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# Design Basis of a Compact Production System for Minimum Size and Maximum Flexibility

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**ABSTRACT**

Over the last decade the oil and gas industry has undergone a significant change in the nature of its producing operations. There has been a continuous drive to reduce capital costs, improve the bottom line for existing operations, and to convert or shift marginal fields to clearly viable developments.

Significant effort has been placed on increasing production efficiencies. The majority of the high profile efforts have centred round drilling technologies, and in comparison new production separation technologies have lagged behind. Literature provides numerous case studies and examples on the “debottlenecking” of process separation equipment as a result of revised reservoir information, or enhanced production through improved drilling technologies. This work illustrates the shortcomings of existing conventional equipment, it is unplanned and reactive, and leads to an expensive piecewise final solution. The only appropriate approach accepts that process separation equipment needs to be flexible enough to handle a number of different production scenarios, with high turndown capabilities on-line.

Developing appropriate process separation systems has involved a move away from the traditional conservative project execution strategy, where a large engineering company determines economic solutions by performing detailed engineering studies, using information from vendors, and then designing facilities from scratch. Apart from lost experience and work efficiencies, this approach requires significant resource involvement from the oil company.

Today the industry increasingly accepts fit for purpose designs, based on good industry practice and standard equipment designs. They use a facilities driven approach, rather than a reservoir driven approach, and accept flexible state-of-the-art process separation equipment. Oil companies are increasingly favouring equipment vendors to supply complete systems. This is sometimes a single source activity and is often based on trust and perceived project execution competence, as well as the vendor's technology portfolio.

The result of this shift is a more flexible, smaller more compact production system, with lower capital, maintenance and operating costs. Smaller sized equipment leads to faster mobilisation time, in terms of construction and installation.

## INTRODUCTION

Today, oil and gas companies are actively seeking out technology leaders, to take a prime role in the development of new process separation technologies and to fulfil industry needs. This is part of the ongoing rationalisation of the industry to 'farm-out" work previously undertaken in-house. This approach by industry is seen as key in the conversion of marginal fields to economic projects.

Technology leaders, like Krebs Petroleum Technologies, are in a unique position to be able to offer:

- all key technologies in-house;
- a proven track record supplying process packages, incorporating in-house and third party technologies;
- small enough to be responsive to clients on a local basis, but with a global reach and sound commercial backing;
- key personnel with the experience necessary to execute any project.

Technology leaders undertake strategic alliances with suppliers of "conventional" equipment, such as vane packs, three phase separator internals, heat-exchangers, and electrostatic coalescers, to supply equipment in their area of expertise. Technology leaders then leverage the performance of this equipment through the integration of state-of-the-art in-house technologies, resulting in substantial performance improvements.

It is this approach which has lead to the Krebs Petroleum Technologies Compact Production System (CPS) concept. The CPS approach to production facilities design sets a flexible operational standard, using cyclone based technology at the heart of the system. This approach drives down the size and weight of the total package to new levels, with the resultant obvious advantages.

The CPS can be used in a variety of "life of field" applications, and is especially powerful for Early Production Systems (EPS), or Extended Well Test (EWT) packages. Small "life of field" applications are typically developed in a fast track fashion. This lack of data pushes the client towards a facilities driven approach as it is difficult to design a facility around a poorly understood and constantly changing production profile. For EPS/EWT applications a CPS delivers a high degree of flexibility, as production data is limited in quantity and quality.

## FEATURES

Figure 1 is a process flow diagram of the CPS. Total process fluids enter the system and undergo solid/liquid, gas/liquid, and liquid/liquid separation through a series of integrated process modules. Together with heating, polishing, and pumping capabilities, the resultant processed fluids are suitable for export pipeline conditions.

The process modules have been designed to operate "as-is". It is the ability to select specific equipment requirements (or modules), which depends on inlet process conditions, and outlet specifications, that allows maximum resource flexibility and optimisation.

Key features include:

- a completed off-the-shelf design that provides flexible features at low cost, in a timely fashion, with a vendor that does not need major input and supervision from the client;
- leveraging throughput and flexibility of conventional equipment through use of compact high efficiency cyclonic equipment;
- optional additional equipment for dealing with most production scenarios, providing cost and time benefits for complex problems;
- provision of solutions (i.e. the Wellhead DeSander) to problems that operators normally ignore, with a subsequent impact on plant availability and OPEX;
- appropriate use of conventional equipment (i.e. gravity separators) to provide an appropriate system residence time (for minimisation of effects of slugs), and the flexibility to deal with varying inlet bulk phase compositions (i.e. changing from oil to water continuous flows);
- use of standard ISO container dimensions (max 40 ft size) for skids, with major benefits in terms of time and cost for both shipping and installation;
- substantially reduced mobilisation time through minimum piping hookups, and electrical plug and socket connections. Use of serial bus control systems (also known as two wire or digital systems) minimises the size and complexity of cabling between skids

Starting with a standard CPS design basis provides enormous benefits. If the design basis does not match specific client requirements, changing the design to suit is simple, without the need to start from scratch.

The advantages of Krebs proprietary cyclonic equipment on the overall process design is essential. While these technologies appear very simple, they offer the ability to greatly reduce the size of gravity separators for a given duty.

Some other general features are:

- The package will be "fit for purpose";
- The package will be environmentally friendly. Emissions to the environment will be minimised;
- The package will be safe in operation. It will be equipped with an automatic shutdown system and fire and gas system;
- Design and layout of any fired equipment will take into consideration the likely hazardous areas;
- The design will be based on appropriate industry and legislative standards;

 

## DESIGN BASIS

The following design basis is provided for the purposes of providing a quantitative and qualitative illustration. To highlight the CPS capabilities, we will continue our discussion based on an EWT or EPS case study as these will provide some of the most challenging applications. Again for significantly differing throughputs, only a modified design, rather than redesign is required.

Case Study : Fixed Installation or Semi-Submersible Rig

Input Conditions

| | |
|---|---|
| Maximum Total Liquid Rate: | Up to 25,000 BPD |
| Maximum Water Rate: | From 0 to 10,000 BPD |
| Maximum Gas Rate: | 20 to 40 MMscfd at 50% of MAWP. |
| Crude Density: | 20 to 50$^o$ API; |
| Crude Viscosity: | 0.7 - 10 cP |
| Contaminants: | $H_2S$ and $CO_2$ |

Output Product Specification

| | |
|---|---|
| BS&W: | 0.5% to 2.0% |
| RVP: | < 12 psi |
| Effluent Oil in Water: | < 25 ppm |

These specifications reflect a very wide range of operating conditions, all of which have a significant impact on final equipment size and selection. The CPS must be able to process a total liquids flowrate of up to 25,000 BPD, and the water production component of this may be negligible, or up to 10,000 BPD. The CPS must handle extremely variable crude types, and gas production levels, and finally the system must handle all this on-line, with no down time.

Figure 2 shows the main CPS process equipment modules required for this application.

KEY TECHNOLOGIES

1. Solids Handling-Wellhead DeSander
2. First Stage Separation-Auger
3. Second Stage Separation-Coalescer
4. Water Treatment Package-DeOiler/DeWaterer

UTILITIES

1. Heat Exchangers
2. Pumps/DeGasser
3. Flare KO Drum

The optional equipment may include:

- Export Metering
- Chemical Injection
- Control Room & Laboratory
- Gas and/or Crude Flare Booms
- Electrical Generators

Figure 3 shows the integrated CPS system. It includes eight separate 40 ft container modules (including an interconnecting pipework module), with a total operating weight of 450,000 lbs. The skid structure will be modular for ease of transportation and installation, as well as providing flexibility in terms of expansion and reconfiguration. A key feature is that all skids will be designed in accordance with the ISO requirements for standard containers with respect to dimensions and lifting attachments. The result is major cost savings during mobilization/demobilization.

## KEY TECHNOLOGIES

### Solids Handling

Many operational personnel still see sand production as an intractable problem, to be handled in an unsophisticated costly manner. Back in the office, many professional engineers either do not know about the problem, or deny it exists. As a result, sand production in the oil and gas industry is an area where significant operating cost reductions are still to be realised. Notwithstanding costly sand reducing measures downhole, at the additional significant expense of reduced, or in some cases lost, production, topsides solids handling is a superior, cost effective alternative.

Sand production causes many problems that propagate throughout the whole production process. They include:

- erosion of choke manifolds, pipework, valves, instrumentation, and vessels.
- filling separators with sand resulting in decreased residence times and poor separation efficiencies.
- plugging equipment, like heat exchangers, causing unscheduled downtime.
- sand in produced water streams has a detrimental effect on water clean up efficiencies.
- installation of inappropriate sand jetting systems adds to the cost of the separator and simply shifts the sand removal problem to another location, while causing vessel erosion.
- the presence of sand in any separator promotes corrosion.

#### *Wellhead DeSander*

The Wellhead DeSander is the CPS solution to sand production. The Wellhead DeSander removes sand upstream of the choke, avoiding the many problems that sand production can cause. The technology is simple, robust, effective, with negligible operating costs. The resultant solids are clean and easy to handle.

The (additional) design specifications for the Wellhead DeSander are:

 

Operating Pressure: 40 to 300 barg;
Operating Temperature: 5 to 100$^{o}$C;
Solids Removal Cut Size: < 75 micron

Although relatively new, the Wellhead DeSander is a well proven technology, used by many of the industry's significant companies including Shell, BP, Statoil, Amoco, Halliburton, and Schlumberger to name a few.

### *Operation & Control*

The Wellhead DeSander typically comprises of a single cyclone insert housed inside a vessel operating at the appropriate wellhead design pressure. The cyclone insert is specifically designed for each application using Krebs in-house validated computer simulations.

Wellstream fluids enter the cyclone tangential inlet, which forces the mixture to spin, and causes the gas to disengage quickly. Both gas and liquids migrate towards the centre of the cyclone, as a reduction in cyclone diameter accelerates the fluid generating strong centrifugal forces. The gas and liquid flow then reverses and moves upward towards the overflow vortex finder. Solids are separated from the gas and liquid, forced towards the cyclone wall, and travel down the length of the conical section of the cyclone in a spiral pattern towards the solids outlet.

Full wellstream fluids pass through the Wellhead DeSander to the downstream separation process. Sand and other solids which are removed collect into an Accumulator, located on the underflow of the Wellhead DeSander for additional handling. The Accumulator vessel is periodically isolated from the Wellhead DeSander, de-pressured to flare, and the sand and solids are flushed out to the cleaning and/or disposal system using plant or produced water. Before being re-opened to the Wellhead DeSander, the Accumulator is re-filled with clean water to prevent hydrocarbons passing down into the Accumulator, and ensures the solids flush is clean.

While the Accumulator is being purged, the Wellhead DeSander remains on-line and has sufficient hold-up volume to collect solids separated while the Accumulator is off-line.

The Wellhead DeSander requires no control system, unless the Accumulator purging cycle is required to be automatic. This can be easily handled. The simplicity of the cyclone design means that cost effective systems can be provided for very high design pressures including well shut-ins.

### *Collection & Disposal*

Solids handling and disposal in the oil & gas industry can be broken down into five main steps: Separate, Collect, Clean, Dewater, and Haulage.

- <u>Separate</u>: The solids must first be removed from the well or process fluid stream. This is accomplished by the Wellhead DeSander.

- Collect: To facilitate a simple system design, all collected or removed solids must be gathered into one central location. In this case, it is collected in the accumulator vessel.
- Clean: In many cases the sand may require cleaning for oil or chemical removal, prior to further handling. The Krebs SandWash System™ can be employed as an optional modular add-on to remove the contaminants.
- Dewater: The total volume of sand slurry to be disposed can be greatly reduced by a dewatering step. The Krebs SandBagger™ is used for this purpose, and will remove water to produce a sand "cake" with less than 10% water. More comprehensive or controlled systems may require a filter press or screw classifier for water removal.
- Haulage: Haulage includes removal, hauling, and disposal of the solids. The design of the haulage system will be dependent upon the location (land based or offshore) and disposal requirements (i.e. disposal well, overboard, landfill, road surfacing, etc.).

These five steps are illustrated in the Decision Diagram shown in figure 4. A specific procedure for most solids disposal systems can be generated from this generic diagram.

## First Stage Separation

A key feature of the CPS First Stage Separation system is the use of Krebs cyclonic equipment upstream and downstream of the gravity based First Stage Separator. This results in:

- up to 300% increase in throughput for a given size gravity separator, through the use of a Krebs Auger gas liquid separator upstream;
- a significant reduction in size, when designing a new separator, for a given throughput;
- major reduction in the water residence time required, based on the use of preseparation hydrocyclones downstream of the First Stage Separator;
- high level of liquids removal through the use proprietary vessel internals;
- enhanced liquid liquid separation due to reduction in required gas capacity, resulting in lower inlet velocities, and therefore lower droplet break-up potential;

The (additional) design specifications for the First Stage Separation system are:

| | |
|---|---|
| Operating Pressure: | 20 to 40 barg; |
| Operating Temperature: | 60 to 100$^{o}$C; |

### *Auger Gas Liquid Separator*

The Auger Separator, shown in figure 5, has the following features:

- no moving parts;
- requires no sophisticated control;
- it has a turndown in excess of 5 to 1 for most applications. As the installation of the Auger is typically targeted at increasing the effective gas capacity of the system by 50 to 200%, this turndown is well in excess of that required;
- for CPS' that are likely to be used on a number of fields, it is possible to reconfigure the Auger for each specific application;
- it is extremely compact;

- due to the high (2000) g forces generated within the Auger, the gas/liquid and liquid/liquid separation within the First Stage Separator is improved;

Although relatively new, the Auger is a well proven technology, used by Arco Alaska for over three years and recently embraced by other operators including BP and Oryx.

Lets address the issues applicable to the design considerations of a conventional three phase separator, and progress to a better integrated solution, using cyclonic technology.

CONVENTIONAL

*Primary Gas/Liquid Separation*

The sizing of a conventional separator is based on residence time assumptions, which typically run in the 5 to 10 minutes range for moderate API crudes, and up to 20 minutes for heavy (20 API) crudes.

Inlet nozzle sizes are determined by a number of parameters. Firstly, the inlet nozzle size is based on a calculation of the maximum inlet momentum ($\rho v^2$). Each vendor has a maximum value, based on their inlet momentum breaker design. Generally, to achieve the appropriate momentum value, the inlet to the separator is 2" to 6" larger in diameter than the inlet pipework. A typical inlet momentum breaker is a simple plate baffle. In the case of central inlet separators, it may be followed by a box filled will pall rings. The main function of the inlet device is to minimise foam formation and remixing of the different phases due to agitation at the inlet.

If the CPS is to be installed on a moving platform (semi-submersible, TLP or ship-shaped facility), then the effect of motion on the First Stage Separator will also need to considered. Motion effects the performance of separators in a number of ways:

- the various phases are mixed together due to surging, and wave action etc.,
- when the separator reaches it's maximum inclination, the spirit level effect reduces the gas void space available in the "lower" end of the vessel. This in turn temporarily increases the gas velocity, reducing the effective gas void space and resulting in possible significant liquid carryover.

*Secondary Gas/Liquid Separation*

To ensure that liquid droplets fall out in the separator, a maximum superficial gas velocity is normally calculated. This velocity then determines the minimum gas space cross sectional area. The height of additional internal coalescing devices can sometimes also be the determining factor for the size of the gas void space in the separator.

*Tertiary Gas/Liquid Separation*

A liquid coalescing device is used on the gas outlet to provide final removal of liquid droplets. This coalescing device can be a wire mesh, vane pack or multi cyclones. Vane packs, whilst more expensive, have a higher separation efficiency and higher turndown. Hence, they are the preferred device when gas flowrates are significant.

ENHANCEMENTS

The specific benefits of installing the Auger upstream of the First Stage Separator include:

- reduced First Stage Separator inlet nozzle size; By removing at least 50% (and up to 80%) of the gas, the effect on the inlet momentum can be dramatic. For example, if the gas void fraction to the First Stage Separator is 75% and the Auger removes 60% of the gas, the inlet momentum would be reduced by approximately 45% and a subsequent reduction in the size of the inlet nozzle;
- reduced turbulence at First Stage Separator primary separation section due to reduced gas loading providing enhanced liquid/liquid separation;
- reduced First Stage Separator diameter due to reduced gas velocities in the Secondary separation zone, and due to the elimination of internal coalescing devices;
- improved gas/liquid separation due to coalescence;
- reduced gas outlet nozzle size;

Other features of the CPS design enable the residence time required for oil water separation in the First Stage Separator to be minimised:

- the produced water treatment system consists of two deoiling hydrocyclones in series. This allows the oil in water specification for the First Stage Separator to be relaxed from 2,000 ppm to over 5%, which in turn allows the water phase residence time to be reduced;
- the First Stage Separator Heat Exchanger increases the temperature of the feed to the First Stage Separator, reducing the viscosity of the water phase and, more importantly, the oil phase. This improves the oil/water separation;

If significant motion induced mixing effects are a problem, a split flow design could be used. A central top inlet would be fitted to the separator, together with a horizontal heave plate running the length of the vessel. Gas/liquid separation occurs in the section above the heave plate. There are two gas outlets, one at each end. The gas velocities in each direction are effectively halved and hence smaller coalescing devices can be used. Internals design must take into account the nature of the crude. Structured packing would generally only be used on crudes above 30 API gravity.

One way flappers can also be fitted at each end of the heave plate to allow liquid to flow underneath the plate, but not return above the plate. The liquid phases then flow to the middle of the vessel, where oil is taken off from the underside of the heave plate and water is taken off at the bottom of the vessel. Structured packing can be installed below the heave plate to minimise movement and mixing of the liquid phases. The liquid velocities are halved, which means that the velocities are low enough for structured packing to have some coalescence effect.

### *Operation & Control*

Multiphase fluid enters axially at the base of the Auger, and is forced to rotate by the unique stationary double helical vanes. The pitch of the vanes controls the proportion of the inlet axial velocity which is converted to a tangential velocity component. The higher the tangential velocity, the higher the radial acceleration field it creates, and thus the higher the radial rate at which the liquid flows to the outer wall due to a difference in phase density. A fraction of the gas passes through ports located on the inner Auger wall, and is removed via cross over tubing.

The liquid and the remainder of the gas continue and exit axially at the top of the Auger. The geometry of the liquid and gas outlets will depend on the application. The largest phase fraction will be allowed to exit at the large diameter outlet at the top of the Auger, while the smaller phase component will be taken off via an elbow. This ensures that the pressure drop across the separator is minimised.

The Auger can be controlled in one of two ways:

- The pressure differential ratio is proportional to the split ratio, i.e. the percentage of gas in the feed stream removed in the gas outlet. Hence, by controlling the pressure differential ratio, the split ratio is kept constant;
- By controlling the gas outlet flowrate, using a standard flowmeter (e.g. vortex, turbine or orifice plate).

The control method chosen depends on the duty of the Auger and the expected operating characteristics. In fields where the most wells have a similar gas void fraction, a split ratio control system in used. In other locations, gas outlet flow control may be used.

In most applications, the Auger is operated well within its capabilities. This reduces the criticality of the control system. In a typical Auger application, the gas void fraction is 70% to 80% and the Auger is used to remove 50% of the gas, thereby greatly reducing the size of the downstream gravity production separator. Hence, there is a wide gap between the operating point of the Auger and the point at which it's performance, in terms of liquid carryover, starts to decline.

The standard configuration of the Auger has the gas outlet being directed to the First Stage Separator pressure control valve and the liquid outlet being directed to the production separator inlet. Hence both outlets see a similar pressure, any difference arising from the pressure drop across the First Stage Separator. The Auger normally exhibits a higher pressure drop on the liquid outlet side and hence a control valve is needed on the Auger gas outlet. This control valve is the only control device on the Auger. There are no other control valves - nor are there any pressure or level switches required. Hence, the Auger has no significant impact on the control requirements for the First Stage Separator. Typically, standard level control, pressure control and interface level control systems would be used. Secondary safety systems, such as a high high pressure switch and high high and low low level switches, would be installed as appropriate.

 

## Second Stage Separation

A key feature of the CPS Second Stage Separation system is the use of the Krebs Cyclonic Coalescer upstream of the gravity based Second Stage Separator.

The (additional) design specifications for the Second Stage Separation system are:

| | |
|---|---|
| Maximum Feed BS&W: | 20% |
| Maximum Gas Rate: | 7MMscfd at 50% of MAWP; |
| Operating Pressure: | 1 to 5 barg; |
| Operating Temperature: | 80 to 100$^{o}$C; |

### *Coalescing Cyclone*

The Cyclonic Coalescer provides the potential to increase droplet size by a factor of 50% to 400%. It increases the effective droplet size by:

- the cyclonic action of the Coalescer itself promotes a high degree of coalescence;
- greatly reducing the pressure drop across the upstream level control valve, reducing the emulsification that occurs across the valve - it uses the pressure energy available in a constructive rather than destructive way;

Given that residence time is proportional to droplet size squared, this translates into the potential for a large increase in the capacity or performance of separators.

In quantitative terms, this results in:

- 50% increase in throughput for a given separator size, and outlet specification;
- a significant reduction in size, when designing a new separator, for a given throughput;
- 50 to 90% reduction in the Second Stage Separator outlet BS&W. This provides the potential to dispense with a downstream Electrostatic Coalescer;

As with most cyclonic equipment, the Cyclonic Coalescer is extremely compact. This is shown clearly in figure 6.

The gas void fraction to the Second Stage Separator is normally relatively low. Hence, gas handling capacity is not normally limiting. The key sizing parameter for the Second Stage Separator is typically the residence time needed to effect the required liquid/liquid separation.

For EWT's and EPS', the crude produced will often be sent by tanker straight to a refinery and hence a refinery BS&W specification (i.e. 0.5% BS&W) will apply. This is difficult to achieve without an Electrostatic Coalescer. For heavier crudes a typical pipeline specification is 2% because there is normally a tank farm at the other end of the pipeline where final decanting of water takes place. Many EWT's and EPS' produce into a dedicated tanker or tankage. This provides an opportunity for final decanting of water, which means that the BS&W specification could be relaxed to 2% or even greater.

Historically, the liquid/liquid separation has been achieved purely by oil and water droplets settling under gravity through the opposite phase. The behaviour of the smaller droplets, that defines the ultimate performance of the separator, is described by Stokes Law.

Figure 7 shows the effect of changes in crude gravity and temperature (and hence viscosity) on settling velocities in a separator. For the 33 API case, it can be seen that a 200 µm water droplet that starts at the top of the liquid phases at the separator inlet would take 18 minutes to reach the water outlet if the liquid phase was 1m deep. For a 40 API crude, the settling time would be 3.7 minutes per metre.

Droplet size is one of the key parameters in determining the residence time required in conventional three phase separators. It has long been recognised that any droplet growth that can be effected will result in a dramatic improvement in the performance of downstream gravity separators.

Coalescence technologies available in the market today falls under three main areas:

- *injection of demulsifier*; This is the main approach used to date to promote droplet growth;
- *gentle agitation*; typically provided through the use of long pipelines. However, this is not a space effective approach, and is really just a perceived benefit of having flowlines running to a central production facility onshore. In reality, the coalescence benefit is offset by the cooling that takes place. This is not feasible offshore. Unsuccessful attempts have been made to provide the same effect in coils of pipe;
- *inline electrostatic fields*; These devices require a power input and sophisticated transformers and electrical equipment. The reliability of these devices have been found to be poor due to shorting of the plates;

Up-to-date actual field trial information of the Cyclonic Coalescer provide a dramatic illustration of this performance improvement. Figure 8 shows that 60% of the water drops out without the use of the Cyclonic Coalescer (this effectively represents the free water). With the Cyclonic Coalescer, 80% of the water drops out. The additional water removed represents emulsified water that does not separate under gravity. This in turn translates to more than a halving of the Second Stage Separator outlet BS&W.

Similarly in Figure 9, the water dropout increases from 70% to 90%, which translates to a 67% reduction in the outlet BS&W. In addition, most of the separation takes place in 1½ minutes with the Coalescer installed, versus 2½ minutes without the Coalescer. This translates to a 40% reduction in residence time required, whilst at the same time providing a higher level of separation.

 

The second enhancement to the liquid/liquid separation in the Second Stage Separator is obtained through increasing the Second Stage Separator feed temperature, using the Second Stage Heat Exchanger. As the crudes get heavier, the effective separation performance of the system will obviously decrease. At a certain point, it will be necessary to supplement the performance of the Second Stage Separator with an Electrostatic Coalescer.

For medium gravity crudes, an electrostatic grid may be retrofitted in the Second Stage Separator, and an additional vessel would be installed underneath the Second Stage Separator. The Second Stage Separator vessel would then carry out the functions of gas removal and initial coalescence. The additional vessel would provide the necessary residence time for the coalesced water droplets to be separated. Note that the additional vessel would have to be installed underneath the Second Stage Separator as the fluids would gravity feed from the Second Stage Separator to the additional vessel.

For heavy crudes, the Second Stage Separator would be used as a two phase separator and an Electrostatic Coalescer would be installed downstream of the Second Stage Separator. This option would provide the highest flexibility in terms of performance. The system configurations envisaged can be summarised in figure 10. These are conservative configurations, and as more field data is collected, the crude gravity shown to be treatable by each configuration should decrease.

The RVP specification is met by heating the crude using the Second Stage Separator Heat Exchanger to flash off the light ends in the Second Stage Separator. The temperature required to meet the RVP specification is dependent on the composition of the crude as it enters the Second Stage Separator (the higher the pressure, the higher the temperature required).

#### *Operation & Control*

The Cyclonic Coalescer has a single inlet and a single outlet, and requires no control system. In most applications, it has a turndown in excess of four to one with a gradual decrease in performance below that point. At flowrates below this point, the increased residence time in the gravity separators upstream and downstream of the Cyclonic Coalescer is sufficient to meet the required performance without the assistance of the Cyclonic Coalescer. If this is not the case, a Krebs Packaged Active Cyclone Systems (PACS) configuration can be adopted.

Control of the Second Stage Separator is unaffected by the Cyclonic Coalescer. Typically, standard level control, pressure control and interface level control systems would be used. Secondary safety systems, such as a high high pressure switch and high high and low low level switches, would be installed as appropriate.

### Produced Water Treatment

There are numerous technologies applicable for produced water treatment, but none has been as successful in the last 10 years as the liquid liquid hydrocyclone.

### *Liquid Liquid Hydrocyclones*

Krebs personnel have the most extensive hydrocyclone track record in the world. A continuous product development strategy has resulted in the Krebs L15 DeOiling hydrocyclone, which is the most efficient hydrocyclone available. In addition, the L15 provides the highest throughput available for a given vessel size.

The hydrocyclones also incorporate the unique Krebs PACS design, which is a significant step forward for hydrocyclone systems. PACS allows groups of hydrocyclone liners to be shut-off using valves external to the vessel, providing a major increase in the turndown of the system. PACS eliminates the need to enter the vessel (as it is not necessary to change out blank liners) for operability purposes. The PACS system is installed throughout the world and has been proven through years of service. It does not rely on any moving parts within the pressure vessel, nor does it rely on small flow paths that may be easily blocked. Conventional hydrocyclone packaging returning turndowns of 2-3 to 1, can be enhanced to 30-40 to 1, on-line, with a single PACS vessel.

The produced water from the First Stage Separator is fed to the Produced Water Treatment Skid. The two stage hydrocyclone system provides the maximum flexibility in terms of inlet concentrations that can be treated. It also provides a lower outlet concentration than a single stage unit. Preseparator and DeOiling hydrocyclones are delivered as a PACS configuration to maximise on-line turndown.

The produced water from the Second Stage Separator is fed to the Second Stage hydrocyclones. In some instances the operating pressure in the Second Stage Separator will be too low to feed the Second Stage hydrocyclones directly. Here a Second Stage Hydrocyclone Pump will be used to boost the pressure to approximately 8 barg. A progressive cavity pump will be used, due to their low shear characteristics, and the low flowrates expected. If the First Stage Separator operates at a pressure of less than 24 barg, it is feasible to pump the water from the Second Stage Separator back to the First Stage Separator, for treatment by the First Stage Separator hydrocyclones.

Downstream of the hydrocyclones, the Degassing Vessel provides the final polishing, as well as removing gas evolved due to a pressure drop from the First Stage Separator. The amount of oil to be removed in the Degasser is typically small. Hence, the Degasser will have a flooded weir with a number of v-notches. The normal operating level in the Degasser is below the v-notches. On a periodic basis, the level in the Degasser is raised and the oil flows through the notches into the oil compartment. The oil (and associated water) is then pumped to the Second Stage Separator. This provides the most efficient method of collection for the oil. The oil skimming process is automated and controlled by the CPS control system.

For moving platforms, the Degasser would be fitted with structured packing to minimise mixing. For more difficult applications (e.g. low operating temperature, high crude density or low outlet specification), the first option to improve the performance of the Produced

 

Water Treatment system is to sparge additional gas into the feed of the Degasser. This additional gas provides an enhanced gas flotation effect. For particularly low outlet specifications, filter / coalescers, walnut shell filters and other conventional methods of treatment can all be used as appropriate.

Filter / Coalescers are better suited to light crudes as heavy crudes are found to blind the filter elements. Also, the OPEX of filter / coalescers is high due to the cost of replacing the filter elements, but the CAPEX required is low. Walnut / Shell Filters are relatively complex due to the backwashing system, which includes a high number of actuated valves. Hence, they are expensive for small flowrate systems, but they are less affected by solids and heavier crudes than other tertiary treatments.

#### *Operation & Control*

The flowrate through the First Stage Separator DeOiler hydrocyclones is controlled by the First Stage Separator interface level control valve. The reject from the First Stage Separator DeOiling hydrocyclones is controlled using a conventional pressure differential ratio control system. Control of the throughput of the Second Stage Separator DeOiling hydrocyclones is carried out using the Second Stage Separator interface level control valve, which is situated downstream of the hydrocyclones.

In cases where the feed pressure from the Second Stage Separator is less than 2 bar, the feed pressure to the hydrocyclones would be increased through the use of low shear pumps. Typically, progressive cavity pumps are the most cost means of achieving this end for flowrates under 10,000 BPD. Above this flowrate, centrifugal pumps, if correctly selected and operated, are found to exhibit the low shear characteristics required.

For pumped systems, the controlling element may be a control valve on the recycle or a variable speed drive on the pump (in the case of progressive cavity pumps), the recycle system being the most common. As the operating pressure of the Second Stage Separator DeOiling hydrocyclones is low (and constant in the case of pump fed systems), a near to constant pressure differential ratio can be maintained manually. A simple globe valve is installed on the reject line. Guidelines are provided to the operator as to the optimal setting. In most situations, the hydrocyclones will operate satisfactorily with this hand control valves left wide open. The control system employed for the tertiary treatment will depend on the technology chosen.

## UTILITIES

Site specific requirements can have a significant effect on the utility requirements. Main items however will include the following.

### Base Case

#### *Heat Exchangers*

The First Stage and Second Stage Heat Exchangers, together with the Export Cooler, are mounted on the Heat Exchanger Skid. The heating medium for the heat exchangers is 150# steam. In some instances this means that a package steam generator is required.

The cheapest fuel for the steam generator is most likely to be offgas from the First Stage Separator, assuming that surplus gas is produced.

The CPS design assumes there is no waste heat recovery. However, if the heating duty is high and the temperature profiles match correctly, then a Cross Exchanger could be provided. This Cross Exchanger would take the hot crude from the Second Stage Separator to heat up the feed to the First Stage Separator. This would reduce the duty of the various exchangers and may even render some of them unnecessary. It is important to heat heavy crudes as they flow to the First Stage Separator, therefore a heat exchanger is always required here, especially during start-ups.

The cooling system is based on a once through design, relying on a large supply of water. This would typically come from the sea or a nearby river. In the absence of a water supply, a small cooling tower or fin fan coolers would be used.

For the First Stage and Second Stage Heat Exchangers, twisted tube exchangers have been selected. These represent a major step forward in Shell and Tube Heat Exchanger design. The use of twisted tubes has the following major benefits:

- the uneven surface promotes turbulence (and increases heat transfer rates) at the inner surface of the tubes, which is normally the zone of highest thermal resistance;
- due to the turbulent flow on the outside of the tubes, baffles are not required. This in turn results in a much higher thermal efficiency;
- the absence of baffles (with the dead zones that are associated with baffles), as well as the high tube surface turbulence, greatly reduces fouling on the tubes. This provides higher heat transfer for longer periods;

The Export Cooler uses sea water to cool the export crude to 75$^{o}$C, which is the export specification assumed. A titanium plate exchanger has been selected. This provides an extremely compact and durable exchanger. Varying specifications can be easily accommodated as additional area can be simply added to plate exchangers.

All heat exchangers are controlled through a temperature transmitter which measures the product temperature and a control valve controlling the flow of steam to the heat exchanger. Similarly with the Export Cooler, a temperature transmitter measures the product temperature and a control valve controls the flow of cooling water to the heat exchanger.

#### *Main Oil Pumps*

Single stage centrifugal pumps will be utilised for the Main Oil Line pumps. These generally provide the lowest life cycle cost and are robust and reliable, although their flexibility in terms of discharge head is limited. We have provided a standard configuration of 3 x 50% units.

NPSH is an area to be carefully considered with any design of Main Oil Pumps. For systems requiring high discharge heads (over 10 bar), the NPSH required is likely to be 2 to 2.5m. If skid height is restricted to 2.9m, the head loss in the suction pipework will be of the order of 0.5m, which translates into a marginal configuration. One solution if the NPSH available is low is to increase the height of the Second Stage Separator. This may be difficult in the context of the space envelope available. An option is the use progressive cavity pumps, which can have lower NPSH requirements, and for which cavitation does not cause mechanical damage (although it does cause a reduction in capacity).

The final control system will depend on the pumps actually selected but may include flow control, back pressure control and vibration and thermal detection.

#### *Flare System*

A Flare system is designed for any expected emergency situation. The gas from the First Stage Separator, Second Stage Separator and Produced Water Degasser will be collected together in a KO drum to remove any liquid carryover. KO Drums are fitted with a cyclonic coalescing/separating cyclone to remove liquid from the gas stream. The Flare KO Drum is designed as a vertical unit to minimise the plot area required. However, a horizontal design can be used.

The Flare KO Drum pumps the separated liquids back to the Second Stage Separator on a batch basis. The Pumps are progressive cavity pumps to provide maximum flexibility in terms of the operating pressures in the Second Stage Separator. A centrifugal pump cannot cope with significant changes in head developed, which would occur if the operating pressure of the Second Stage Separator was changed during operation. Blowdown valves are provided on the First and Second Stage Separators, these vessels containing the bulk of the inventory. The flare boom itself would normally be outside the scope of the CPS, but can be supplied if required.

There are no controls required for the flare system, apart from the flare ignition system and those required for the blowdown system. The flare ignition system will vary from case to case, but is likely to consist of an ignitor, a pilot and flame detector for the pilot. The blowdown valves would open on a fire signal or by manual intervention by an operator.

### Optional

#### *Export Metering*

The accuracy of metering required will be dependent on the requirements of the client and the local authorities. Typical accuracies may include:

- Fiscal Metering — 0.25% oil, 1.0% gas
- Continuous Allocation or Custody Transfer — 0.5% to 1.0% for oil, 2.0% to 3% gas
- Intermittent Allocation — 5% for oil and gas

- Fuel and Utilities — 2.0% to 4.0% gas
- Flare — 10.0% to 20.0%
- EWT's — 1.0% to 2.0% oil, 2.0% to 4.0% gas
- Reservoir Management — 5.0% to 10%

For fiscal metering, a vortex meter system, complete with prover loop is normally installed, which is an expensive solution. Also, the prover loop in particular requires a large amount of space. Coriolis meters are gaining market share of this application. However, they are again not inexpensive.

For life of field developments, the authorities in some areas are now moving from fiscal metering to custody transfer. This allows dual ultrasonic flow meter systems to be used in place of a the vortex meter system, which in turn results in considerable cost savings. The pressure drop of these systems is very low, no upstream filters are required and being non-intrusive, maintenance work can be carried out without breaking containment. These systems are provided with pressure/temperature compensation to provide an accuracy better than 0.5%. This accuracy can be enhanced by combining the system with any existing tank gauging systems. For many applications, either single or dual ultrasonic flow meters, with pressure and temperature compensation, may be acceptable.

The control systems required for the metering system (e.g. pressure and/or flow) would typically be integral with the metering system. Note that the ultrasonic system requires no control systems.

### *Chemical Injection*

Facilities for the injection of production chemicals will be provided. This would typically include 7 day storage tanks and chemical injection pumps. The chemicals injected may include:

- scale inhibitor;
- corrosion inhibitor;
- anti foam;
- forward demulsifier;
- reverse demulsifier;
- hydrate inhibitor

Suitable injection points will be provided on the various skids.

Control of the dosing pumps can either be manual (using drum gauges and manual stroke and frequency adjustment on the pumps) or automatic, using the control system and more sophisticated injection pumps.

### *Control Room/Laboratory*

In some cases, the site will have an existing laboratory complete with all required instruments. However, if a laboratory is not available on site, it can supplied as part of the

CPS. The laboratory will be suitable for carrying out standard production chemistry tests, including BS&W's, OIW's using standard IR techniques, RVP tests and other simple analysis.

The CPS will be self sufficient in terms of control and shutdown facilities. Hence, a pressurised container, suitable for use in a hazardous area, would be appropriate. The container would house all control panels, fire & gas systems, ESD systems, communications systems (including satellite uplink if required) and ancillary equipment. This container will also house the laboratory, with a central division between the control room and the laboratory.

The container could have the following features:

- The lab container will be certified to DNV 2.7.1 & 2.7.2 if required;
- The container will be fitted with all equipment required for operation in a Zone 1 area, such as gas detection, pressurisation systems, emergency lighting, etc.
- The air intake will be from a safe area. Hence, inlet air duct may need to be run some distance from a safe area to the container;
- The test lab container will be able to utilise power supply ranging from 380 to 480 V 50-60 Hz;
- The air-conditioning system for the control room/laboratory will maintain an internal temperature between $+18^{o}$C and $+23^{o}$C

The control system could have the following features:

- The system will be equipped to interface to the associated platform ESD/PSD status and Fire & Gas system and the Emergency Quick Disconnect system (EQDC) for the tanker offloading system, where applicable;
- The system will be fully re-programmable (via PC) on site and will be sufficiently robust to withstand rough offshore transportation treatment;
- The PSD / ESD system will provide failure detection, alarm handling & recovery;
- The hardware configuration will include as a minimum the following:
- Two PC's with keyboards and screens
- field mounted or control room mounted PLC's;
- I/O cards;
- Two printers;
- The capability for gathering real time data will be provided;
- The system is to have the flexibility to cater for a number of additional facilities, such as satellite data transfer and running third party software packages;

### *Secondary Flare Scrubbers*

Dripping flares is a common undesirable emission. The most likely causes are:

- high gas and/or liquid rates to the Flare KO Drum. This can be due to running the system at over design gas rates or to foaming, which is particularly common on heavy crude systems;
- condensation in the flare line between the Flare KO Drum and the Flare tip.

The primary method of preventing this problem is simply the correct configuration of the flare system, viz. the flare line sloping back to the Flare Drum and the Flare Drum located as close to the flare boom as possible. However, it may not be possible to provide these features, particularly in the case of EWT's.

Hence, as an option, small inline flare scrubbers may be provided immediately upstream of the flare boom to catch any liquids that may be present. Disposal of the condensate collected would be provided on a case by case basis, but may involve heating of the scrubber liquid zone to flash off the condensate, gravity draining the condensate to a suitable location or draining by hand for disposal.

***Electrical Generator***

On locations where a power supply cannot be easily provided, a dedicated genset can be supplied as part of the CPS. In most applications, an internal combustion diesel engine will be used as the driver, but if feasible, a gas engine would be used to cut down on diesel consumption (and hence OPEX). For the relatively small driver size needed for the CPS, there are no dual fired engines available.

## CONCLUSIONS

The design basis for a CPS has been provided for minimum size and maximum flexibility. This state-of-the-art production separation system has been developed by utilizing proven proprietary cyclonic technology, and the best available conventional (including gravity based) technology. By attending to the proper integration, and applying new design considerations, the resultant CPS will enable operators to keep pace with the technological advances in other associated production areas of the oil and gas industry.

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# Compact Production System : PFD

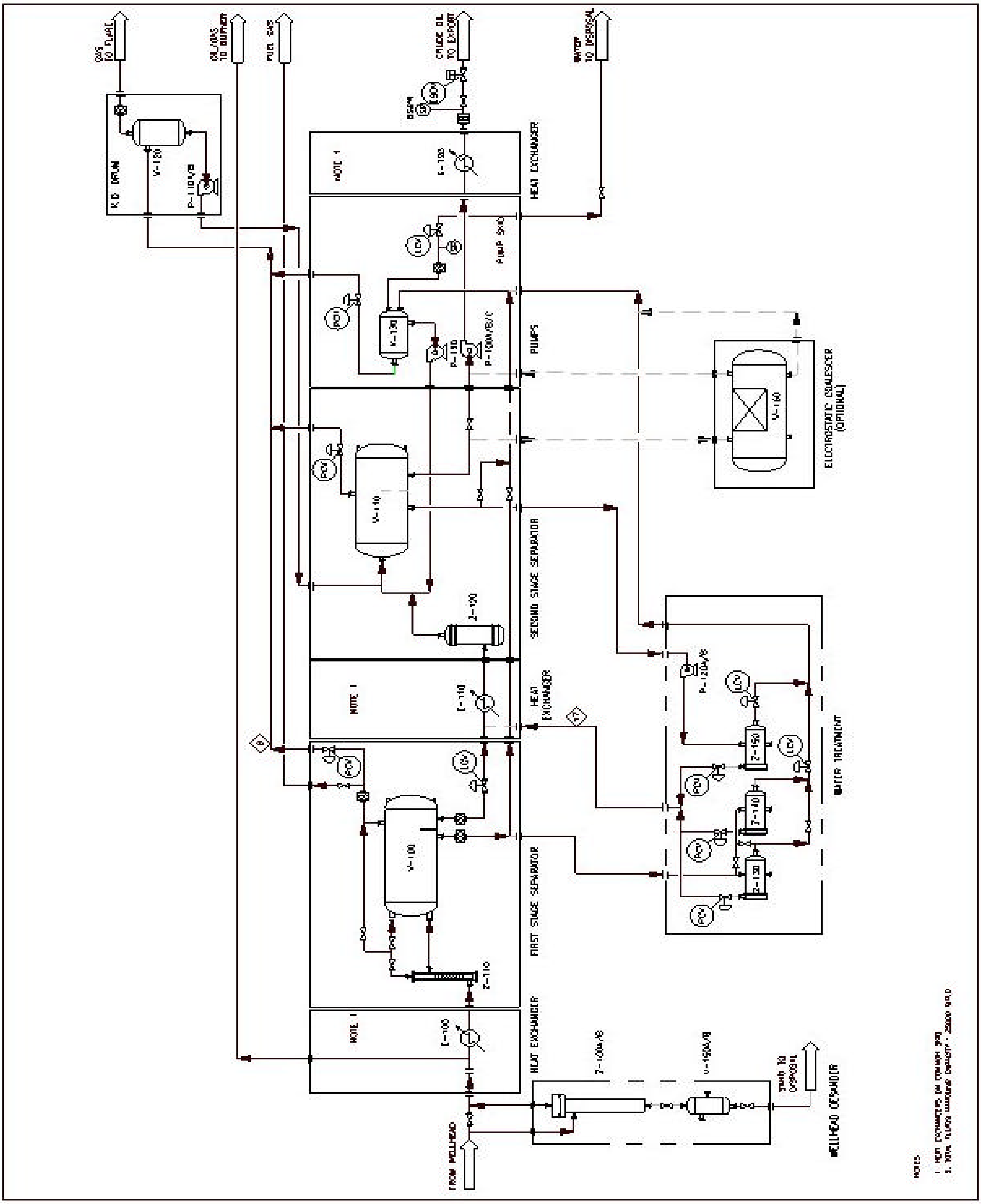

FIGURE 1

## Individual Modules

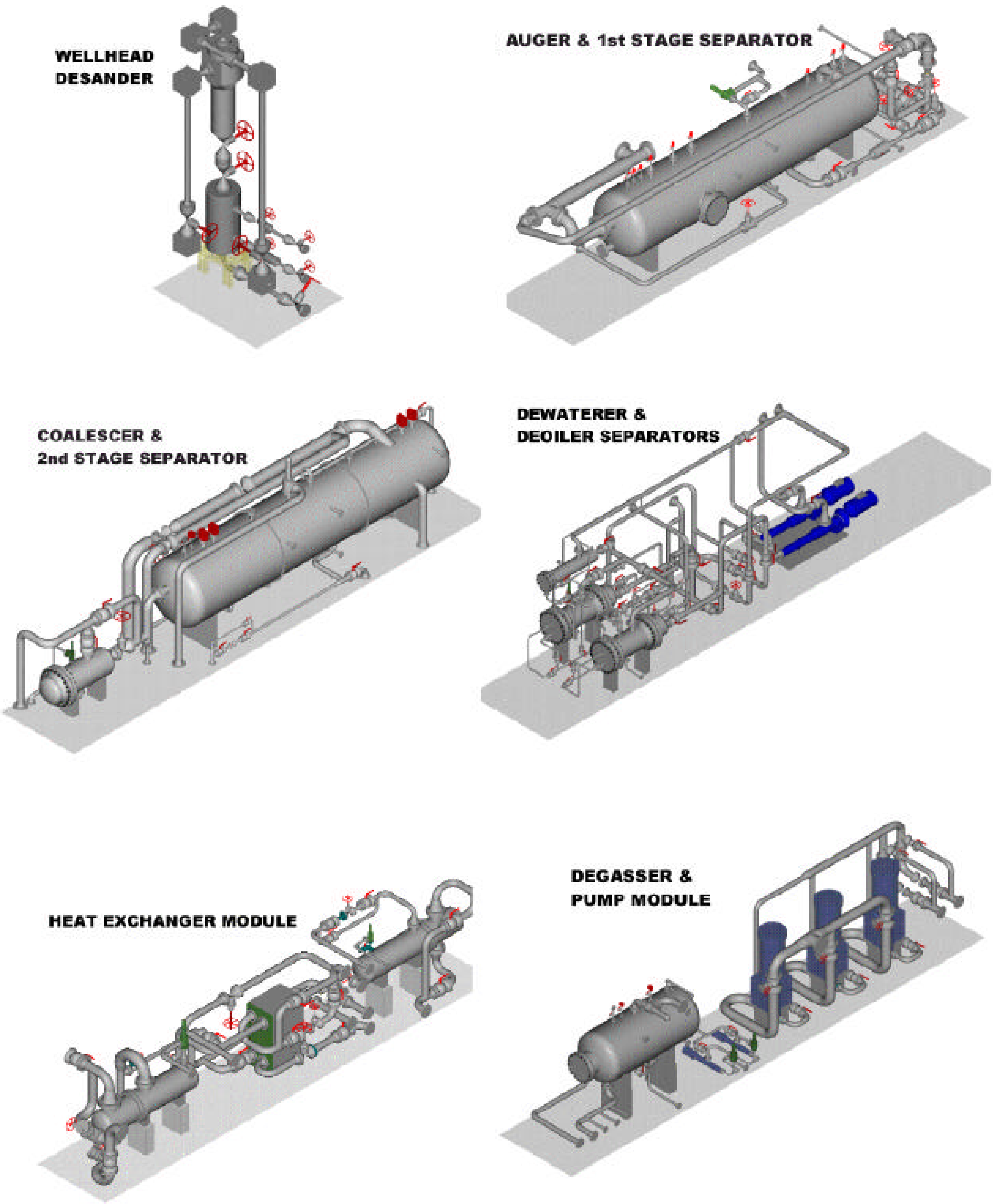


FIGURE 2

## Total System

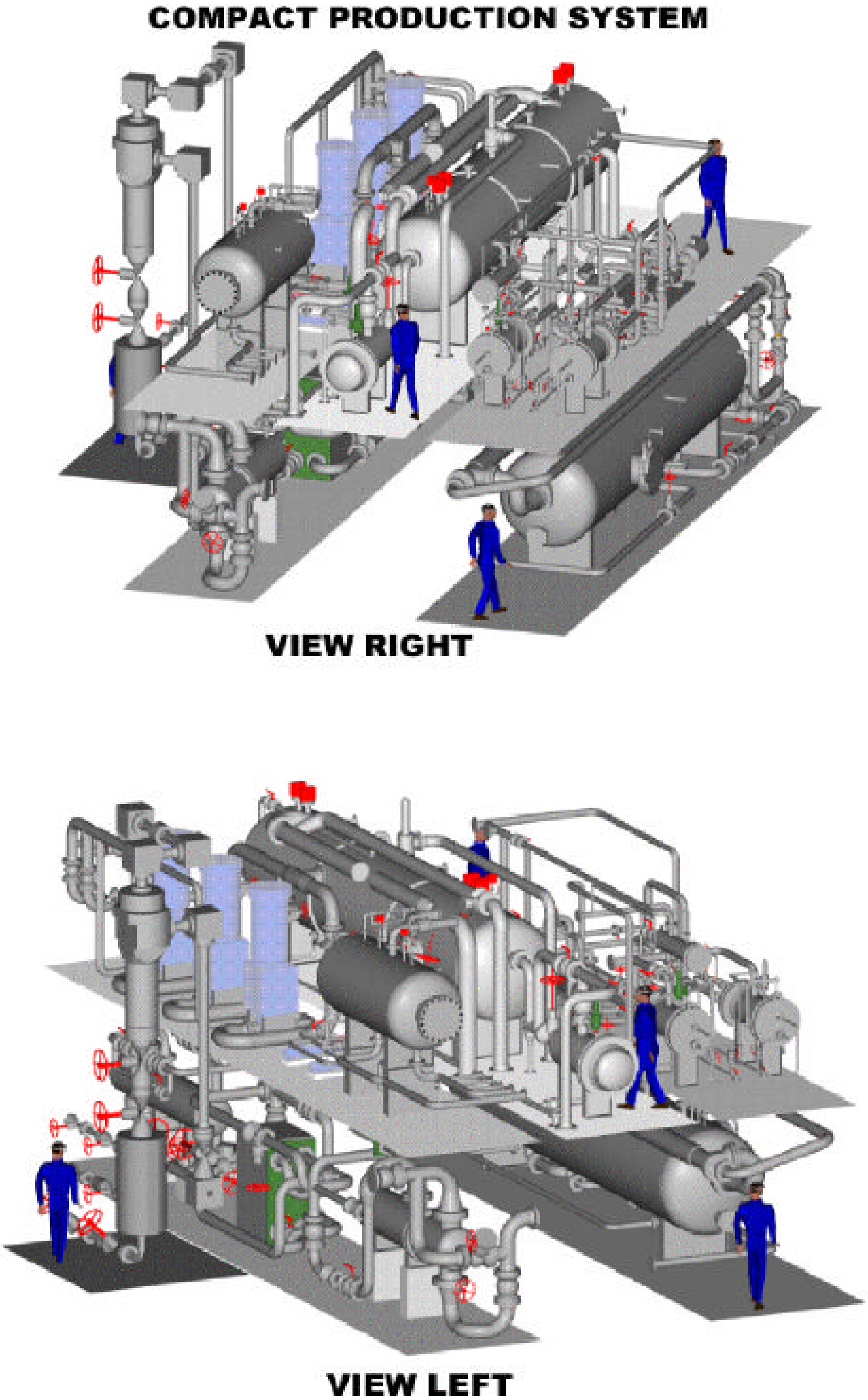


FIGURE 3

 

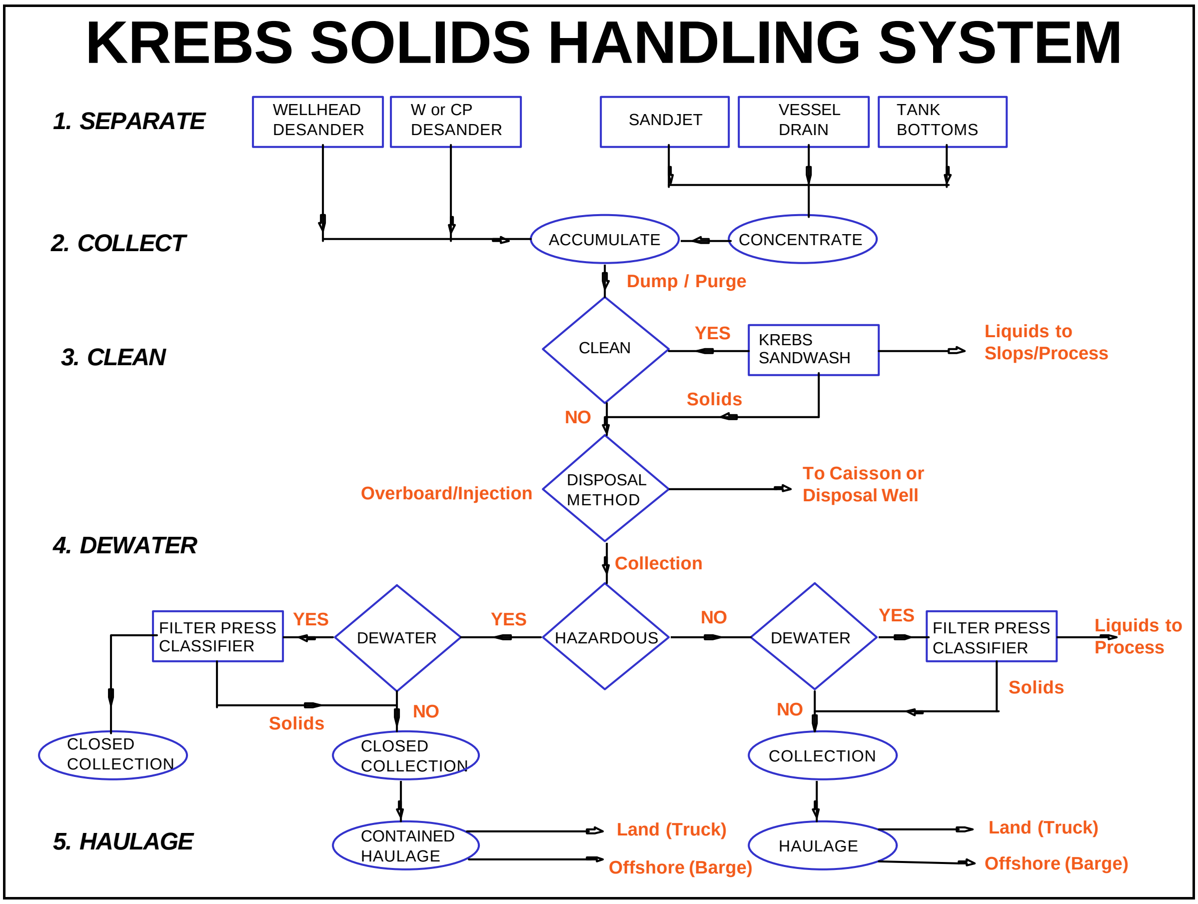


FIGURE 4

Auger Operation

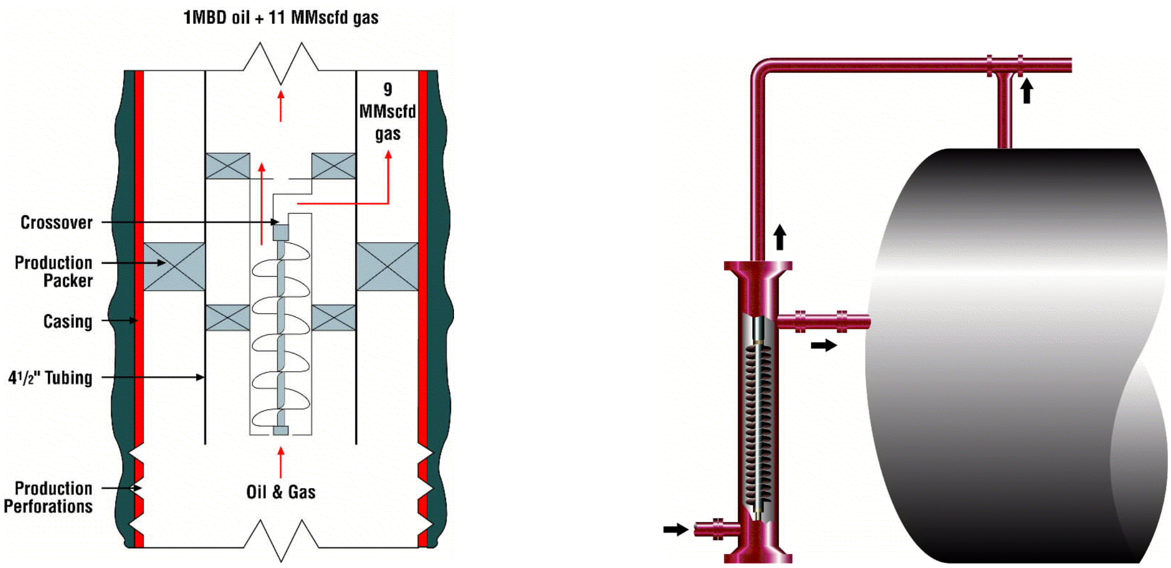


FIGURE 5

 

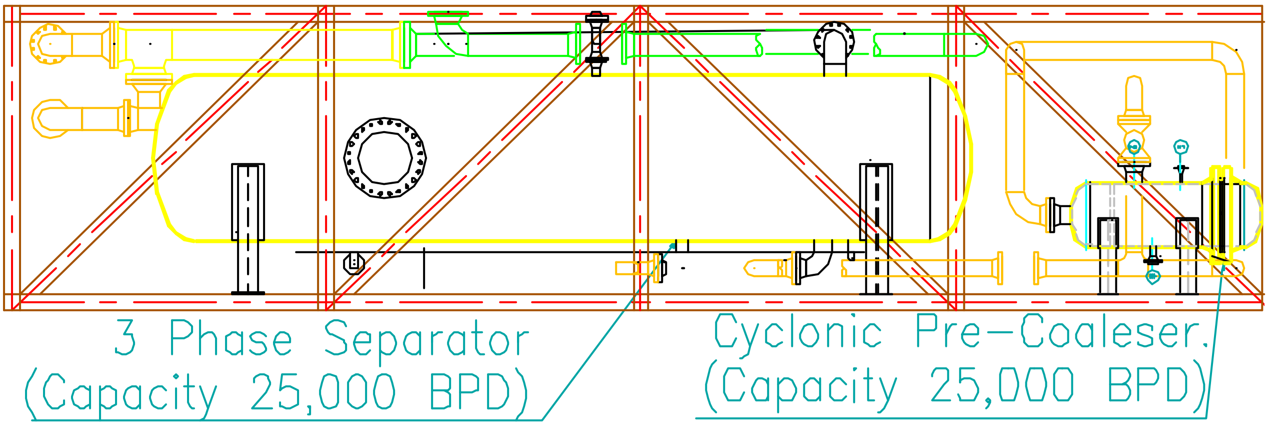


FIGURE 6

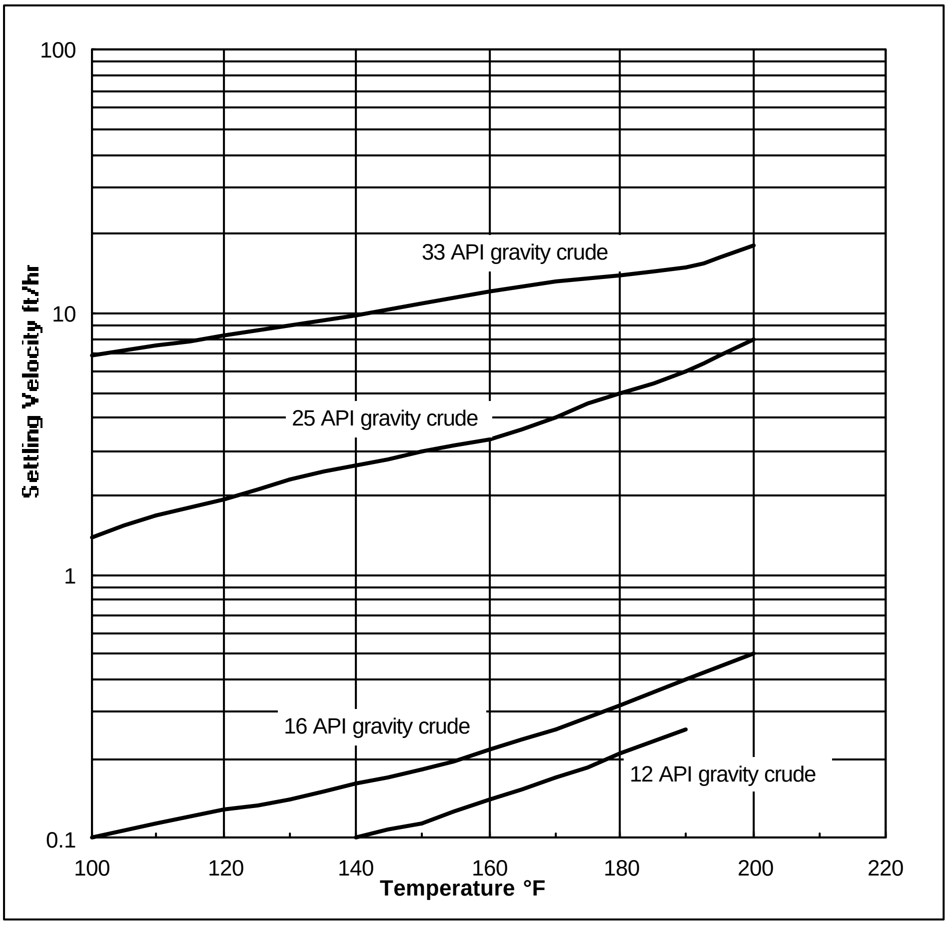


FIGURE 7

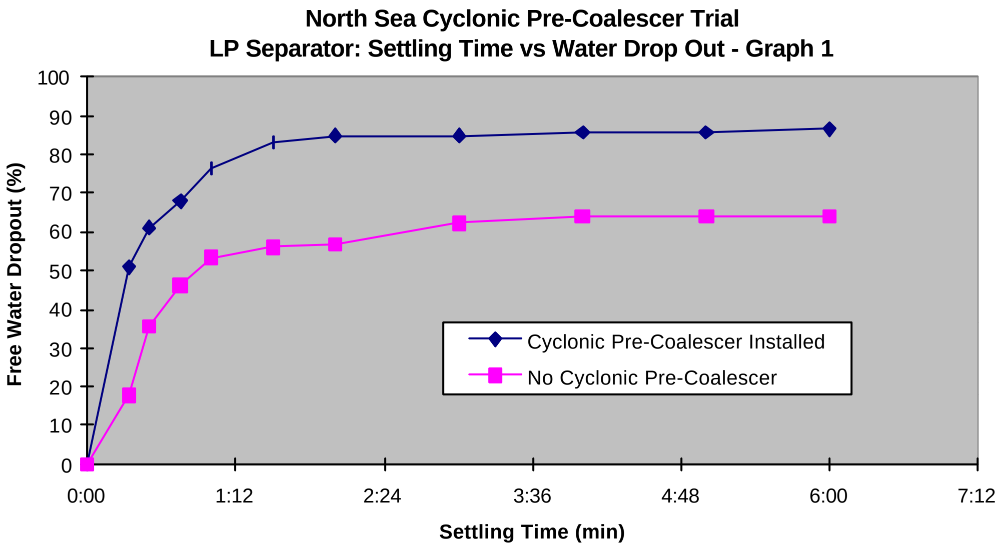


FIGURE 8

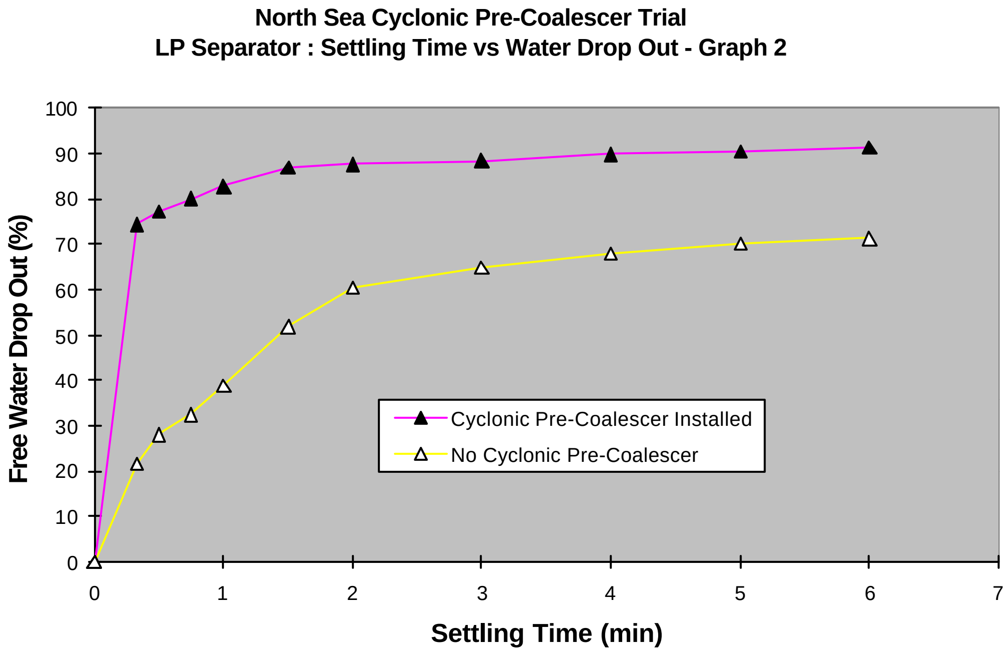


FIGURE 9

 

## 2% BS&W SPECIFICATION

| Crude Gravity | Second Stage Separator | Electrostatic Coalescer |
|---|---|---|
| 35 to 50 | Fitted with coalescing material (eg structured packing) | Not required due to effect of Coalescer, structured packing and low viscosity of crude. |
| 25 to 35 | Fitted with electrostatic grid | Required. Takes the form of separate water collection vessel downstream of Second Stage Separator. |
| 20 to 25 | Two phase separator | Required. Takes the form of separate dedicated Electrostatic Coalescer. |

## 0.5% BS&W SPECIFICATION

| Crude Gravity | Second Stage Separator | Electrostatic Coalescer |
|---|---|---|
| 30 to 50 | Fitted with electrostatic grid | Required. Takes the form of separate water collection vessel downstream of Second Stage Separator. |
| 20 to 30 | Two phase separator | Required. Takes the form of separate dedicated Electrostatic Coalescer. |

FIGURE 10