gravity drainage and horizontal wells.* Petroleum Geoscience, 1996. **2**(3): p. 249-258.
33. Skiftesvik, P.K. and J.A. Svaeren, *Multiphase Pumps and Flow Meters - Status of Field Testing*. Offshore Technology Conference.
34. Standing, M.B., *A Pressure-Volume-Temperature Correlation For Mixtures Of California Oils And Gases*. American Petroleum Institute.
35. Urdahl, O., A.O. Fredheim, and K.-P. Løken, *Viscosity measurements of water-in-crude-oil emulsions under flowing conditions: A theoretical and practical approach.* Colloids and Surfaces A: Physicochemical and Engineering Aspects, 1997. **123**: p. 623-634.
36. Brinkman, H., *The viscosity of concentrated suspensions and solutions.* The Journal of Chemical Physics, 1952. **20**(4): p. 571-571.
37. Beal, C., *The Viscosity of Air, Water, Natural Gas, Crude Oil and Its Associated Gases at Oil Field Temperatures and Pressures.*
38. McKetta, J.J. and A. Wehe, *Hydrocarbon-water and formation water correlations.* Petroleum Production Handbook, 1962. **2**: p. 22-1.
39. Dodson, C.R. and M.B. Standing, *Pressure-Volume-Temperature And Solubility Relations For Natural-Gas-Water Mixtures*. American Petroleum Institute.
40. Labedi, R., *Use of production data to estimate volume factor, density and compressibility of reservoir fluids.* Journal of Petroleum Science and Engineering, 1990. **4**(4): p. 375-390.
41. Omar, M.I. and A.C. Todd, *Development of New Modified Black Oil Correlations for Malaysian Crudes*. Society of Petroleum Engineers.

APPENDIX A SNØHVIT FIELD

Properties of the Reservoir

Table A 1 Characteristics of Snøhvit Field[25, 26]

Property	Value	Units
Initial gas in place	134 E 9	[Sm^3]
Initial reservoir pressure	264.4	[bara]
Initial reservoir temperature	91.4	[°C]
Specific gravity of gas	0.755	[-]
Specific gravity of condensate	0.814	[-]
Average TVD of well (m RKB)	2584	[m]
Average water depth	337	[m]
Diameter of casing	11	[in]
Diameter of tubing	7	[in]
Condensate/Gas Ratio	19	[STB/MMSCF]

Table A 2 Characteristics of Albatross Field[25, 26]

Property	Value	Units
Initial gas in place	69 E 9	[Sm^3]
Initial reservoir pressure	208.3	[bara]
Initial reservoir temperature	65	[°C]
Specific gravity of gas	0.748	[-]
Specific gravity of condensate	0.804	[-]
Average TVD of well (m RKB)	1920	[m]
Average water depth	325	[m]
Diameter of casing	11	[in]
Diameter of tubing	7	[in]

Table A 3 Characteristics of Askeladd Field[25, 26]

Property	Value	Units
Initial gas in place	114 E 9	[Sm^3]
Initial reservoir pressure	237	[bara]
Initial reservoir temperature	78	[°C]
Specific gravity of gas	0.68	[-]
Specific gravity of condensate	0.818	[-]
Average TVD of well (m RKB)	2325	[m]
Average water depth	280.8	[m]
Diameter of casing	11	[in]
Diameter of tubing	7	[in]

Table A 4 Initial Fluid in Place, Snøhvit Unit[26]

Property	Value	Units
Initial gas in place	317 E 9	[Sm^3]
Initial oil/condensate in place	34 E 6	[Sm^3]

Table A 5 PROSPER Inputs, Snøhvit Field[26]

Property	Value	Units
Fluid Type	Dry and Wet Gas	[-]
Method	Black Oil	[-]
Flow type	Tubing Flow	[-]
Gas specific gravity	0.755	[ ]
Condensate to gas ratio (CGR)	19	[STB/MMSCF]
Condensate specific gravity	0.814	[-]
Reservoir Model	Back pressure	[-]
Back pressure coefficient, C	1000	[Sm^3/day/Bar^2]
Back pressure coefficient, n	1	[-]
Overall heat transfer coefficient	1	[Btu/hr/ft^2/°F]

Table A 6 PROSPER Inputs, Askeladd Field[26]

Property	Value	Units
Fluid Type	Dry and Wet Gas	[-]
Method	Black Oil	[-]
Flow type	Tubing Flow	[-]
Gas specific gravity	0.68	[ ]
Condensate to gas ratio (CGR)	19	[STB/MMSCF]
Condensate specific gravity	0.818	[-]
Reservoir Model	Back pressure (C and n)	[-]
Back pressure coefficient, C	1000	[$Sm^3/day/Bar^2$]
Back pressure coefficient, n	1	[-]
Overall heat transfer coefficient	1	[$Btu/hr/ft^2/°F$]
Deviation angle	0	[-]

Table A 7 PROSPER Inputs, Albatross Field[26]

Property	Value	Units
Fluid Type	Dry and Wet Gas	[-]
Method	Black Oil	[-]
Flow type	Tubing Flow	[-]
Gas specific gravity	0.804	[ ]
Condensate to gas ratio (CGR)	19	[STB/MMSCF]
Condensate specific gravity	0.804	[-]
Reservoir Model	Back pressure (C and n)	[-]
Back pressure coefficient, C	1000	[$Sm^3/day/Bar^2$]
Back pressure coefficient, n	1	[-]
Overall heat transfer coefficient	1	[$Btu/hr/ft^2/°F$]
Deviation angle	0	[-]

Table A 8 GAP Inputs, Snøhvit Field[23, 26]

Parameter	Value	Units
Heat Transfer variables		
Seabed temperature	4	[°C]
Overall heat transfer coefficient	5.678	[W/m^2/K]
Oil heat capacity	2.219	[kJ/kg/K]
Gas heat capacity	2.135	[kJ/kg/K]
Water heat capacity	4.186	[kJ/kg/K]
Separator pressure	65	[bara]
Flow lines dimensions		
Snøhvit template to PLEM		
Template-D/E/F till PLEM		
Diameter	14	[in]
Length	3	[km]
Albatross template(N) to PLEM		
Diameter	14	[in]
Length	11	[km]
Askeladd templates to manifold		
Template-1		
Diameter	14	[in]
Length	6	[km]
Template-2		
Diameter	14	[in]
Length	2	[km]
Template-3		
Diameter	14	[in]
length	15	[km]
Askeladd manifold to Snøhvit PLEM		
Diameter	17	[in]
Length	[km]	

Trunk line (PLEM to On-shore Separator)		
Diameter	26	[in]
Length	144	[km]
Separator pressure	65	[bara]

Water Balance on Critical Nodes

Sensitivity analysis for the Snøhvit field requires evaluating the performance of the booster considering the gas saturated with water and the gas without any dissolved water. To calculate the water gas ratio, the gas was assumed to be saturated with water in the reservoir. Then at proceeding node in the network, the quantity of dissolved water was re-calculated at the pressure and temperature of the node. Then at each node, the calculated value of saturated water was subtracted from the preceding node to find the quantity of water at free state. Once the balance was applied on all the nodes, then the free water at all nodes was combined to calculate the water/gas ratio (WGR), and the number was input in the well model of the network. The methodology for water balance can be schematically represented as,

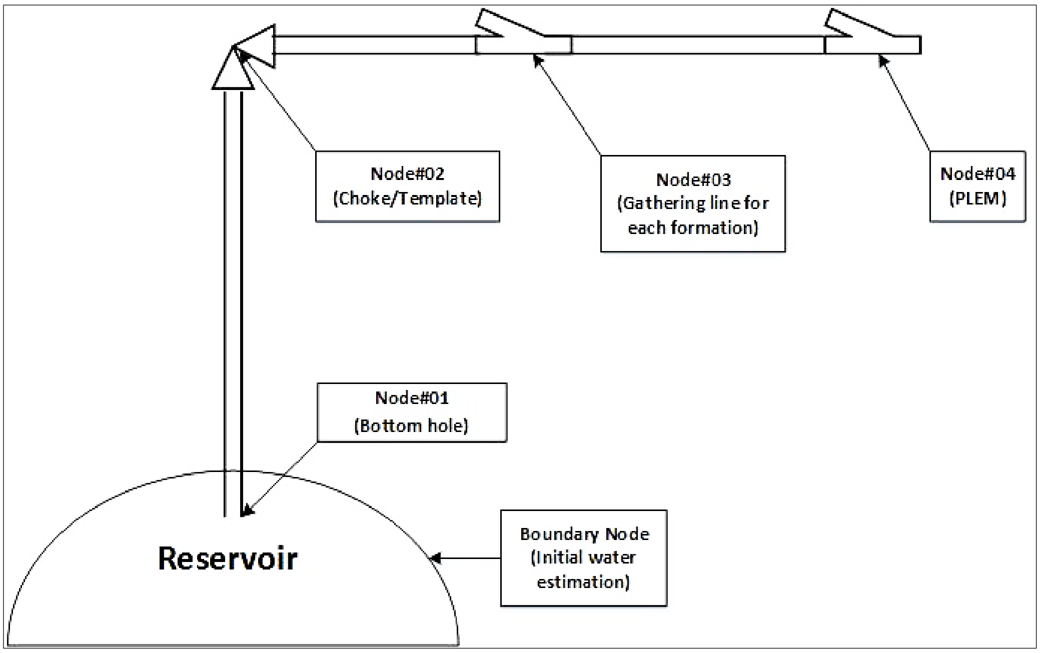


Figure A 1 Critical Nodes in Saturated Water Calculations

To estimate the quantity of water saturated in the gas at each node, the relation of water dissolved in natural gas [8], based on the plots relating correction of water solubility in natural gas for varying salinity and gas gravity [38, 39], was used.

The relation was transformed as a function in Excel VBA. Following script represents the equation to calculated the amount of water dissolved in the natural gas,

```
Function rsw_kg_MCM(p, T, G, Cs)
'p, pressure in Bara'
'T, Temperature, C'
'G=gas gravity, air=1.0'
'Cs=water salinity, ppm, mg/liter'
'rsw_kg_MCM=water solubility in kg/MSm^3'or kg/10^6 Sm^3'
'yw0=water mole fraction in Mehtane"
'yw=water mole fraction in gas'
lnyw0 = (0.05227 * 14.5 * p + 142.3 * Log(p * 14.5) - 9625) / ((T +
273) * 1.8) - 1.117 * _
Log(p * 14.5) + 16.44
yw0 = Exp(lnyw0)
A1 = 1 + (G - 0.55) / (((1.55 * 10 ^ 4) * G * (1.8 * T + 32) ^ -1.446)
- (1.83 * 10 ^ 4) * _
((1.8 * T + 32) ^ -1.288))
A2 = 1 - (3.92 * 10 ^ -9) * Cs ^ 1.44
yw = yw0 * A1 * A2
rsw_kg_MCM = 762712 * (yw / (1 - yw))
End Function
```

Following table contains the calculated values of water balance at each node within the network for each formation.

Table A 9 Snøhvit Field, Results for Saturated Water Case

Year [-]	Reservoir Pressure [bara]	Reservoir Temperature [°C]	Sat. water, at Reservoir [kg/MMSm^3]	Sat. water, at PLEM [kg/MMSm^3]	Water/Gas Ratio [-]
2024	138.6	91.4	5545	931	4.61E-06
2025	134.8	91.4	5661	934	4.73E-06
2026	130	91.4	5818	855	4.96E-06
2027	125	91.4	5993	832	5.16E-06
2028	121.2	91.4	6136	868	5.27E-06
2029	116.66	91.4	6319	929	5.39E-06
2030	111.36	91.4	6551	973	5.58E-06
2031	106.06	91.4	6805	1020	5.79E-06

2033	90.9	91.4	7692	711	6.98E-06
2034	84.1	91.4	8190	577	7.61E-06
2035	81.06	91.4	8439	573	7.87E-06
2036	81.06	91.4	8439	353	8.09E-06

Table A 10 Albatross Field, Results for Saturated Water Case

Year	**Reservoir Pressure**	**Reservoir Temperature**	**Sat. water, at Reservoir**	**Sat. water, at PLEM**	**Water/Gas Ratio**
[-]	**[bara]**	**[°C]**	[kg/MMSm^3]	[kg/MMSm^3]	[-]
2024	129.55	65	2128	931	1.20E-06
2025	125.8	65	2174	934	1.24E-06
2026	122.72	65	2214	855	1.36E-06
2027	120.5	65	2244	832	1.41E-06
2028	116.7	65	2298	868	1.43E-06
2029	114.4	65	2332	929	1.40E-06
2030	110.6	65	2391	973	1.42E-06
2031	106.1	65	2467	1020	1.45E-06
2032	103.03	65	2522	891	1.63E-06
2033	99.24	65	2595	711	1.88E-06
2034	98.48	65	2610	577	2.03E-06
2035	95.45	65	2673	573	2.10E-06
2036	98.484	65	2610	353	2.26E-06

Table A 11 Askeladd Field, Results for Saturated Water Case

Year	Reservoir Pressure	Reservoir Temperature	Sat. water, at Reservoir	Sat. water, at PLEM	Water/Gas Ratio
[-]	[bara]	[°C]	[kg/MMSm^3]	[kg/MMSm^3]	[-]
2024	180.3	78	2816	931	1.89E-06
2025	173.48	78	2891	934	1.96E-06
2026	166.67	78	2972	855	2.12E-06
2027	159.85	78	3060	832	2.23E-06
2028	154.55	78	3134	868	2.27E-06
2029	146.21	78	3261	929	2.33E-06
2030	139.39	78	3375	973	2.40E-06
2031	131.82	78	3516	1020	2.50E-06
2032	125.76	78	3641	891	2.75E-06
2033	120.45	78	3761	711	3.05E-06
2034	113.64	78	3929	577	3.35E-06
2035	109.09	78	4054	573	3.48E-06
2036	112.12	65	2610	353	2.26E-06

Performance Evaluation Using Ms Excel

To comply with objective for the task#01, initial performance evaluation for the proposed wet gas compressor was conducted using Ms Excel. In contrast to the analysis conducted using GAP, the Excel spreadsheet was formulated to estimate the maximum available flow through each formation. The difference in the production rate through each formation was calculated to keep the required pressure boosting within the design limit of the proposed booster. Such approach will only provide an initial approximation for the years when the proposed booster might not maintain the required production rate. Although, low production rate through each formation, due to declining formation’s natural flow potential, can be compensated by increasing the production rate from higher energy formations. But, such approach requires detailed network simulation which was performed using GAP.

The performance of the booster, approximated through flowing potential of each formation can be reflected through following plots, where the deviation among the initially estimated production rates (original flow rate) and the revised production rate obtained through establishing the pressure balance within the system indicates the production year where the booster might not suitable to produce the original flow rate.

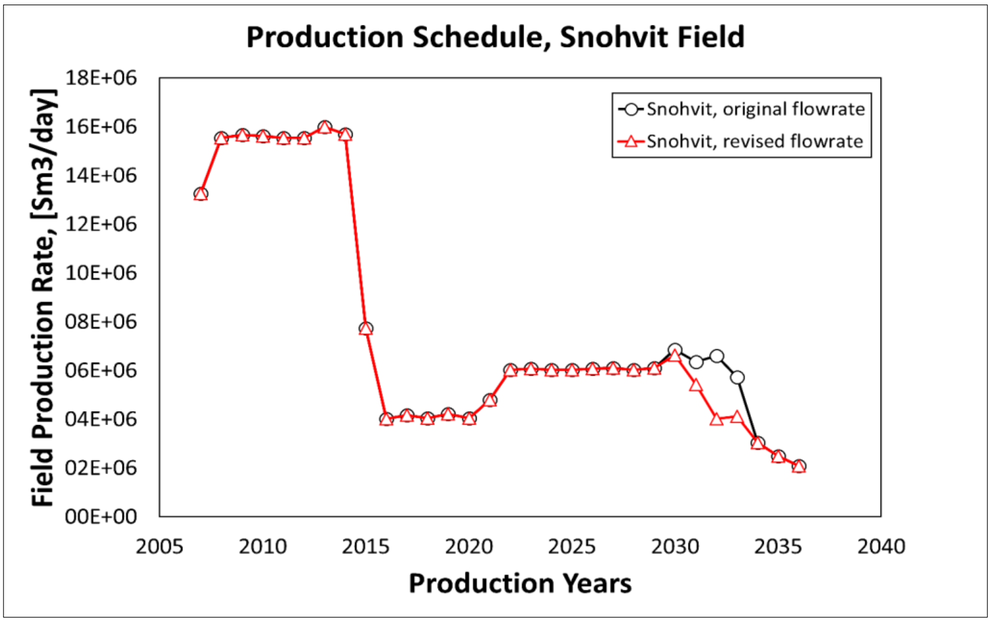


Figure A 2 Production Profile Comparison, Snøhvit Field[23]

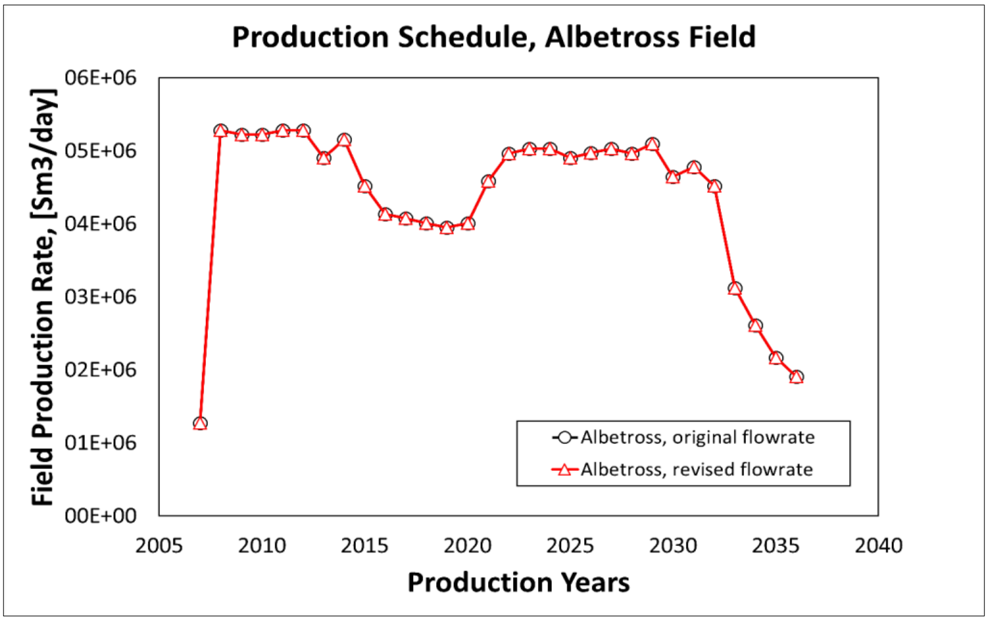


Figure A 3 Production Profile Comparison, Albatross Field[23]

As indicated by Figure A-2, the production rate of the Snøhvit field requires some reduction as the pressure boosting ability of the proposed wet gas compressor is limiting the flow. While for the case of Albatross field, the initially estimated rate is within the boosting limit of the wet gas compressor.

The production profile for Askeladd field also indicates that the natural flowing potential of the field is good enough to meet the required production rate through the Askeladd field by honouring the design constraint of the proposed wet gas compressor.

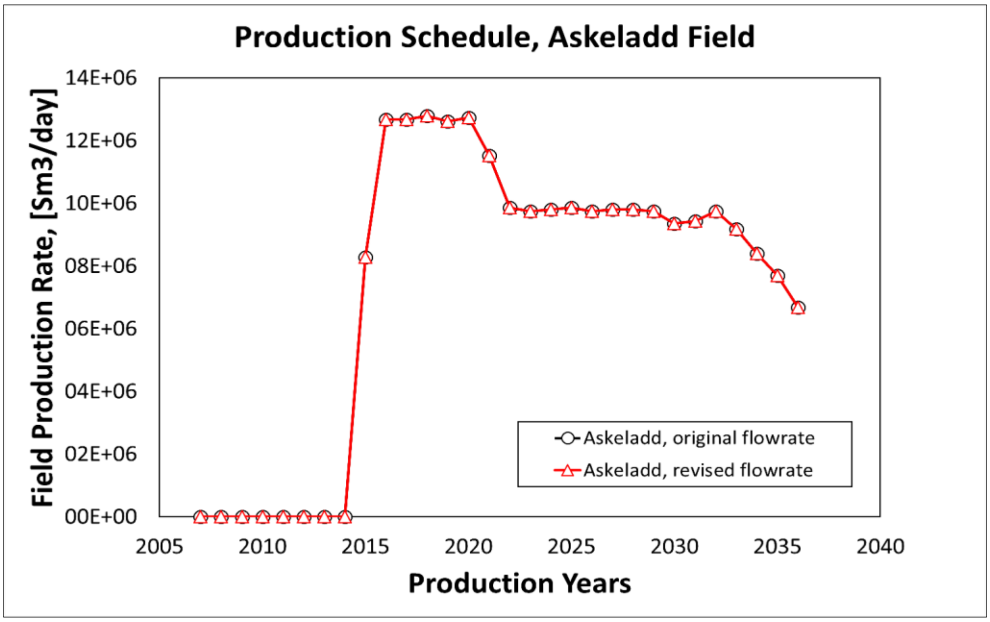


Figure A 4 Production Profile Comparison, Askeladd Field[23]

As mentioned earlier, the calculated plots only provide an initial approximation for the production years that may require some reduction in initially estimated flow rate. Since the Excel spreadsheet was not formulated to cover the elevation profile of the trunk line, also the calculations are done for the dry gas case, therefore, the obtained results are uncertain. The methodology adapted for the network simulation using GAP will yield more accurate results, that may be considered for further studies.

Polytropic Efficiency for Inline (general) Element

To determine the polytropic efficiency of the axial compressor by honouring the flow coefficient of the proposed booster, the initial plot containing the relation between flow coefficient and polytropic efficiency provided by Gary A. Ehlers[28] was taken as reference. The data from the plot was used to generate a polynomial equation that relates a flow coefficient with the polytropic efficiency of the multistage axial compressor. Following plot indicates the relation, and the developed polynomial equation,

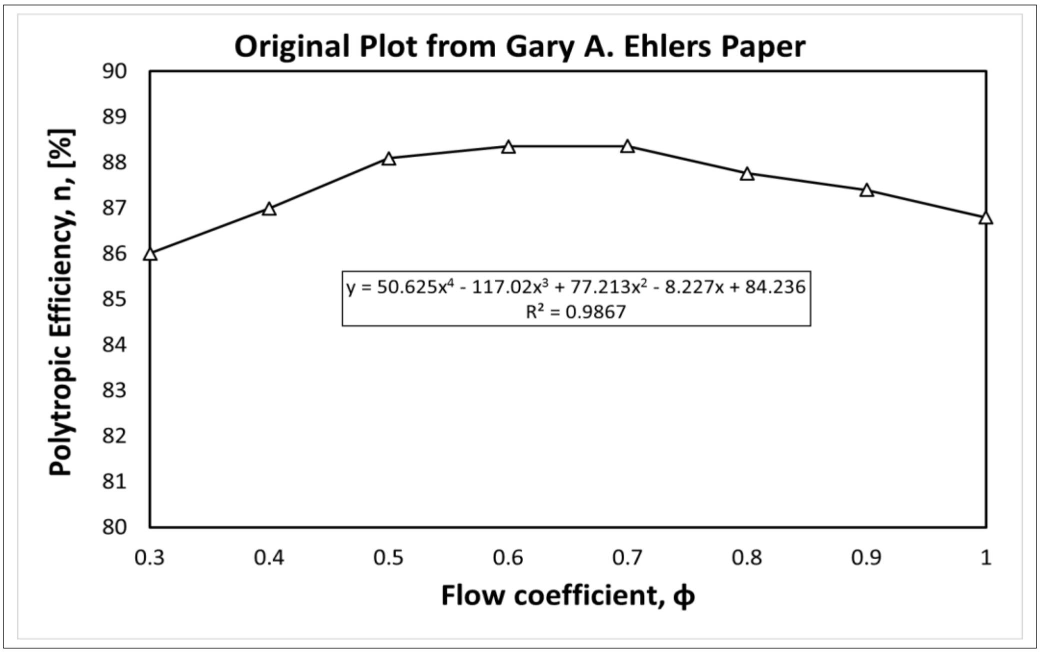


Figure A 5 Polytropic Efficiency for Axial Impellers (Gary A. Ehlers)[28]

To convert the flow coefficient into the flow rate range for the proposed wet gas compressor (WGC-4000), maximum shaft speed and impeller diameter was required. From the design specification of WGC-4000, maximum shaft speed was obtained as 4500 [rpm], whereas, Ms Excel solver was used to calculate the impeller diameter by keeping the maximum flow rate of WGC-4000 at the flow coefficient of 1. The impeller diameter was calculated as 2.09 [ft]. Later, all variables were input in the following set of equations to generate a relation between approximated polytropic efficiency against the actual flow range of WGC-4000.

$$\textit{Flow coefficient}, \varphi = \frac{\mathbf{(700.3)} * \boldsymbol{Q_s}}{\boldsymbol{N} * \boldsymbol{D^3}} \quad , \textit{[Qs is in ft3/sec]} \qquad \text{Eq. A 1}$$

$$k = 1.46 - 0.16(\text{Ɣ} - 0.55)\,(1 - 0.0067\text{Ɣ} - 0.000272T \qquad \text{Eq. A 2}$$

$$\text{Polytropic exponent, } \mathrm{n_p} = \frac{1}{1 - \frac{\frac{\mathrm{k}-1}{\mathrm{k}}}{\eta_\mathrm{p}}} \qquad \text{Eq. A 3}$$

$$T_{out} = T_{in} * (Comp.\ ratio)^{\frac{n-1}{n}} \qquad \text{Eq. A 4}$$

$$\text{Adiabatic efficiency, } \eta_{\text{adiabatic}} = \text{Work}_{\text{adiabatic}}/\text{Work}_{\text{actual}} \qquad \text{Eq. A 5}$$

$$Adiabatic\ efficiency,\ \eta_{\mathrm{adiabatic}} = ((\mathrm{comp.\ ratio})^{\frac{k-1}{k}} - 1)/((\frac{T_{out}}{T_{in}}) - 1) \quad \text{Eq. A 6}$$

$$\text{Overall efficiency},\ \eta_{\mathrm{overall}} = \frac{\mathrm{Work_{adaibatic}}}{\eta_{\mathrm{adiabatic}} * \eta_{\mathrm{mechanical}}} \quad \text{Eq. A 7}$$

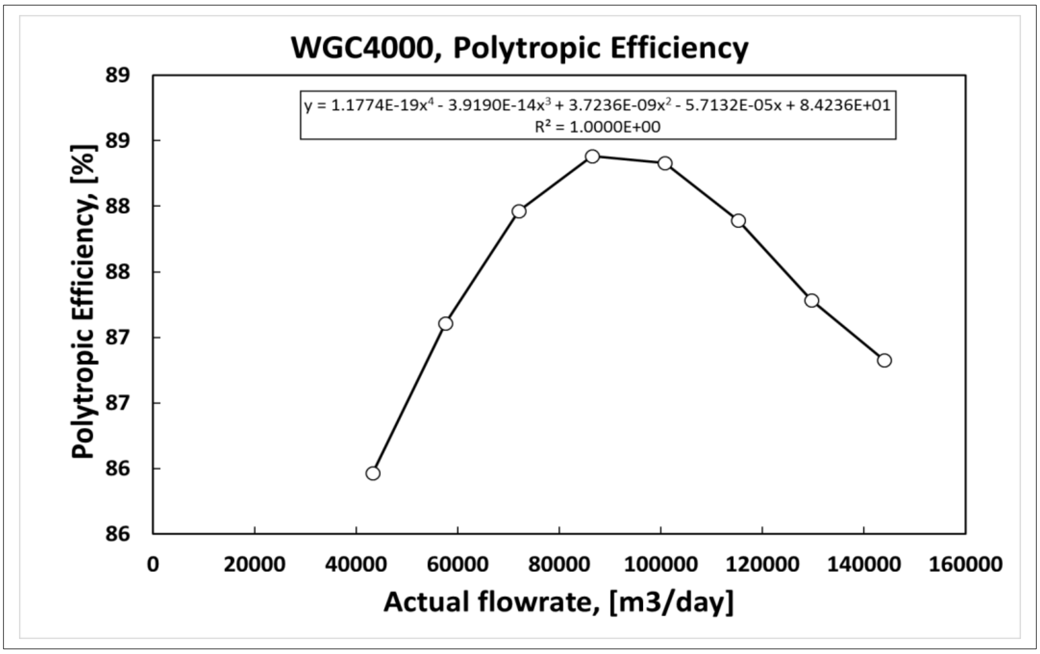


Figure A 6 Polytropic Efficiency Relation, WGC-4000

Within the script for Inline Element representing the wet gas compressor, the polynomial equation as mentioned in the Figure A6 was used to evaluate the polytropic efficiency against the given total flow rate.

Inline (general) Element's Script

```
// Script for Inline(general) Element; based on homogeneous fluid model
// Fixing constant values for WGC-4000
// Copying data from Inlet Stream at Joint 'PLEM'

DP_MAX=DP_MAXI;

QINGAS= 0.0281725889*MOD.JOINT[{PLEM}].FLOW.QGAS;//Sm3/day
QINGAS1= 0.0281725889*MOD.JOINT[{J3}].FLOW.QGAS;//Sm3/day
QINOIL=(MOD.JOINT[{PLEM}].FLOW.QOIL)/6.289582883;//Sm3/day
QINWAT=(MOD.JOINT[{PLEM}].FLOW.QWAT)/6.289582883;
TIN = (((MOD.JOINT[{PLEM}].FLOW.TEMP)-32)/1.8)+273.15;
PIN = 0.06894757*(MOD.JOINT[{PLEM}].FLOW.PRES);
RHOGS=1.23010047766737*(MOD.JOINT[{PLEM}].FLOW.SGG);
RHOLS=1000*(MOD.JOINT[{PLEM}].FLOW.SOG);
```

```
//Calculating PVT properties

CALCPVTOIL();
RHOL=1000*(PVTRHOOIL);
BO=PVTOILFVF;

CALCPVTGAS();
ZIN=PVTFACTOZ;
BG=PVTGASFVF;//(1.01325/288.71)*(ZIN*TIN/PIN);
RHOG=1000*(PVTRHOGAS);

CALCPVTWAT();
RHOW=1000*PVTRHOWAT;
BW=PVTWATFVF;

QINLIQ=(BW*QINWAT)+(BO*QINOIL);
QACTUAL = ((QINGAS*BG)+(QINLIQ))/NOC;
MG=(QINGAS*RHOGS);
MO=(QINOIL*RHOLS);
MW=(QINWAT*RHOW);
MT=MG+MO+MW;
ML=MW+MO;
BETAL=MO/ML;
BETA=MG/MT;
GVF=QINGAS*BG/(NOC*QACTUAL);
OWF=(BO*QINOIL)/((BO*QINOIL)+(BW*QINWAT));
OWFS=QINOIL/(QINOIL+QINWAT);
RHOLT=(OWF*RHOL)+((1-OWF)*RHOW);
RHOLTS=(OWFS*RHOLS)+((1-OWFS)*(RHOW/BW));
RHOTP=(GVF*RHOG)+((1-GVF)*RHOLT);

EFF_POLY        =        ((A*QACTUAL*QACTUAL*QACTUAL*QACTUAL)        -
(B*QACTUAL*QACTUAL*QACTUAL)+  (C*QACTUAL*QACTUAL)  -  (D*QACTUAL)  +
E)/100;
KCOEFF=1.46 - 0.16 * ((RHOGS/1.23010047766737) - 0.55) * (1 - 0.0067
* (RHOGS/1.23010047766737) - (0.000272 * (TIN)));
K_EXP=(KCOEFF-1)/KCOEFF;
POLY_COEFF=1/(1-(K_EXP/EFF_POLY));

//SETTING OUTLET PRESSURE

jmax=300;

for (i=0;i<jmax;i++)

{
POUT=PIN+DP_MAX;
RP=POUT/PIN;
P_EXP=(POLY_COEFF-1)/POLY_COEFF;
TOUT=(TIN)*POW(RP,P_EXP);
ERROR2=TMAX-TOUT;

EFF_ADIA=(POW(RP,K_EXP)-1)/((TOUT/TIN)-1);
EFF_OVERALL=EFF_MECH*EFF_ADIA;
```

```
TEST=POW(RP,K_EXP)-1;
HEAD_ADIABATIC=(BETA*8314*ZIN*(TIN)*(POW(RP,K_EXP)-
1)/(23.649*RHOGS*9.81*K_EXP))+((1-
BETA)*DP_MAX*100000/(RHOLTS*9.81));

P_HYD=(QACTUAL*9.81*HEAD_ADIABATIC*RHOTP/86400)/1000;

P_SHAFT=P_HYD/EFF_OVERALL;
ERROR=POWER_MAX-P_SHAFT;
ERROR3=(QG_MAX-QINGAS)/QG_MAX;

if((ERROR<0)||(ERROR2<0))
{
DP_MAX=DP_MAX*0.97;
}
else
{
DP_MAX=DP_MAX;
i=jmax;
}
}

//Setting final value of outlet pressure and temperature at outlet
joint

PRESOUT=POUT*14.503377438972831;
TEMPOUT=((TOUT-273.15)*1.8)+32;
```

APPENDIX B DRAUGEN FIELD

Method to Use Ms Excel Spreadsheet for Draugen Field Booster Performance Analysis

To evaluate the performance of the booster proposed for Draugen SMUBS-II, the user requires to input the necessary data about the field.

At first, the user need to input following data into the Excel spreadsheet,

Table B 1 Data Required for Draugen SMUBS-II Analysis

Property	Units
API gravity of oil	[°API]
Specific gravity of gas	[-]
Initial gas oil ratio	[Sm^3/Sm^3]
Desired oil flow rate	[Sm^3/day]
Water-cut	[-]
Booster inlet pressure	[bara]
Booster inlet temperature	[°C]
Separator pressure	[bara]
No. of boosters in parallel	[-]

Then the user to need to tune the equation of state[34] by manipulating the tuning factor 'F01'such that the calculated gas/oil ratio at the reservoir conditions should get matched with the given gas/oil ratio. The spreadsheet has default tuned equation of state for the producing gas/oil ratio of 60 [Sm^3/Sm^3].

After tuning the equation of state, the spreadsheet will calculate the difference between the solution gas oil ratio at the reservoir condition and at the booster inlet conditions. The difference between the GORs will determine the volume of free gas with respect to the oil flow rate. Later, the black oil formation volume factors for oil and gas [34, 40, 41] will be used to calculate the actual flow rates at the booster inlet conditions. By dividing the total actual gas flow rate with the total actual mixture flow rate, the GVF at the booster inlet will be determined.

The next step in the evaluation is to check the producibility of the desired total flow rate at the given booster inlet pressure. To evaluate the maximum achievable flow rate at the given booster inlet pressure, data from the field was processed to develop a relation through polynomial regression.

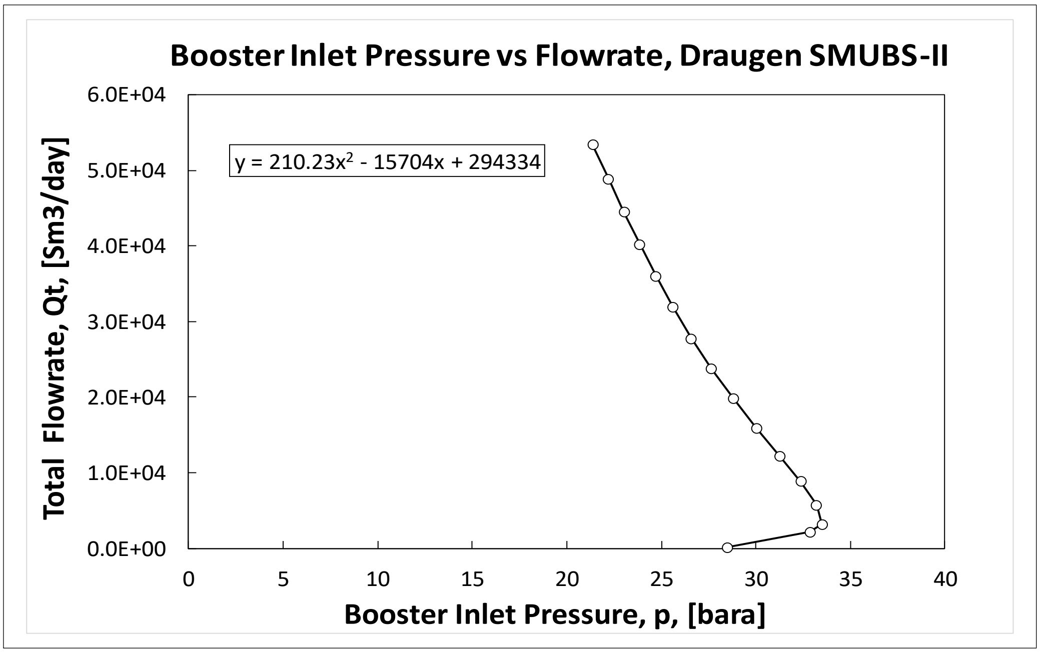


Figure B 1 Relation Between Booster Inlet Pressure and Producible Flow rates

The polynomial equation obtained from Figure B 1 was used to approximate the maximum total flow rate at the booster inlet. In the case that the desired flow rate at the booster inlet conditions exceeds the maximum producible rate, then the user may either manually decrease the desired oil rate, or the pre-programmed macro 'Calculate Max. Rate' can be pressed to calculate the maximum producible rate at the booster inlet conditions.

Then, the spreadsheet will follow the discretised tabulated calculation to calculate the required rate at the booster outlet. The difference between the inlet and outlet pressure of the booster will determine the required pressure difference across the booster.

By calculating the required pressure difference and the total flow rate at the booster inlet, the VBA functions developed to generate performance map of the booster for Draugen SMUBS-II will take the calculated GVF as an input to generate a full performance map for the speeds.

By overlapping the operating point on the performance map, the operability of the booster at the given conditions can be estimated.

VBA Script

Viscosity Calculation for Oil and Gas

```
Function viscosity_gas(gamma, Pin, Tin)
'Using Lee-Gonzalez gas viscosity correlation, source SPE Monograph,
Page

Rho = Rhog(Pin, Tin, ZfacStanding(Pin, Tin, gamma, 2), gamma)
Mg = gamma * 28.97
Trankine = (Tin + 273.15) * 1.8

A1 = ((9.379 + 0.01607 * Mg) * (Trankine ^ 1.5)) / (209.2 + (19.26 *
Mg) + Trankine)
A2 = 3.448 + (986.4 / Trankine) + 0.01009 * Mg
A3 = 2.447 - 0.2224 * A2
viscosity_gas = A1 * 10 ^ -4 * Exp(A2 * (Rho / 1000) ^ A3) 'Eq 3.65a
SPE Monograph)
End Function

Function viscosity_Oil(API, T)
'Using Standing's equation, SPE Monograph, Eq.3.117, page 36

Tfar = (T * 1.8) + 32
viscosity_Oil = -1 + 10 ^ (Tfar ^ (-1.163) * Exp(6.9824 - (0.04658 *
API)))
End Function
```

Friction Factor within the Trunk Line

```
Function MTP_frcdp(mueO, mueW, mueG, Qgg, Qww, Qoo, d, Rhog, RhoO,
RhoTP)
'Viscosities are in cP
'Calculating area
r = d / 2
Ac = 3.142 * (r ^ 2)
Qo = Qoo / 86400
Qw = Qww / 86400
Qg = Qgg / 86400

'Calculating superficial velocity of liquid and gas, taking water and
oil as single phase emulsion
Vsg = (Qg) / Ac
Vsl = ((Qw + Qo)) / Ac
Vm = Vsg + Vsl 'Mean velocity
'Calculating area fractions
LemdaG = Vsg / Vm
LemdaL = Vsl / Vm
'Calculating average density of emulsion
Rhol = ((Qo * RhoO) + (Qw * 1000)) / (Qo + Qw)
RhoM = (Rhog * LemdaG) + (Rhol * LemdaL)
'Viscosity of Liquid
WC = Qw / (Qw + Qo)
If WC <= 0.5 Then
mueC = mueO
```

```
dispfact = WC
rhoC = RhoO
Else
mueC = mueW
dispfact = 1 - WC
rhoC = 1000
End If

mueL = (mueC) * (1 - dispfact) ^ (-2.5)
mueLL = rhoC * mueL / 1000000
mueGG = Rhog * mueG / 1000000

'Two phase Reynold number
Rm = RhoM * Vm * d / ((mueGG * LemdaG) + (mueLL * LemdaL))
'Equivalent single phase frition
fric_sp = 0.16 * (Rm) ^ (-0.172)
'To calculate correction factor, Assuming that gas and liquid flowing
at same speed yl = LemdaL
yl = LemdaL '(Qw + Qo) / (Qg + Qw + Qo)

C_TP = ((Rhog * yl * (1 - LemdaL) ^ 2) + (Rhol * (1 - yl) * LemdaL ^
2)) / (RhoM * yl * (1 - yl))

friction = C_TP * fric_sp
MTP_frcdp = (0.5 * friction * RhoM * (Vm ^ 2) / d) / 100000

End Function
```

Polynomial for Booster Performance Map

```
Function Qmin_Flow_Draugen(Speed, GVF, Qmax) 'percentage
A = 10.15586151
B = -12.10441178
C = 4.67315041
d = -0.42006068
E = 0.59027778
FA = 0.000000191279 * (Speed ^ 4) + -0.0000363049 * (Speed ^ 3) +
0.002399402 * (Speed ^ 2) + -0.064367571 * (Speed ^ 1) + 0.595533146
FB = 0.000000191137 * (Speed ^ 4) + -0.0000361208 * (Speed ^ 3) +
0.002356487 * (Speed ^ 2) + -0.061679871 * (Speed ^ 1) + 0.583674475
FC = 0.000000197518 * (Speed ^ 4) + -0.0000370889 * (Speed ^ 3) +
0.002386583 * (Speed ^ 2) + -0.06138597 * (Speed ^ 1) + 0.576746416
FD = 0.000000426528 * (Speed ^ 4) + -0.0000791428 * (Speed ^ 3) +
0.004849529 * (Speed ^ 2) + -0.122200575 * (Speed ^ 1) + 1.119068689
FE = 0.0000000411434 * (Speed ^ 4) + -0.00000772918 * (Speed ^ 3) +
0.000480586 * (Speed ^ 2) + -0.002818974 * (Speed ^ 1) + 0.081112132
AA = FA * A
BB = FB * B
CC = FC * C
DD = FD * d
EE = FE * E
Qmin_Flow_Draugen = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD
* GVF + EE) * Qmax
End Function
```

```
Function Qmin_dP_Draugan(Speed, GVF, MaxHead) 'percentage
A = -4.80577726671
B = 1.15146066318
C = 0.08054014851
d = -0.01887148268
E = 0.99966666667
FA = 0.000000454323 * (Speed ^ 4) + -0.0000802431 * (Speed ^ 3) +
0.004473946 * (Speed ^ 2) + -0.096569092 * (Speed ^ 1) + 0.672290772
FB = 0.00000222958 * (Speed ^ 4) + -0.000398779 * (Speed ^ 3) +
0.021951775 * (Speed ^ 2) + -0.461887464 * (Speed ^ 1) + 3.235073733
FC = -0.0000140426 * (Speed ^ 4) + 0.002572124 * (Speed ^ 3) + -
0.144755556 * (Speed ^ 2) + 3.037743469 * (Speed ^ 1) + -21.27574467
FD = -0.0000173855 * (Speed ^ 4) + 0.003242795 * (Speed ^ 3) + -
0.191699948 * (Speed ^ 2) + 4.480002692 * (Speed ^ 1) + -30.89940866
FE = -0.0000000624819 * (Speed ^ 4) + 0.0000117946 * (Speed ^ 3) + -
0.000613433 * (Speed ^ 2) + 0.017207129 * (Speed ^ 1) + -0.118311659
AA = FA * A
BB = FB * B
CC = FC * C
DD = FD * d
EE = FE * E
Qmin_dP_Draugan = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD *
GVF + EE) * MaxHead
End Function

Function Booster_Qmax(GVF, Speed, Qmax)
A = -26.33714555
B = 31.85090695
C = -12.52570472
d = 1.8611675
E = 1.00940157
FA = 0.0000000610735 * (Speed ^ 4) + -0.00000768986 * (Speed ^ 3) +
0.000257379 * (Speed ^ 2) + -0.002260491 * (Speed ^ 1) + 0.231678536
FB = 0.0000000436901 * (Speed ^ 4) + -0.00000476349 * (Speed ^ 3) +
0.000109129 * (Speed ^ 2) + 0.001334326 * (Speed ^ 1) + 0.170537341
FC = 0.0000000215873 * (Speed ^ 4) + -0.0000012826 * (Speed ^ 3) + -
0.0000429726 * (Speed ^ 2) + 0.004744789 * (Speed ^ 1) + 0.08487814
FD = 0.00000000491376 * (Speed ^ 4) + 0.000000675287 * (Speed ^ 3) +
-0.0000467707 * (Speed ^ 2) + 0.003073667 * (Speed ^ 1) + 0.003153682
FE = 0.000000000883288 * (Speed ^ 4) + -0.000000185407 * (Speed ^ 3)
+ 0.0000118987 * (Speed ^ 2) + 0.009755572 * (Speed ^ 1) + 0.001576637
AA = FA * A
BB = FB * B
CC = FC * C
DD = FD * d
EE = FE * E
Booster_Qmax = ((AA * GVF ^ 4) + (BB * GVF ^ 3) + (CC * GVF ^ 2) + (DD
* GVF) + EE) * Qmax
End Function
```

APPENDIX C EXCEL UTILITY FOR OPTIMUM BOOSTER SELECTION

VBA Script for Automated Booster Selection

Script to Select the Best Booster, with Optimum Configuration

```
Private Sub CommandButton2_Click()
Dim GVF As Double
Dim dPreq As Double
Dim Qtreq As Double
Dim dPavail As Double
Dim Qt_avail As Double
Dim BoosterName As String
Dim Pin As Double
Dim Pout As Double
Dim Pout_new As Double
Dim a As Double
Dim b As Double
Dim c As Double
Dim ii As Double
Dim z As Double
Dim Qmin As Double
Dim Qmax As Double
Dim Modelname As String
Dim Slope As Double
Dim yintercept As Double
Dim dp38 As Double
Dim dp45 As Double
Dim dp120 As Double
Dim dp180 As Double
Dim e As Double
Dim s As Double
Dim BS As Double
Dim nn As Double
Dim d As Double

'Saving user input as GVF, dPreq and Qreq
GVF = Worksheets("Map_data").Range("B4").Value
dPreq = Worksheets("Map_data").Range("B7").Value
Qtreq = Worksheets("Map_data").Range("B6").Value
Pin = Worksheets("Calculations").Range("F6").Value
Pout = Worksheets("Calculations").Range("K4").Value
BoosterName = "_Booster_o_"

'Generating initial booster catagory selection
dp38 = Boosterfunction(11, 100, GVF)
dp45 = Boosterfunction(6, 100, GVF)
dp120 = Boosterfunction(7, 100, GVF)
dp180 = Boosterfunction(3, 100, GVF)
'Initial screening of the boosters against dP required
ii = 1
i = 1
```

```
nn = 1
BS = 1
Do 'nn = i To ii Step 1
'Loop for Initial booster screening
a = 4 'Initial row number for booster model code
'b is the last booster on the list
'c is the name of the column for each booster catagory
If dPreq < dp38 Then
b = 6
c = 18
Exit Do
Else
If dPreq < dp45 Then
b = 7
c = 6
Exit Do
Else
If dPreq < dp120 Then
b = 6
c = 10
Exit Do
Else
If dPreq < dp180 Then
b = 6
c = 14
Exit Do
'Else
'Call SeriesConfig(GVF, DP)
End If
End If
End If
End If

Rem Finding a series configuration

dPreq = dPreq / (BS + 1)
nn = nn + 1
BS = BS + 1
Loop Until BS = 4
' loop to execute the booster loop for dp screening at given GVF and
100[%] speed
' Selection is based to evaluate maximum pressure at given GVF
d = a
DD = a
For d = a To b Step 1
    Speed = 100
    z = Worksheets("Boosters").Cells(d, c).Value
    dPavail = Boosterfunction(z, Speed, GVF)
    Qmin = BoosterQmin(z, Speed, GVF)
    Qmax = BoosterQmax(z, Speed, GVF)

    Slope = (dPavail - 0.01) / (Qmin - Qmax)
    yintercept = (dPavail - (Slope * Qmin))
    Qt_avail = (dPreq - yintercept) / Slope
    If Qtreq <= (0.9 * Qt_avail) And dPavail > dPreq Then ' And dPavail
> dPreq Then
```

```
        Modelname = Worksheets("Boosters").Cells(d, c + 1).Value
        Worksheets("Calculations").Range("B23").Value = Modelname
        Exit For
    End If

Next
par = 1
   'Looking for parallel combination
If Qtreq > (0.9 * Qt_avail) Then
    For par = 2 To 4 Step 1
        Qtreq_new = Qtreq / (par)
        DD = a

            For DD = a To b Step 1

            z = Worksheets("Boosters").Cells(DD, c).Value
            dPavail = Boosterfunction(z, Speed, GVF)
            Qmin = BoosterQmin(z, Speed, GVF)
            Qmax = BoosterQmax(z, Speed, GVF)
            Slope = (dPavail - 0.01) / (Qmin - Qmax)
            yintercept = (dPavail - (Slope * Qmin))
            Qt_avail = (dPreq - yintercept) / Slope
            If Qtreq_new < (0.9 * Qt_avail) And dPavail > dPreq Then
                Modelname  =  Worksheets("Boosters").Cells(DD,  c  +
1).Value
                Worksheets("Calculations").Range("B23").Value        =
Modelname
                GoTo PumpSelected
                Exit For
            End If
          Next DD
   Next par
PumpSelected:
End If
Worksheets("Calculations").Range("B24").Value = BS
Worksheets("Calculations").Range("B25").Value = par
rowin = 2

For n = 10 To 100 Step 10
    QminOil = (BoosterQmin(z, n, GVF))
    Qminwater = (BoosterQmin_w(z, n, GVF))
    QmaxOil = (BoosterQmax(z, n, GVF))
    Qmaxwater = (BoosterQmax_w(z, n, GVF))
    dPQmin = (Boosterfunction(z, n, GVF))
    dPQmin_w = (Boosterfunction_w(z, n, GVF))
    Worksheets("Map_data").Cells(rowin, 9).Value = QminOil
    Worksheets("Map_data").Cells(rowin, 11).Value = Qminwater
    Worksheets("Map_data").Cells(rowin, 13).Value = dPQmin
    Worksheets("Map_data").Cells(rowin, 15).Value = dPQmin_w
    Worksheets("Map_data").Cells(rowin, 17).Value = QmaxOil
    Worksheets("Map_data").Cells(rowin, 19).Value = Qmaxwater
    rowin = rowin + 1
Next
End Sub
```

Compound Functions for the Booster Selection Script

```
Function Boosterfunction(z, Speed, GVF)
If z = 1 Then
Boosterfunction = dpQmin_Booster_o_1(Speed, GVF)
Else
If z = 2 Then
Boosterfunction = dPQmin_Booster_o_2(Speed, GVF)
Else
If z = 3 Then
Boosterfunction = dpQmin_Booster_o_3(Speed, GVF)
Else
If z = 4 Then
Boosterfunction = dpQmin_Booster_o_4(Speed, GVF)
Else
If z = 5 Then
Boosterfunction = dpQmin_Booster_o_5(Speed, GVF)
Else
If z = 6 Then
Boosterfunction = dpQmin_Booster_o_6(Speed, GVF)
Else
If z = 7 Then
Boosterfunction = dpQmin_Booster_o_7(Speed, GVF)
Else
If z = 8 Then
Boosterfunction = dpQmin_Booster_o_8(Speed, GVF)
Else
If z = 9 Then
Boosterfunction = dpQmin_Booster_o_9(Speed, GVF)
Else
If z = 10 Then
Boosterfunction = dpQmin_Booster_o_10(Speed, GVF)
Else
If z = 11 Then
Boosterfunction = dpQmin_Booster_o_11(Speed, GVF)
Else
If z = 12 Then
Boosterfunction = dpQmin_Booster_o_12(Speed, GVF)
Else
If z = 13 Then
Boosterfunction = dpQmin_Booster_o_13(Speed, GVF)
End If
End If
End If
End If
End If
End If
End If
End If
End If
End If
End If
End If
End If
End Function
Function BoosterQmin(z, Speed, GVF)
```

```
If z = 1 Then
BoosterQmin = Qmin_Booster_o_1(Speed, GVF)
Else
If z = 2 Then
BoosterQmin = Qmin_Booster_o_2(Speed, GVF)
Else
If z = 3 Then
BoosterQmin = Qmin_Booster_o_3(Speed, GVF)
Else
If z = 4 Then
BoosterQmin = Qmin_Booster_o_4(Speed, GVF)
Else
If z = 5 Then
BoosterQmin = Qmin_Booster_o_5(Speed, GVF)
Else
If z = 6 Then
BoosterQmin = Qmin_Booster_o_6(Speed, GVF)
Else
If z = 7 Then
BoosterQmin = Qmin_Booster_o_7(Speed, GVF)
Else
If z = 8 Then
BoosterQmin = Qmin_Booster_o_8(Speed, GVF)
Else
If z = 9 Then
BoosterQmin = Qmin_Booster_o_9(Speed, GVF)
Else
If z = 10 Then
BoosterQmin = Qmin_Booster_o_10(Speed, GVF)
Else
If z = 11 Then
BoosterQmin = Qmin_Booster_o_11(Speed, GVF)
Else
If z = 12 Then
BoosterQmin = Qmin_Booster_o_12(Speed, GVF)
Else
If z = 13 Then
BoosterQmin = Qmin_Booster_o_13(Speed, GVF)
End If
End If
End If
End If
End If
End If
End If
End If
End If
End If
End If
End If
End If
End Function

Function BoosterQmax(z, Speed, GVF)
Select Case z
    Case 1
```

```
        BoosterQmax = Qmax_Booster_o_1(Speed, GVF)
    Case 2
        BoosterQmax = Qmax_Booster_o_2(Speed, GVF)
    Case 3
        BoosterQmax = Qmax_Booster_o_3(Speed, GVF)
    Case 4
        BoosterQmax = Qmax_Booster_o_4(Speed, GVF)
    Case 5
        BoosterQmax = Qmax_Booster_o_5(Speed, GVF)
    Case 6
        BoosterQmax = Qmax_Booster_o_6(Speed, GVF)
    Case 7
        BoosterQmax = Qmax_Booster_o_7(Speed, GVF)
    Case 8
        BoosterQmax = Qmax_Booster_o_8(Speed, GVF)
    Case 9
        BoosterQmax = Qmax_Booster_o_9(Speed, GVF)
    Case 10
        BoosterQmax = Qmax_Booster_o_10(Speed, GVF)
    Case 11
        BoosterQmax = Qmax_Booster_o_11(Speed, GVF)
    Case 12
        BoosterQmax = Qmax_Booster_o_12(Speed, GVF)
    Case 13
        BoosterQmax = Qmax_Booster_o_13(Speed, GVF)
End Select
End Function

Function Boosterfunction_w(z, Speed, GVF)
If z = 1 Then
Boosterfunction_w = dpQmin_Booster_w_1(Speed, GVF)
Else
If z = 2 Then
Boosterfunction_w = dPQmin_Booster_w_2(Speed, GVF)
Else
If z = 3 Then
Boosterfunction_w = dpQmin_Booster_w_3(Speed, GVF)
Else
If z = 4 Then
Boosterfunction_w = dpQmin_Booster_w_4(Speed, GVF)
Else
If z = 5 Then
Boosterfunction_w = dpQmin_Booster_w_5(Speed, GVF)
Else
If z = 6 Then
Boosterfunction_w = dpQmin_Booster_w_6(Speed, GVF)
Else
If z = 7 Then
Boosterfunction_w = dpQmin_Booster_w_7(Speed, GVF)
Else
If z = 8 Then
Boosterfunction_w = dpQmin_Booster_w_8(Speed, GVF)
Else
If z = 9 Then
Boosterfunction_w = dpQmin_Booster_w_9(Speed, GVF)
Else
```

```
If z = 10 Then
Boosterfunction_w = dpQmin_Booster_w_10(Speed, GVF)
Else
If z = 11 Then
Boosterfunction_w = dpQmin_Booster_w_11(Speed, GVF)
Else
If z = 12 Then
Boosterfunction_w = dpQmin_Booster_w_12(Speed, GVF)
Else
If z = 13 Then
Boosterfunction_w = dpQmin_Booster_w_13(Speed, GVF)
End If
End If
End If
End If
End If
End If
End If
End If
End If
End If
End If
End If
End If
End Function
Function BoosterQmin_w(z, Speed, GVF)
If z = 1 Then
BoosterQmin_w = Qmin_Booster_w_1(Speed, GVF)
Else
If z = 2 Then
BoosterQmin_w = Qmin_Booster_w_2(Speed, GVF)
Else
If z = 3 Then
BoosterQmin_w = Qmin_Booster_w_3(Speed, GVF)
Else
If z = 4 Then
BoosterQmin_w = Qmin_Booster_w_4(Speed, GVF)
Else
If z = 5 Then
BoosterQmin_w = Qmin_Booster_w_5(Speed, GVF)
Else
If z = 6 Then
BoosterQmin_w = Qmin_Booster_w_6(Speed, GVF)
Else
If z = 7 Then
BoosterQmin_w = Qmin_Booster_w_7(Speed, GVF)
Else
If z = 8 Then
BoosterQmin_w = Qmin_Booster_w_8(Speed, GVF)
Else
If z = 9 Then
BoosterQmin_w = Qmin_Booster_w_9(Speed, GVF)
Else
If z = 10 Then
BoosterQmin_w = Qmin_Booster_w_10(Speed, GVF)
Else
```

```
If z = 11 Then
BoosterQmin_w = Qmin_Booster_w_11(Speed, GVF)
Else
If z = 12 Then
BoosterQmin_w = Qmin_Booster_w_12(Speed, GVF)
Else
If z = 13 Then
BoosterQmin_w = Qmin_Booster_w_13(Speed, GVF)
End If
End If
End If
End If
End If
End If
End If
End If
End If
End If
End If
End If
End If
End Function

Function BoosterQmax_w(z, Speed, GVF)
If z = 1 Then
BoosterQmax_w = Qmax_Booster_w_1(Speed, GVF)
Else
If z = 2 Then
BoosterQmax_w = Qmax_Booster_w_2(Speed, GVF)
Else
If z = 3 Then
BoosterQmax_w = Qmax_Booster_w_3(Speed, GVF)
Else
If z = 4 Then
BoosterQmax_w = Qmax_Booster_w_4(Speed, GVF)
Else
If z = 5 Then
BoosterQmax_w = Qmax_Booster_w_5(Speed, GVF)
Else
If z = 6 Then
BoosterQmax_w = Qmax_Booster_w_6(Speed, GVF)
Else
If z = 7 Then
BoosterQmax_w = Qmax_Booster_w_7(Speed, GVF)
Else
If z = 8 Then
BoosterQmax_w = Qmax_Booster_w_8(Speed, GVF)
Else
If z = 9 Then
BoosterQmax_w = Qmax_Booster_w_9(Speed, GVF)
Else
If z = 10 Then
BoosterQmax_w = Qmax_Booster_w_10(Speed, GVF)
Else
If z = 11 Then
BoosterQmax_w = Qmax_Booster_w_11(Speed, GVF)
```

```
Else
If z = 12 Then
BoosterQmax_w = Qmax_Booster_w_12(Speed, GVF)
Else
If z = 13 Then
BoosterQmax_w = Qmax_Booster_w_13(Speed, GVF)
End If
End If
End If
End If
End If
End If
End If
End If
End If
End If
End If
End If
End If
End Function
```

Polynomial Functions for the Booster Models

Framo 310/1100/120

```
Function Qmin_Booster_w_1(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = -23.60026042
b = 37.21788194
c = -17.76258681
d = 2.68663194
e = 0.62152778
FA = 0.000000222891 * (Speed ^ 4) + -0.0000427412 * (Speed ^ 3) +
0.002716592 * (Speed ^ 2) + -0.061994731 * (Speed ^ 1) + 0.42900902
FB = 0.000000238061 * (Speed ^ 4) + -0.0000457458 * (Speed ^ 3) +
0.002912396 * (Speed ^ 2) + -0.067126003 * (Speed ^ 1) + 0.467239128
FC = 0.000000258975 * (Speed ^ 4) + -0.0000500313 * (Speed ^ 3) +
0.00319608 * (Speed ^ 2) + -0.074178272 * (Speed ^ 1) + 0.522512705
FD = 0.000000257575 * (Speed ^ 4) + -0.0000508436 * (Speed ^ 3) +
0.003323717 * (Speed ^ 2) + -0.077767236 * (Speed ^ 1) + 0.548654584
FE = 0.0000000170308 * (Speed ^ 4) + -0.00000235325 * (Speed ^ 3) +
0.0000981062 * (Speed ^ 2) + 0.006705209 * (Speed ^ 1) + 0.004626397
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmin_Booster_w_1 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD *
GVF + EE) * Qmax
End Function

Function dpQmin_Booster_w_1(Speed, GVF) 'Speed is in [%]
MaxdP = 120
a = 3.12087673611
b = -8.56605902778
```

```
c = 4.27620659722
d = -0.53839930556
e = 0.9995
FA = -0.000000683624 * (Speed ^ 4) + 0.000120055 * (Speed ^ 3) + -
0.006543991 * (Speed ^ 2) + 0.159507382 * (Speed ^ 1) + -1.083756345
FB = -0.000000312786 * (Speed ^ 4) + 0.0000530582 * (Speed ^ 3) + -
0.002667558 * (Speed ^ 2) + 0.063558108 * (Speed ^ 1) + -0.423646227
FC = -0.000000168621 * (Speed ^ 4) + 0.0000236279 * (Speed ^ 3) + -
0.00070258 * (Speed ^ 2) + 0.012933295 * (Speed ^ 1) + -0.061822626
FD = -0.0000000583431 * (Speed ^ 4) + -0.00000995216 * (Speed ^ 3) +
0.002233978 * (Speed ^ 2) + -0.062731412 * (Speed ^ 1) + 0.520186402
FE = -0.0000000620951 * (Speed ^ 4) + 0.0000104765 * (Speed ^ 3) + -
0.000443305 * (Speed ^ 2) + 0.012437508 * (Speed ^ 1) + -0.079548802
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
dpQmin_Booster_w_1 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD
* GVF + EE) * MaxdP
If dpQmin_Booster_w_1 > 120 Then
dpQmin_Booster_w_1 = 120
End If
End Function

Function Qmax_Booster_w_1(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 4.87158556
b = -8.19409733
c = 3.34353532
d = 0.11501915
e = 1.01311799
FA = -0.000000156785 * (Speed ^ 4) + 0.000028441 * (Speed ^ 3) + -
0.001583749 * (Speed ^ 2) + 0.044709446 * (Speed ^ 1) + -0.371918503
FB = -0.000000127453 * (Speed ^ 4) + 0.000024107 * (Speed ^ 3) + -
0.001431973 * (Speed ^ 2) + 0.042583673 * (Speed ^ 1) + -0.284045451
FC = -0.000000130814 * (Speed ^ 4) + 0.0000266225 * (Speed ^ 3) + -
0.001773629 * (Speed ^ 2) + 0.054619714 * (Speed ^ 1) + -0.257684409
FD = 0.000000615807 * (Speed ^ 4) + -0.000136969 * (Speed ^ 3) +
0.010863655 * (Speed ^ 2) + -0.33317703 * (Speed ^ 1) + 1.080458923
FE = -0.0000000029803 * (Speed ^ 4) + 0.000000723054 * (Speed ^ 3) +
-0.0000608178 * (Speed ^ 2) + 0.011900647 * (Speed ^ 1) + -0.006845708
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmax_Booster_w_1 = ((AA * GVF ^ 4) + (BB * GVF ^ 3) + (CC * GVF ^ 2)
+ (DD * GVF) + EE) * Qmax
End Function

Function Qmin_Booster_o_1(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = -4.52112269
b = 5.49768519
c = -1.77228009
```

```
d = 0.53530093
e = 0.52777778
FA = -0.00000000832241 * (Speed ^ 4) + -0.00000165149 * (Speed ^ 3) +
0.000388715 * (Speed ^ 2) + -0.005389739 * (Speed ^ 1) + 0.136979167
FB = -0.0000000176239 * (Speed ^ 4) + -0.000000595051 * (Speed ^ 3) +
0.00037589 * (Speed ^ 2) + -0.005817194 * (Speed ^ 1) + 0.183388158
FC = -0.0000000569947 * (Speed ^ 4) + 0.00000510882 * (Speed ^ 3) +
0.000107813 * (Speed ^ 2) + 0.002864341 * (Speed ^ 1) + 0.237935799
FD = -0.0000000897849 * (Speed ^ 4) + 0.0000135094 * (Speed ^ 3) + -
0.000532457 * (Speed ^ 2) + 0.018440479 * (Speed ^ 1) + -0.027871622
FE = 0.0000000180492 * (Speed ^ 4) + -0.00000333288 * (Speed ^ 3) +
0.000200066 * (Speed ^ 2) + 0.004934358 * (Speed ^ 1) + 0.029194079
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmin_Booster_o_1 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD *
GVF + EE) * Qmax
End Function
Function dpQmin_Booster_o_1(Speed, GVF) 'Speed is in [%]
MaxdP = 120
a = 8.34635416667
b = -13.93576388889
c = 5.1703125
d = -0.55881944444
e = 0.99933333333
FA = -0.0000000823243 * (Speed ^ 4) + 0.0000144474 * (Speed ^ 3) + -
0.00069995 * (Speed ^ 2) + 0.019339509 * (Speed ^ 1) + -0.136318253
FB = -0.000000102069 * (Speed ^ 4) + 0.0000184928 * (Speed ^ 3) + -
0.000956723 * (Speed ^ 2) + 0.024728562 * (Speed ^ 1) + -0.173366866
FC = -0.000000205116 * (Speed ^ 4) + 0.0000380329 * (Speed ^ 3) + -
0.002133354 * (Speed ^ 2) + 0.052154887 * (Speed ^ 1) + -0.362370807
FD = -0.000000605489 * (Speed ^ 4) + 0.000113097 * (Speed ^ 3) + -
0.006664196 * (Speed ^ 2) + 0.163527628 * (Speed ^ 1) + -1.124218549
FE = -0.0000000397698 * (Speed ^ 4) + 0.00000752144 * (Speed ^ 3) + -
0.000355983 * (Speed ^ 2) + 0.011005237 * (Speed ^ 1) + -0.075626807
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
dpQmin_Booster_o_1 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD
* GVF + EE) * MaxdP
If dpQmin_Booster_o_1 > 120 Then
dpQmin_Booster_o_1 = 120
End If
End Function

Function Qmax_Booster_o_1(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 22.703911
b = -27.64263873
c = 8.52097986
d = -0.01898573
e = 1.00807234
```

```
FA = -0.000000106991 * (Speed ^ 4) + 0.0000239794 * (Speed ^ 3) + -
0.001747557 * (Speed ^ 2) + 0.056427319 * (Speed ^ 1) + -0.408228111
FB = -0.0000000822009 * (Speed ^ 4) + 0.0000198323 * (Speed ^ 3) + -
0.001547693 * (Speed ^ 2) + 0.052289781 * (Speed ^ 1) + -0.330104326
FC = -0.0000000657617 * (Speed ^ 4) + 0.0000181943 * (Speed ^ 3) + -
0.001598287 * (Speed ^ 2) + 0.05682491 * (Speed ^ 1) + -0.282446228
FD = -0.00000191773 * (Speed ^ 4) + 0.00065378 * (Speed ^ 3) + -
0.071756567 * (Speed ^ 2) + 2.657900106 * (Speed ^ 1) + -7.532539527
FE = 0.000000000927577 * (Speed ^ 4) + -0.000000146118 * (Speed ^ 3)
+ 0.00000326236 * (Speed ^ 2) + 0.010148113 * (Speed ^ 1) + 0.006175829
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmax_Booster_o_1 = ((AA * GVF ^ 4) + (BB * GVF ^ 3) + (CC * GVF ^ 2)
+ (DD * GVF) + EE) * Qmax
End Function
```

Framo 310/1100/45

```
Function Qmin_Booster_w_2(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = -44.4175697
b = 49.25534968
c = -18.05317197
d = 2.77519088
e = 0.86111111
FA = 0.000000225081 * (Speed ^ 4) + -0.0000360303 * (Speed ^ 3) +
0.001646109 * (Speed ^ 2) + -0.023183308 * (Speed ^ 1) + 0.282706645
FB = 0.000000185791 * (Speed ^ 4) + -0.0000272416 * (Speed ^ 3) +
0.001020625 * (Speed ^ 2) + -0.008153798 * (Speed ^ 1) + 0.188891109
FC = 0.0000000933877 * (Speed ^ 4) + -0.00000805924 * (Speed ^ 3) + -
0.000250056 * (Speed ^ 2) + 0.021882095 * (Speed ^ 1) + -0.016474555
FD = -0.0000000268527 * (Speed ^ 4) + 0.0000150491 * (Speed ^ 3) + -
0.001649052 * (Speed ^ 2) + 0.0542982 * (Speed ^ 1) + -0.29804998
FE = -0.0000000152994 * (Speed ^ 4) + 0.00000201625 * (Speed ^ 3) +
0.0000239155 * (Speed ^ 2) + 0.002273574 * (Speed ^ 1) + 0.036185316
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmin_Booster_w_2 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD *
GVF + EE) * Qmax
End Function

Function dPQmin_Booster_w_2(Speed, GVF) 'Speed is in [%]
MaxdP = 120
a = 0.23496563069
b = -0.24137311586
c = 0.06836616358
d = -0.00512795266
e = 0.37466666667
FA = 0.0000169279 * (Speed ^ 4) + -0.001641943 * (Speed ^ 3) + -
0.090830251 * (Speed ^ 2) + 9.535263219 * (Speed ^ 1) + -78.78046333
```

```
FB = 0.0000121013 * (Speed ^ 4) + -0.000613974 * (Speed ^ 3) + -
0.167525736 * (Speed ^ 2) + 11.90153935 * (Speed ^ 1) + -93.97334852
FC = -0.00000208802 * (Speed ^ 4) + 0.002676521 * (Speed ^ 3) + -
0.424620144 * (Speed ^ 2) + 19.40011277 * (Speed ^ 1) + -143.890083
FD = -0.0000338325 * (Speed ^ 4) + 0.010999288 * (Speed ^ 3) + -
1.167949276 * (Speed ^ 2) + 44.06120013 * (Speed ^ 1) + -318.7547651
FE = 0.000000132063 * (Speed ^ 4) + -0.0000284966 * (Speed ^ 3) +
0.001804462 * (Speed ^ 2) + -0.018025233 * (Speed ^ 1) + 0.068762974
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
dPQmin_Booster_w_2 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD
* GVF + EE) * MaxdP
If dPQmin_Booster_w_2 > 45 Then
dPQmin_Booster_w_2 = 45
End If
End Function

Function Qmax_Booster_w_2(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 30.38892784
b = -35.7322789
c = 11.23409271
d = -0.1026584
e = 1.01612911
FA = -0.000000104753 * (Speed ^ 4) + 0.0000218173 * (Speed ^ 3) + -
0.001352233 * (Speed ^ 2) + 0.034580026 * (Speed ^ 1) + -0.255935973
FB = -0.000000076003 * (Speed ^ 4) + 0.0000159057 * (Speed ^ 3) + -
0.000954181 * (Speed ^ 2) + 0.024156037 * (Speed ^ 1) + -0.161119437
FC = -0.0000000408213 * (Speed ^ 4) + 0.00000899102 * (Speed ^ 3) + -
0.000504912 * (Speed ^ 2) + 0.012028172 * (Speed ^ 1) + -0.04790878
FD = 0.0000000333632 * (Speed ^ 4) + 0.00000229475 * (Speed ^ 3) + -
0.000350586 * (Speed ^ 2) + -0.022510577 * (Speed ^ 1) + 1.275795917
FE = 0.00000000155847 * (Speed ^ 4) + -0.000000311037 * (Speed ^ 3) +
0.0000196611 * (Speed ^ 2) + 0.009551189 * (Speed ^ 1) + 0.004091249
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmax_Booster_w_2 = ((AA * GVF ^ 4) + (BB * GVF ^ 3) + (CC * GVF ^ 2)
+ (DD * GVF) + EE) * Qmax
End Function

Function Qmin_Booster_o_2(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 16.63446382
b = -22.77175383
c = 6.89283982
d = 0.52695367
e = 0.81944444
FA = -0.000000695308 * (Speed ^ 4) + 0.000138234 * (Speed ^ 3) + -
0.008344076 * (Speed ^ 2) + 0.176897731 * (Speed ^ 1) + -1.620950229
```

```
FB = -0.000000550032 * (Speed ^ 4) + 0.000108984 * (Speed ^ 3) + -
0.00652687 * (Speed ^ 2) + 0.138993165 * (Speed ^ 1) + -1.312736629
FC = -0.000000602157 * (Speed ^ 4) + 0.000117175 * (Speed ^ 3) + -
0.006848183 * (Speed ^ 2) + 0.143166666 * (Speed ^ 1) + -1.418083278
FD = 0.00000103529 * (Speed ^ 4) + -0.000191387 * (Speed ^ 3) +
0.010681801 * (Speed ^ 2) + -0.20415477 * (Speed ^ 1) + 1.896059077
FE = -0.0000000485735 * (Speed ^ 4) + 0.00000942711 * (Speed ^ 3) + -
0.000511728 * (Speed ^ 2) + 0.016037481 * (Speed ^ 1) + -0.058295816
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmin_Booster_o_2 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD *
GVF + EE) * Qmax
End Function

Function dPQmin_Booster_o_2(Speed, GVF) 'Speed is in [%]
MaxdP = 120
a = -2.43175233834
b = 1.86533922624
c = -0.41359709609
d = 0.02682519684
e = 0.37440833333
FA = -0.0000055888 * (Speed ^ 4) + 0.001086734 * (Speed ^ 3) + -
0.062544531 * (Speed ^ 2) + 1.045999818 * (Speed ^ 1) + -6.652737022
FB = -0.00000723281 * (Speed ^ 4) + 0.001401653 * (Speed ^ 3) + -
0.079378657 * (Speed ^ 2) + 1.233021646 * (Speed ^ 1) + -7.785502384
FC = -0.00000869861 * (Speed ^ 4) + 0.001629262 * (Speed ^ 3) + -
0.085039811 * (Speed ^ 2) + 0.961696967 * (Speed ^ 1) + -5.596269109
FD = -0.0000120286 * (Speed ^ 4) + 0.002033251 * (Speed ^ 3) + -
0.078030271 * (Speed ^ 2) + -0.60410666 * (Speed ^ 1) + 7.624933917
FE = 0.000000146428 * (Speed ^ 4) + -0.000033256 * (Speed ^ 3) +
0.002323743 * (Speed ^ 2) + -0.038362202 * (Speed ^ 1) + 0.227672179
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
dPQmin_Booster_o_2 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD
* GVF + EE) * MaxdP
If dPQmin_Booster_o_2 > 45 Then
dPQmin_Booster_o_2 = 45
End If
End Function

Function Qmax_Booster_o_2(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 2.77813579
b = -2.74839287
c = -0.34140977
d = 0.95009828
e = 1.0079367
FA = -0.00000156233 * (Speed ^ 4) + 0.000347115 * (Speed ^ 3) + -
0.024754882 * (Speed ^ 2) + 0.604989094 * (Speed ^ 1) + -2.6386253
```

```
FB = -0.00000163819 * (Speed ^ 4) + 0.000368883 * (Speed ^ 3) + -
0.026659783 * (Speed ^ 2) + 0.652249155 * (Speed ^ 1) + -2.523369092
FC = 0.00000378356 * (Speed ^ 4) + -0.000879744 * (Speed ^ 3) +
0.065676554 * (Speed ^ 2) + -1.595859881 * (Speed ^ 1) + 4.974001235
FD = 0.000000117974 * (Speed ^ 4) + -0.0000279875 * (Speed ^ 3) +
0.002239196 * (Speed ^ 2) + -0.053151757 * (Speed ^ 1) + 0.111320664
FE = 0.000000000408957 * (Speed ^ 4) + -0.0000000707788 * (Speed ^ 3)
+ 0.00000178949 * (Speed ^ 2) + 0.010139699 * (Speed ^ 1) + -
0.001791994
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmax_Booster_o_2 = ((AA * GVF ^ 4) + (BB * GVF ^ 3) + (CC * GVF ^ 2)
+ (DD * GVF) + EE) * Qmax
End Function
```

Framo 310/250/180

```
Function Qmin_Booster_w_3(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 2.40184643
b = -3.56038411
c = 1.42980505
d = -0.02712674
e = 0.16276042
FA = 0.000000199678 * (Speed ^ 4) + -0.0000395413 * (Speed ^ 3) +
0.002662399 * (Speed ^ 2) + -0.067350542 * (Speed ^ 1) + 0.62745098
FB = 0.000000207431 * (Speed ^ 4) + -0.0000417561 * (Speed ^ 3) +
0.00285416 * (Speed ^ 2) + -0.072679019 * (Speed ^ 1) + 0.669312169
FC = 0.000000199759 * (Speed ^ 4) + -0.0000414824 * (Speed ^ 3) +
0.002947952 * (Speed ^ 2) + -0.077760695 * (Speed ^ 1) + 0.714756258
FD = 1.11893E-20 * (Speed ^ 4) + -0.00000341557 * (Speed ^ 3) +
0.001276952 * (Speed ^ 2) + -0.104818214 * (Speed ^ 1) + 1.840277778
FE = 0.0000000019425 * (Speed ^ 4) + 0.00000216913 * (Speed ^ 3) + -
0.000289821 * (Speed ^ 2) + 0.016331261 * (Speed ^ 1) + -0.077777778
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmin_Booster_w_3 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD *
GVF + EE) * Qmax
End Function

Function dpQmin_Booster_w_3(Speed, GVF) 'Speed is in [%]
MaxdP = 180
a = -16.13642939815
b = 19.35677083333
c = -7.09377893519
d = 0.77329861111
e = 0.99938888889
FA = 0.000000139839 * (Speed ^ 4) + -0.0000261141 * (Speed ^ 3) +
0.00168929 * (Speed ^ 2) + -0.041062502 * (Speed ^ 1) + 0.283758237
```

```
FB = 0.000000172772 * (Speed ^ 4) + -0.000032708 * (Speed ^ 3) +
0.002118293 * (Speed ^ 2) + -0.051987247 * (Speed ^ 1) + 0.361363265
FC = 0.000000173664 * (Speed ^ 4) + -0.0000332372 * (Speed ^ 3) +
0.00217962 * (Speed ^ 2) + -0.05415465 * (Speed ^ 1) + 0.377904092
FD = 0.0000000789683 * (Speed ^ 4) + -0.00000932912 * (Speed ^ 3) +
0.000340276 * (Speed ^ 2) + -0.010946438 * (Speed ^ 1) + 0.050607691
FE = -0.0000000507381 * (Speed ^ 4) + 0.00000724119 * (Speed ^ 3) + -
0.000169019 * (Speed ^ 2) + 0.005347332 * (Speed ^ 1) + -0.025643912
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
dpQmin_Booster_w_3 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD
* GVF + EE) * MaxdP
If dpQmin_Booster_w_3 > 180 Then
dpQmin_Booster_w_3 = 180
End If
End Function

Function Qmax_Booster_w_3(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 9.49361198
b = -11.63805139
c = 3.7096568
d = -0.04602503
e = 0.30653689
FA = 0.000000140451 * (Speed ^ 4) + -0.0000353049 * (Speed ^ 3) +
0.00306623 * (Speed ^ 2) + -0.087202074 * (Speed ^ 1) + 0.345070806
FB = 0.000000154465 * (Speed ^ 4) + -0.0000371106 * (Speed ^ 3) +
0.003080607 * (Speed ^ 2) + -0.086485907 * (Speed ^ 1) + 0.530643972
FC = 0.000000216173 * (Speed ^ 4) + -0.0000501193 * (Speed ^ 3) +
0.003980533 * (Speed ^ 2) + -0.112325508 * (Speed ^ 1) + 0.951678063
FD = 0.00000285263 * (Speed ^ 4) + -0.000667032 * (Speed ^ 3) +
0.052384427 * (Speed ^ 2) + -1.553199322 * (Speed ^ 1) + 14.34557475
FE = 0.0000000204994 * (Speed ^ 4) + -0.00000506855 * (Speed ^ 3) +
0.000423229 * (Speed ^ 2) + -0.003245182 * (Speed ^ 1) + 0.109882006
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmax_Booster_w_3 = ((AA * GVF ^ 4) + (BB * GVF ^ 3) + (CC * GVF ^ 2)
+ (DD * GVF) + EE) * Qmax
End Function

Function Qmin_Booster_o_3(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 0.63578288
b = -0.81945349
c = 0.31365289
d = 0.04634151
e = 0.13563368
FA = -0.000000360982 * (Speed ^ 4) + 0.0000749482 * (Speed ^ 3) + -
0.005179843 * (Speed ^ 2) + 0.14489122 * (Speed ^ 1) + -0.509259259
```

```
FB = -0.000000481774 * (Speed ^ 4) + 0.000097182 * (Speed ^ 3) + -
0.006518718 * (Speed ^ 2) + 0.179106047 * (Speed ^ 1) + -0.663793103
FC = -0.000000673182 * (Speed ^ 4) + 0.0001312 * (Speed ^ 3) + -
0.008360646 * (Speed ^ 2) + 0.217219492 * (Speed ^ 1) + -0.877627628
FD = 0.000000452342 * (Speed ^ 4) + -0.0000869838 * (Speed ^ 3) +
0.005417342 * (Speed ^ 2) + -0.117644077 * (Speed ^ 1) + 0.262195122
FE = 0.0000000737179 * (Speed ^ 4) + -0.0000136733 * (Speed ^ 3) +
0.000826836 * (Speed ^ 2) + -0.011169386 * (Speed ^ 1) + 0.131666667
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmin_Booster_o_3 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD *
GVF + EE) * Qmax
End Function

Function dpQmin_Booster_o_3(Speed, GVF) 'Speed is in [%]
MaxdP = 180
a = -3.93431712963
b = 1.81608796296
c = 0.01403935185
d = -0.04508796296
e = 0.99983333333
FA = -0.000000278868 * (Speed ^ 4) + 0.0000560184 * (Speed ^ 3) + -
0.003437162 * (Speed ^ 2) + 0.07871775 * (Speed ^ 1) + -0.550145866
FB = -0.00000117457 * (Speed ^ 4) + 0.000233866 * (Speed ^ 3) + -
0.014650485 * (Speed ^ 2) + 0.338079126 * (Speed ^ 1) + -2.359383298
FC = 0.0000888155 * (Speed ^ 4) + -0.017653505 * (Speed ^ 3) +
1.116798866 * (Speed ^ 2) + -26.05703906 * (Speed ^ 1) + 182.4284144
FD = 0.00000258291 * (Speed ^ 4) + -0.000560091 * (Speed ^ 3) +
0.037901244 * (Speed ^ 2) + -0.835712574 * (Speed ^ 1) + 6.097537393
FE = -0.0000000614479 * (Speed ^ 4) + 0.0000113846 * (Speed ^ 3) + -
0.000574462 * (Speed ^ 2) + 0.016272021 * (Speed ^ 1) + -0.110584171
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
dpQmin_Booster_o_3 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD
* GVF + EE) * MaxdP
If dpQmin_Booster_o_3 > 180 Then
dpQmin_Booster_o_3 = 180
End If
End Function

Function Qmax_Booster_o_3(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 8.60639804
b = -10.6295761
c = 3.38340288
d = -0.02620676
e = 0.30653689
FA = -0.0000000610445 * (Speed ^ 4) + 0.00000915305 * (Speed ^ 3) + -
0.000183362 * (Speed ^ 2) + 0.000642082 * (Speed ^ 1) + -0.266474304
```

```
FB = -0.0000000558276 * (Speed ^ 4) + 0.00000976415 * (Speed ^ 3) + -
0.000392418 * (Speed ^ 2) + 0.008708785 * (Speed ^ 1) + -0.11710437
FC = -0.0000000601572 * (Speed ^ 4) + 0.0000124171 * (Speed ^ 3) + -
0.000747044 * (Speed ^ 2) + 0.020252157 * (Speed ^ 1) + 0.05486593
FD = -0.000000936345 * (Speed ^ 4) + 0.000210612 * (Speed ^ 3) + -
0.016180407 * (Speed ^ 2) + 0.435042925 * (Speed ^ 1) + 2.461315188
FE = 1.39648E-22 * (Speed ^ 4) + 0.00000000687611 * (Speed ^ 3) + -
0.00000448666 * (Speed ^ 2) + 0.010332563 * (Speed ^ 1) + 0.004424779
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmax_Booster_o_3 = ((AA * GVF ^ 4) + (BB * GVF ^ 3) + (CC * GVF ^ 2)
+ (DD * GVF) + EE) * Qmax
End Function
```

Framo 310/400/180

```
Function Qmin_Booster_w_4(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 2.40184643
b = -3.56038411
c = 1.42980505
d = -0.02712674
e = 0.16276042
FA = 0.000000199678 * (Speed ^ 4) + -0.0000395413 * (Speed ^ 3) +
0.002662399 * (Speed ^ 2) + -0.067350542 * (Speed ^ 1) + 0.62745098
FB = 0.000000207431 * (Speed ^ 4) + -0.0000417561 * (Speed ^ 3) +
0.00285416 * (Speed ^ 2) + -0.072679019 * (Speed ^ 1) + 0.669312169
FC = 0.000000199759 * (Speed ^ 4) + -0.0000414824 * (Speed ^ 3) +
0.002947952 * (Speed ^ 2) + -0.077760695 * (Speed ^ 1) + 0.714756258
FD = 1.11893E-20 * (Speed ^ 4) + -0.00000341557 * (Speed ^ 3) +
0.001276952 * (Speed ^ 2) + -0.104818214 * (Speed ^ 1) + 1.840277778
FE = 0.0000000019425 * (Speed ^ 4) + 0.00000216913 * (Speed ^ 3) + -
0.000289821 * (Speed ^ 2) + 0.016331261 * (Speed ^ 1) + -0.077777778
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmin_Booster_w_4 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD *
GVF + EE) * Qmax * (9600 / 6000)
End Function

Function dpQmin_Booster_w_4(Speed, GVF) 'Speed is in [%]
MaxdP = 180
a = -16.13642939815
b = 19.35677083333
c = -7.09377893519
d = 0.77329861111
e = 0.99938888889
FA = 0.000000139839 * (Speed ^ 4) + -0.0000261141 * (Speed ^ 3) +
0.00168929 * (Speed ^ 2) + -0.041062502 * (Speed ^ 1) + 0.283758237
FB = 0.000000172772 * (Speed ^ 4) + -0.000032708 * (Speed ^ 3) +
0.002118293 * (Speed ^ 2) + -0.051987247 * (Speed ^ 1) + 0.361363265
```

```
FC = 0.000000173664 * (Speed ^ 4) + -0.0000332372 * (Speed ^ 3) +
0.00217962 * (Speed ^ 2) + -0.05415465 * (Speed ^ 1) + 0.377904092
FD = 0.0000000789683 * (Speed ^ 4) + -0.00000932912 * (Speed ^ 3) +
0.000340276 * (Speed ^ 2) + -0.010946438 * (Speed ^ 1) + 0.050607691
FE = -0.0000000507381 * (Speed ^ 4) + 0.00000724119 * (Speed ^ 3) + -
0.000169019 * (Speed ^ 2) + 0.005347332 * (Speed ^ 1) + -0.025643912
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
dpQmin_Booster_w_4 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD
* GVF + EE) * MaxdP
If dpQmin_Booster_w_4 > 180 Then
dpQmin_Booster_w_4 = 180
End If
End Function

Function Qmax_Booster_w_4(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 9.49361198
b = -11.63805139
c = 3.7096568
d = -0.04602503
e = 0.30653689
FA = 0.000000140451 * (Speed ^ 4) + -0.0000353049 * (Speed ^ 3) +
0.00306623 * (Speed ^ 2) + -0.087202074 * (Speed ^ 1) + 0.345070806
FB = 0.000000154465 * (Speed ^ 4) + -0.0000371106 * (Speed ^ 3) +
0.003080607 * (Speed ^ 2) + -0.086485907 * (Speed ^ 1) + 0.530643972
FC = 0.000000216173 * (Speed ^ 4) + -0.0000501193 * (Speed ^ 3) +
0.003980533 * (Speed ^ 2) + -0.112325508 * (Speed ^ 1) + 0.951678063
FD = 0.00000285263 * (Speed ^ 4) + -0.000667032 * (Speed ^ 3) +
0.052384427 * (Speed ^ 2) + -1.553199322 * (Speed ^ 1) + 14.34557475
FE = 0.0000000204994 * (Speed ^ 4) + -0.00000506855 * (Speed ^ 3) +
0.000423229 * (Speed ^ 2) + -0.003245182 * (Speed ^ 1) + 0.109882006
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmax_Booster_w_4 = ((AA * GVF ^ 4) + (BB * GVF ^ 3) + (CC * GVF ^ 2)
+ (DD * GVF) + EE) * Qmax * (9600 / 6000)
End Function

Function Qmin_Booster_o_4(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 0.63578288
b = -0.81945349
c = 0.31365289
d = 0.04634151
e = 0.13563368
FA = -0.000000360982 * (Speed ^ 4) + 0.0000749482 * (Speed ^ 3) + -
0.005179843 * (Speed ^ 2) + 0.14489122 * (Speed ^ 1) + -0.509259259
FB = -0.000000481774 * (Speed ^ 4) + 0.000097182 * (Speed ^ 3) + -
0.006518718 * (Speed ^ 2) + 0.179106047 * (Speed ^ 1) + -0.663793103
```

```
FC = -0.000000673182 * (Speed ^ 4) + 0.0001312 * (Speed ^ 3) + -
0.008360646 * (Speed ^ 2) + 0.217219492 * (Speed ^ 1) + -0.877627628
FD = 0.000000452342 * (Speed ^ 4) + -0.0000869838 * (Speed ^ 3) +
0.005417342 * (Speed ^ 2) + -0.117644077 * (Speed ^ 1) + 0.262195122
FE = 0.0000000737179 * (Speed ^ 4) + -0.0000136733 * (Speed ^ 3) +
0.000826836 * (Speed ^ 2) + -0.011169386 * (Speed ^ 1) + 0.131666667
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmin_Booster_o_4 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD *
GVF + EE) * Qmax * (9600 / 6000)
End Function

Function dpQmin_Booster_o_4(Speed, GVF) 'Speed is in [%]
MaxdP = 180
a = -3.93431712963
b = 1.81608796296
c = 0.01403935185
d = -0.04508796296
e = 0.99983333333
FA = -0.000000278868 * (Speed ^ 4) + 0.0000560184 * (Speed ^ 3) + -
0.003437162 * (Speed ^ 2) + 0.07871775 * (Speed ^ 1) + -0.550145866
FB = -0.00000117457 * (Speed ^ 4) + 0.000233866 * (Speed ^ 3) + -
0.014650485 * (Speed ^ 2) + 0.338079126 * (Speed ^ 1) + -2.359383298
FC = 0.0000888155 * (Speed ^ 4) + -0.017653505 * (Speed ^ 3) +
1.116798866 * (Speed ^ 2) + -26.05703906 * (Speed ^ 1) + 182.4284144
FD = 0.00000258291 * (Speed ^ 4) + -0.000560091 * (Speed ^ 3) +
0.037901244 * (Speed ^ 2) + -0.835712574 * (Speed ^ 1) + 6.097537393
FE = -0.0000000614479 * (Speed ^ 4) + 0.0000113846 * (Speed ^ 3) + -
0.000574462 * (Speed ^ 2) + 0.016272021 * (Speed ^ 1) + -0.110584171
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
dpQmin_Booster_o_4 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD
* GVF + EE) * MaxdP
If dpQmin_Booster_o_4 > 180 Then
dpQmin_Booster_o_4 = 180
End If
End Function

Function Qmax_Booster_o_4(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 8.60639804
b = -10.6295761
c = 3.38340288
d = -0.02620676
e = 0.30653689
FA = -0.0000000610445 * (Speed ^ 4) + 0.00000915305 * (Speed ^ 3) + -
0.000183362 * (Speed ^ 2) + 0.000642082 * (Speed ^ 1) + -0.266474304
FB = -0.0000000558276 * (Speed ^ 4) + 0.00000976415 * (Speed ^ 3) + -
0.000392418 * (Speed ^ 2) + 0.008708785 * (Speed ^ 1) + -0.11710437
```

```
FC = -0.0000000601572 * (Speed ^ 4) + 0.0000124171 * (Speed ^ 3) + -
0.000747044 * (Speed ^ 2) + 0.020252157 * (Speed ^ 1) + 0.05486593
FD = -0.000000936345 * (Speed ^ 4) + 0.000210612 * (Speed ^ 3) + -
0.016180407 * (Speed ^ 2) + 0.435042925 * (Speed ^ 1) + 2.461315188
FE = 1.39648E-22 * (Speed ^ 4) + 0.00000000687611 * (Speed ^ 3) + -
0.00000448666 * (Speed ^ 2) + 0.010332563 * (Speed ^ 1) + 0.004424779
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmax_Booster_o_4 = ((AA * GVF ^ 4) + (BB * GVF ^ 3) + (CC * GVF ^ 2)
+ (DD * GVF) + EE) * Qmax * (9600 / 6000)
End Function
```

Framo 310/500/180

```
Function Qmin_Booster_w_5(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 2.40184643
b = -3.56038411
c = 1.42980505
d = -0.02712674
e = 0.16276042
FA = 0.000000199678 * (Speed ^ 4) + -0.0000395413 * (Speed ^ 3) +
0.002662399 * (Speed ^ 2) + -0.067350542 * (Speed ^ 1) + 0.62745098
FB = 0.000000207431 * (Speed ^ 4) + -0.0000417561 * (Speed ^ 3) +
0.00285416 * (Speed ^ 2) + -0.072679019 * (Speed ^ 1) + 0.669312169
FC = 0.000000199759 * (Speed ^ 4) + -0.0000414824 * (Speed ^ 3) +
0.002947952 * (Speed ^ 2) + -0.077760695 * (Speed ^ 1) + 0.714756258
FD = 1.11893E-20 * (Speed ^ 4) + -0.00000341557 * (Speed ^ 3) +
0.001276952 * (Speed ^ 2) + -0.104818214 * (Speed ^ 1) + 1.840277778
FE = 0.0000000019425 * (Speed ^ 4) + 0.00000216913 * (Speed ^ 3) + -
0.000289821 * (Speed ^ 2) + 0.016331261 * (Speed ^ 1) + -0.077777778
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmin_Booster_w_5 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD *
GVF + EE) * Qmax * (12000 / 9600)
End Function

Function dpQmin_Booster_w_5(Speed, GVF) 'Speed is in [%]
MaxdP = 180
a = -16.13642939815
b = 19.35677083333
c = -7.09377893519
d = 0.77329861111
e = 0.99938888889
FA = 0.000000139839 * (Speed ^ 4) + -0.0000261141 * (Speed ^ 3) +
0.00168929 * (Speed ^ 2) + -0.041062502 * (Speed ^ 1) + 0.283758237
FB = 0.000000172772 * (Speed ^ 4) + -0.000032708 * (Speed ^ 3) +
0.002118293 * (Speed ^ 2) + -0.051987247 * (Speed ^ 1) + 0.361363265
```

```
FC = 0.000000173664 * (Speed ^ 4) + -0.0000332372 * (Speed ^ 3) + 0.00217962 * (Speed ^ 2) + -0.05415465 * (Speed ^ 1) + 0.377904092
FD = 0.0000000789683 * (Speed ^ 4) + -0.00000932912 * (Speed ^ 3) + 0.000340276 * (Speed ^ 2) + -0.010946438 * (Speed ^ 1) + 0.050607691
FE = -0.0000000507381 * (Speed ^ 4) + 0.00000724119 * (Speed ^ 3) + -0.000169019 * (Speed ^ 2) + 0.005347332 * (Speed ^ 1) + -0.025643912
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
dpQmin_Booster_w_5 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD * GVF + EE) * MaxdP
If dpQmin_Booster_w_5 > 180 Then
dpQmin_Booster_w_5 = 180
End If
End Function

Function Qmax_Booster_w_5(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 9.49361198
b = -11.63805139
c = 3.7096568
d = -0.04602503
e = 0.30653689
FA = 0.000000140451 * (Speed ^ 4) + -0.0000353049 * (Speed ^ 3) + 0.00306623 * (Speed ^ 2) + -0.087202074 * (Speed ^ 1) + 0.345070806
FB = 0.000000154465 * (Speed ^ 4) + -0.0000371106 * (Speed ^ 3) + 0.003080607 * (Speed ^ 2) + -0.086485907 * (Speed ^ 1) + 0.530643972
FC = 0.000000216173 * (Speed ^ 4) + -0.0000501193 * (Speed ^ 3) + 0.003980533 * (Speed ^ 2) + -0.112325508 * (Speed ^ 1) + 0.951678063
FD = 0.00000285263 * (Speed ^ 4) + -0.000667032 * (Speed ^ 3) + 0.052384427 * (Speed ^ 2) + -1.553199322 * (Speed ^ 1) + 14.34557475
FE = 0.0000000204994 * (Speed ^ 4) + -0.00000506855 * (Speed ^ 3) + 0.000423229 * (Speed ^ 2) + -0.003245182 * (Speed ^ 1) + 0.109882006
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmax_Booster_w_5 = ((AA * GVF ^ 4) + (BB * GVF ^ 3) + (CC * GVF ^ 2) + (DD * GVF) + EE) * Qmax * (12000 / 9600)
End Function

Function Qmin_Booster_o_5(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 0.63578288
b = -0.81945349
c = 0.31365289
d = 0.04634151
e = 0.13563368
FA = -0.000000360982 * (Speed ^ 4) + 0.0000749482 * (Speed ^ 3) + -0.005179843 * (Speed ^ 2) + 0.14489122 * (Speed ^ 1) + -0.509259259
FB = -0.000000481774 * (Speed ^ 4) + 0.000097182 * (Speed ^ 3) + -0.006518718 * (Speed ^ 2) + 0.179106047 * (Speed ^ 1) + -0.663793103
```

```
FC = -0.000000673182 * (Speed ^ 4) + 0.0001312 * (Speed ^ 3) + -
0.008360646 * (Speed ^ 2) + 0.217219492 * (Speed ^ 1) + -0.877627628
FD = 0.000000452342 * (Speed ^ 4) + -0.0000869838 * (Speed ^ 3) +
0.005417342 * (Speed ^ 2) + -0.117644077 * (Speed ^ 1) + 0.262195122
FE = 0.0000000737179 * (Speed ^ 4) + -0.0000136733 * (Speed ^ 3) +
0.000826836 * (Speed ^ 2) + -0.011169386 * (Speed ^ 1) + 0.131666667
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmin_Booster_o_5 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD *
GVF + EE) * Qmax * (12000 / 9600)
End Function

Function dpQmin_Booster_o_5(Speed, GVF) 'Speed is in [%]
MaxdP = 180
a = -3.93431712963
b = 1.81608796296
c = 0.01403935185
d = -0.04508796296
e = 0.99983333333
FA = -0.000000278868 * (Speed ^ 4) + 0.0000560184 * (Speed ^ 3) + -
0.003437162 * (Speed ^ 2) + 0.07871775 * (Speed ^ 1) + -0.550145866
FB = -0.00000117457 * (Speed ^ 4) + 0.000233866 * (Speed ^ 3) + -
0.014650485 * (Speed ^ 2) + 0.338079126 * (Speed ^ 1) + -2.359383298
FC = 0.0000888155 * (Speed ^ 4) + -0.017653505 * (Speed ^ 3) +
1.116798866 * (Speed ^ 2) + -26.05703906 * (Speed ^ 1) + 182.4284144
FD = 0.00000258291 * (Speed ^ 4) + -0.000560091 * (Speed ^ 3) +
0.037901244 * (Speed ^ 2) + -0.835712574 * (Speed ^ 1) + 6.097537393
FE = -0.0000000614479 * (Speed ^ 4) + 0.0000113846 * (Speed ^ 3) + -
0.000574462 * (Speed ^ 2) + 0.016272021 * (Speed ^ 1) + -0.110584171
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
dpQmin_Booster_o_5 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD
* GVF + EE) * MaxdP
If dpQmin_Booster_o_5 > 180 Then
dpQmin_Booster_o_5 = 180
End If
End Function

Function Qmax_Booster_o_5(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 8.60639804
b = -10.6295761
c = 3.38340288
d = -0.02620676
e = 0.30653689
FA = -0.0000000610445 * (Speed ^ 4) + 0.00000915305 * (Speed ^ 3) + -
0.000183362 * (Speed ^ 2) + 0.000642082 * (Speed ^ 1) + -0.266474304
FB = -0.0000000558276 * (Speed ^ 4) + 0.00000976415 * (Speed ^ 3) + -
0.000392418 * (Speed ^ 2) + 0.008708785 * (Speed ^ 1) + -0.11710437
```

```
FC = -0.0000000601572 * (Speed ^ 4) + 0.0000124171 * (Speed ^ 3) + -
0.000747044 * (Speed ^ 2) + 0.020252157 * (Speed ^ 1) + 0.05486593
FD = -0.000000936345 * (Speed ^ 4) + 0.000210612 * (Speed ^ 3) + -
0.016180407 * (Speed ^ 2) + 0.435042925 * (Speed ^ 1) + 2.461315188
FE = 1.39648E-22 * (Speed ^ 4) + 0.00000000687611 * (Speed ^ 3) + -
0.00000448666 * (Speed ^ 2) + 0.010332563 * (Speed ^ 1) + 0.004424779
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmax_Booster_o_5 = ((AA * GVF ^ 4) + (BB * GVF ^ 3) + (CC * GVF ^ 2)
+ (DD * GVF) + EE) * Qmax * (12000 / 9600)
End Function
```

Framo 310/500/45

```
Function Qmin_Booster_w_6(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 11.93576389
b = -17.07175926
c = 6.46701389
d = -0.30671296
e = 0.32986111
FA = 0.0000000742441 * (Speed ^ 4) + -0.00000870277 * (Speed ^ 3) +
0.000213232 * (Speed ^ 2) + 0.001695123 * (Speed ^ 1) + -0.026357323
FB = 0.0000000508151 * (Speed ^ 4) + -0.00000360316 * (Speed ^ 3) + -
0.000156797 * (Speed ^ 2) + 0.012079876 * (Speed ^ 1) + -0.11076536
FC = 0.00000000996154 * (Speed ^ 4) + 0.0000060478 * (Speed ^ 3) + -
0.000908013 * (Speed ^ 2) + 0.033751235 * (Speed ^ 1) + -0.298844146
FD = -0.000000209645 * (Speed ^ 4) + 0.0000657737 * (Speed ^ 3) + -
0.006042737 * (Speed ^ 2) + 0.186505593 * (Speed ^ 1) + -1.660966981
FE = -0.0000000344091 * (Speed ^ 4) + 0.00000650802 * (Speed ^ 3) + -
0.000320944 * (Speed ^ 2) + 0.011989518 * (Speed ^ 1) + -0.04002193
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmin_Booster_w_6 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD *
GVF + EE) * Qmax
End Function

Function dpQmin_Booster_w_6(Speed, GVF) 'Speed is in [%]
MaxdP = 120
a = 12.16189312
b = -16.80826786
c = 6.13340982
d = -0.1830211
e = 0.40574091
FA = -0.000000079636 * (Speed ^ 4) + 0.0000168426 * (Speed ^ 3) + -
0.001191116 * (Speed ^ 2) + 0.042792825 * (Speed ^ 1) + -0.222328493
FB = -0.0000000556713 * (Speed ^ 4) + 0.0000123466 * (Speed ^ 3) + -
0.0009103 * (Speed ^ 2) + 0.035095244 * (Speed ^ 1) + -0.169090623
```

```
FC = -0.0000000446571 * (Speed ^ 4) + 0.0000108162 * (Speed ^ 3) + -
0.000865401 * (Speed ^ 2) + 0.034685951 * (Speed ^ 1) + -0.154302769
FD = -0.000000200239 * (Speed ^ 4) + 0.0000508333 * (Speed ^ 3) + -
0.004503068 * (Speed ^ 2) + 0.159312005 * (Speed ^ 1) + -0.697792041
FE = -0.00000000323188 * (Speed ^ 4) + 0.000000800183 * (Speed ^ 3) +
-0.0000681493 * (Speed ^ 2) + 0.012193616 * (Speed ^ 1) + -0.015477703
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
dpQmin_Booster_w_6 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD
* GVF + EE) * MaxdP
If dpQmin_Booster_w_6 > 45 Then
dpQmin_Booster_w_6 = 45
End If
End Function

Function Qmax_Booster_w_6(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 12.16189312
b = -16.80826786
c = 6.13340982
d = -0.1830211
e = 0.40574091
FA = -0.000000079636 * (Speed ^ 4) + 0.0000168426 * (Speed ^ 3) + -
0.001191116 * (Speed ^ 2) + 0.042792825 * (Speed ^ 1) + -0.222328493
FB = -0.0000000556713 * (Speed ^ 4) + 0.0000123466 * (Speed ^ 3) + -
0.0009103 * (Speed ^ 2) + 0.035095244 * (Speed ^ 1) + -0.169090623
FC = -0.0000000446571 * (Speed ^ 4) + 0.0000108162 * (Speed ^ 3) + -
0.000865401 * (Speed ^ 2) + 0.034685951 * (Speed ^ 1) + -0.154302769
FD = -0.000000200239 * (Speed ^ 4) + 0.0000508333 * (Speed ^ 3) + -
0.004503068 * (Speed ^ 2) + 0.159312005 * (Speed ^ 1) + -0.697792041
FE = -0.00000000323188 * (Speed ^ 4) + 0.000000800183 * (Speed ^ 3) +
-0.0000681493 * (Speed ^ 2) + 0.012193616 * (Speed ^ 1) + -0.015477703
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmax_Booster_w_6 = ((AA * GVF ^ 4) + (BB * GVF ^ 3) + (CC * GVF ^ 2)
+ (DD * GVF) + EE) * Qmax
End Function

Function Qmin_Booster_o_6(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 11.93576389
b = -17.07175926
c = 6.46701389
d = -0.30671296
e = 0.32986111
FA = 0.0000000742441 * (Speed ^ 4) + -0.00000870277 * (Speed ^ 3) +
0.000213232 * (Speed ^ 2) + 0.001695123 * (Speed ^ 1) + -0.026357323
FB = 0.0000000508151 * (Speed ^ 4) + -0.00000360316 * (Speed ^ 3) + -
0.000156797 * (Speed ^ 2) + 0.012079876 * (Speed ^ 1) + -0.11076536
```

```
FC = 0.0000000996154 * (Speed ^ 4) + 0.0000060478 * (Speed ^ 3) + -
0.000908013 * (Speed ^ 2) + 0.033751235 * (Speed ^ 1) + -0.298844146
FD = -0.000000209645 * (Speed ^ 4) + 0.0000657737 * (Speed ^ 3) + -
0.006042737 * (Speed ^ 2) + 0.186505593 * (Speed ^ 1) + -1.660966981
FE = -0.0000000344091 * (Speed ^ 4) + 0.00000650802 * (Speed ^ 3) + -
0.000320944 * (Speed ^ 2) + 0.011989518 * (Speed ^ 1) + -0.04002193
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmin_Booster_o_6 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD *
GVF + EE) * Qmax
End Function

Function dpQmin_Booster_o_6(Speed, GVF) 'Speed is in [%]
MaxdP = 120
a = 12.16189312
b = -16.80826786
c = 6.13340982
d = -0.1830211
e = 0.40574091
FA = -0.000000079636 * (Speed ^ 4) + 0.0000168426 * (Speed ^ 3) + -
0.001191116 * (Speed ^ 2) + 0.042792825 * (Speed ^ 1) + -0.222328493
FB = -0.0000000556713 * (Speed ^ 4) + 0.0000123466 * (Speed ^ 3) + -
0.0009103 * (Speed ^ 2) + 0.035095244 * (Speed ^ 1) + -0.169090623
FC = -0.0000000446571 * (Speed ^ 4) + 0.0000108162 * (Speed ^ 3) + -
0.000865401 * (Speed ^ 2) + 0.034685951 * (Speed ^ 1) + -0.154302769
FD = -0.000000200239 * (Speed ^ 4) + 0.0000508333 * (Speed ^ 3) + -
0.004503068 * (Speed ^ 2) + 0.159312005 * (Speed ^ 1) + -0.697792041
FE = -0.00000000323188 * (Speed ^ 4) + 0.000000800183 * (Speed ^ 3) +
-0.0000681493 * (Speed ^ 2) + 0.012193616 * (Speed ^ 1) + -0.015477703
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
dpQmin_Booster_o_6 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD
* GVF + EE) * MaxdP
If dpQmin_Booster_o_6 > 45 Then
dpQmin_Booster_o_6 = 45
End If
End Function

Function Qmax_Booster_o_6(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 12.16189312
b = -16.80826786
c = 6.13340982
d = -0.1830211
e = 0.40574091
FA = -0.000000079636 * (Speed ^ 4) + 0.0000168426 * (Speed ^ 3) + -
0.001191116 * (Speed ^ 2) + 0.042792825 * (Speed ^ 1) + -0.222328493
FB = -0.0000000556713 * (Speed ^ 4) + 0.0000123466 * (Speed ^ 3) + -
0.0009103 * (Speed ^ 2) + 0.035095244 * (Speed ^ 1) + -0.169090623
```

```
FC = -0.0000000446571 * (Speed ^ 4) + 0.0000108162 * (Speed ^ 3) + -
0.000865401 * (Speed ^ 2) + 0.034685951 * (Speed ^ 1) + -0.154302769
FD = -0.000000200239 * (Speed ^ 4) + 0.0000508333 * (Speed ^ 3) + -
0.004503068 * (Speed ^ 2) + 0.159312005 * (Speed ^ 1) + -0.697792041
FE = -0.0000000323188 * (Speed ^ 4) + 0.000000800183 * (Speed ^ 3) +
-0.0000681493 * (Speed ^ 2) + 0.012193616 * (Speed ^ 1) + -0.015477703
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmax_Booster_o_6 = ((AA * GVF ^ 4) + (BB * GVF ^ 3) + (CC * GVF ^ 2)
+ (DD * GVF) + EE) * Qmax
End Function
```

Framo 310/600/120

```
Function Qmin_Booster_w_7(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 17.72280093
b = -28.13946759
c = 12.7025463
d = -1.00115741
e = 0.20486111
FA = 0.000000259002 * (Speed ^ 4) + -0.0000484485 * (Speed ^ 3) +
0.003003699 * (Speed ^ 2) + -0.070337816 * (Speed ^ 1) + 0.475884885
FB = 0.000000264085 * (Speed ^ 4) + -0.0000497443 * (Speed ^ 3) +
0.003104997 * (Speed ^ 2) + -0.072826583 * (Speed ^ 1) + 0.494426816
FC = 0.000000285972 * (Speed ^ 4) + -0.0000544864 * (Speed ^ 3) +
0.003438971 * (Speed ^ 2) + -0.081433111 * (Speed ^ 1) + 0.555223608
FD = 0.000000494715 * (Speed ^ 4) + -0.0000967277 * (Speed ^ 3) +
0.006213971 * (Speed ^ 2) + -0.151357257 * (Speed ^ 1) + 1.064995033
FE = -0.0000000213439 * (Speed ^ 4) + 0.00000311078 * (Speed ^ 3) + -
0.000151791 * (Speed ^ 2) + 0.015254505 * (Speed ^ 1) + 0.007856638
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmin_Booster_w_7 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD *
GVF + EE) * Qmax
End Function

Function dpQmin_Booster_w_7(Speed, GVF) 'Speed is in [%]
MaxdP = 120
a = -16.50238715278
b = 19.88098958333
c = -7.32250868056
d = 0.80086458333
e = 1#
FA = 0.000000219197 * (Speed ^ 4) + -0.0000396669 * (Speed ^ 3) +
0.00243948 * (Speed ^ 2) + -0.0613975 * (Speed ^ 1) + 0.425792972
FB = 0.000000249809 * (Speed ^ 4) + -0.0000456653 * (Speed ^ 3) +
0.002833832 * (Speed ^ 2) + -0.072547062 * (Speed ^ 1) + 0.508636352
FC = 0.000000243031 * (Speed ^ 4) + -0.0000445304 * (Speed ^ 3) +
0.002794931 * (Speed ^ 2) + -0.073642939 * (Speed ^ 1) + 0.524157729
```

```
FD = 0.000000133569 * (Speed ^ 4) + -0.0000174108 * (Speed ^ 3) +
0.000763768 * (Speed ^ 2) + -0.028694111 * (Speed ^ 1) + 0.202867669
FE = -0.0000000518678 * (Speed ^ 4) + 0.00000743801 * (Speed ^ 3) + -
0.000182235 * (Speed ^ 2) + 0.005900349 * (Speed ^ 1) + -0.031354167
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
dpQmin_Booster_w_7 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD
* GVF + EE) * MaxdP
If dpQmin_Booster_w_7 > 120 Then
dpQmin_Booster_w_7 = 120
End If
End Function

Function Qmax_Booster_w_7(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = -0.63791577
b = -4.10269145
c = 1.63277177
d = 0.31454308
e = 0.64326631
FA = 0.0000018588 * (Speed ^ 4) + -0.000454158 * (Speed ^ 3) +
0.033183204 * (Speed ^ 2) + -0.630154129 * (Speed ^ 1) + 0.568320248
FB = -0.000000338785 * (Speed ^ 4) + 0.0000852193 * (Speed ^ 3) + -
0.006476074 * (Speed ^ 2) + 0.143785833 * (Speed ^ 1) + 0.017644022
FC = -0.00000031456 * (Speed ^ 4) + 0.0000808949 * (Speed ^ 3) + -
0.006427317 * (Speed ^ 2) + 0.156831636 * (Speed ^ 1) + 0.125146307
FD = 0.000000201031 * (Speed ^ 4) + -0.0000497011 * (Speed ^ 3) +
0.004091362 * (Speed ^ 2) + -0.102130089 * (Speed ^ 1) + -0.085635654
FE = -0.00000000155561 * (Speed ^ 4) + 0.000000270376 * (Speed ^ 3) +
-0.0000143964 * (Speed ^ 2) + 0.010341686 * (Speed ^ 1) + -0.005032401
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmax_Booster_w_7 = ((AA * GVF ^ 4) + (BB * GVF ^ 3) + (CC * GVF ^ 2)
+ (DD * GVF) + EE) * Qmax
End Function

Function Qmin_Booster_o_7(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = -0.63296699
b = 0.68722242
c = -0.36531103
d = 0.24160927
e = 0.33333333
FA = 0.000000391859 * (Speed ^ 4) + -0.0000688662 * (Speed ^ 3) +
0.004078283 * (Speed ^ 2) + -0.117867198 * (Speed ^ 1) + 1.398423574
FB = 0.000000865178 * (Speed ^ 4) + -0.000157171 * (Speed ^ 3) +
0.009376481 * (Speed ^ 2) + -0.254353973 * (Speed ^ 1) + 2.797795062
FC = 0.0000011774 * (Speed ^ 4) + -0.000220102 * (Speed ^ 3) +
0.013276048 * (Speed ^ 2) + -0.33530954 * (Speed ^ 1) + 3.493080347
```

```
FD = 0.000000314436 * (Speed ^ 4) + -0.0000622828 * (Speed ^ 3) +
0.004021001 * (Speed ^ 2) + -0.094556925 * (Speed ^ 1) + 0.891170021
FE = 0.0000000391061 * (Speed ^ 4) + -0.00000694198 * (Speed ^ 3) +
0.000409514 * (Speed ^ 2) + -0.001328831 * (Speed ^ 1) + 0.064615885
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmin_Booster_o_7 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD *
GVF + EE) * Qmax
End Function

Function dpQmin_Booster_o_7(Speed, GVF) 'Speed is in [%]
MaxdP = 120
a = -2.376953125
b = -0.27612847222
c = 0.826015625
d = -0.13430902778
e = 0.99966666667
FA = -0.000000653431 * (Speed ^ 4) + 0.000136224 * (Speed ^ 3) + -
0.008686365 * (Speed ^ 2) + 0.185018074 * (Speed ^ 1) + -1.295432758
FB = 0.0000103424 * (Speed ^ 4) + -0.002136455 * (Speed ^ 3) +
0.13801165 * (Speed ^ 2) + -3.017205566 * (Speed ^ 1) + 21.1428403
FC = 0.00000192363 * (Speed ^ 4) + -0.000396315 * (Speed ^ 3) +
0.025818649 * (Speed ^ 2) + -0.580692549 * (Speed ^ 1) + 4.091728669
FD = 0.00000121777 * (Speed ^ 4) + -0.000276009 * (Speed ^ 3) +
0.019411238 * (Speed ^ 2) + -0.427815517 * (Speed ^ 1) + 3.136691787
FE = -0.0000000592954 * (Speed ^ 4) + 0.000010794 * (Speed ^ 3) + -
0.00052486 * (Speed ^ 2) + 0.014934433 * (Speed ^ 1) + -0.100530038
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
dpQmin_Booster_o_7 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD
* GVF + EE) * MaxdP
If dpQmin_Booster_o_7 > 120 Then
dpQmin_Booster_o_7 = 120
End If
End Function

Function Qmax_Booster_o_7(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = -0.63791577
b = -4.10269145
c = 1.63277177
d = 0.31454308
e = 0.64326631
FA = 0.0000018588 * (Speed ^ 4) + -0.000454158 * (Speed ^ 3) +
0.033183204 * (Speed ^ 2) + -0.630154129 * (Speed ^ 1) + 0.568320248
FB = -0.000000338785 * (Speed ^ 4) + 0.0000852193 * (Speed ^ 3) + -
0.006476074 * (Speed ^ 2) + 0.143785833 * (Speed ^ 1) + 0.017644022
FC = -0.00000031456 * (Speed ^ 4) + 0.0000808949 * (Speed ^ 3) + -
0.006427317 * (Speed ^ 2) + 0.156831636 * (Speed ^ 1) + 0.125146307
```

```
FD = 0.000000201031 * (Speed ^ 4) + -0.0000497011 * (Speed ^ 3) +
0.004091362 * (Speed ^ 2) + -0.102130089 * (Speed ^ 1) + -0.085635654
FE = -0.00000000155561 * (Speed ^ 4) + 0.000000270376 * (Speed ^ 3) +
-0.0000143964 * (Speed ^ 2) + 0.010341686 * (Speed ^ 1) + -0.005032401
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmax_Booster_o_7 = ((AA * GVF ^ 4) + (BB * GVF ^ 3) + (CC * GVF ^ 2)
+ (DD * GVF) + EE) * Qmax
End Function
```

Framo 310/700/45

```
Function Qmin_Booster_w_8(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = -0.36168981
b = 3.83391204
c = -4.28240741
d = 1.10532407
e = 0.56944444
FA = -0.000000794908 * (Speed ^ 4) + 0.000258416 * (Speed ^ 3) + -
0.024543224 * (Speed ^ 2) + 0.749735182 * (Speed ^ 1) + -6.889322917
FB = 0.000000279074 * (Speed ^ 4) + -0.0000389619 * (Speed ^ 3) +
0.001311582 * (Speed ^ 2) + -0.009135618 * (Speed ^ 1) + -0.151778695
FC = 0.000000286435 * (Speed ^ 4) + -0.000049154 * (Speed ^ 3) +
0.002661282 * (Speed ^ 2) + -0.054738771 * (Speed ^ 1) + 0.323316969
FD = 0.000000167269 * (Speed ^ 4) + -0.0000282536 * (Speed ^ 3) +
0.001534025 * (Speed ^ 2) + -0.030651116 * (Speed ^ 1) + 0.203281795
FE = -0.0000000208926 * (Speed ^ 4) + 0.00000332206 * (Speed ^ 3) + -
0.0000616968 * (Speed ^ 2) + 0.00363544 * (Speed ^ 1) + 0.01902312
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmin_Booster_w_8 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD *
GVF + EE) * Qmax
End Function

Function dpQmin_Booster_w_8(Speed, GVF) 'Speed is in [%]
MaxdP = 120
a = -3.52061631944
b = 5.63932291667
c = -2.68552951389
d = 0.34169791667
e = 0.37445
FA = -0.0000000633988 * (Speed ^ 4) + -0.00000194822 * (Speed ^ 3) +
0.001590401 * (Speed ^ 2) + -0.07475741 * (Speed ^ 1) + 0.635401899
FB = -0.0000000383134 * (Speed ^ 4) + -0.00000190082 * (Speed ^ 3) +
0.001188373 * (Speed ^ 2) + -0.058326233 * (Speed ^ 1) + 0.492261859
FC = 0.0000000430891 * (Speed ^ 4) + -0.0000154971 * (Speed ^ 3) +
0.00181895 * (Speed ^ 2) + -0.066721308 * (Speed ^ 1) + 0.516709199
```

```
FD = 0.0000000973326 * (Speed ^ 4) + -0.0000322084 * (Speed ^ 3) +
0.003597326 * (Speed ^ 2) + -0.137266821 * (Speed ^ 1) + 1.052426184
FE = 0.000000151947 * (Speed ^ 4) + -0.0000340136 * (Speed ^ 3) +
0.002323732 * (Speed ^ 2) + -0.035992438 * (Speed ^ 1) + 0.199218112
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
dpQmin_Booster_w_8 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD
* GVF + EE) * MaxdP
If dpQmin_Booster_w_8 > 45 Then
dpQmin_Booster_w_8 = 45
End If
End Function

Function Qmax_Booster_w_8(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 20.17729387
b = -25.11179415
c = 8.19379882
d = -0.19915399
e = 0.64918003
FA = -0.000000108658 * (Speed ^ 4) + 0.0000260053 * (Speed ^ 3) + -
0.001967841 * (Speed ^ 2) + 0.058438452 * (Speed ^ 1) + -0.299968131
FB = -0.0000000902335 * (Speed ^ 4) + 0.0000223227 * (Speed ^ 3) + -
0.001727528 * (Speed ^ 2) + 0.05203324 * (Speed ^ 1) + -0.219424059
FC = -0.0000000927917 * (Speed ^ 4) + 0.0000236721 * (Speed ^ 3) + -
0.001891923 * (Speed ^ 2) + 0.057271137 * (Speed ^ 1) + -0.187230845
FD = -0.000000468761 * (Speed ^ 4) + 0.000116171 * (Speed ^ 3) + -
0.009585391 * (Speed ^ 2) + 0.283782534 * (Speed ^ 1) + -0.712233879
FE = -0.00000000223667 * (Speed ^ 4) + 0.000000430896 * (Speed ^ 3) +
-0.0000297856 * (Speed ^ 2) + 0.010952044 * (Speed ^ 1) + -0.003322051
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmax_Booster_w_8 = ((AA * GVF ^ 4) + (BB * GVF ^ 3) + (CC * GVF ^ 2)
+ (DD * GVF) + EE) * Qmax
End Function

Function Qmin_Booster_o_8(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = -0.36168981
b = 3.83391204
c = -4.28240741
d = 1.10532407
e = 0.56944444
FA = -0.000000794908 * (Speed ^ 4) + 0.000258416 * (Speed ^ 3) + -
0.024543224 * (Speed ^ 2) + 0.749735182 * (Speed ^ 1) + -6.889322917
FB = 0.000000279074 * (Speed ^ 4) + -0.0000389619 * (Speed ^ 3) +
0.001311582 * (Speed ^ 2) + -0.009135618 * (Speed ^ 1) + -0.151778695
FC = 0.000000286435 * (Speed ^ 4) + -0.000049154 * (Speed ^ 3) +
0.002661282 * (Speed ^ 2) + -0.054738771 * (Speed ^ 1) + 0.323316969
```

```
FD = 0.000000167269 * (Speed ^ 4) + -0.0000282536 * (Speed ^ 3) +
0.001534025 * (Speed ^ 2) + -0.030651116 * (Speed ^ 1) + 0.203281795
FE = -0.0000000208926 * (Speed ^ 4) + 0.00000332206 * (Speed ^ 3) + -
0.0000616968 * (Speed ^ 2) + 0.00363544 * (Speed ^ 1) + 0.01902312
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmin_Booster_o_8 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD *
GVF + EE) * Qmax
End Function

Function dpQmin_Booster_o_8(Speed, GVF) 'Speed is in [%]
MaxdP = 120
a = -3.52061631944
b = 5.63932291667
c = -2.68552951389
d = 0.34169791667
e = 0.37445
FA = -0.0000000633988 * (Speed ^ 4) + -0.00000194822 * (Speed ^ 3) +
0.001590401 * (Speed ^ 2) + -0.07475741 * (Speed ^ 1) + 0.635401899
FB = -0.0000000383134 * (Speed ^ 4) + -0.00000190082 * (Speed ^ 3) +
0.001188373 * (Speed ^ 2) + -0.058326233 * (Speed ^ 1) + 0.492261859
FC = 0.0000000430891 * (Speed ^ 4) + -0.0000154971 * (Speed ^ 3) +
0.00181895 * (Speed ^ 2) + -0.066721308 * (Speed ^ 1) + 0.516709199
FD = 0.0000000973326 * (Speed ^ 4) + -0.0000322084 * (Speed ^ 3) +
0.003597326 * (Speed ^ 2) + -0.137266821 * (Speed ^ 1) + 1.052426184
FE = 0.000000151947 * (Speed ^ 4) + -0.0000340136 * (Speed ^ 3) +
0.002323732 * (Speed ^ 2) + -0.035992438 * (Speed ^ 1) + 0.199218112
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
dpQmin_Booster_o_8 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD
* GVF + EE) * MaxdP
If dpQmin_Booster_o_8 > 45 Then
dpQmin_Booster_o_8 = 45
End If
End Function

Function Qmax_Booster_o_8(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 20.17729387
b = -25.11179415
c = 8.19379882
d = -0.19915399
e = 0.64918003
FA = -0.000000108658 * (Speed ^ 4) + 0.0000260053 * (Speed ^ 3) + -
0.001967841 * (Speed ^ 2) + 0.058438452 * (Speed ^ 1) + -0.299968131
FB = -0.0000000902335 * (Speed ^ 4) + 0.0000223227 * (Speed ^ 3) + -
0.001727528 * (Speed ^ 2) + 0.05203324 * (Speed ^ 1) + -0.219424059
FC = -0.0000000927917 * (Speed ^ 4) + 0.0000236721 * (Speed ^ 3) + -
0.001891923 * (Speed ^ 2) + 0.057271137 * (Speed ^ 1) + -0.187230845
```

```
FD = -0.000000468761 * (Speed ^ 4) + 0.000116171 * (Speed ^ 3) + -
0.009585391 * (Speed ^ 2) + 0.283782534 * (Speed ^ 1) + -0.712233879
FE = -0.0000000223667 * (Speed ^ 4) + 0.000000430896 * (Speed ^ 3) +
-0.0000297856 * (Speed ^ 2) + 0.010952044 * (Speed ^ 1) + -0.003322051
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmax_Booster_o_8 = ((AA * GVF ^ 4) + (BB * GVF ^ 3) + (CC * GVF ^ 2)
+ (DD * GVF) + EE) * Qmax
End Function
```

Framo 310/800/120

```
Function Qmin_Booster_w_9(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 1.98929398
b = -1.80844907
c = -0.81741898
d = 1.00115741
e = 0.43055556
FA = 0.000000410885 * (Speed ^ 4) + -0.00008393 * (Speed ^ 3) +
0.005831328 * (Speed ^ 2) + -0.157622416 * (Speed ^ 1) + 1.084161932
FB = 0.000000408517 * (Speed ^ 4) + -0.0000883189 * (Speed ^ 3) +
0.006544938 * (Speed ^ 2) + -0.184542213 * (Speed ^ 1) + 1.184635417
FC = 0.000000224251 * (Speed ^ 4) + -0.0000319608 * (Speed ^ 3) +
0.000946924 * (Speed ^ 2) + 0.009943281 * (Speed ^ 1) + 0.201500277
FD = 0.000000207879 * (Speed ^ 4) + -0.0000395838 * (Speed ^ 3) +
0.002475785 * (Speed ^ 2) + -0.054355921 * (Speed ^ 1) + 0.426183917
FE = -0.0000000163164 * (Speed ^ 4) + 0.00000414475 * (Speed ^ 3) + -
0.000319965 * (Speed ^ 2) + 0.017726779 * (Speed ^ 1) + -0.067876344
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmin_Booster_w_9 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD *
GVF + EE) * Qmax
End Function

Function dpQmin_Booster_w_9(Speed, GVF) 'Speed is in [%]
MaxdP = 120
a = -12.50824652778
b = 13.3328125
c = -4.26821180556
d = 0.3708125
e = 0.99958333333
FA = 0.00000024809 * (Speed ^ 4) + -0.0000458999 * (Speed ^ 3) +
0.002896606 * (Speed ^ 2) + -0.074739717 * (Speed ^ 1) + 0.518302306
FB = 0.000000312922 * (Speed ^ 4) + -0.0000577382 * (Speed ^ 3) +
0.003608181 * (Speed ^ 2) + -0.093874066 * (Speed ^ 1) + 0.649383928
FC = 0.000000324643 * (Speed ^ 4) + -0.0000581938 * (Speed ^ 3) +
0.003539513 * (Speed ^ 2) + -0.094009327 * (Speed ^ 1) + 0.639617187
```

```
FD = 0.000000284265 * (Speed ^ 4) + -0.0000337506 * (Speed ^ 3) +
0.00098602 * (Speed ^ 2) + -0.035789664 * (Speed ^ 1) + 0.143469905
FE = -0.0000000618585 * (Speed ^ 4) + 0.0000101393 * (Speed ^ 3) + -
0.000403453 * (Speed ^ 2) + 0.011462761 * (Speed ^ 1) + -0.071080311
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
dpQmin_Booster_w_9 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD
* GVF + EE) * MaxdP
If dpQmin_Booster_w_9 > 120 Then
dpQmin_Booster_w_9 = 120
End If
End Function

Function Qmax_Booster_w_9(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 24.60720734
b = -29.82882238
c = 9.53677175
d = -0.28749559
e = 0.83529947
FA = -0.0000000521082 * (Speed ^ 4) + 0.0000127378 * (Speed ^ 3) + -
0.000894177 * (Speed ^ 2) + 0.025395918 * (Speed ^ 1) + -0.115027075
FB = -0.0000000407208 * (Speed ^ 4) + 0.0000110362 * (Speed ^ 3) + -
0.000827157 * (Speed ^ 2) + 0.023536296 * (Speed ^ 1) + -0.035291943
FC = -0.0000000360493 * (Speed ^ 4) + 0.0000113944 * (Speed ^ 3) + -
0.000955044 * (Speed ^ 2) + 0.02737304 * (Speed ^ 1) + 0.037428373
FD = -0.000000119232 * (Speed ^ 4) + 0.0000414416 * (Speed ^ 3) + -
0.00405333 * (Speed ^ 2) + 0.118064675 * (Speed ^ 1) + 0.26575147
FE = 0.000000000479759 * (Speed ^ 4) + -0.0000000165597 * (Speed ^ 3)
+ -0.00000715313 * (Speed ^ 2) + 0.010426542 * (Speed ^ 1) + -
0.002246254
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmax_Booster_w_9 = ((AA * GVF ^ 4) + (BB * GVF ^ 3) + (CC * GVF ^ 2)
+ (DD * GVF) + EE) * Qmax
End Function

Function Qmin_Booster_o_9(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = -0.36168981
b = -0.36168981
c = 0.66550926
d = 0.05787037
e = 0.45138889
FA = 0.00000073535 * (Speed ^ 4) + -0.000167061 * (Speed ^ 3) +
0.012555624 * (Speed ^ 2) + -0.349906633 * (Speed ^ 1) + 3.790343862
FB = -0.00000106192 * (Speed ^ 4) + 0.000241307 * (Speed ^ 3) + -
0.017943368 * (Speed ^ 2) + 0.513220001 * (Speed ^ 1) + -5.781103817
FC = -0.000000224311 * (Speed ^ 4) + 0.0000543041 * (Speed ^ 3) + -
0.004085416 * (Speed ^ 2) + 0.11389169 * (Speed ^ 1) + -1.394954278
```

```
FD = -0.000000489055 * (Speed ^ 4) + 0.0000632368 * (Speed ^ 3) + -
0.001849128 * (Speed ^ 2) + 0.050670933 * (Speed ^ 1) + 0.35410793
FE = 0.000000094022 * (Speed ^ 4) + -0.0000198587 * (Speed ^ 3) +
0.001401116 * (Speed ^ 2) + -0.02767722 * (Speed ^ 1) + 0.215610956
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmin_Booster_o_9 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD *
GVF + EE) * Qmax
End Function

Function dpQmin_Booster_o_9(Speed, GVF) 'Speed is in [%]
MaxdP = 120
a = -0.75499131944
b = -1.58567708333
c = 0.55655381944
d = -0.03976041667
e = 0.9995
FA = -0.000000297434 * (Speed ^ 4) + 0.0000824478 * (Speed ^ 3) + -
0.00573444 * (Speed ^ 2) + 0.063089412 * (Speed ^ 1) + -0.503688799
FB = 0.000000111007 * (Speed ^ 4) + -0.0000377705 * (Speed ^ 3) +
0.002910397 * (Speed ^ 2) + -0.016995868 * (Speed ^ 1) + 0.169960402
FC = -0.000000334012 * (Speed ^ 4) + 0.0000448149 * (Speed ^ 3) + -
0.002124345 * (Speed ^ 2) + 0.115306752 * (Speed ^ 1) + -0.709300996
FD = -0.00000535086 * (Speed ^ 4) + 0.000977714 * (Speed ^ 3) + -
0.058975878 * (Speed ^ 2) + 1.598614499 * (Speed ^ 1) + -10.65242482
FE = -0.0000000532789 * (Speed ^ 4) + 0.0000102143 * (Speed ^ 3) + -
0.000532895 * (Speed ^ 2) + 0.015580406 * (Speed ^ 1) + -0.10450503
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
dpQmin_Booster_o_9 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD
* GVF + EE) * MaxdP
If dpQmin_Booster_o_9 > 120 Then
dpQmin_Booster_o_9 = 120
End If
End Function

Function Qmax_Booster_o_9(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 23.06636575
b = -27.99519221
c = 8.90769892
d = -0.23598061
e = 0.83057934
FA = -0.0000000270118 * (Speed ^ 4) + 0.0000078925 * (Speed ^ 3) + -
0.000644489 * (Speed ^ 2) + 0.023317845 * (Speed ^ 1) + -0.094606882
FB = -0.0000000100548 * (Speed ^ 4) + 0.0000049003 * (Speed ^ 3) + -
0.000478094 * (Speed ^ 2) + 0.018589849 * (Speed ^ 1) + 0.009872245
FC = 0.00000000790364 * (Speed ^ 4) + 0.00000238885 * (Speed ^ 3) + -
0.000410415 * (Speed ^ 2) + 0.017777747 * (Speed ^ 1) + 0.124027609
```

```
FD = 0.000000129008 * (Speed ^ 4) + -0.00000907178 * (Speed ^ 3) + -
0.000956606 * (Speed ^ 2) + 0.05659713 * (Speed ^ 1) + 0.951431421
FE = 0.00000000316327 * (Speed ^ 4) + -0.000000652221 * (Speed ^ 3) +
0.0000419566 * (Speed ^ 2) + 0.009076086 * (Speed ^ 1) + 0.007642563
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmax_Booster_o_9 = ((AA * GVF ^ 4) + (BB * GVF ^ 3) + (CC * GVF ^ 2)
+ (DD * GVF) + EE) * Qmax
End Function
```

Framo 310/900/45

```
Function Qmin_Booster_w_10(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = -21.61096644
b = 33.02228009
c = -16.10604745
d = 2.80237269
e = 0.69444444
FA = 0.000000450237 * (Speed ^ 4) + -0.0000866093 * (Speed ^ 3) +
0.005413183 * (Speed ^ 2) + -0.125162372 * (Speed ^ 1) + 0.883651499
FB = 0.000000447021 * (Speed ^ 4) + -0.0000858177 * (Speed ^ 3) +
0.005357075 * (Speed ^ 2) + -0.124250744 * (Speed ^ 1) + 0.884663655
FC = 0.000000412173 * (Speed ^ 4) + -0.0000786875 * (Speed ^ 3) +
0.004889778 * (Speed ^ 2) + -0.113291172 * (Speed ^ 1) + 0.821067492
FD = 0.000000310173 * (Speed ^ 4) + -0.0000579914 * (Speed ^ 3) +
0.003530037 * (Speed ^ 2) + -0.079852255 * (Speed ^ 1) + 0.591139111
FE = -0.0000000275919 * (Speed ^ 4) + 0.00000449408 * (Speed ^ 3) + -
0.000134671 * (Speed ^ 2) + 0.006073305 * (Speed ^ 1) + 0.006054688
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmin_Booster_w_10 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD
* GVF + EE) * Qmax
End Function

Function dpQmin_Booster_w_10(Speed, GVF) 'Speed is in [%]
MaxdP = 120
a = 2.81336805556
b = -4.68940972222
c = 2.37027777778
d = -0.37790277778
e = 0.37475
FA = 0.000000674966 * (Speed ^ 4) + -0.0000926458 * (Speed ^ 3) +
0.002003989 * (Speed ^ 2) + 0.070830269 * (Speed ^ 1) + -0.795219454
FB = 0.000000601998 * (Speed ^ 4) + -0.0000859388 * (Speed ^ 3) +
0.002236796 * (Speed ^ 2) + 0.051052065 * (Speed ^ 1) + -0.60189537
FC = 0.00000044619 * (Speed ^ 4) + -0.0000593588 * (Speed ^ 3) +
0.000976387 * (Speed ^ 2) + 0.066959068 * (Speed ^ 1) + -0.642245455
```

```
FD = 0.000000195459 * (Speed ^ 4) + -0.0000047835 * (Speed ^ 3) + -
0.003018566 * (Speed ^ 2) + 0.178669249 * (Speed ^ 1) + -1.397777466
FE = 0.000000132308 * (Speed ^ 4) + -0.0000285279 * (Speed ^ 3) +
0.001804834 * (Speed ^ 2) + -0.017928564 * (Speed ^ 1) + 0.062845601
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
dpQmin_Booster_w_10 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 +
DD * GVF + EE) * MaxdP
If dpQmin_Booster_w_10 > 45 Then
dpQmin_Booster_w_10 = 45
End If
End Function

Function Qmax_Booster_w_10(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 32.38809992
b = -40.38883583
c = 13.670652
d = -0.61085778
e = 0.84029086
FA = 0.0000000239859 * (Speed ^ 4) + -0.0000039629 * (Speed ^ 3) +
0.000279193 * (Speed ^ 2) + -0.002876917 * (Speed ^ 1) + 0.067668487
FB = 0.0000000326927 * (Speed ^ 4) + -0.00000520488 * (Speed ^ 3) +
0.000318463 * (Speed ^ 2) + -0.003339615 * (Speed ^ 1) + 0.090329741
FC = 0.0000000459699 * (Speed ^ 4) + -0.00000716083 * (Speed ^ 3) +
0.000386412 * (Speed ^ 2) + -0.004271873 * (Speed ^ 1) + 0.130173654
FD = 0.000000132389 * (Speed ^ 4) + -0.0000209171 * (Speed ^ 3) +
0.000922521 * (Speed ^ 2) + -0.009741986 * (Speed ^ 1) + 0.428626004
FE = 0.0000000013677 * (Speed ^ 4) + -0.000000289105 * (Speed ^ 3) +
0.0000183823 * (Speed ^ 2) + 0.009633711 * (Speed ^ 1) + 0.005369749
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmax_Booster_w_10 = ((AA * GVF ^ 4) + (BB * GVF ^ 3) + (CC * GVF ^ 2)
+ (DD * GVF) + EE) * Qmax
End Function

Function Qmin_Booster_o_10(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 13.4729456
b = -23.98003472
c = 12.35170718
d = -1.41059028
e = 0.65972222
FA = 0.000000333566 * (Speed ^ 4) + -0.0000648842 * (Speed ^ 3) +
0.004213246 * (Speed ^ 2) + -0.104804193 * (Speed ^ 1) + 0.703614374
FB = 0.000000308667 * (Speed ^ 4) + -0.0000594328 * (Speed ^ 3) +
0.003812736 * (Speed ^ 2) + -0.093325937 * (Speed ^ 1) + 0.618464052
FC = 0.000000305014 * (Speed ^ 4) + -0.0000580526 * (Speed ^ 3) +
0.00367001 * (Speed ^ 2) + -0.088647495 * (Speed ^ 1) + 0.573564849
```

```
FD = 0.000000362272 * (Speed ^ 4) + -0.0000675042 * (Speed ^ 3) +
0.004155923 * (Speed ^ 2) + -0.100969975 * (Speed ^ 1) + 0.638995726
FE = -0.0000000799054 * (Speed ^ 4) + 0.0000165023 * (Speed ^ 3) + -
0.001028423 * (Speed ^ 2) + 0.02926329 * (Speed ^ 1) + -0.155084978
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmin_Booster_o_10 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD
* GVF + EE) * Qmax
End Function

Function dpQmin_Booster_o_10(Speed, GVF) 'Speed is in [%]
MaxdP = 120
a = -3.02170138889
b = 3.62847222222
c = -1.32986111111
d = 0.14325694444
e = 0.37474166667
FA = -0.000000938091 * (Speed ^ 4) + 0.000175543 * (Speed ^ 3) + -
0.009585425 * (Speed ^ 2) + 0.157103798 * (Speed ^ 1) + -0.879760964
FB = -0.00000110919 * (Speed ^ 4) + 0.00021133 * (Speed ^ 3) + -
0.011834666 * (Speed ^ 2) + 0.197300049 * (Speed ^ 1) + -1.135706738
FC = -0.00000117037 * (Speed ^ 4) + 0.000222962 * (Speed ^ 3) + -
0.012356197 * (Speed ^ 2) + 0.193252607 * (Speed ^ 1) + -1.092752665
FD = -0.00000135192 * (Speed ^ 4) + 0.000243232 * (Speed ^ 3) + -
0.011475426 * (Speed ^ 2) + 0.070937285 * (Speed ^ 1) + -0.024145822
FE = 0.000000155167 * (Speed ^ 4) + -0.000035268 * (Speed ^ 3) +
0.002473442 * (Speed ^ 2) + -0.042185519 * (Speed ^ 1) + 0.250985864
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
dpQmin_Booster_o_10 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 +
DD * GVF + EE) * MaxdP
If dpQmin_Booster_o_10 > 45 Then
dpQmin_Booster_o_10 = 45
End If
End Function

Function Qmax_Booster_o_10(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 31.88713239
b = -39.49649135
c = 13.21316383
d = -0.53773523
e = 0.83125752
FA = -0.0000000228599 * (Speed ^ 4) + 0.00000514961 * (Speed ^ 3) + -
0.000288139 * (Speed ^ 2) + 0.010365427 * (Speed ^ 1) + -0.016429144
FB = -0.0000000103467 * (Speed ^ 4) + 0.00000308604 * (Speed ^ 3) + -
0.000192239 * (Speed ^ 2) + 0.008563671 * (Speed ^ 1) + 0.01515159
FC = 0.00000000157659 * (Speed ^ 4) + 0.0000012889 * (Speed ^ 3) + -
0.000127219 * (Speed ^ 2) + 0.007682231 * (Speed ^ 1) + 0.055913533
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FD = 0.0000000170086 * (Speed ^ 4) + 0.00000130081 * (Speed ^ 3) + -
0.00046561 * (Speed ^ 2) + 0.023950923 * (Speed ^ 1) + 0.253199933
FE = -0.000000000592392 * (Speed ^ 4) + 0.000000103131 * (Speed ^ 3)
+ -0.00000804427 * (Speed ^ 2) + 0.010352384 * (Speed ^ 1) +
0.001408696
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmax_Booster_o_10 = ((AA * GVF ^ 4) + (BB * GVF ^ 3) + (CC * GVF ^ 2)
+ (DD * GVF) + EE) * Qmax
End Function
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Framo 360/1200/38

```
Function Qmin_Booster_w_10(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = -21.61096644
b = 33.02228009
c = -16.10604745
d = 2.80237269
e = 0.69444444
FA = 0.000000450237 * (Speed ^ 4) + -0.0000866093 * (Speed ^ 3) +
0.005413183 * (Speed ^ 2) + -0.125162372 * (Speed ^ 1) + 0.883651499
FB = 0.000000447021 * (Speed ^ 4) + -0.0000858177 * (Speed ^ 3) +
0.005357075 * (Speed ^ 2) + -0.124250744 * (Speed ^ 1) + 0.884663655
FC = 0.000000412173 * (Speed ^ 4) + -0.0000786875 * (Speed ^ 3) +
0.004889778 * (Speed ^ 2) + -0.113291172 * (Speed ^ 1) + 0.821067492
FD = 0.000000310173 * (Speed ^ 4) + -0.0000579914 * (Speed ^ 3) +
0.003530037 * (Speed ^ 2) + -0.079852255 * (Speed ^ 1) + 0.591139111
FE = -0.0000000275919 * (Speed ^ 4) + 0.00000449408 * (Speed ^ 3) + -
0.000134671 * (Speed ^ 2) + 0.006073305 * (Speed ^ 1) + 0.006054688
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmin_Booster_w_10 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD
* GVF + EE) * Qmax
End Function

Function dpQmin_Booster_w_10(Speed, GVF) 'Speed is in [%]
MaxdP = 120
a = 2.81336805556
b = -4.68940972222
c = 2.37027777778
d = -0.37790277778
e = 0.37475
FA = 0.000000674966 * (Speed ^ 4) + -0.0000926458 * (Speed ^ 3) +
0.002003989 * (Speed ^ 2) + 0.070830269 * (Speed ^ 1) + -0.795219454
FB = 0.000000601998 * (Speed ^ 4) + -0.0000859388 * (Speed ^ 3) +
0.002236796 * (Speed ^ 2) + 0.051052065 * (Speed ^ 1) + -0.60189537
```

```
FC = 0.00000044619 * (Speed ^ 4) + -0.0000593588 * (Speed ^ 3) +
0.000976387 * (Speed ^ 2) + 0.066959068 * (Speed ^ 1) + -0.642245455
FD = 0.000000195459 * (Speed ^ 4) + -0.0000047835 * (Speed ^ 3) + -
0.003018566 * (Speed ^ 2) + 0.178669249 * (Speed ^ 1) + -1.397777466
FE = 0.000000132308 * (Speed ^ 4) + -0.0000285279 * (Speed ^ 3) +
0.001804834 * (Speed ^ 2) + -0.017928564 * (Speed ^ 1) + 0.062845601
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
dpQmin_Booster_w_10 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 +
DD * GVF + EE) * MaxdP
If dpQmin_Booster_w_10 > 45 Then
dpQmin_Booster_w_10 = 45
End If
End Function

Function Qmax_Booster_w_10(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 32.38809992
b = -40.38883583
c = 13.670652
d = -0.61085778
e = 0.84029086
FA = 0.0000000239859 * (Speed ^ 4) + -0.0000039629 * (Speed ^ 3) +
0.000279193 * (Speed ^ 2) + -0.002876917 * (Speed ^ 1) + 0.067668487
FB = 0.0000000326927 * (Speed ^ 4) + -0.00000520488 * (Speed ^ 3) +
0.000318463 * (Speed ^ 2) + -0.003339615 * (Speed ^ 1) + 0.090329741
FC = 0.0000000459699 * (Speed ^ 4) + -0.00000716083 * (Speed ^ 3) +
0.000386412 * (Speed ^ 2) + -0.004271873 * (Speed ^ 1) + 0.130173654
FD = 0.000000132389 * (Speed ^ 4) + -0.0000209171 * (Speed ^ 3) +
0.000922521 * (Speed ^ 2) + -0.009741986 * (Speed ^ 1) + 0.428626004
FE = 0.0000000013677 * (Speed ^ 4) + -0.000000289105 * (Speed ^ 3) +
0.0000183823 * (Speed ^ 2) + 0.009633711 * (Speed ^ 1) + 0.005369749
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmax_Booster_w_10 = ((AA * GVF ^ 4) + (BB * GVF ^ 3) + (CC * GVF ^ 2)
+ (DD * GVF) + EE) * Qmax
End Function

Function Qmin_Booster_o_10(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 13.4729456
b = -23.98003472
c = 12.35170718
d = -1.41059028
e = 0.65972222
FA = 0.000000333566 * (Speed ^ 4) + -0.0000648842 * (Speed ^ 3) +
0.004213246 * (Speed ^ 2) + -0.104804193 * (Speed ^ 1) + 0.703614374
FB = 0.000000308667 * (Speed ^ 4) + -0.0000594328 * (Speed ^ 3) +
0.003812736 * (Speed ^ 2) + -0.093325937 * (Speed ^ 1) + 0.618464052
```

```
FC = 0.000000305014 * (Speed ^ 4) + -0.0000580526 * (Speed ^ 3) +
0.00367001 * (Speed ^ 2) + -0.088647495 * (Speed ^ 1) + 0.573564849
FD = 0.000000362272 * (Speed ^ 4) + -0.0000675042 * (Speed ^ 3) +
0.004155923 * (Speed ^ 2) + -0.100969975 * (Speed ^ 1) + 0.638995726
FE = -0.0000000799054 * (Speed ^ 4) + 0.0000165023 * (Speed ^ 3) + -
0.001028423 * (Speed ^ 2) + 0.02926329 * (Speed ^ 1) + -0.155084978
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmin_Booster_o_10 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD
* GVF + EE) * Qmax
End Function

Function dpQmin_Booster_o_10(Speed, GVF) 'Speed is in [%]
MaxdP = 120
a = -3.02170138889
b = 3.62847222222
c = -1.32986111111
d = 0.14325694444
e = 0.37474166667
FA = -0.000000938091 * (Speed ^ 4) + 0.000175543 * (Speed ^ 3) + -
0.009585425 * (Speed ^ 2) + 0.157103798 * (Speed ^ 1) + -0.879760964
FB = -0.00000110919 * (Speed ^ 4) + 0.00021133 * (Speed ^ 3) + -
0.011834666 * (Speed ^ 2) + 0.197300049 * (Speed ^ 1) + -1.135706738
FC = -0.00000117037 * (Speed ^ 4) + 0.000222962 * (Speed ^ 3) + -
0.012356197 * (Speed ^ 2) + 0.193252607 * (Speed ^ 1) + -1.092752665
FD = -0.00000135192 * (Speed ^ 4) + 0.000243232 * (Speed ^ 3) + -
0.011475426 * (Speed ^ 2) + 0.070937285 * (Speed ^ 1) + -0.024145822
FE = 0.000000155167 * (Speed ^ 4) + -0.000035268 * (Speed ^ 3) +
0.002473442 * (Speed ^ 2) + -0.042185519 * (Speed ^ 1) + 0.250985864
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
dpQmin_Booster_o_10 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 +
DD * GVF + EE) * MaxdP
If dpQmin_Booster_o_10 > 45 Then
dpQmin_Booster_o_10 = 45
End If
End Function

Function Qmax_Booster_o_10(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 31.88713239
b = -39.49649135
c = 13.21316383
d = -0.53773523
e = 0.83125752
FA = -0.0000000228599 * (Speed ^ 4) + 0.00000514961 * (Speed ^ 3) + -
0.000288139 * (Speed ^ 2) + 0.010365427 * (Speed ^ 1) + -0.016429144
FB = -0.0000000103467 * (Speed ^ 4) + 0.00000308604 * (Speed ^ 3) + -
0.000192239 * (Speed ^ 2) + 0.008563671 * (Speed ^ 1) + 0.01515159
```

```
FC = 0.00000000157659 * (Speed ^ 4) + 0.0000012889 * (Speed ^ 3) + -
0.000127219 * (Speed ^ 2) + 0.007682231 * (Speed ^ 1) + 0.055913533
FD = 0.0000000170086 * (Speed ^ 4) + 0.00000130081 * (Speed ^ 3) + -
0.00046561 * (Speed ^ 2) + 0.023950923 * (Speed ^ 1) + 0.253199933
FE = -0.000000000592392 * (Speed ^ 4) + 0.000000103131 * (Speed ^ 3)
+ -0.00000804427 * (Speed ^ 2) + 0.010352384 * (Speed ^ 1) +
0.001408696
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmax_Booster_o_10 = ((AA * GVF ^ 4) + (BB * GVF ^ 3) + (CC * GVF ^ 2)
+ (DD * GVF) + EE) * Qmax
End Function
```

Framo 360/1500/38

```
Function Qmax_Booster_w_12(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 42.513312
b = -53.53784698
c = 17.92582885
d = -0.57206331
e = 1.27912691
FA = -0.0000000851085 * (Speed ^ 4) + 0.0000172289 * (Speed ^ 3) + -
0.001029225 * (Speed ^ 2) + 0.026493734 * (Speed ^ 1) + -0.073782158
FB = -0.0000000679912 * (Speed ^ 4) + 0.0000143404 * (Speed ^ 3) + -
0.000885954 * (Speed ^ 2) + 0.023524288 * (Speed ^ 1) + -0.036376963
FC = -0.0000000587737 * (Speed ^ 4) + 0.000013177 * (Speed ^ 3) + -
0.000863893 * (Speed ^ 2) + 0.023235981 * (Speed ^ 1) + 0.007200474
FD = -0.000000145078 * (Speed ^ 4) + 0.0000348963 * (Speed ^ 3) + -
0.002676585 * (Speed ^ 2) + 0.070340283 * (Speed ^ 1) + 0.267359618
FE = 0.00000000319504 * (Speed ^ 4) + -0.000000635467 * (Speed ^ 3) +
0.0000391113 * (Speed ^ 2) + 0.009112884 * (Speed ^ 1) + 0.010626754
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmax_Booster_w_12 = ((AA * GVF ^ 4) + (BB * GVF ^ 3) + (CC * GVF ^ 2)
+ (DD * GVF) + EE) * Qmax
End Function

Function Qmin_Booster_w_12(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 27.48842593
b = -55.84490741
c = 33.18865741
d = -5.24884259
e = 1.13194444
FA = 0.000000134935 * (Speed ^ 4) + -0.0000237869 * (Speed ^ 3) +
0.00148038 * (Speed ^ 2) + -0.037394368 * (Speed ^ 1) + 0.224369518
```

```
FB = 0.000000111021 * (Speed ^ 4) + -0.0000191824 * (Speed ^ 3) +
0.001179979 * (Speed ^ 2) + -0.028931541 * (Speed ^ 1) + 0.1700197
FC = 0.000000104371 * (Speed ^ 4) + -0.0000177372 * (Speed ^ 3) +
0.001070373 * (Speed ^ 2) + -0.025505374 * (Speed ^ 1) + 0.144716289
FD = 0.000000126303 * (Speed ^ 4) + -0.0000218468 * (Speed ^ 3) +
0.001317939 * (Speed ^ 2) + -0.031439856 * (Speed ^ 1) + 0.182466809
FE = -0.00000000726343 * (Speed ^ 4) + 0.0000000394664 * (Speed ^ 3)
+ 0.000182928 * (Speed ^ 2) + -0.002080624 * (Speed ^ 1) + 0.061884905
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmin_Booster_w_12 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD
* GVF + EE) * Qmax
End Function

Function dpQmin_Booster_w_12(Speed, GVF) 'Speed is in [%]
MaxdP = 120
a = -3.83940972222
b = 6.04739583333
c = -2.83809027778
d = 0.35402083333
e = 0.31633333333
FA = 0.000000626302 * (Speed ^ 4) + -0.000157169 * (Speed ^ 3) +
0.013224173 * (Speed ^ 2) + -0.399119492 * (Speed ^ 1) + 2.932964994
FB = 0.000000507906 * (Speed ^ 4) + -0.000128977 * (Speed ^ 3) +
0.011092453 * (Speed ^ 2) + -0.345464669 * (Speed ^ 1) + 2.552373228
FC = 0.000000456505 * (Speed ^ 4) + -0.00011555 * (Speed ^ 3) +
0.009980774 * (Speed ^ 2) + -0.314512924 * (Speed ^ 1) + 2.310770163
FD = 0.000000610371 * (Speed ^ 4) + -0.000156196 * (Speed ^ 3) +
0.01366281 * (Speed ^ 2) + -0.438773587 * (Speed ^ 1) + 3.179056245
FE = 0.0000000950613 * (Speed ^ 4) + -0.0000181225 * (Speed ^ 3) +
0.000817404 * (Speed ^ 2) + 0.016668344 * (Speed ^ 1) + -0.198515982
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
dpQmin_Booster_w_12 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 +
DD * GVF + EE) * MaxdP
If dpQmin_Booster_w_12 > 38 Then
dpQmin_Booster_w_12 = 38
End If
If dpQmin_Booster_w_12 < 0 Then
dpQmin_Booster_w_12 = 0
End If
End Function

Function Qmax_Booster_o_12(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 42.513312
b = -53.53784698
c = 17.92582885
d = -0.57206331
e = 1.27912691
```

```
FA = -0.0000000851085 * (Speed ^ 4) + 0.0000172289 * (Speed ^ 3) + -
0.001029225 * (Speed ^ 2) + 0.026493734 * (Speed ^ 1) + -0.073782158
FB = -0.0000000679912 * (Speed ^ 4) + 0.0000143404 * (Speed ^ 3) + -
0.000885954 * (Speed ^ 2) + 0.023524288 * (Speed ^ 1) + -0.036376963
FC = -0.0000000587737 * (Speed ^ 4) + 0.000013177 * (Speed ^ 3) + -
0.000863893 * (Speed ^ 2) + 0.023235981 * (Speed ^ 1) + 0.007200474
FD = -0.000000145078 * (Speed ^ 4) + 0.0000348963 * (Speed ^ 3) + -
0.002676585 * (Speed ^ 2) + 0.070340283 * (Speed ^ 1) + 0.267359618
FE = 0.00000000319504 * (Speed ^ 4) + -0.000000635467 * (Speed ^ 3) +
0.0000391113 * (Speed ^ 2) + 0.009112884 * (Speed ^ 1) + 0.010626754
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmax_Booster_o_12 = ((AA * GVF ^ 4) + (BB * GVF ^ 3) + (CC * GVF ^ 2)
+ (DD * GVF) + EE) * Qmax
End Function

Function Qmin_Booster_o_12(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 27.48842593
b = -55.84490741
c = 33.18865741
d = -5.24884259
e = 1.13194444
FA = 0.000000134935 * (Speed ^ 4) + -0.0000237869 * (Speed ^ 3) +
0.00148038 * (Speed ^ 2) + -0.037394368 * (Speed ^ 1) + 0.224369518
FB = 0.000000111021 * (Speed ^ 4) + -0.0000191824 * (Speed ^ 3) +
0.001179979 * (Speed ^ 2) + -0.028931541 * (Speed ^ 1) + 0.1700197
FC = 0.000000104371 * (Speed ^ 4) + -0.0000177372 * (Speed ^ 3) +
0.001070373 * (Speed ^ 2) + -0.025505374 * (Speed ^ 1) + 0.144716289
FD = 0.000000126303 * (Speed ^ 4) + -0.0000218468 * (Speed ^ 3) +
0.001317939 * (Speed ^ 2) + -0.031439856 * (Speed ^ 1) + 0.182466809
FE = -0.00000000726343 * (Speed ^ 4) + 0.0000000394664 * (Speed ^ 3)
+ 0.000182928 * (Speed ^ 2) + -0.002080624 * (Speed ^ 1) + 0.061884905
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmin_Booster_o_12 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD
* GVF + EE) * Qmax
End Function
Function dpQmin_Booster_o_12(Speed, GVF) 'Speed is in [%]
MaxdP = 120
a = -3.83940972222
b = 6.04739583333
c = -2.83809027778
d = 0.35402083333
e = 0.31633333333
FA = 0.000000626302 * (Speed ^ 4) + -0.000157169 * (Speed ^ 3) +
0.013224173 * (Speed ^ 2) + -0.399119492 * (Speed ^ 1) + 2.932964994
FB = 0.000000507906 * (Speed ^ 4) + -0.000128977 * (Speed ^ 3) +
0.011092453 * (Speed ^ 2) + -0.345464669 * (Speed ^ 1) + 2.552373228
```

```
FC = 0.000000456505 * (Speed ^ 4) + -0.00011555 * (Speed ^ 3) + 0.009980774 * (Speed ^ 2) + -0.314512924 * (Speed ^ 1) + 2.310770163
FD = 0.000000610371 * (Speed ^ 4) + -0.000156196 * (Speed ^ 3) + 0.01366281 * (Speed ^ 2) + -0.438773587 * (Speed ^ 1) + 3.179056245
FE = 0.0000000950613 * (Speed ^ 4) + -0.0000181225 * (Speed ^ 3) + 0.000817404 * (Speed ^ 2) + 0.016668344 * (Speed ^ 1) + -0.198515982
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
dpQmin_Booster_o_12 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD * GVF + EE) * MaxdP
If dpQmin_Booster_o_12 > 38 Then
dpQmin_Booster_o_12 = 38
End If
If dpQmin_Booster_o_12 < 0 Then
dpQmin_Booster_o_12 = 0
End If
End Function
```

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```
Function Qmax_Booster_w_12(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 42.513312
b = -53.53784698
c = 17.92582885
d = -0.57206331
e = 1.27912691
FA = -0.0000000851085 * (Speed ^ 4) + 0.0000172289 * (Speed ^ 3) + -0.001029225 * (Speed ^ 2) + 0.026493734 * (Speed ^ 1) + -0.073782158
FB = -0.0000000679912 * (Speed ^ 4) + 0.0000143404 * (Speed ^ 3) + -0.000885954 * (Speed ^ 2) + 0.023524288 * (Speed ^ 1) + -0.036376963
FC = -0.0000000587737 * (Speed ^ 4) + 0.000013177 * (Speed ^ 3) + -0.000863893 * (Speed ^ 2) + 0.023235981 * (Speed ^ 1) + 0.007200474
FD = -0.000000145078 * (Speed ^ 4) + 0.0000348963 * (Speed ^ 3) + -0.002676585 * (Speed ^ 2) + 0.070340283 * (Speed ^ 1) + 0.267359618
FE = 0.00000000319504 * (Speed ^ 4) + -0.000000635467 * (Speed ^ 3) + 0.0000391113 * (Speed ^ 2) + 0.009112884 * (Speed ^ 1) + 0.010626754
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmax_Booster_w_12 = ((AA * GVF ^ 4) + (BB * GVF ^ 3) + (CC * GVF ^ 2) + (DD * GVF) + EE) * Qmax
End Function

Function Qmin_Booster_w_12(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 27.48842593
b = -55.84490741
c = 33.18865741
d = -5.24884259
e = 1.13194444
```

```
FA = 0.000000134935 * (Speed ^ 4) + -0.0000237869 * (Speed ^ 3) +
0.00148038 * (Speed ^ 2) + -0.037394368 * (Speed ^ 1) + 0.224369518
FB = 0.000000111021 * (Speed ^ 4) + -0.0000191824 * (Speed ^ 3) +
0.001179979 * (Speed ^ 2) + -0.028931541 * (Speed ^ 1) + 0.1700197
FC = 0.000000104371 * (Speed ^ 4) + -0.0000177372 * (Speed ^ 3) +
0.001070373 * (Speed ^ 2) + -0.025505374 * (Speed ^ 1) + 0.144716289
FD = 0.000000126303 * (Speed ^ 4) + -0.0000218468 * (Speed ^ 3) +
0.001317939 * (Speed ^ 2) + -0.031439856 * (Speed ^ 1) + 0.182466809
FE = -0.00000000726343 * (Speed ^ 4) + 0.0000000394664 * (Speed ^ 3)
+ 0.000182928 * (Speed ^ 2) + -0.002080624 * (Speed ^ 1) + 0.061884905
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmin_Booster_w_12 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD
* GVF + EE) * Qmax
End Function

Function dpQmin_Booster_w_12(Speed, GVF) 'Speed is in [%]
MaxdP = 120
a = -3.83940972222
b = 6.04739583333
c = -2.83809027778
d = 0.35402083333
e = 0.31633333333
FA = 0.000000626302 * (Speed ^ 4) + -0.000157169 * (Speed ^ 3) +
0.013224173 * (Speed ^ 2) + -0.399119492 * (Speed ^ 1) + 2.932964994
FB = 0.000000507906 * (Speed ^ 4) + -0.000128977 * (Speed ^ 3) +
0.011092453 * (Speed ^ 2) + -0.345464669 * (Speed ^ 1) + 2.552373228
FC = 0.000000456505 * (Speed ^ 4) + -0.00011555 * (Speed ^ 3) +
0.009980774 * (Speed ^ 2) + -0.314512924 * (Speed ^ 1) + 2.310770163
FD = 0.000000610371 * (Speed ^ 4) + -0.000156196 * (Speed ^ 3) +
0.01366281 * (Speed ^ 2) + -0.438773587 * (Speed ^ 1) + 3.179056245
FE = 0.0000000950613 * (Speed ^ 4) + -0.0000181225 * (Speed ^ 3) +
0.000817404 * (Speed ^ 2) + 0.016668344 * (Speed ^ 1) + -0.198515982
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
dpQmin_Booster_w_12 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 +
DD * GVF + EE) * MaxdP
If dpQmin_Booster_w_12 > 38 Then
dpQmin_Booster_w_12 = 38
End If
If dpQmin_Booster_w_12 < 0 Then
dpQmin_Booster_w_12 = 0
End If
End Function
Function Qmax_Booster_o_12(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 42.513312
b = -53.53784698
c = 17.92582885
d = -0.57206331
```

```
e = 1.27912691
FA = -0.0000000851085 * (Speed ^ 4) + 0.0000172289 * (Speed ^ 3) + -
0.001029225 * (Speed ^ 2) + 0.026493734 * (Speed ^ 1) + -0.073782158
FB = -0.0000000679912 * (Speed ^ 4) + 0.0000143404 * (Speed ^ 3) + -
0.000885954 * (Speed ^ 2) + 0.023524288 * (Speed ^ 1) + -0.036376963
FC = -0.0000000587737 * (Speed ^ 4) + 0.000013177 * (Speed ^ 3) + -
0.000863893 * (Speed ^ 2) + 0.023235981 * (Speed ^ 1) + 0.007200474
FD = -0.000000145078 * (Speed ^ 4) + 0.0000348963 * (Speed ^ 3) + -
0.002676585 * (Speed ^ 2) + 0.070340283 * (Speed ^ 1) + 0.267359618
FE = 0.00000000319504 * (Speed ^ 4) + -0.000000635467 * (Speed ^ 3) +
0.0000391113 * (Speed ^ 2) + 0.009112884 * (Speed ^ 1) + 0.010626754
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmax_Booster_o_12 = ((AA * GVF ^ 4) + (BB * GVF ^ 3) + (CC * GVF ^ 2)
+ (DD * GVF) + EE) * Qmax
End Function

Function Qmin_Booster_o_12(Speed, GVF) 'Speed is in [%]
Qmax = 31850
a = 27.48842593
b = -55.84490741
c = 33.18865741
d = -5.24884259
e = 1.13194444
FA = 0.000000134935 * (Speed ^ 4) + -0.0000237869 * (Speed ^ 3) +
0.00148038 * (Speed ^ 2) + -0.037394368 * (Speed ^ 1) + 0.224369518
FB = 0.000000111021 * (Speed ^ 4) + -0.0000191824 * (Speed ^ 3) +
0.001179979 * (Speed ^ 2) + -0.028931541 * (Speed ^ 1) + 0.1700197
FC = 0.000000104371 * (Speed ^ 4) + -0.0000177372 * (Speed ^ 3) +
0.001070373 * (Speed ^ 2) + -0.025505374 * (Speed ^ 1) + 0.144716289
FD = 0.000000126303 * (Speed ^ 4) + -0.0000218468 * (Speed ^ 3) +
0.001317939 * (Speed ^ 2) + -0.031439856 * (Speed ^ 1) + 0.182466809
FE = -0.00000000726343 * (Speed ^ 4) + 0.0000000394664 * (Speed ^ 3)
+ 0.000182928 * (Speed ^ 2) + -0.002080624 * (Speed ^ 1) + 0.061884905
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
Qmin_Booster_o_12 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 + DD
* GVF + EE) * Qmax
End Function
Function dpQmin_Booster_o_12(Speed, GVF) 'Speed is in [%]
MaxdP = 120
a = -3.83940972222
b = 6.04739583333
c = -2.83809027778
d = 0.35402083333
e = 0.31633333333
FA = 0.000000626302 * (Speed ^ 4) + -0.000157169 * (Speed ^ 3) +
0.013224173 * (Speed ^ 2) + -0.399119492 * (Speed ^ 1) + 2.932964994
FB = 0.000000507906 * (Speed ^ 4) + -0.000128977 * (Speed ^ 3) +
0.011092453 * (Speed ^ 2) + -0.345464669 * (Speed ^ 1) + 2.552373228
```

```
FC = 0.000000456505 * (Speed ^ 4) + -0.00011555 * (Speed ^ 3) +
0.009980774 * (Speed ^ 2) + -0.314512924 * (Speed ^ 1) + 2.310770163
FD = 0.000000610371 * (Speed ^ 4) + -0.000156196 * (Speed ^ 3) +
0.01366281 * (Speed ^ 2) + -0.438773587 * (Speed ^ 1) + 3.179056245
FE = 0.0000000950613 * (Speed ^ 4) + -0.0000181225 * (Speed ^ 3) +
0.000817404 * (Speed ^ 2) + 0.016668344 * (Speed ^ 1) + -0.198515982
AA = FA * a
BB = FB * b
CC = FC * c
DD = FD * d
EE = FE * e
dpQmin_Booster_o_12 = (AA * GVF ^ 4 + BB * GVF ^ 3 + CC * GVF ^ 2 +
DD * GVF + EE) * MaxdP
If dpQmin_Booster_o_12 > 38 Then
dpQmin_Booster_o_12 = 38
End If
If dpQmin_Booster_o_12 < 0 Then
dpQmin_Booster_o_12 = 0
End If
End Function
```