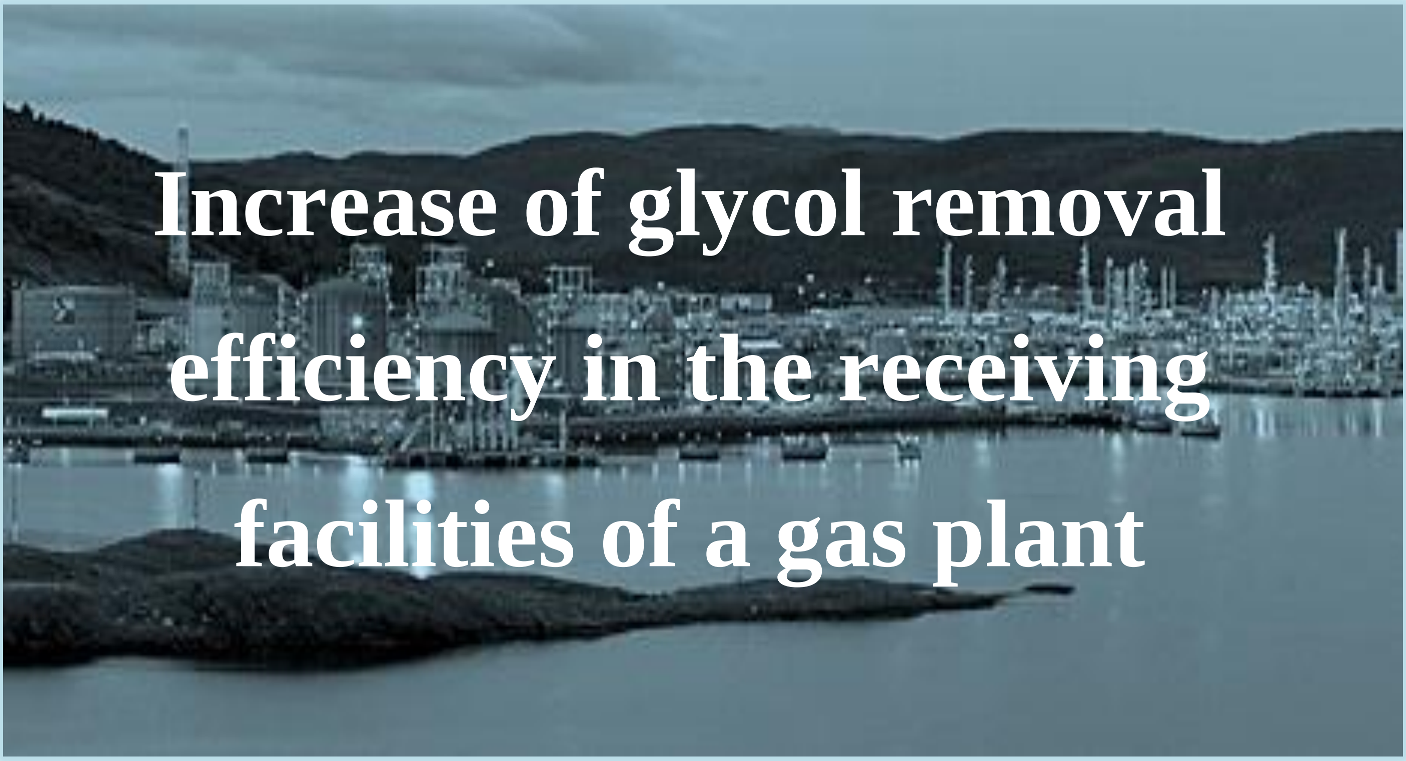

Increase of glycol removal efficiency in the receiving facilities of a gas plant

Hovedprosjekt utført ved
Høgskolen Stord/Haugesund – Studie for ingeniørfag
Maskin, Energi- og Prosessteknikk og Maskin, Marin
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Haugesund   Våren 2013

HØGSKOLEN STORD/HAUGESUND

Foreword

This bachelor thesis is done as part of the engineering studies at the college of Stord/Haugesund.

The assignment was given by Statoil. When we started writing the assignment, the scope was not decided. The last changes in the assignment were made the 7th. of March.

The assignment has been both challenging and interesting, and we feel that our learning curve has increased this last semester. Process technique I and II, Petroleum production and fluid mechanics is topics that have come to extra use when working with this assignment. The report is built up in a way that enables people without a profound knowledge of process engineering to understand the content.

The calculation basis is integrated in the report, the whole calculations are found as an appendix.

We would like to thank our supervisors Adriana Kurman Rivero from Statoil and Jorunn Stueland Nysted from HSH for excellent guidance regarding the technical part of the assignment in addition to guidance with the English writing.

We would also like to thank the vendors that we have been in contact with, and a special thanks to Kees Tjeenk Willink from TwisterBV and Danny Thierens from ASCOM for the time and effort they spent helping us.

Haugesund 08.05.2013

Karoline Opheim | Ingvild Bjørnevik | Trine Halsnes

Summary

When gas is dried at the platforms connected to the Åsgard transport pipe, it is used TEG. Because of the high pressures from the fields, some of the TEG will enter a gas phase and become carried over with the gas. At the Åsgard inlet facilities at Kårstø the TEG is recovered by separators.

The separation efficiency of the current separators is not sufficient, and in this assignment there will be investigation on how the glycol separation can get better. There is a focus on the letdown station and the two filter separators in the KUP train.

The methodology used in this study includes literature study, contact with vendors of new separation technology and valves. This study is based on a report from Statoil's R&D center in Trondheim.

The valves at the letdown station have been consider replaced with the Twister SwirlValve™ to minimize turbulence created in the flow upstream the separators. This could help the separation because the size range distribution of droplets would probably decrease, and therefore get easier to separate. The effect this change would have on the glycol recovery efficiency is impossible to determine, and Statoil have to decide rather or not they want to do a test on the Twister SwirlValve™ in this application.

The current separators have been evaluated for further use with new internals, but calculations show that they are undersized.

Further on there is evaluations of new separators and internals, both vertical and horizontal. The conclusion is that a new separator should be horizontal to prevent a large intervention at the plant. The new horizontal separator should contain a vane type inlet device as a primary separation and HiPer cyclones or a combination of mesh and vane as demister.

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HØGSKOLEN STORD/HAUGESUND

Statoil

1. Introduction

Statoil is an international oil and gas company stock listed in Oslo and New York. The state of Norway is the main shareholder with 67% of the stocks. Statoil started up in 1972 and gained enough experience through developing the Norwegian continental shelf to become a world class oil and gas company. It is located in 35 countries and has approximately 21.000 employees. The main office is located Stavanger [1].

Kårstø is Europe's biggest onshore gas processing plant and is located near Stavanger. The first gas arrived at the plant through Statpipe on the 25th of June 1985. In October the same year dry gas began to be dispatched to Emden, Germany [2].

In the year 2000, Åsgard transport was finished. This pipeline transports natural gas from the Åsgard field in the north of the Norwegian continental shelf to Kårstø for processing. There are many other fields connected to the transport pipe such as Mikkel, Draugen, Norne and Heidrun. In 2005 the Kristin field was connected as well. The pipeline is 707 km long and 42'' wide and has an available capacity of 70 MMSCMD [5].

Natural gas is a fossil fuel created over millions of years by the decomposition of plants, animals and microorganisms [3]. The gas can be found under the surface of the earth, trapped in geological formations consisting of layers of porous, sedimentary rock and a denser impermeable layer of rock. Natural gas consists of a mixture of hydrocarbon gases, mainly methane, and is one of the cleanest and most important energy sources available [4]. It is primarily used for heating, cooking, electricity and as fuel, but normally it needs to be processed before use. Through processing, the gas is cleaned and impurities removed to meet market specifications. Impurities in natural gas include water, H_2S, CO_2 and sand. This processing is performed at the Kårstø plant.

In untreated natural gas, water is one of the most important impurities to remove [6]. At low temperatures and/or high pressure, water vapor will condense to liquid. In liquid form, water can create crystalline compounds with natural gas, also known as hydrates. This may cause blockage in pipelines and other units. To avoid this from occurring, the natural gas can be dehydrated by a range of different techniques.

Absorption is the most commonly used dehydration process to meet the required pipeline specifications [7]. In an absorption process the water vapor is absorbed by certain liquids that have a strong affinity to water. Glycols meet these criteria and are therefore the most typical absorbents. There are four different glycols; monoethylen glycol (MEG), diethylene glycol (DEG), triethylene glycol (TEG) and tetraethylene glycol (TREG).

1.1 Background

When gas from the Åsgard transport pipe arrives at Kårstø, it goes through the inlet facilities. This is where gas is prepared for processing. As shown in Figure 1 the gas will part into two trains: approximately 39 MSm^3/d goes through the upper train called the KUP train, and 27 MSm^3/d goes through the lower train called NET-1.

The cyclone separators 15-CB-202 and 15-CB-401 in Figure 1 perform a primary separation of sand, TEG and water from the feed to protect the heat exchangers and pressure- reduction valves. Before the pressure is reduced, the rich gas is heated by means of low pressure steam (6 barg), in heat exchangers 15-HA-201 and 15-HA-401, in order to prevent hydrate formation after pressure reduction, and to satisfy the temperature requirements at the intake to the extraction process (+5 °C). After this section the gas goes through a letdown station where the pressure of the stream is controlled. The letdown station consists of a parallel set of valves, six valves in the KUP train and four valves in the NET-1 train; this is not figuratively explained by the pfd. Further on there is a non-regulated crossover where flow is expected to equalize between the trains.

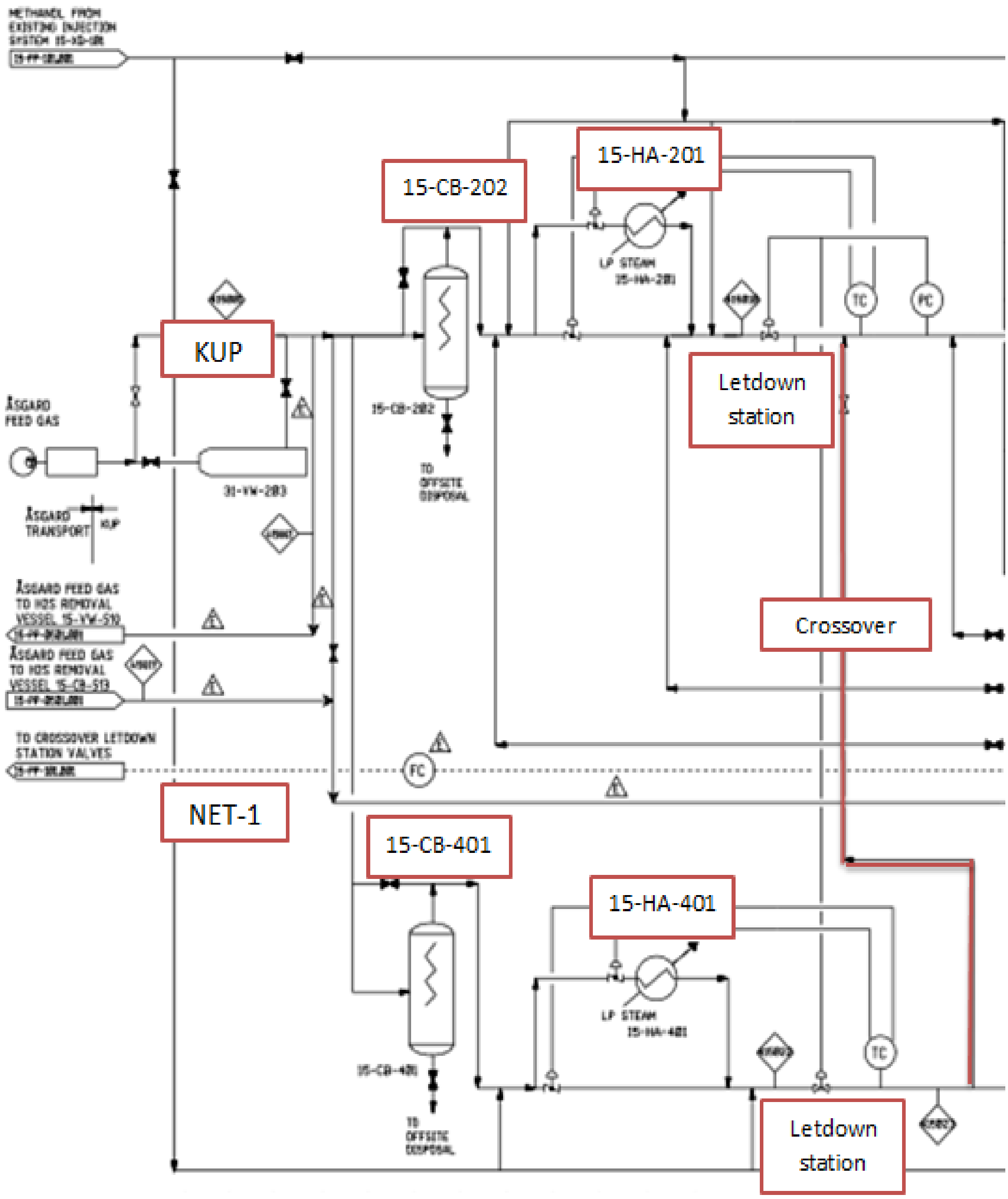

Figure 1 First section of the process flow diagram [18].

As shown in Figure 2 the gas arrives at filter separators 15-CB-201 A/B in the KUP train and the filter separator 15-CB-403 in the NET-1 train. This is where a more thorough separation of glycol will take place before the gas enters the mercury remover vessels. The mercury remover vessel contains molecular sieves that will absorb any mercury in the flow.

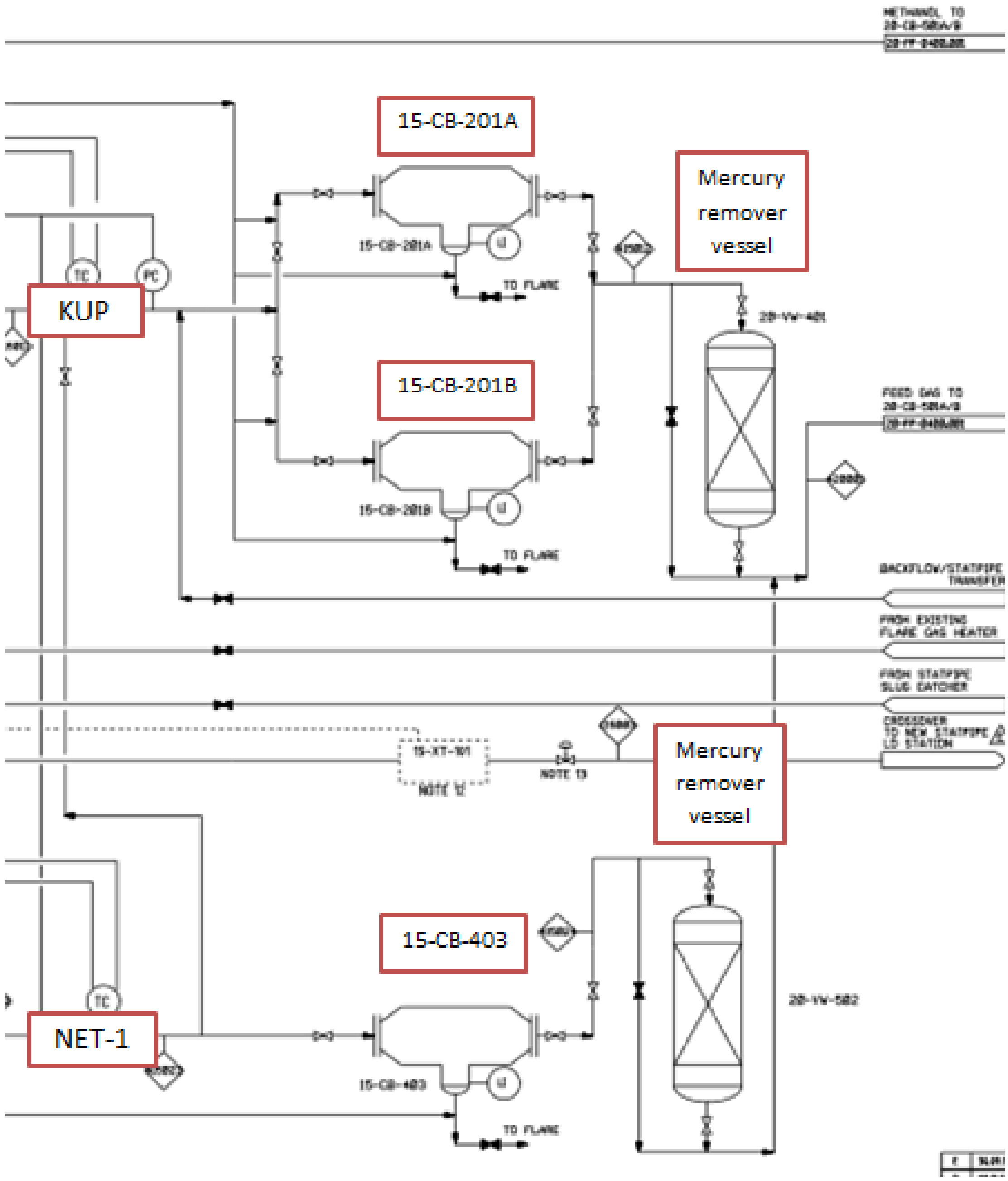

Figure 2 Second section of the process flow diagram [18].

The problem is that almost no TEG has been separated in any of the separators since the start of Åsgard facilities. Statoil's R&D center in Trondheim has issued a study [15] on the problem and has proposed numerous possible solutions. One of them is to:

-Remove the initial cyclone separators 15-CB-202 and 15-CB-401.

-Relocate the heat exchangers to fit in between the filter separators and the mercury remover vessels; this is done to ensure that TEG carryover from the separators is in a gas phase when passing through the molecular sieves of the mercury remover vessel.

-Focus on increasing separation efficiency on the filter separators 15-CB-201A/B and 15-CB-403. This can be done by replacing technology used in the letdown valves to condition better the inlet at the filter separators and/or replacing the internals of the separators or the whole vessel.

The rest of the process will remain as today.

A new separation solution should account for improved separation performance and minimum changes in the process to reduce costs, as well as reducing the pressure drop in the system. Reduced pressure drop at the Åsgard inlet facilities will lead to increased capacity of Åsgard transport because a lower landing pressure at Kårstø will increase the flow that the compressors offshore are able to send, while meeting the corresponding backpressure.

1.2 Goal

The purpose of this study is to develop the solution proposed by the Statoil R&D center and previously explained in the background section. This report contains investigations, calculations and discussions of new relevant technology for the letdown station and the filter separators. The goal is to conduct a proposal which will better the glycol recovery efficiency.

1.3 Limitations

This report has a focus on the challenges faced in the KUP train which concerns the letdown station and filter separators 15-CB-201 A/B.

The KUP train is more flexible to solutions because of the opportunity to redirect the feed into five of the six valves at the letdown station and into one of the separators 15-CB-201 A/B. One valve/separator can be excluded from the process. This makes it possible to work on new installations without requiring shutdown of the production.

The correction factors for k-value have been neglected for the calculations.

2. Method

The methodology used in this study includes literature study and contact with vendors and Statoil R&D center in Trondheim via e-mail and telephone.

The following methods have been used to assess new technology for the letdown station. Analyze current separators and internals and investigation of new internals, vessels and configurations of internals.

2.1 Literature study

In the initial phase of this study relevant literature was use to get familiar with the technology around this case. This includes relevant literature, articles on vendor homepages, Statoil's own guidelines [16] [17] and parts of the report from Statoil R&D center in Trondheim [15] which this study is based on. The reliability of the sources is considered sufficiently good based on expert assessment.

2.2 Dialogue with vendors

There has been a dialogue with different vendors of valves and separation equipment, where the goal has been to get the vendors to share experiences with the applications they deliver as well as recommendations for this specific case. The vendors have also been asked to share literature and knowledge regarding glycol separation.

- Twister BV is an engineering company with headquarters in the Netherlands. They offer gas processing solutions such as the Twister SwirlValve™ which will be further assessed in this report.

- Pall Corporation provides filtration, separation and purification solutions, and they have offices worldwide. Pall is the vendor of the current internals in the filter separator 15-CB-403.

- AMACS is the product of a recent merge between AMISTCO Separation Products Inc. and ACS Industries LP. AMACS is a manufacturer and supplier of separation technologies like mesh, vane and phase contacting process internals.

- ASCOM BV develops, design and supply 2- and 3-phase separation technologies and other equipment for use in processing facilities onshore and offshore.

- FMC Technologies, Inc. is a global provider of technology solutions for the energy industry.

The vendors have been requested to carry out simulations of the different case studies assessed in this report using the internals they deliver to retrofit into the exciting vessel. This is done to investigate the case with new internals in the separators. Some vendors have also been asked to propose solutions for a new separator.

2.3 Dialogue with Statoil R&D center in Trondheim

There has been contact with Oddbjørn Rekaa Nilssen[1] at the Statoil R&D center in Trondheim, concerning the suggested solution and calculations of the separators. They also provided supplementary explanation with reference to their study [15].

2.4 HYSYS

HYSYS v. 7.2 has been used as a tool to calculate molecular mass and compressibility factor.

[1] Co-author of R&D Trondheim report[15]

2.5 Guidelines

All calculations and proposals are based on Statoil's internal guidelines, GL1965 [16], and technical and professional requirements, TR1965 [17]

2.6 External supervisor

As an employee in Statoil the external supervisor, Adriana Kurman Rivero[2], has provided internal documents with relevance to this study.

[2] Process engineer at Statoil.

3. Letdown station

In this chapter a new solution for the letdown station will be investigated to find out if changes made at this point in the process will better the TEG recovery in the separators.

The letdown station contains six axial flow control valves delivered by Mokveld. Five valves are operating while one is in standby. The control valves stabilize the pressure of the feed at approximately 116.5 barg. This is done to meet the design conditions for the processing facilities. The pressure drop will also lead to less costly vessels.

There is a concern that the letdown station will generate smaller droplets of TEG due to the turbulence it creates. This makes it more difficult to recover TEG in the separators downstream the letdown station.

3.1 Valves upstream separators

Valves are used in the oil and gas industry to control pressure, temperature and flow. When gas is throttled over the valves it causes the gas to loose pressure and temperature, this is called the Joule Thompson effect. The Joule Thompson effect causes some of the TEG that is still in the gas phase to condensate, it is therefore beneficial to locate the TEG separators downstream the choke valves as presented in Figure 3. Another result of the throttling process is an intensive mixing of the gas and liquid phase. This diminishes the separation efficiency of separators downstream letdown station.

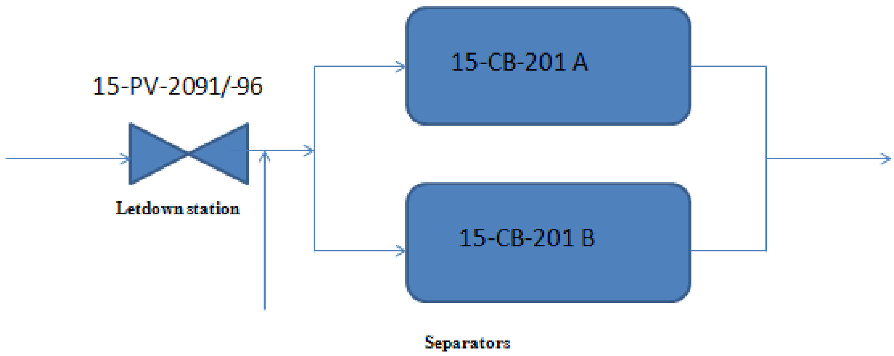

Figure 3 Separators downstream letdown station.

3.2 Twister SwirlValve™

Twister BV have developed and tested a new gas processing product called Twister SwirlValve™ which is a modified choke valve.

The working principle of the Twister SwirlValve™ is to force the flow into a swirling motion by using tangential slots in the cage as shown in Figure 4.When the flow gets a swirling motion, the droplets are lead to the outer circumference of the flow area, where they agglomerate into larger droplets.

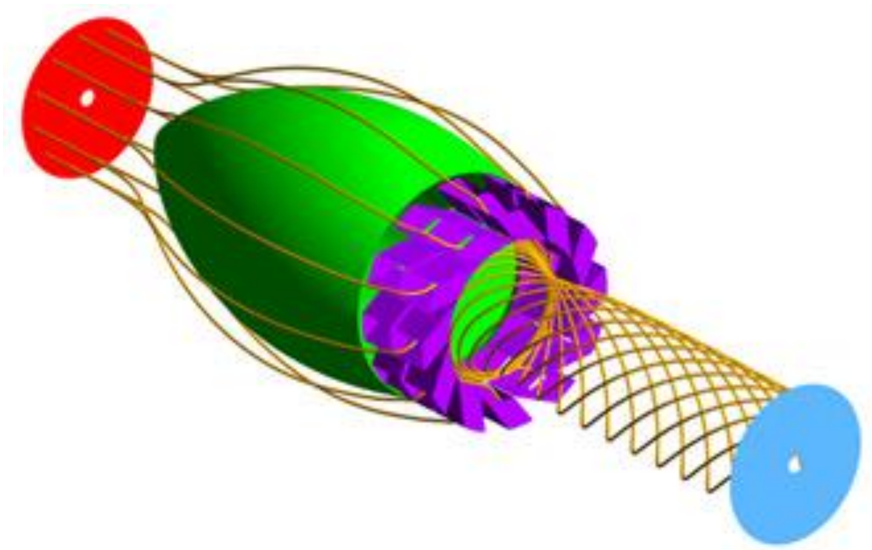

Figure 4 Working principle of Twister SwirlValve™ [23].

As shown in Figure 5 the throttling in a tangential cage valve is gentler than in a conventional linear cage valve. Illustrated in Figure 6 the Swirl cage valve will gather the droplets at the periphery of the pipe.

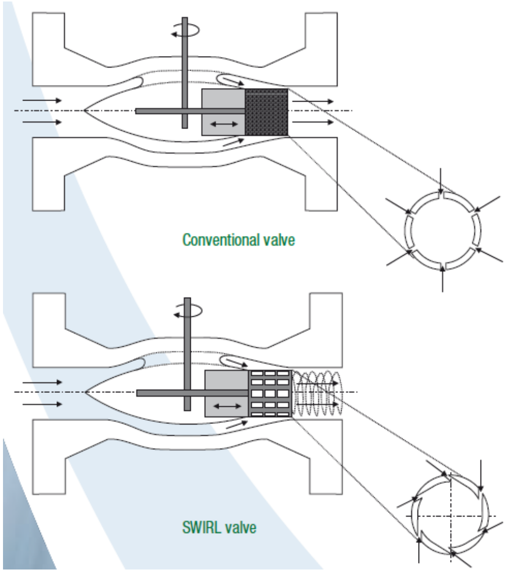

Figure 5 Traditional cage valve flow pattern compared to the SWIRL cage valve flow pattern [23].

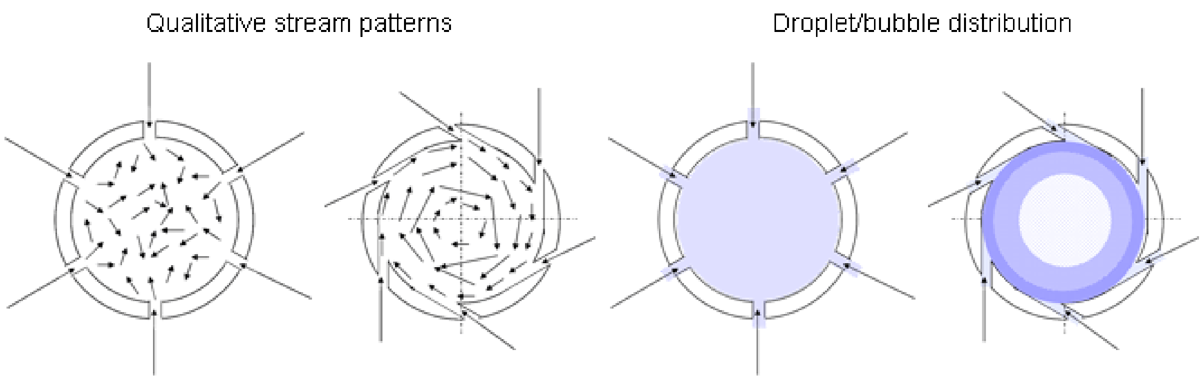

Figure 6 Distribution of droplets [23].

The advantage of using rotational flow is two folded:

1. It will cause a regular velocity pattern, less interfacial shear and less droplet brake up.
2. It will cause droplets to concentrate along the perimeter of the pipe wall, increasing droplet density, improving coalescence of droplets and therefore cause bigger droplets to form.

The technology of Twister SwirlValve™ is being used for optimization of existing Joule-Thompson systems to reduce liquid carryover i.e. designed to replace the traditional JT-valve.

According to Twister BV the Twister SwirlValve™ enlarges the mean diameter of the dispersed droplets as illustrated in Figure 7. The agglomeration effect enlarges droplet size with a least a factor of 5 [23].

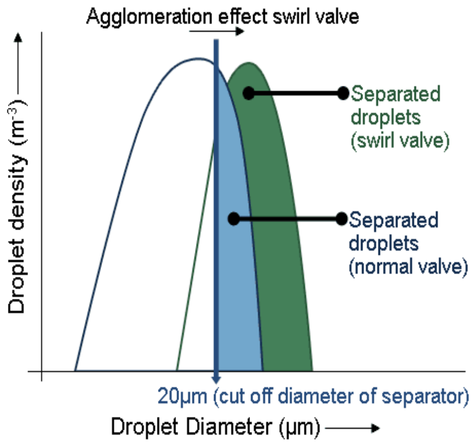

Figure 7 Amount of separated droplets before/after installing the Twister SwirlValve™ [9].

Twister SwirlValve™ use available pressure to create a strong rotational motion in the fluid resulting in an instant segregation of the phases. Twister BV[3] states that the pressure drop over the valve needs to be 10% to achieve full effect of the Twister SwirlValve™. A pressure drop of this amount will not be feasible at the Åsgard inlet facilities. A pressure drop of this amount will not be feasible at the Åsgard inlet facilities. TwisterBV also stated that even though the pressure drop at the letdown station is far from 10% the Twister SwirlValve™ will have good effect.

[3] Telephone conversation with CEO/CTO Kees Tjeenk Willink at Twister BV.

4. Glycol recovery

In this chapter there is information about gas/liquid separation, dimensioning of separators and various separation technologies. There is also provided calculations on the dimensions of the exciting separator internals and vessel.

First there is an assessment of the existing separator and internals, then investigation of new separation technologies.

4.1 Gas- Liquid separation

Gas-Liquid separation is needed to protect process equipment and to meet product specifications. The TEG that is present in the rich gas from the Åsgard transport pipe is carryover from a dehydration process on the platform and needs to be separated once the gas reaches shore. There will always be TEG carryover from the absorption units offshore, partly because the TEG will evaporate and get mixed with the gas. As the temperature and pressure of the gas decreases through the transport pipe the TEG condensates. Since some of the TEG is still in gas phase there will be precipitates of TEG at different locations in the plant, but it is important to separate as much TEG as possible early in the process so that the damages of un-separated TEG is held to a minimum.

As seen in Figure 8 typical gas-liquid separator consists of three stages:

1. Pre-separation: Inlet device that distributes the gas throughout the separator area, in addition it performs a primary separation of the liquid.
2. Agglomeration: Coalescing part, where small droplets are gathered to bigger ones and separated.
3. Demisting: Final demisting part, were the remaining droplets are separated.

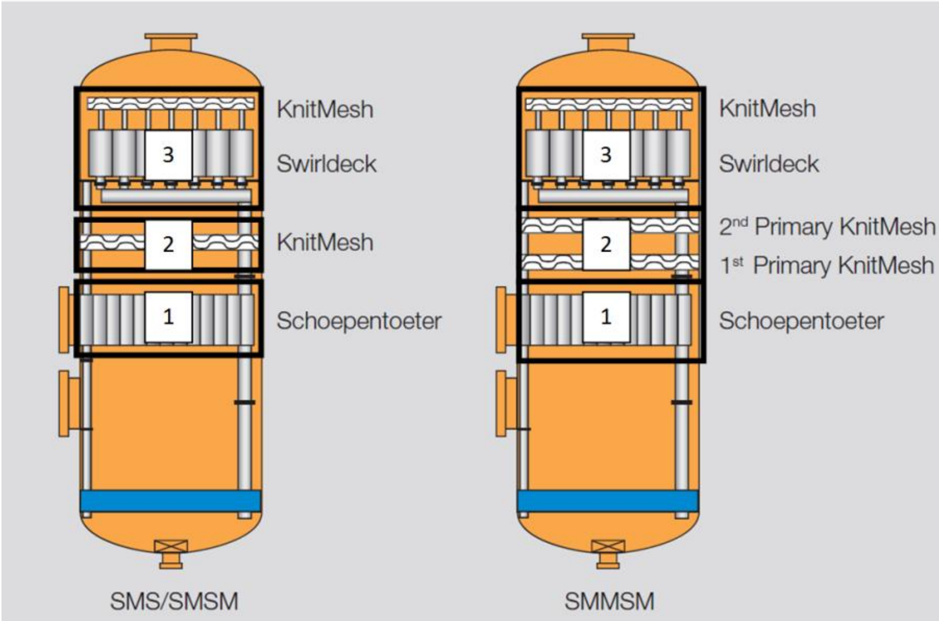

Figure 8 Examples of three stage separation [21].

According to GL1965 [16] the preferred design for scrubbers in Statoil are a two stage separation, one inlet section that separates most of the liquids and one outlet section where the remaining liquid is separated. A gas scrubber is a gas-liquid separator that separates gas with less than 5 volume percentage of liquid. An example of a two stage separation is given in Figure 9.

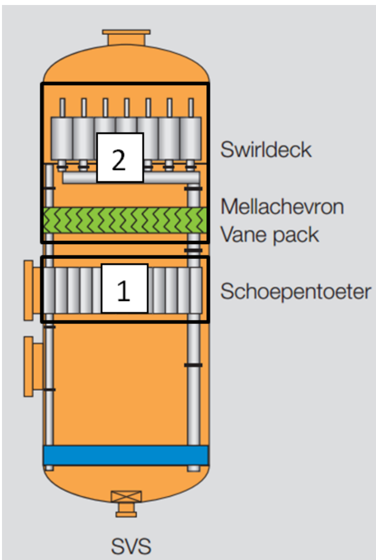

Figure 9 Example of two stage separation configuration [21].

4.1.1 Dimensioning of gas-liquid separators

Statoil started to do research on internals of gas-liquid separators in 2000. Before this the vendors often designed the separators from air/water data and use of results from low-pressure tests. Factors like available space, weight and process layout were more important deciding factors for sizing of scrubbers. The separator efficiency often collapsed when put into real operating conditions. In later years Statoil has been operating high pressure test facilities, one of them is K-lab at Kårstø which has been operating since 2004.

Gas-liquid separation is based on three working mechanisms: gravitational forces, impingement/filtration and centrifugal forces (momentum). It is a general requirement for these separation techniques that the phases are not mixable.

The configuration of separators is dependent on a range of parameters to avoid over/under dimensioning and carryover [10];

- Available space at the location
- Flow
- Liquid/gas ratio
- Pressure
- Water production if there is water
- Emulsion and/or foam problem
- Sand production if there is sand
- Droplet diameter
- Gas and liquid viscosity
- Gas and liquid loading
- Re-entrainment (droplets that has been separated is thorn up and carried with the gas out of the separator.)

The sizing of gas-liquid separators is often carried out on an empirical ground. The k-value is an empirical factor that gives a god indication of how satisfactory the separator will perform, and is the factor used for dimensioning in this report. The k-value that decides if the separation will be efficient is determined experimentally; this is the k-value where the gas velocity equals the velocity of the mean droplet size.

The k-value is an element in the Sounders-Brown equation. The Sounders-Brown equation (1.1) is giving the force balance of a liquid droplet in a gas streaming upwards. The equation would initially give the maximum speed the gas can have for a sufficient separation to take place.

(1.1)

(1.1)

Were:

v_g: Gas Velocity	[m/s]
$\rho_{l:}$ Liquid density	[kg/m^3]
$\rho_{g:}$ Gas density	[kg/m^3]
k: k-factor, Gas/liquid load factor	[m/s]

As demonstrated in eq. (1.2) various assumptions is done to make the k-factor a constant value e.g. drag force coefficient and droplet size is constant, gas viscosity is neglected and the Reynolds number is very high or similar at different pressures [22]. The definition of the k-factor is:

(1.2)

Were:

g: gravitational constant [m/s^2]

d: droplet diameter [m]

C_d: Drag force coefficient

According to NORSOK P-100 the k-value for a horizontal scrubber should not exceed 0.10 – 0.25 m/s depending on internals.

4.1.2 Vertical separators

In a vertical separator the droplet will fall in a countercurrent of the gas. The smaller the droplet the slower it will sink. The smallest droplet that can be separate in a vertical separator is droplets which have the same sinking velocity (v_d) as the gas velocity (v_g) [10]. In Figure 10 the direction of the gas and liquid is demonstrated for a vertical separator.

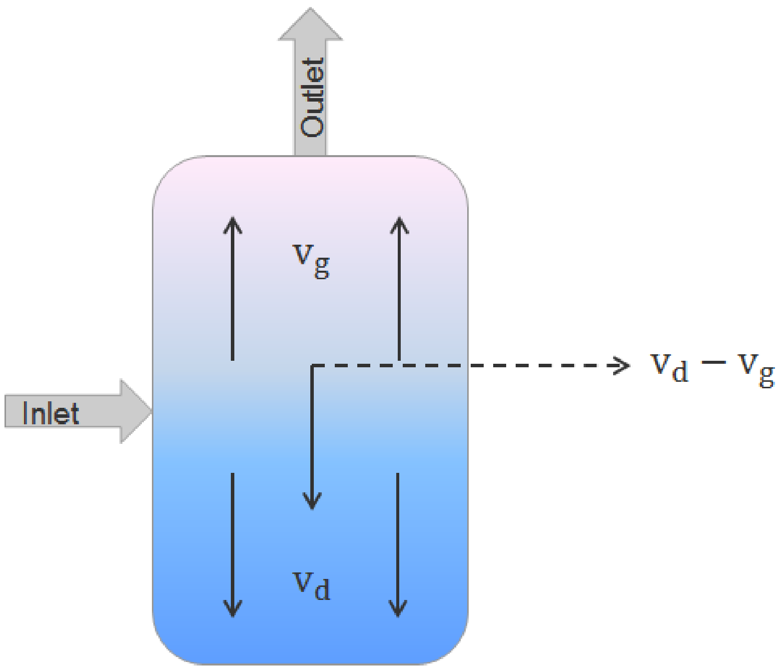

Figure 10 Direction of gas and liquid in a vertical separator.

4.1.3 Horizontal separators

In a horizontal separator the sinking direction for a droplet is perpendicular to the gas flow direction. This means that the droplet sinking velocity can be less than the gas velocity without necessarily obstructing the separation. In Figure 11 the direction of the droplets in a horizontal separator is shown.

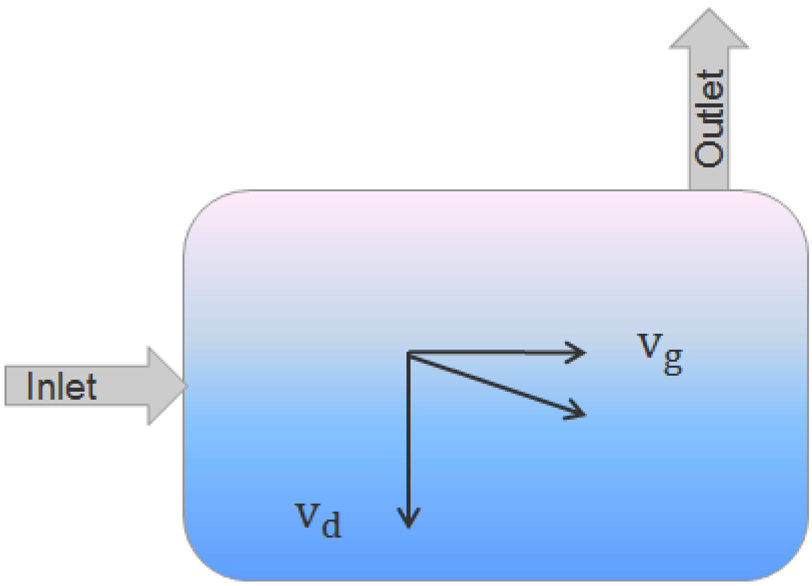

Figure 11 Direction of gas and liquid in a horizontal separator.

4.1.4 Cyclone separators

In a cyclone separator the flow is rotational as shown in Figure 12. The gas is set into a swirling motion, and the acceleration force made in a cyclone separator is greater than the acceleration caused by gravity. The working principle of the cyclone separator demands different densities of the substances that are being separated. This is because the acceleration force that is acting on the substances will have greater effect on the substance that is heavier.

Because the forces that are acting on the gas/glycol mix are so much greater than the gravitational forces the separators volume and the retention time needed are much less than in a regular separator.

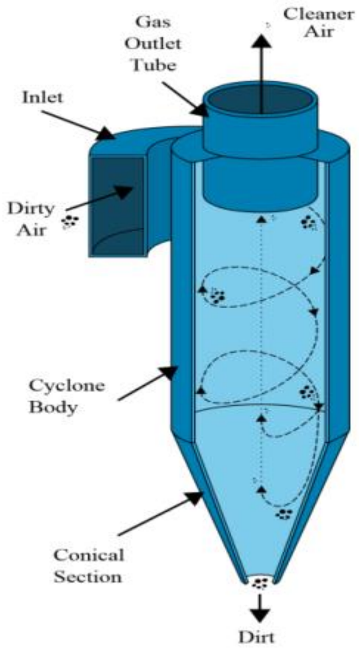

Figure 12 Mono cyclone separator [24].

In Figure 12 it is presented a mono cyclone, these are robust and compact separators that can separate solids and water from oil and gas.

Another type of cyclone separator is a cyclone bundle; this contains smaller, more delicate cyclones and is often used for gas-liquid separation. The cyclone bundle can be made up of vortex tubes. Once the gas is inside the tube a vortex generator is causing the gas to get a strong swirling motion. The swirling of the gas inside the tubes causes the liquid to be directed to the wall where there are gaps that allows the liquid to exit and be collected in the bottom of the vessel.

4.2 Separation efficiency using existing equipment

The feed gas filter separators have its function to remove solids and droplets from the feed. The separation challenge is closely linked to the operation of the mercury removal unit, H_2S removal unit and the feed gas driers. If TEG is not separated it will be absorbed in the units and thereby shorten their lifetime.

4.2.1 Separators 15-CB-201 A/B

In the Åsgard inlet facility the glycol recovery takes place in three different separators, two of them are 15-CB-201A/B located after the letdown station. They are identical and called glycol filter separators. Even though they are called filter separators they do not contain filters, but 25 vortex tubes (cyclones) as seen in Figure 13. The separators 15-CB-201 A/B do not contain any inlet device to help distribute the gas throughout the cross section of the vessel. The gas enters through the inlet nozzle, passes through the horizontal vortex tubes and exits through the horizontal outlet as demonstrated in Figure 14.

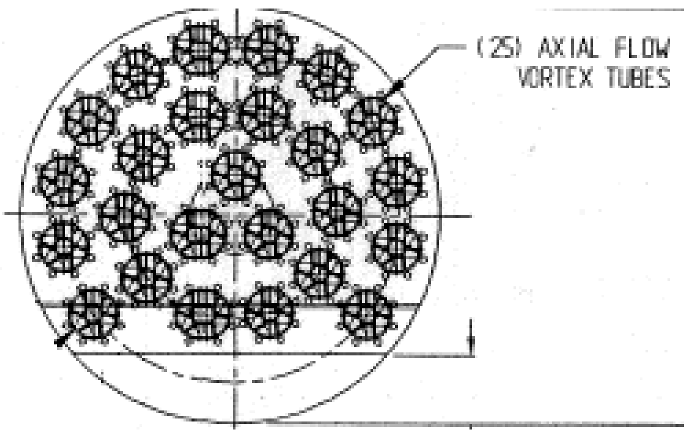

Figure 13 25 vortex tubes inside separators 15-CB-201A/B [15].

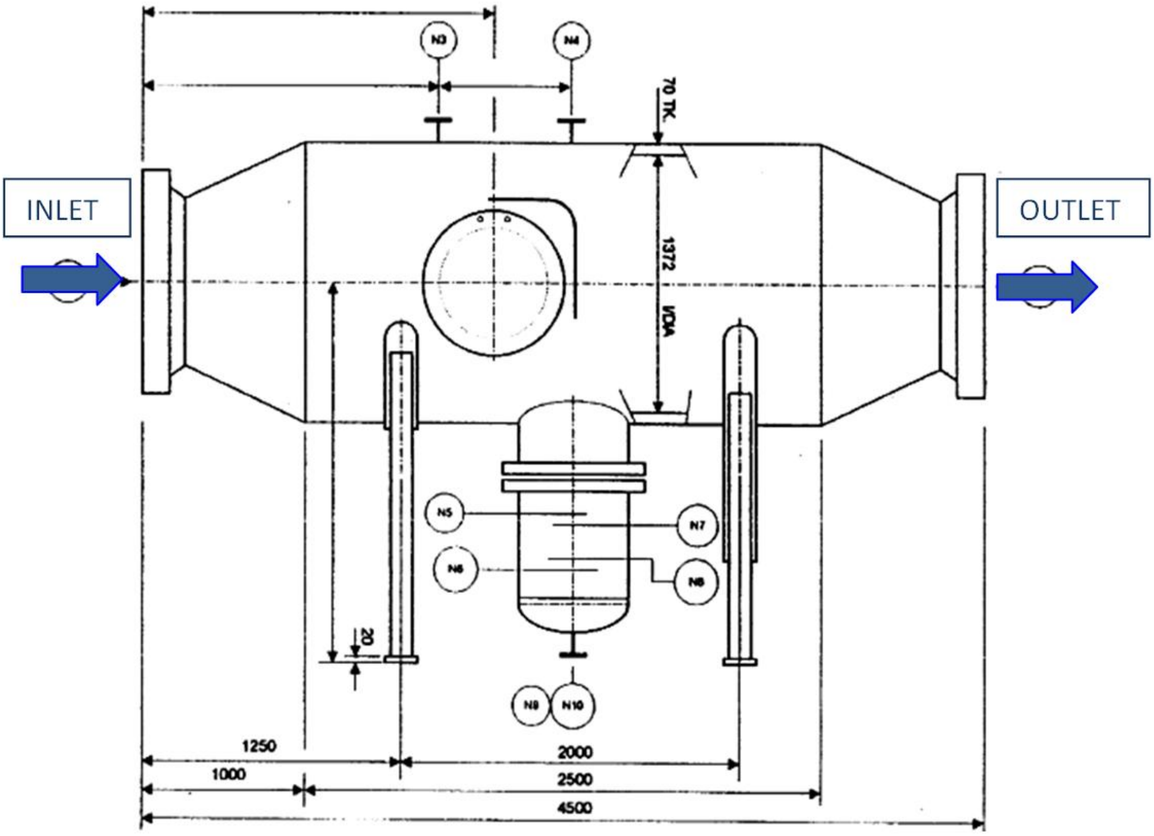

Figure 14 Horizontal separators 15-CB-201A/B [25].

4.2.2 Rating of existing separation equipment

Due to separation difficulties in filter separators 15-CB-201A/B it is necessary to research why the separators do not work properly. In the following subchapters there will be a presentation of different case studies, the design basis and calculations done in conjunction with these.

4.2.2.1 Case studies

There are eight case studies in this report. Case 1 to 4 addresses the separator with the current internals, with flow and number of separators in use as variables. When the gas arrives to the inlet facilities at Kårstø, it splits into two trains. The design flowrate for the KUP train is 39

MMSCMD, which is the focus in this study, The design flowrate for the NET-1 train is 27MMSCMD.

In case 1 the total design flowrate of 39 MMSCMD is sent through one of the separators, 15-CB-201 A or B. In case 2 the flow will split and 19.5 MMSCMD will go through each of the separators. For case 3 and 4, it will be assumed that the gas running through NET-1 and KUP equalizes to 50% of the total design inlet flow at the crossover, 33 MMSCMD in each train. For case 3 the gas flow will be 33 MMSCMD through one separator. For case 4 the gas flow will be 16.5 MMSCMD through each separator.

Cases	No. Separators in use	Flowrate [MMSCMD]
1	**1**	**39**
2	**2**	**39 (19.5 each)**
3	**1**	**33**
4	**2**	**33 (16.5 each)**

Table 1 Case 1 to 4

4.2.2.2 Design basis

Process specifications upstream separators 15-CB-201 A/B given by Statoil:

- Operating temperature: 5 °C / 41 °F [25]
- Ambient temperature min/max: -10 °C / 21 °C, 14 °F / 70 °F [TR1303]
- Max 2 % mole CO_2[TR1303]

Process specifications upstream separators 15-CB-201 A/B provided by external supervisor:

- Max water dew point at 69 barg is -18°C (it is safe to assume there is no water in liquid phase at these conditions)
- Operating pressure: 1690 psig (116,5 barg)

- Gas content
- Flow rates (see Table 1 Case 1 to 4)
- TEG content: Normal 2 litres/MMSCMD, Maximum 8 litres/MMSCMD
- Liquid density 1119 kg
- Gas density 175 kg/

H_2S (ppmv)	N_2	CO_2	C1	C2	C3	iC4	nC4	iC5	nC5	C6	C7	C8	C9
4.76	0.69	2.42	82.04	8.29	4.12	0.57	1.09	0.24	0.24	0.13	0.10	0.05	0.01

Table 2 Gas content.

Process specifications upstream separators 15-CB-201 A/B found in HYSYS, Appendix A:

- Molecular weight: 20.9 kg/kmol
- z-factor: 0.6

Dimensions 15-CB-201A/B

- Inlet section
  -Diameter 743 [mm]
  -Areal
- Vortex tubes
  -Diameter 143 [mm]
  -Areal
  -Number of cyclones: 25
- Vessel
  -Diameter 1372[mm]
  -Areal

4.2.2.3 Calculations

There has been done calculations to be able to rate the existing separator.

The flow rate in the case studies is given in MMSCMD. To convert this into ideal gas law is used to compare the density of the gas in standard conditions (15°C, 1 bara) and real conditions (5°C, 116.5barg)

(1.3)

(1.4)

Each gas contains 0.88 kg. For each there is 175 kg passing through the separators. By multiplying the flow [MMSCMD] with the density at standard conditions [ ], the flow is given in kg per day.

(1.5)

To find the flow rate Q [ ] the mass flow rate ( ) is divided by the density of gas in real conditions ( ) and 86400 [s/d].

(1.6)

Case	Q [ ]

1	2.27
2	1.13
3	1.92
4	0.96

Table 3 Gas flow rate for one vessel for case 1 to 4.

The gas velocity is given by;

$$ \text{———} \quad (1.7) $$

The velocity is found for the different parts of the separators 15-CB-201A/B.

[ ]			
Case	Inlet section	Vortex tubes	Vessel
1	5.23	5.64	1.54
2	2.60	2.81	0.76
3	4.42	4.78	1.30
4	2.21	2.39	0.65

Table 4 Velocity at different locations for each case

The k-value is given by Sounder-Brown Eq. (1.2)

k-value[ ]			
Case	Inlet section	Vortex tubes	Vessel
1	2.25	2.43	0.66
2	1.12	1.21	0.33
3	1.90	2.05	0.56
4	0.95	1.03	0.28

Table 5 k-value for different parts of the excising separator.

Table gives an overview of important values found in these calculations. The complete calculations are given in Appendix B.

	Case 1	Case 2	Case 3	Case 4
Q[m^3/s]	2.27	1.13	1.92	0.96
[m/s]	5.23	2.60	4.42	2.21
[m/s]	5.64	2.81	4.78	2.39
[m/s]	1.54	0.76	1.30	0.65
[m/s]	2.25	1.12	1.90	0.95
[m/s]	2.43	1.21	2.05	1.03
[m/s]	0.66	0.33	0.56	0.28

Table 6 Total view.

By combining equation (1.1) and (1.7) with respect to the flow rate, the maximum flow rate a single vessel can handle, with different internals, can be found. The k-values given in NORSOK P-100 [31] for different demisting internals and results are presented in Table 7 Calculation of maximum flowrate..

(1.8)

Demisting internals	k-value [m/s] []	Q [MMSCMD]
Vessel (with inlet vane, mesh and cyclones)	**0.15**	**8.85**
Demisting Vane	**0.20 - 0.25**	**11.8 - 14.8**
Mesh pad	**0.10**	**5.9**

Table 7 Calculation of maximum flowrate.

4.2.3 Assessment of existing separation equipment

Calculations in the previous chapter show a k-value that is higher than any of the limits from NORSOK P-100 which is aligned with Statoil's internal documents TR1965 and GL1965. Calculations show that the maximum flow rate a single vessel, with inlet vane, mesh and cyclones can handle is approximately 8.85 MMSCMD, which is less than any of the flow rates in the case studies.

4.3 Separation efficiency using new technologies

In this sub chapter investigation on new separation technology is presented.

4.3.1 Internals: inlet device

An inlet device is placed at the inlet of a gas-liquid separator to perform a primarily separation of liquid, as showed in chapter 4.1.According to TR1965 [17] the inlet section should ensure that the gas and liquid that come into the separator is properly distributed, so that the entire cross section of the demisting part is utilized. The inlet section should also ensure that the demisting section is not overloaded with liquid.

There are different types of inlet devices e.g. inlet vane, inlet cyclones, spinlet or inlet tangential baffle.

ASCOM [30] states that only the inlet vane- and inlet cyclone device will increase the separation performance. Other inlet devices will cause liquid re-entrainment and poor distribution of the gas. The inlet vane is the most common on Statoil's installations.

A vane type of inlet device has closely spaced plates that is distributing the gas throughout the cross section of the separator.

It is stated in GL 1965 [16] that "*high efficiency inlet devices*" is:

- Vane type inlet devices, with a vessel k-value below 0.15 m/s.
- Inlet cyclones.

The Schoepentoeter™ (see Figure 15) delivered by Shell is an example of a vane type inlet device.

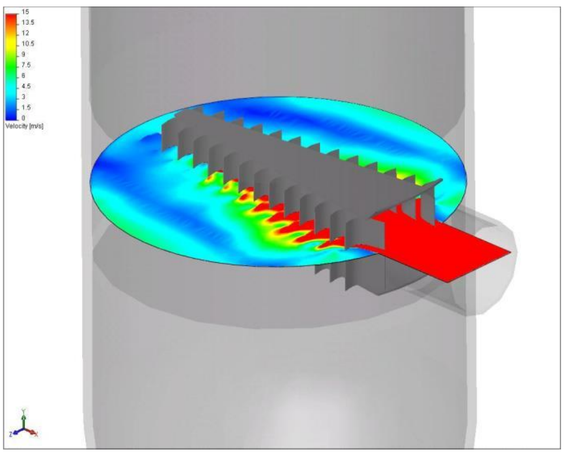

Figure 15 The Schoepentoeter™ vane type inlet device [20].

The vendor of the existing separators, Plenty[4], states that the technology used in the installed separators is dated, and that low separation efficiency is partly caused by the lack of an inlet device.

4.3.2 Internals: mist eliminators

In a gas-liquid system the liquid entrained in a gas flow is in the form of droplets. Mist elimination is used to remove entrained liquid droplets from the gas stream.

4.3.2.1 Mesh pads

Mesh pads is thin metal or plastic wire knitted loosely together to form a filtrating pad. The diameter of the wire is typically 0.15-0.3 mm [26]. The wire in the mesh pad is laid in many directions, the gas flows freely in between the wire. Mesh pads can be made in many shapes and sizes depending on the application it will be used in. A typical mesh pad is round with a frame that provides rigidity, as illustrated in Figure 16.

Figure 16 Round mesh pad [27].

[4] Mail correspondance with external supervisor.

Figure 17 illustrates how a strand acts as an obstruction at the droplets in the gas. The gas turns aside sharply were some mist droplets are unable to follow, and then they coalesce and fall away.

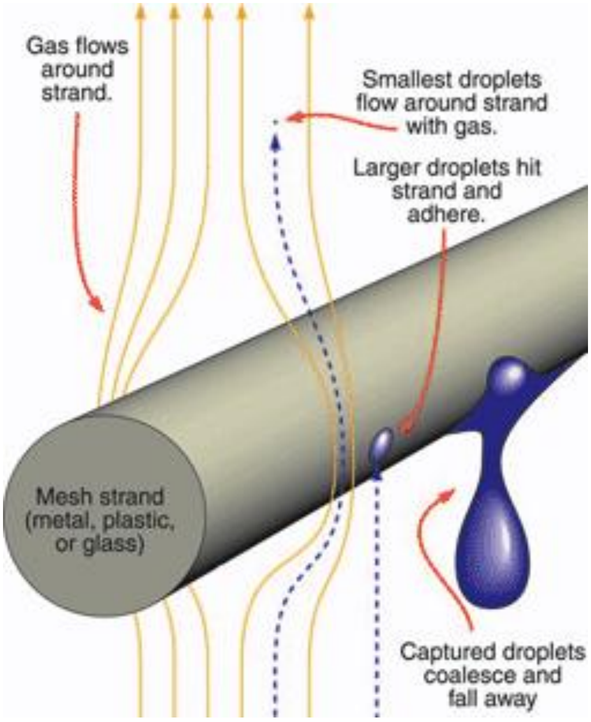

Figure 17 Droplet coalesces after striking a wire [27].

The mesh pads can be used for both vertical and horizontal separators, according to GL1965 the mesh pad should be placed vertically with a horizontal flow

Traditional mesh pads capture droplet sizes as small as 5 µm. The relatively new development in design of mesh pads is the composite pad, where the mesh is made up of combinations of one or more materials. The composite-knit provides high surface area, void volume and increased mist removal efficiency in the 1-3 µm particle size range which were not previously capture with older designs [28].

To provide a mesh pad that is suitable for one specific application there is a need to know the size range of the droplets the mesh is supposed to capture. Mist demands a higher density mesh pad than droplets. Wire diameter, size of loops and amplitude of crimp is variables that will be determined for different applications [28]. Entrained liquid consists of a broad range of droplet sizes that depends very much on the mechanism by which they are generated. The first step in engineering a mist eliminator is to determine the mechanism by which the droplets are generated and assume an average droplet size.

In Figure 18 it is presented different assumed size ranges for the droplets determined by the state of the liquid. Since the TEG that is present in the feed from Åsgard transport pipe has gone from gas to liquid it is natural to believe that the droplet size range that fits best will be close to "from saturated vapor". The average droplet size of saturated vapor is from 3-20 µm [19].

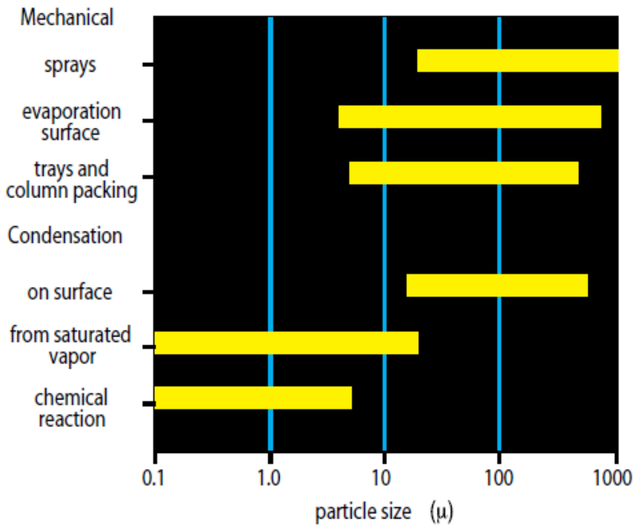

Figure 18 Assumed droplet size range [19].

For mesh pad as a demister the k-value should be below 0.10 m/s. [31] Calculations from chapter 4.2.2.3. shows that the maximum flow rate a single vessel can handle, with mesh pad as demister, is approximately 5.9 MMSCMD.

4.3.2.2 Vane packs

Vane pack is a unit consisting of closely spaced corrugated plates as presented in Figure 19. When gas, containing liquid droplets, is led through the vane pack the flow will change direction several times. The droplets will, due to the higher density, hit the walls and form a liquid film which will be drained off. Vane arrays can be mounted both horizontally and vertically, and the vane units are usually round or rectangular. These devices are generally not efficient for mist droplets smaller than 20 µm.

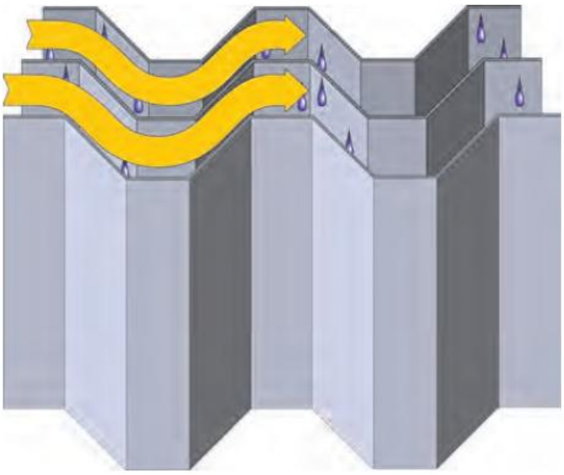

Figure 19 Capture of mist droplets in a vane array with horizontal flow [29].

There are double pocket vanes illustrated in Figure 20 that can operate at a higher capacity and higher efficiency than conventional vanes. This design prevents re-entrainment of the separated liquid droplets, because the liquid is drained down in layers between the flowing gas.

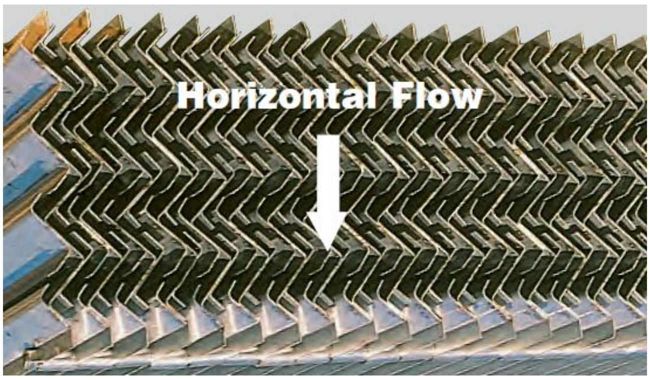

Figure 20 Double pocket vanes [29].

GL1965 states that; when the vane is the final demisting element it shall be of a double pocket type, and it should be installed vertical with a horizontal flow.

Demisting vane has a k-value of 0.20 – 0.25 m/s according to NORSOK P-100 [31]. With the existing vessel this means a maximum flow rate of 11.8 – 14.8 MMSCMD (Table 7).

4.3.2.3 Mesh-vane combinations

Vanes are more effective at higher velocities and greater droplet sizes while mesh is more suitable for removing smaller particles at lower velocities. As presented in Figure 21 a vane unit installed before a mesh pad combines the superior efficiency of the mesh with the k-factor of the vanes. Mesh pad serves as an agglomerator or coalescer when operating above the design velocities.

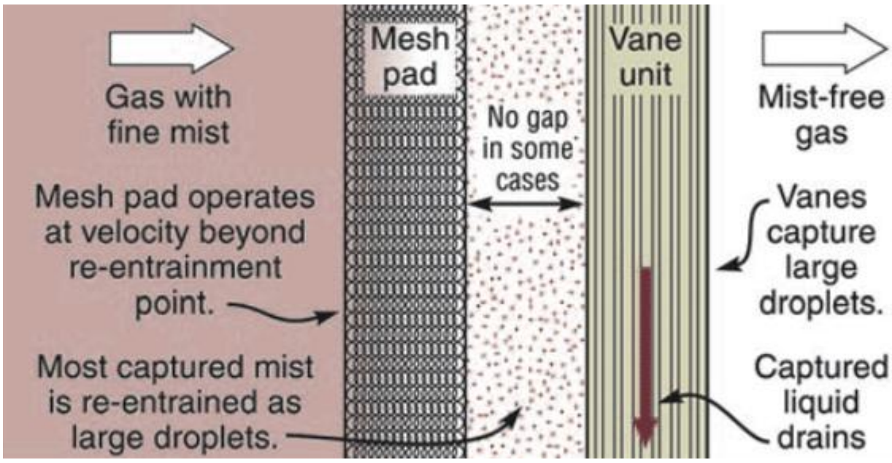

Figure 21 Boosting efficiency of a mesh pad by following up with a vane unit[29].

Mounting a vane unit upstream of a mesh pad, as shown in Figure 22, combines the efficiency of mesh with the ability of vane loads and solids handling. The rating k-factor is decided by the mesh [29].

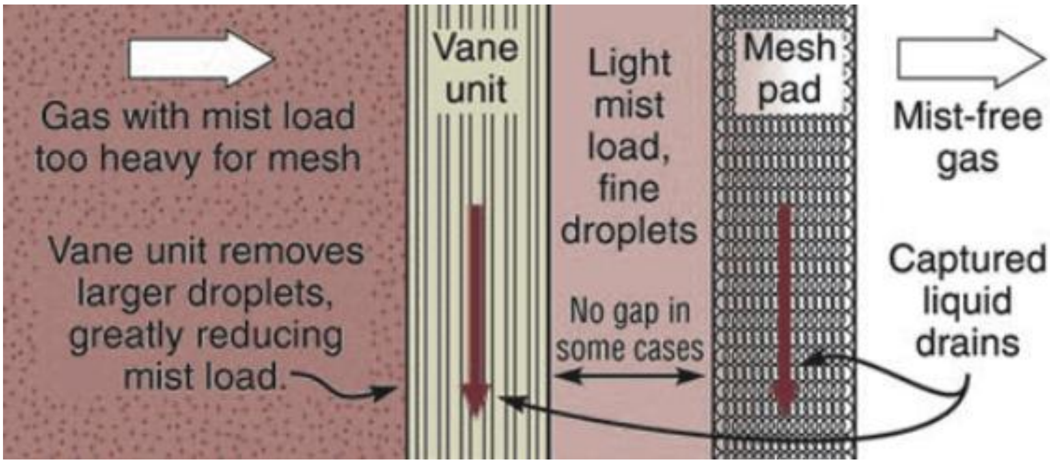

Figure 22 Shielding a mesh pad from a very heavy mist load with a vane unit in front [29].

4.3.2.4 Coalescers

A coalescer is a device that gathers small droplets to make bigger droplets that will, because of gravity, descend to the bottom of the vessel where they can be collected.

There are two types of working methods for the coalescer. One is mechanical, which uses a set of walls, filters and dividers to lead the liquids away from the gas and to make them collect together. The other working method is to use weak electric charge to attract the water molecules [11].

Pall[5] suggested to install SepraSol™ Plus in a vertical vessel at the site.

This is a liquid/gas coalescer that is able to remove liquids from a large gas flow. The SepraSol™ Plus has a very high performance when it comes to separating liquid, and therefore it will often eliminate the need for other separators downstream the coalescer.

Pall recommended that if SepraSol™ coalescers where to be installed it would need to be in a vertical vessel, therefore changing the internals of existing vessel is not feasible with this solution. Pall has developed a vessel for the SepraSol™ coalescers called SepraSol™ Housing. They will deliver this housing special made for whatever internals the separators will need. Since this housing is costume made, it will decrease the vessel size needed, and it will make the vessel as light and cost efficient as possible. Standard sizes are made to fit to separators with 1-70 coalescing elements inside.

[5] Mail correspondence with Tactical marketing manager Doug Harris at Pall.

The SepraSol ™ Housing has had a patented oleophobic/hydrophobic treatment which among others makes them able to handle more liquids and drain the liquids quicker it will also contribute to a smaller vessel as this makes the separator require fewer elements [14].

Pall installed the SepraSol ™ housing with SepraSol ™ housing in a gas plant in Texas to better glycol recovery efficiency as presented in Figure 23. The installation viewed great results with a glycol, recovery efficiency of 99.98% after installation. The pressure in the Åsgard facilities is higher than the pressure at the gas plant in Texas, but in return the Texas gas plant had almost double flow rate [13].

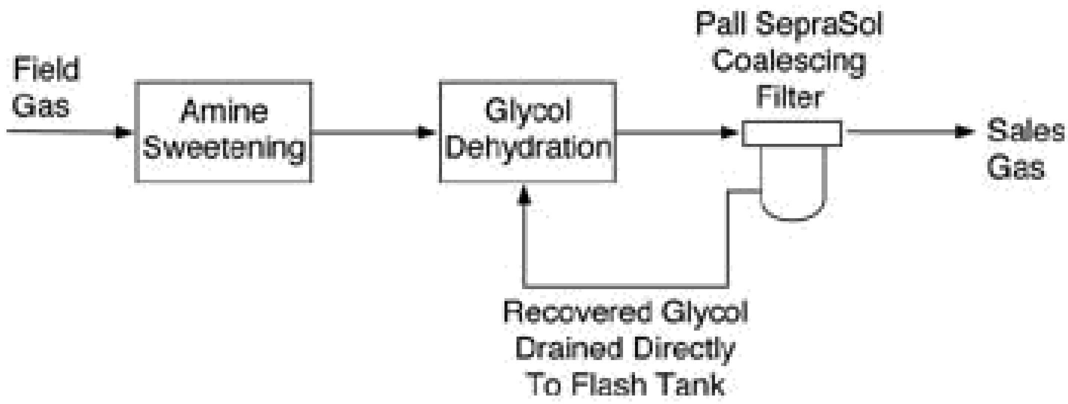

Figure 23 Part of the gas plant in Texas [13].

4.3.2.5 Cyclone

ASCOM[6] recommended that the Separators 15-CB-201A/B were changed with a new vessel with their HiPer Cyclone Mist Eliminators as a demisting part. The HiPer cyclones are a recent type of cyclones which are more suitable for demanding process conditions and more efficient than the predecessors.

ASCOM gave calculations that showed that for case 1 and 3 (Table 1) with full gas flow rate (33-39 MMSCMD) through one vessel, it will require an inside diameter of approximately 2500 mm. For case 2 and 4 (Table 1) with full gas flow rate (33-39 MMSCMD) through two parallel vessels the inside diameter required is approximately 1800 mm. ASCOM states that

[6] Mail correspondance with regional manager Europe Danny Thierens from ASCOM.

there is done field test of the HiPer cyclone mist eliminator in hydrocarbon service with pressure ranging up to 180 barg.

The complete proposal from ASCOM can be seen in Appendix C.

5. Discussion

In this chapter thoughts and details around the investigations done in this report will be discussed.

5.1 Letdown station

The report carried out by the Statoil R&D center suggests replacing the valves at the letdown station with the Twister SwirlValve™ to help improve glycol recovery efficiency.

The six valves that are currently in place at the letdown station in the KUP train are axial flow control valves. As described in chapter 3 the gas flowing through conventional valves may cause turbulence in the flow that will make the droplets smaller and more difficult to separate.

The Twister SwirlValve™ technology is relatively new, and it has not yet been tested under high pressure conditions (>100barg). A field test has been carried out at a NAM[7] gas treatment plant in Opende Oost in September/November of 2008. This showed an increase in glycol recovery in the separators, an increase in noise levels and a decrease in pressure drop. The conditions of this field test were not similar to the conditions at the Åsgard inlet facilities so the results cannot be directly applied to this case, but used as an indicator. TwisterBV[8] stated that there was going to be a high pressure field test of the SwirlValve™ together with a separator delivered by Twister at Shells test facilities in Netherland in October of 2013.

TwisterBV recommended replacing one of the six valves at the letdown station with the SwirlValve™ technology. This would give an accurate result of the performance the Twister SwirlValve™ would have at the Åsgard inlet facilities, and if the replacement is not feasible the valve would be returned to TwisterBV. To take full advantage of the Twister SwirlValve it is recommended a pressure drop of 10%. Although the pressure drop will be less at the letdown station, TwisterBV vouched that the mean droplet size would get bigger by using the SwirlValve™.

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[7] De Nederlandse Aardolie Maatschappij BV (NAM)- the Dutch Petroleum society.
[8] Telephone conversation with CEO/CTO Kees Tjeenk Willink at Twister BV.

The concerns regarding the SwirlValve™ is that it might generate more noise and that because of the centrifugal forces it provides it might be necessary to reinforce the piping after the letdown station. This will need further research.

Production engineer at Kårstø, Kurt Seland, states that if the technology of the valves at the letdown station is to be changed, the most feasible way is to replace only the excising cage of the valve with the cage of a SwirlValve™. Then the settings of the control valve process monitoring will be maintained. TwisterBV have previously changed a cage of a Mokveld valve at a NAM facility, this worked to an extent, but the soft seal of the Mokveld valve was not sufficient due to erosion of the seal. The seal in a SwirlValve™ should be a metal to metal seal. TwisterBV would not be able to deliver a customized cage for the Mokveld valves because Mokveld did not want to share their design details. TwisterBV proposed different options for changing the cage of a Mokveld valve. One option was that they could modify the Mokveld valve at their workshop in Netherland. Another was to get a new SwirlValve™ designed for this installation by ControlSeal which has license from TwisterBV.

Since there is little experience with use of SwirlValve™ as of today, one option is to wait for more field tests and results to support the decision of changing the present technology at the letdown station. On the other hand no field test can predict the exact performance of the SwirlValve™ at the Åsagrd facilities. Because there is one valve in standby at the letdown station, it is possible to change and test one valve without obstructing the production. Stop of production is by far the largest cost of installations and the possibility to remove this cost makes a field test of the SwirlValve™ feasible. Since Statoil is a large exporter of gas the experience they would gain through installing the SwirlValve™ might be useful in other installations/locations.

5.2 Current separators 15-CB-201 A/B

Today the separators have close to zero efficiency. The report from Statoil R&D center stated that the gas load for the scrubbers with the current internals is too high which has been verified by the calculations in sec. 4.2.2.3.

One alternative that has been investigated in this report is to retrofit the existing vessels with new internals. Today each vessel consists of 25 vortex tubes. Calculations done by ASCOM show that retrofitting the existing vessel with the maximum number of new cyclones, the flow rate processed in a single vessel will be approximately 10.5 MMSCMD. This estimation is supported by calculations presented in chapter 4.2.2.3.

An inlet device should be installed to ensure even distribution of the gas as well as the first stage separation. This device would help the separation efficiency. For a second stage of separation it could be an option to install a vane pack. According to GL1965 this has to be of a double pocket type if it is the final demisting part.

In the case studies of this report there is a minimum flow rate of 16.5 MMSCMD and maximum flow rate of 39 MMSCMD flowing through one separator, the k-values calculated for the existing vessels and its internals where too high for separation to be efficient compared to k-values for similar internals. For the case with the lowest flowrate (16.5MMSCMD) the vessel k-value is 0.28 m/s (Table 6). This means that when the total area available is utilized the maximum rated k-value is still very high compared with the vessel k-value of 0.15 m/s, given in NORSOK P-100. As shown in Table 7 to achieve good glycol recovery efficiency with the current vessel the flow rate through one separator could be maximum 8.85 MMSCMD. The dimensioning factor for the internals will not be necessary to evaluate any further because the vessel will not be able to handle the flow regardless of what kind of internals that is retrofitted into the vessel.

It is clear that the separators 15-CB-201A/B are undersized and have too high gas load for all cases given in Table 1. Retrofitting the existing separators will have little effect on the glycol recovery efficiency. An option is to replace the scrubbers with new horizontal or vertical vessels.

5.2.1 Solution 1: new horizontal separators

The solution that will have less intervention at the location is to replace the existing horizontal separators with a new horizontal separator. To have a sufficient glycol recovery with the design flow rate, the diameter of the separator vessel has to be increased.

Since bundle of cyclone is a good choice for high pressure, high flow rate applications the choice of getting a new dimensioned vessel with cyclones as a demisting part should be taken into consideration. ASCOM performed calculations on the vessel dimensions with ASCOM's HiPer Cyclone Mist Eliminators as demisting part. The diameter of the vessel would be 1800 mm for case 2 and 3 (Table 1) where the flow is going through both separators. ASCOM states that a field test of the HiPer cyclone mist eliminator in hydrocarbon service with pressure ranging up to 180 barg has been done; this ensures that there is experience with the HiPer cyclone separators for similar conditions available.

If the space available for enlargement of the separator diameter is limited, double pocket vane pack might be the best choice. The vane pack is the separation technology that can withstand the highest k-value and may therefore result in a smaller vessel diameter. The vane pack performs the best separation of droplets larger than 20 μm. To secure separation of smaller droplets the vane pack should be installed in conjunction with either a coalescing element in front or an new element, behind that will separate the smaller droplets for example a mesh pad as presented in chapter 4.3.2.3. If the SwirlValve™ is installed and it has the desired effect in agglomeration of droplets that might make it possible to install only the double pocket vane demister.

If the diameter of a new separator is larger than the diameter of the old separator it is even more important to have an inlet device that makes sure the entire cross section is being utilized.

By installing a new horizontal separator the modification scope at the location can be held at a minimum, this is a great argument for choosing this solution in comparison to the vertical vessel due to the cost saving of less intrusion at the plant. It might be possible to install a new separator with bigger diameter flange to flange with the existing pipe arrangement.

5.2.2 Solution 2: new vertical separators

Vertical separators are often used in gas-liquid separation. The biggest advantage comparing the vertical and horizontal separators is that it has a smaller foot print. It is often the separator of choice at platform installation where available space can be very limited.

The solution suggested by Pall for this specific case was to change the existing horizontal vessels to a vertical separator with SepraSol™ coalescing elements and SepraSol™ housing. If the whole separators where to be delivered by Pall, one vendor, instead of different vendors for each parts of the separator, the amount of vendors Statoil would have to relate to is less. It would also be easier to get a tailor made application when dealing with one vendor.

There is experience with using SepraSol™ coalescing elements and housing in glycol removal applications, these had great results but these are not directly transmitted to the Åsgard inlet facilities because of the higher pressure at this location.

One concern regarding the vertical separator is that the high pressure inside the vessel and the dense gas flowing upwards can prevent the droplets from falling downwards and droplets separated will get re-entrained.

If the horizontal vessels at the location were to be changed with a vertical separator it would most likely demand a big modification at the location. The rearrangement of the piping that would be necessary for installing a vertical separator would be of a much greater extent than replacing the horizontal vessel with a new horizontal separator.

It is of great interest to keep the intervention needed for replacement as small as possible so that the possibility of changing one separator without stop in production is more likely.

6. Conclusion

The conclusion is that the current separators 15-CB-201 A/B are undersized and should be changed with new horizontal separators. The new horizontal separator should have a vane type inlet device and a larger demisting cross section.

Because of the lack of experience regarding the Twister SwirlValve™ in this application and the obstructions regarding installation at the letdown station today, Statoil have to consider if they want to do a field test on the Twister SwirlValve™ at the Åsgard inlet facilities. If new Glycol separators are installed and the glycol recovery efficiency is sufficient, the installation of the SwirlValve™ will not be necessary.

7. Definitions and abbreviations

TEG	Triethylene glycol
JT	Joule-Thompson
JT-LTS	Joule-Thompson low temperature system
PFD	Process flow diagram
Scrubber	Gas-Liquid separator with low liquid rates
MMSCMD	Metric million standard cubic meters per day [Sm^3/d]

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APPENDIX A

HYSYS

APPENDIX B

Complete calculations

HØGSKOLEN STORD/HAUGESUND

Statoil

Calculations of k-value

Equation

To find we can look at the density of the gas in Standard conditions and Reel conditions.

For each there is 0.88kg passing through the separators. And for each there is 175kg passing through the separators.

The four cases with current internals:

Caluculations of different k-values on the vessel:

k-value of inlet section

k-value of vessel

HØGSKOLEN STORD/HAUGESUND

HØGSKOLEN STORD/HAUGESUND

Statoil

APPENDIX C

Proposal from AMACS

HØGSKOLEN STORD/HAUGESUND

Statoil

Thanks for your mail. Please accept our apology for the late reply, caused by our current workload.

Please find below our preliminary technical input, for your review, based on applying ASCOM's HiPer Cyclone Mist Eliminators :

- The existing vessels (and the number of vortex tubes / cyclones) are too small to process the new flow rates, for all 4 cases. When retrofitting the existing separators with the maximum number of new cyclones, we estimate that a single vessel can process a maximum gas flow rate of approx. 10,5 MMSCMD. We see 2 options to upgrade the facility to function properly at the full new flow rates :

  (1) replace the existing horizontal vessels with new horizontal ones of larger diameter (with a vertical boot section to control the glycol liquid level) or
  (2) replace the existing horizontal vessels with new vertical ones of larger diameter (requiring re-routing of the gas outlet piping, as a minimum external modification)

- For cases 1 and 3, with the full gas flow rate (33-39 MMSCMD) flowing through a single vessel, we calculate that option (1) requires a vessel inside diameter of approx. 2500 mm. Option (2) requires a vessel of approx. 2950 mm inside diameter by 4400 mm T-T length, in order to comply with the typical requirements of STATOIL's TR 1965 (section 2.8.2 and 2.8.3). For the vertical option (2) design, the equipment scope is expanded from only the HiPer Cyclone Mist Eliminator to an additional HiPer Vane Diffuser (inlet device) and a HiPer Mesh Agglomerator, which will both assist in boosting the separation performance in this challenging application (high operating pressure, high liquid viscosity (low temperature glycol, assumed 10 cP but could be higher), low liquid loading).

- For cases 2 and 4, with the full gas flow rate (33-39 MMSCMD) flowing through 2 parallel vessels, we calculate that option (1) requires a vessel inside diameter of approx. 1800 mm. Option (2) requires a vessel of approx. 2100 mm inside diameter by 4400 mm T-T length, in order to comply with the typical requirements of STATOIL's TR 1965 (section 2.8.2 and 2.8.3). For the vertical option (2) design, the equipment scope is expanded from only the HiPer Cyclone Mist Eliminator to an additional HiPer Vane Diffuser (inlet device) and a HiPer Mesh Agglomerator, which will both assist in boosting the separation performance in this challenging application (high operating pressure, high liquid viscosity (low temperature glycol, assumed 10 cP but could be higher), low liquid loading).

- Please find attached our fact sheet on the HiPer Cyclone Mist Eliminators, for your info. ASCOM has benchmarked the performance of this equipment in full hydrocarbon service at operating pressures up to 180 barg, allowing us to have a detailed performance prediction model across a wide variety of operating conditions, taking into account key design parameters such as gas flow rate, gas density, liquid flow rate, liquid density, liquid viscosity and liquid surface tension.

We hope this is of interest and look forward to your feedback.

Best regards, Danny

HØGSKOLEN STORD/HAUGESUND

Statoil

APPENDIX D

Spread sheet delivered to vendors

Company information

Company: Statoil ASA

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PROCESS CONDITIONS

Operating temperatur: 5 deg C / 41 deg F

Operating pressure: 1690 psig (116,5 barg)

Gas content

H2S (ppmv)	N2	CO2	C1	C2	C3	iC4	nC4	iC5	nC5	C6	C7	C8	C9
4.76	0.69	2.42	82.04	8.29	4.12	0.57	1.09	0.24	0.24	0.13	0.10	0.05	0.01

- Molecular weight: 20.3Kg/Kmol

- Max 2% mol CO2

- Max water dew point at 69barg is -18°C (it is safe to assume we have no water in liquid phase at these conditions)

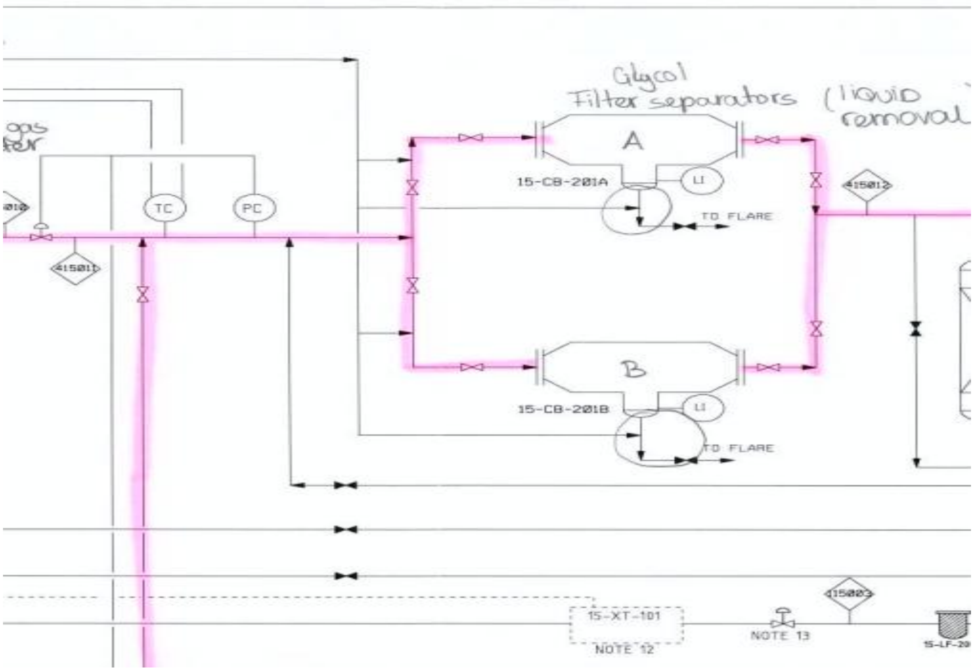
- TEG content: Normal 2litres/MMSCMD, Maximum 8litres/MMSCMD

Flow rate:

We have 4 cases for the flow rate through the separators as shown in table below:

Cases	No. Separators in use	Flowrate (MMSCMD)	Internals
1	1	39	new
2	2	39 (19.5 each)	new
3	1	33	new
4	2	33 (16.5 each)	new

The location of the separators:



Dimensions of the existing separators (which we are interested in keeping)

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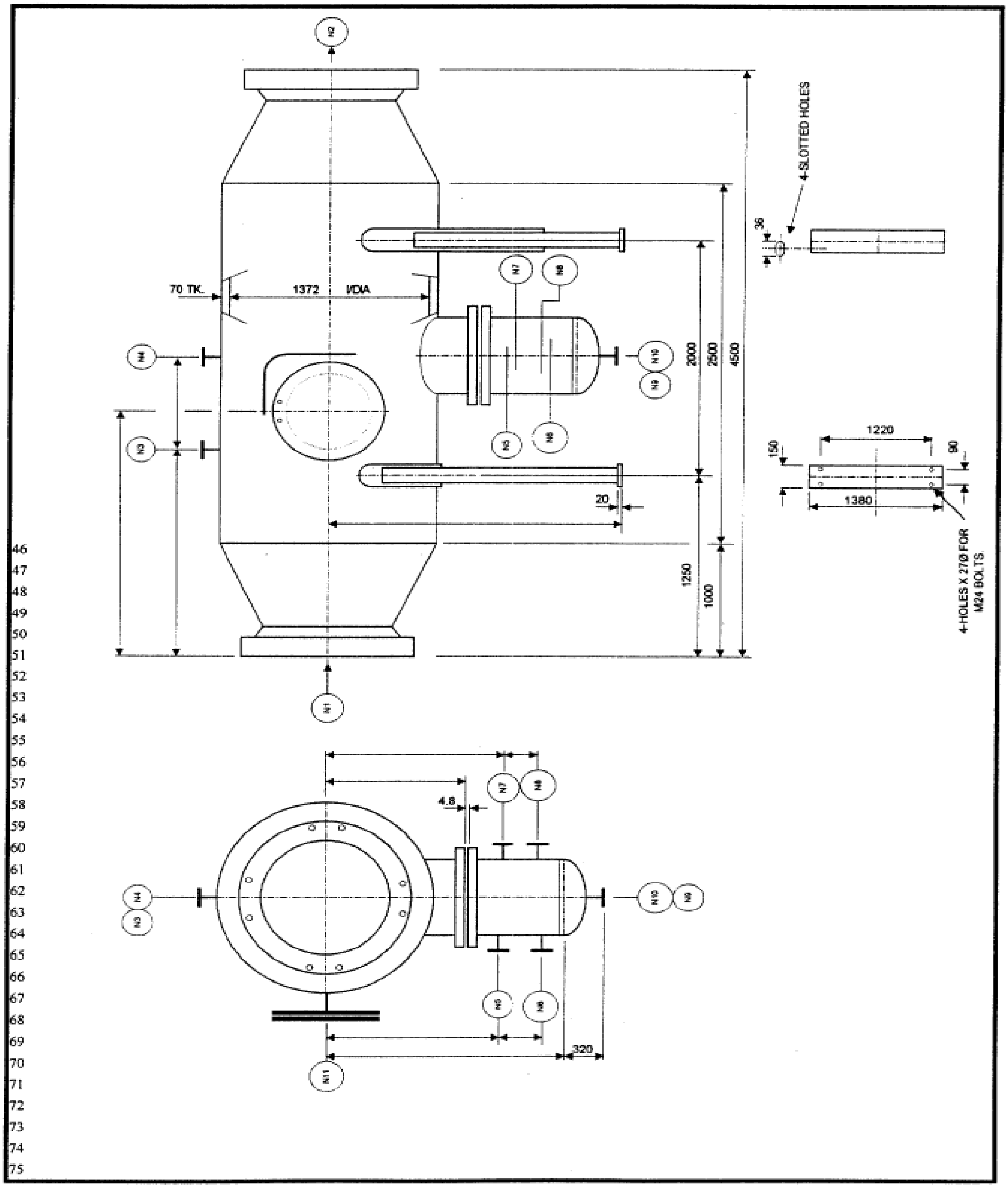

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76	NOZZLE LIST						
77	MARK	No.	NB (in.)	RATING#	PROJECTION	Type	SERVICE
78	N1	1	30	900	See Sketch.	RTJ	INLET Note 14.
79	N2	1	30	900	See Sketch.	RTJ	OUTLET Note 14.
80	N3	1	3	900	990	RTJ	FLARE
81	N4	1	4	900	990	RTJ	VENT
82	N5	1	2	900	425	RTJ	LEVEL.
83	N6	1	2	900	425	RTJ	LEVEL.
84	N7	1	2	900	425	RTJ	LEVEL.
85	N8	1	2	900	425	RTJ	LEVEL.
86	N9	1	2	900	345	RTJ	DRAIN.
87	N10	1	2	900	914	RTJ	VESSEL DRAIN
88	N11	1	24	900	1100	RTJ	MANWAY. Note 15.
89							

Goal

Our goal is to get better TEG recovery efficiency, we want to look into changing the internals of two existing filter separators, and we want to know if your products are applicable for this, either as a part of the separator or as a complete separator.