



**Improve Hydrocarbon Condensate Dehydration Performance –
Diagnostics and Solutions**

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Abstract

Hydrocarbon condensate separated from natural gas carries varying concentrations of impurities in the form of water, salts and solids. The effects of these contaminants can be severe and costly to the condensate stabilization plant and the export pipeline. Problems that have been encountered include off-spec condensate and final products, compromised plant performance and maintenance issues including corrosion and fouling of equipment by solid deposits.

Improving the condensate dehydration or ‘dewatering’ step requires a good understanding of the nature of the contaminants, as well as the features and the limitations of the separation technologies that are used to eliminate these contaminants.

Analytical means and field methods are available in the industry to evaluate contaminants and to diagnose separation problems in the field. Results from field surveys highlight that water carryover from existing separators can be significant. Condensate dehydration is often made difficult due to the formation of stable condensate/water emulsions caused by the presence of surfactants

such as hydrate inhibitors and corrosion inhibitors that lower the interfacial tension.

Various separation technologies are available to eliminate water from unstabilized condensate. The selection of the appropriate technology should be evaluated with care to ensure that it is capable of separating potentially stable emulsions. The evaluation should also consider its maintainability, running cost and investment cost.

The use of high efficiency polymeric cartridge coalescers is an effective and economical way to improve the condensate dehydration step due to their ability to separate difficult emulsions. This technology features several advantages including no need for chemicals nor utilities to aid the separation. The implementation of cartridge coalescers involves certain design considerations related to the presence of solid impurities and the potential of degassing. Commercial experience illustrates that the use of this advanced coalescer technology has been proven as an effective solution to optimize low performance condensate dehydration systems.

Introduction

Hydrocarbon Condensate produced with natural gas increases the profitability of gas development projects. The condensate will be used or marketed under various forms depending on the production rate, composition, and available downstream markets and transportation network. It can be used as a fuel or blended with crude oil to

increase its API density. It can be fractionated into various marketable hydrocarbon products such as ethane, propane or LPG (Liquefied Petroleum Gas) and Natural Gasoline (also referred to as C5+, condensate or naphtha). These products are sold as final products or as feed stocks to the petrochemical or refining

industries. Hydrocarbon condensate that do not require any specific processing can be directly sent to the export pipeline; this is typically the case at offshore production platforms. At onshore production facilities condensate is usually treated by a stabilization process prior to export. This operation aims at reducing the vapour pressure of the condensate (natural gasoline) by eliminating the light fractions to make it safe for storage at atmospheric conditions and for transportation ^{1,2,3}. While a stabilization plant usually involves a single tower process, the condensate may also go through a more extensive fractionation process to split the lightest hydrocarbon constituents into separate final products. The number and type of columns in the fractionation plant is dependent on the downstream markets requirements and the feed condensate composition.

The unstabilized condensate separated from the gas at the production separator carries varying concentrations of formation water that is also sometimes called 'brine' due to its intrinsic salinity caused by dissolved salts. The condensate typically has particulate contaminant present as well. The effects of these contaminants can be severe and costly to the condensate stabilization

plant and the export pipeline. Problems that have been encountered include off-spec condensate and final products, poor plant reliability, compromised plant performance and maintenance issues including corrosion and fouling of equipment by solid deposits.

The dehydration or 'dewatering' of the unstabilized condensate is therefore a necessary step in processing or transporting hydrocarbon condensate to reduce the ingress of water, salts and solids to as low levels as possible. Hence the dehydration step requires a careful evaluation of the condensate/water separation technology. The formation of stable condensate/water emulsions is a very common challenge that can make some separation technologies ineffective in eliminating water down to the requested specification. Improving the condensate dehydration step requires a good understanding of the nature of the contaminants that are present in the unstabilized condensate and the analytical means to diagnose separation problems, as well as a good understanding of the features and the limitations of the separation technologies that are used to eliminate these contaminants.

Impact of Ineffective Condensate Dehydration

The presence of salty, acidic water and solid particulate in the unstabilized condensate is known to cause various problems in the stabilization plant or in the export pipeline. Field experience in various regions of the world has shown that the separation of the water phase from the condensate can be problematic and require specialized equipment. Even though the condensate viscosity is low and the density difference with water is high, other impurities tend to create stable condensate/water emulsions that are difficult to separate efficiently.

Literature reports little about problems that operators can experience as consequences of ineffective condensate dehydration. However discussions in the field with operators in the Middle East, North Africa, Australia and North America have reported that several of the following consequences may arise due to water

carryover that contains dissolved salts, and/or solids:

- Plant upsets and reduced stability of the plant operation
- Quality issues of the final products such as gasoline and LPG and possible need to reprocess
- Excessive corrosion and deposits inside the stabilizer and re-boiler⁴, as illustrated in Figures 1 and 2 on the next page
- Increased power consumption due to the ingress of excessive levels of water and loss of heat transfer caused by contaminant deposits
- Frequent shutdown of the stabilization train for cleaning purposes, causing a drop in production and hence a loss of revenue if the flow rate can not be compensated by the other stabilization trains

Figure 1:
Salt deposits in de-ethanizer reboiler top tubesheet before (left) and after (right) cleaning (by courtesy of Crew Energy Inc.)



Figure 2:
Deposits collected from reboiler tubes at Middle East plant



The presence of water in the stabilized condensate can also create corrosion products in the export condensate storage tank and in the export pipeline, also referred to as 'black powder' particles. Corrosion of the export pipeline may

also represent a major integrity issue that could lead to premature replacement of some sections of the pipeline if left unattended. Finally, off-specification products can cause issues at the end user's plant, and complaints.

The cost of ineffective condensate dehydration is highly dependent on the magnitude of the problems and the size of the stabilization plant, however it is not uncommon that small plants with a daily production of few thousands barrels of unstabilized condensate experience several hundred thousands of US Dollars of annual losses of revenues, as reported in a case history below. In the condensate export pipeline, impurities will primarily affect the integrity of the pipeline itself due to the corrosion of the inner walls, when the pipeline is not made of lined or clad steels.

Typical Contaminants in Hydrocarbon Condensate and Diagnostic Methods

Contaminants found in the unstabilized condensate include free, emulsified and dissolved water, salts, acidic components, corrosion inhibitors, hydrate inhibitors (Mono Ethylene Glycol (MEG), methanol, and Kinetic Hydrate Inhibitors), and solid particles (corrosion products, sand) and solid-like particles (waxes, gels). Water, salts and particles impact on the stabilizer operation and the export pipeline by creating the above mentioned issues so eliminating them is of paramount importance to ensure that these assets are protected efficiently. This section introduces some analytical methods available in the industry that can be used to diagnose and quantify these impurities.

The impurities that mostly affect the water separation are the corrosion inhibitors, MEG or methanol as they act as surfactants lowering the Interfacial Tension (IFT) and creating stable emulsions that cause water carryover. Results

from field surveys are detailed below and show that water carryover is a common issue from various types of separators.

Water in condensate downstream of inlet separators is typically present in concentrations varying from few hundreds ppmw (parts per million by weight) up to 5%. The salinity of the water contamination is determined by the formation water and also varies significantly from a few hundred ppm up to few hundred thousands ppm. Quality specifications of the dehydrated condensate prior to the stabilizer or prior to the export pipeline are project dependent and typically show free water concentrations ranging from <10 ppmv (parts per million by volume) to <100 ppmv. A very efficient condensate dehydration step also has the advantage of maximizing the recovery of MEG for its subsequent regeneration, when it is present.

Evaluating Water Concentration

Water as a contaminant in hydrocarbon liquids has been classified into different categories usually as free, emulsified, dissolved and total water.

- **Free Water:** water component that is not dissolved. In some cases it is characterized as the bulk fraction of water that separates out more easily, however in terms of the analytical methods it is not distinguished this way. So for the purpose of this paper, the authors define it as both the bulk water fraction and the emulsified water fraction.
- **Emulsified Water:** water that is contained in small drops typically 0.1 micron to 50 micron and usually more difficult to separate. Emulsified water in the condensate will usually form a haze that enables a quick visual evaluation of the condensate quality; a 'clear & bright' condensate indicates that the emulsified water left is very close to the solubility limit.
- **Soluble Water:** water that is dissolved at the molecular level in the hydrocarbon phase. It is not removed by separators or coalescers. The solubility of water in the condensate is dependent on the fluid temperature and the composition of the condensate, its aromatic content (increasing water solubility) and as a consequence it can range between 50 and 500 ppm typically.
- **Total Water:** sum of the dissolved and free water.

Total Water – Karl Fischer: Dissolved as well as free water will be measured together. This test typically requires samples to be collected in the

field and transported to a lab setting for analysis. Any volatile hydrocarbons will be flashed off for samples collected at atmospheric pressure. A back calculation is possible to evaluate the actual water content by calculating the weight of the lightest fraction that has flashed off.

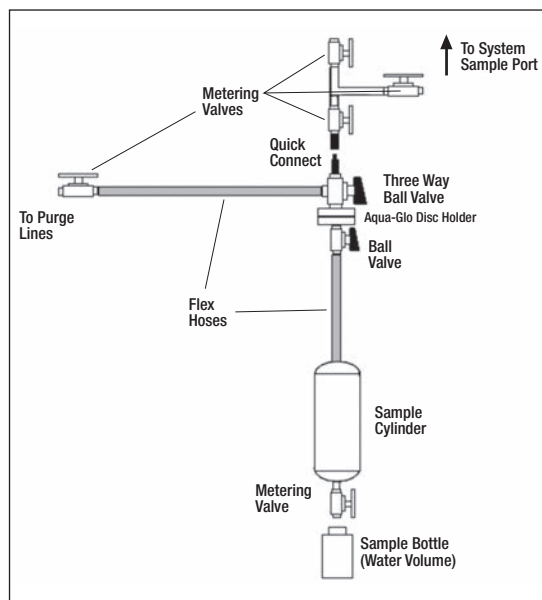
Free Water – Aqua-Glo*: This method is particularly appropriate to measure the actual performance of separators since they only eliminate the free water portion. Furthermore it can be modified by using a water displacement technique to keep the sample disc under system pressure so that the volatile fraction of the unstabilized condensate remains in liquid form. The apparatus for this test is displayed in Figure 3. This method uses a filter disc that is impregnated with a fluorescein dye that reacts with only free water. A known volume of the process fluid is passed through the test disc and is then placed in the Aqua-Glo apparatus that contains an ultraviolet light source and photometric detector. The UV light causes the sampled disc to fluoresce and the intensity of the light emitted is correlated to the free water content.

For both the Karl Fisher and the Aqua-Glo tests, the process stream is sampled for a short period. The use of a pilot liquid / liquid coalescer allows for longer duration testing which can be quite valuable in assessing periodic slugs that otherwise might be missed.

Pilot Liquid / Liquid Coalescer Test: Testing the process stream over longer periods of time can be accomplished by use of this device. The pilot test equipment is connected to the process and a side stream with a flow rate of only a few liters per minute is sampled. This test measures the amount of water present in the hydrocarbon condensate over several days to weeks and also is a useful way to demonstrate the removal capability of the cartridge coalescer at actual process conditions for the water, salts and solids specifications. A photograph of a horizontal pilot test rig is given in Figure 4.

A small test coalescer is used along with a test pre-filter to protect the coalescer from plugging with solids. The flow first enters the pre-filter and then enters the horizontal coalescer housing. As the fluid passes through the coalescer small drops in the emulsion are forced into close contact

Figure 3: Modified Aqua-Glo sampling technique using the water displacement method



* Trade mark of Gammon Technical Products, Inc.

Figure 4:
Pilot Liquid / Liquid
Coalescer Test Rig

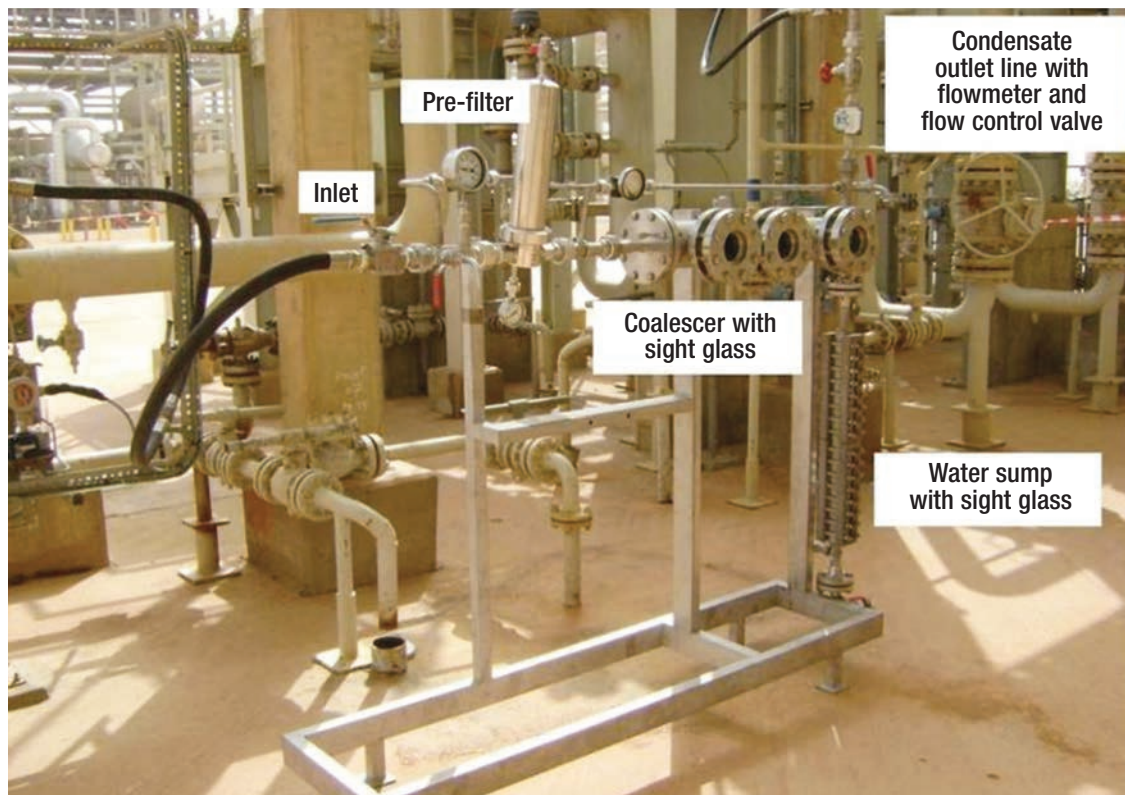
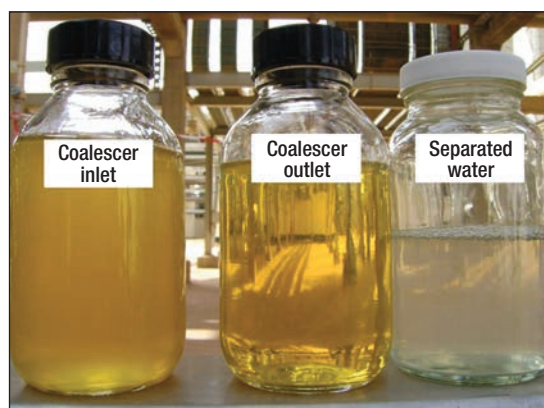


Figure 5:
Typical condensate
samples collected
during field surveys



across a fiber bed and emerge with drop sizes several orders of magnitude larger. The large drops settle along the length of the coalescer housing and removed by a sump. The dewatered condensate exits at the top of the housing.

Different types of coalescer cartridges can be evaluated as well as varying fluxes to assess the most optimum separation conditions according to the actual stability of the emulsion. Throughout the test, inlet and outlet condensate samples are collected to measure the efficiency of the existing separator by measuring the water concentration as per the Karl Fischer or Aqua-Glo methods. Samples of the separated water are also collected to measure the salinity. Samples that

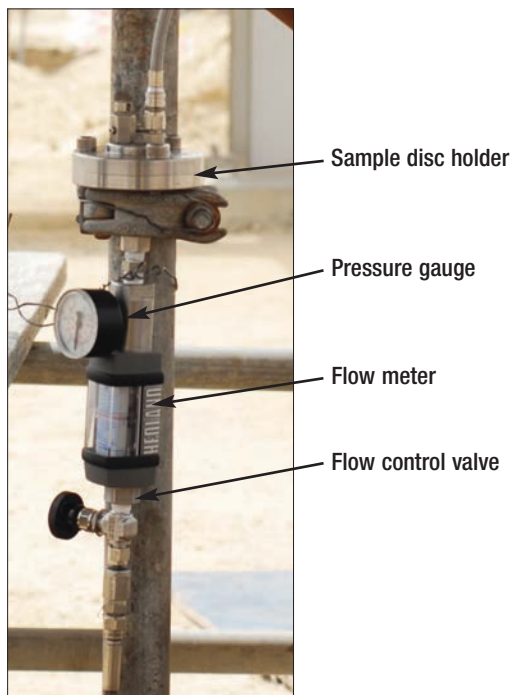
are typically collected during tests are shown in Figure 5.

Evaluating Solid Contamination

Total Suspended Solids (TSS) Content: it can be measured by the use of an in-line test jig containing solids collection membranes - typically rated at 0.45 micron removal. This method offers the benefit of sampling under process conditions so that the correct amount of liquids are processed without flashing. The solids weight gain is corrected for the volume of fluid sampled and the results reported in milligrams per liter (mg/L). A figure of the solids sampling apparatus is provided in Figure 6 on the next page.

Particle Size Distribution (PSD): a smaller volume of the liquid condensate is passed through a 0.45 micron membrane disc to collect solids for PSD analysis using the same apparatus used for the TSS membrane preparation. The sample is prepared so that the solids do not concentrate on the membrane and overlap so as to be able to count discrete particles. Once the test disc is prepared, an automatic image analyzer using electronic microscope is used to automatically count the particles which are classified according to their size.

Figure 6:
Test Apparatus for
preparing TSS and
PSD solids
evaluation
membranes



Elemental Analysis: A Scanning Electron Microscope (SEM) coupled with Energy Dispersive X-ray (EDX) analysis can provide valuable information concerning the qualitative evaluation of the elemental composition of the solid material that can be interpreted to discern the nature of the solid contaminants usually classified as corrosion products (iron, sulfur, oxygen), salt precipitates (calcium and barium sulfates) or sand (silica).

Dissolved Solids

The dissolved solid components in the aqueous phase are typically characterized as Total Dissolved Solids (TDS) or by specific ions. TDS is determined by measuring the conductivity using a portable dip type probe and resistivity meter. Most commonly, chloride ion concentration is measured by ion chromatography.

Field Test Results

Water carryover from separators and the subsequent ingress of water, salts and solids in downstream equipment are quite common. The reasons for carryover are basically due to the presence of condensate/water emulsions that existing separators are unable to remove effectively, either due to intrinsic performance limitations or sometimes due to plant capacity increase that has made the existing separator undersized. The water carryover issue can be easily evaluated through a field survey using the above described methods. A summary of the results gathered at four different plants in the Middle East and North Africa region is provided below.

All four plants were facing various production issues in the stabilizers and entered troubleshooting programs which included surveys for the evaluation of the condensate contamination. More specific production issues were reported as follows: Plant A experienced issues with heat exchanger plugging and reduced capacity of stabilizer, as well as corrosion issues in the export tanks and pipeline; Plant B experienced too frequent replacements of the molecular sieve driers used for final condensate dehydration, and off specification products causing corrosion issues in the export line; Plant C had severe fouling issues in the stabilizer, which required regular shutdown for water wash every 3-4 months; Plant D experienced fouling of the reboiler and deposits on the column's trays causing distortions.

The condensate was tested downstream of existing separators which consisted of gravity settlers, knock-out drums with mesh pads and glass fiber cartridge coalescer (Table A). Results of tests

Table A: Contamination Levels in Condensate at Outlet of Existing Separators

| Plant Location | Type of Separator | Flowrate Am ³ /h (BPD) | TSS (mg/L) | Nature of Solids | Free Water* (ppmw) | Condensate Visual Appearance | Chloride (mg/L) |
|------------------------|------------------------------|-----------------------------------|------------|---|--------------------|------------------------------|-----------------|
| Plant A – Middle East | Gravity Separator | 165 (24900) | 6 | FeS, CaSO ₄ | 1800-4800 | Hazy | 240-310 |
| Plant B – Middle East | Glass Fiber Coalescer | 62 (9360) | 16 | FeS | 75 | Slightly hazy | Not measured |
| Plant C – North Africa | Knock-Out Drum with Mesh Pad | 70 (10570) | 3 | FeS, CaSO ₄ , SiO ₂ | 400-500 | Hazy | 5470 |
| Plant D – North Africa | Gravity Separator | 25 (3770) | 12 | Iron oxides | 2000-7000 | Hazy | 25000-32000 |

* Free water content evaluated from water volume separated by pilot coalescer

Table B: Performance of Pilot Scale Coalescer

| Plant Location | *Free Water (ppmv) | Condensate Visual Appearance |
|------------------------|--------------------|------------------------------|
| Plant A – Middle East | <16 | Clear & Bright |
| Plant B – Middle East | <12 | Clear & Bright |
| Plant C – North Africa | Not measured | Clear & Bright |
| Plant D – North Africa | Not measured | Clear & Bright |

* Measured by Aqua-Glo method at outlet of pilot coalescer

downstream of the pilot high efficiency PhaseSep® polymeric coalescer are also reported (Table B).

The free water at the outlet of the pilot scale coalescers was not measured at Plants C and D due to unavailability of the test equipment. The visual inspection of the samples, however did indicate clear & bright and this demonstrates good coalescer performance with free water concentrations expected to be very close to the solubility limit as obtained at plants A and B.

These field surveys illustrate that water carryover downstream of separators can be minor (plant B) to very significant (plants A & D). Water

concentrations measured downstream of separators are case dependent and figures shown should not be considered as typical of these separators. Nevertheless, the relative significance of the water carryover is typical of the expected relative separation performance of these types of separators in the presence of stable emulsions, that is gravity settlers being more prone to carryover than knock out drums with mesh pads, and then cartridge coalescers. These field surveys also highlight that a very significant improvement is achievable as regards to possibilities in further separation performance. The troubleshooting programs carried out at these plants all concluded that carryover of contamination was the primary root cause for the problems experienced in stabilizers. In fact even concentrations perceived as minor can actually cause significant problems due to the fact that they often represent large quantities when scaled up to the full flow rate of the installation.

The evaluation of water, salt and solid contamination levels is therefore very useful in diagnosing the root causes for poor condensate dehydration and if possible it is a recommended step in searching for ways to improve a stabilization plant.

Reasons for Ineffective Dehydration: Presence of Stable Emulsions

This section discusses the reasons for water carryover being due to the presence of stable condensate/water emulsions that many separation technologies are not capable of processing. Carryover due to undersized separators after plant capacity increase is not discussed here.

Emulsions

Emulsions consist of the three components: oil (representing hydrocarbon or organic liquids), water (including any aqueous mixtures) and surfactants. Depending on the ratio of these components, oil-in-water emulsions or water-in-oil emulsions can exist. The structure of the emulsions is well defined with spherical droplets of the dispersed phase surrounded by a bulk continuous phase and surfactant surrounding the droplets at the interface. Surfactants contain both hydrophilic (water loving) and hydrophobic (water fearing) portions in the same molecule. This unique structure allows them to associate

at water-oil interfaces and helps them to stabilize the droplet shape. In order to make an emulsion the system must be subjected to shear or mixing to allow the three components to re-distribute into many small droplet structures. Depending on the stability of the emulsion, the separation can occur naturally in a matter of seconds or months.

Surfactants

Surfactants can be broadly classified into three groups: cationic, anionic and nonionic. All surfactants consist of polar or hydrophilic groups joined to non polar or hydrophobic hydrocarbon chains. Cationic surfactants contain polar head groups that have a positive charge while anionic surfactants have polar groups that have negative charges. Nonionic surfactants have polar groups that are neutral and are typically made up of ethylene oxide groups, but glycols and alcohols also can fit this category.

The sources of surfactants found in industrial processes include: intentional additives, surfactants found in nature, and surfactants created inadvertently through reaction processes. Some examples of surfactants classified this way are given below

- Additives: corrosion inhibitors, de-emulsifiers, scale inhibitors, flocculants, Hydrate inhibitors such as Mono Ethylene Glycol (MEG) or methanol.
- Natural: petroleum naphtha sulfonates, naphthenic acids and mercaptides in crude oil⁵.

Interfacial Tension (IFT)

IFT is created at the interface between two immiscible liquids. It is the amount of work required to create additional surface area. The measurement of IFT is based on the difference between the surface energies of the liquids. The units of IFT are dyne/cm (force per distance) or erg/cm² (energy per area). The IFT measures the stability of an emulsion. The lower the IFT, the more stable the emulsion, and the smaller the droplets.

The IFT can be measured in the laboratory from actual condensate and water samples collected in the field by a number of methods including the Du Nouy ring pull method or the drop volume method. Currently these measurements are restricted to atmospheric pressure and as a result unstabilized condensate cannot be evaluated accurately and instead only the non-volatile fraction that remains after the lighter ends flash can be estimated by these methods.

The drop volume method has the potential to be adapted to higher pressures and research is currently underway to this end.

Effect of Surfactants on IFT

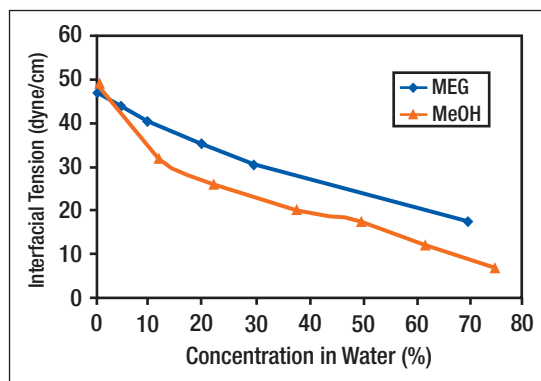
IFT between hydrocarbon products and water, such as in a refinery, can be as high as >40 dyne/cm at operating conditions. In the condensate dehydration application according to experience IFTs would however typically range between as low as <2 dyne/cm up to 20 dyne/cm at operating conditions. This is also well illustrated in the case histories below.

As mentioned above IFT between unstabilized condensate and water cannot be measured accurately. To simulate the effect of surfactants on IFT in the laboratory, synthetic mixtures can also be used. To simulate hydrocarbon condensate, pentane is often chosen as a similar solvent. For the purpose of this paper solutions were made up of different concentrations of MEG and water containing 1000 ppm of sodium chloride. The aqueous mixtures were tested for IFT with pentane. IFT tests that were performed previously with mixtures of methanol (MeOH) in water and pentane are also presented⁶. The results confirm that these additives have a strong influence in significantly lowering the IFT. It is expected that this decrease in IFT would be even more significant in the presence of surfactants such as corrosion inhibitors that are routinely used by industry.

Disarming

'Disarming' is specific to cartridge coalescers whose coalescer medium is made of glass fiber. When surfactants concentrate on the coalescer fibers, they are shielded from the passing aqueous droplets resulting in poor separation efficiency. Generally, the disarming phenomenon does not occur unless the IFT is less than 20 dyne/cm. When specially formulated polymeric coalescer medium is used instead of glass fiber, disarming was not observed⁷. The coalescing performance of a polymeric medium can be greatly enhanced by modification of surface properties which cannot be accomplished with glass fiber medium.

Figure 7:
Effect of MEG and MeOH on Pentane / Water IFT



Overview of Available Separation Technologies for Condensate Dehydration

Various sorts of separation technologies are available in the industry to eliminate salty water from unstabilized condensate. They typically consist of gravity settlers, knock-out vessels with mesh pads, electrostatic desalters and cartridge coalescers. All technologies have specific features which make them suitable for a given set of operating conditions. For instance not all technologies are capable of separating stable emulsions with low IFTs. Hence with the objective of improving the condensate dehydration step, the selection of the appropriate technology or combination of technologies requires a good understanding of their advantages and limitations.

The separation mechanisms involved are gravity decantation, and coalescence. As a consequence only the free and emulsified water is separated; the dissolved fraction remains in the condensate.

Coalescence

Coalescence consists in the enlargement of finely dispersed droplets of the 'dispersed' phase (water in the case of condensate dehydration) into larger drops that are eventually able to separate from the bulk 'continuous' phase (condensate).

Coalescence can be made through a media that usually consists of fibers which are made of metal such as in demister pads, or made of glass fiber or polymer as in cartridge coalescers. Coalescence can also be made under the influence of an electric field as in electrostatic desalters.

Gravity Settlers

- **Separation principle:** gravity settlers rely on the Stokes law and on the residence time given to the water droplets to decant.

- **Separation performance:** although capable to accommodate large and fluctuating concentrations of water in the inlet stream, gravity settlers are not capable of separating very fine droplets. The sizing of this type of separator is precisely not always straightforward as it requires that the size of the inlet water droplets is assumed or measured. Gravity settlers should be considered for bulk pre-treatment and will not be effective for stable emulsions. Gravity settlers can often be subject to

significant water carryover in the case that assumptions made for the inlet droplet size are incorrect or in the case of a decrease in the IFT due to the presence of additional surface active chemicals. Separation of the particulate contamination is of limited efficiency.

- **Maintainability:** this separator is easy to maintain due to no specific internals being present.

- **Running cost:** this separator does not require any replacement parts nor utilities, thus running costs are usually low. In the case a 'rag layer' forms and thickens over time and affects the condensate/water interface detection, demulsifying chemicals may be added.

- **Investment cost:** as a consequence of long residence times to allow for the separation of fine droplets, gravity settlers consist of very large pressure vessels which can represent significant investment costs when special construction materials and high design pressures are required.

Knock-out vessels with mesh pads

This type of separator has the same features and limitations as gravity settlers, but it incorporates internals in the form of a mesh pad on the entrance of the separator to coalesce the water and help decantation. Although the installation of the mesh pad does not add a significant investment cost, it can require some cleaning operations due to the possible plugging of the mesh pad due to particulate contamination. While an improvement over decanting, the mesh pad is typically very coarse in pore size and will not be able to separate stable emulsions.

Electrostatic Desalters

- **Separation principle:** electrostatic desalters rely on the polarity of water molecules to coalesce under a high voltage electric field. The electric field is provided by electrode grids positioned inside the vessel, between which the condensate/water emulsion is distributed through the inlet header and where coalescence takes place. The enlarged water droplets settle by gravity to the bottom of the desalter.

- **Separation performance:** thanks to the electric field that creates almost virtually instantaneous coalescence, electrostatic desalters are capable of separating relatively stable emulsions containing fine water droplets. Desalters are capable of processing bulk concentrations of water in the inlet stream. The separation can be affected by sticky deposits that adhere to the electrodes, as well as the formation of an emulsion or rag layer at the condensate/water interface⁴. Separation of the particulate contamination is of limited efficiency.
- **Maintainability:** easy to maintain due to no specific internals that are prone to fouling. The cleaning of the electrodes is sometimes required in the presence of heavy hydrocarbons that mix with the corrosion particles and adhere to the electrodes. Slugs of water can sometimes cause the electrodes to short out requiring replacement.
- **Running cost:** a local power supply is required to create the electric field. Desalters often require the injection of wash water (typically around 5%) to get a sufficient population of water droplets to coalesce and to extract soluble salts down to the requested specification. The need for wash water adds on running costs to supply a fresh low-salinity water source, as well as on power consumption costs due to the need for extra injection pumps. Desalters also sometimes use demulsifying chemicals to avoid the build-up of an interface emulsion layer and to enhance the separation.

- **Investment cost:** desalters usually consist of very large pressure vessels with one or more transformers to generate the electrical field, hence they are relatively expensive equipment whose cost is significantly dependent of the construction materials and the design pressure. The possible requirement for dilution water also impacts on the investment cost due to the need for a water source, pump and supply piping.

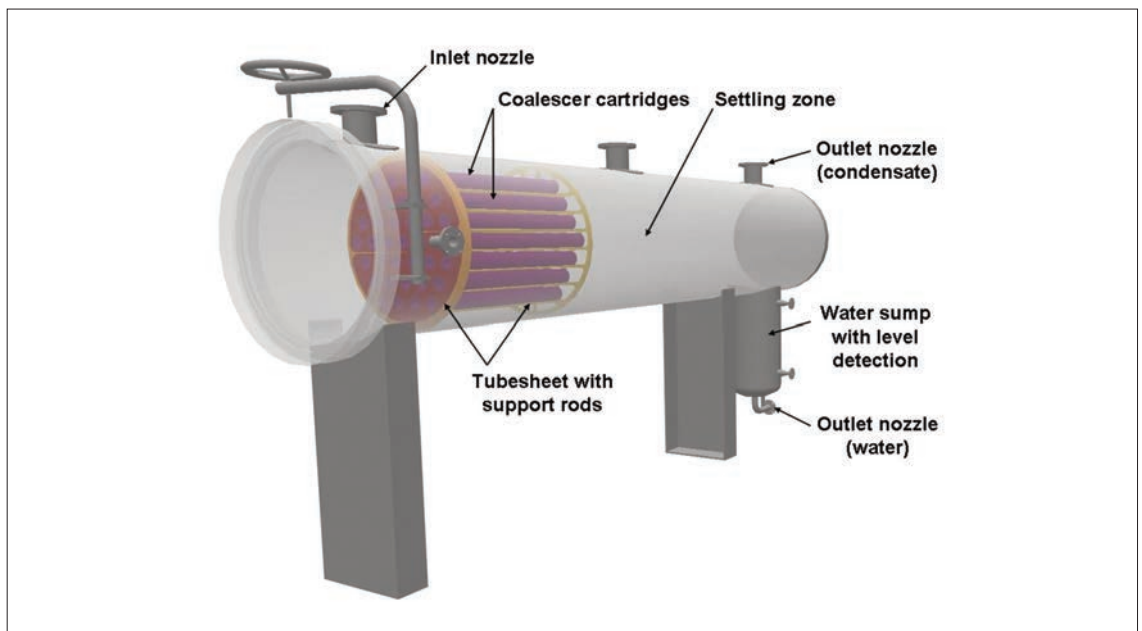
Cartridge Coalescers

- **Separation principle:** cartridge coalescers use the ability of the fine fibrous medium to coalesce the finely dispersed droplets. Cartridge coalescers do not require the use of chemicals nor electricity to achieve the separation. The separation is only based on the ability of the medium to capture the droplet to the fiber through adsorption, coalesce two droplets to form a larger one at fiber intersections, and release of the droplet from fiber intersections due to increased drag caused by the bulk flow.

Cartridge coalescers can either be vertically or horizontally configured. The horizontal configuration is the most common one. Figure 8 below depicts a typical view of horizontal coalescer.

In this configuration the coalescer consists of a horizontal coalescer cartridge stage followed by a settling zone that relies on the density difference between the water and the condensate to separate the coalesced droplets. The coalescer cartridges are mounted on a tubesheet (filter plate) and supported by tie-rods. The

Figure 8: Overview of typical cartridge coalescer layout in a horizontal configuration



condensate/water mixture flows from the inside of the coalescer cartridges radially outward causing the enlargement or coalescing of the fine water droplets. The coalesced droplets then flow axially in the horizontal direction through the settling zone downward by gravity and are collected in a sump located at the bottom of the housing at the end of the settling zone opposite to the condensate outlet nozzle. The level of the condensate/water interface is monitored in the sump by level control which automatically controls the opening of the drain valve.

Coalescers can also be vertically configured. This configuration involves the same coalescer stage, while the separation stage is achieved by another type of cartridge with hydrophobic barrier capabilities to allow the condensate stream go through while retaining the coalesced water droplets. A vertical configuration is not suitable for very low IFT (<3 dyne/cm) due to the inherent fragile nature of the coalesced droplets that make the separator cartridge become ineffective.

- **Separation performance:** cartridge coalescers have varying performances according to the type of coalescer cartridge that is used. Due to disarming of glass fiber made coalescers in the presence of surfactants, 'conventional' cartridge coalescers are usually restricted to emulsions featuring IFTs of not less than 20 dyne/cm typically. Given the features of the condensate/water emulsion in the condensate dehydration application, 'high efficiency' cartridge coalescers are therefore more appropriate. High efficiency coalescers are particularly suited to handle emulsions featuring low IFTs (<15 dyne/cm) to very low IFTs (<5 dyne/cm) High efficiency coalescers are constructed with specially formulated polymer medium with enhanced surface properties that can influence the adsorption of droplets and the ultimate release of the coalesced droplets. Cartridge coalescers can accommodate relatively high (up to 5% typically) and fluctuating inlet water concentrations.

- **Maintainability:** coalescer cartridges can plug over time due to the presence of particulate contamination and need to be replaced after a certain period of time, typically of few months to a couple of years. Cartridge coalescers are easy to maintain, as they only require the

replacement of the used cartridges by new ones. The criterion for change-out is the differential pressure across the coalescer, which will steadily increase over time while the coalescer is fouled by particulate contamination. Typically recommended change-out for differential pressures is in the range 0.5-1 bar (7 -15 psid). The installation of a particulate pre-filter upstream of the coalescer greatly extends the service life of the coalescer, beyond one or two years as it is seen in practice. The particulate pre-filter is also required to meet solids contamination specifications.

- **Running cost:** the separation is achieved without any chemicals or electricity which enable low running costs. However coalescer and pre-filter cartridges are consumables, whose replacement is dependent on the solids concentration, and represent most of the running cost.

- **Investment cost:** cartridge coalescers are compact technologies that enable smaller pressure vessels. Besides no ancillary equipment is required since their operation does not require specific utilities or chemicals injection. As compared to other conventional technologies, overall investment cost is typically lower.

As described above all technologies have varying separation capabilities for stable emulsions. High efficiency cartridge coalescers certainly represent the most reliable solution for the low IFT featuring condensate dehydration application when stringent quality specifications are necessary for the water, salts, solids or MEG levels in the dewatered condensate.

Cartridge coalescers require cartridges to be replaced and this is often perceived as a drawback due to the additional maintenance and disposal costs it creates. However the selection of properly designed filters and coalescers can exhibit long service lives and the capital investment for cartridge coalescers can be much lower than other options due to their smaller footprint. Cartridge coalescers also do not require the use of chemicals nor utilities whose costs should be taken into account when comparing different separation solutions in terms of operating and capital expenditures.

The use of high efficiency polymeric cartridge coalescers offers an improved means for the elimination of the salty water from the unstabilized condensate. The implementation of cartridge coalescers requires however a careful evaluation of the sizing criteria, and it involves certain design considerations that are related to the presence of solid impurities and the vapor pressure of the fluid.

Sizing

The sizing of a cartridge coalescer is basically based on the condensate flow rate, the physical properties of the condensate and the water (density and viscosity) at operating pressure and temperature, as well as based on the IFT between the water and the condensate and the inlet water content.

The IFT impacts on the flux per cartridge and hence on the quantity of elements that are necessary to handle a given flow rate thus on the diameter of the coalescer vessel. Emulsions featuring low IFTs are stable which means that the water droplets are very fine in size; this requires that low fluxes are considered to ensure that the droplets are efficiently captured and coalesced within the coalescer medium, and released from the coalescer cartridge without any risk of shearing and breaking back into finer droplets. Besides, the IFT impacts on the size of the coalesced droplets and hence on the length of the settling zone located downstream of the cartridge bundle where the separation takes place. Therefore the sizing of the coalescer is dependent on the IFT. If possible at existing fields, the IFT should be estimated from actual water and condensate (non-volatile fraction) samples, so that the influence of all surfactants present is taken into account. The IFT can typically range between as low as <2 dyne/cm up to 20 dyne/cm at operating conditions. In the case the IFT cannot be measured, as it is the case in 'greenfield' projects, it is recommended that an IFT of <10 dyne/cm is considered.

The inlet water content does not impact on the flux per cartridge as cartridge coalescers usually have the ability to handle relatively large amounts of water, typically up to 3 to 5% in volume. In the case of higher inlet water concentrations, the coalescer may have to be oversized by adding

more coalescer cartridges in order to provide more coalescing surface, or a coarse pre-separation device located upstream of the cartridge bundle within the coalescer vessel should be considered.

Particulate Pre-Filter

The unstabilized condensate contains varying concentrations of solid and solid-like particles. Although the solids content is usually in the ppm range, it may represent a solids loading of several kilograms per day when scaled up to the full flow rate of the installation, hence the importance of eliminating this solid contamination before entering the stabilizer. Besides, particle contamination tends to increase the stability of the liquid/liquid emulsion. Cartridge coalescers, although only designed for the separation of two liquid phases, have to some extent the ability to act as particle filters due to the fine pore structure of the coalescer medium and would plug over time. A frequent replacement of the coalescer cartridges is not cost-effective over time due to change-out, maintenance and used cartridge disposal costs. So it is usually recommended that a separate pre-filter is installed upstream of the coalescer to remove particulate matter. The installation of a pre-filter extends the service life of the coalescer significantly and reduces particulate concentration to meet solids specifications. The removal rating of the pre-filter should be selected according to the pore size structure of the coalescer medium, as well as according to the size distribution of the solid contaminants. The particulate pre-filter increases the investment cost of the cartridge coalescer solution, but overall reduces the running costs of the coalescer assembly.

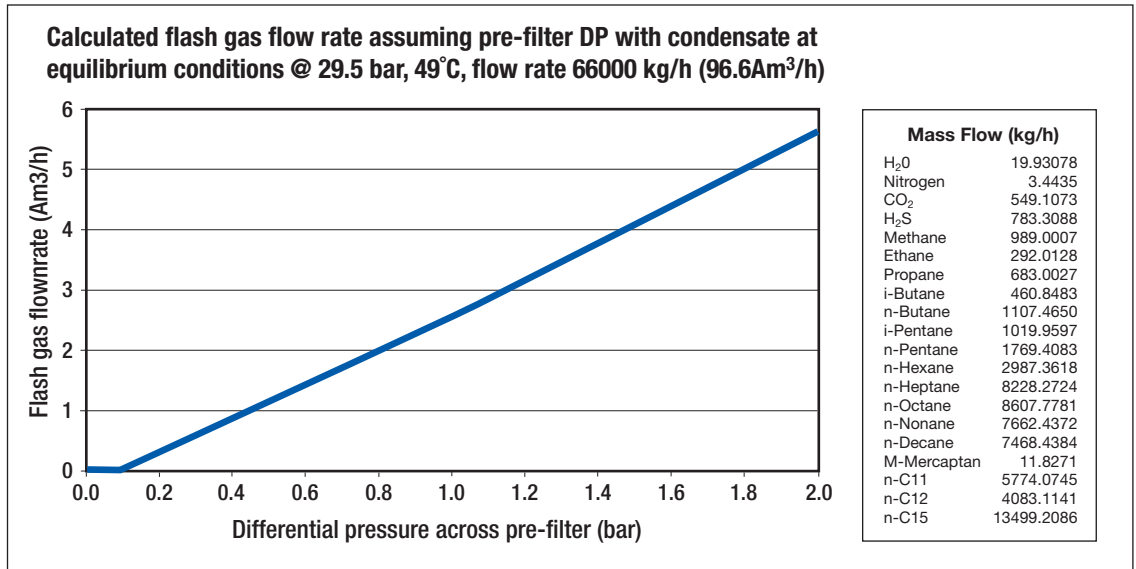
Degassing

Dehydrating unstabilized condensate requires a careful evaluation of the risk of flash off due to drops in operating pressure. The presence of gas inside a coalescer should be avoided at all time because gas bubbles may disrupt the coalescing mechanism inside the coalescer medium, hence adversely affect the coalescer performance. Degassing is dependent on the condensate's composition and operating pressure and temperature. Degassing is not an issue when the condensate is processed at a pressure much higher than the vapor pressure, so that the fluid is kept

as a liquid state. At the phase equilibrium any pressure drop flashes off the lightest components hence creating varying volumes of gas. Such conditions are met when operating a coalescer assembly comprising of a pre-filter and a coalescer. The increasing pressure drop across the pre-filter, due to its progressive fouling over time, may create increasingly large volumes of gas that can flow to the downstream coalescer.

Particulate pre-filters typically generate less than 0.1 bar clean differential pressure (DP), but they can be typically operated up to 2 bar DP before change-out, where corresponding gas volumes could be significant. Figure 9 illustrates gas volumes generated as a function of DP, based on a Middle East case. Calculations are based on Peng-Robinson's equation.

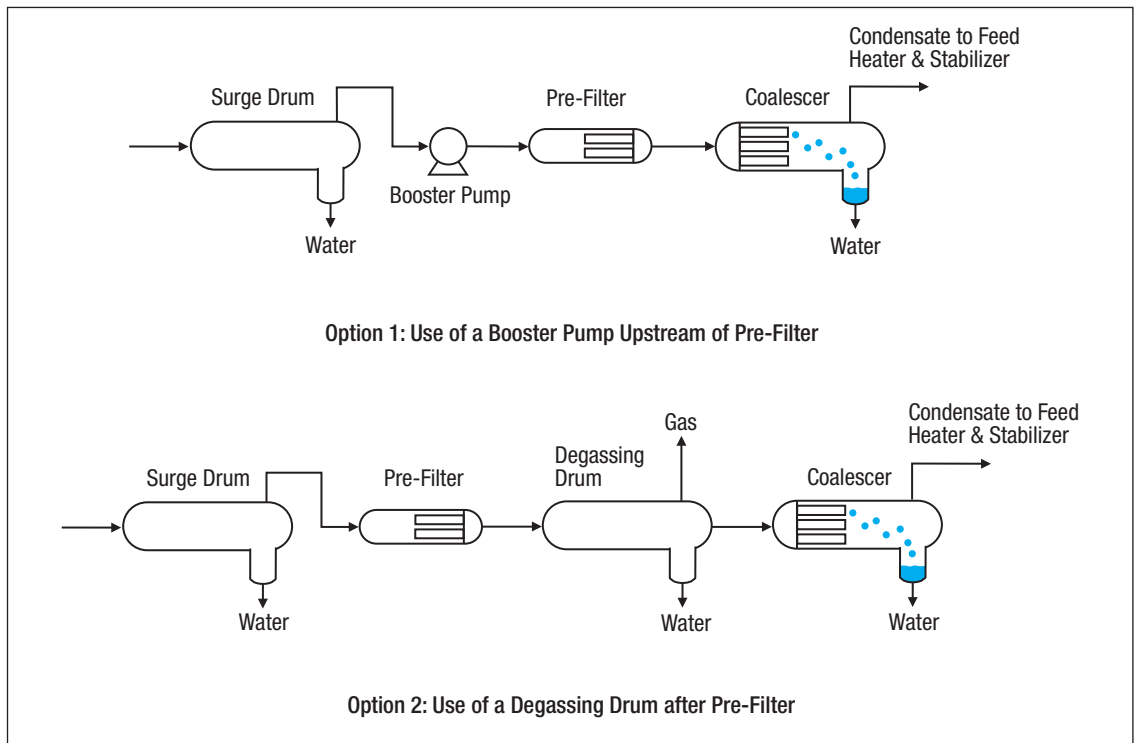
Figure 9:
Simulated gas volumes generated at various DP across pre-filter and stream composition



Degassing should be avoided, or flash gas should be removed from the condensate before entering the coalescer. Different arrangements can be

considered to avoid gas from entering the coalescer, as illustrated in Figure 10.

Figure 10:
Possible arrangements to avoid gas from entering the coalescer



One possible arrangement considers a booster pump that is installed downstream of the Surge Drum and upstream of the pre-filter to overcome the pressure drop generated by the increasingly fouled pre-filter. Ideally the pump should deliver a discharge pressure that is 3 bar higher. Elevation between the pump and the Surge Drum should be evaluated with care so that the Net Pressure Suction Head (NPSH) is high enough. Another possible arrangement consists

of incorporating a degassing vessel between the pre-filter and the coalescer, so that gas generated across the pre-filter is separated before the condensate enters the coalescer. The sizing of the degassing drum is dependent on the residence time that is necessary to eliminate the gas. A possible alternative to this arrangement is to have the pre-filter located upstream of the Surge Drum, so that savings are made on the additional degassing drum.

Commercial Case Histories

Crew Energy Inc., Septimus Gas Plant, Canada

This plant is located in British Columbia and was built in 2009. It was designed for a gas flow rate of 50 MMSCFD and currently produces and processes approximately 38 MMSCFD of gas and 100 m³/day (630 BPD) of condensate. The LPG and condensate are recovered through a conventional refrigeration process (complete with a de-ethanizer). The LPG and condensate are split in the de-butanizer and both products are sent to onsite storage for future sale. After the Inlet Separator, the condensate flows to the condensate pumps then onto the surge vessel prior to entering the de-ethanizer. The de-ethanizer receives raw condensate from the inlet separator as well as hydrocarbon liquids from the low temperature separator in the refrigeration skid.

Quickly after start-up the plant encountered a continuous carryover of water that caused salt deposits inside the de-ethanizer column and the reboiler, resulting in excessive plant upsets and loss of product quality due to the reduced heat transfer from the de-ethanizer re-boiler. The plant had to go for a monthly-based maintenance program to clean the internals of the de-ethanizer and the re-boiler of the salt deposits and restore

the heat transfer. This maintenance operation was forcing the plant to shutdown the liquid processing facilities for 12 hours, causing a net loss of production of 50 m³ (315 BBL). The plant evaluated that the combined loss of production and the maintenance costs for cleaning the re-boiler represented an overall annual cost of up to 725,000 USD.

Pall Corporation was consulted to perform on-site pilot trials to quantify the water levels in the condensate and to demonstrate the effectiveness of the coalescer technology in eliminating that water down to a specification of 15 ppmv or below. Field trials showed a great variability in the inlet free water contents, ranging from 28 ppmv to 1190 ppmv over the test period, with an average free water content of 127 ppmv. The coalescer produced a 'clear & bright' looking condensate with free water contents ranging between 2-9 ppmv, while the separated brine had a hazy yellowish appearance. The IFT measured between the non-volatile fraction of the dehydrated condensate and the brine collected from the coalescer outlets exhibited a low value of 9.5 dyne/cm at the operating temperature.

Based on the successful results and field data collected from trials, Pall supplied a coalescer system comprised of duty-standby 8" diameter horizontally-configured 20 micron absolute rated prefilter vessels, followed by a single 12" diameter horizontally-configured coalescer vessel equipped with two 40" long PhaseSep[®] coalescer cartridges. An overview of the coalescer system is shown in Figure 11.

The coalescer system was put online in December 2010. After four months of operation of the coalescer system the plant did not report any salt carry-over issue.

Figure 11: Overview of the Pall coalescer assembly with coalescer (forefront) and duty-standby pre-filters (background)



Figure 12:
Retrofit module
internals to fit inside
existing cartridge
coalescer



Offshore gas production platform, Australia

This platform has a production capacity of 1815 MMSCFD. After the Production Separator, the condensate flows to Condensate Coolers, onto the Primary Condensate/water Separator, then onto Condensate Filters and Condensate Coalescers for dehydration, prior to the export line where the condensate is exported with the dehydrated gas.

Originally Condensate Coalescers were equipped with conventional coalescer cartridges. The Condensate Coalescer is horizontally configured. The plant reported that coalescers were not meeting the required water content specification, in fact around 1000 ppm water were remaining downstream of the coalescers. The reasons for the very low performance of the coalescers were expected to be on the one hand, a very stable condensate/water emulsion, characterised by a low IFT of 13 dyne/cm simulated from actual produced water samples with pentane because of the presence of corrosion inhibitor added at the wellheads, on the other hand the coalescers were subject to disarming in the presence of the corrosion inhibitor that was causing the coalescer performance to drop over time and required the coalescer cartridges to be replaced on a monthly basis.

In 1999 as part of a debottleneck project the plant decided to upgrade the Condensate Coalescers on one train. Pall's PhaseSep® coalescers were selected and custom-made bolt-in module internals were designed and manufactured to fit the cartridges inside the existing coalescer vessel without any modification on that vessel. The retrofit module internals are shown on Figure 12. Each retrofit module holds 31 off 20" long coalescer cartridges, to handle a total flow rate of 4134 m³/day (26,000 BPD) at 113 bar.

The Condensate Filters were upgraded as well with 10 micron absolute rated Pall Coreless Profile® filter technology, in order to protect the coalescer against solid particles. Upgraded filters and coalescers were sized to handle inlet free water contents of 1000 ppmv and 2000 ppmv as peak conditions, and to produce condensate with a free water content specification of <100 ppmv.

The upgraded Condensate Coalescer has been performing according to the plant's expectations since 2001. Pre-filter cartridges are currently replaced each three months on average. In 2005 all remaining trains were upgraded using the same Pall PhaseSep coalescer technology.

Conclusions

Condensate dehydration is often made difficult due to the presence of stable emulsions that cause conventional condensate/water separation technologies to be ineffective in meeting quality specifications.

Improving the performance of the condensate dehydration step requires a good understanding

of the contaminants present. Analytical as well as field methods are available in the industry for diagnosing contaminant issues. The stability of the emulsion should also be assessed with care during the selection of the separation technology, to ensure that the technology is capable of separating potentially stable emulsions. To this end, the presence of corrosion inhibitors and

hydrate inhibitors should be well characterized since they are the main contributors to the emulsion stability.

Hydrocarbon condensate separated from natural gas carries varying concentrations of impurities in the form of water, salts and solids. The effects of these contaminants can be severe and costly to the condensate stabilization plant and the export pipeline. Problems that have been encountered include off-spec condensate and final products, compromised plant performance and maintenance issues including corrosion and fouling of equipment by solid deposits.

Improving the condensate dehydration or 'dewatering' step also requires a good understanding of the features and the limitations of the separation technologies that are used to eliminate contaminants. The selection of the appropriate technology should be evaluated with care to ensure that it is capable of separating potentially stable emulsions.

Evaluation should consider its maintainability, running cost and investment cost.

Results from field surveys highlight that water carryover from existing separators (gravity separators, mesh pads and glass cartridge coalescers) can be significant. The use of high efficiency polymeric cartridge coalescers, however, was found to be an effective and economical way to improve the condensate dehydration step due to their ability to separate difficult emulsions. This technology features several advantages including that no chemicals or utilities are needed to aid the separation. The implementation of cartridge coalescers involves certain design considerations relating to the presence of solid impurities and the potential for degassing. Commercial experience at condensate plants in Canada and Australia show that the use of this advanced coalescer cartridge technology has been proven as an effective and economical way to optimize hydrocarbon condensate stabilization plants.

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