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# SEPARATION TECHNOLOGIES IN OIL AND GAS PRODUCTION

**Sebastian Osvaldo Zuniga Benavides**

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Hovedveileder: Jon Steinar Gudmundsson, IPT

Norges teknisk-naturvitenskapelige universitet
Institutt for petroleumsteknologi og anvendt geofysikk

# INTRODUCTION

Fields that have been producing until now face new challenges.

The need for alternative recovery methods is faced by Brownfields in which the production has gone down and extraction is no longer profitable as for Greenfields where the use of a platform or pipe segment to shore is unrealistic due to the low income or high costs resulting momentarily in no production from them. The method which can be used for these fields to continue or start production and is targeted in this project is the use of already available separator technology to be placed offshore either topside or subsea. A topside separator may handle some constraints in the flow for the primary separator that may not be able to handle an increase in water or pressure getting rid of it by discharging it overboard according to the specifications of the region the platform is placed. A separator placed subsea could in the same manner handle an excess of water produced and enable it for re-injection by the use of a pump increasing the pressure down in the reservoir which would result in an increase in the total produced hydrocarbons. Much in the same way water is removed there is technology available to separate sand and make the transport to land smoother and with less erosion on the piping equipment. It is also possible to use the separators to adapt the specifications of the flow on nearby fields to make it possible for them to be transported to shore in an already existing nearby pipe. There also exists the possibility of changing the internals of the already installed separating equipment to handle new flow conditions. What is going to be presented here are calculations of the effects of such equipment offshore.

This project contains a number of existing separation technologies already applied in the production of oil and gas offshore, the physics and following calculation of some of its factors in the separation of oil and gas from water and the related possibilities it opens up for. What it means to separate subsea or topside and the restrictions in overboard water discharge as well as technologies available to comply with these.

Technology that makes it possible to separate! It does not differ much from the technology based in land, it could be said it is even the same. What makes it different is the limited space and restrictions the technology has to cope with and in which way they are affected and can still give out the same outcome or better.

**Appendix**

## List of figures

# 1. USE OF SEPARATION TECHNOLOGY OFFSHORE

To increase production by reduction of inlet pressure– as the reservoir pressure decreases the difference in pressure with the inlet pressure also decreases and this results in a lower production of hydrocarbons. To increase this differential pressure it is necessary to either increase the reservoir pressure which is commonly done by injection of either gas or water, or to lower the inlet pressure – which requires modifications on the installed process equipment including the separator.

To increase production by increase of water production – it follows that water production increases with time. As the equipment may not be able to handle it, production may stop or be lowered to cope with the specifications by the manufacturer. Technology capable of handling the excess of water would need to be installed.

To adapt the production to other specifications – in which case new system requirements would be needed for which the less change the better.

To allow for the hydrocarbons of nearby fields to combine using less pipe extensions – for which the contents of the flow would need to be similar.

One of the biggest weaknesses with separation equipment of the type of gravity separation is the fact that it allows little to no changes to what it can handle. New separators may not be installed. This is the not the case for cyclone separator which due to its size can be replaced according to the specifications needed – but only top-side, this opportunity does not present itself subsea. There exist the possibility of changing the internals of the separation equipment previously installed and also the use of INLINE separation technology. The latter one usually adapts pretty well and can be installed topside and subsea.

For the rest of the project, a definition of compact separation technology: a combination of equipment adapted together in a form that will lessen the place occupied.

## 2. SEPARATION BY USE OF GRAVITY

This method of separation consists in using the gravity force to separate a flow. It is ruled by a difference in density. In the case of oil and gas present, the oil would naturally settle in the lower part of the separator while the gas would remain in the upper part. For this to happen, some settle time is required. This is governed by the relative velocity between the liquid flow and the gas flow, the more the difference in density, the higher the difference in velocity which would result in a lower settling time. As can be understood from this, the larger the settling time, the longer a separator would need to be. Due the characteristics of the inclination a separator is given, gravity separators are divided in two types, namely horizontal and vertical separators. Usually horizontal separators would be used for separating liquid driven flows while vertical separators for gas driven flows. This because horizontal separators separate based on the distance covered so that the separator base and length is longer than the height while vertical separators due to the amount of gas need a larger coalescing area or wall which is gained from covering a longer distance in the vertical direction.

To calculate the distance needed for separation the following equation gives an estimate based solely on gravity, buoyance and drag forces.

$$\sum \mathbf{F} = m_p \mathbf{a} = \mathbf{F}_{\mathrm{g}} - \mathbf{F}_{\mathrm{b}} - \mathbf{F}_{\mathrm{D}}$$

$$\sum \mathbf{F} = m_p \mathbf{a} = m_p \mathbf{g} - \rho_f \forall_p \mathbf{g} - \frac{1}{2} C_D A_p \rho_f \mathbf{w}^2$$

This equation has restrictions like the flow behavior (creep) and presence of spherical drops or bubbles.

Thus for the case of the separation of liquids with not so far apart densities like oil and water, a typical gravity separator would need to be large. In this type of separator aside from the gravity force, the drag force is also present. This force acts in the opposite direction of movement or separation.

What also play a role in the efficiency of a separator of a given size are the bubble and drop diameters present of gas and liquids. This is because drag forces are also present and they act the opposite direction of movement or separation. For drop or bubbles with smaller diameter, it will be harder to overcome and pass through the other face which will in turn result in greater settling times or in some case due to the low diameter, no separation at all. The same can be said about viscosity, if present at high values, the resistance to movement will be greater and would increase the settling time. For a very viscous system the effect of separation may also be affected which is why viscous fluids are applied heat before separating.

$$C_D \equiv \frac{F_D}{\frac{1}{2}\pi r^2 \rho_f w^2} \equiv \frac{F_D}{\frac{1}{8}\pi d^2 \rho_f w^2} \qquad C_D = \frac{24}{Re_p}$$

As is well known, a denser substance would after some time encounter itself underneath a less dense. Thus the denser phase, in this case the liquid, would naturally place itself in the bottom while the gas would remain in the top. For this to happen some settle time is needed since this is dominated by the relative velocity between the two.

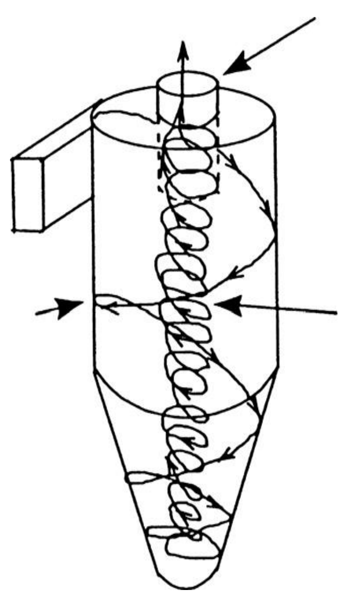
A flow would be usually predominated by either a gas or an oil composition. It can even by dominated by water. This method for separating consists in using the different densities of the fluids and gas present to adequately separate them and create 2 or 3 flows exiting the separator.

## 3. CYCLONE SEPARATORS

They rely in an induced cyclonic rotation which behaves similarly to gravity separators in that forces push heavier particles or liquid phases outwards while the lighter ones remain in the middle section. This induced rotation generates forces far greater than gravity. The same forces are present which could be identified in the gravity separator are present here. The key difference is that those other forces present do not amount to much compared to the centrifugal forces

A cyclone separator is composed of an entrance, body and two exits. It can only separate up to 2 different flows. The entrance to the separator is the one responsible of inducing a cyclonic or rotational flow along the body of the separator and by controlling the pressure of the valves out of each exit of the separator a regulation in the effectiveness of separation is possible.

Before inline technology was introduced, the outlet of the gas phase in the separator could be found at the top and centered in the middle in what is called a vortex finder while the liquid outlet phase would be placed at the end of the separator and in the bottom. Rotation would pull the liquid phase to the walls and rotate downwards while the gas phase would move to the center and end up rotating out of the vortex finder. This can be observed in fig 1.



Inline technology however has the exit for both the phases located at the same place, the end of the separator, being the gas outlet circular shaped exit placed in the center and surrounded by the liquid outlet all the way to the walls of the pipe. This can be observed in fig 2.

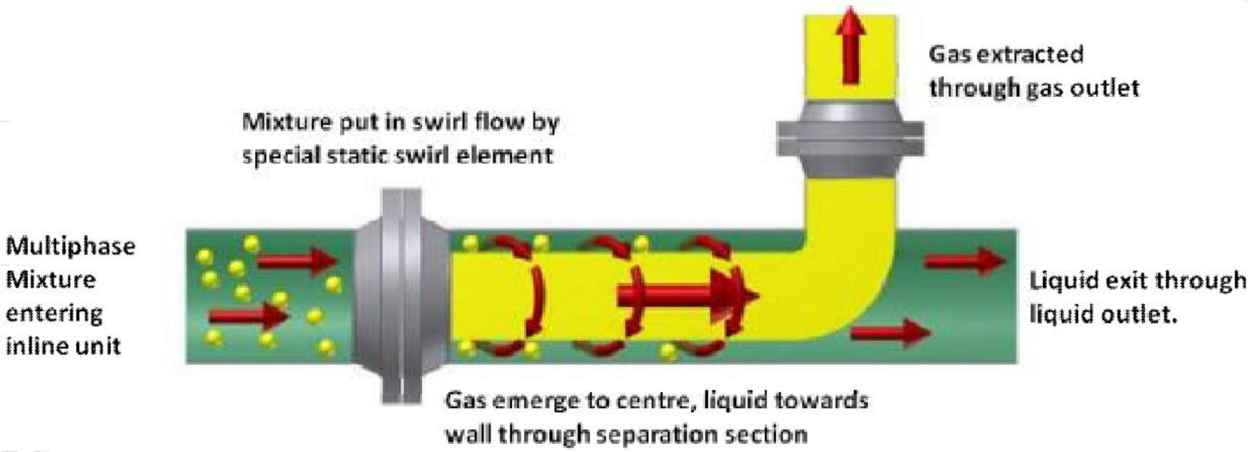


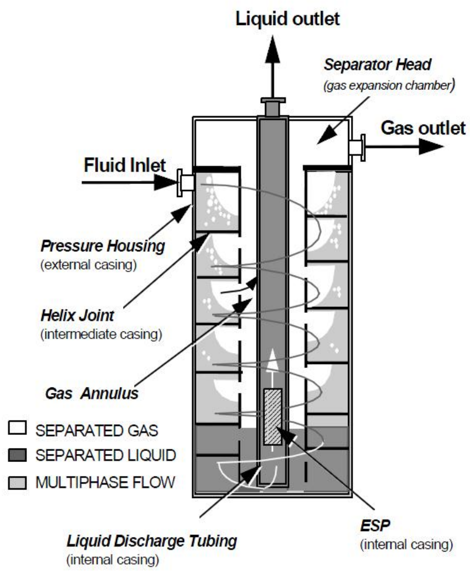

Image extracted from SPE 135492

The more the difference between the densities of the phases is, the easier it is to separate.

## 4. SEPARATOR TECHNOLOGY

### - VASPS

This technology has been around for some time and consists of a vertical separator with the inlet near the top with a helix and compartments in which the liquid falls to and a pump at the bottom to pump the liquid phase out and upwards out of the center of the separator positioned at the top. Due to the helix and low density, the gas gets collected in the center and flows out of the gas outlet near the top of the separator in the opposite side of the inlet. As can be understood by the previous explanation, there are 2 compartments, an outer cylindrical compartment where the gas is separated to and where the liquid phase initially encounters and then inner cylindrical compartment where the liquid gets pumped out. This technology was in 2001 used in the marimba field in Brazil by Petrobras and can be seen below in fig 3.



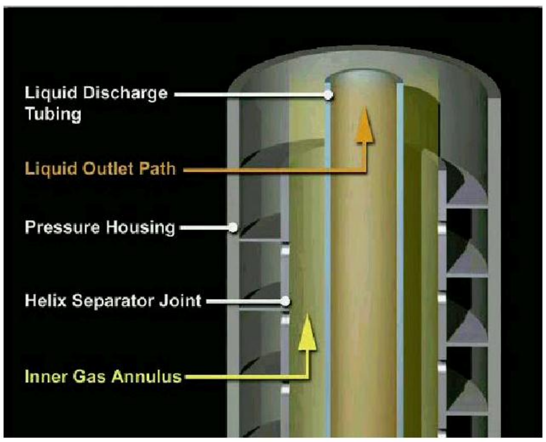




Image extracted from OTC 14003

- **Gas Harp**

Technology developed by Statoil. It separates gas from liquid phase. This separation does not include the entrained gas in the liquid phase. It consists of a main pipe that is connected to five consecutive vertical spools connected with each other and that transport the gas further.  Free gas is prevented further from the liquid phase through a liquid blockage. This technology is able to dampen the effects of slugs through the effect of the spools. How much of it is determined by the height of the spools. It can be viewed in fig 4.

- **Pipe Separator**

It is the liquid/liquid separation that occurs along the extension of a pipe. That would be the separation of water from oil. It works the same way as gravity separators but since the diameter of a pipe is smaller, the travelling distance for settlement is much shorter and hence separation occurs faster. A long enough pipe would suit the requirements for separation. Can be viewed in fig 4.

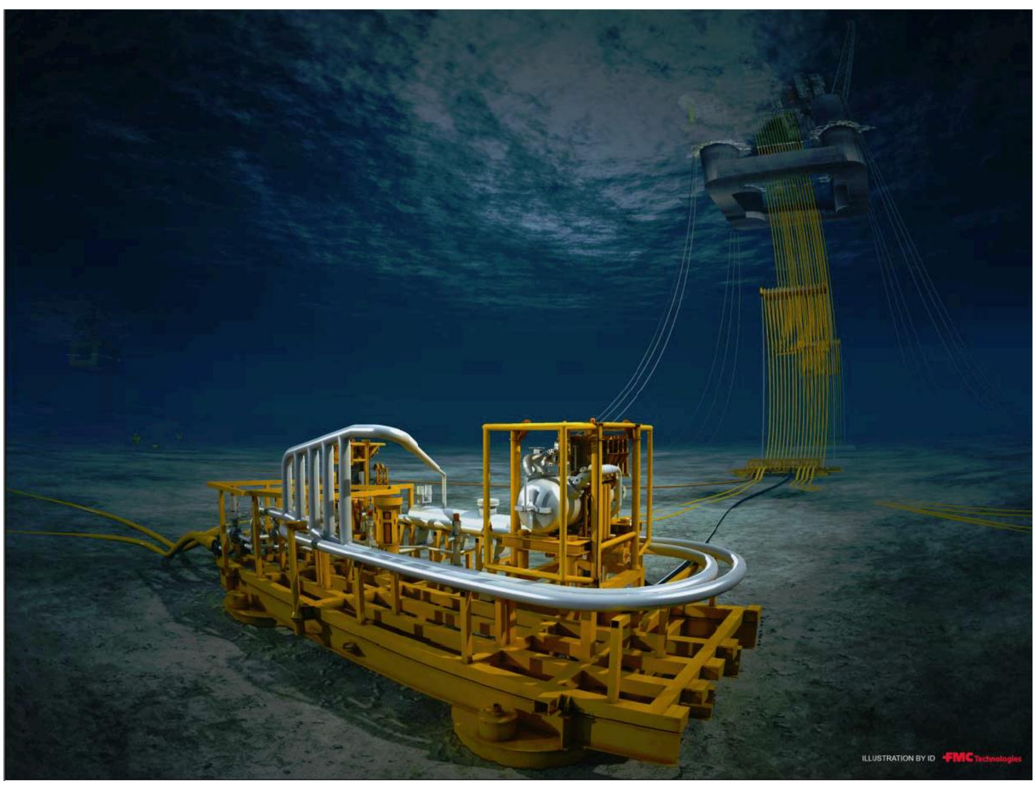


Image extracted from OTC 19389

- **Caisson separator**

The caisson is alike the VASPS also installed in a dummy well. This one however is very tall and according to SPE 123159 has a length of approximately 100 meters. It has a tangential inlet and uses a vertical gas liquid cylindrical cyclonic (GLCC) separator to separate the multiphase flow into gas and liquid streams. This is located in what is called inlet assembly. As it is a tangential inlet, the flow passes through a deviated pipe inducing circular motion before entering the separator which results in some separation of the two phases before entering the separator unit. Due to the separator unit being so big it is able to handle slugs and give enough residence time. Gas then flows through the caisson riser while the liquid gets pumped with the ESP which is part of it all and corresponds to the lower part of the system. All of this can be viewed in fig 5. [OTC 20882]

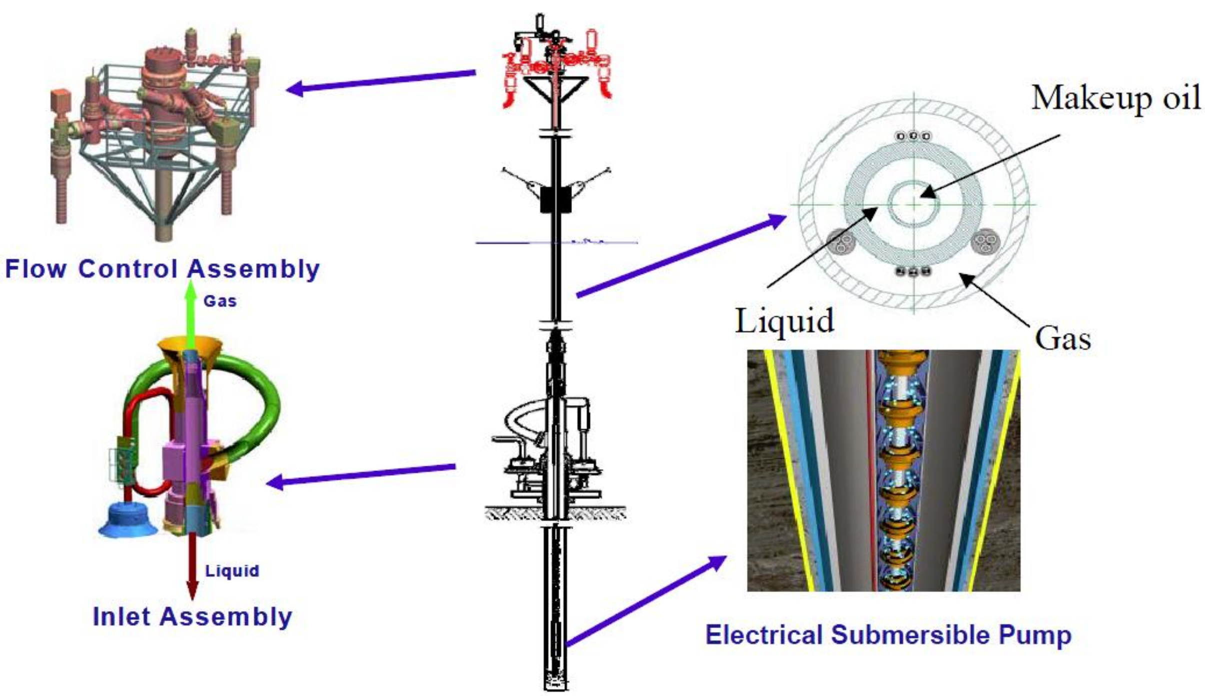



Image extracted from OTC 20882

- **Gas liquid cylindrical cyclone (GLCC) separator**

Base model of the separator used in the caisson and VASPS separators. As its name indicates it is a cylindrical formed cyclone, it has a tangential inlet to produce the swirling and it has a downwards inclination of about 27 degrees for optimal flow and liquid carryover in the gas outlet stream. This separator has been around for about 30 years and has this last decade been implemented topside and subsea. As a cyclone, it uses the advantages of the centrifugal force to separate at higher G forces than normal gravity separators would. The inside is filled with nothing but the incoming multiphase flow and ideally a revolution of the stream is expected to happen untouched to the flow level inside it. As stated by Kouba et al 1996, the liquid level should be about 3L/D distance from the inlet. Any more than that would cause the friction with the wall to induce decay in the tangential velocity which would result in a lack in separation performance while a shorter distance would prove itself disruptive as liquid droplets would be carried over to the gas outlet.

## 5. FIELDS AND THEIR TECHNOLOGY

### - Troll C

The separator station is installed at 340 water depth approx. 3.5 km from the Troll-C production platform. It had 2 main objectives, to improve the water treatment capacity of the troll C platform by removing the excess of water to be separated topside which is limited and demonstrate commercial viability of a separation and boosting system. Note that there are more than 50 subsea wells and lowering the intake of water to the topside facility from some wells opens up for other wells to be treated and produce thus increasing the oil recovery. [OTC -20619 and OTC -15172]

Water from oil was believed to be hardest to separate and thus a horizontal gravity separator was chosen. Since the separation of importance was water from oil, no coalescing unit or pressure control facilities were needed. The separator is cylindrical and 11.8 meters long with a diameter if 2.8 meters.

The main design parameters of the separator are:

| | |
|---|---|
| Water: | 6000 m3/day |
| Oil: | 4000 m3/day |
| Total Liquid: | 10 000 m3/day |
| Gas: | 800 000 Sm3/day |

Some other key data:

| | |
|---|---|
| Oil Gravity: | API 37 |
| Design Pressure: | 179 bar |
| Operating Pressure: | 35 to 105 bar |
| Operating Temperature: | 60 oC |

A resilient inlet arrangement that allowed for maximum gravity settling distance by means of reducing the momentum and able to handle slugs of all types and varied GOR was chosen, namely the cyclonic inlet device. It would also offer a minimum of shearing between oil and water so as to prevent emulsion.

An outlet arrangement of a weir plate and an appurtenant baffle plate was chosen. This way exiting oil would not incite slug flow and would have a volume of oil as safe measure stored for periods of only gas output.

Additionally this separator has a sand removal system included and located at the bottom of the separator. This system consists of a set of pipes that flush the bottom of the shell as well as another set that suck up out the particles.

And for maintaining the liquid level appropriate for effective separation, two sets of level detection systems were installed, each of them durable and distributed along vertically of the separator.

What makes the separation reliable and possible is the robustness of the separator, simplicity and minimum control that leads to a stable and undisturbed process.

- **Tordis**

Located 11 km from the Gullfaks C platform in the north sea and at a water depth of 210 m, the field is developed as a subsea tieback to Gullfaks C facility. It was faced with an increase in water production as the face matured until it became a bottleneck for gullfaks. It was decided to decrease the wellhead pressure to produce more oil and water, pumping the oil to Gullfaks while the water got reinjected to a nearby disposal well. Its purpose was to increase production from 49% to 55%. The tordis project, SSBI (subsea separation with boosting and injection) consisted of a separator unit, pump and sand handling device among others. [OTC – 20619 and OTC – 20080]

The main design parameters of the separator are:

| | |
|---|---|
| Water: | 24 000 m3/day |
| Oil: | 9000 m3/day |
| Total Liquid: | 33 000 m3/day |
| Gas: | 1 000 000 Sm3/day |

Some other key data:

| | |
|---|---|
| Oil Gravity: | 839 kg/m3 (API 37) |
| Operating Pressure: | 25 – 40 bar |
| Operating Temperature: | 75 oC |

The separator consists of a horizontal gravity separator, much like the Troll separator, for handling oil and water separation and with an inlet cyclone device, though the gas would bypass the separator and connect directly to the outlet. The gas is the recombined with the oil and pumped to Gullfaks C platform. The separator is 17 m long with a diameter of 2.1 m offering a retention time of 3 minutes.

The sand handling part would be carried out by a sand jetting arrangement in the separator. The sand gets fluidized and flows into a desander module. When sufficient sand is accumulated it gets fluidised and discharged into the water line downstream of the injection pump (as it can only pump fluid and sand would corrode the pump) and injected into the disposal well. A nucleonic and capacitive separator level detector are included.

- **Marimba**

The Marimba field is located in Campos Basin, Brazil. Its subsea separation system consists of the VASPS (Vertical Annular Separation and Pumping System). The VASPS is a two-phase liquid –gas subsea separation and pumping system. It is placed in the seafloor within a 30 – 36 inch conductor in a dummy well. The separator part of the system is much like a Gas liquid Cylindrical Cyclone (GLCC), it is vertical and has an inclined inlet but is different in that it contains a helix which makes the mixture go through a helicoidal channel to separate. The separator is composed  by a pressure housing, 6 joints 12 m long with a diameter of 26 in and a helix, 6 joints of 12 ¾ in diameter. [OTC – 14003 and SPE - 95039]

Data for VASPS – Marimba field

| | |
|---|---|
| Design Liquid Flowrate: | up to 1 500 m3/d |
| Design Gas Rate: | up to 190 000 m3/d @ 20 oC, 1atm |
| Separation Pressure: | 8 – 12 bar |
| Design Pressure: | 3000 psi |
| Pump Head & Power: | up to 70 bar & 150 kW |
| Platform Arrival Pressure: | 7 bar |

Well Fluid Properties:

| | |
|---|---|
| Oil Density: | 29 API |
| Dead Oil Viscosity: | 14,3 cP @38 oC – 7.6 cP @ 60 oC |

The separator is illustrated in fig 3.

The VASPS separates gas from liquid. The gas finds it way through the riser and up to the platform without intervention while the liquid falls and settles at the base of the separation unit and gets pumped by and ESP.  What this enabled for the marimba field was the production from the reservoir at lower wellhead pressure. Initially the wellhead pressure was 36 kgf/cm2 (~35 bar) and producing 750 m3/d fluid but by using the VASPS the well was able to produce with 11 kgf/cm2 (~11 bar) which resulted in an increase of 250 m3/d of fluid. An increase of 33% and producing with gas lift to without.

- **<u>BC – 10 Parque das Conchas</u>**

Located in Brazil at the Campos Basin and 1780 water depth, the separation unit subsea used is the Caisoon, ESP and has been used to develop the fields Ostra ad Abalone. It separates gas from liquid in the same way the GLCC separator does. The key difference in the separation unit is that it has a surge volume that extends the length of the separator to around 100 meters. This separator is vertical and positioned in a dummy well the same way the VASPS is. Challenges arise from the variety of oil and GOR with depth ranging from heavy and low GOR fluids to light and high GOR fluids. And also from the fact that for economic recovery of hydrocarbons, gas lift is required.

Separation occurs in both the tangential and inclined inlet as well as within the separator itself. Heavy liquid is directed to the wall due to centrifugal forces while light gas gets directed to the center and flows out from the top gas outlet. An ESP is located in the liquid outlet positioned in the center of the cilyndrical separator. It is built as a smaller diameter in the center for liquid outlet with the entrance at the bottom surrounded by the cylindrical diameter. The space between each diameter is the settling section and more liquid concentrated fluids are encountered at the bottom. Liquid gets separated in a circular motion as it falls until the liquid level is reached. Some gas is carried under to the liquid outlet and pumped further wth the liquid while some liquid carryover happens at the gas outlet. What causes this undesired effect is the foaming at the liquid gas interface. Defoamer injection was used to solve the problem and that made the BC – 10 the first application subsea that required chemical defoamers. It also required developing and testing of new products. In this type of separator contineous delivery of defoarmers is needed as experience has showed that when the delivery of defoamers is not satisfied the foaming on the caisson increases rapidly and a stop on defoaming would lead to shut down of the system. The liquid level is regulated by the speed of the ESP. When there is a lack of oil circulation, dead oil will be provided by the FPSO for the pump to operate efficiently so that the system will not stop. [OTC – 21611 and OTC - 20647]

Operational Pressure: 1200 psig [by the time it was written OTC – 21611]
Parque das Conchas: 16 – 42 API [OTC – 20647]
Ostra Field: 24 API
Abalone Field: 42 API
Ostra Field Viscosity: 8 cP [OTC – 20599]
Design Pressure: 4500 psi [**O. F. Jahnsen, M. Storvik]**

An illustration of two Caisson separators for the BC – 10 is illustrated below, fig 6.

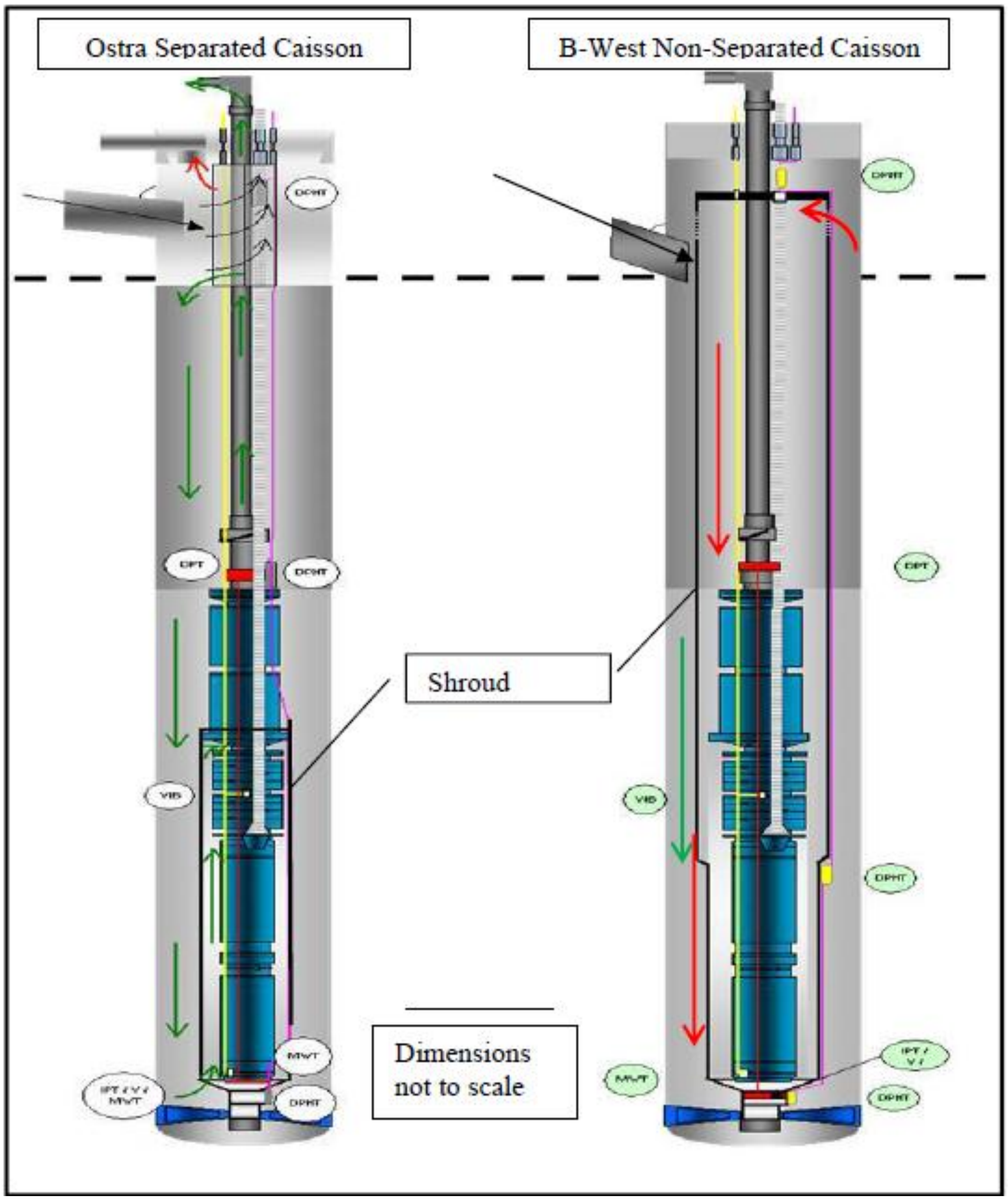



Image extracted from OTC 21611

The effects of gas carry under affect the ESP and result in a lower power draw at a higher motor speed. An increase in gas carry under would result in a reduced capacity and is what happened when the registered low GOR of the Ostra fluid with a gas carry under of less than 10% was commingled with the high GOR of the Abalone fluid and resulted in a separator capacity of 65% of design capacity.

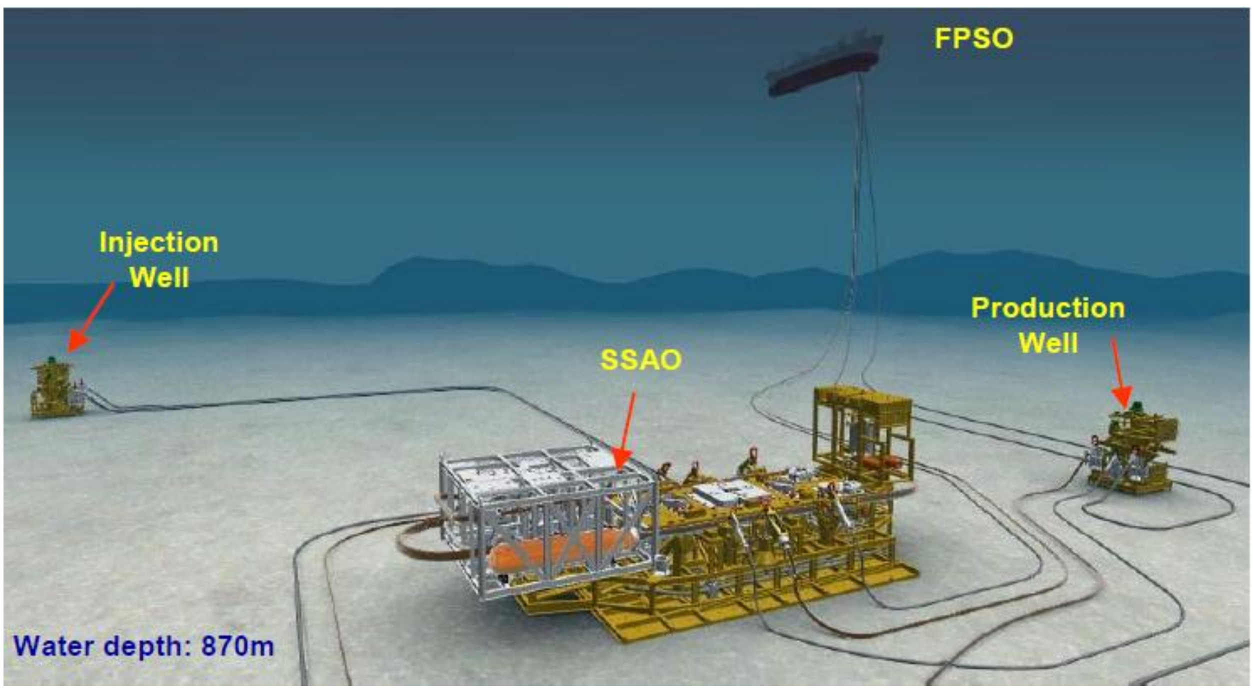
- **Perdido**

It is located in the Western Gulf of Mexico for water depth of 2800 meters. The Perdido development includes the fields Great White, Silvertip and Tobago. These are all fields with subsea tieback to the host. The API values range from 17 to 40 much like the Parque das Conchas and GOR from 350 to 2600 scf/bbl for low temperature and low pressure reservoirs. Since the GOR is high, gas injection was not a realistic, neither was water injection since reservoirs to be produced from have very low aquifer support. [SPE – 123159]

It was decided to use a Caisson with a vertical GLCC much like for the BC-10 of a 35 in diameter and 350 foot long Caisson inserted into the seabed for liquid retention. It also employs the smart inner tube for dead oil to flow down from topside to continue pumping when there is low liquid flow into the Caisson. The objective is to separate as much gas as possible from the liquid to enable for a more effective pumping to the spar platform. Design pressure of the separator is 4500 psi.

- **Marlim**

The field is located in Campos Basin, Brazil and uses an oil water pipe subsea separator at 870 water depth. The separation station is 29 m long, 10,8 m width and with a height of 8,4 m. the separation unit will separate water from and sand and re-inject it into the Marlim reservoir via a centrifugal pump. This is a new implementation of technology. The water separation happens in the Pipe Separator based on gravitational forces. Then the separated water with entrained oil gets passed through a cyclone and meets the requirements for re-injection. The total separation equipment also includes a system for removal of sand to minimize the impacts of solids. These impacts would be great since the diameter of a pipe is several times lower than that of a typical gravity separator. The complete system including the injection well, separation unit and production well can be seen in the image below, fig 7. [OTC – 23417 and OTC 23552]




The system works as follow: the flow from the production well gets routed to the separation unit. The first equipment it encounters is the inline multiphase sand remover. As its name implies, it is responsible for the removal of the highest amount possible of sand that enters the system. It is followed by the gas harp. This arrangement of interconnected vertical pipes has the objective to remove free gas present in the flow. Doing this enables the following section of pipe separator to handle a predominant liquid phase for which case the low presence of gas would not produce turbulence by the difference in velocity and shear stress. The gas removed in the gas harp is routed directly to the outlet separator where it is later recombined with the separated oil. The oil and water present after the gas harp liquid-gas separation flows through the Pipe Separator and over its length gets separated by normal gravity force. By that time the flow should distinguishable between water at the bottom and oil at the top. That arrangement then enters the outlet separator. This outlet separator does not need to be big or long as the separation has already occurred. Gas and oil are recombined and free flow to the stationary production unit. Water exists from another outlet and passes through another inline sand remover followed by two continuously set of hydrocyclones. The function of the hydrocyclone is to protect the equipment and minimize the frequency at which the pipe separator and outlet separator are flushed and cleaned.

For the oil density of 19 API some requirements followed for the separator to handle:

| | |
|---|---|
| Liquid Flow Rate: | 13500 m3/d |
| Initial Water Cut: | 65% |
| Separator Pressure: | 22 bar |

Notice that production came from four linked wells and that the separator system would need to be able to handle as much as continuous production from all of them as well as only one of them. It also includes the ability to handle slugs which is also the reason for opting for the gas harp system of gas liquid separation and surge volume (dependent on the harps vertical pipe diameter and height). Viscosity is another issue the system has to be able to handle. The previous installation of pipe separator in the troll B has showed that the long distance covered by the pipe separator facilitates the separation of viscous oil by means of different flowing rates for water and oil having a thin emulsion layer. The difference in velocity exposes the emulsion to high shear forces making them break and enhance separation. The re-injection of water satisfies an oil content of below 100 ppm and a maximum solid suspension of 10 ppm. [OTC - 24161, OTC – 19389 and OTC - 23230]

- **Pazfor**

Pazflor is a development for the fields Oligocene (light oil at medium pressure and temperature) and the Miocene (heavy oil with low pressure and temperature) located in Angola at a water depth of 800 meters. It is a Greenfield development and consists of a low energy reservoir with high viscosity oil and stable emulsion that would not be able to be produced if it was not for the separation system implemented. It was calculated that high water production would be encountered already after four years of production and due to the conditions it is in, continuous amount of methanol is needed to prevent hydrate formation. The separation is done in a vertical gas-liquid separator. This vertical separator has a specially increased inlet pipe size in order to achieve bulk gas removal. This because during the testing of the separator with the reservoir fluid showed that gas was pulled down by high viscous fluid free falling from the separator to the liquid leg. Another unique trait was the used EvenFlow system that followed the entrance to the separator tank. This resulted in an even distribution of the flow over the inlet section to the separator, releasing free gas. Finally liquid collection plates right underneath the EvenFlow and over the cross sectional area of the separator led the liquid to the wall down a spiral path. An illustration of how this looks can be seen below, fig 8.

Image extracted from OTC 23178

This separator arrangement allowed for sand flow and sand slug. An enlarged inlet piping to the separator would result in better gas bulk separation but affect sand settling in a negative way as less diameter would result in a stronger flow that would mobilize the sand. Studies were performed and a size was decided upon. The same was done with the helix downward tilt as the separator should avoid blocking of the helix path. Finally the separator has a cone outlet which made it easier for sand to flow out and avoid sand settling and cogging at the outlet. The enlarged inlet and EvenFlow assisted the slug handling and it was showed that the higher the GVF the residence time increased. In the same way, higher liquid bulk velocities were related to higher GVF. Oil densities to be separated ranged from 17-22 API and high viscosity of 3-10 cP to a light oil of 35-38 API. [OTC – 23178 and SPE -123787]

Separator characteristics:

| | |
|---|---|
| Liquid Treatment Capacity: | 110 kblpd |
| Gas Treatment Capacity: | 1 MSm3/d |
| Weight SSU: | ~900 tons (including pump) |

# 6. DESCRIPTION OF TECHNOLOGIES PRESENTED

Vertical GLCC

It consists of a vertical cylinder with a tangential inlet inclined ~27 degrees. Technology of this type has been in development for several years and has recently been brought down to subsea level to be used together with a pumping unit in what would be described as a subsea separator and subsea system. To date there are two such systems, the Caisson ESP and the VASPS. The Caisson includes the use of a pump and a Caisson volume surge inserted into the seafloor whilst the VASPS includes an internal helix on top of the changes of the Caisson ESP.

The vertical cylindrical separator separates in two places. First in the inclined inlet previous to entering the cylindrical part where the flow gets stratified and secondly inside the cylindrical separator where the tangential forces push the heavier liquid phase to the wall as it follows a circumferential motion downwards. Eventually the liquids reach a liquid leg in the separator where it later exits the separator or gets pumped further (VASPS and Caisson ESP) while the gas flows upwards and out of the gas outlet. Usually the gas outlet has an internal to prevent some liquid carry over. The separation is ruled by the radial velocity at a distance R from the center of the cylinder. The further away from the center the greater this radial velocity is and is where the heavier liquid settles.

Pipe Separator

The pipe separator can be understood as a very small diameter horizontal separator that separates liquid-liquid phase. Gravity forces drive the heavier phase to settle under the less heavy phase with an emulsion in between for the cases of high viscosity. Since the distance the liquid drop has to travel to get separated is considerably less (less diameter), separation occurs faster. The weakness of a system occupying such a small diameter is the type of flow in it. For this technology to be successfully implemented the incoming flow should have little momentum and as little disturbance as possible meaning no gas to little gas present, thus inducing a stratified flow which just requires time and distance to be separated. Its benefit lies in that it does not include internals and the freedom it has to be installed over a small place. Aside from having a smooth trajectory that can be decided upon needs.

Multipipe Separator

This type of separator distributes the flow in a pipe into an increased amount of pipes. This technology has been thought to handle slugs as increasing the amount of pipes also increases the volume the receiver can handle. An example of this is the multipipe finger-type slug catcher in figure 1. Its system allows for extra space and leads the liquid to the lower pipes acting on gravity. The lower and upper pipes are connected twice and open up for gas that initially flowed down to flow up as velocity has settled and the same for liquid that passed with the gas. This system is rough which is why no fine separation happens and is rather used as a slug catcher. Another type of multipipe separator is the harp gas used for the marimba field. Consecutive vertical pipes one after another are connected with the main pipe. Free gas present would rise up the vertical pipes and exit the main pipe allowing for removal of it. The system uses a five continuous vertical pipes allowing for the gas that wasn't able to reach in a first instance to be separated in the latter ones. Free gas would also not be able to flow back to the main pipe of liquids due to a liquid blockage present at the vertical pipes. What having these vertical pipes also allows is the resilience to slug flows. Higher content of GOR would rapidly separate out of the vertical pipes and lower GOR slugs would increase the liquid level present in these pipes resulting in a fairly controlled system

Inline Separation Technology (Desander, degasser, deliquidizer, etc)

This technology is applicable for gas-liquid, liquid-liquid and solids separation. Separation is achieved in pipe segments by the use of cyclonic flow. Before entering the pipe cyclonic segment, the flow goes through a swirl element which induces cyclonic movement to the flow. The heavier phase moves to the outer wall while the lighter phase moves to the center as it flows axially. At the liquid outlet there is an anti-swirl element that stops the rotation.

For the inline gas-liquid separation, the following types are available:

- GasUnie: bulk separation of gas and liquid

- Inline PhaseSplitter: its purpose is to split the flow in a GVF ranging from 10% to 90%. Usually covers a first stage separation before some finer separation is done to the separated flow.

- Inline DeGasser: usually used to remove gas from a liquid stream. The gas outlet includes a second stage separator system for removing of the drops that got entrained in the gas.

- Inline DeLiquidizer: usually used to remove liquid from a gas stream. The liquid outlet includes a second stage separator system for removing of bubbles that followed the liquid.

- Inline DeMisterer: a bundle of small diameter demisting cyclones (Spiralflow) in a pipe spool.

The LVF and GVF are regulated by the chokes of the gas and liquid outlets. Characteristic presented for these technologies are presented. [SPE – 136390 and SPE - 135492]

| | GasUnie™ | Degasser | Deliquidiser | Phase Splitter | Demister Spiraflow |
|---|---|---|---|---|---|
| Separation Efficiency | 90-99 % removal of incoming gas | 90-99 % removal of incoming gas | 90-99 % removal of incoming liquid | About 98 %* | 99.99 % removal of incoming liquid |
| Continuous Phase | Gas or Liquid | Liquid | Gas | Gas or Liquid | Gas |
| Dispersed Phase | GVF** < 10 % | GVF < 60 % | LVF*** < 10 % | 20 % < GVF < 95 % | LVF < 5% |
| Second Stage Separation | NA | Scrubber | Liquid boot | NA | MashPad |
| Control System required | Yes | Yes | Yes | No**** | No |
| Control Strategy | Liquid level in GasUnie | Liquid level in scrubber | Liquid level in boot | Application dependent | — |
| Turndown Ratio | 50 % | 50 % | 50 % | 50 % | 50 % |
| Pressure drop | 0.2 to 1 bar depending on operating pressure | 0.45 to 2.5 bar depending on operating pressure | 0.4 to 0.7 bar depending on operating pressure | 0.4 to 0.7 bar depending on operating pressure | 0.2 to 0.7 bar depending on operating pressure |
| Slug handling capability | High | Moderate | Moderate | Low | High |
| Fouling Tolerance | High | Low | Low | Low | High |

* depends on operation strategy

**GVF Gas volume fraction

***LVF Liquid volume fraction

****depends on customer requirements, if high performance is required, control system must be included.

Image extracted from SPE – 136390

The inline liquid-liquid separation exists for the separation of water from oil as water cut increases from reservoir production.it is intended to give high efficiency separation and has already been used for the Pazflor development. The technology is called the DeWaterer and is considerably smaller in size than a horizontal separator. Characteristics of this technology are that it is gas tolerant, in other words no increase in pressure drop for GVF for 0- 50%. It works solely for water cuts of at least 50% and gives typical oil in water concentrations of less than 1000 ppm. Pressure drop ranges from 1-1,5 bar. And the technology separates both light oils of 35 API to less than 20 API.

The effectiveness increases with water cut inlet as shown in fig 9. [SPE – 135492]

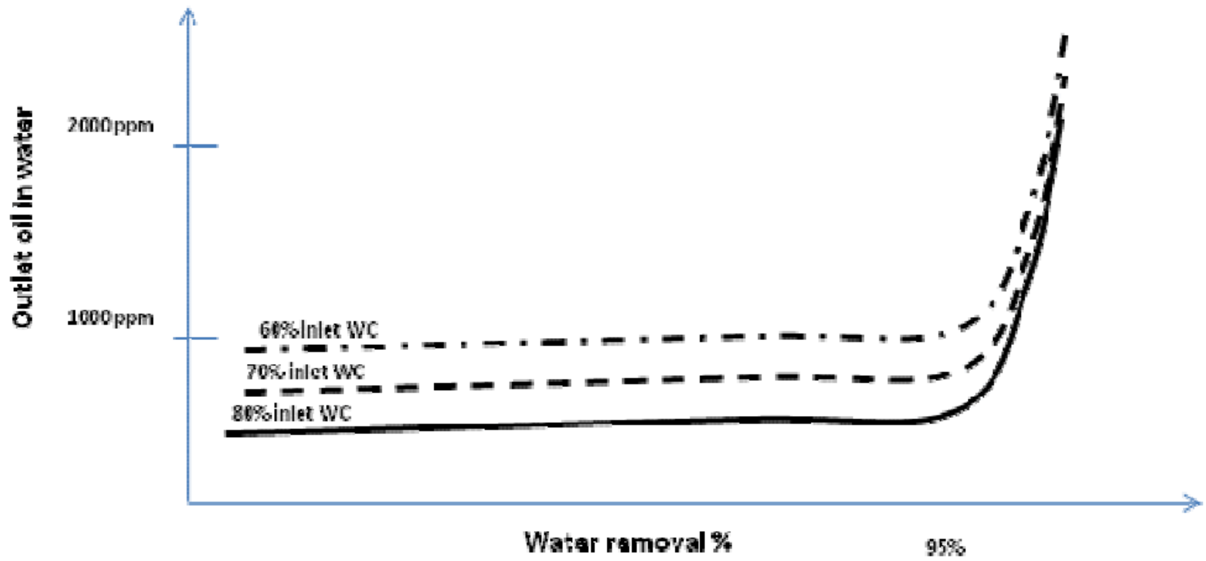



Image extracted from SPE - 135492

Inline technology use up little space and can be used as subsea tie in, for subsea separation as was the case for pazflor or bottlenexk issues at top side facilities with the restricted place for modifications as was done for the BP – ETAP in the use of an inline DeLiquidizer illustrated below, fig 10. [SPE – 136390]


Image extracted from SPE - 136390

Inline Electrostatic Coalescence: use of static pressure to react on the water phase to grow the size of water in oil droplets and emulsion breakdown for a better water oil separation. The inline electrostatic coalesce is to be installed upstream of the separator to optimize the separation. It makes the water droplets crash with each other and form bigger droplets that once inside a separator would be separator faster if separated at all. This happens because the bigger the droplet, the higher the gravity effects on it. And this is what cyclone, gravity separators and pipe separators base their separation upon.

Inline Sand Separation: sand clogs and deteriorates the equipment. For this purpose sand must be removed as soon and as close as possible to the well. This technology has been tested and proved successful in the Marlim development in Brazil. It consists of an inline system where the flow enters axially without any rotation as with the gas-liquid inline separators. Once it enters it encounters with a swirl produced by an element rotating in the center of the path. Sand gets drawn inwards and follows the element along its length where the entrance of an exit is, getting separated. This separation results in a low pressure drop. [SPE – 135492]

Inlet devices: the cyclonic inlet and EvenFlow HE. The first one gives a rotational separating the bulk of free gas and possible bypassing the following separator while the EvenFlow HE allows for a dispersed and even flow that slows gas to escape and flow naturally afterwards inside the separator in question. They can be viewed in figure 11.

Image extracted from SPE - 136390

The effect of settling was compared for centrifugal and gravity forces. From this the effect of cylindrical movement in the separator is clear. Separation occurs faster as the force and thus velocity it separates from is several times higher than for normal gravity separators. The sizing of the cylindrical separator was based on cyclone configurations presented in [Theoretical study of cyclone design, Lingjuan Wang] following the 27 degree inlet suggested for the GLCC in [A REVIEW OF GAS-LIQUID CYLINDRICAL CYCLONE (GLCC) TECHNOLOGY, Kouba et al.]

| | | | | $\rho_{WATER}$ | 1,09 | Kg/m³ | | | | $\rho_{WATER}$ | 1,17 | Kg/m³ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{Re}$ | Diameter | $F_G$ | 5,59879E-18 | 5,59879E-18 | 5,59879E-18 | 5,59879E-18 | 5,59879E-18 | 5,59879E-18 | 5,5988E-18 | 5,5988E-18 | 5,59879E-18 | 5,59879E-18 | 5,59879E-18 | 5,59879E-18 |
| | (Micron) | $F_B$ | 7,05756E-19 | 6,74937E-19 | 1,34987E-18 | 1,61389E-18 | 2,43368E-18 | 4,31672E-18 | 7,0576E-19 | 6,7494E-19 | 1,34987E-18 | 1,61389E-18 | 2,43368E-18 | 4,31672E-18 |
| Low | 0,1 | $F_D$ | 4,89303E-18 | 4,92385E-18 | 4,24892E-18 | 3,9849E-18 | 3,16511E-18 | 1,28207E-18 | 5,304E-18 | 5,3348E-18 | 4,65984E-18 | 4,39582E-18 | 3,57603E-18 | 1,69299E-18 |
| | | $F_C$ | 1,4499E-13 | 1,4499E-13 | 1,4499E-13 | 1,4499E-13 | 1,4499E-13 | 1,4499E-13 | 1,4499E-13 | 1,4499E-13 | 1,4499E-13 | 1,4499E-13 | 1,4499E-13 | 1,4499E-13 |
| $N_{Re}$ | Diameter | $F_G$ | 4,47903E-17 | 4,47903E-17 | 4,47903E-17 | 4,47903E-17 | 4,47903E-17 | 4,47903E-17 | 4,479E-17 | 4,479E-17 | 4,47903E-17 | 4,47903E-17 | 4,47903E-17 | 4,47903E-17 |
| | (Micron) | $F_B$ | 5,64605E-18 | 5,39949E-18 | 1,0799E-17 | 1,29111E-17 | 1,94694E-17 | 3,45337E-17 | 5,646E-18 | 5,3995E-18 | 1,0799E-17 | 1,29111E-17 | 1,94694E-17 | 3,45337E-17 |
| Low | 0,2 | $F_D$ | 3,91443E-17 | 3,93908E-17 | 3,39913E-17 | 3,18792E-17 | 2,53209E-17 | 1,02566E-17 | 4,2432E-17 | 4,2678E-17 | 3,72787E-17 | 3,51666E-17 | 2,86083E-17 | 1,35439E-17 |
| | | $F_C$ | 5,79958E-13 | 5,79958E-13 | 5,79958E-13 | 5,79958E-13 | 5,79958E-13 | 5,79958E-13 | 5,7996E-13 | 5,7996E-13 | 5,79958E-13 | 5,79958E-13 | 5,79958E-13 | 5,79958E-13 |
| $N_{Re}$ | Diameter | $F_G$ | 6,99849E-16 | 6,99849E-16 | 6,99849E-16 | 6,99849E-16 | 6,99849E-16 | 6,99849E-16 | 6,9985E-16 | 6,9985E-16 | 6,99849E-16 | 6,99849E-16 | 6,99849E-16 | 6,99849E-16 |
| | (Micron) | $F_B$ | 8,82195E-17 | 8,43671E-17 | 1,68734E-16 | 2,01736E-16 | 3,04209E-16 | 5,3959E-16 | 8,8219E-17 | 8,4367E-17 | 1,68734E-16 | 2,01736E-16 | 3,04209E-16 | 5,3959E-16 |
| Low | 0,5 | $F_D$ | 9,78607E-17 | 9,84771E-17 | 8,49783E-17 | 7,9698E-17 | 6,33023E-17 | 2,56414E-17 | 6,6299E-16 | 6,6685E-16 | 5,8248E-16 | 5,49478E-16 | 4,47004E-16 | 2,11624E-16 |
| | | $F_C$ | 3,62474E-12 | 3,62474E-12 | 3,62474E-12 | 3,62474E-12 | 3,62474E-12 | 3,62474E-12 | 3,6247E-12 | 3,6247E-12 | 3,62474E-12 | 3,62474E-12 | 3,62474E-12 | 3,62474E-12 |
| $N_{Re}$ | Diameter | $F_G$ | 5,59879E-12 | 5,59879E-12 | 5,59879E-12 | 5,59879E-12 | 5,59879E-12 | 5,59879E-12 | 5,5988E-12 | 5,5988E-12 | 5,59879E-12 | 5,59879E-12 | 5,59879E-12 | 5,59879E-12 |
| | (Micron) | $F_B$ | 7,05756E-13 | 6,74937E-13 | 1,34987E-12 | 1,61389E-12 | 2,43368E-12 | 4,31672E-12 | 7,0576E-13 | 6,7494E-13 | 1,34987E-12 | 1,61389E-12 | 2,43368E-12 | 4,31672E-12 |
| Low | 10 | $F_D$ | 4,89303E-12 | 4,92385E-12 | 4,24892E-12 | 3,9849E-12 | 3,16511E-12 | 1,28207E-12 | 5,304E-12 | 5,3348E-12 | 4,65984E-12 | 4,39582E-12 | 3,57603E-12 | 1,69299E-12 |
| | | $F_C$ | 1,4499E-09 | 1,4499E-09 | 1,4499E-09 | 1,4499E-09 | 1,4499E-09 | 1,4499E-09 | 1,4499E-09 | 1,4499E-09 | 1,4499E-09 | 1,4499E-09 | 1,4499E-09 | 1,4499E-09 |
| $N_{Re}$ | Diameter | $F_G$ | 4,47903E-11 | 4,47903E-11 | 4,47903E-11 | 4,47903E-11 | 4,47903E-11 | 4,47903E-11 | 4,479E-11 | 4,479E-11 | 4,47903E-11 | 4,47903E-11 | 4,47903E-11 | 4,47903E-11 |
| | (Micron) | $F_B$ | 5,64605E-12 | 5,39949E-12 | 1,0799E-11 | 1,29111E-11 | 1,94694E-11 | 3,45337E-11 | 5,646E-12 | 5,3995E-12 | 1,0799E-11 | 1,29111E-11 | 1,94694E-11 | 3,45337E-11 |
| Low | 20 | $F_D$ | 3,91443E-11 | 3,93908E-11 | 3,39913E-11 | 3,18792E-11 | 2,53209E-11 | 1,02566E-11 | 4,2432E-11 | 4,2678E-11 | 3,72787E-11 | 3,51666E-11 | 2,86083E-11 | 1,35439E-11 |
| | | $F_C$ | 5,79958E-09 | 5,79958E-09 | 5,79958E-09 | 5,79958E-09 | 5,79958E-09 | 5,79958E-09 | 5,7996E-09 | 5,7996E-09 | 5,79958E-09 | 5,79958E-09 | 5,79958E-09 | 5,79958E-09 |
| $N_{Re}$ | Diameter | $F_G$ | 6,99849E-10 | 6,99849E-10 | 6,99849E-10 | 6,99849E-10 | 6,99849E-10 | 6,99849E-10 | 6,9985E-10 | 6,9985E-10 | 6,99849E-10 | 6,99849E-10 | 6,99849E-10 | 6,99849E-10 |
| | (Micron) | $F_B$ | 8,82195E-11 | 8,43671E-11 | 1,68734E-10 | 2,01736E-10 | 3,04209E-10 | 5,3959E-10 | 8,8219E-11 | 8,4367E-11 | 1,68734E-10 | 2,01736E-10 | 3,04209E-10 | 5,3959E-10 |
| Low | 50 | $F_D$ | 6,11629E-10 | 6,15482E-10 | 5,31115E-10 | 4,98112E-10 | 3,95639E-10 | 1,60259E-10 | 6,6299E-10 | 6,6685E-10 | 5,8248E-10 | 5,49478E-10 | 4,47004E-10 | 2,11624E-10 |
| | | $F_C$ | 3,62474E-08 | 3,62474E-08 | 3,62474E-08 | 3,62474E-08 | 3,62474E-08 | 3,62474E-08 | 3,6247E-08 | 3,6247E-08 | 3,62474E-08 | 3,62474E-08 | 3,62474E-08 | 3,62474E-08 |

| | | | | | |
|---|---|---|---|---|---|
| length inlet | D/4 | 6 | in | 0,1524 | m |
| height inlet | D/2 | 12 | in | 0,3048 | m |
| diameter | D | 24 | in | 0,6096 | m |
| area inlet | L*H | 72 | in2 | 0,0465 | m2 |
| inlet velocity | | | | 4,0000 | m/s |
| | tangential velocity = v-inlet * cos 27 | | | 3,564026097 | m/s |
| | axial velocity | | | 1,815961999 | m/s |

Using these specifications the distance in the axial direction it takes 1 revolution was calculated. Increase of revolution increases the separation efficiency as more distance is available for separation to occur. An increase to 6 effective turns would have the effect of a height to diameter ratio of around 6:1 which is not so far apart the ratio of horizontal separators. Calculation can be seen below.

| | | | | | |
|---|---|---|---|---|---|
| Perimeter | 2pi()r | | | 1,915114882 | m |
| tangential velocity | | | | 3,564026097 | m/s |
| time for 1 revolution | | | | 0,53734592 | s |
| distance vertically for 1 revolution | | | | 0,975799771 | m |
| 6 turns equals | | | | 5,854798625 | m |
| diameter | | | | 0,6096 | m |

# CONCLUSION

Available technologies for different water depths exist. Most of these separation technologies come along with a pump unit (ESP) to pump the oil further. The separation makes it possible for the gas to flow on its own to top side facility. Proof of the success of lowering the wellhead pressure for an increase of oil production is present. Technology based on cyclonic and swirling method proofs more compact than straight line separation. Calculations show that this effect is lower as the drops or bubbles present increase in size and also that the ratio of length to diameter of cyclone devices is similar to traditional gravity separator, only more compact. The project lacks more calculations in terms of pressure stability, loss of pressure and drag for the systems presented. But even then the information presented shows that viscosity brings forth problems in term smooth separation and inconveniences when shut-off. By reviewing the separator technologies used, restrictions can be shown at very deep water and the industry is not willing to take proper risks yet, at least not all of them. If not then the use of the Caisson and VASPS separator would not have been chosen in light of new findings as for the case of the Pazflor and Marimba fields.

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