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MASTER'S THESIS

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CREDITS

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My wife Grete and daughter Natalie, for giving me motivation every day.

SUMMARY

The EPCI (Engineering, Procurement, Construction and installation) contractor which delivered the PSVs to Alvheim states that the PSVs are sized to handle a gas blowby scenario. Marathon Norge AS does not hold any documentation of this. The object for this thesis is to verify and document that the PSVs can handle a gas blowby scenario.

The equipments which have been investigated are:

- The Alvheim/3rd party Inlet separator
- The 2nd stage separator
- The produced water degassing drum
- Glycol Flash Drum
- Cargo tanks

It is concluded that it is not sufficient to only consider the gas blowby case without including the effect of closed outlets due to high pressure. It seems that the EPCI contractor has not included closed outlet when sizing the PSVs for a gas blowby scenario.

The PSVs for Alvheim/3rd party Inlet separator and Glycol Flash drum are verified in this report by conservative calculations and simulations assuming a gas blowby scenario with closed outlets.

The conservative computation does not verify that the PSVs for the 2nd stage separator, the produced water degassing drum and the cargo tanks are sized for gas blowby. However, the dynamic simulation shows that the conservative scenarios are too conservative. The trivial dynamic simulation shows that the PSVs for the 2nd stage separator are large enough to handle a gas blowby scenario with closed outlets. In spite of this result it is recommended that a more detailed dynamic simulation is to be designed to verify sufficient PSV capacity for these scenarios. First of all it is recommended to implement more details into the steady state simulation for the 2nd stage separator and the degassing drum and investigate if it is possible to assume open liquid outlets even though the downstream pumps trip.

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1 INTRODUCTION

Overpressure may damage process equipment and eventually cause loss of containment and unwanted hazard. Pressure safety valves (PSV) are installed as secondary protection to ensure that overpressure due to material or energy build up in some part of the system does not occur. The PSVs are connected to a flare trough a flare network. Different worst case scenarios like fire, blocked outlet or power failure must be evaluated to see if the size of the PSV can prevent overpressure and hence operate safe.

The EPCI contractor which delivered the PSVs to Alvheim has validated that the PSVs are sized to handle a relevant gas blow-by scenario, but Marathon does not hold documentation for this. A Gas blow by scenario could occur if the oil-outlet valve does not close when liquid level in the upstream separator drops. Gas will then start to flow down to the equipment downstream and the pressure will increase until the pressure reaches the PSV set pressure. The object of this thesis is to calculate the needed PSV size for different process equipment, and to compare them against the current PSV size.

The flow through the PSV can be two phase flow hence the Recommended Practice (RP) 521 of the American Petroleum Institute (API) which includes Homogeneous Equilibrium Model (HEM) is used.

A simulation of the process is needed in order to calculate the maximum two phase flow that might have to pass through the PSV. The software HYSYS from Aspen Tech is used for this application.

In the report there are references to Marathon technical document which are marked with 1,2,3 etc. The other references are marked with I,II,III, etc and are collected at the end of the report.

2 PROCESS SAFETY

Process safety is covered by systems and equipment which will control abnormal operating conditions to prevent hydrocarbon release. Two independent system levels called primary and secondary protection are required to stop hydrocarbon flow, shut down process and utility equipment, and pressure relief. The primary and secondary protection shall be independent of each other according to PSA regulations[I].

In the case of a gas blowby scenario the primary protection is covered by a LSL (Level Safety Low) sensor which either closes the outlet valve or shuts off the inflow of the pressurized equipment. The Secondary protection is provided by a PSV (Pressure safety valve) on the downstream equipment in the case of gas blowby.

2.1 OVERPRESSURE

Every pressure vessel in danger of having blocked outlets needs to have a pressure relief system to alleviate pressure build up due to thermal expansion of trapped gases or fluids. In addition to blocked or restricted outlet API 14C states the following[II] causes for overpressure:

A pressure vessel receiving fluid from a higher pressurized source needs to have a pressure relief device to protect the vessel for high pressure. When the upstream source has a higher pressure this hazard is always present even if the pressure upstream is created by a pump. The undesirable event is called gas blowby and is caused by low liquid level in the high pressure vessel. Eventually gas from the high pressure vessel will escape through the liquid outlet and raise the pressure in the low pressure vessel.

Another cause leading to overpressure is if the inflow exceeds the outflow of the vessel. The pressure will increase towards the pressure in the upstream source.

Thermal expansion is a cause for overpressure either by high inlet temperature or because of fire.

Overpressure can also be caused by control system failure.

The undesirable event which requires the largest PSV is the basis for sizing the PSV.

A term which is often used when talking about overpressure is double jeopardy. This issue is also discussed in this thesis. Double jeopardy is when two unrelated causes of overpressure happen at the same time. API Standard states that a scenario with double jeopardy is not to be considered when sizing the PSVs.

2.1.1 MAXIMUM DESIGN PRESSURE

According to Norsok standard the criteria in Table 2.1-A shall be used unless the manufacturer of the PSV can guarantee that use of other margins is acceptable. The minimum margin visualized in Figure 2.1-A is created to avoid that the PSV opens unintentional.

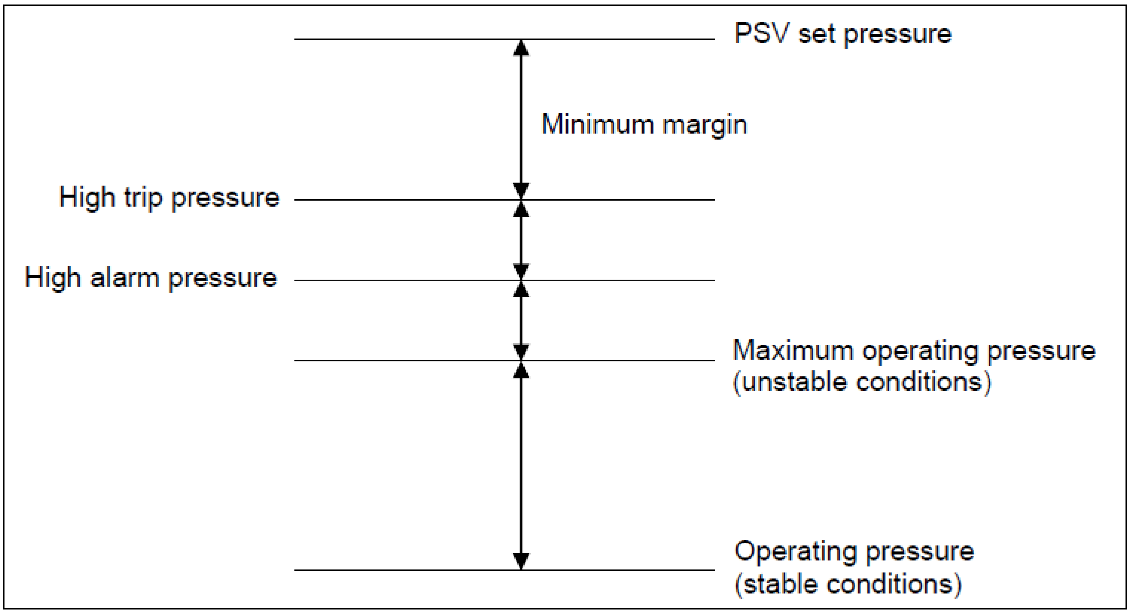

Figure 2.1-A – PSV pressure relation[III]

Table 2.1-A - Design pressure criteria for pressurised systems[III]

High trip pressure (1),(2) barg	Minimum margin between high trip pressure (1),(2) and PSV set pressure bar
0 to 35	3,5
over 35	10 % of PSV set pressure

(1) For systems without a high pressure trip, the minimum margin shall be applied between the maximum operating pressure and the PSV set pressure.
(2) Maximum operating pressure for compressor suction scrubbers and coolers shall be the maximum settle-out pressure, calculated from coincident high trip pressures on both suction and discharge sides of the compressor, and the minimum margin shall be applied between the maximum operating pressure and the PSV set pressure.

2.1.2 *SECONDARY PRESSURE PROTECTION – MECHANICALLY BASED*

NORSOK Standard states that “mechanically based pressure protection systems (e.g. PSV) shall be the preferred solution for secondary pressure protection”.

A PSV can come in many different styles, but since the PSVs that are represented in this report are pilot operated pressure relief valve, these are the ones that are presented.

The PSVs are available in different standard orifice sizes. The required area for the worst case scenario is calculated, so that the wanted PSV size can be chosen from a table. The size is always chosen to be greater than the required area.

2.1.2.1 SPRING LOADED PSV

The spring loaded PSV has the spring load to vary the pressure at which the valve open. All PSVs has to be able to operate during all times even if there is a power failure. This means that it is the process fluids energy which drives the PSV. The design of the valve is supposed to be as simple as possible. The reliability is directly related to the complexity of the valve. In Figure 2.1-B it is showed how the disc is forced by a spring against the nozzle to prevent flow under operating conditions.

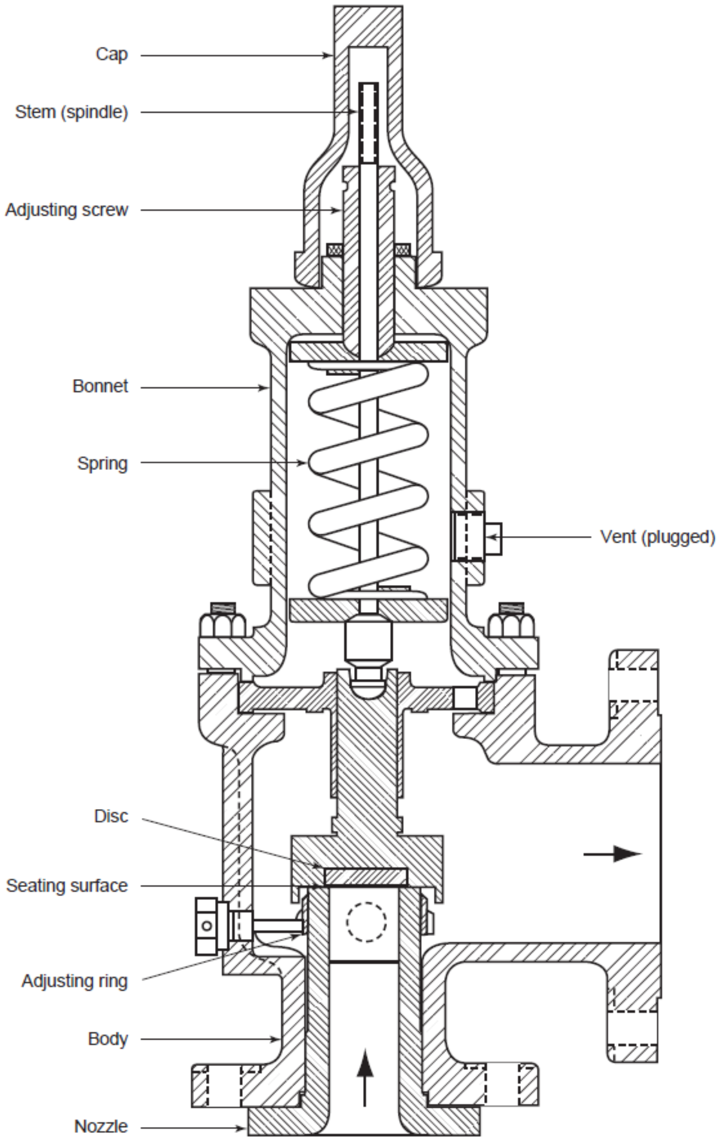

Figure 2.1-B – Conventional Spring Loaded PSV[VI]

Since it is a spring, the set-pressure for when the valve opens is adjustable. The force of the spring must be equal to the set pressure multiplied with the area of the nozzle (Figure 2.1-C). The spring force increases as it is compressed, so there is need for a secondary control chamber to enhance lift.

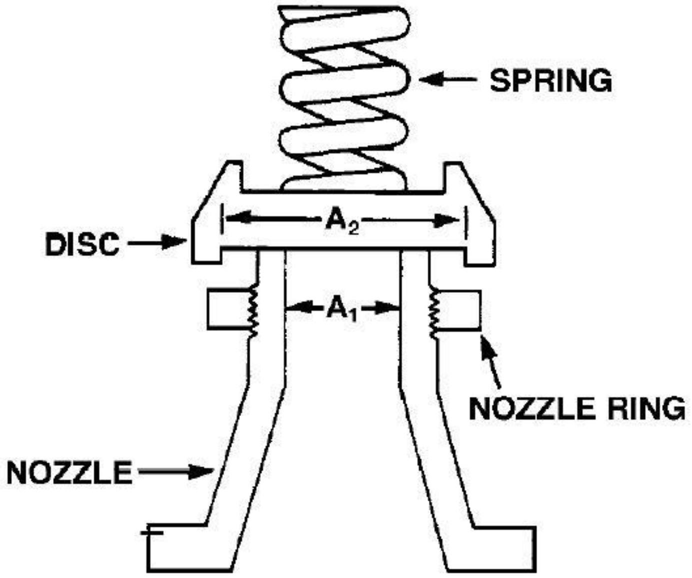

Figure 2.1-C - Trim Areas Diagram[IV]

The allowable overpressure is generally 10%[IV] of the set-pressure. With a control chamber or huddling chamber a larger area is exposed for the pressure and a higher force is applied on the disc which compress the spring to fully open rapidly. The momentum effect resulting from the change in flow direction contributes in open the disc within the allowable overpressure.

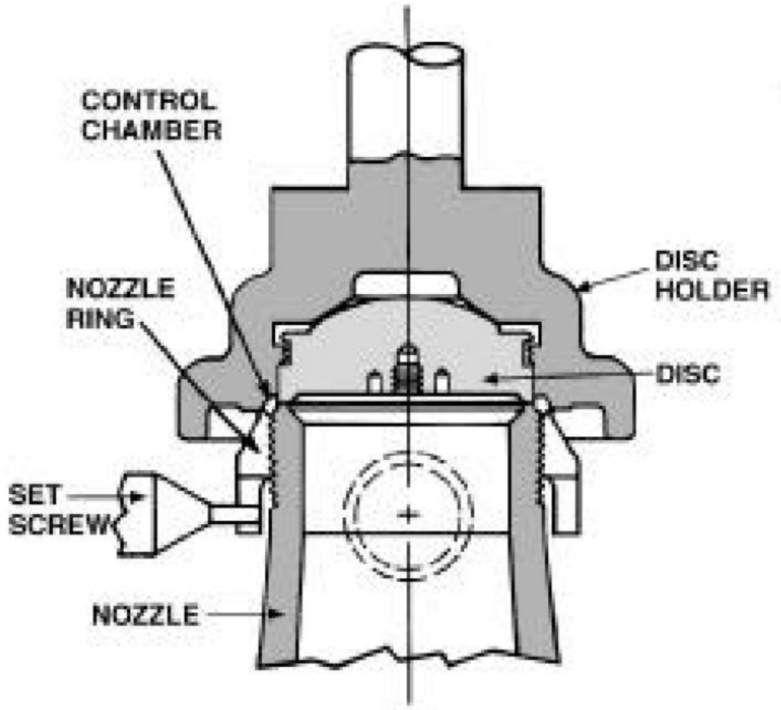

Figure 2.1-D Crosby style JOS PSV Trim[IV]

Due to the larger area exposed for the pressure, the closing-pressure will be less than the set-pressure. This difference is called the blow down pressure and is often expressed as a percentage of the set-pressure. The nozzle ring in Figure

2.1-D is used to meet the different operating requirements when it comes to opening and closing.

2.1.2.2 BALANCED BELOW

A recommended PSV when the back pressure is variable. When the valve vents into the atmosphere this is not needed. When the pressurized fluids/gases are toxic, corrosive, valuable or dangerous they are vented into a system (flare-system) with potential of variable back-pressure.

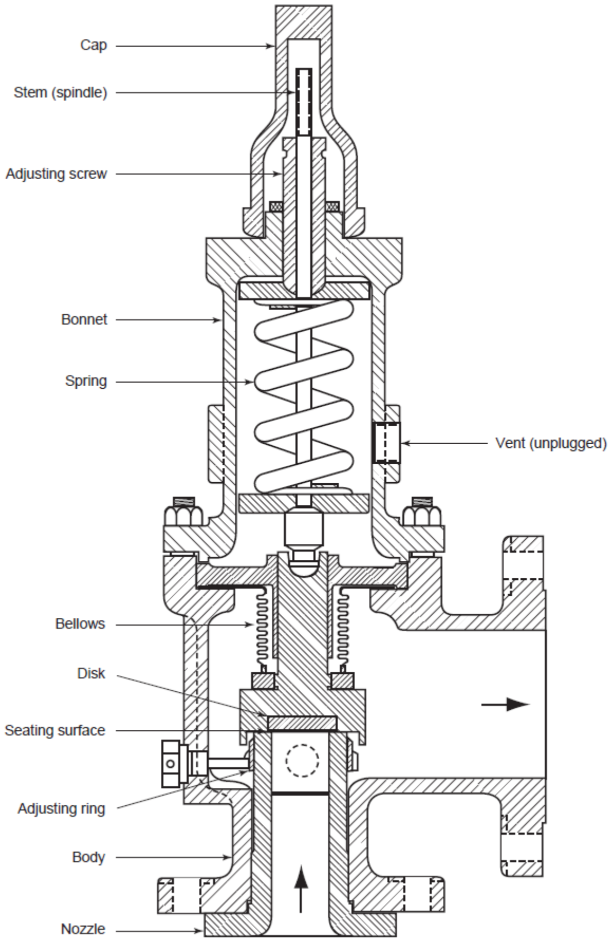

Figure 2.1-E - Balanced PSV[VI]

A natural consequence of a variable (superimposed) back-pressure is a variable set-pressure, because the back pressure functions as a counteractive force to the disc. A balanced PSV has a bellows or piston with an effective pressure area equal to the seat area of the disc. The vent showed in Figure 2.1-E assures that the backpressure working on the upside of the disc is atmospheric. This way the back pressure will not affect the set-pressure.

2.1.2.3 PILOT OPERATED PSV

A pilot operated PSV uses the pilot to allow system pressure into the piston chamber under normal operating pressure. This is showed in Figure 2.1-F.

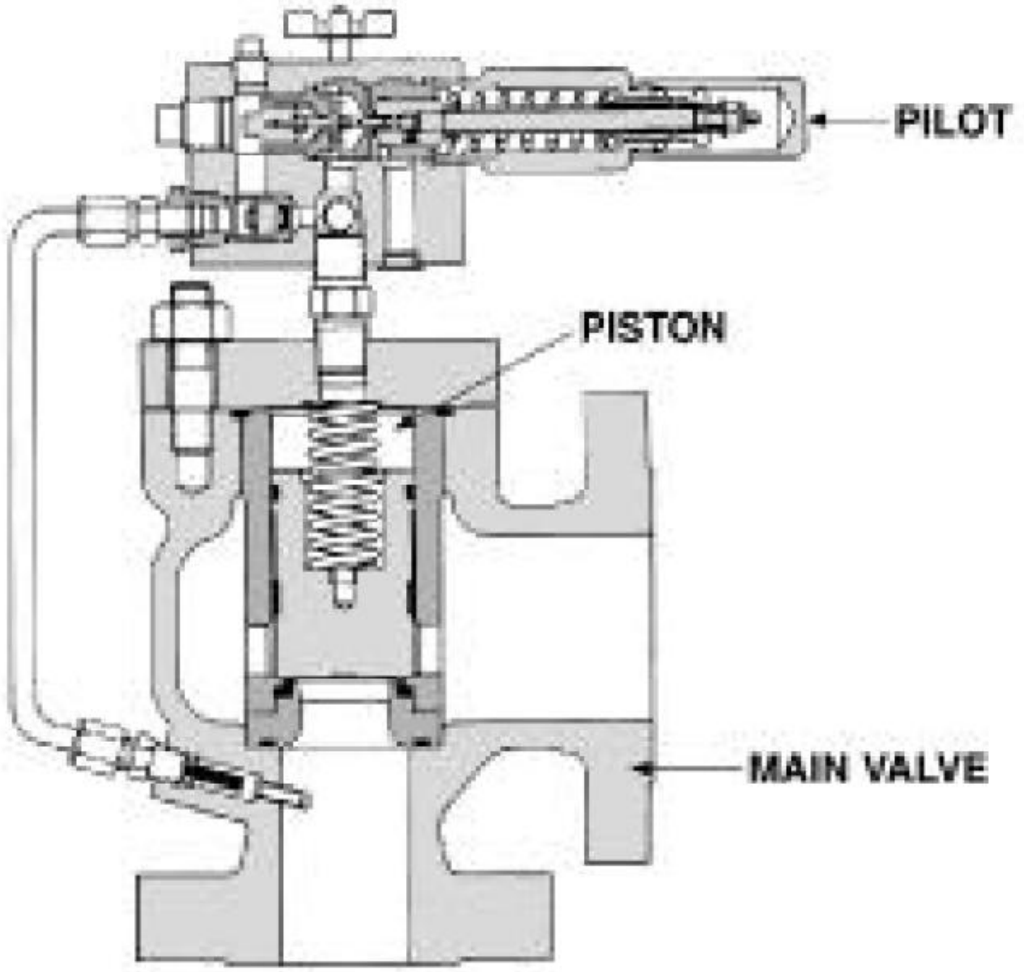

Figure 2.1-F- Crosby snap acting style JPV Pilot Operated Pressure Relief Valve[IV]

Since the piston area is greater than the disc area, the valve will remain closed. When the set-pressure is reach the pilot closes and simultaneously vents the piston chamber, which will open the disc. The other systems described above will have some leakage around the set-pressure, but this system will have no leakage before it reaches set-pressure because of the same pressure both places and higher area on the top. This way fluid loss is reduced.

3 THEORY

3.1 GENERAL ABOUT THE HOMOGENEOUS EQUILIBRIUM MODEL

When several phases flow together, the velocities can be different. Depending on the different parameters like velocity different flow regimes like dispersed bubble, slug or annular flow can occur. The homogeneous equilibrium model (HEM) assumes that the variables velocity, temperature and pressure are equal for the phases. This assumption is made based on the belief that the momentum, energy and mass transfer between the phases will change rapidly so that equilibrium is reached.

3.1.1 CRITICAL FLOW

When a single phase fluid moves through a nozzle or in this case a PSV, a certain pressure drop will create choked flow.

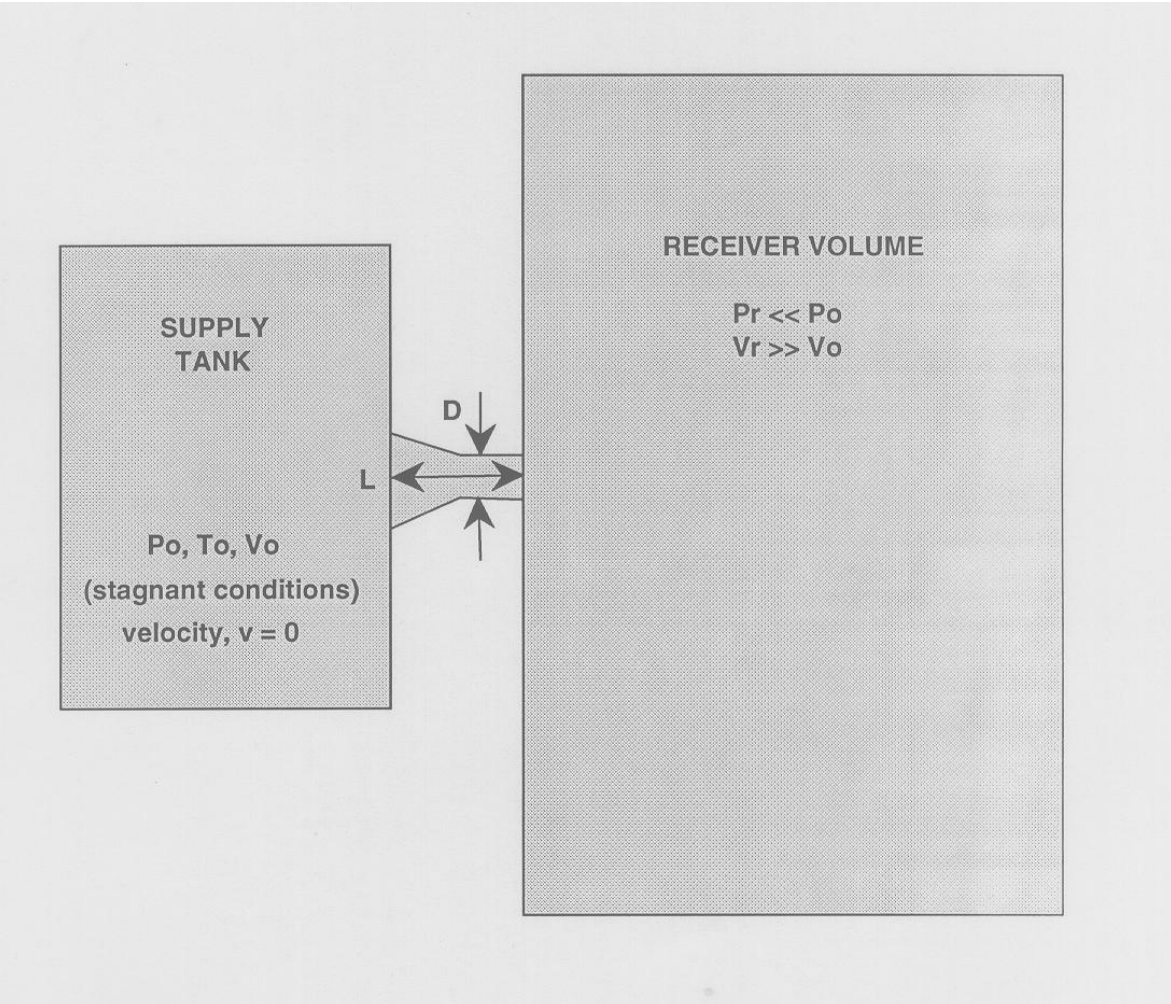

Figure 3.1-A – Conceptual Picture of Fluid Blow down[V]

Figure 3.1-A explains this phenomenon. When the pressure in the receiver volume, P_r, is lowered a higher mass velocity will travel through the narrowing, due

to the increased pressure drop. At a certain pressure P_r, the mass flow will stay constant although the pressure drop increases. This is called choked flow or critical flow. The fluid holds a velocity that is similar to its sound speed at the same conditions and in the same medium (Mach=1). Figure 3.1-B illustrates this phenomena assuming air or nitrogen. For air or nitrogen the single phase fluids mach number reaches unity at P_r/P_o= 0,53.

$$M = \frac{V}{a}$$

Equation 3.1-A – Mach number

V: the relative velocity of the source to the medium

a: the speed of sound in the medium

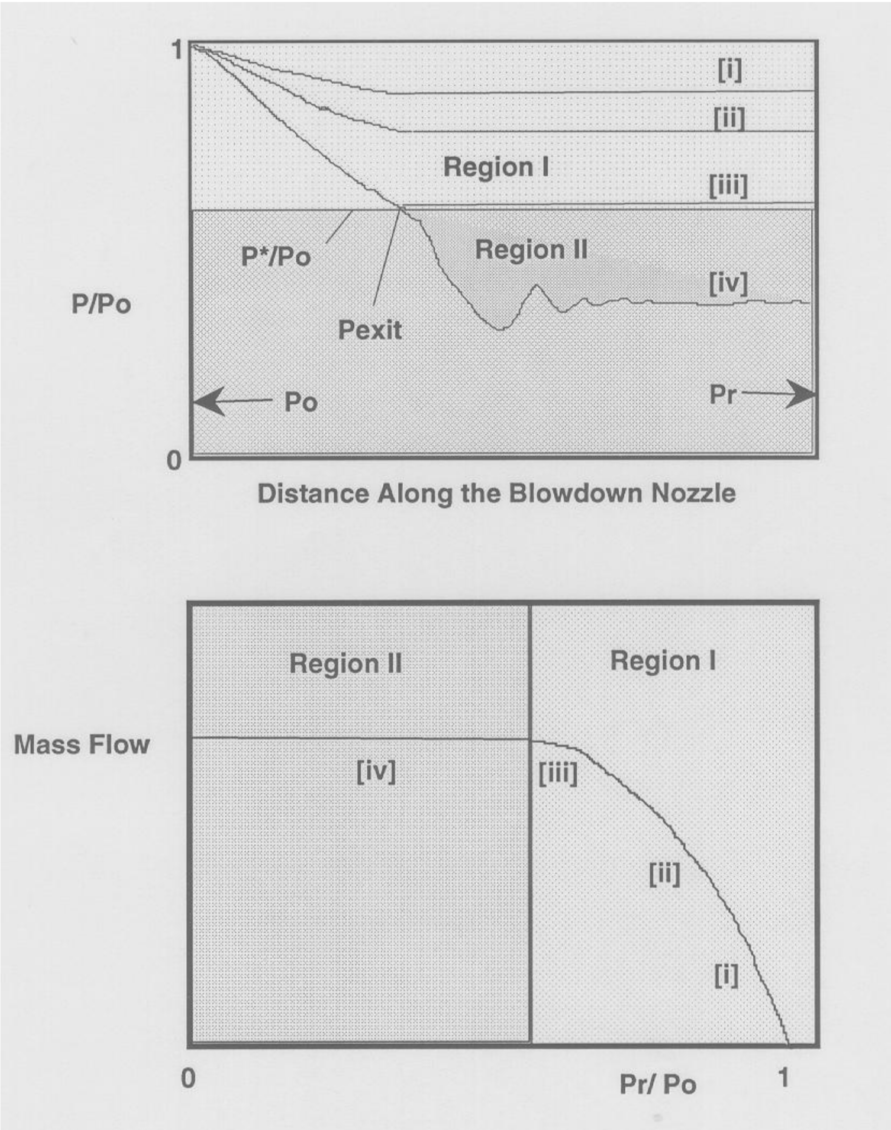

Figure 3.1-B - Conceptual picture of single phase critical flow[V]

A two-phase flow behaves different due to several phases which all in practice has different sound speed. Depending of the flow regime, there can be a sound speed for the gas, liquid phase or for the mixture. This is an explanation to why the choked flow speed for fluid is not equal to its sound speed as is the case for a single phased fluid.

In section 3.2 the assumptions for the homogeneous equilibrium model are listed. Once these assumptions are stated, the relations from single phase choked flow can be translated to multiphase conditions. Since the flow is assumed to be isentropic the only contributor to the pressure drop is the acceleration pressure drop.

3.2 ASSUMPTIONS FOR THE HOMOGENEOUS EQUILIBRIUM MODEL

The procedure and assumptions in section 3.2, 3.3 and 3.4 can be found in API Standard 521 and 520, but is reproduced here to give the needed theory.

When performing PSV size calculations using HEM the following assumptions are made:

- The nozzle between the inlet opening and the seating surface is the only element limiting the flow.
- An acceptable estimation can be performed by determine the theoretical maximum flow through the nozzle and adjust it for deviations from idealistic conditions.
- The thermodynamic path to determine the theoretical maximum flow through the nozzle is adiabatic and reversible (isentropic). This is a common assumption that has been validated experimentally for well-formed nozzles[VI].
- The flow is one-dimensional.
- The fluid is homogeneous. No heat transfer between the phases. No slip (The phases travelling with the same velocity). This means it is in thermal and mechanical equilibrium. The density is uniform across the cross section.

Given these assumptions the following equation is formed using the general volumetric energy balance for isentropic nozzle flow of a homogeneous fluid:

$$G^2 = \left[\frac{-2 \times \int_{P_1}^{P} v \times dP}{v_t^2}\right]_{max}$$

Equation 3.2-A – Mass flux (SI-units)[VI]

G: Mass flux, kg/s*m^2

P: Stagnation pressure of the fluid, absolute Pa

v: Specific volume of the fluid, m^3/h

$_1$: Fluid condition at the inlet to the nozzle

$_t$: Fluid condition at the throat of the nozzle where the cross-sectional area is minimized

To solve this integral the Trapezoidal rule can be used. Divide the interval into smaller parts, and define v as an average of two values. When dP gets smaller the accuracy increases.

$$\int_{P_1}^{P_n} v \times dP \approx \sum_{j=1}^{n-1} (P_{j+1} - P_j) \times \left(\frac{v_{j+1} + v_j}{2}\right)$$

Equation 3.2-B - Trapezoidal Rule to solve the isentropic mass flux integration[VI]

P: Pressure of the fluid, absolute Pa

n: Fluid condition at the assumed endpoint pressure

j: Increment counter used for summation purposes

3.3 TWO-PHASE FLOW THROUGH A PSV USING THE OMEGA METHOD

The Omega method**[VI]** can be used for PSV sizing when there is either flashing or non-flashing flow. The omega parameter is determined by running an isentropic flash calculation in HYSYS. For low-quality mixtures far from the thermodynamic critical point an adiabatic flash is adequate for the purpose.

Start by calculating the Omega parameter using two specific volume points from different pressures (two-point method). The omega parameter is a measure of the compressibility of the discharged fluid.

$$\omega = 9\left(\frac{v_9}{v_0} - 1\right)$$

Equation 3.3-A Omega Parameter[VI]

v_9 – specific volume at 90% of the inlet pressure, m^3/kg

v_0 – specific volume of the two-phase system at the PSV inlet, m^3/kg

The omega parameter is used to find the critical pressure, P_c, which can determine if there is a critical or subcritical flow through the valve. If P_c is greater than the downstream backpressure, P_a, critical flow occurs. The critical pressure is a function of the inlet PSV pressure and the critical pressure ratio:

$$P_c = \eta_c P_0$$

Equation 3.3-B Critical Pressure[VI]

P_c: Critical pressure, absolute Pa

P_o: Pressure at PSV inlet (Set pressure + 10%), absolute Pa

The critical pressure ratio, $\eta_{c,}$ can be found by the following equation.

$$\eta_c^2 + (\omega^2 - 2\omega)(1-\eta_c)^2 + 2\omega^2 ln(\eta_c) + 2\omega^2(1-\eta_c) = 0$$

Equation 3.3-C Critical Pressure Ratio [VI]

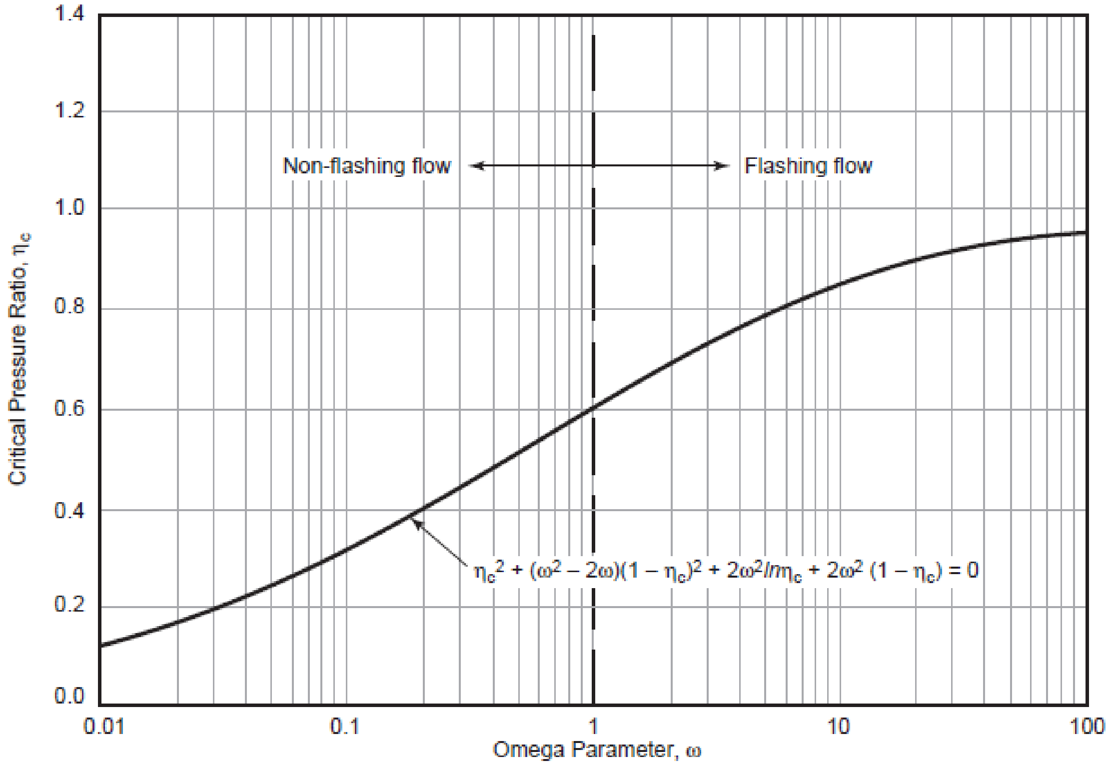

Figure 3.3-A – Critical Pressure Ratio vs Omega Parameter [VI]

For practical reasons this following approximation is proposed from API 520.

$$\eta_c = [1 + (1.0446 - 0.0093431 \times \omega^{0.5}) \times \omega^{-0.56261}]^{(-0.70356 + 0.014685 \times ln\omega)}$$

Equation 3.3-D Critical pressure ratio approach [VI]

To find the mass flux, two different equations should be used depending if there is sub-critical or critical flow.

When $P_c \geq P_a$, the mass flux is calculated as critical flow:

$$G = \eta_c \sqrt{\frac{P_0}{v_0 \omega}}$$

Equation 3.3-E Mass flux when critical flow [VI]

When $P_c < P_a$ the mass flux is calculated as sub-critical flow:

$$G = \frac{\{-2 \times [\omega \ln(\eta_a) + (\omega - 1)(1 - \eta_a)]\}^{1/2}}{\omega\left(\frac{1}{\eta_a} - 1\right) + 1} \sqrt{\frac{P_0}{v_0}}$$

Equation 3.3-F Mass flux when sub-critical flow[VI]

G: Mass flux, kg/s*m^2

P_a: Backpressure, absolute Pa

A: Required area of the PSV

η_a: the ratio between the backpressure and the inlet pressure. As seen from the equation for sub-critical flow.

W: mass flow rate, kg/h

$$A = \frac{0{,}04W}{K_d K_b K_c K_v G}$$

Equation 3.3-G Area required[VI]

The different coefficients are explained more in detail in section 3.6.

3.4 ISENTROPIC FLASH CALCULATION

v_9 in Equation 3.3-A is found by performing an isentropic flash calculation. If the entropy is held constant and the pressure is reduced to 90% of original, what is then the new specific volume? This can be performed by HYSYS.

3.5 C_V FOR VALVES

The flow coefficient C_v is a measure of how much flow the valve can provide. An ordinary orifice only needs data for two diameters, pressures and density to provide a measure for flow. Figure 3.5-A give an impression of the complexity of calculating flow through a valve.

C_v is defined as how many U.S. gallon per minute that will pass through a valve with a pressure difference equal to 1 PSI.

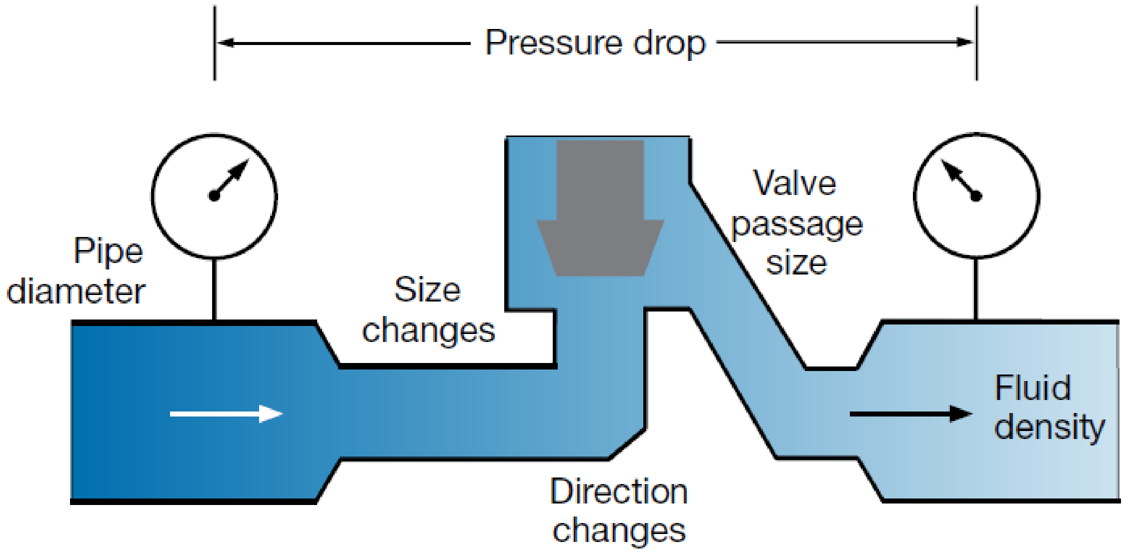

Figure 3.5-A Calculation of flow though a valve[VII]

Since liquid is incompressible the formula for calculating flow is less complex than the formula for gas.

$$q = N_1 C_V \sqrt{\frac{\Delta P}{G_f}}$$

Equation 3.5-A – Flow equation for liquid through a valve[VII]

q = flow rate, L/min

ΔP = pressure drop, bar

G_f = liquid specific gravity

N_1 = Constant for units, 14,42 (when q:[L/min] and P:[bar]

C_V = flow coefficient

The equation for gas flow is more complex due to compressibility of gas and the choked flow condition.

$$q = N_2 C_V P_1 \left(1 - \frac{2\Delta P}{3P_1}\right) \sqrt{\frac{\Delta P}{P_1 G_g T_1}}$$

Equation 3.5-B - Flow equation for gas through a valve at low pressure drop (P_2>1/2P_1)[VII]

N_2 = Constant for units, 6950 (when q:[std L/min], P:[bar] and T_1:[K]

P_1 = Inlet pressure, bar

G_g = Gas specific gravity

The equation for gas flow at high pressure drop is easier since it only depends on the inlet pressure and the temperature. This is due to the choked condition where the gas does not manage to get higher velocity than its sound speed.

$$q = 0{,}471 N_2 C_V P_1 \sqrt{\frac{1}{G_g T_1}}$$

Equation 3.5-C – Flow equation for gas through a valve at high pressure drop (P_2<1/2P_1)[VII]

T_1 = Absolute upstream temperature, Kelvin

3.6 COEFFICIENTS

3.6.1 DISCHARGE COEFFICIENT, K_D

In two phase flow there is always a possibility for different phase velocities, called slip, for gas and liquid. The HEM calculations are performed under the assumption that there is no-slip. To compensate for this assumption a discharge coefficient is used; K_d. Typically the PSV-manufacturer gives the discharge coefficient for liquid and gas separately. A way to create the coefficient for the fluid is to use a volume-weighted value.

$$K_d = \frac{(q_G K_{dG}) + (q_L K_{dL})}{q_G + q_L}$$

Equation 3.6-A [VIII]

q_G: Gas flow (actual) m^3/h
q_L: Liquid flow (actual) m^3/h
K_{dG}: Gas discharge coefficient
K_{dL}: Liquid discharge coefficient

There has been debates regarding this discharge coefficient and the approach in Equation 3.6-A Joseph C. Leung[VIII] suggest that for flashing (two phase) discharge at low quality, K_d should be near unity instead of approaching K_{dL} as suggested by Equation 3.6-A The method he recommends for determine K_d contains the omega parameter, ω.

His results can be used to determine the discharge coefficient K_d when the K_{dL} or the K_{dG} is given from the manufacturer.

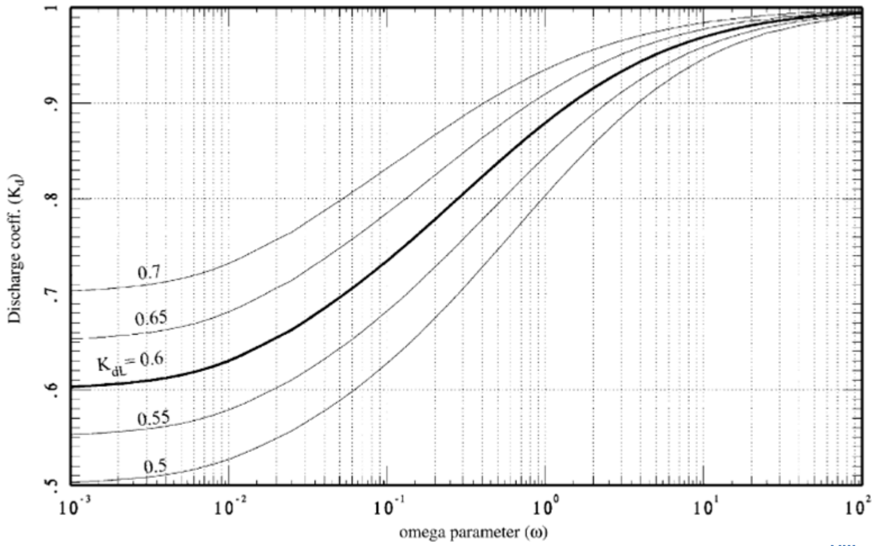

Figure 3.6-A - K_d as function of ω for K_{dL} VIII

K_d can be found by using Figure 3.6-A if K_{dL} is known or with Figure 3.6-B if K_{dG} is known.

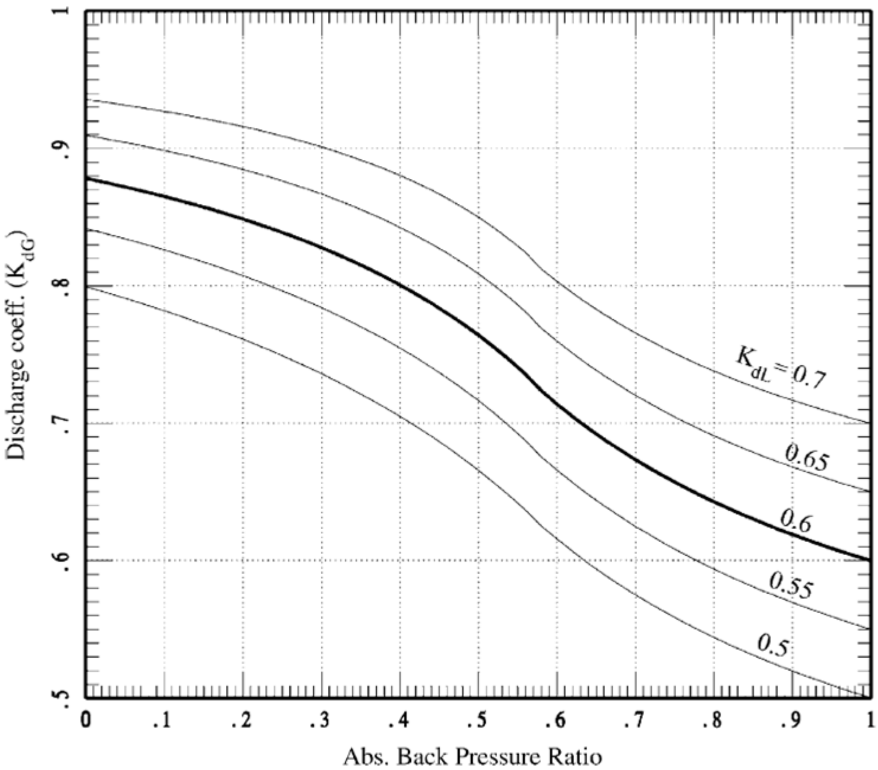

Figure 3.6-B - K_{dG} as a function of back pressure ratio VIII

The published certified K_{dG} and K_{dL} has to be converted to the actual value by diving by 0,9 (Safety factor) before the figures are used.

3.6.2 BACKPRESSURE CORRECTION FACTOR, K_B

K_b is the correction factor for vapour due to back pressure in the flare system. This factor applies only to balanced-bellows only and the manufacturer gives this coefficient.

4 METHODOLOGY

Gas blowby happens when the oil level in multi-phased equipment drops below oil outlet level. This might happen if the downstream control valve stuck fully open due to a failure. According to API Standard 521[IX] it is stated that the control system cannot be considered as a barrier against a worst case scenario. Hence it must be considered that the control valve could be fully open while the emergency valves are open. The next stage is designed to handle a lower pressure. When the oil level drops, gas starts to go through the oil-outlet and the pressure starts to increase until the set pressure is reached and the Pressure Safety Valves (PSVs) starts to open. API Standard 521 states that the source of gas blowby has to be set to trip pressure[II]. That assumption is based upon that the operator can freely choose to operate just below the trip pressure if that is wanted.

The PSV has to be sized to handle both the gas coming from the gas blowby source while handling the gas coming from other inlets as well.

As discussed in section 7.5 the PSVs has to handle both the gas and the liquid arriving, due to potential closed outlets.

Some may claim it is sufficient to assume that a gas blowby scenario will happen without the outlets of the equipment being closed. Both results for the Alvheim inlet separator and the 2nd stage separator are presented in this thesis.

The following gas blowby scenarios are presented in this section:

- Alvheim/3rd party inlet separator
  - Gas blowby from 2nd stage compressor scrubber
  - Gas blowby from 2nd stage compressor scrubber with closed outlet
- 2nd stage separator
  - Gas blowby from Alvheim inlet separator
  - Gas blowby from Alvheim inlet separator with closed outlet
    - Under normal gas blowby conditions
    - Assuming gas blowby rate as maximum gas into the Alvheim inlet separator
    - Assuming that test-pressure is reached in the 2nd stage separator
- Produced water degassing drum
  - Gas blowby from Alvheim inlet separator with closed outlet
- Glycol Flash drum
  - Gas blowby from the Glycol Contactor with closed outlet
- Cargo Tanks
  - Gas blowby from the 2nd stage separator

In addition the inlet separators can experience a gas blowby scenario from a well referred to as an inadvertent opening of a pressurised flow line. The scenario when a 1st stage separator handles a gas blowby from a well is covered in a previous verification done by Vetco[1].

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[1] Marathon document, Verification of Inlet Separator PSV Capacity upon Volund 3150-T-VAB-P-TN-00-0001-00

The methodology for the Alvheim inlet separator is carefully explained. The other pressurized vessels follow the same methodology more or less and the methodology is not repeated unless it is necessary.

4.1 ALVHEIM/3RD PARTY INLET SEPARATOR – GAS BLOWBY FROM 2ND STAGE COMPRESSOR SCRUBBER, TRAIN 100/200

There are two first stage separators, the Alvheim inlet separator and the 3rd party inlet separator. The majority of the inlet flow to the Alvheim separator is from the 18" production flow line from Alvheim manifold. Figure 4.1-A shows that there are also three 2" lines coming from the glycol contactor, 2nd stage export compressor scrubber train 100/200 and from the fuel gas scrubber.

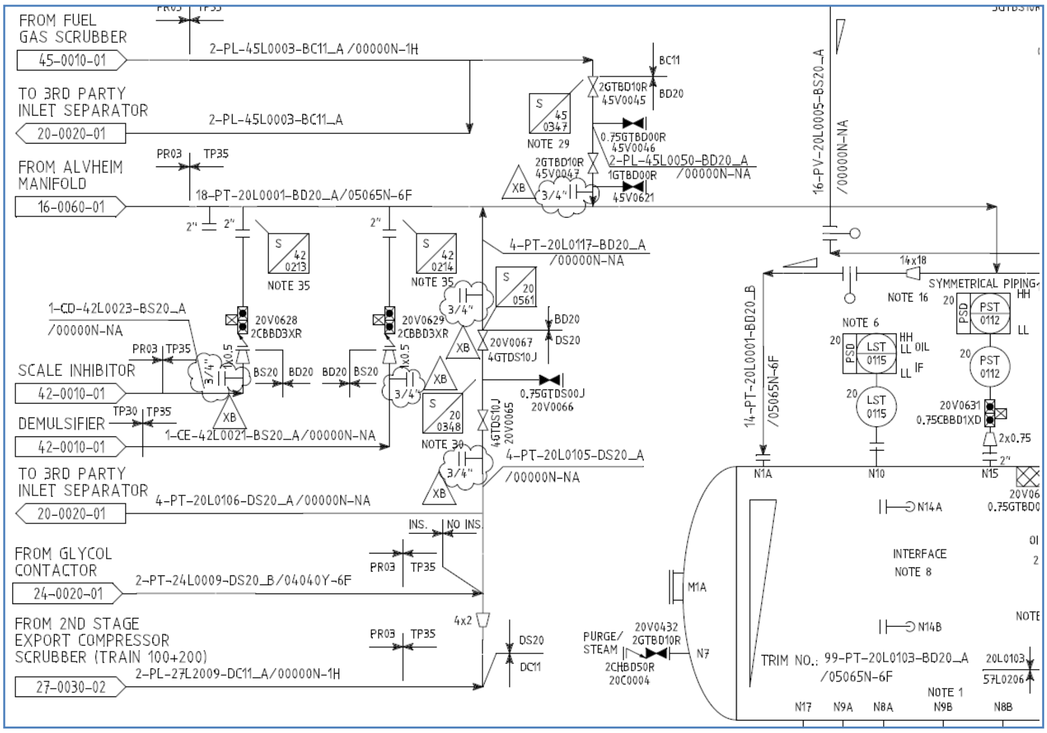

Figure 4.1-A - P&ID Alvheim inlet separator inlets

The PSV set pressure for the Alvheim separator is 30barg. With an allowable overpressure of 10% it means that the PSV will be fully open at 34,1 bara.

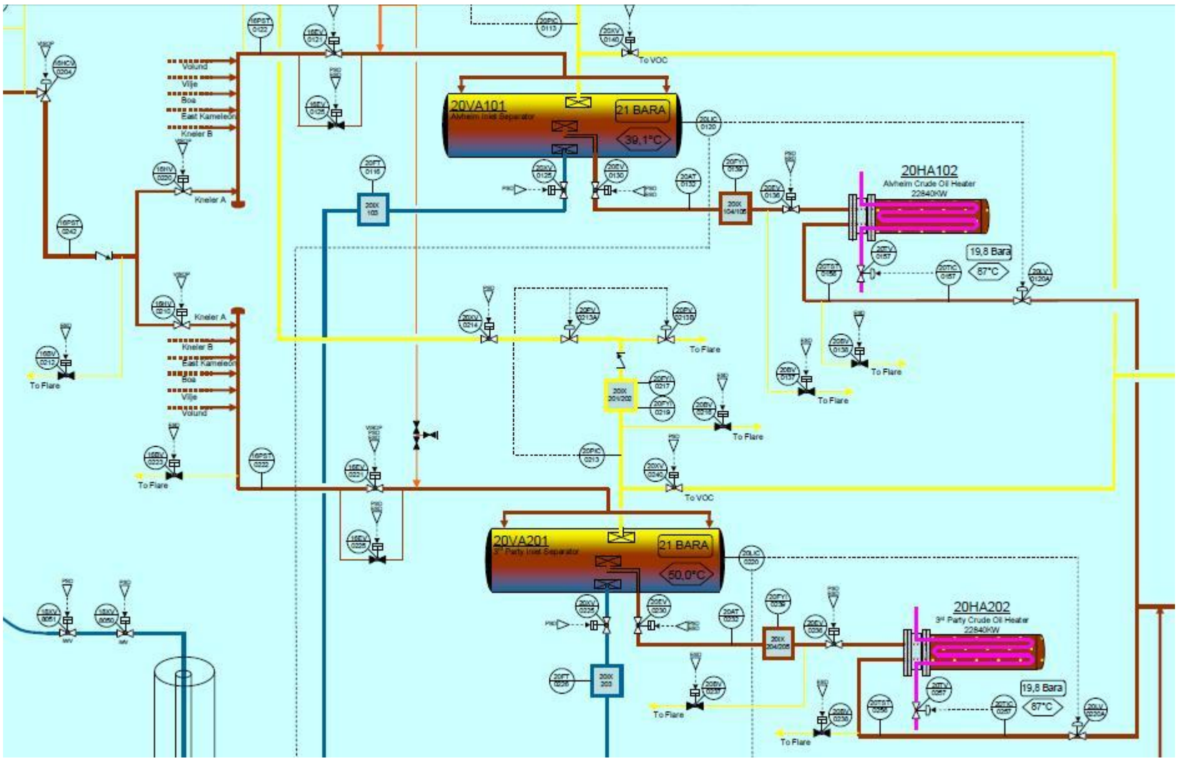

Figure 4.1-B Schematic drawing of the two inlet separators[2]

One gas blowby scenario for the Alvheim inlet separator is if the oil level in the 2nd stage compressor scrubber drops and the gas starts to flow through the oil-outlet. Then gas will start to flow from the 2nd stage compressor scrubber to Alvheim inlet separator until the PSVs open. At the same time there is flow from the other inlets.

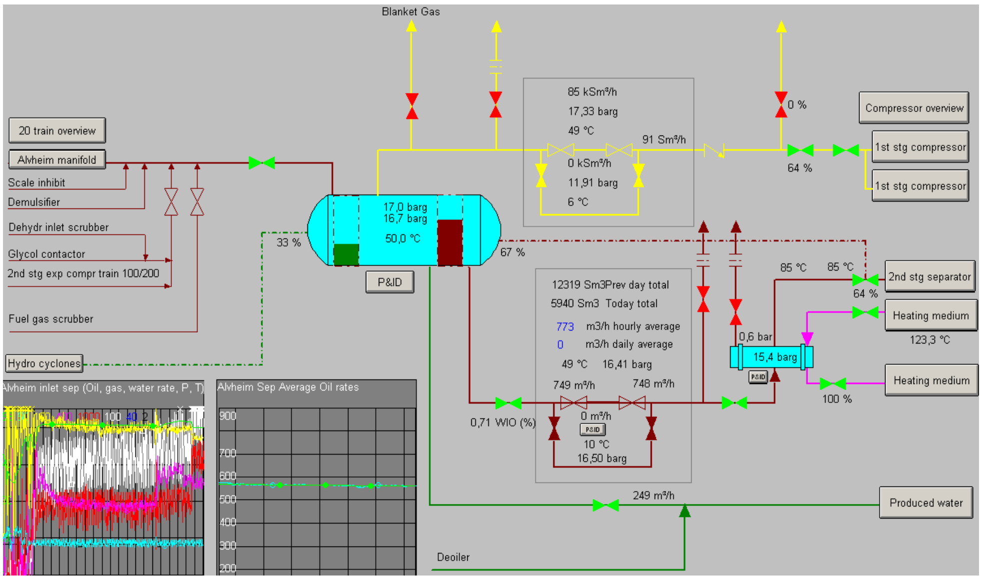

Figure 4.1-C - Flow under normal operating conditions[3]

[2] Marathon document, Alvheim Overview Drawing, 3203-0-MPC-P-XA-00-0001

[3] Screenshot from PI ProcessBook

4.1.1 *SIMULATION - GAS BLOWBY FROM 2ND STAGE COMPRESSOR SCRUBBER WITHOUT CLOSED OUTLET*

A simulation file developed for the Alvheim Process is used for the compositions used in the simulations.

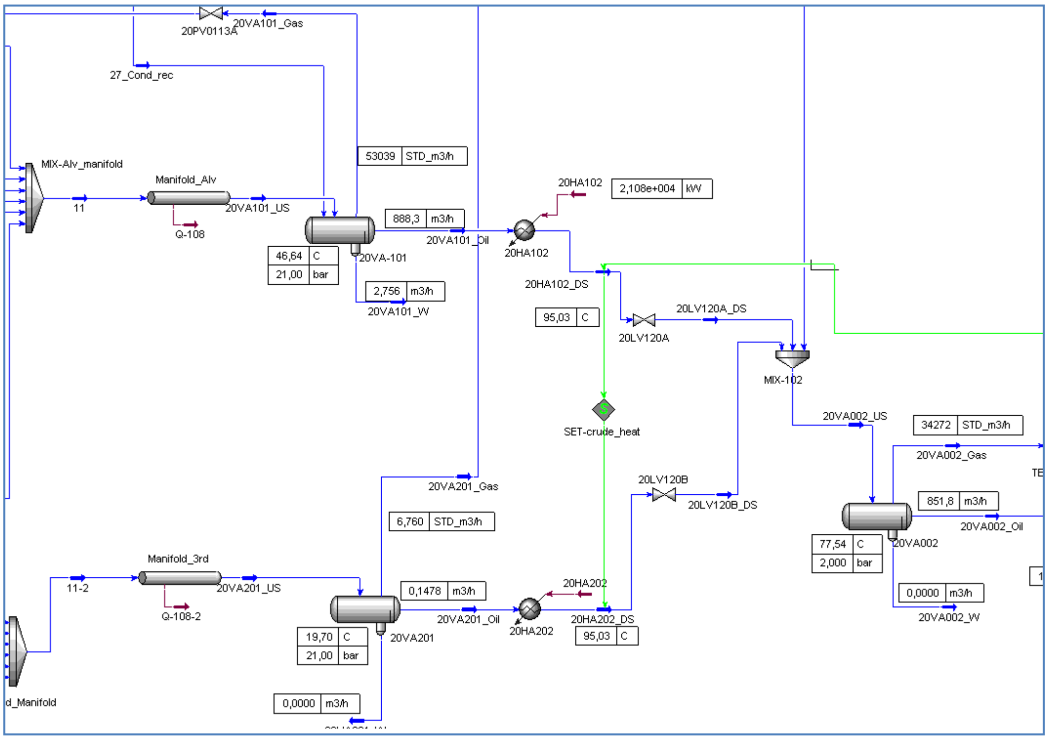

Figure 4.1-D – A limited view of the HYSYS file for the Alvheim process area

Based on this file (Figure 4.1-D) the compositions are defined for the different streams. The used compositions are also gathered in Appendix 9.3. The temperature, pressures and flow rates are inserted by evaluation. The fluid package is Peng-Robinson.

The following set up is used in HYSYS for this scenario:

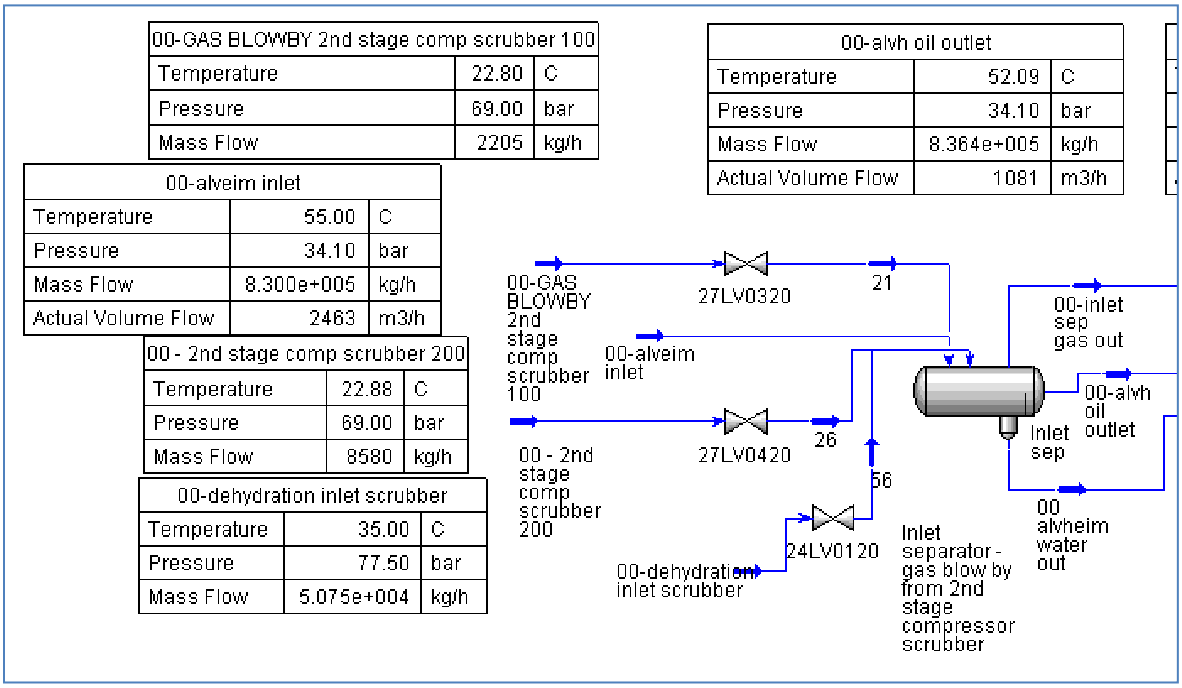

Figure 4.1-E- HYSYS- Alvheim inlet separator gas blow by scenario

4.1.1.1 *ASSUMPTIONS*

Assume that the gas out of the separator in Figure 4.1-E is the gas escaping through the PSV (00-inlet sep gas out).

There will be flow from the glycol contactor which normally operates under 58,4 bara. To be conservative the simulation is under 77,5bara which is the trip pressure for the equipment.

The fuel gas scrubber operates with pressures below 39bara. The valve control the liquid level is an on/off valve which normally is closed. We assume that there will be no flow from the fuel gas Scrubber. The small contribution of oil flowing from this scrubber could in any case be neglected.

4.1.1.2 *C_V SIZING*

The C_V constant is used to find the maximum possible flow through the upstream control valve. The maximum flow rate will be defined as what can go through the control valve with the given pressure drop. It is a conservative approach independent of the actual gas production.

Table 4.1-A - Alvheim Inlet separator CV constants

Control Valve	C_V	Eq%	Upstream Pressure (bara)	Downstream Pressure (bara)	Temperature (^{0}C)

27LV0320	2,5[8]	100	69	34,1	22,8
27LV0420	2,5[8]	100	69	34,1	22,8
24LV0120	9[8]	100	77,5	34,1	35

Using HYSYS the maximum flow rate can be performed with an iterative approach. Let HYSYS calculate the C_V for two different flow rates when the valve is 100% open and when both the temperature and pressure is unchanged. These two points create an equation which can be used to find the flow rate that gives the correct C_V. The relationship between the points is linear.

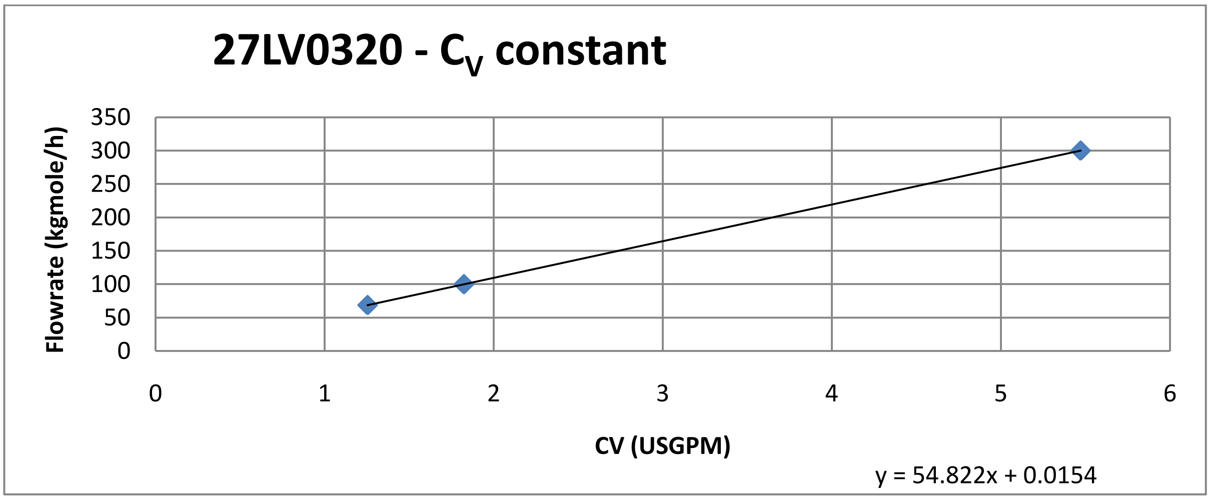

Figure 4.1-F – C_V vs flow rate in HYSYS 27LV0320

Use the equation found in Figure 4.1-F. When the correct CV is entered into the equation, the flow rate is given. The flow in this case is 137 kgmole/h =3034 kg/h. This is an iterative approach which is easily performed in HYSYS. Alternatively it is possible to do iterative guesses of the flow rate until the correct CV is reached. That approach is used for defining the maximum flow rate through a valve in this report. Figure 4.1-F was showed only to explain the concept of the iterative approach.

Since the CV calculation can change depending on which set up is used in HYSYS, the designer calculation software is used as a verification of the CV calculations performed in HYSYS. The calculations performed with the kentintrol software are presented in the appendix.

4.1.1.3 INPUT VALUES

The pressure in the 2nd stage compressor scrubber is defined as PSV set pressure, which is 69bara. This is more conservative than the requirement from the API standard of trip pressure. The temperature is set to 23^{o}C, which is the operating temperature.

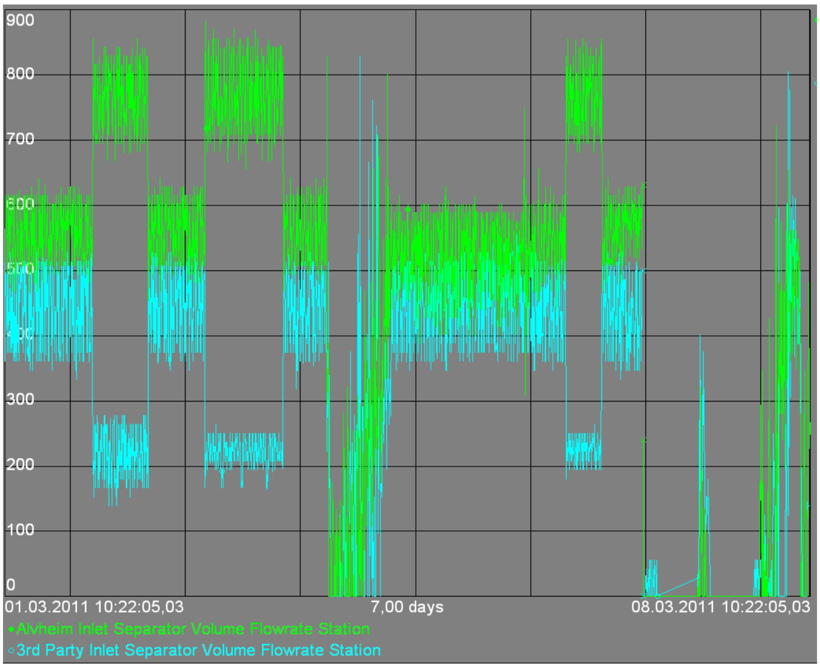

Figure 4.1-G Data showing the relation between 3rd party and Alvheim inlet separator

In Table 4.1-C it is showed that normal flow rate of oil out from the Alvheim inlet separator is around 800 m^3/h. The flow meter needs to operate with flow rates around 800 Am^3/h due to accuracy. By choosing the Alvheim inlet stream to be 830 000 kg/h the oil phase actual rate is 998,3 Am^3/h which is conservative. Figure 4.1-G visualises the relation between the 3rd party and the Alvheim inlet separator regarding flow rates. When the Alvheim inlet separator produces much the 3rd party separator produces less. The total production is around 1000 Am^3/h (Table 4.1-C).

Table 4.1-B – Input values to Alvheim inlet separator simulation

	Gas blowby 2nd stage compressor scrubber (100)	Alvheim inlet stream	2nd stage compressor scrubber (200)	Dehydration inlet scrubber
Mass flow, kg/h	2205	830000	8580	50 750
Temp, ^0C	22,8	55	22,8	35
Pressure, bara	69	34,1	69	77,5
Composition	27VG012_gas	20VA101_US	27VG102_Cond	24VG_001_cond

In Table 4.1-C some guidelines for production is given due to capacity.

Table 4.1-C – Guidelines PSVs capacity[4]

	Actual oil flow rate (m^3/h)	Actual water flow rate (m^3/h)	Gas flow (Sm^3/h)
Alvheim inlet separator	840	475	140 000
3rd party inlet separator	840	475	140 000
2nd stage separator	1060	5,6	29500
Cargo tanks			14000

4.1.1.4 *HEM PROCEDURE*

The HEM calculation follows the procedure in section 3.3 and the results are displayed in section 5.1.

4.1.1.5 *ISENTROPIC FLASH CALCULATION*

The calculation follows the procedure presented in section 3.3.

- HYSYS is used to perform the isentropic flash calculation which obtains the v_9.

As stated in section 4.1.1.1 the gas out from the separator is used for the area calculations.

Table 4.1-D – Input values for one Isentropic flash calculation in HYSYS

	Flow rate(kg/h)	Pressure(bara)	Temp(^oC)	Entropy(J/gmole*C)
Inlet stream	53 660	34,01	51,61	161,1
Isentropic 90% flash	53 660	30,61	45,25	161,1

[4] Marathon document, Senior Process Engineer Håvard T. Haslerud, Alvheim limitations.pptx

Entropy flash calculation		
Molar constant entropy	318.4	kJ/kgmole-C
Inlet density	85.55	kg/m3
90% density	76.96	kg/m3
P0	16.36	bar
P9	14.72	bar
Mass flow	6.186e+005	kg/h

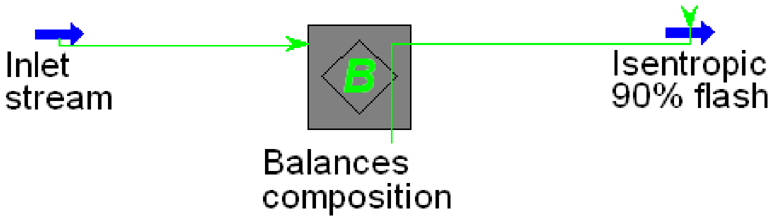

Figure 4.1-H – HYSYS – Example for set up for determine the isentropic flash calculation

Define the inlet stream in Figure 4.1-H from the fluid entering the PSV (Table 4.1-D). Then the composition, pressure and temperature are correct. Start the solver, and v_0 and v_9 will appear. What the simulator does is quite simple. The Balance operator just copies the composition from Inlet stream to Isentropic 90% flash. Through a spreadsheet the entropy for “Isentropic 90% flash” stream is copied from the “Inlet stream”. The same applies for the molar flow. The pressure downstream is defined as 90% of the pressure upstream. HYSYS then calculates the density at these conditions given the pressure, flow and entropy.

This way the omega parameter, ω, can be determined using Equation 3.3-A.

Another way to solve this in HYSYS is to go to attachment – utilities in the inlet stream. Create a new “attached utility”. Define entropy to be constant (State value) and pressure to be incremental between the inlet pressure and 90% of the inlet pressure. Define mass density as a dependent property. The result is then shown in the performance tab.

4.1.1.6 COEFFICIENTS FOR THE HEM CALCULATION

For the Alvheim inlet separator the procedure described in section 3.6.1 is used. The result of this is presented in section 5.1.

4.1.2 SIMULATION – GAS BLOWBY FROM 2ND STAGE COMPRESSOR SCRUBBER AND CLOSED OUTLETS

Since the pressure in the Alvheim inlet separator is larger than the trip pressure, the downstream equipment may trip as well. A calculation assuming closed outlet at the same time is therefore performed. This matter is discussed more in section 7.5 regarding the 2nd stage separator.

The compositions and flow conditions are the same as in Table 4.1-B. The methodology is the same as for section 4.1.1, except in this simulation there is a mixer combining all the outlets, since all the fluids needs to escape through the PSV (Figure 4.1-I).

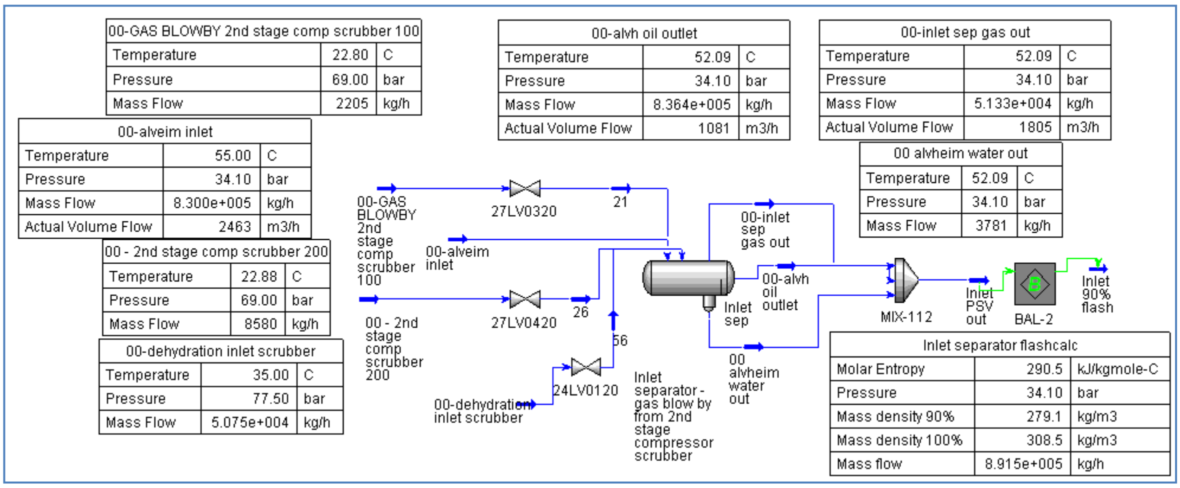

Figure 4.1-I - HYSYS set up Alvheim inlet separator Gas blowby & closed outlets

4.2 ALVHEIM/3RD PARTY INLET SEPARATOR – GAS BLOWBY FROM THE DEHYDRATION INLET SCRUBBER

Another gas blowby source for the Alvheim inlet separator could be the dehydration inlet scrubber. This could happen if the control valve 24LV0120 by some reason should be locked fully open. The liquid level would then drop, and in the gas blowby scenario the primary pressure protection does not function.

4.2.1 SIMULATION – GAS BLOWBY FROM THE DEHYDRATION INLET SCRUBBER WITHOUT CLOSED OUTLET

The same set up showed in Figure 4.1-E is used for this scenario. Now the source of the gas blowby is the dehydration inlet scrubber. The methodology is more or less the same as described in section 4.1.1.

4.2.1.1 ASSUMPTIONS

The same assumptions as made in 4.1.1.1 are valid here as well. The flow from the Alvheim manifold will be unchanged. 2nd stage compressor scrubber 100 will be the same as train 200.

4.2.1.2 SIZE CV

Valve 24LV0120 has to be sized again because of the change in composition. 2nd stage compressor scrubber 100 will be exactly similar as train 200.

4.2.1.3 INPUT VALUES

Table 4.2-A – Input Gas blowby from Dehydration to Alvheim inlet separator

	2nd stage compressor scrubber (100)	Alvheim inlet stream	2nd stage compressor scrubber (200)	Gas blowby Dehydration inlet scrubber
Mass flow, kg/h	11 180	830 000	11 180	9965
Temp, ^{0}C	22,8	55[5]	22,8	35
Pressure, bara	91,5	34	91,5	86
Composition	27VG102_cond	20VA101_US	27VG102_Cond	DRY GAS

The pressure in 2nd stage compressor scrubber 100/200 and Gas blowby dehydration inlet scrubber is at set-pressure as a conservative approach.

[5] Conservative observed normal temperature.

4.2.2 SIMULATION – GAS BLOWBY FROM THE DEHYDRATION INLET SCRUBBER WITH CLOSED OUTLET

Since the pressure in the Alvheim inlet separator is larger than the trip pressure, the downstream equipment will most likely trip as well. A calculation assuming closed outlet at the same time is therefore performed.

Use the same input data as Table 4.2-A and the following set up in HYSYS is used. The only difference from the simulation without closed outlet is that all the fluid entering the separator needs to escape through the PSVs. This is simulated using a mixer (Figure 4.2-A).

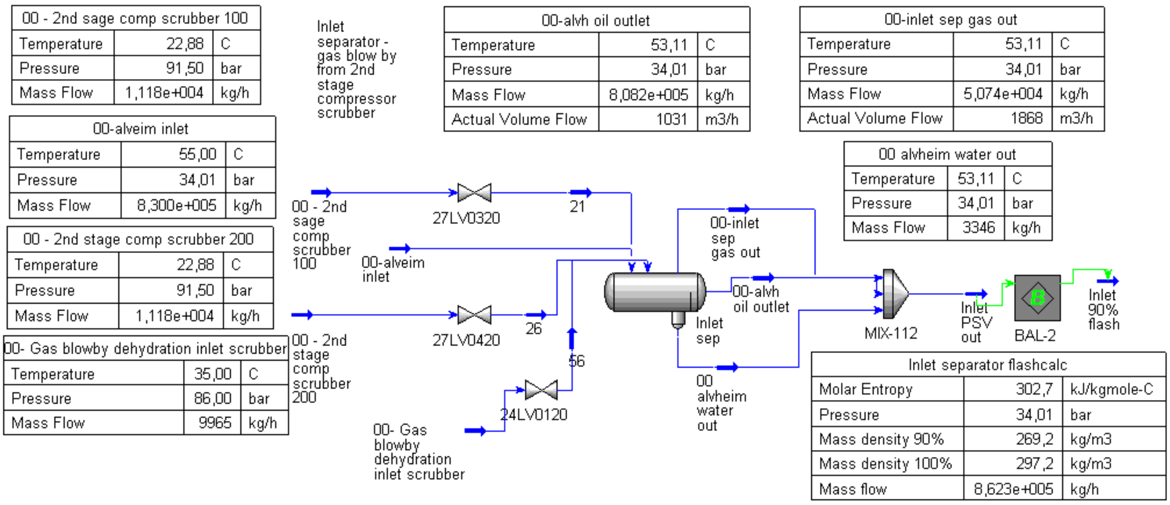

Figure 4.2-A – HYSYS set up Gas blowby from the dehydration inlet scrubber & closed outlets

4.3 2ND STAGE SEPARATOR

Assuming a failure with the control valve, the oil level in the upstream separator could decrease below oil outlet level. Gas can flow down to the second stage separator. A gas blowby situation occurs and it leads to a pressure increase in the second stage separator. When the set pressure of 15bara is reached, the PSVs will start to open, and they will be fully open within the allowable overpressure which in total is 16,5bara. The PSV must be sized to handle the gas blow by from the Alvheim inlet separator and at the same time high production flow from the 3rd party inlet separator and in addition oil from produced water cyclones, 2nd stage separator produced water pumps, crude oil pumps, 1st stage recompressor pumps (train 100 and 200), 1st stage export compressor scrubber (train 100 and 200) and condensate from glycol flash drum.

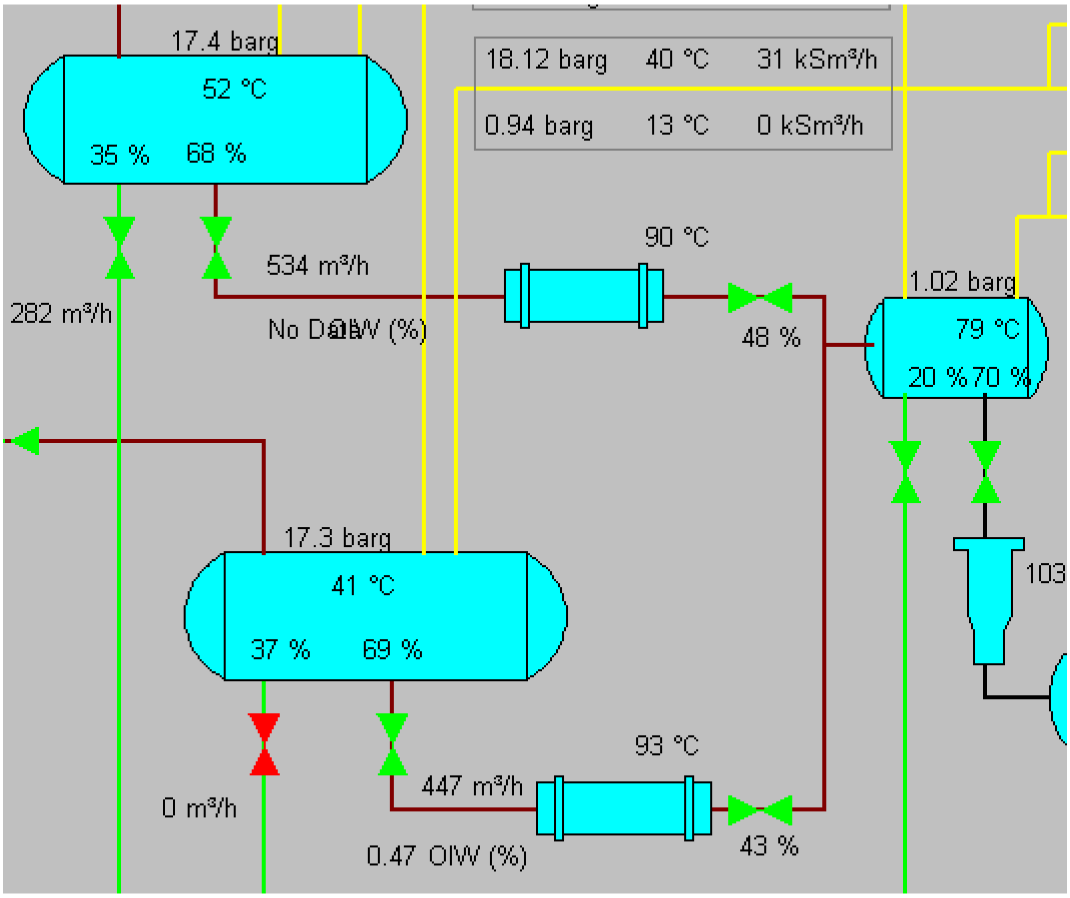

Figure 4.3-A - Drawing showing normal operation conditions for the inlet separators and for the 2nd stage separator

4.3.1 *SIMULATION – GAS BLOWBY FROM ALVHEIM INLET SEPARATOR WITHOUT CLOSED OUTLETS*

The compositions are collected from Appendix 9.3. Peng-Robinson fluid package is used and Figure 4.3-B shows the set up in HYSYS.

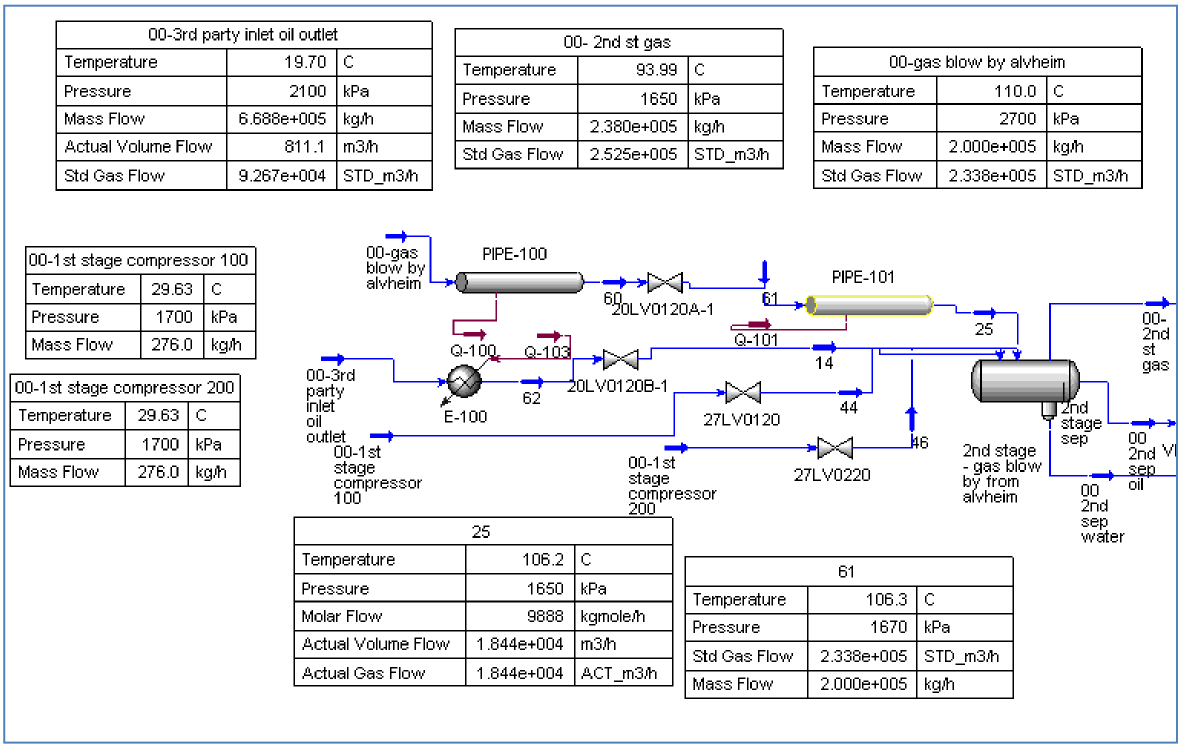

Figure 4.3-B – HYSYS set up Gas blowby 2nd stage separator

The flow rates, pressures and temperatures are inserted on the basis of evaluations. The methodology is more or less the same as in section 4.1.1

4.3.1.1 ASSUMTIONS

The gas coming out from the separator (Figure 4.3-B) is used as the basis for the HEM calculations (Flow rate, composition and pressure). In other words the oil and water will exit trough the outlets of the separator and not the PSV.

When calculating the needed area for flow through the PSV, the other inlets to the 2nd stage separator have to be included. At the moment when the PSVs are fully open the pressure inside the second stage will be the set pressure + 10% overpressure, 16.5bara. If the source has an operating pressure that is below 16.5bara it does not flow into the 2nd stage separator at fully open PSVs.

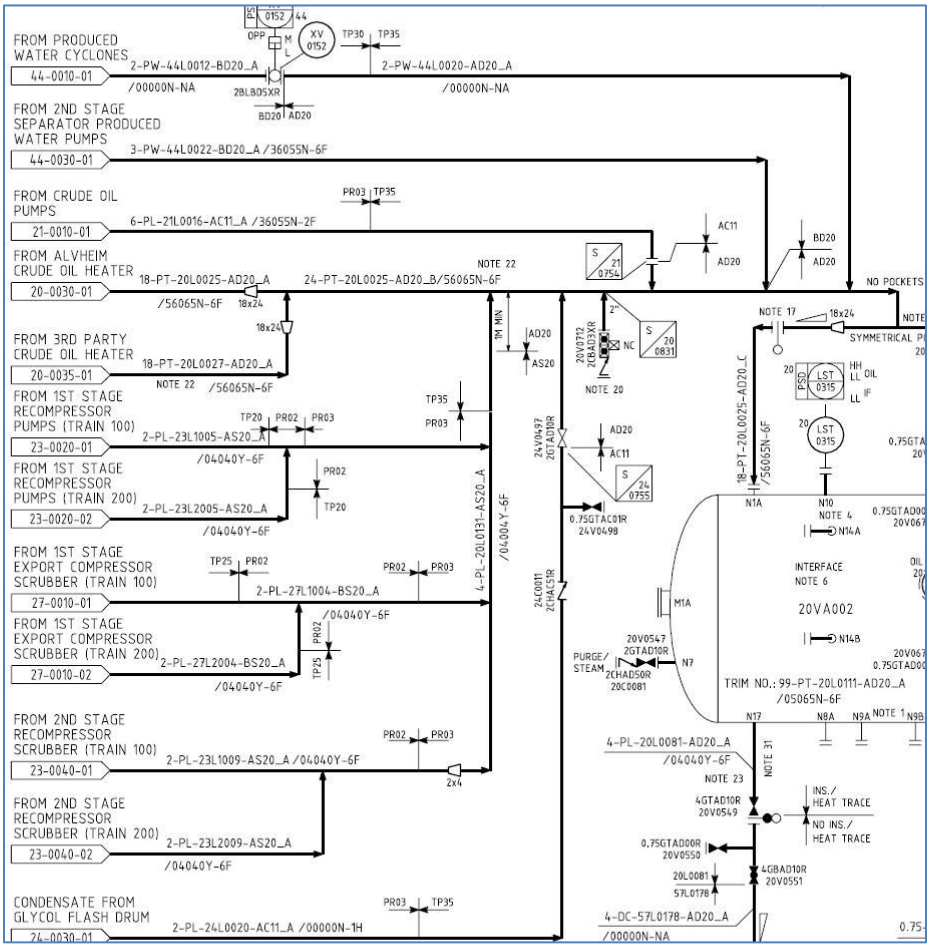

Figure 4.3-C – A view from the second stage separator P&ID

Figure 4.3-C shows that oil from the centrifuges enters the second stage separator. The highest pressure observed in December 2010 – January 2011 is 4,5barg in the low pressure centrifuges and 14,7barg in the high pressure centrifuges. The set pressure is 14barg[6] , so there will not be flow from this source with the gas blowby scenario.

Normal operating pressure from the Crude oil pumps is 6barg. The set pressure for PSV is also 14barg[6], this means that there will be no flow from this source with the gas blowby scenario.

The normal operating pressure in the oil outlet from the 1st stage recompressor pumps (train 100/200) is less than 2,5barg and the set pressure for the PSV protecting the scrubber is 14barg. There will be no flow from this source with the gas blowby scenario.

Normal pressure for the 2nd stage recompressor pumps (train 100/200) is around 4-5barg and the set pressure for the PSVs is 14barg, which means that there will be no flow from this source with a gas blowby scenario.

The gas phase in from the glycol flash drum has an operating pressure less then 3,5barg, which leads to no flow to the second stage separator for this scenario.

[6] NOR Instruments, Instrument Data Sheets for PSV's 3203-T-NOR-R-I-DS-00-0001-00

The oil outlet from the 1st stage export compressor scrubber has a normal pressure of 16barg. When the pressure in the second stage separator increases up to 16,5bara the pressure in the oil outlet will increase naturally. A natural response to this would be to open the valve on the oil outlet more. This is also accounted for in the simulation.

4.3.1.2 PIPE SEGMENTS

The first conservative calculations (not showed in the report) give a need for higher area in the PSVs than there is as built. Pipe segments are implemented in the HYSYS model to take account for pressure drop in the pipe (Figure 4.3-B).

The pressure drop from 3rd party oil is neglected since a certain volumetric flow is obtained by the control valve downstream the inlet separator. The pressure drop from the compressor is neglected due to the small amount of flow.

Upstream control valve 20LV0120A there is a crude heater which will also have a certain pressure drop. It is stated that the maximum pressure drop across this heater is 0,51bar[7]. This calculation is done with production fluids (HC & produced water). In other words this maximum pressure drop in a gas blowby situation would be higher. In this report it is assumed a pressure drop of 0,5bar which is subtracted from the pressure in “00-gas blowby Alvheim”.

Sometimes HYSYS have problems solving the pressure drop in the pipe between 20LV0120A and the 2nd stage separator. As a result of this a static pressure drop of 0,2bar is chosen based on similar fluids, flow rates and pressure drops.

4.3.1.3 CV SIZING

Table 4.3-A – Known parameters for Alvheim inlet separator oil Control Valve

Control Valve	CV	Eq%	Upstream Pressure (bara)	Downstream Pressure (bara)	Temperature (^0C)
20LV0120A	670[8]	100	27,0[9]	16,5	102[9]
20LV0120B	670[8]	100	27,0[9]	16,5	102[9]
27LV0120	0,45[6]	100	28,0[9]	16,5	35
27LV0220	0,45[6]	100	28,0[9]	16,5	35

An iterative approach is used to find the correct flow rate entering the 2nd stage separator through the control valve. By changing the flow rate and calculating the CV, the right flow rate with a given pressure drop can be found.

Kentintrol, which is the vendor has an own sizing software which has been used to verify the HYSYS calculations. This is presented in the Appendix.

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[7] Marathon document, Pressure drop across crude heaters, 3203-T-VAB-P-DS-20-0509-00
[8] Kentintrol document, Control valves, 3203-T-KIV-I-CA-A-0001-00
[9] High high alarm. When the equipment will trip

4.3.1.4 INPUT VALUES

Table 4.3-B – Input values 2nd stage sep gas blowby from Alvheim

	Gas blowby Alvheim	3rd party oil outlet	1st stage compressor (100)	1st stage compressor (200)
Mass flow, kg/h	200 000	668 800	276	276
Volumetric flow, Am^3/h	10 970	835	0,4238	0,4238
Temp, ^0C	102	46,6	35	35
Pressure, bara	27,0	21	17	17
Composition	20VA101_Gas	20VA201_Oil	27VG101_cond	27VG101_cond

The Gas blowby rate is defined by the pressure drop and the C_V constant of a fully open control valve.

The rate from 3rd party oil outlet is defined to be around 800 Am^3/h of oil. The meter downstream the inlet separator starts to compromise accuracy when the flow rates go higher than 800 actual m^3/h of oil. This will be controlled by the control valve 20LV0120B.

4.3.1.5 HEM PROCEDUES

The calculation follows the same procedure as the one in section 4.1.1.4.

4.3.1.6 COEFFICENTS

For the 2nd stage separator the procedure described in section 3.6.1 is used. The result of this is presented in section 5.1.

4.4 2ND STAGE SEP GAS BLOWBY AND CLOSED OUTLETS

When the pressure in the 2nd stage separator increases up to set pressure the 1st stage recompressor and the Crude oil pumps downstream will trip. In other words the only way out of the 2nd stage separator is through the PSVs. So even if API 521 states that double jeopardy should not be taken into account, we have to consider both blocked outlets and gas blow by in this case.

The same procedure as in section is being used. Figure 4.4-A shows how the set up is in HYSYS. Assume that all the fluid entering the 2nd stage separator has to exit through the PSVs.

The only difference from the scenario in section 4.3.1 is that there is a mixer leading all the fluid through the PSVs (Figure 4.4-A).

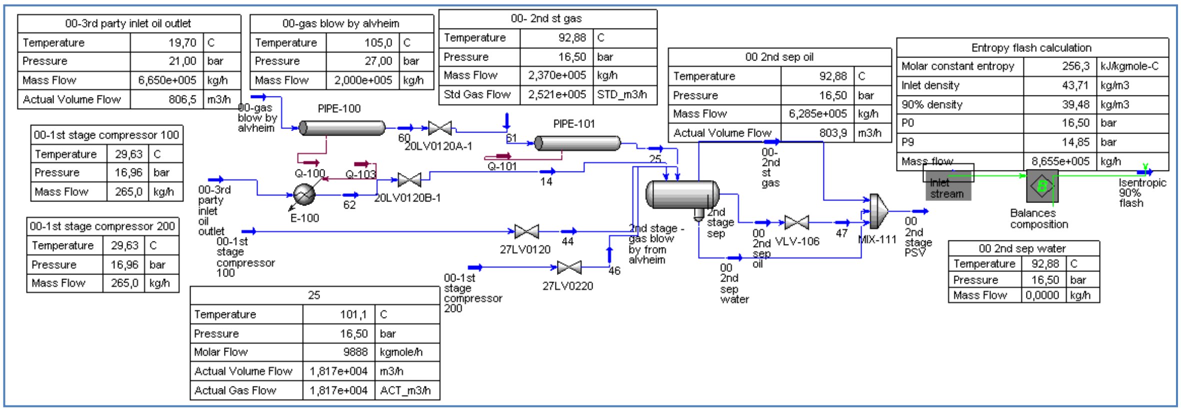


Figure 4.4-A - HYSYS 2nd stage blowby and closed outlets

4.4.1 2ND STAGE SEPARATOR GAS BLOWBY&CLOSED OUTLET (ASSUMING DIFFERENT GAS BLOWBY RATE)

This scenario is a result of the discussion in section 7.5.1. The scenario is similar as the one showed in Figure 4.4-A. The gas blowby rate is defined as max gas into the Alvheim inlet separator which is 140 000 Sm^3/h.

4.4.2 2ND STAGE SEPARATOR GAS BLOWBY&CLOSED OUTLET (ASSUMING THAT TEST-PRESSURE IS REACHED)

This scenario is a result of the discussion in section 7.5.2. The scenario is similar as the one showed in Figure 4.4-A. The pressure in the 2nd stage separator is set to test pressure which is 21bara. Do to the high pressure in the 2nd stage separator there will be no flow from the 3rd party inlet separator and the 1st stage compressor. The gas blowby rate is also much smaller due to the decreased pressure drop. See section 4.4.2 for the result.

4.5 PRODUCED WATER DEGASSING DRUM GAS BLOWBY FROM 2ND STAGE SEPARATOR

The degassing drum is the final stage before the water enters the water injection booster pumps. This degassing drum can experience gas blowby from either the Alvheim Inlet separator or the 3rd party inlet separator. The methodology is the same as used for the 2nd stage separator in section 4.1.2.

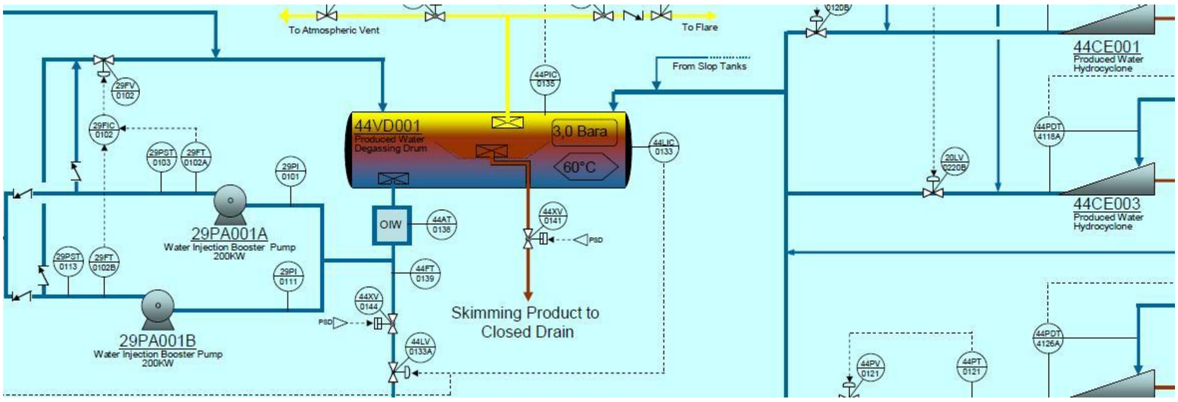


Figure 4.5-A Schematic drawing of the Produced Water Degassing Drum

Normal operating pressure in the degasser is around 1,2barg. Normal pressure in the inlet separators can be found in Figure 4.3-A.

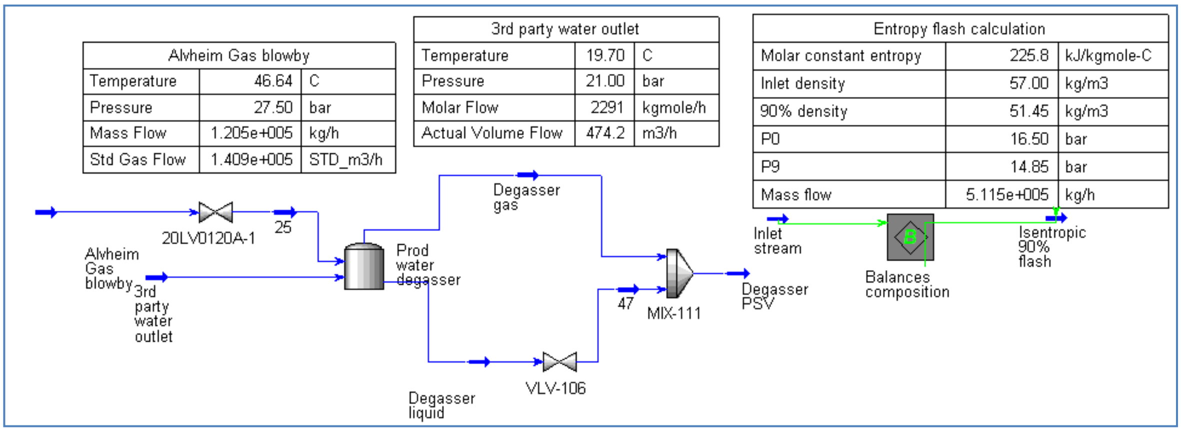


Figure 4.5-B – Set up in HYSYS for degassing drum gas blowby scenario

The input values are displayed in the table below. The max gas blowby rate is defined by the C_V constant and the pressure drop over the control valve. The water rate is defined by maximum water capacity[4] for the 3rd party inlet separator.

Table 4.5-A - Input values for Degassing drum

	Alvheim Gas blowby	3rd party water outlet	20LV0120B
Mass flow, kg/h	120 500	391 000	
Temp, ^{0}C	46,64	19,7	

Pressure, bara	27,5	21	
Composition	20VA101-Gas	20VA201-W	
C_V			610

4.6 GLYCOL FLASH DRUM – GAS BLOWBY FROM GLYCOL CONTACTOR

The same methodology as in section 4.1.2 is followed to calculate the required area for the PSV installed at the Glycol flash drum. A gas blowby can happen if by some reason the control valve downstream the Glycol contactor 24LV0155 (Figure 4.6-A) is fully open and the liquid level drops. The gas blowby rate is defined by the C_V and pressure drop of 20LV0155.

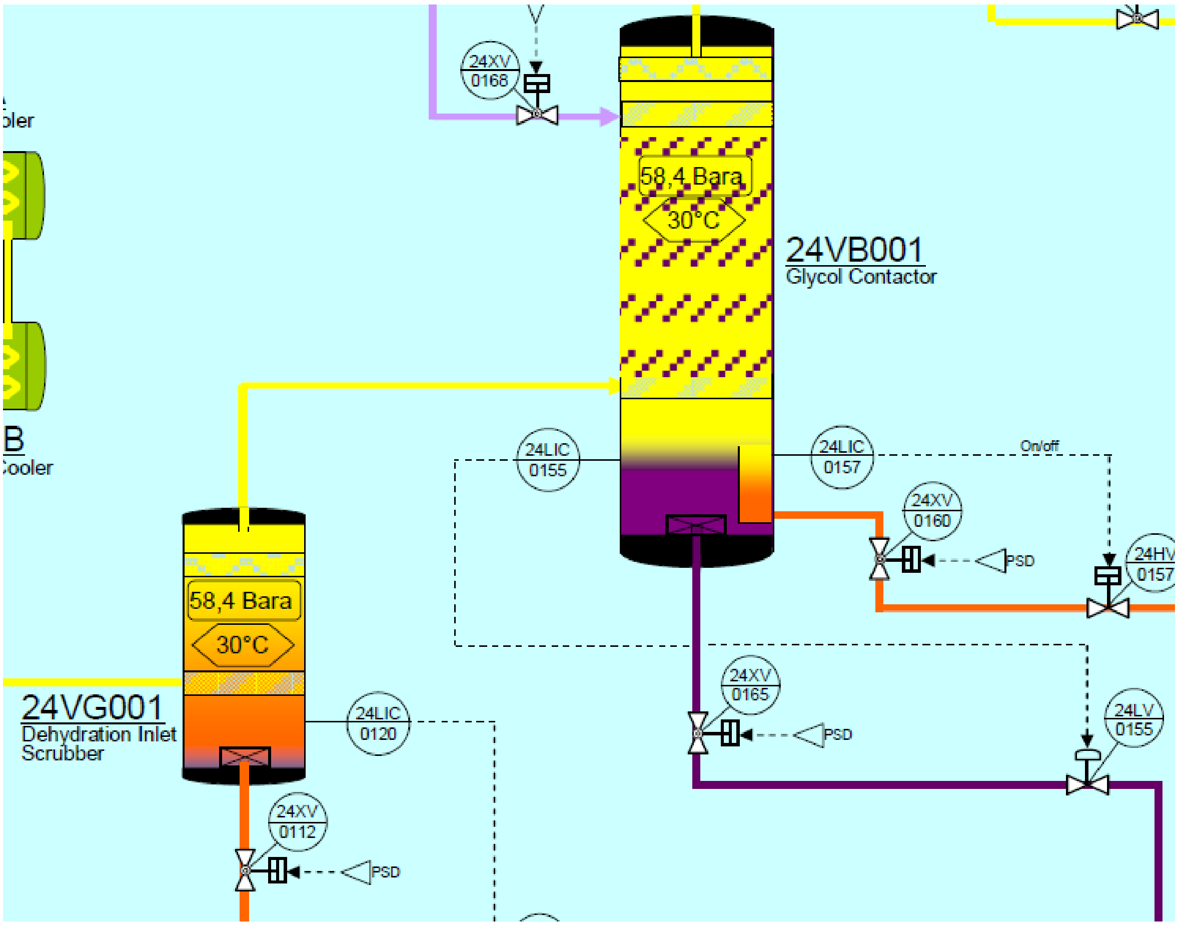


Figure 4.6-A Drawing of the Glycol contactor

In the scenario the gas will travel from the Glycol Contactor (Figure 4.6-A) through the check valve 24XV0165 and the control valve 24LV0155 and enter the Glycol flash drum after travelled through the Glycol Reflux Condenser (Figure 4.6-B).

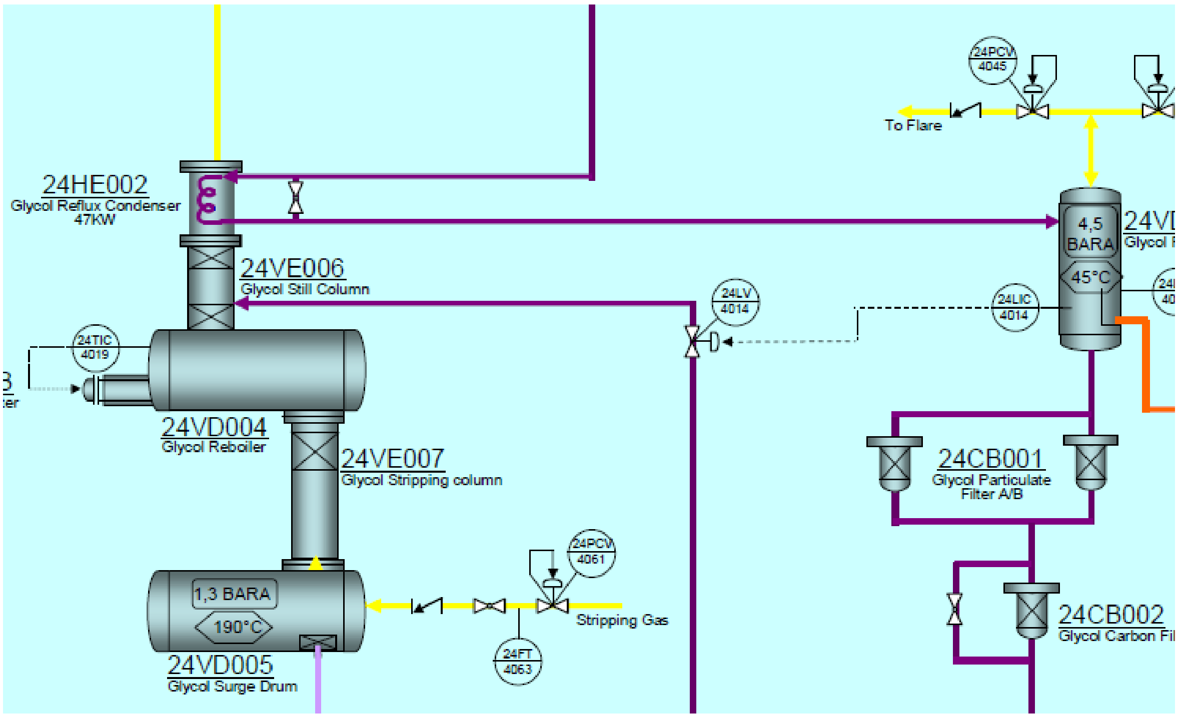
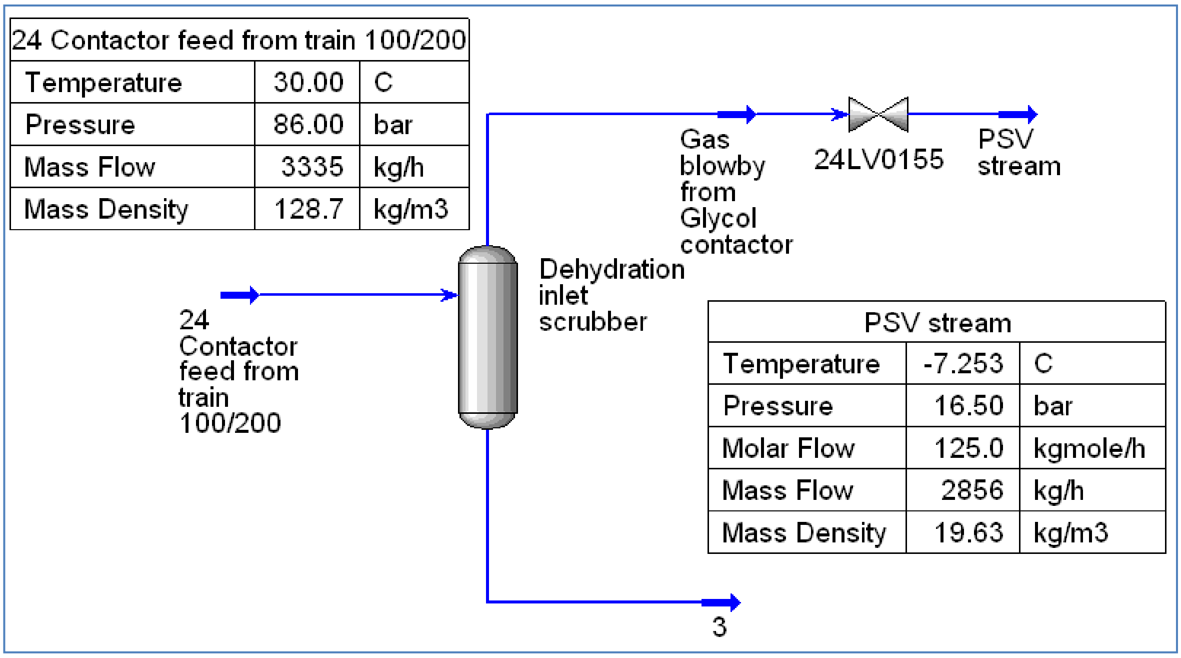


Figure 4.6-B Overview of the Glycol Flash Drum

Figure 4.6-A and Figure 4.6-B shows the relation between the Glycol Contactor and the Glycol Flash Drum. The Flash Drum has one inlet, so the simulation to get the parameters for the HEM calculation is more trivial than for the previous simulation.



24 Contactor feed from train 100/200		
Temperature	30.00	C
Pressure	86.00	bar
Mass Flow	3335	kg/h
Mass Density	128.7	kg/m3

PSV stream		
Temperature	-7.253	C
Pressure	16.50	bar
Molar Flow	125.0	kgmole/h
Mass Flow	2856	kg/h
Mass Density	19.63	kg/m3

Figure 4.6-C HYSYS set up for Glycol Flash Drum

The Gas stream (24 Contactor feed from train 100/200) is set to the trip pressure for the glycol contactor and separated in the inlet scrubber to simulate pure gas through the control valve 24LV0155 at the given pressure drop over the valve.

4.6-A - Input values for the Glycol Flash drum gas blowby:

	Gas blowby from Glycol contactor	PSV stream	24LV0155
Pressure	86bara	16,5bara[10]	
Temperature	30		
Composition	24_Contactor_feed		
C_V			2,5[8]

The result is displayed in Table 5.6-A.

4.7 CARGO TANK – GAS BLOWBY FROM 2ND STAGE SEPARATOR

The cargo tank can experience a gas blowby if the control valve 20LV0320 downstream the 2nd stage separator is stuck open. The gas will then travel down to the Cargo tank.

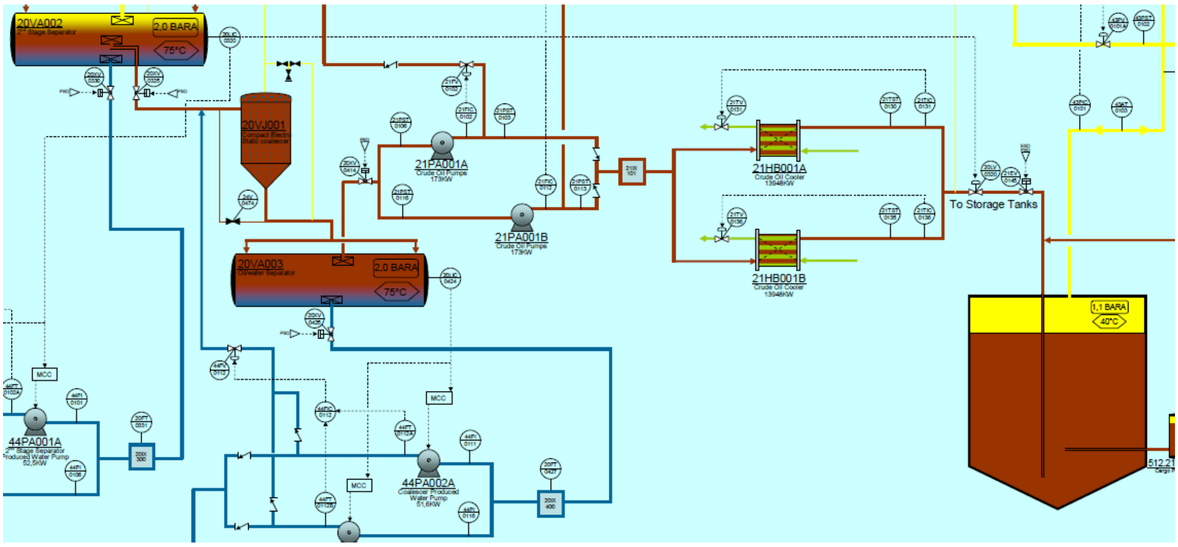


Figure 4.7-A Overview of the cargo tank

The valves protecting the Cargo tanks from overpressure are different than the other PSVs handled in this thesis. Pres-vac have installed 2x100% vocon-m-7 valves which is a simple device consisting of a disc with a load weight above to counteract the VOC pressure. This valve will be called a PSV in this thesis. The PSV capacity is given as 11900 kg/h[11] with blanket gas.

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10 Marathon document, 24PSV0171A/B Glycol flash tank, 3203-T-VAB-I-DS-24-0153-00
11 Marathon document, VOC System Relief capacity checks and vent rate cases, 3203-M-MPC-P-CA-43-0001-00

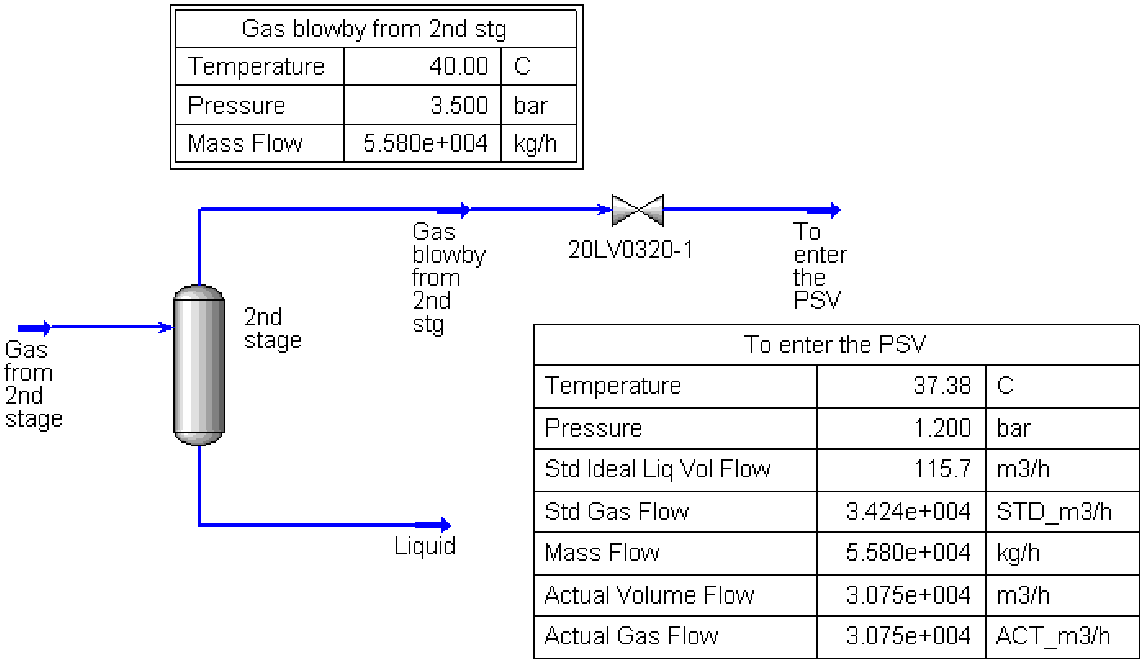


Figure 4.7-B - Set up in HYSYS for the Cargo Tank

The set up used in HYSYS is simple due to the fact that the only inlet is from the 2nd stage separator.

The reason why the simulation is done is to check how much gas that can enter through the control valve 20LV0320. This is the basis of the conservative calculations.

Table 4.7-A- Input values for Cargo tank simulation

	Gas blowby from 2nd stg separator	To enter the PSV	20LV0320
Pressure	3,5 bara	1,20 bara[11]	
Temperature	40 °C		
Composition	20VA002_Gas		
C_V			1120[8]

The trip pressure for the 2nd stage separator is 5bara, so that it does not trip at peak pressure higher than 3,5bara. If the pressure stays above 3,5bara more than 15 seconds the 2nd stage separator will trip. In other words the pressure in 2nd stage separator is set to 3,5bara in the simulation (Figure 4.7-B)

The result is given in Figure 4.7-B. The mass flow will be compared with the PSV capacity which is also given in kg/h. See section 5.7.

5 RESULTS

5.1 ALVHEIM/3RD PARTY INLET SEPARATOR – GAS BLOWBY FROM 2ND STAGE COMPRESSOR SCRUBBER, TRAIN 100/200

5.1.1 CONSERVATIVE APPROACH WITHOUT CLOSED OUTLET

The stream out from the separator is given in this table:

Table 5.1-A - Output values Alvheim separator (2nd stage compressor scrubber 100)

	Gas out	Oil out	Water out
Pressure, bara	34,1	34,1	34,1
Temperature, ^{o}C	52,14	52,14	52,14
Mass flow, kg/h	50 340	837 400	3 782
Vol flow, Am^3/h	1721	1083	

The result from section 4.1.1is showed in this table. All inserted values are yellow and all calculated values are green.

Table 5.1-B – HEM calculation Alvheim inlet separator conservative scenario (2nd stage compressor scrubber 100)

Inserted values	HEM calculation				Calculated
Density (ro)9	26,80	kg/m3	v9 - Specific volume	0,037313	m3/kg
Density (ro)0	29,25	kg/m3	v0 - specific volume	0,0342	m3/kg
Set pressure	30,00	barg	omega parameter	0,82	
Overpressure	10,00	%	nc -	0,58	
Temperature	55,00	degC	Non-flash/Flashing flow	Non-flashing	
Backpressure	5,60	barg	Po	3401325,00	Paa (inc atm)
W, mass flowrate	50340,00	kg/h	Pa	661325,00	Paa (inc atm)
KdG, discharge gas	0,975		na, backpressure ratio	0,19	
KdL, discharge liq	0,740		Pc, critical pressure	1976532,91	Paa (inc atm)
Kd - discharge coeff	0,730		G mass flux (critical flow)	6390,08	kg/s*m2
Kb - backpresse corr	1,000		G mass flux (subcritical)	3905,68	kg/s*m2
Kc - rupture disk	1,00		Critical/subcritical flow	Critical flow	
Kv - viscosity corr fact	0,975		Correct G, mass flux	6390,08	kg/s*m2
Area required				30,75	cm2

Area pr PSV (3+1reserve)	10,25	cm2

As built PSVs have a Q orifice of 71,29cm^2. This is more than what is needed with a gas blowby without closed outlet as showed in Table 5.1-B. The same result is valid for gas blowby from 2nd stage compressor scrubber train 200. The result is also identical to the result for the 3rd party inlet separator.

5.1.2 CONSERVATIVE APPROACH WITH CLOSED OUTLET

Table 5.1-C - HEM Calculation conservative approach with closed outlets

Inserted values			HEM calculation		Calculated
Density (ro)9	287,30	kg/m3	v9 - Specific volume	0,003481	m3/kg
Density (ro)0	317,40	kg/m3	v0 - specific volume	0,0032	m3/kg
Set pressure	30,00	barg	omega parameter	0,94	
Overpressure	10,00	%	nc -	0,60	
Temperature	22,80	degC	Non-flash/Flashing flow	Non-flashing	
Backpressure	5,60	barg	Po	3411457,50	Paa (inc atm)
W, mass flowrate	891500,00	kg/h	Pa	661325,00	Paa (inc atm)
KdG, discharge gas	0,975		na, backpressure ratio	0,19	
KdL, discharge liq	0,740		Pc, critical pressure	2043207,08	Paa (inc atm)
Kd - discharge coeff	0,730		G mass flux (critical flow)	20295,94	kg/s*m2
Kb - backpressure corr	1,000		G mass flux (subcritical)	11935,28	kg/s*m2
Kc - rupture disk	1,00		Critical/subcritical flow	Critical flow	
Kv - viscosity corr fact	0,975		Correct G, mass flux	20295,94	kg/s*m2
Area required				171,44	cm2
Area pr PSV (3+1reserve)				57,15	cm2

Table 5.1-C shows that the capacity of the present PSVs are good enough to handle a gas blowby with closed outlets. This also applies for gas blowby from 2nd stage compressor scrubber train 200. The result is also identical to the result for the 3rd party inlet separator.

5.2 ALVHEIM/3RD PARTY INLET SEPARATOR – GAS BLOWBY FROM THE DEHYDRATION INLET SCRUBBER

5.2.1 CONSERVATIVE APPROACH WITHOUTH CLOSED OUTLET

Table 5.2-A - Output values Alvheim separator (dehydration inlet scrubber)

	Gas out	Oil out	Water out
Pressure, bara	34,01	34,01	34,01
Temperature, ^{o}C	53,34	53,34	53,34
Mass flow, kg/h	48 070	807 600	3342
Vol flow, Am^3/h	1773	1030	3,387

Table 5.2-B - HEM calculation Alvheim inlet separator conservative scenario (dehydration inlet scrubber)

Inserted values			HEM calculation		Calculated
Density (ro)9	24,85	kg/m3	v9 - Specific volume	0,040241	m3/kg
Density (ro)0	27,10	kg/m3	v0 - specific volume	0,0369	m3/kg
Set pressure	30,00	barg	omega parameter	0,81	
Overpressure	10,00	%	nc -	0,58	
Temperature	22,80	degC	Non-flash/Flashing flow	Non-flashing	
Backpressure	5,60	barg	Po	3401325,00	Paa (inc atm)
W, mass flowrate	48070,00	kg/h	Pa	661325,00	Paa (inc atm)
KdG, discharge gas	0,975		na, backpressure ratio	0,19	
KdL, discharge liq	0,740		Pc, critical pressure	1972238,04	Paa (inc atm)
Kd - discharge coeff	0,730		G mass flux (critical flow)	6166,95	kg/s*m2
Kb - backpresse corr	1,000		G mass flux (subcritical)	3779,08	kg/s*m2
Kc - rupture disk	1,00		Critical/subcritical flow	Critical flow	
Kv - viscosity corr fact	0,975		Correct G, mass flux	6166,95	kg/s*m2
Area required				30,42	cm2
Area pr PSV (3+1reserve)				10,14	cm2

The needed area for this scenario is lower than the current PSV capacity, of 71,29cm^2 for each PSV. The result is also identical to the result for the 3rd party inlet separator.

5.2.2 CONSERVATIVE APPROACH WITH CLOSED OUTLETS

Table 5.2-C - HEM calculation Alvheim inlet separator conservative scenario with closed outlet (dehydration inlet scrubber)

Inserted values		HEM calculation			Calculated
Density (ro)9	269,20	kg/m3	v9 - Specific volume	0,003715	m3/kg
Density (ro)0	297,20	kg/m3	v0 - specific volume	0,0034	m3/kg
Set pressure	30,00	barg	omega parameter	0,94	
Overpressure	10,00	%	nc -	0,60	
Temperature	22,80	degC	Non-flash/Flashing flow	Non-flashing	
Backpressure	5,60	barg	Po	3401325,00	Paa (inc atm)
W, mass flowrate	862300,00	kg/h	Pa	661325,00	Paa (inc atm)
KdG, discharge gas	0,975		na, backpressure ratio	0,19	
KdL, discharge liq	0,740		Pc, critical pressure	2033930,84	Paa (inc atm)
Kd - discharge coeff	0,730		G mass flux (critical flow)	19650,51	kg/s*m2
Kb - backpresse corr	1,000		G mass flux (subcritical)	11601,83	kg/s*m2
Kc - rupture disk	1,00		Critical/subcritical flow	Critical flow	
Kv - viscosity corr fact	0,975		Correct G, mass flux	19650,51	kg/s*m2
Area required				171,27	cm2
Area pr PSV (3+1reserve)				57,09	cm2

The needed area for this scenario is lower than the current PSV capacity, of 71,29cm^2 for each PSV. The result is also identical to the result for the 3rd party inlet separator.

5.3 RESULTS – THE 2ND STAGE SEPARATOR GAS BLOWBY SCENARIOS

5.3.1 CONSERVATIVE APPROACH WITHOUT CLOSED OUTLET

Table 5.3-A - Output values 2nd stage separator

	Gas out	Oil out	Water out
Pressure, bara	16,40	16,40	16,40
Temperature, °C	90,66	90,66	90,66
Mass flow, kg/h	240 000	62 880	0
Vol flow, Am³/h	18 930	804,0	0

Table 5.3-B – HEM calculation 2nd stage separator conservative scenario

Inserted values			HEM calculation		Calculated
Density (ro)9	11.61	kg/m3	v9 - Specific volume	0.0861	m3/kg
Density (ro)0	12.68	kg/m3	v0 - specific volume	0.0789	m3/kg
Set pressure	14.00	barg	omega parameter	0.83	
Overpressure	10.00	%	nc -	0.58	
Temperature	93.84	degC	Non-flash/Flashing flow	Non-flashing	
Backpressure	3.80	barg	Po	1651457.50	Paa (inc atm)
W, mass flowrate	240000.00	kg/h	Pa	481325.00	Paa (inc atm)
KdG, discharge gas	0.975		na, backpressure ratio	0.29	
KdL, discharge liq			Pc, critical pressure	961430.38	Paa (inc atm)
Kd - discharge coeff	0.783		G mass flux (critical flow)	2925.14	kg/s*m2
Kb - backpresse corr	0.977		G mass flux (subcritical)	2294.13	kg/s*m2
Kc - rupture disk	1.00		Critical/subcritical flow	Critical flow	
Kv - viscosity corr fact	1.00		Correct G, mass flux	2925.14	kg/s*m2
Area required				297.95	cm2
Area pr PSV (4+1reserve)				74.49	cm2

As seen from Table 5.3-B the needed area for this scenario is slightly higher than the current installed Q orifice area of 71,29cm².

5.4 CONSERVATIVE APPROACH WITH CLOSED OUTLES

Table 5.4-A - HEM calculation 2nd stage separator conservative scenario with closed outlets

Inserted values			HEM calculation		Calculated
Density (ro)9	40.81	kg/m3	v9 - Specific volume	0.0245	m3/kg
Density (ro)0	45.18	kg/m3	v0 - specific volume	0.0221	m3/kg
Set pressure	14.00	barg	omega parameter	0.96	
Overpressure	10.00	%	nc -	0.60	
Temperature	93.84	degC	Non-flash/Flashing flow	Non-flashing	
Backpressure	3.80	barg	Po	1651457.50	Paa (inc atm)
W, mass flowrate	869400.00	kg/h	Pa	481325.00	Paa (inc atm)
KdG, discharge gas	0.975		na, backpressure ratio	0.29	
KdL, discharge liq			Pc, critical pressure	993785.86	Paa (inc atm)
Kd - discharge coeff	0.783		G mass flux (critical flow)	5294.85	kg/s*m2
Kb - backpresse corr	0.977		G mass flux (subcritical)	4026.07	kg/s*m2
Kc - rupture disk	1.00		Critical/subcritical flow	Critical flow	
Kv - viscosity corr fact	1.00		Correct G, mass flux	5294.85	kg/s*m2
Area required				596.27	cm2
Area pr PSV (4+1reserve)				149.07	cm2

The required area increases dramatically due to an increase in mass flow rate and in mass flux. The steady state calculation does not verify a sufficient PSV size.

5.4.1 GAS BLOWBY RATE DEFINED AS MAXIMUM GAS IN TO THE ALVHEIM INLET SEPARATOR SCENARIO WITH CLOSED OUTLETS

Table 5.4-B - HEM calculation 2nd stage max gas to Alvheim inlet separator scenario

Inserted values			HEM calculation		Calculated
Density (ro)9	56,19	kg/m3	v9 - Specific volume	0.0178	m3/kg
Density (ro)0	62.31	kg/m3	v0 - specific volume	0.0160	m3/kg
Set pressure	14.00	barg	omega parameter	0.98	
Overpressure	10.00	%	nc -	0.60	
Temperature	93.84	degC	Non-flash/Flashing flow	Non-flashing	
Backpressure	3.80	barg	Po	1651457.50	Paa (inc atm)
W, mass flowrate	785500.00	kg/h	Pa	481325.00	Paa (inc atm)
KdG, discharge gas	0.975		na, backpressure ratio	0.29	
KdL, discharge liq			Pc, critical pressure	997425.85	Paa (inc

					atm)
Kd - discharge coeff	0.783		G mass flux (critical flow)	6188.11	kg/s*m2
Kb - backpresse corr	0.977		G mass flux (subcritical)	4688.64	kg/s*m2
Kc - rupture disk	1.00		Critical/subcritical flow	Critical flow	
Kv - viscosity corr fact	1.00		Correct G, mass flux	6188.11	kg/s*m2
Area required				460.96	cm2
Area pr PSV (4+1reserve)				115.24	cm2

The required area is still larger than the PSVs as built.

5.4.2 *TEST-PRESSURE SCENARIO WITH CLOSED OUTLET*

Table 5.4-C – 2nd stage test-pressure scenario

Inserted values			HEM calculation		Calculated
Density (ro)9	21,86	kg/m3	v9 - Specific volume	0,0457	m3/kg
Density (ro)0	24,03	kg/m3	v0 - specific volume	0,0416	m3/kg
Set pressure	18,09	barg	omega parameter	0,89	
Overpressure	10,00	%	nc -	0,59	
Temperature	93,84	degC	Non-flash/Flashing flow	Non-flashing	
Backpressure	3,80	barg	Po	2101457,50	Paa (inc atm)
W, mass flowrate	285000,00	kg/h	Pa	481325,00	Paa (inc atm)
KdG, discharge gas	0,975		na, backpressure ratio	0,23	
KdL, discharge liq			Pc, critical pressure	1243843,98	Paa (inc atm)
Kd - discharge coeff	0,783		G mass flux (critical flow)	4449,96	kg/s*m2
Kb - backpresse corr	0,977		G mass flux (subcritical)	2966,24	kg/s*m2
Kc - rupture disk	1,00		Critical/subcritical flow	Critical flow	
Kv - viscosity corr fact	1,00		Correct G, mass flux	4449,96	kg/s*m2
Area required				232,58	cm2
Area pr PSV (4+1reserve)				58,14	cm2

This result shows that the pressure will never reach test pressure (21bara).

Table 5.4-B and Table 5.4-C are presented to give an impression of what might happen with a dynamic simulation.

5.5 PRODUCED WATER DEGASSING DRUM GAS BLOWBY SCENARIOS WITH CLOSED OUTLETS

Table 5.5-A – HEM calculation Produced water degassing drum conservative scenario

Inserted values			HEM calculation		Calculated
Density (ro)9	32.38	kg/m3	v9 - Specific volume	0.0309	m3/kg
Density (ro)0	35.76	kg/m3	v0 - specific volume	0.0280	m3/kg
Set pressure	14.00	barg	omega parameter	0.94	
Overpressure	10.00	%	nc -	0.60	
Temperature	93.84	degC	Non-flash/Flashing flow	Non-flashing	
Backpressure	3.80	barg	Po	1641325.00	Paa (inc atm)
W, mass flowrate	632000.00	kg/h	Pa	481325.00	Paa (inc atm)
KdG, discharge gas	0.975		na, backpressure ratio	0.29	
KdL, discharge liq			Pc, critical pressure	982248.31	Paa (inc atm)
Kd - discharge coeff	0.800		G mass flux (critical flow)	4730.22	kg/s*m2
Kb - backpresse corr	0.977		G mass flux (subcritical)	3628.87	kg/s*m2
Kc - rupture disk	1.00		Critical/subcritical flow	Critical flow	
Kv - viscosity corr fact	1.00		Correct G, mass flux	4730.22	kg/s*m2
Area required				474.88	cm2
Area pr PSV (2+1reserve)				237.44	cm2

The conservative steady state simulation with HEM calculation does not verify that the current PSV Orifice dimension of 167.7cm^2 (T) is large enough.

Since the gas blowby rate is defined by the control valve CV and pressure drop, an assumption is made to get a result when the max gas blowby equals the max gas capacity on Alvheim.

Table 5.5-B - Produced water degassing drum MAX gas scenario

Inserted values			HEM calculation		Calculated
Density (ro)9	51.45	kg/m3	v9 - Specific volume	0.0194	m3/kg
Density (ro)0	57.00	kg/m3	v0 - specific volume	0.0175	m3/kg
Set pressure	14.00	barg	omega parameter	0.97	
Overpressure	10.00	%	nc -	0.60	
Temperature	93.84	degC	Non-flash/Flashing flow	Non-flashing	
Backpressure	3.80	barg	Po	1641325.00	Paa (inc atm)
W, mass flowrate	511500.00	kg/h	Pa	481325.00	Paa (inc atm)
KdG, discharge gas	0.975		na, backpressure ratio	0.29	

KdL, discharge liq			Pc, critical pressure	989254.73	Paa (inc atm)
Kd - discharge coeff	0.800		G mass flux (critical flow)	5916.61	kg/s*m2
Kb - backpresse corr	0.878		G mass flux (subcritical)	4508.25	kg/s*m2
Kc - rupture disk	1.00		Critical/subcritical flow	Critical flow	
Kv - viscosity corr fact	1.00		Correct G, mass flux	5916.61	kg/s*m2
Area required				341.92	cm^2
Area pr PSV (2+1reserve)				170.96	cm^2

The result of the max gas scenario require 1.8% larger PSVs than the ones which are current installed.

By assuming test pressure in the degassing drum, it is possible to conclude if the pressure will exceed the test pressure for the separator.

Table 5.5-C – HEM calculation produced water degassing drum test-pressure scenario

Inserted values			HEM calculation		Calculated
Density (ro)9	15.74	kg/m3	v9 - Specific volume	0.0635	m3/kg
Density (ro)0	17.18	kg/m3	v0 - specific volume	0.0582	m3/kg
Set pressure	14.00	barg	omega parameter	0.82	
Overpressure	10.00	%	nc -	0.58	
Temperature	93.84	degC	Non-flash/Flashing flow	Non-flashing	
Backpressure	3.80	barg	Po	1641325.00	Paa (inc atm)
W, mass flowrate	200000.00	kg/h	Pa	481325.00	Paa (inc atm)
KdG, discharge gas	0.975		na, backpressure ratio	0.29	
KdL, discharge liq			Pc, critical pressure	953947.04	Paa (inc atm)
Kd - discharge coeff	0.800		G mass flux (critical flow)	3401.25	kg/s*m2
Kb - backpresse corr	0.878		G mass flux (subcritical)	2680.70	kg/s*m2
Kc - rupture disk	1.00		Critical/subcritical flow	Critical flow	
Kv - viscosity corr fact	1.00		Correct G, mass flux	3401.25	kg/s*m2
Area required				232.56	cm^2
Area pr PSV (2+1reserve)				116.28	cm^2

Since the required area 116.28cm^2 pr PSV is less than the as built area, it is possible to say that with this scenario the pressure will not increase above test pressure.

5.6 GLYCOL FLASH DRUM GAS BLOWBY SCENARIO

Table 5.6-A- HEM calculation Glycol Flash Drum conservative scenario

Inserted values			HEM calculation		Calculated
Density (ro)9	17.88	kg/m3	v9 - Specific volume	0.0559	m3/kg
Density (ro)0	19.63	kg/m3	v0 - specific volume	0.0509	m3/kg
Set pressure	14.00	barg	omega parameter	0.88	
Overpressure	10.00	%	nc -	0.59	
Temperature	30.00	degC	Non-flash/Flashing flow	Non-flashing	
Backpressure	2.50	barg	Po	1651457.50	Paa (inc atm)
W, mass flowrate	2855.00	kg/h	Pa	351325.00	Paa (inc atm)
KdG, discharge gas	0.975		na, backpressure ratio	0.21	
KdL, discharge liq			Pc, critical pressure	974440.55	Paa (inc atm)
Kd - discharge coeff	0.783		G mass flux (critical flow)	3579.52	kg/s*m2
Kb - backpresse corr	1.000		G mass flux (subcritical)	2281.74	kg/s*m2
Kc - rupture disk	1.00		Critical/subcritical flow	Critical flow	
Kv - viscosity corr fact	1.00		Correct G, mass flux	3579.52	kg/s*m2
Area required				2.83	cm2
Area pr PSV (1+1reserve)				2.83	cm2

This is below the as built orifice dimension which is 5,06cm^2 (H).

5.7 CARGO TANKS – CONSERVATIVE GAS BLOWBY SCENARIO

Since the PSV capacity for the cargo tank is given as 11900 kg/h blanket gas, a HEM calculation is not performed to find the required area. Figure 4.7-B shows that a much larger mass flow, 55800 kg/h is gained in the static simulation. This is further discussed in section 7.7.

6 ANALYSIS

6.1 SENSITIVITY ANALYSIS - COMPOSITION

Since the basis for the stream compositions can be different it would be natural to look at the effect of a change in the composition. The input values in the HYSYS model is based on old data, and it is reasonable to assume that in time, the gas content would be higher due to more gas from the reservoir is being produced.

These simulations are done to do a sensitivity analysis on the composition of the gas blowby. The composition is changed to create a random lighter gas, and look at the effect on the required area.

The composition of “00-gas blow by Alvheim” (Figure 4.3-B) is changed and then the correct CV in the valve determine the new flow from this source which again give a new composition for the gas escaping through the PSV and its mass flux.

Table 6.1-A - Composition analysis – Gas blowby rate

Composition	Gas blowby flow (10^3 kg/m^3)	Total flow through PSV (10^3 kg/m^3)	Mass flux (kg/s*m^2)	Area required (cm^2)	Deviation (%)
Already used	119,5	150,2	2908,8	46,88	0,00
0,8-CH_4, 0,2-C_2H_6	115,0	154,3	2889,1	46,88	0,00
0,9-CH_4, 0,1-C_2H_6	110,3	151,7	2807,4	48,25	2,92
1,0-CH_4	105,6	149,2	2739,3	49,45	5,48

The table shows that the effect of having a lighter gas coming from the inlet separator to the 2nd stage separator does not affect the required area to a large extent.

6.2 DIRECT INTEGRATION INSTEAD OF THE OMEGA-METHOD

The HEM direct integration method is used to compare the results with the HEM omega method. The set up for the 2nd stage separator is used with gas blowby from the Alvheim inlet separator and without closed outlet, but the conditions are different from what is in Table 5.1-B. The same conditions are applied for the omega-method and for the direct integration method, to compare the two.

Equation 3.2-A is used to check how the results will change.

The following is done in HYSYS. The stream “00-2nd stage gas out” from Figure 4.3-B is selected. In the tab called “attachments” there is an option called “utilities”. Create a utility and choose “property table”. Then choose entropy as a static independent variable and fill in the correct entropy for the stream. Define pressure as an independent variable with a maximum pressure to be 14,01 bar and minimum pressure 5 bar with 30 increments. Also define mass density as a dependent property, and calculate. A spreadsheet is created, and this information is used for the Trapezoidal method to decide the critical pressure and the max flux rate with Equation 3.2-B. The rest of the simulation is similar to the procedure for the other calculations. The results are displayed in section 6.2.1.

6.2.1 RESULTS – DIRECT INTEGRATION EXAMPLE

The result of the trapezoidal method is showed in Figure 6.2-A. The top of the curve represents the maximum mass flux through the nozzle. It shows also the critical pressure which in this example is 9,32bara compared to 9,56bara for the omega-method with the same conditions.

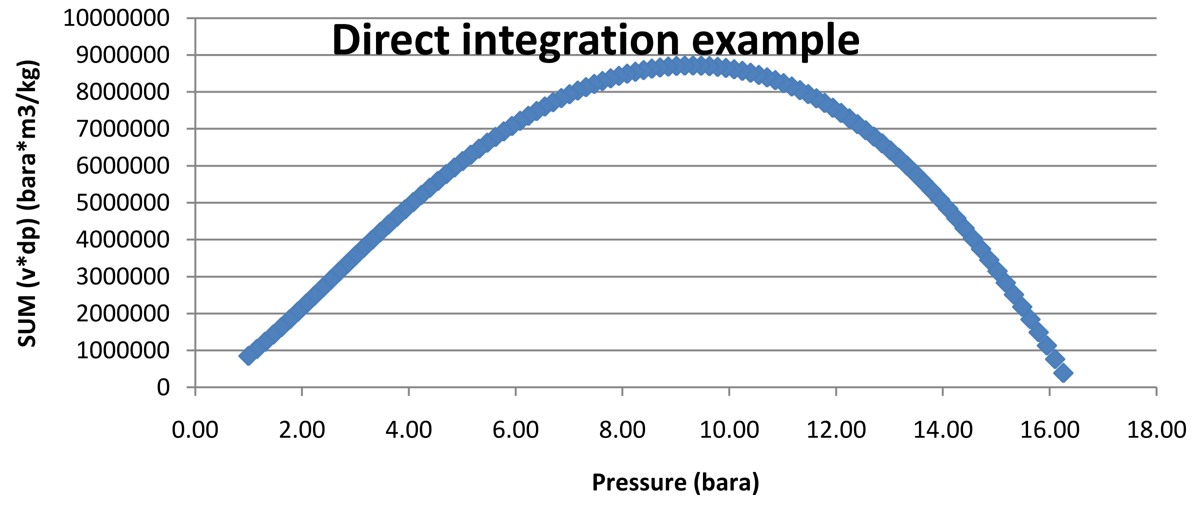


Figure 6.2-A - Direct integration example

Use Equation 3.2-A to find the mass flux rate through the nozzle (narrowest point in the PSV). The result is displayed in the table below:

Table 6.2-A - Direct integration result

Inserted values			HEM calculation		Calculated
Density (ro)9		kg/m3	v9 - Specific volume		m3/kg
Density (ro)0		kg/m3	v0 - specific volume		m3/kg
Set pressure	14,00	barg	omega parameter		
Overpressure	10,00	%	nc -		
Temperature	93,84	degC	Non-flash/Flashing flow		
Backpressure	3,80	barg	Po	1641325	Paa (inc atm)
W, mass flowrate	150200	kg/h	Pa	481325	Paa (inc atm)
KdG, discharge gas	0,975		na, backpressure ratio	0,29	
KdL, discharge liq			Pc, critical pressure	932140	Paa (inc atm)
Kd - discharge coeff	0,783		G mass flux (critical flow)		kg/s*m2

Kb - backpresse corr	0,977		G mass flux (subcritical)		kg/s*m2
Kc - rupture disk	1,00		Critical/subcritical flow	Critical flow	
Kv - viscosity corr fact	1,00		Correct G, mass flux	2950,71	kg/s*m2
Area required				18484,98	mm2
Area pr PSV (4+1reserve)				46,21	cm2

Area required is a bit smaller with this method than with the omega-method. The direct integration is 1,43% less than the omega-method. This result concludes that it is sufficient to use the two-point method.

6.3 2ND STAGE SEPARATOR – NOT PURE GAS FROM THE INLET SEPARATOR

It is reasonably to believe that there will not be pure gas flowing from the Alvheim separator to the 2nd stage separator. Even though the oil level is below the oil outlet, the liquid coming into the separator needs to escape somewhere. Figure 6.3-A shows the relation between having pure gas flowing from Alvheim separator and less gas regarding to area required for the PSV.

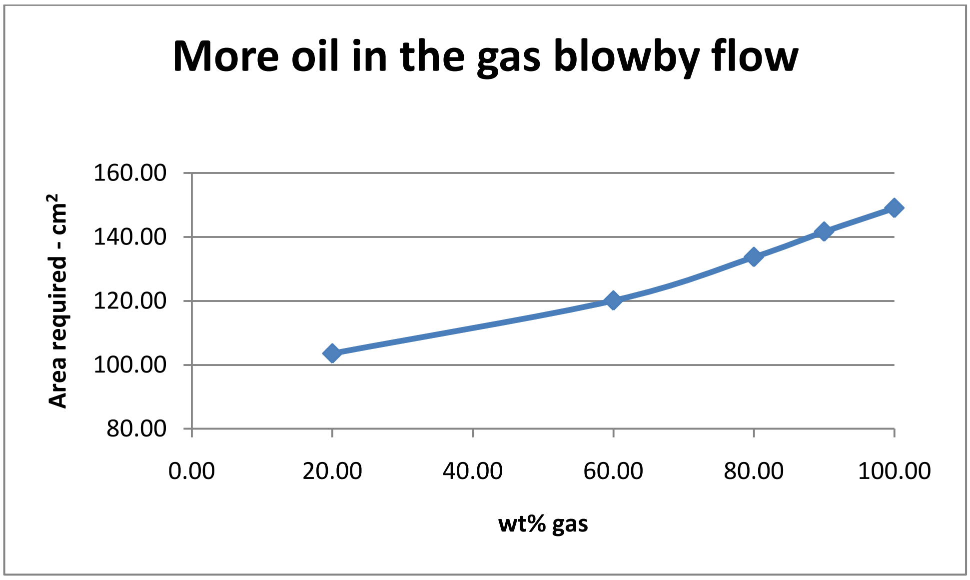


Figure 6.3-A Area required with less wt% gas

The point representing 100 wt% gas is the same as in scenario 5.4. 60 wt% gas means that 60% of the fluid is gas from the Alvheim inlet separator and 40% of the fluid is oil from the Alvheim inlet separator. This figure shows that the more oil occupying space from the gas, the less area is required. A dynamic simulation could include this effect.

6.4 DYNAMIC SIMULATION – GAS BLOWBY 2ND STAGE SEPARATOR

This section is a result of the discussion made in section 7.5.5. A trivial dynamic simulation is created to analyse the behaviour of different parameters when a gas blowby situation occurs from the Alvheim inlet separator into the 2nd stage separator.

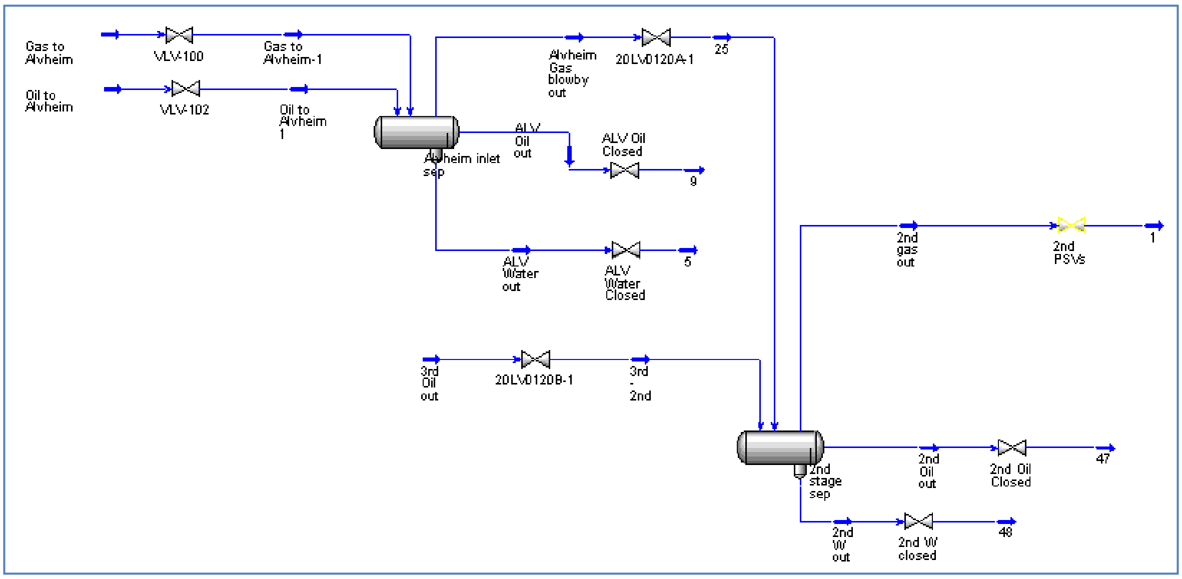


Figure 6.4-A - Dynamic set up - 2nd stage gas blowby

As discussed in section 7.5.1 the maximum calculated gas flow through the control valve 20LV0120A is greater than the limited capacity of gas into the Alvheim inlet separator. To simulate the flow into the Alvheim inlet separator, the limited flow rates are created by simulating a choked flow. A high pressure upstream the valve is set to create this. Depending on the fluid this pressure needs to be more than 1.8 times greater than the downstream pressure. In this simulation a pressure of 70bara is selected to ensure choked conditions for the fluid. The same method is used to create a constant mass flow from the 3rd party inlet separator (Table 6.4-A).

By sizing the C_V for VLV-100, VLV-102 and 20LV0120B-1, a constant mass flow can be obtained through the valve independent of the pressure in “Gas to Alvheim-1” and “Oil to Alvheim-1” (Figure 6.4-A) as long as the pressure upstream the valve is approximate twice the pressure downstream (choked flow condition). The approach is not optimal, due to phase change when the inlet fluid pressure is changed.

Table 6.4-A Inputs for the dynamic simulation

	Max gas	Max oil	3rd party
CV	69,41	122,2	207,0 (89,07%)
Mass flow, kg/h	51 330	603 100	534 200
Std Gas flow, Sm^3/h	60 000	60 000	74 020
Actual volume flow (liquid)	0	799,9	683,3
Pressure, bara	70	70	40
Composition	20VA101_Gas	20VA101_Oil	20VA201_Oil

The liquid level in the Alvheim inlet separator is set to 0.1% which means that the separator will be full of gas at the start of the simulation. The 2nd stage separator is set to start with 80% liquid level which is a normal operating level.

A PSV is implemented on the Alvheim inlet separator to ensure that the pressure does not increase above 27bara.

A valuable lesson in doing the dynamic simulation was to not reset the integrator when manipulating wanted conditions. An easier way is to set the clock to start at zero at the start of the part which is logged.

The results are displayed in the section below

6.4.1 DYNAMIC SIMULATION RESULTS

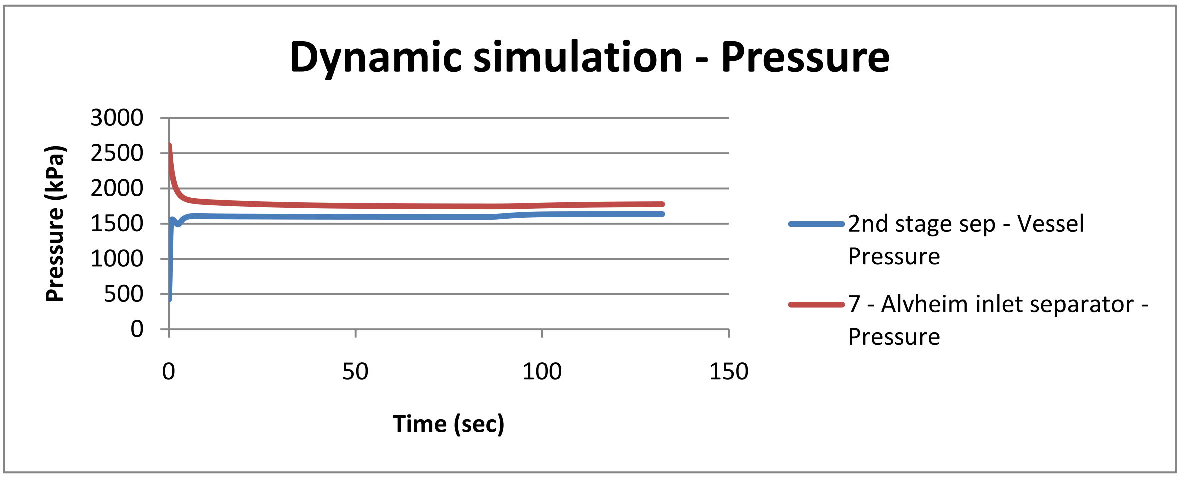


Figure 6.4-B - Dynamic simulation – Pressure

The pressures drop decreases rapidly due to the high flow rates showed in Figure 6.4-D

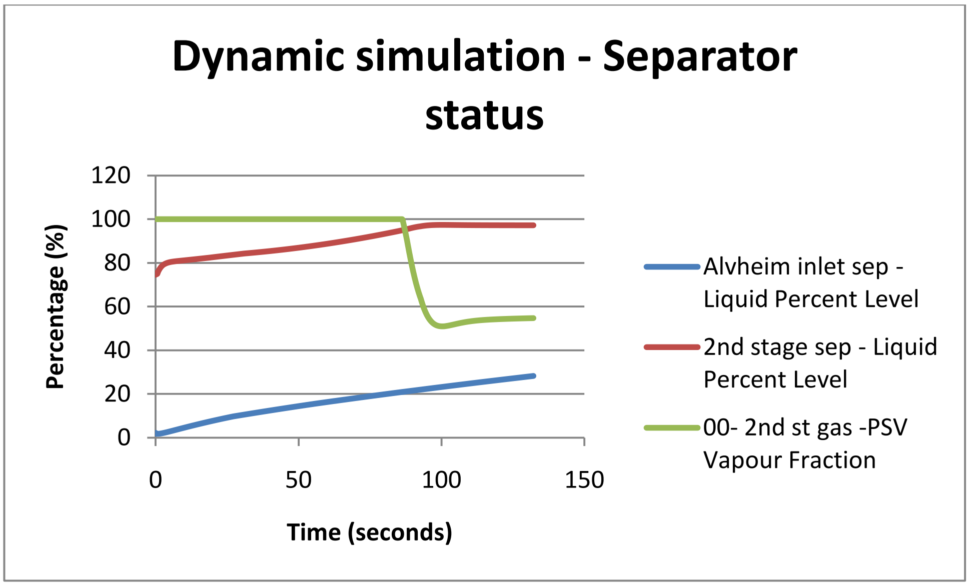


Figure 6.4-C - Dynamic simulation - Separator status

Figure 6.4-C indicates that there will not be pure gas flowing through the PSV (PSV vapour fraction).

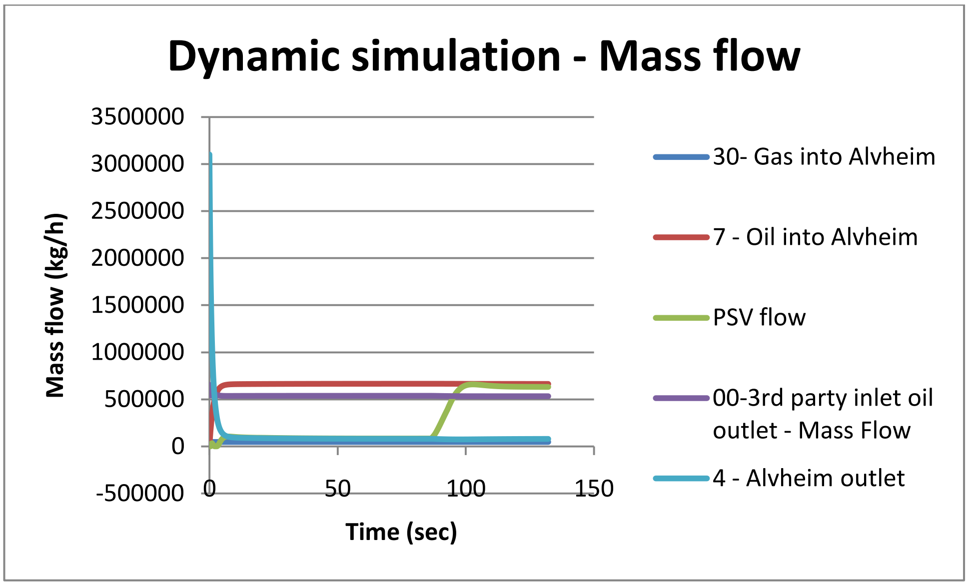


Figure 6.4-D - Dynamic simulation - Mass flow

The mass flow rate out of the Alvheim Inlet separator decreases rapidly. Figure 6.4-D shows that the PSV has an increase in mass flow at around 80 seconds due to the change in the mass density of the fluid exiting through the PSVs. It is worth mentioning that the pressure in the 2nd stage does a small increase when this happens, but the pressure inside the 2nd stage does not exceed 16,5bara (set pressure).

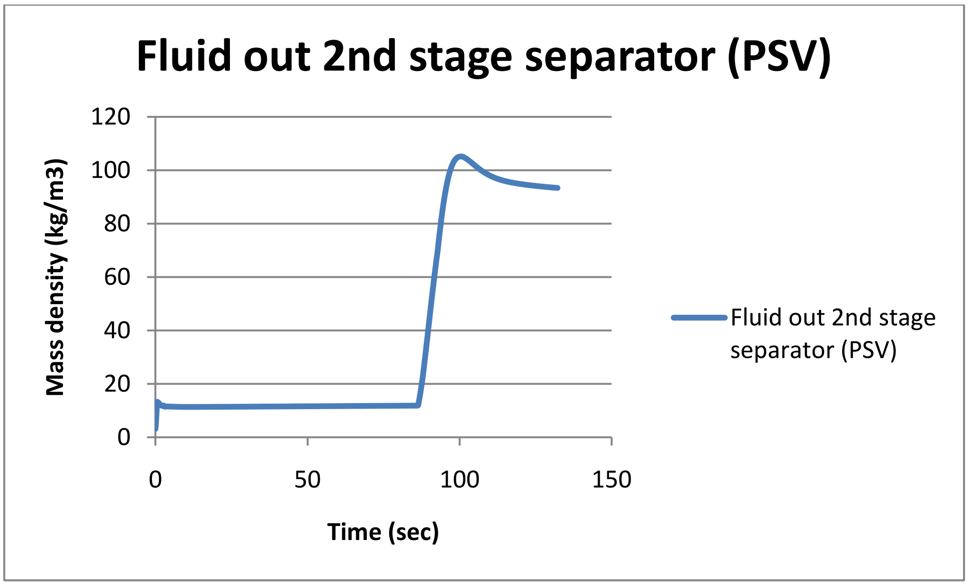


Figure 6.4-E Dynamic simulation - Fluid out 2nd stage separator (PSV)

This figure only show that when the 2nd stage separator is full the liquid needs to exit through the PSVs.

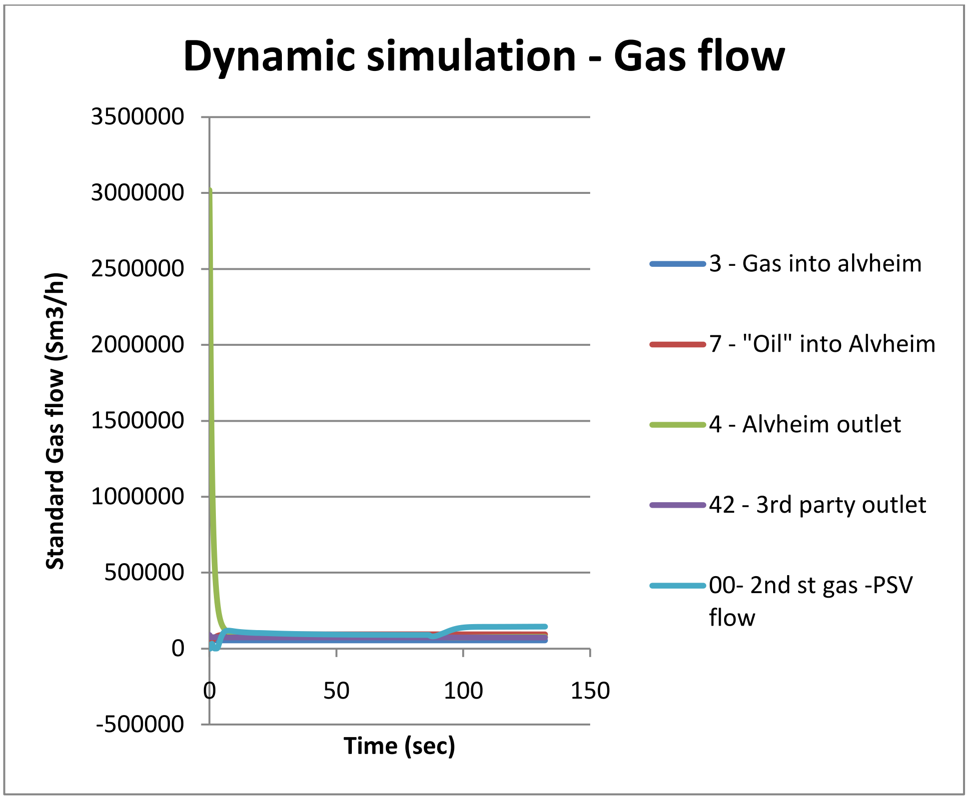


Figure 6.4-F - Dynamic simulation - Gas flow

The gas blowby rate decreases rapidly according to this figure. This is reasonable since the potential gas though 20LV0120A is greater than the max gas into the inlet separators.

6.4.2 CHECKING HYSYS PSV CALCULATIONS VS HEM CALCULATIONS

Two spot values are used to check if HYSYS calculates the PSV rate in a similar way as the HEM calculation. The dynamic simulation is randomly stopped two times to get the conditions. The composition, pressure, molar flow rate and temperature are copied over to the Entropy flash calculation in steady state mode. This way the conditions necessary to perform an isentropic flash calculation are available in steady state mode in HYSYS. The required area calculated in Table 6.4-B and Table 6.4-C is compared to the area of the actual PSV which is inserted into the HYSYS model, 71.29cm^2.

Table 6.4-B - HEM calculation to check HYSYS when the PSVs are fully opened

Inserted values			HEM calculation		Calculated
Density (ro)9	11.07	kg/m3	v9 - Specific volume	0.0903	m3/kg
Density (ro)0	12.09	kg/m3	v0 - specific volume	0.0827	m3/kg
Set pressure	14.00	barg	omega parameter	0.83	
Overpressure	10.00	%	nc -	0.58	
Temperature	93.84	degC	Non-flash/Flashing flow	Non-flashing	
Backpressure	3.80	barg	Po	1600857.50	Paa (inc

					atm)
W, mass flowrate	94100.00	kg/h	Pa	481325.00	Paa (inc atm)
KdG, discharge gas	0.975		na, backpressure ratio	0.30	
KdL, discharge liq			Pc, critical pressure	931924.64	Paa (inc atm)
Kd - discharge coeff	0.783		G mass flux (critical flow)	2812.35	kg/s*m2
Kb - backpresse corr	0.977		G mass flux (subcritical)	2244.08	kg/s*m2
Kc - rupture disk	1.00		Critical/subcritical flow	Critical flow	
Kv - viscosity corr fact	1.00		Correct G, mass flux	2812.35	kg/s*m2
Area required				12150.54	mm2
Area pr PSV (4+1reserve)				30.38	cm2

At this condition from the HYSYS simulation, the required area calculated by the HEM calculation is less than the actual area (71.29cm^2). In other words this seems like HYSYS has a more conservative calculation. The pressure at this condition is 16,01bara which is less than 16,5bara. This means that the PSV might not be fully open and explains why the flow at this condition represents such a small required area. It is not easy to conclude anything from this result.

The next condition is when the mass density has stabilized at 85kg/m^3.

Table 6.4-C - HEM calculation to check HYSYS after the 2nd stage is full of liquid

Inserted values			HEM calculation		Calculated
Density (ro)9	76.96	kg/m3	v9 - Specific volume	0.0130	m3/kg
Density (ro)0	85.55	kg/m3	v0 - specific volume	0.0117	m3/kg
Set pressure	14.00	barg	omega parameter	1.00	
Overpressure	10.00	%	nc -	0.61	
Temperature	85.55	degC	Non-flash/Flashing flow	Non-flashing	
Backpressure	3.80	barg	Po	1636057.50	Paa (inc atm)
W, mass flowrate	618600.00	kg/h	Pa	481325.00	Paa (inc atm)
KdG, discharge gas	0.975		na, backpressure ratio	0.29	
KdL, discharge liq			Pc, critical pressure	993314.20	Paa (inc atm)
Kd - discharge coeff	0.783		G mass flux (critical flow)	7166.58	kg/s*m2
Kb - backpresse corr	0.977		G mass flux (subcritical)	5432.41	kg/s*m2
Kc - rupture disk	1.00		Critical/subcritical flow	Critical flow	
Kv - viscosity corr fact	1.00		Correct G, mass flux	7166.58	kg/s*m2
Area required				31345.40	mm2
Area pr PSV (4+1reserve)				78.36	cm2

For this condition the HEM calculated area is 10% higher than the area used in HYSYS (78,36 cm^2 compared to 71,29cm^2). The pressure is 16,36bara which means that the PSV is almost fully open. This result shows that the HEM calculated flow rates are more conservative than the HYSYS calculated ones.

6.5 2ND STAGE SEPARATOR – CHANGING UPSTREAM SETPRESSURES

The effect of reducing the trip pressures in the Alvheim inlet separators is analysed here. The same procedure as in section 4.4 is used. The only difference is that the trip pressure upstream is changed. This is only done as an analysis.

Table 6.5-A Different upstream set-pressures

Alvheim inlet set-pressure (bara)	Mass flow (kg/m^3)	Total Mass flow through PSVs (kg/m^3)	Required area (cm^2)/PSV
27,00	200 000	869 400	149,07
26,00	190 000	859 400	137,12
25,00	178 000	847 400	132,04
24,00	164 000	833 400	126,17
23,00	150 000	819 400	120,10
22,00	138 000	807 400	114,79
21,00	123 000	792 400	107,96

The total mass flow at 21bara upstream is larger than the one for the case with maximum gas in to the Alvheim inlet separator (Table 5.4-B). This means that the peak flow rate will change.

The same table is used, only this time it is considered to use every valve instead of having one spare, i.e five out of five PSVs. This action would of course result is several procedures on how to change these valves under production if necessary.

Figure 6.5-A Different upstream set-pressures with non spare

Alvheim inlet set-pressure (bara)	Mass flow from Alvheim (kg/m^3)	Total Mass flow trough PSVs (kg/m^3)	Required area (cm^2)/PSV
27,00	200 000	869 400	120,73
26,00	190 000	859 400	109,70
25,00	178 000	847 400	105,63
24,00	164 000	833 400	100,94
23,00	150 000	819 400	96,08
22,00	138 000	807 400	91,38

21,00	123 000	792 400	86,37

The table shows the required area is greater than the as built orifice which is 71,29cm^2.

7 DISCUSSION

7.1 COMPOSITION

The HYSYS file from which the compositions are gathered from is based on older data. The composition of the production fluid changes with time. The composition changes when the GOR of the produced fluid increases. Since the gas blowby rates are based upon the C_V size of the upstream control valve, the mass flow change will not be very large. A lighter gas has a lower mass flux through the control valve. This also applies for the orifice (smallest point) in the PSV. The mass flux will be less so required area is higher. In other words by having a lighter gas the flow will be less, but at the same time, it requires bigger area, so the net change is not that big from a pure logic perspective. Table 6.1-A tells us that there is some change in area required when the composition has changed, but the difference is not very large.

7.2 DISCUSSION – DIRECT INTEGRATION METHOD

The method seems to be more accurate taken into account that the omega-method is based on a two-point method. The example in this report results in 1,43% less required area for each PSV. In this example the omega-method is the most conservative method. At the same time the omega-method is more an engineering approach with less work in HYSYS. It only requires two values, instead of a table. Either way both methods are proposed by API Standard 520.

7.3 ALVHEIM/3RD PARTY INLET SEPARATOR

The conservative approach showed that the PSVs will handle a gas blowby without any problems. This applies for both the scenarios, with and without closed outlets. The result is also identical to the result for the 3rd party inlet separator.

7.4 2ND STAGE SEPARATOR WITHOUT CLOSED OUTLET

It is possible to argument that a gas blowby scenario should be considered while the outlets are still functional. Some might even claim that closed outlet and gas blowby are unrelated and thereby considered a double jeopardy. If that conclusion should be used, the result requires 74,5cm^2 when 71,3cm^2 is installed. Considering that the result is quite conservative regarding the pressures and total flow from Alvheim and 3rd party inlet separator, this result is within what is acceptable. It seems like this scenario has been the basis when the EPCI contractor has done the sizing for gas blowby.

Section 7.5 explains why the result has to include a closed outlet.

7.5 2ND STAGE SEPARATOR WITH CLOSED OUTLET

For a gas blowby to occur the inlet separator liquid level needs to drop. The control valve downstream the inlet separator, 20LV0120A is programmed to maintain a certain liquid height in the separator. If the liquid level continues to drop this can mean that the control valve do not function as supposed, and eventually a gas blowby situation can occur (Assuming that the primary protection does not work). API Standard 521 states that the control system should not be considered a barrier against a worst case scenario. When the results in Table 5.4-A are presented it is tempting to conclude that since API 521 states that "*The simultaneous occurrence of two or more unrelated causes of overpressure (also known as double or multiple jeopardy) is not a basis for design",* we can assume that this scenario is not necessary to take account for. API Standard 521 talks about unrelated happenings, like blocked outlet which can happen as an unforeseen happening. But in this case the outlets close since the high pressure in the 2nd stage separator will force the downstream pumps and the recompressor to trip. In other words it needs to be taken into account. This matter is poorly discussed in the standards concerning process safety, and it is important to emphasize the effect of this.

7.5.1 ALVHEIM GAS CAPACITY

It is important to consider that the simulations done as a basis for the HEM calculations are based on a steady state simulation. The result represents a peak at conservative conditions. The gas blowby rate calculated to be 200 000 kg/h from the Alvheim inlet separator to 2nd stage separator represents 233 890 Sm^3/h. The overpressure protection of the Alvheim inlet separator is limited to 140 000 Sm^3/h at 30barg, which in simple words means that the inflow of gas will not continuous surpass this limit due to operational settings. Let's assume max calculated gas blowby rate through the control valve upstream the 2nd stage separator. The pressure upstream will decrease rapidly since there is approximately 100 000 Sm^3/h more gas leaving the inlet separator than entering the separator. With a decreasing pressure the gas blowby rate will decrease until it reaches the inlet rate of 140 000 Sm^3/h. Table 5.4-B shows that the required area for this scenario still is higher than what is currently installed.

7.5.2 TEST PRESSURE REACHED IN THE 2ND STAGE SEPARATOR

If a max gas blowby rate trough the upstream control valve is assumed, the pressure in the 2nd stage separator will increase rapidly.

The design pressure of the separator is 14barg with a maximum design temperature of 110 ^oC. The separator is designed to handle the design pressure plus the allowable overpressure which is 10% without decreasing the separators strength. However, it is known that the separator will handle a test pressure of 20barg, but in this case the separator needs to be changed after reaching the test pressure. In Table 5.4-C it is showed that the required area is less than current available area when test pressure is reached. During the pressure build up from set-pressure to test pressure, the pressure in the inlet separator will decrease since there is less energy entering than leaving the inlet separator. Most likely if the pressure reaches test pressure, the flow rate of gas would be less than what is used in Table 5.4-C. (This is illustrated in the analysis with the dynamic simulation in section 7.5.5.

This scenario shows that loss of containment is unlikely; hence high potential incident is unlikely. One suggestion is to investigate and calculate the probability of the separator to reach design pressure and test-pressure. This probability can be compared to the acceptable criteria for this separator to experience design pressure and test-pressure. The consequence of a pressurised vessel containing a pressure larger than design pressure plus allowable overpressure is that the vessel needs to be investigated to check if the pressure has impaired the strength of the vessel. A check of the 2nd stage separator would cost money and lead to loss of production in the period.

It is important to not forget to check the capacity of the flare system as well, if this suggestion is considered. Can the flare system take the higher flow rates coming from the 2nd stage separator? It should also be investigated if the upstream equipment (pipe, heaters) can handle that pressure.

7.5.3 FULL OIL PRODUCTION AND HIGH GAS RATE

The assumption with max gas blowby rate through the control valve while producing at approximately 800m^3/h from the other inlet separator is likely to happen. It is the same chance for the separator with less production to experience gas blowby as for the separator with the highest production. The flow through an inlet separator is limited to around 800m^3/h due to some metering limitations. The two inlet separators will produce oil not exceeding 1060 m^3/h out of the 2nd stage separator due to limitations. This is showed in Figure 4.1-G. Usually the separator with most oil production has a oil rate of around 600m^3/h, so the executed simulations are conservative.

7.5.4 ASSUMPTION THAT THERE IS PURE GAS FLOWING

Another assumption is that there will only flow gas from the Alvheim inlet separator to the 2nd stage separator. Most likely there will be oil occupying some space for the gas. Table 6.1-A shows the results of this analysis. The difference is not so big due to the fact that greater weight percentage of oil means higher flux through the control valve as well as through the PSV.

7.5.5 DYNAMIC SIMULATION

As we discussed in section 7.5.1 the max gas blowby rate through the control valve is greater than the flow rate of gas into the inlet separator. The result in Table 5.4-B tells that the required area decreases rapidly when the gas blowby rate is decreased. A dynamic simulation could show how fast these rates would change and how the pressures would act.

In section 7.5.2 the case with test-pressure is discussed. It concludes that the PSVs will have a great enough area to handle the gas blowby plus the other inlet streams. With a dynamic simulation it would be possible to look at how high the pressure would develop and how low fast it all would happen.

Define the inlets of Alvheim inlet separator to be 140 kSm^3/h gas and 800 Am^3/h of oil. The 3rd party inlet separator can be defined as to deliver 800 Am^3/h, even though it should have been lower.

The quality of the dynamic solution should be discussed because of several different reasons:

- Phase equilibrium

HYSYS calculates phase equilibrium in the separators. It is unknown how well HYSYS manages to calculate with volumes in the separator.

- Difference in results due to resetting the integrator

Dynamic simulation for a more complex system is hard to simulate. The fact that there is some inconsistency between different solutions that are more or less similar, gives an impression that the software or the set up is not sufficient for the application.

- The result in this work has been obtained by HEM calculations done by the procedure in API Standard 520. The relieving capacity in the HYSYS dynamic simulation is defined by HYSYS. The user has to input the area of the PSV, but does not have the knowledge of how HYSYS calculates the mass flow through the PSV. Analysis from Table 6.4-C shows that HYSYS calculates a higher relieve rate compared to the HEM calculations. It might be possible to use another setting for the PSV calculation in HYSYS to obtain a more conservative flow rate calculation.
- The approach to define the mass flow rates into the Alvheim inlet separator and out from the 3rd party separator gives inaccuracy both in composition and in actual volume rates.
- To simulate the gas blowby rate from the inlet separator the gas out from the separator is used. It would be more correct to simulate the gas blowby through the oil-outlet due to low liquid level. Then the correct fluid would be simulated as the gas blowby rate.
- In this simple dynamic simulation it is assumed closed outlet in the 2nd stage separator from the start of the simulation. This would not occur until the pressure had surpassed the trip pressure of 4barg.

Figure 6.4-B shows that the pressure will never surpass the allowable overpressure which is a total of 16,5bara, which in other words means that the PSVs can handle the gas blowby scenario. It is questioned if the dynamic simulation is good enough to verify this. It is recommended to use more time to create a sufficient model.

7.6 DISCUSSION – PRODUCED WATER DEGASSING DRUM

The capacity for each PSV is 167,7cm^2. The required area from HEM calculation using the steady state relieve rate is 237,44 cm^2. As for the 2nd stage separator a dynamic simulation is needed to see the development of the pressures before the set pressure is reached.

An option would also be to operate with all three PSVs with no spare. That would decrease the required area pr PSV down to 156cm^2 pr PSV which is less than as built.

7.7 DISCUSSION – CARGO TANKS

The gas blowby rate given by the conservative static simulation is much larger than the capacity of the PSV installed on the cargo tank. This is due to the large control valve upstream the cargo tank. The simple steady state simulation done in section 4.7 does not take into account the pressure drop through the long pipeline between the 2nd stage separator and the cargo tank. There is also a water/oil separator and a cooler between, which would also create a pressure drop.

The amount of gas going into the 2nd stage separator is limited, so even if the potential gas blowby rate from the 2nd stage separator to the cargo tank at the given pressures is large, the presence of gas in the 2nd stage separator would rapidly disappear.

The inlet to the cargo tanks are at the bottom of the tank. The volume of one tank is around 7000 m^3. Normal liquid level in the 2nd stage separator is 80%, which leaves a potential of 20% of 142m^2 which is 28m^2. At a pressure of 2,5barg this volume represents approximate 70 Sm^3. If the cargo tank is assumed to be empty at the start of the simulation, the pressure increase in the tank as a result of the gas blowby volume could be neglected.

If the cargo tank is assumed to be full at the start, this represents approximate 1,6bar knowing that the height is more than 20 meters and assuming a mass density of 800 kg/m^3 of the oil.

A dynamic simulation including the pipelines, coolers, separators and one tank has to be performed to see how much of the actual need of relieve would be in a gas blowby situation.

7.8 STEADY STATE SIMULATION

It is recommended to implement more details into the steady state gas blowby scenario simulations for the 2nd stage separator, produced water degassing drum and cargo tanks. Pressure drop along pipelines, bends, heaters, coolers, cyclones and other equipments can be taken into account. This way the steady state simulations might verify and document that the PSVs have a sufficient orifice size to handle a gas blowby scenario.

- 2nd stage separator

  As concluded in chapter 8 the gas blowby scenarios has to include closed outlets. An argument could be that even though the crude oil pumps downstream the 2nd stage separator trips, the oil will still flow through them. The same might be argued for the hydro cyclones downstream the water outlet. If this is to be used, it should be clearly documented. For this scenario with a more detailed simulation the HEM calculation would be sufficient to verify the PSV size for the 2nd stage separator.

- Produced water degassing drum

The same argument applies for the degassing drum that even though the booster pumps trip, the flow out of the degassing drum might continue. This matter should be investigated more and documented. For this scenario the HEM calculation would be sufficient to verify the PSV size for the produced water degassing drum

8 CONCLUSION

Some may claim that it would be sufficient to consider these gas blowby cases without closed outlet. As long as a natural consequence of the gas blowby case is closed outlets, I conclude that this has to be considered. This is too poorly discussed in the API Standards. The API Standard should state the importance of investigating the consequences of gas blowby on neighbouring equipment.

- **Alvheim/3rd party Inlet separator – Gas blowby from 2nd stage compressor scrubber, Train 100/200**

  The required area pr PSV (3+1reserve) is 57,15 cm^2 which is less than the as built Orifice dimension of 71.29 cm^2 (Q). In other words it is verified that the PSVs are sized for a gas blowby scenario.

  Alvheim/3rd party Inlet separator – Gas blowby from Dehydration inlet scrubber

  The required area pr PSV (3+1reserve) is 57,09cm^2 which is less than the as built Orifice dimension of 71,29 cm^2 (Q). In other words it is verified that the PSVs are sized for a gas blowby scenario.

- **2nd stage separator – Gas blowby from Alvheim/3rd party inlet separator**

  The steady state simulation give a HEM calculated orifice area to be 149,07 cm^2 when the as built orifice is 71,29cm^2. This is far too much, and further analysis needed to be run.

  It is recommended to create a more detailed steady state simulation and to analyse if the oil will actually manage to flow though the crude oil pumps as discussed in section 7.8.

  The steady state simulation assuming that test-pressure is reached requires 58,14cm^2 which is less than as built. In other words the 2nd stage separator will never reach test pressure. If the company would like to use this result as a basis for validation, an analysis must be performed to check if the flare system would handle test pressure in the 2nd stage separator. And as discussed in 7.5.2 the probability of reaching test-pressure needs to be compared to the acceptable criteria for that to happen.

  The dynamic simulation shows that the pressure in the 2nd stage will never surpass the PSV set-pressure which is 16,5bara.

  The dynamic simulation was performed to analyse more than to conclude. It still gives some valuable insight of how the pressure will develop. The simulation needs improvement. It should be possible to define the inlet streams by using actuators rather than to apply the property of the fluid to experience choked flow. In other words there is need for more work to verify that the PSVs are sized for a gas blowby scenario.

- **Produced water degasser – Gas blowby from the Alvheim/3rd party inlet separator**

As for the 2nd stage separator the steady state relieve rate gives a too high HEM calculated orifice area. It is recommend at first to implement a more detailed steady state simulation and to investigate if the liquid might be able to flow even though the water injection booster pumps trip.

If not it is recommended to complete a dynamic simulation of the scenario. In other words there is need for more work to verify that the PSVs are sized for a gas blowby scenario.

- **Glycol flash drum - Gas blowby from the Glycol Contactor**

  The required area pr PSV (1+1reserve) is 2,83cm^2 which is less than the as built area of 5,06cm^2. In other words it is verified that the PSV is sized for a gas blowby scenario.

- **Cargo tanks**

  The capacity of the PSV relieving the Cargo Tanks for overpressure is given as flow rate of a given gas (Air or calculated to blanket gas). It is recommended to do a dynamic simulation to look at how large capacity is needed to compensate for a conservative gas blowby scenario.

  Instead of using the given flow rates assuming a certain fluid, an equivalent area might be calculated for the PSV.

9 APPENDIX

9.1 APPENDIX 9.1: COMPOSITION – ALVHEIM INLET SEPARATOR

Table 9.1-A – Composition – Alvheim inlet separator

Mole fractions - Alvheim inlet separator blow by scenario					
	00- Gas blow by 2nd stage comp	00- Alvheim inlet	00 - 2nd stg comp scrubber 200	00- Dehydration inlet scrubber	00-inlet sep gas out
Nitrogen	0,0105052	0,0046659	0,0016849	0,0016478	0,0009107
CO2	0,0030703	0,0013939	0,0020053	0,0018890	0,0011322
H2S	0,0000000	0,0000000	0,0000000	0,0000000	0,0000000
Methane	0,7525880	0,3352755	0,2715053	0,2582905	0,1330947
Ethane	0,1088258	0,0503017	0,1295731	0,1197081	0,0548205
Propane	0,0734732	0,0394597	0,2100366	0,1952146	0,0790048
i-Butane	0,0232129	0,0175611	0,1232979	0,1186969	0,0465412
n-Butane	0,0201826	0,0192402	0,1367701	0,1349018	0,0533768
22-Mpropane	0,0001982	0,0002523	0,0016223	0,0016422	0,0006802
i-Pentane	0,0039124	0,0108472	0,0490524	0,0535685	0,0255662
n-Pentane	0,0028595	0,0126096	0,0438208	0,0500828	0,0268286
n-Hexane	0,0001512	0,0087896	0,0050684	0,0075936	0,0120967
C6*	0,0002317	0,0128805	0,0076861	0,0114651	0,0178069
C6_1*	0,0004182	0,0020497	0,0066570	0,0077375	0,0042635
n-Heptane	0,0000038	0,0052168	0,0002718	0,0006069	0,0062771
C7*	0,0000094	0,0137679	0,0006879	0,0015666	0,0165580
C7_1*	0,0001455	0,0233505	0,0063482	0,0108324	0,0299254
C7_2*	0,0001679	0,0012810	0,0031175	0,0037931	0,0024124
n-Octane	0,0000001	0,0030339	0,0000127	0,0000476	0,0035926
C8*	0,0000002	0,0091381	0,0000342	0,0001352	0,0108197
C8_1*	0,0000031	0,0309446	0,0003516	0,0010896	0,0367356
C8_2*	0,0000040	0,0041163	0,0002714	0,0005955	0,0049771
n-Nonane	0,0000000	0,0030417	0,0000012	0,0000079	0,0035990
C9*	0,0000000	0,0104057	0,0000036	0,0000259	0,0123120
C9_1*	0,0000001	0,0122881	0,0000140	0,0000746	0,0145396
C9_2*	0,0000006	0,0096616	0,0000745	0,0002541	0,0114552
C10*	0,0000000	0,0292365	0,0000016	0,0000185	0,0346027
C11*	0,0000000	0,0229065	0,0000002	0,0000032	0,0271181
C12*	0,0000000	0,0197316	0,0000000	0,0000008	0,0233628
C13*	0,0000000	0,0199927	0,0000000	0,0000002	0,0236740
C14*	0,0000000	0,0186808	0,0000000	0,0000000	0,0221218
C15*	0,0000000	0,0203713	0,0000000	0,0000000	0,0241246
C16*	0,0000000	0,0168727	0,0000000	0,0000000	0,0199818

C17*	0,0000000	0,0156652	0,0000000	0,0000000	0,0185519
C18*	0,0000000	0,0144381	0,0000000	0,0000000	0,0170987
C19*	0,0000000	0,0127867	0,0000000	0,0000000	0,0151430
C20*	0,0000000	0,0104631	0,0000000	0,0000000	0,0123912
C21*	0,0000000	0,0094383	0,0000000	0,0000000	0,0111776
C22*	0,0000000	0,0085832	0,0000000	0,0000000	0,0101649
C23*	0,0000000	0,0074083	0,0000000	0,0000000	0,0087735
C24*	0,0000000	0,0067817	0,0000000	0,0000000	0,0080315
C25*	0,0000000	0,0061355	0,0000000	0,0000000	0,0072662
C26*	0,0000000	0,0056786	0,0000000	0,0000000	0,0067251
C27*	0,0000000	0,0052152	0,0000000	0,0000000	0,0061763
C28*	0,0000000	0,0048171	0,0000000	0,0000000	0,0057047
C29*	0,0000000	0,0045299	0,0000000	0,0000000	0,0053646
C30*	0,0000000	0,0041904	0,0000000	0,0000000	0,0049627
C31*	0,0000000	0,0037466	0,0000000	0,0000000	0,0044370
C32*	0,0000000	0,0033027	0,0000000	0,0000000	0,0039114
C33*	0,0000000	0,0029568	0,0000000	0,0000000	0,0035017
C34*	0,0000000	0,0026370	0,0000000	0,0000000	0,0031229
C35*	0,0000000	0,0024803	0,0000000	0,0000000	0,0029374
C36+*	0,0000000	0,0352598	0,0000000	0,0000000	0,0417574
C10+*	0,0000000	0,0000000	0,0000000	0,0000000	0,0000000
C10+_1*	0,0000000	0,0000000	0,0000000	0,0000000	0,0000000
H2O	0,0000363	0,0441202	0,0000294	0,0185094	0,0184880
	1,0000000	1,0000000	1,0000000	1,0000000	1,0000000

9.2 APPENDIX 9.2: COMPOSITION 2ND STAGE SEPARATOR

Table 9.2-A - Composition 2nd stage blowby scenario

Mole fractions - 2nd stage blow by scenario					
	00-gas blow by alvheim	00-3rd party inlet oil outlet	00-1st stage compressor 100	00-1st stage compressor 200	00-2nd stage gas out
Nitrogen	0,0122961	0,0007101	0,0002350	0,0002350	0,0112219
CO2	0,0026316	0,0010436	0,0005391	0,0005391	0,0027535
H2S	0,0000000	0,0000000	0,0000000	0,0000000	0,0000000
Methane	0,8178217	0,1129768	0,0492806	0,0492806	0,7713218
Ethane	0,0882188	0,0432802	0,0381403	0,0381403	0,0943343
Propane	0,0428653	0,0469891	0,0975725	0,0975725	0,0528631
i-Butane	0,0115012	0,0235708	0,0875713	0,0875713	0,0165178
n-Butane	0,0100162	0,0266664	0,1182682	0,1182682	0,0156303

22-Mpropane	0,0001012	0,0003585	0,0016655	0,0016655	0,0001737
i-Pentane	0,0025639	0,0159746	0,0773729	0,0773729	0,0055790
n-Pentane	0,0022993	0,0187763	0,0865344	0,0865344	0,0057007
n-Hexane	0,0005363	0,0133600	0,0289672	0,0289672	0,0021449
C6*	0,0008002	0,0195699	0,0424685	0,0424685	0,0031910
C6_1*	0,0003600	0,0030538	0,0139059	0,0139059	0,0009068
n-Heptane	0,0001209	0,0079658	0,0054917	0,0054917	0,0006629
C7*	0,0003172	0,0210212	0,0142487	0,0142487	0,0017574
C7_1*	0,0010606	0,0355561	0,0548352	0,0548352	0,0047268
C7_2*	0,0001812	0,0019205	0,0079105	0,0079105	0,0005023
n-Octane	0,0000275	0,0046388	0,0010832	0,0010832	0,0001919
C8*	0,0000813	0,0139720	0,0031987	0,0031987	0,0005761
C8_1*	0,0004285	0,0472908	0,0172651	0,0172651	0,0027108
C8_2*	0,0001111	0,0062818	0,0050691	0,0050691	0,0005877
n-Nonane	0,0000111	0,0046528	0,0004481	0,0004481	0,0000947
C9*	0,0000382	0,0159171	0,0015437	0,0015437	0,0003304
C9_1*	0,0000722	0,0187930	0,0028560	0,0028560	0,0005516
C9_2*	0,0001200	0,0147672	0,0047573	0,0047573	0,0007859
C10*	0,0000552	0,0447277	0,0023071	0,0023071	0,0005402
C11*	0,0000207	0,0350460	0,0008841	0,0008841	0,0002358
C12*	0,0000099	0,0301894	0,0004283	0,0004283	0,0001264
C13*	0,0000055	0,0305892	0,0002378	0,0002378	0,0000783
C14*	0,0000025	0,0285821	0,0001083	0,0001083	0,0000407
C15*	0,0000012	0,0311688	0,0000504	0,0000504	0,0000223
C16*	0,0000004	0,0258159	0,0000182	0,0000182	0,0000095
C17*	0,0000002	0,0239684	0,0000074	0,0000074	0,0000044
C18*	0,0000001	0,0220908	0,0000033	0,0000033	0,0000023
C19*	0,0000000	0,0195642	0,0000016	0,0000016	0,0000012
C20*	0,0000000	0,0160089	0,0000007	0,0000007	0,0000006
C21*	0,0000000	0,0144409	0,0000003	0,0000003	0,0000003
C22*	0,0000000	0,0131327	0,0000002	0,0000002	0,0000002
C23*	0,0000000	0,0113350	0,0000001	0,0000001	0,0000001
C24*	0,0000000	0,0103763	0,0000000	0,0000000	0,0000001
C25*	0,0000000	0,0093876	0,0000000	0,0000000	0,0000000
C26*	0,0000000	0,0086885	0,0000000	0,0000000	0,0000000
C27*	0,0000000	0,0079795	0,0000000	0,0000000	0,0000000
C28*	0,0000000	0,0073703	0,0000000	0,0000000	0,0000000
C29*	0,0000000	0,0069309	0,0000000	0,0000000	0,0000000
C30*	0,0000000	0,0064115	0,0000000	0,0000000	0,0000000
C31*	0,0000000	0,0057324	0,0000000	0,0000000	0,0000000
C32*	0,0000000	0,0050533	0,0000000	0,0000000	0,0000000
C33*	0,0000000	0,0045240	0,0000000	0,0000000	0,0000000
C34*	0,0000000	0,0040347	0,0000000	0,0000000	0,0000000

C35*	0,0000000	0,0037950	0,0000000	0,0000000	0,0000000
C36+*	0,0000000	0,0539488	0,0000000	0,0000000	0,0000000
C10+*	0,0000000	0,0000000	0,0000000	0,0000000	0,0000000
C10+_1*	0,0000000	0,0000000	0,0000000	0,0000000	0,0000000
H2O	0,0053225	0,0000000	0,2347235	0,2347235	0,0031205
	1,0000000	1,0000000	1,0000000	1,0000000	1,0000000

9.3 APPENDIX 9.3: COMPOSITIONS FROM THE MARATHON HYSYS FILE

	20VA101_US	20VA101_Oil	20VA101_Gas	20VA201_W	20VA002_Gas	24VG_001_cond
Nitrogen	0.004666	0.000567	0.012296	0.000710	0.001668	0.001648
CO2	0.001394	0.000839	0.002632	0.001044	0.002394	0.001889
H2S	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Methane	0.335276	0.087650	0.817822	0.112977	0.256178	0.258291
Ethane	0.050302	0.038457	0.088219	0.043280	0.108993	0.119708
Propane	0.039460	0.052978	0.042865	0.046989	0.142014	0.195215
i-Butane	0.017561	0.030306	0.011501	0.023571	0.074571	0.118697
n-Butane	0.019240	0.034932	0.010016	0.026666	0.082377	0.134902
22-Mpropane	0.000252	0.000462	0.000101	0.000359	0.001004	0.001642
i-Pentane	0.010847	0.019245	0.002564	0.015975	0.035698	0.053569
n-Pentane	0.012610	0.021644	0.002299	0.018776	0.036620	0.050083
n-Hexane	0.008790	0.013281	0.000536	0.013360	0.011540	0.007594
C6*	0.012881	0.019483	0.000800	0.019570	0.016717	0.011465
C6_1*	0.002050	0.003489	0.000360	0.003054	0.005793	0.007738
n-Heptane	0.005217	0.007663	0.000121	0.007966	0.002895	0.000607
C7*	0.013768	0.020223	0.000317	0.021021	0.007380	0.001567
C7_1*	0.023350	0.034691	0.001061	0.035556	0.023534	0.010832
C7_2*	0.001281	0.002112	0.000181	0.001920	0.003152	0.003793
n-Octane	0.003034	0.004455	0.000027	0.004639	0.000708	0.000048
C8*	0.009138	0.013419	0.000081	0.013972	0.002028	0.000135
C8_1*	0.030945	0.045409	0.000428	0.047291	0.010522	0.001090
C8_2*	0.004116	0.006048	0.000111	0.006282	0.002640	0.000596
n-Nonane	0.003042	0.004472	0.000011	0.004653	0.000306	0.000008
C9*	0.010406	0.015299	0.000038	0.015917	0.001014	0.000026
C9_1*	0.012288	0.018056	0.000072	0.018793	0.001866	0.000075
C9_2*	0.009662	0.014178	0.000120	0.014767	0.003046	0.000254
C10*	0.029237	0.043009	0.000055	0.044728	0.001538	0.000019
C11*	0.022906	0.033708	0.000021	0.035046	0.000610	0.000003
C12*	0.019732	0.029040	0.000010	0.030189	0.000305	0.000001
C13*	0.019993	0.029427	0.000005	0.030589	0.000176	0.000000
C14*	0.018681	0.027497	0.000002	0.028582	0.000084	0.000000
C15*	0.020371	0.029986	0.000001	0.031169	0.000042	0.000000
C16*	0.016873	0.024837	0.000000	0.025816	0.000016	0.000000
C17*	0.015665	0.023059	0.000000	0.023968	0.000007	0.000000
C18*	0.014438	0.021253	0.000000	0.022091	0.000003	0.000000
C19*	0.012787	0.018822	0.000000	0.019564	0.000002	0.000000
C20*	0.010463	0.015402	0.000000	0.016009	0.000001	0.000000
C21*	0.009438	0.013893	0.000000	0.014441	0.000000	0.000000
C22*	0.008583	0.012635	0.000000	0.013133	0.000000	0.000000
C23*	0.007408	0.010905	0.000000	0.011335	0.000000	0.000000
C24*	0.006782	0.009983	0.000000	0.010376	0.000000	0.000000

C25*	0.006136	0.009032	0.000000	0.009388	0.000000	0.000000
C26*	0.005679	0.008359	0.000000	0.008689	0.000000	0.000000
C27*	0.005215	0.007677	0.000000	0.007979	0.000000	0.000000
C28*	0.004817	0.007091	0.000000	0.007370	0.000000	0.000000
C29*	0.004530	0.006668	0.000000	0.006931	0.000000	0.000000
C30*	0.004190	0.006168	0.000000	0.006412	0.000000	0.000000
C31*	0.003747	0.005515	0.000000	0.005732	0.000000	0.000000
C32*	0.003303	0.004862	0.000000	0.005053	0.000000	0.000000
C33*	0.002957	0.004352	0.000000	0.004524	0.000000	0.000000
C34*	0.002637	0.003882	0.000000	0.004035	0.000000	0.000000
C35*	0.002480	0.003651	0.000000	0.003795	0.000000	0.000000
C36+*	0.035260	0.051903	0.000000	0.053949	0.000000	0.000000
C10+*	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
C10+_1*	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
H2O	0.044120	0.028026	0.005323	0.000000	0.162558	0.018509
	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000

	24_Contactor_feed	27VG012_Gas	27VG102_Cond	27VG101_cond
Nitrogen	0.009621	0.010505	0.001685	0.000235
CO2	0.002949	0.003070	0.002005	0.000539
H2S	0.000000	0.000000	0.000000	0.000000
Methane	0.703188	0.752588	0.271505	0.049281
Ethane	0.110128	0.108826	0.129573	0.038140
Propane	0.086376	0.073473	0.210037	0.097573
i-Butane	0.032829	0.023213	0.123298	0.087571
n-Butane	0.031257	0.020183	0.136770	0.118268
22-Mpropane	0.000332	0.000198	0.001622	0.001666
i-Pentane	0.008140	0.003912	0.049052	0.077373
n-Pentane	0.006782	0.002860	0.043821	0.086534
n-Hexane	0.000854	0.000151	0.005068	0.028967
C6*	0.001284	0.000232	0.007686	0.042469
C6_1*	0.001030	0.000418	0.006657	0.013906
n-Heptane	0.000093	0.000004	0.000272	0.005492
C7*	0.000242	0.000009	0.000688	0.014249
C7_1*	0.001295	0.000146	0.006348	0.054835
C7_2*	0.000473	0.000168	0.003118	0.007911
n-Octane	0.000012	0.000000	0.000013	0.001083
C8*	0.000036	0.000000	0.000034	0.003199
C8_1*	0.000232	0.000003	0.000352	0.017265
C8_2*	0.000089	0.000004	0.000271	0.005069
n-Nonane	0.000003	0.000000	0.000001	0.000448
C9*	0.000010	0.000000	0.000004	0.001544

C9_1*	0.000024	0.000000	0.000014	0.002856
C9_2*	0.000059	0.000001	0.000075	0.004757
C10*	0.000008	0.000000	0.000002	0.002307
C11*	0.000002	0.000000	0.000000	0.000884
C12*	0.000000	0.000000	0.000000	0.000428
C13*	0.000000	0.000000	0.000000	0.000238
C14*	0.000000	0.000000	0.000000	0.000108
C15*	0.000000	0.000000	0.000000	0.000050
C16*	0.000000	0.000000	0.000000	0.000018
C17*	0.000000	0.000000	0.000000	0.000007
C18*	0.000000	0.000000	0.000000	0.000003
C19*	0.000000	0.000000	0.000000	0.000002
C20*	0.000000	0.000000	0.000000	0.000001
C21*	0.000000	0.000000	0.000000	0.000000
C22*	0.000000	0.000000	0.000000	0.000000
C23*	0.000000	0.000000	0.000000	0.000000
C24*	0.000000	0.000000	0.000000	0.000000
C25*	0.000000	0.000000	0.000000	0.000000
C26*	0.000000	0.000000	0.000000	0.000000
C27*	0.000000	0.000000	0.000000	0.000000
C28*	0.000000	0.000000	0.000000	0.000000
C29*	0.000000	0.000000	0.000000	0.000000
C30*	0.000000	0.000000	0.000000	0.000000
C31*	0.000000	0.000000	0.000000	0.000000
C32*	0.000000	0.000000	0.000000	0.000000
C33*	0.000000	0.000000	0.000000	0.000000
C34*	0.000000	0.000000	0.000000	0.000000
C35*	0.000000	0.000000	0.000000	0.000000
C36+*	0.000000	0.000000	0.000000	0.000000
C10+*	0.000000	0.000000	0.000000	0.000000
C10+_1*	0.000000	0.000000	0.000000	0.000000
H2O	0.002650	0.000036	0.000029	0.234724
	1.000000	1.000000	1.000000	1.000000

9.4 APPENDIX 9.4: CV CALCULATIONS USING KENTINTROLS SOFTWARE "INLET SEPARATOR"

This software is only used to calculate the C_V of different valves. Look at "Calculated C_V" in the "Calculated values" chapter.

kentintrol
27/05/2011

Armytage Road,
Brighouse,
West Yorks. HD6 1QF,
England

Form CIV1203

Quotation					Order		
No.	Item No.	Cust. Item	Rev.	Qty.	No.	Item No.	Rev.
RK-00006	10	10	A	1			

Customer	Enquiry Ref.	Sales Eng.
Marathon Petroleum Norge		Rune Kvammen

Project	Quality	Serial No.	Tag No.
			Gas blowby 27LV0320

Valve Design Details

Valve :	Series 12 Globe	Design CV :	3.5	Flow Characteristic	Eq%
Valve Size (in.cm.out):	1.5x1.5x1.5 Inch	Shut Off Press.	79 barg	Leakage Class	ANSI Class IV
Body Rating :	ANSI 600	Line Fluid	HC GAS	Inlet Pipe Size / Sched.	2 Inch /80
Trim Design :	HF	Flow Direction :	Flow Under	Outlet Pipe Size / Sched.	2 Inch /40

Process Conditions

Header	Uom	Cond. 1
Gas Flow Rate	kg/hour	2205
Inlet Pressure	bar	69
Outlet Pressure	bar	35.1
Pressure Drop	bar	33.9
Inlet Temperature	°C	22.8
Outlet Temperature	°C	6
Molecular Weight		22.13
Ratio of Specific Heats		
Compressibility		
Duration %		

Calculated Values

Header	Uom	Cond. 1
Expansion Factor		1.3
Inlet Spec Volume	m³/kg	0.0161
Calculated Cv	US Units	2.25

Valve Opening	%	76.0
Gas Recovery Factor		0.746
Fluid State		Normal
Predicted Noise Level	dBA	70.0
System Noise Level	dBA	70.0
Body Inlet Velocity	m/sec	8.7
Body Outlet Velocity	m/sec	14.6
Body Outlet Mach No.		0.038
Mach No. Condition		OK
Sys. Outlet Velocity	m/sec	16.0
Sys. Outlet Mach No.		0.042
Sys Mach No. Condition		OK
Pipework Corr. Factor		1.00
Energy Level	MW	0.04
Velocity Head	barg	25.01
Specific Volume In	m³/kg	0.0161
Specific Volume Out	m³/kg	0.0299
Min DP 100% Open		14.047
Max Flow 100% Open		3,425.1

Customer	Enquiry Ref.	Sales Eng.
Marathon Petroleum Norge		Rune Kvammen

Project	Quality	Serial No.	Tag No.
			Oil through 24LV0120

Valve Design Details

Valve :	Series 1200 Globe	Design CV :	30	Flow Characteristic	Eq%
Valve Size (in.cm.out):	1.5x1.5x1.5 Inch	Shut Off Press.	80 barg	Leakage Class	ANSI Class IV
Body Rating :	ANSI 600	Line Fluid	HC LIQUID	Inlet Pipe Size / Sched.	2 Inch /80
Trim Design :	HF	Flow Direction :	Flow Over	Outlet Pipe Size / Sched.	2 Inch /80

Process Conditions

Header	Uom	Cond. 1
Liquid Flow Rate	kg/hour	50750

Inlet Pressure	bar	77.5
Outlet Pressure	bar	35.1
Pressure Drop	bar	42.4
Inlet Temperature	°C	22.8
Specific Gravity		0.461
Vapour Pressure	bar	77.49
Critical Pressure	bar	45
Viscosity	Centi-Poise	0.09
Duration %		

Calculated Values

Header	Uom	Cond. 1
Calculated Cv	US Units	16.6
Valve Opening	%	75.9
Pressure Recovery Factor		0.947
Cavitation Index		N/A
Fluid State		FLASHING
Predicted Noise Level	dBA	70.0
System Noise Level	dBA	70.0
Inlet / Outlet Velocity	m/sec	24.3
Pipework Corr. Factor		1.01
Viscosity Corr. Factor		1.00
Energy Level	MW	0.16
Min DP 100% Open		8.353
Max Flow 100% Open		91,577.6

Pressure Drop & Cavitation

Header	DP Stage	Cond. 1
Pressure Drop	1	42.40
Cavitation Index	1	N/A

The HYSYS calculation used is more conservative then the kentintrol calculation for this valve.

9.5 APPENDIX 9.5: CV CALCULATIONS USING KENTINTROLS SOFTWARE "2ND STAGE SEPARATOR"

This software is only used to calculate the C_V of different valves. Look at "Calculated C_V" in the "Calculated values" chapter.

kentintrol
16/03/2011

Armytage Road,
Brighouse,
West Yorks. HD6 1QF,
England

Form CIV1203

Quotation					Order		
No.	Item No.	Cust. Item	Rev.	Qty.	No.	Item No.	Rev.
RK-00006	7	7	A	1			

Customer	Enquiry Ref.	Sales Eng.
Marathon Petroleum Norge		Rune Kvammen

Project	Quality	Serial No.	Tag No.
			Gas blowby 20LV0120A

Valve Design Details

Valve :	Series 12 Globe	Design CV :	1220	Flow Characteristic	Eq%
Valve Size (in.cm.out):	12x12x12 Inch	Shut Off Press.	30 barg	Leakage Class	ANSI Class IV
Body Rating :	ANSI 300	Line Fluid	PROCESS GAS	Inlet Pipe Size / Sched.	12 Inch /20
Trim Design :	XHF	Flow Direction :	Flow Under	Outlet Pipe Size / Sched.	18 Inch /20

Process Conditions

Header	Uom	Cond. 1	Cond. 2	Cond. 3
Gas Flow Rate	kg/hour	200000	210000	205000
Inlet Pressure	bar	26.14	26.14	26.4
Outlet Pressure	bar	16.6	16.6	16.6
Pressure Drop	bar	9.54	9.54	9.8
Inlet Temperature	°C	105	105	105
Outlet Temperature	°C	101	101	101
Molecular Weight		20.23	20.23	20.23
Ratio of Specific Heats				
Compressibility		0.9612	0.9612	0.9612
Duration %				

Calculated Values

Header	Uom	Cond. 1	Cond. 2	Cond. 3
Expansion Factor		1.2	1.2	1.2
Inlet Spec Volume	m³/kg	0.0571	0.0571	0.0566
Calculated Cv	US Units	675.3	709.1	681.8

Valve Opening	%	75.8	77.6	76.2
Gas Recovery Factor		0.749	0.749	0.749
Fluid State		Normal	Normal	Normal
Predicted Noise Level	dBA	88.3	88.4	88.6
System Noise Level	dBA	88.3	88.4	88.6
Body Inlet Velocity	m/sec	45.4	47.6	46.0
Body Outlet Velocity	m/sec	69.9	73.4	71.7
Body Outlet Mach No.		0.151	0.158	0.155
Mach No. Condition		OK	OK	OK
Sys. Outlet Velocity	m/sec	70.7	74.2	72.4
Sys. Outlet Mach No.		0.152	0.160	0.156
Sys Mach No. Condition		OK	OK	OK
Pipework Corr. Factor		1.00	1.00	1.00
Energy Level	MW	3.53	3.71	3.69
Velocity Head	barg	5.21	5.21	5.37
Specific Volume In	m^3/kg	0.0571	0.0571	0.0566
Specific Volume Out	m^3/kg	0.0890	0.0890	0.0890
Min DP 100% Open		2.923	3.223	3.061
Max Flow 100% Open		361,338.0	361,302.3	366,818.3

9.6 APPENDIX 9.6: CV CALCULATIONS USING KENTINTROLS SOFTWARE “PRODUCED WATER DEGASSING DRUM”

This software is only used to calculate the C_V of different valves. Look at “Calculated C_V” in the “Calculated values” chapter.

kentintrol
27/05/2011

Armytage Road,
Brighouse,
West Yorks. HD6 1QF,
England

Form CIV1203

Quotation					Order		
No.	Item No.	Cust. Item	Rev.	Qty.	No.	Item No.	Rev.
RK-00006	12	12	A	1			

Customer	Enquiry Ref.	Sales Eng.
Marathon Petroleum Norge		Rune Kvammen

Project	Quality	Serial No.	Tag No.
			20LV0120B Gas blowby

Valve Design Details

Valve :	Series 12 Globe	Design CV :	1220	Flow Characteristic	Eq%
Valve Size (in.cm.out):	12x12x12 Inch	Shut Off Press.	30 barg	Leakage Class	ANSI Class IV
Body Rating :	ANSI 300	Line Fluid	HC GAS	Inlet Pipe Size / Sched.	12 Inch /20
Trim Design :	XHF	Flow Direction :	Flow Under	Outlet Pipe Size / Sched.	12 Inch /20

Process Conditions

Header	Uom	Cond. 1
Gas Flow Rate	kg/hour	234900
Inlet Pressure	bar	27.5
Outlet Pressure	bar	16.5
Pressure Drop	bar	11
Inlet Temperature	°C	47
Outlet Temperature	°C	30
Molecular Weight		22.58
Ratio of Specific Heats		
Compressibility		
Duration %		

Calculated Values

Header	Uom	Cond. 1
Expansion Factor		1.2
Inlet Spec Volume	m^3/kg	0.0428

Calculated Cv	US Units	651.8
Valve Opening	%	74.5
Gas Recovery Factor		0.750
Fluid State		Normal
Predicted Noise Level	dBA	89.3
System Noise Level	dBA	89.3
Body Inlet Velocity	m/sec	40.0
Body Outlet Velocity	m/sec	62.4
Body Outlet Mach No.		0.158
Mach No. Condition		OK
Sys. Outlet Velocity	m/sec	63.1
Sys. Outlet Mach No.		0.160
Sys Mach No. Condition		OK
Pipework Corr. Factor		1.00
Energy Level	MW	3.65
Velocity Head	barg	5.86
Specific Volume In	m^3/kg	0.0428
Specific Volume Out	m^3/kg	0.0676
Min DP 100% Open		3.139
Max Flow 100% Open		439,686.3

The HYSYS calculation is more conservative than the kentintrol software.

9.7 APPENDIX 9.7: CV CALCULATIONS USING KENTINTROLS SOFTWARE "GLYCOL FLASH DRUM"

This software is only used to calculate the C_V of different valves. Look at "Calculated C_V" in the "Calculated values" chapter.

kentintrol
27/05/2011

Armytage Road,
Brighouse,
West Yorks. HD6 1QF,
England

Form CIV1203

Quotation					Order		
No.	Item No.	Cust. Item	Rev.	Qty.	No.	Item No.	Rev.
RK-00006	13	13	A	1			

Customer	Enquiry Ref.	Sales Eng.
Marathon Petroleum Norge		Rune Kvammen

Project	Quality	Serial No.	Tag No.
			Gas blowby 24LV0155

Valve Design Details

Valve :	Series 12 Globe	Design CV :	3.5	Flow Characteristic	Eq%
Valve Size (in.cm.out):	1x1x1 Inch	Shut Off Press.	95 barg	Leakage Class	ANSI Class IV
Body Rating :	ANSI 900	Line Fluid	HC GAS	Inlet Pipe Size / Sched.	2 Inch /80
Trim Design :	HF	Flow Direction :	Flow Under	Outlet Pipe Size / Sched.	2 Inch /80

Process Conditions

Header	Uom	Cond. 1
Gas Flow Rate	kg/hour	2856
Inlet Pressure	barg	85
Outlet Pressure	barg	15.5
Pressure Drop	barg	69.5
Inlet Temperature	°C	30
Outlet Temperature	°C	-7
Molecular Weight		22.84
Ratio of Specific Heats		
Compressibility		
Duration %		

Calculated Values

Header	Uom	Cond. 1
Expansion Factor		1.5
Inlet Spec Volume	m³/kg	0.0128
Calculated Cv	US Units	2.24

Valve Opening	%	75.8
Gas Recovery Factor		0.746
Fluid State		Choked
Predicted Noise Level	dBA	82.7
System Noise Level	dBA	82.7
Body Inlet Velocity	m/sec	26.5
Body Outlet Velocity	m/sec	94.8
Body Outlet Mach No.		0.258
Mach No. Condition		OK
Sys. Outlet Velocity	m/sec	121.4
Sys. Outlet Mach No.		0.330
Sys Mach No. Condition		OK
Pipework Corr. Factor		1.00
Energy Level	MW	0.12
Velocity Head	barg	31.26
Specific Volume In	m³/kg	0.0128
Specific Volume Out	m³/kg	0.0587
Min DP 100% Open		26.077
Max Flow 100% Open		4,454.4

The HYSYS C_V calculation is more conservative than the kentintrol software for this case.

9.8 APPENDIX 9.8: CV CALCULATIONS USING KENTINTROLS SOFTWARE "CARGO TANKS"

This software is only used to calculate the C_V of different valves. Look at "Calculated C_V" in the "Calculated values" chapter.

kentintrol

27/05/2011

Armytage Road,
Brighouse,
West Yorks. HD6 1QF,
England

Form CIV1203

Quotation					Order		
No.	Item No.	Cust. Item	Rev.	Qty.	No.	Item No.	Rev.
RK-00006	14	14	A	1			

Customer	Enquiry Ref.	Sales Eng.
Marathon Petroleum Norge		Rune Kvammen

Project	Quality	Serial No.	Tag No.
			20LV0320 Gas blowby

Valve Design Details

Valve :	Series 12 Globe	Design CV :	1030.23886157156	Flow Characteristic	Eq%
Valve Size (in.cm.out):	10x10x10 Inch	Shut Off Press.	14 barg	Leakage Class	ANSI Class IV
Body Rating :	ANSI 150	Line Fluid	HC GAS	Inlet Pipe Size / Sched.	10 Inch /20
Trim Design :	HF	Flow Direction :	Flow Over	Outlet Pipe Size / Sched.	10 Inch /20

Process Conditions

Header	Uom	Cond. 1
Gas Flow Rate	kg/hour	78280
Inlet Pressure	barg	4
Outlet Pressure	barg	0.2
Pressure Drop	barg	3.8
Inlet Temperature	°C	40
Outlet Temperature	°C	36
Molecular Weight		36.75
Ratio of Specific Heats		
Compressibility		
Duration %		

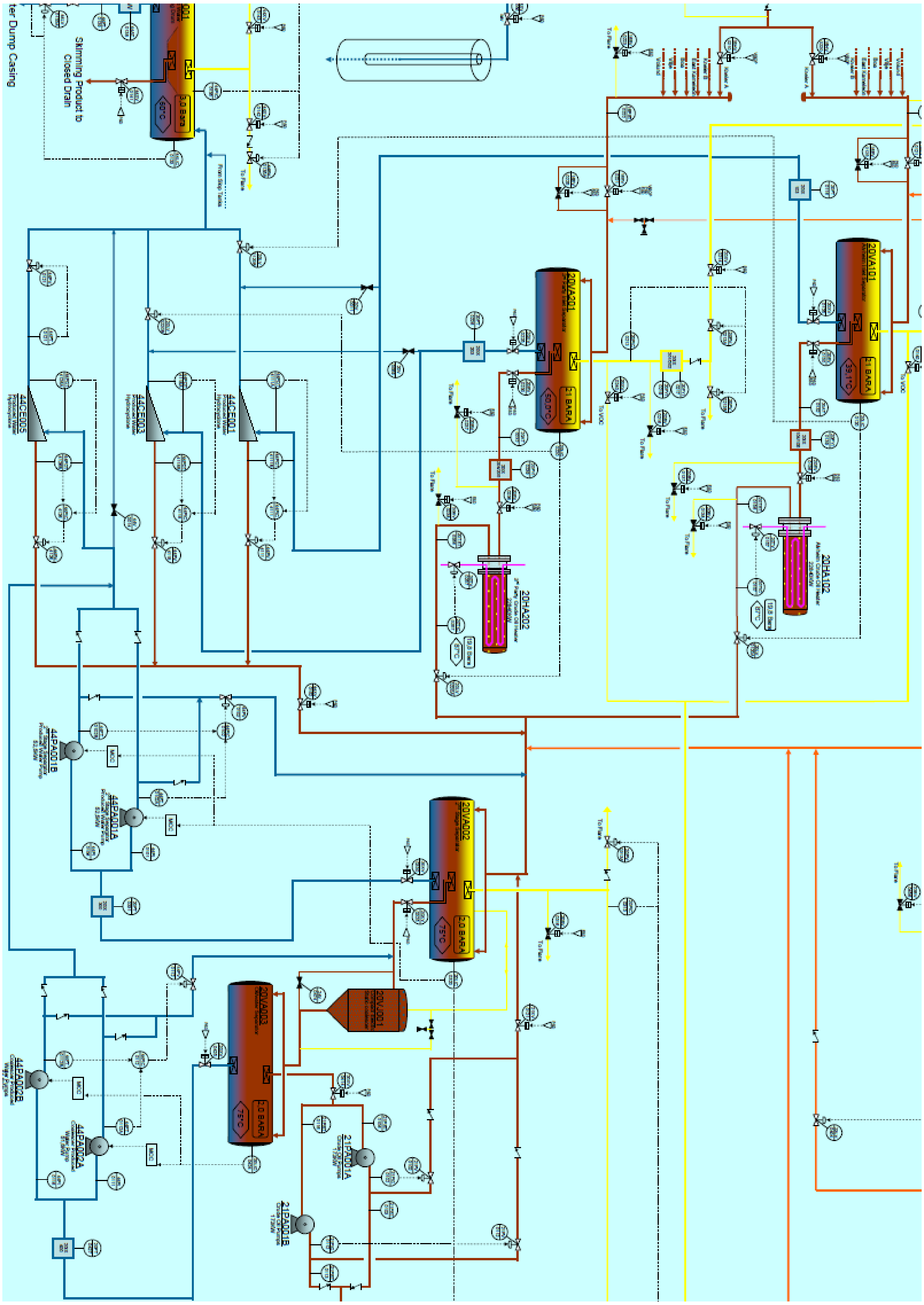
Calculated Values

Header	Uom	Cond. 1
Expansion Factor		1.5
Inlet Spec Volume	m^3/kg	0.1416
Calculated Cv	US Units	851.4

Valve Opening	%	91.3
Gas Recovery Factor		0.735
Fluid State		Choked
Predicted Noise Level	dBA	105.7
System Noise Level	dBA	105.7
Body Inlet Velocity	m/sec	63.9
Body Outlet Velocity	m/sec	258.1
Body Outlet Mach No.		0.825
Mach No. Condition		HIGH MACH NO.
Sys. Outlet Velocity	m/sec	263.0
Sys. Outlet Mach No.		0.841
Sys Mach No. Condition		HIGH MACH NO.
Pipework Corr. Factor		1.00
Energy Level	MW	1.80
Velocity Head	barg	1.92
Specific Volume In	m^3/kg	0.1416
Specific Volume Out	m^3/kg	0.5825
Min DP 100% Open		2.497
Max Flow 100% Open		94,718.5

9.9 APPENDIX 9.9: SCHEMATIC DRAWING OF THE OIL TRAIN

Figure 9.9-A - Schematic drawing of the oil train



10 FIGURES

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