NTNU
Department of Mechanical
and Industrial Engineering

Startup, operation and shutdown procedure

Wet Gas Compression Laboratory

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Subsea Process Control Laboratory

NTNU
Department of Mechanical
and Industrial Engineering

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Wet Gas Compression

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1 Introduction

This document is made with the sole intention to ensure safe and efficient operation of the wet gas compression laboratory at MTP Valgrinda. The procedure of startup, operation and shutdown of the facility is based on the theoretical design made by [1] and [2].

The laboratory (lab) is a *Subsea Process Control Facility*, with the purpose of simulating the environment of a subsea installation. This includes piping, gas-liquid separation, gas compression (piston and centrifugal type) cooling with heat exchangers and control valves. The lab is instrumented with pressure, temperature, level and speed transmitters to complete the control system signal acquirements for optimal control.

1.1 Operating scenarios

Modes of operations:

Case A. Subsea separation and gas compression. Separator, piston and centrifugal compressor are active *
Case B. Subsea separation and gas compression. Piston compressor is bypassed
Case C. Direct wet gas compression. Direct inlet wet gas to the centrifugal compressor, bypassing both the separator and the piston compressor
Case D. Dry Gas Compression, bypassing the separator (No liquid injected) **
Case E. Dry Gas Compression II, only piston compressor is active (No liquid injected)
Case F. Dry Gas Compression III, only centrifugal compressor is active (No liquid injected).

* The piston compressor is not recommended to operate in the wet gas scenario. Please consult the laboratory responsible, or move on to Case B or C.

** Case D - F follows the same start up protocols as A-C.

Note: The piston compressor is intended to be controlled by a variable frequency drive (VFD) located in the control cabinet, adjusting the speed of the crankshaft.

The procedures A-F explained in this document will have the system Piping and Instrumentation Diagram (P&ID) as reference available, included in Appendix A.

1.2 Nomenclature

- VFD Variable frequency drive
- GVF Gas Volume Fraction
- LVF Liquid Volume Fraction
- Barg Bar gauge

1.3 Table nomenclature

This section explains the columns in the startup, operational and shutdown table procedures.

1. MANUAL VALVE ADJUSTMENT PROCEDURE BEFORE STARTUP			
2. Step	3. Action/Activity	4. Description/check	5. Confirm/check

1. Headline, explaining the objective for the list of tasks
2. Operation steps, indicating the number of the current and following steps to be executed
3. Action or activity to be performed at the current step
4. Descriptive text of what the action or activity yields and/or an indication of what to check for in the environment
5. Confirm or check the result of the action or activity performed in 3.

2 HMS

The wet gas compression facility must be operated with **at least two** persons present to avoid harm or damage to personnel and equipment.

1. **Never** operate the facility without the permission from laboratory responsible (see Section 3).
2. **Follow** the workshop rules where the facility is stationed
3. **Use** hard boots and eye wear protection when operating the facility
4. **Never** open the control cabinet with electrical wiring without consulting trained personnel

For guidelines and regulations on performing work and experiments at NTNU laboratory and workshops, please consult the *Laboratory and Workshop Handbook* found at:

https://innsida.ntnu.no/wiki/-/wiki/English/Laboratory+and+workshop+handbook

Regulations for health, safety and environment according to NTNU in *HSE-Handbook for NTNU*:

http://www.ntnu.no/c/document_library/get_file?uuid=bb98f1f9-a03d-4380-95d8-94e248ae7069&groupId=10137

2.1 Contact information

Laboratory Responsible:

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3 Commissioning

This section contains the startup procedure for dry gas and wet gas in the laboratory. Technical data on the laboratory is included in Table 3.1

Table 3.1 Volume specifications for the laboratory

Item	Description	Volume [m^3]
Piping	Plastic, rubber and silicon piping	0.0380
F-001	Vertical gas-liquid separator	0.0967
W-002	Heat exchanger, cooling	0.0012
Total volume	Piping, F-001, W-002	0.1359

Gas volume fraction (GVF) and liquid volume fraction (LVF) measurements are included in Table 3.2. These are based on calculated values, and there may exist deviation from the real process conditions.

Table 3.2 GVF and LVF for the laboratory

GVF [%]	LVF [%]	V_{water} $[l]$	V_{water} $[l]$**	V_{gas} $[m^3]$	V_{gas} $[m^3]$**
95	5	6.795	1.96	0.1291	0.00196
96	4	5.436	1.568	0.1305	0.00157
97	3	4.077	1.176	0.1318	0.00118
98	2	2.718	0.784	0.1332	0.000784
99	1	1.359	0.392	0.1345	0.000392
99.5	0.5	0.6795	0.196	0.1352	0.000196
100	0	0	0	0.1359	0

**** - no separation**

3.1 Laboratory startup

This section contains the preliminary procedure for startup and initiation of the facility with dry or wet gas. The following operations indicated in the section tables **must be followed from Table 1 to 3.**

1. MANUAL VALVE ADJUSTMENTS PRIOR LABORATORY STARTUP			
Step	Action/Activity	Description/check	Confirm/check
1	Close pneumatic supply valve	Close the supply valve located in the work shop	-
2	Connect pneumatic supply line to rig	Connect the rig pneumatic supply line from V1-006 to the connection point X01	-
3	Close V1-007	Manual air supply valve to turbine inlet	Leakages around quick-release connection
4	Close V1-006	Air supply valve to pneumatic line	-
5	Close V1-012	Air supply valve to pipeline	-
6	Open pneumatic supply valve	Open the work shop pneumatic supply valve to pressurize the supply line	Leakages around quick-release connection
7	Connect VU-001 to W-002 inlet	Connecting the hose to area water supply for the counter flow cooler	Leakages at the bottom connection
8	Connect water hose to W-002 outlet	Connect outlet of W-002 to water hose and place it in the area drainage	-
9	Open VU-001	Open the water supply valve approximately 10-20%	Leakages, steady flow from the cooler to the drainage
10	Proceed to Table 2.	-	-

2. LABORATORY POWER SUPPLY CONNECTION			
Step	Action/Activity	Description/check	Confirm/check
1	Close the control cabinet door	Closing the door allows powering the main circuit.	For foreign objects inside the cabinet
2	Connect the main power cord	Locate and connect the main power cord (400V-red) to the main socket (red below cabinet)	Connection is proper
3	ES01-02 to NC	Check if the emergency stop switches are set to NC (pull out)	The system will not be power if ES01-02 = NO
4	Turn S1 to ON	System on/off switch S1	PL2 = green

5	Turn S3 to ON	24 VDC power supply to control valves	PL4 = green
6	Verify water pump circuit	Check if the water pump circuit has a fault	PL6 = No light If RED, go to Section 6
7	Verify cabinet fan running	Check if the cabinet fan (QF01) is operational and working	If not, go to Section 6
8	Proceed to Table 3.	-	-

3. LABORATORY SOFTWARE STARTUP			
Step	Action/Activity	Description/check	Confirm/check
1	Start Labview Software	Locate the software in the start menu	-
2	Run global.vi	.vi located in folder "Labview/global/global.vi"	-
3	Connect DAQ to USB	Connect the DAQ to the USB port on the computer	-
4	Set to RUN mode	Set the Labview progam to run (upper left corner arrow)	-
5	Verify transmitter readings	Pressure and temperature readings	Readings reflect real values
6	Verify safe working conditions	Locate the alarm list in the HMI and acknowledge	Alarm list, post-fault logs
7	Check control valve positions	Locate the control valve positioning feedback in the HMI **and** check with Table 3.3	0% - closed 100% - open
8	Proceed to Section 3.1.1 or 3.1.2		

Table 3.3 – Control valve positions

Control valve positioning protocol			
Item	Description	Value	Check
CH01	Choke valve downstream of check valve V3-002	Full open, 1 (100%)	-
CH02	Choke valve downstream of water pump P-001	Full open, 1 (100%)	-
CV01	Anti-surge compressor control valve	Fully closed, 0 (0%)	-
CV02	Turbine air supply valve	Fully closed, 0 (0%)	-

3.1.1 Dry gas startup

After performing the tasks in Section 3.1, the dry gas startup can be executed.

DRY GAS STARTUP			
Step	Action/Activity	Description/check	Confirm/check
1	Close V1-013	Liquid injection port valve	Connection leakages
2	Close V1-012	Rig air supply valve to pipeline	-
3	Open V1-007	Manual air supply valve to turbine inlet	-
4	Open V1-006	Rig air supply valve	-
5	Open V1-012	Rig air supply valve to pipeline	MAN02 = 2 barg
6	Close V1-012	Air supply to piping valve after step 4 is done	Leakages (large decline in pressure at MAN02)
7	Proceed to CASE D-F	-	-

3.1.2 Wet gas startup

After performing the tasks in Section 3.1, the wet gas startup can be executed.

WET GAS STARTUP			
Step	Action/Activity	Description	Confirm/check
1	Close V1-007	Manual air supply valve to turbine inlet	Leakages around quick-release connection
2	Close V1-006	Rig air supply valve	-
3	Close V1-012	Rig air supply valve to pipeline	-
4	Close V1-001	Bypasses separator (F-001)	-
5	Close V1-002	Close separator inlet valve (F-001)	-
6	Close V1-003	Close inlet supply to piston compressor (V-001)	-
4	Close V1-005	Close outlet to piston compressor (V-001)	-
5	Close V1-011	Centrifugal compressor (V-002) bypass	-
6	Measure system LVF	Measure LVF for pipeline volume to achieve desired GVF	According to *Table 3.1*
7	Connect supply to V1-013	Liquid injection hose to the injection port	-

8	Fill liquid	Pour measured liquid into the system	Check for leakage around port
9	Close V1-013	Liquid Injection port valve	-
10	Connect supply to X01	Work shop air supply hose to air supply connection	Leakages around quick-release connection
11	Open V1-006	Rig air supply valve	-
12	Open V1-012	Rig air supply valve to pipeline	MAN02 = 2 barg
13	Close V1-012	Rig air supply valve to pipeline	-
14	Open V1-007	Manual air supply valve to turbine inlet	Leakages around turbine inlet
15	Proceed to Case A-C	-	-

4 Laboratory operation (Case A – F)

4.1 Wet gas compression cases

Case A: Subsea separation and gas compression (**Separator, piston compressor** and **centrifugal compressor**)			
Step	Action/Activity	Description	Check
1	Open VU-001	Supply counter flow cooler (W-002) with water	Leakages around connections
2	Close V1-001	Close separator (F-001) bypass	-
3	Close V1-004	Close piston compressor (V-001) bypass	-
4	Close V1-011	Close bypass valve for centrifugal compressor (V-002)	-
5	Open V1-002	Open separator (F-001) inlet valve	-
6	Open V1-003	Open piston compressor (V-001) inlet	-
7	Open V1-005	Open piston compressor (V-001) outlet	-
8	Open V1-008	Open centrifugal compressor (V-002) inlet	-
9	Open V1-010	Open centrifugal compressor (V-002) outlet	-
10	Switch S3 to ON	Turn on the oil pump, centrifugal compressor cooling	Check green light at PL3
Software steps			
1	Set desired set point for V-002 speed	Done in Labview, global.vi. This will gradually supply the turbine with air to generate torque to the compressor shaft	Leakages around centrifugal compressor
2	Read PT04	Read pressure at V-001 outlet	Verify if reading is below 6 barg
3	Fix speed of V-001	Set to constant speed, check if control algorithm ensures this	-

Case B: Subsea separation and gas compression (**Separator** and **Centrifugal Compressor**)			
Step	Action/Activity	Description	Check
1	Open VU-001	Supply counter flow cooler (W-002) with water	Leakages around connections
2	Close V1-001	Close separator (F-001) bypass	-
3	Close V1-003	Close piston compressor (V-001) inlet	-
4	Close V1-005	Close piston compressor (V-001) outlet	-
5	Open V1-002	Open separator (F-001) inlet	-
6	Open V1-004	Bypass piston compressor (V-001)	-
7	Close V1-011	Close centrifugal compressor (V-002) bypass	-
8	Switch S4 to ON	Turn on the oil pump, centrifugal compressor cooling	Check green light at PL3
Software steps			
1	Turn ON the frequency converter	Switch the power supply on to the frequency converter.	-
2	Set desired speed for V-001	In PROGRAM set the VFD frequency to (see documentation for conversion between frequency and speed)	-
3	Read PT05	Read pressure at outlet of V-001	Verify if ok/reached desired
4	Set desired set point for V-002 speed	Done in Labview, global.vi. This will gradually supply the turbine with air to generate torque to the compressor shaft	Leakages around centrifugal compressor
5	Read PT04	Read pressure at V-001 outlet	Verify if reading is below 6 barg
6	Fix speed of V-001	Set to constant speed, check if control algorithm ensures this	-

Case C: Direct inlet wet gas compression (**Centrifugal Compressor**)			
Step	Action/Activity	Description	Check
1	Open VU-001	Supply counter flow cooler W-002 with water	Leakages around connections
2	Close V1-002	Close separator (F-001) inlet	-
3	Close V1-003	Close piston compressor (V-001) inlet	-
4	Close V1-005	Close piston compressor (V-001) outlet	-
5	Close V1-011	Close centrifugal compressor (V-002) bypass	-

6	Open V1-001	Bypass separator (F-001)	-
7	Open V1-008	Open centrifugal compressor (V-002) inlet	-
8	Open V1-010	Open centrifugal compressor (V-002) outlet	-
9	Switch S4 to ON	Turn on the oil pump, centrifugal compressor cooling	Check green light at PL3
Software steps			
1	Gradually open CV-02	Gradually supply the turbine with air to generate torque to the compressor shaft	Leakages around centrifugal compressor
2	Set desired set point for V-002 speed	Done in Labview, global.vi. This will gradually supply the turbine with air to generate torque to the compressor shaft	Leakages around centrifugal compressor
3	Read PT04	Read pressure at V-001 outlet	Verify if reading is below 6 barg
4	Fix speed of V-001	Set to constant speed, check if control algorithm ensures this	-

4.2 Dry gas compression cases

Case D: Dry Gas Compression, **piston** and **centrifugal compressor**			
Step	Action/Activity	Description	Check
1	Open VU-001	Supply counter flow cooler (W-002) with water	Leakages around connections
2	Close V1-002	Close separator (F-001) inlet	-
3	Open V1-003	Open piston compressor (V-001) inlet	-
4	Open V1-005	Open piston compressor (V-001) outlet	-
5	Close V1-004	Close piston compressor (V-001) bypass	-
6	Close V1-011	Close centrifugal compressor (V-002) bypass	-
7	Open V1-001	Bypass separator (F-001)	-
8	Open V1-008	Open centrifugal compressor (V-002) inlet	-
9	Open V1-010	Open centrifugal compressor (V-002) outlet	-
10	Switch S4 to ON	Turn on the oil pump, centrifugal compressor cooling	Check green light at PL3
Software steps			
1	Turn ON the frequency converter	Switch the power supply on to the frequency converter.	-
2	Set desired speed for V-001	In PROGRAM set the VFD frequency to (see documentation for conversion between frequency and speed)	-
3	Read PT05	Read pressure at outlet of V-001	Verify if ok/reached desired
4	Set desired set point for V-002 rpm	Done in Labview, global.vi. This will gradually supply the turbine with air to generate torque to the compressor shaft	Leakages around centrifugal compressor
5	Read PT04	Read pressure at V-001 outlet	Verify if reading is below 6 barg
6	Fix speed of V-001	Set to constant speed, check if control algorithm ensures this	-

Case E: Dry Gas Compression, **piston compressor**			
Step	Action/Activity	Description	Check
1	Open VU-001	Supply counter flow cooler (W-002) with water	Leakages around connections

2	Close V1-002	Close separator (F-001) inlet	-
3	Open V1-001	Open separator (F-001) bypass	-
4	Open V1-003	Open piston compressor (V-001) inlet	-
5	Open V1-005	Open piston compressor (V-001) outlet	-
6	Close V1-004	Close piston compressor (V-001) bypass	-
7	Open V1-011	Open centrifugal compressor (V-002) bypass	-
8	Close V1-008	Close centrifugal compressor (V-002) inlet	-
9	Close V1-010	Close centrifugal compressor (V-002) outlet	-
Software steps			
1	Turn ON the frequency converter	Switch the power supply on to the frequency converter.	-
2	Set desired speed for V-001	In PROGRAM set the VFD frequency to (see documentation for conversion between frequency and speed)	-

Case F: Dry Gas Compression, **centrifugal compressor**			
Step	Action/Activity	Description	Check
1	Open VU-001	Supply counter flow cooler (W-002) with water	Leakages around connections
2	Close V1-002	Close separator (F-001) inlet	-
3	Open V1-001	Open bypass of separator (F-001)	-
4	Close V1-003	Close piston compressor (V-001) inlet	-
5	Close V1-005	Close piston compressor (V-001) outlet	-
6	Open V1-004	Open bypass of piston compressor (V-001)	-
7	Close V1-011	Close bypass for centrifugal compressor (V-002)	-
8	Open V1-008	Close centrifugal compressor (V-002) inlet	-
9	Open V1-010	Close centrifugal compressor (V-002) outlet	-
10	Switch S4 to ON	Turn on the oil pump, centrifugal compressor cooling	Check green light at PL3
Software steps			
1	Set desired set point for V-002 rpm	Done in Labview, global.vi. This will gradually supply the turbine with air to generate torque to the compressor shaft	Leakages around centrifugal compressor
2	Read PT04	Read pressure at V-001 outlet	Verify if reading is below 6 barg
3	Fix speed of V-001	Set to constant speed, check if control algorithm ensures this	-

5 Shut down procedure

The following operation table shows the procedure to perform a shutdown of the laboratory.

Shutdown - Manual instructions			
Step	Action/Activity	Description	Check
1*	Ramp down M-001	Ramp down the speed of the piston compressor to avoid damage to internal crankshaft	Verify that the compressor is not running
2	**Go to step 1** in **software instructions**	-	-
3	Switch S4 to OFF	Shutting off the oil pump for centrifugal compressor cooling	-
4	Close VU-001	Shut off the water supply to counter flow cooler (W-002)	-
5	Open V1-002	Open separator (F-001) inlet	-
6	Close V1-013	Ensure the air supply valve is closed	-
7	Close workshop air supply valve	Close the work shop air supply valve and ensure there are no pressure at rig supply point X01	-
8	Open V1-006	Rig air supply valve	-
9	Open F-001 drainage valve	Locate the drainage hose for F-001 and gradually open to depressurize system	-
10	Close F-001 drainage valve	Ensure that the air is at 0 barg at MAN02, if not = wait with closure of F-001 drainage valve	MAN02 = 0 (1 atm)
11	**Go to step 3** in **Software instructions**	-	-
Shut down - Software / Electrical steps			
1	Set global.vi to <initiate manual shutdown>	Shut down ensures opening of all critical valves to reduce pressure in the system	-
2	**Go back to step 3** in **manual instructions**	-	-
3	Switch S1 to OFF	Shutting off the power supply to M-001 to 3	-
4	Disconnect DAQ from USB	-	-

* Can be excluded if not operating with piston compressor in test loop

6 Troubleshooting

1. No readings from measurement I/O
   Solution proposal: Check USB connection to computer. Restart Labview and locate potential wire breaks to control cabinet.
2. Program goes to SHUTDOWN MODE immediately
   Solution proposal: Check the pressure and temperature readings of the system, and if the values are beyond what is recommended.
3. PL6 light is red, water pump **is not running** or motor protection circuit breaker has tripped
   Solution proposal: Turn of the system equipment. Switch off the power supply (S1) and call certified personnel to inspect the water pump and control cabinet.
4. Cabinet fan is not working
   Solution proposal: Turn of the system equipment. Switch off the power supply (S1) and call certified personnel to inspect the fan circuit inside the control cabinet

Comment to 3: PL6 is wired on the NC pair on the motor protection relay for C2-water pump circuit. This ensures that when the circuit is powered and the water pump is not running, the pilot light glows. This is a design issue, since the motor protection relay does not have a separate contact pair for fuse trip. Therefore, it is wired to the NC pair.

If non of the above is a solution, please consult laboratory responsible.

7 References

[1] M. Brænden Bordal, E. Flatlandsmo and J.-H. Krøke Medby, “Subsea Gas Boosting Laboratory: Design and Construction,” Department of Production and Quality Engineering, NTNU, Trondheim, 2016.

[2] D. Nedregård, “Subsea Boosting Lab: Completion of Build,” Department of Production and Quality Engineering, NTNU, Trondheim, 2016.

FAT: Control labeling on field and diagram components and if correctly positioned	
Signature:	Date:
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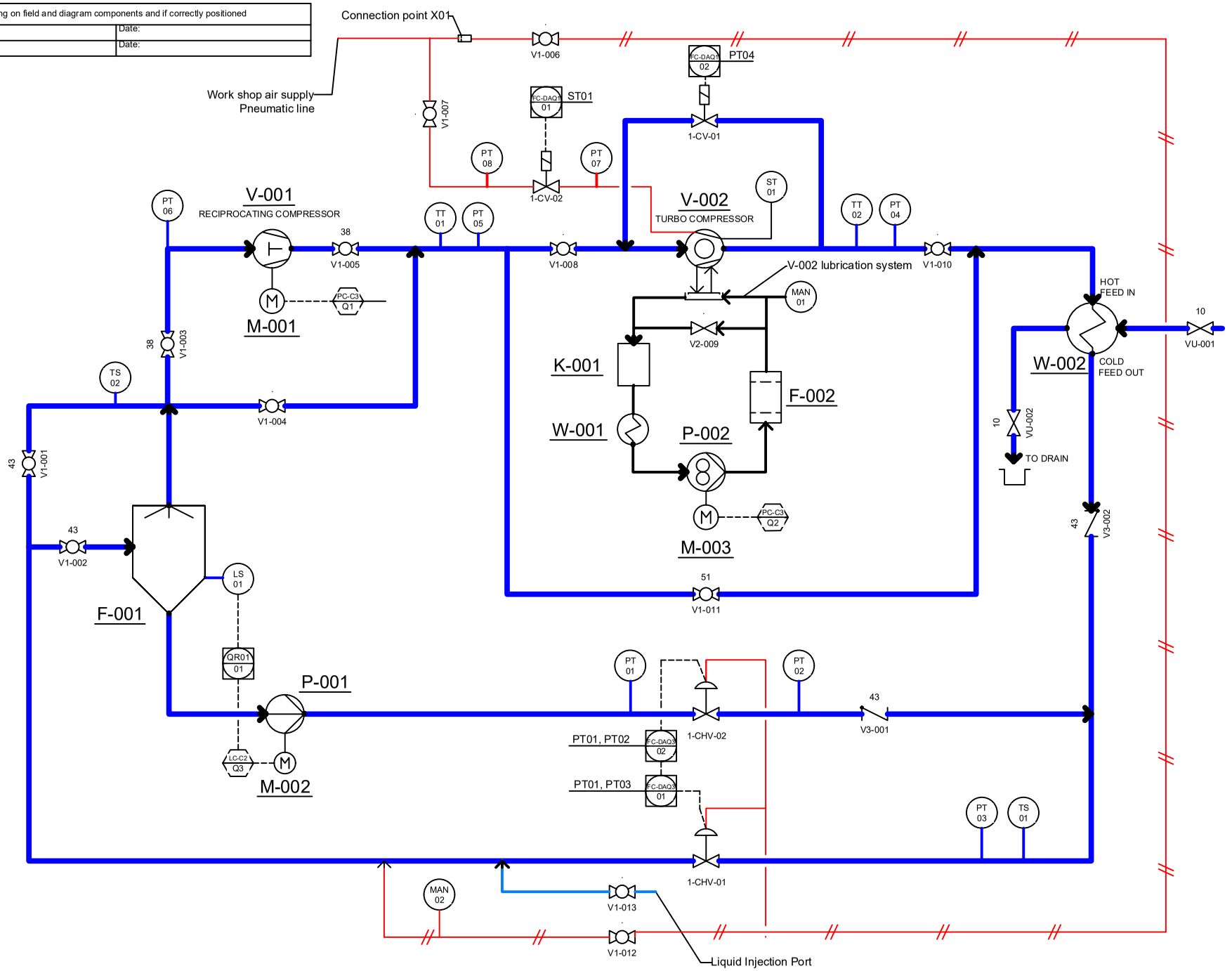

Nomenclature:

W - Heat Exchangers | F - Separator | K - Reservoir (Oil) | P - Pump | M - Motor drive
V1 - Ball valve | V2 - Needle Valve | V3 - Check Valve | VU - Valve Utility | CV - Control Valve | CHV - Choke Control Valve
LS - Level Sensor | TS - Temperature Sensor | TT - Temperature Transmitter | ST - Speed Transmitter | PT - Pressure Transmitter | MAN - Manometer
PC - Pressure Controller | LC - Level Controller | FC - Flow Controller | DAQ - Data Aquisition Unit (Measurement and Control I/O)

P&ID for process laboratory		Department of Mechanical and Industrial Engineering (MTP), NTNU
Wet Gas Compression		
Designed by: N.T., D.N.	Rev: 06-24/05-17, N.T.	Subsea Process Control Laboratory
Date: 13.03.2017	Scale: A4 | Sheet 1 of 1	