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GAS LIQUID VANE SEPARATORS IN HIGH PRESSURE APPLICATIONS

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ABSTRACT

Vane separators are inertial devices used to remove entrained liquids from gas. They are utilized in pressure vessels operating at a wide range of temperatures and pressures.

Computational Fluid Dynamics (CFD) modeling and sizing calculations are used to evaluate the loading to a vane separator and determine the maximum overall gas and liquid handling capacity of the pressure vessel.

Test results, performed at operating pressures up to 133 bar (1931 psia) using live natural gas illustrate that, when sized correctly based on the vane's capacity curves and CFD modeling, vane separators continue to have high separation efficiency at very high operating pressures.

INTRODUCTION

A full scale test at high pressure is performed to evaluate the separation performance of a vane unit in high pressure service. The test rig (Fig. 1) is housed at K-Lab, Statoil's gas metering and technology laboratory in Karsto, Norway which has been in operation since 2004.

Fig. 1, Test Vessel at Statoil's Karsto Test Facility

This rig contains a vertical test vessel with an inside diameter of 33 inch (840mm). This test vessel is part of a flow loop that utilizes hydrocarbon gas and liquid condensate (live fluids) at pressure up to 2100 psia (145 bar).

The purpose of the test at Statoil's facility is to determine if the vane separators can be sized and their gas and liquid capacity can be predicted at high pressures where the liquid surface tension is low and the density difference (liquid density minus gas density) is also low.

An inlet baffle and a vane unit were designed, fabricated, and installed in the test vessel. The gas and liquid handling capacity of the vessel were determined using CFD modeling and capacity curves specific to the vane unit utilized. The vessel's separation performance, as a whole, was tested at high operating pressures. Results illustrate that, when sized properly, vane separators continue to perform with high efficiency at high operating pressures.

VANE SEPARATORS

Vane profiles are typically designed to form a zigzag gas path between each two adjacent vanes. A set of eight double pocketed vanes is shown in Fig. 2, bundled together to form a vane bank. The vanes are metallic and their depth, from the two phase flow inlet to the dry gas outlet typically varies between 2 to 10 inches (51 to 254 mm).

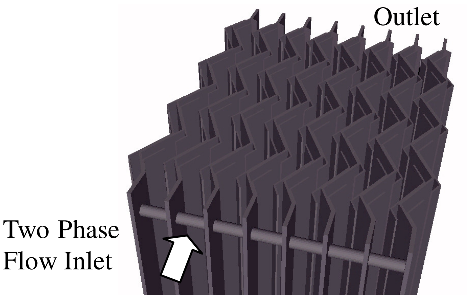


Fig. 2, Eight Double Pocketed Vanes

The gas flows from the two phase flow inlet face to the dry gas flow outlet face. Liquid droplets that enter the vane with the gas deposit on the vane walls and form a liquid film. Pockets, strategically placed within the vane's body, are used to capture the liquid film and provide regions for liquid drainage within the vane body that are sheltered from the gas velocities (Fewel and Kean, 1992).

Vane banks are typically installed within a frame such as the one shown in Fig. 3. The size of this frame is determined based on the flow rates and properties of the gas and the liquid that is being removed. The liquid, captured in the vanes, drains to the bottom of this frame and is transported by gravity out of the frame through a down comer pipe. This down comer pipe terminates in a liquid collection section away from the gas path.

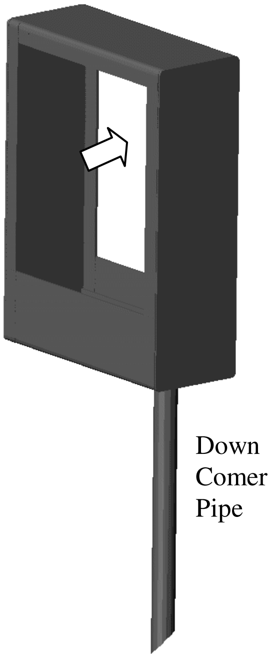


Fig. 3, Vane Bank Frame

DESIGN OF INTERNALS

The design shown in Fig. 4 was selected for the high pressure test. This design consists of a primary tangential inlet baffle and a secondary vane unit with mesh pad on the vane bank's inlet face. It is a standard design used by Peerless to handle a wide range of flow rates and conditions, including those expected in the Statoil test vessel.

The primary tangential baffle consists of a channel secured to the vessel shell at an angle from the inlet flow direction. The two-phase flow stream entering the vessel is deflected sideways by the baffle towards the cylindrical vessel shell. The gas swirls inside the vessel and flows upwards as a significant amount of liquid is separated due to the centrifugal and gravitational forces on the liquid droplets. This baffle design provides bulk removal efficiencies in excess of 85% of the incoming liquid.

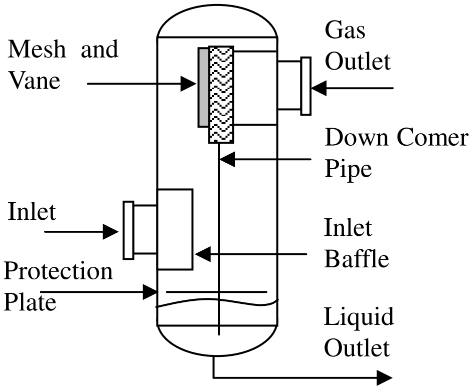


Fig. 4, Peerless Two-Stage Vertical Vane Separator

COMPUTATIONAL FLUID DYNAMICS

Since the proportions of the test vessel (inlet to vessel diameter ratio) are not specifically designed per the standard design criteria for the mesh pad and vane being tested, a computational fluid dynamics study is performed. The purpose of this study is to evaluate the steam velocities and liquid loading to the vane unit.

The vessel is modeled using Fluent CFD software. The inlet baffle and the vane unit are included in the test section shown in Fig. 5. The vane unit is modeled as a porous region (Nield and Bejan 1992).

The flow is incompressible and the K-epsilon model of turbulence is used with standard wall functions on all the solid walls.

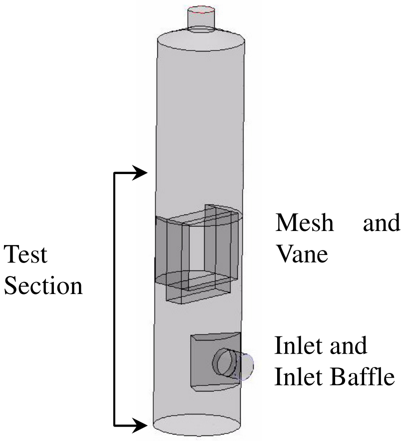
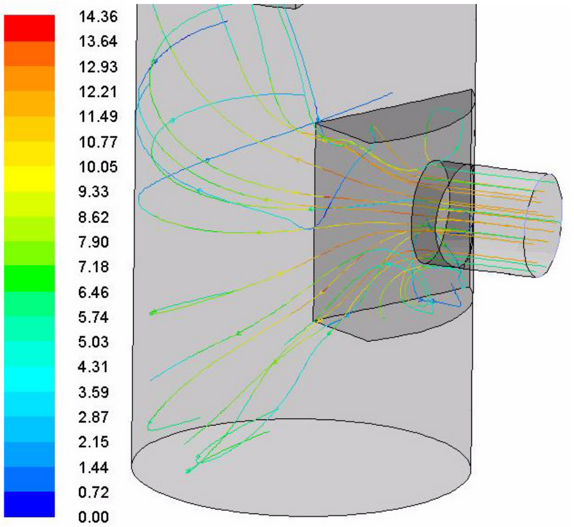
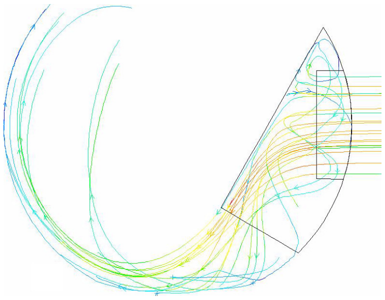


Fig. 5, Test Section

The inlet is defined as a constant velocity gas inlet with 10% turbulence intensity. The gas entering the vessel rotates inside the vessel due to the inlet baffle specified. This rotation is expected to cause bulk liquid separation, as relatively heavy liquids carried with the lighter gas move towards the wall (due to centrifugal motion) and fall downwards to the bottom of the cylindrical vessel (due to gravity). Path lines representing the gas flow near the inlet are shown in Fig. 6.



(a) General View



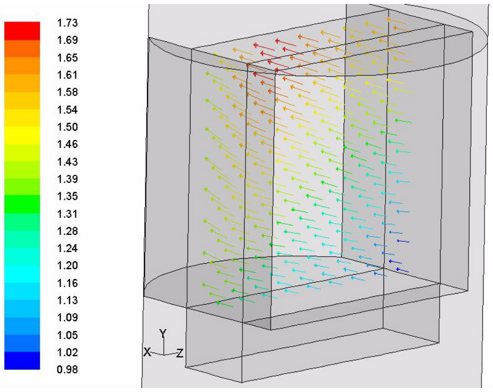
(b) Top View

Fig. 6, Gas Path Lines Entering the Vessel Colored by Velocity Magnitude (m/s)

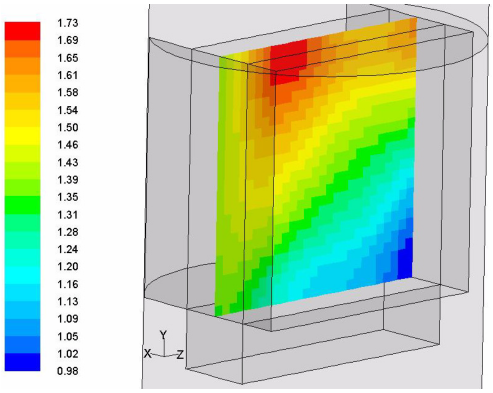
While the rotating flow in the vessel is desired for bulk liquid removal, it also causes an undesirable non-uniform velocity profile within the vane bank. Velocity vectors and contours in the middle of the vane bank representing the gas velocity are shown in Fig. 7. These capture the non-uniformity in the gas flow within the vane bank as calculated in the cell centers of the computational mesh within the vane bank.

A non-dimensional velocity mal-distribution is defined as the ratio of maximum to average gas velocity in the vane bank. Specifically, based on the maximum and average velocities of Fig. 7, the mal-distribution is 1.24. The maximum gas velocity shown in Fig. 7 is 24% higher than the average gas velocity in the vane bank.

The results are checked for numerical accuracy. Grid independence and convergence tests proved that the CFD model is grid independent and numerically converged.



(a) Vectors



(b) Contours

Fig. 7, Velocity Vectors and Contours in the Vane Bank (m/s)

LIQUID REMOVAL AND LIQUID DISTRIBUTION

The liquid removal efficiency due to the inlet centrifugal motion can be calculated using a coupled or non-coupled discrete phase droplet trajectory analysis. However, one dimensional calculations can also be used (Hoffman and Stein, 2008, Perry and Green, 1997, or other proprietary calculations). These one dimensional calculations are found to be significantly less computationally expensive while their results remain quantitatively well representative of the separation performance.

Proprietary mechanistic calculations similar to those referenced above (specific to the tangential inlet baffle utilized here) are used to evaluate the separation efficiency of the inlet section and the average liquid loading to the vane bank. These calculations are performed based on the velocities and the flow properties of the CFD simulation but are performed separately from the CFD simulation.

Further, the liquid loading to the vane bank is expected to be non-uniform. A liquid mal-distribution can be evaluated by a discrete phase droplet trajectory analysis. Alternatively, a constant liquid to gas ratio can be assumed. Based on previous experience with modeling the separation equipment presented in this paper, the constant liquid to gas ratio provides a conservative liquid mal-distribution value which is appropriate for the design of this equipment. Using the constant liquid to gas ratio conservative assumption yields a liquid mal-distribution equal to the gas mal-distribution, which is 24% higher than the average loading to the vane bank.

The mal-distribution value, for the gas and liquid, is used to determine the maximum allowable gas and liquid flow rates in the vessel such that the loading to the vane area is within the vane's capacity for 100% of the vane's area (Fadda, 1998).

VANE'S CAPACITY

Each vane profile has a capacity curve, obtained from experimental testing or CFD calculations, in addition to correction correlations for the actual gas and liquid physical properties. The description of methods used to obtain a capacity curve and correction correlations fall outside the scope of this paper. However, a description of its use in conjunction with CFD modeling is presented.

The curve shown in Fig. 8 relates the liquid loading (Ql) to the gas flux (Qg) through a vane bank. While the shape of this curve remains as shown, the values on its axes are a highly dependent on the vane type used in addition to the operating gas and liquid physical properties.

The curve is used as follows: for a given gas flow rate through the vane bank and liquid loading to the bank a representative set of points can be plotted on this curve. If the plotted points are below (or to the left of) this capacity curve, the vane will be able to capture and remove the incoming liquids. However, if some (or all) the plotted points are above (or to the right of) this curve, liquid carryover will be expected downstream of the vane bank due to capacity failure. A well designed vane bank operates within its capacity over 100% of the vane area (Fewel and Kean 1992 and Fewel et al., 2000).

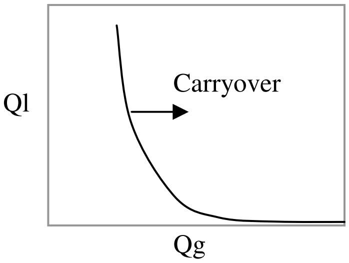


Fig. 8, Vane Capacity

The mesh pad placed at the inlet of the vane bank acts as flow straightening devices that improve the velocity profile within the vane. It also causes coalescing of small droplets and improves the vane bank's overall separation efficiency.

TESTING AND TEST RESULTS

The gas and liquid physical properties at Statoil's laboratory include those shown in Table 1 for low, medium, and high pressure. The gas density and viscosity are shown in addition to the liquid surface tension, density, and viscosity at each pressure.

Table 1, Gas and Liquid Properties

Pressure Bar,g	Temp C	Gas Density Kg/m^3	Gas Viscosity m Pas	Surface Tension m N/m	Liquid Density Kg/m^3	Liquid Viscosity Pas
29	32	23.0	0.0121	11.8	703	0.399
89	30	82.0	0.0144	5.5	647	0.256
133	30	130.4	0.0173	3.1	634.4	0.217

Maximum flow rates are calculated for each of the operating conditions shown in Table 1, based on CFD modeling and the vane capacity curves as described in this paper. Specifically, for each operating condition, the maximum gas flow rate is determined such that 100% of the vane area operates within the capacity of the vane.

The calculated maximum capacity of the vessel, as a whole, is shown in Table 2. Closely examining the numbers in this table reveals that the gas flow rate must be de-rated 35% of the original rate, as the pressure is increased from 29 to 133 bar,g. The de-rating is due to the changes in densities and viscosities of the gas and liquid in addition to the surface tension.

Table 2, Gas Capacity

Pressure Bar,g	Gas Capacity m3/hr
29	1969
89	977
133	687

The bulk overall efficiency of the vessel is measured experimentally by Statoil. This efficiency is calculated as a percentage ratio of the captured liquid volume in the vessel to the incoming liquid volume at the inlet of the vessel. The liquid removal efficiency is shown in Fig. 9 for all three operating pressures.

The liquid removal efficiency shown is observed to slightly decrease at high pressure. This behavior is consistent with inertial separation (GPSA 1999). However, due to proper sizing and de-rating, the decrease in efficiency is minimal and the vessel performance is very high. As shown in Fig. 9, this overall removal efficiency remained very high for all pressures.

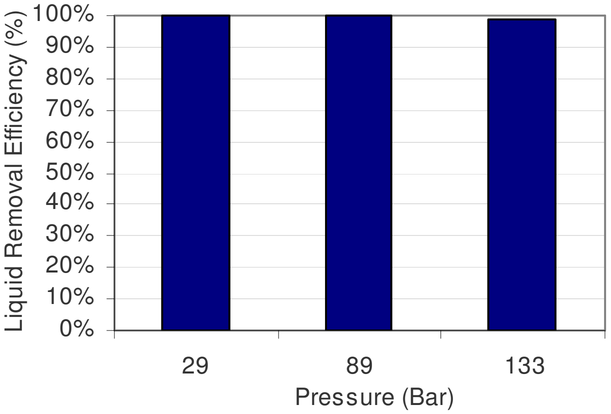


Fig. 9, Bulk Liquid Removal Efficiency

CONCLUSION

Vane separators are appropriate for high pressure separation applications. Test results, performed at operating pressures up to 133 bar (1931 psia) using live natural gas fluids illustrate that, when sized correctly based on sizing calculations and CFD modeling, vane separators continue to have high separation efficiency at very high operating pressures.

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