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# Modelling of the VIEC- a new device which aids separation

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## ABSTRACT

In the oil and gas industry large tanks, separators, are used to try to separate out oil, gas and water. The VIEC (Vessel Internal Electrostatic Coalescer), is a special kind of coalescer which can be used in an inlet separator. The VIEC causes the water droplets to join together to form bigger droplets, which then drop out of the oil more readily. The VIEC is designed in such a way that, unlike traditional coalescers, it can cope with a wide range of water content. The VIEC has been installed on Troll C, and more recently FPSO Munin which both lead to improved separation. The effect of the VIEC on the multiphase flow has been modelled by simulating water droplet growth. Experimental work has been used to verify that the CFD model simulates reality.

## NOMENCLATURE

*A – projected area of a particle in the flow*
*$C_D$ –drag coefficient*
*d droplet size*
*D-drag force*
*p- pressure*
*Re –particle Reynolds number*
*S-source term*
*t-time*
*u,v,w velocity components*
*x-horizontal coordinate*
*y-horizonal coordinate*
*z-vertical coordinate*
*$\alpha$-light opening*
*$\rho$-density*

## INTRODUCTION

When oil and gas are extracted from a well they emerge as a mixture of oil, water, gas, solids and other components. One of the challenges that the oil and gas industry faces today is to separate out the useful from the unwanted parts, and dispose of the unwanted parts in an environmentally friendly way. It is, for example, not acceptable to dump unwanted water to sea if there is still a significant proportion of oil within it.

One technique which has been used by the oil and gas industry is to use large vessels, called separators, which largely rely on gravity to separate out the oil, water and gas. Usually a series of tanks are used, with the first being called the inlet separator. A significant amount of work has been done over the years on making separators more efficient. One method is to use an electrostatic coalescer, which encourages the dispersed phase droplets to grow in size. However, traditional coalescers are not able to be fitted in the inlet separator due to highly turbulent conditions. In addition they can be susceptible to short-circuiting if any free gas or water exists. However, a new piece of equipment, the Vessel Internal Electrostatic Coalescer (VIEC) has been developed which can be fitted in the inlet separator.

It is very important that when any piece of equipment is fitted inside a separator, that the effect of that piece of equipment on the flow patterns is known. This paper examines the modelling by CFD of the VIEC and looks at the flow patterns which are generated. Comparison is made between the CFD results and experiments. Finally a discussion is presented on how the CFD model has been used to help a field installation.

## THE VIEC

When oil comes out of a well it does not come out as a pure substance, but mixed with gas, water, solids and pollutants. One particular problem is that when the oil and water mix, an emulsion forms. This emulsion may be extremely tough to split into its components. In addition even basic knowledge of its properties, such at viscosity, may be difficult to determine.

The VIEC is a piece of equipment which is installed into a separator which helps to break up the emulsion. The VIEC is installed in a manner as demonstrated in Figure 1.

The VIEC is made up of a series of blocks which have slits through which the liquids travel, see Figure 2. Within the blocks themselves are positioned electrodes which are completely sealed off from the liquids.

As the oil and water mixture passes through the elements the droplets of water become charged and form dipoles. The droplets then become attracted to each other and start to form bigger droplets. The larger the droplets that are formed, the larger the drag force on the droplets of water and hence they are more likely to to sink to the bottom of the flow. It has been found experimentally that the average droplet diameter can increase by up to a factor of 10.

As the VIEC increases the separation greatly, it is generally so that initially there is less separation upstream the VIEC and greater separation downstream the VIEC as shown in Figure 1. However, after the VIEC has been operational for some time the fluid flow tries to balance out the pressure difference between up- and downstream the VIEC, and some clean oil flows back through the

VIEC at the top, and water at the bottom. This particular phenomena is something that is not special to the VIEC but can happen when any severe stratification occurs, for example if the oil were very light. In the Vetco laboratory a plexiglass separator has been built in which a VIEC has been installed. When the VIEC is switched on this backflow can be seen. It is this feature which we try to reproduce using CFD.

## MODELLING

The modelling is done using CFX 5.7. In modelling the VIEC two factors must be taken into account: Firstly the VIEC produces a resistive force to the flow, and secondly the VIEC makes the droplets of water grow in size.

We begin by looking at the resistive force caused by the porous nature of the VIEC. Formulae exist (see Blevin, 1992) for the pressure drop for flow through a grill. The pressure drop is proportional to velocity squared. In the case where the VIEC is not very long, $u$ is the approach velocity and $\alpha$ is the porosity of the VIEC:

$$\frac{\Delta p}{\Delta x} = -\frac{0.5\rho K u^2}{\Delta x} \qquad (1)$$

where

$$K = \frac{0.5(1-\alpha) + (1-\alpha^2)}{\alpha^2} \quad (2)$$

We will solve the standard Navier-Stokes equations using CFX. The equations to be solved are:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0 \ (3)$$

and

$$\frac{\partial \rho \mathbf{u}}{\partial t} + \nabla \cdot (\rho \mathbf{u}\mathbf{u}) = -\nabla p + \nabla.\mu\nabla \mathbf{u} + S \ (4)$$

where S is a source term. In this case where gravity is present it will be included as a source term.

Now we consider the resistive force of the plates. The gradient of the pressure is equivalent to the momentum lost due to the porosity of the region and is equivalent to adding in a source term corresponding to equation (1) into equation (4) within the porous region. It should be noted here that the resistive term is mainly in the direction of the flow (horizontal), but that there will be some resistance in the perpendicular directions which, from experience, have been set to 15% of the magnitude in the direction of flow.

Next we will consider modelling the coalescence. We will model the flow with an eulerian-eulerian inhomogeneous particle model where we will take the water to be the dispersed phase and the oil to be the continuous phase. Momentum is transferred between the phases due to interfacial forces. The largest contribution of the increase in droplet size on the equations of motion is via the drag force. This drag force causes momentum to be transferred between the phases.

The magnitude of the drag force on a droplet, D, is given by:

$$D = 0.5 C_D \rho_\alpha (U_\alpha - U_\beta) A \ (5),$$

where $U_\alpha$-$U_\beta$ is the relative speed of the phases, A is the projected area of the particle in the flow, and $C_D$ is the drag coefficient. Note here that

$$A \propto d^2 \ (6),$$

where d is the droplet size.

For this study we assume that the particles can be modelled as spheres and use the Schiller Naumann correlation where $C_D$ is given by:

$$C_D = \frac{24}{\mathrm{Re}}(1 + 0.15\,\mathrm{Re}^{0.687}) \ (7)$$

where Re is the particle Reynolds number and is proportional to the dispersed phases droplet diameter. Providing Re is small this is a good approximation.

Hence as d increases so does the drag force between the phases and so the bigger droplets of water drop out more readily from the oil.

Solving extra equations in the Navier-Stokes solver can be extremely computationally expensive. Hence, a simple model of droplet growth is used here. From experimental evidence we assume an ‘average’ drop size of 600µm before the VIEC and that after the VIEC the dropsize has increased to 3000µm.

The flow enters the separator via an inlet cyclone. It is assumed that the inlet cyclone has worked 100% effectively and that only water and oil comes out of the bottom of the cyclone and into the separator.

## RESULTS

We begin by modelling a separator which does not have the VIEC present. If we examine figure 3 then we can see the phase distribution through the separator when no coalescence takes place.

The black part on the left hand side of the separator figure is the inlet cyclone, and the gray vertical stripes are porous baffle plates. Note that here we show only the bottom part of the separator where the oil and water are present. We can see here that a large portion of the phase distribution is shown by pale blue / green. This corresponds to an oil-water emulsion layer. This particular form of flow will occur if the oil is particularly heavy or the flow rates high. Next, we examine the flow velocities for the water phase, see figure 4.

Here we can see that the flow is relatively smooth with all flow in a left-to-right direction. The arrows tend to have a downwards direction as the water is tending to settle to the bottom of the tank.

We will examine what happens after the VIEC has been installed and running for some time, as shown in figure 5.

The VIEC is shown by a dark red semi-circle and blue plates denote porous regions. Here we can see that the separation is now very strong. In fact to the right of the VIEC there is very little green emulsion. One important thing to note here is that if we compare figure 3 and 5 and look at the flow before (to the left of) the VIEC we can see that there has been some backflow of clean oil and water through the VIEC and baffle plate. This is something which has also been observed experimentally.

If we now examine figure 6, which is a velocity vector plot of the flow after the VIEC has been switched on then we can see that the flow is no longer all in the left to right direction. If we zoom in a little (see figure 7) to the flow just after the VIEC then we can see a strong backflow.

This is something that occurs whenever strong separation occurs, whether it is from coalescence or a light oil. This can be seen more clearly if the magnitude of the velocity in the horizontal direction is plotted, see figure 8. Here we can see a strong blue patch at the bottom of the tank after the VIEC. This corresponds to the backflow. This backflow was also seen experimentally.

Whilst this backflow clearly does not hamper the separation too much (as seen by the good separation in figure 5), it is not ideal. We now consider the effect of putting in a set of double perforate baffles a short distance away from the VIEC. If we examine figure 9, which is the horizontal velocity with the extra plate and compare with figure 8 then we can see that the backflow of water has been very much reduced.

## FPSO MUNIN

This model was then used to help design an installation of the VIEC onto the FPSO (Floating Production, Storage Offshore) Munin owned by Bluewater. The separator in question was due to have a large increase in flow rate. To cope with this a VIEC was installed. A CFD study was carried out and the inlet device was shown to create a very uneven flow pattern within the separator, see figure 10. The inlet device was re-designed by replacing it with a T-piece inlet. A new CFD study was carried out, and smooth flow patterns were observed. If we examine figure 11 and compare with figure 10 (which have the same scale) we can see that a much more even flow pattern is achieved.

Finally, if we look at figure 12 we can see the separation in the FPSO Munin installation.

The installation on Munin was a success, meeting oil and water quality requirements.

## CONCLUSION

The CFD model of the coalescence due to a VIEC installation was shown to successfully simulate backflow seen experimentally. In general, fluid flows in the simulations were seen to be very similar to those seen experimentally. The CFD model has been used to successfully design the separator inlet and layout of a VIEC installation on an FPSO.

## REFERENCES

BLEVINS, R. D. (1992) Applied Fluid Dynamics Handbook

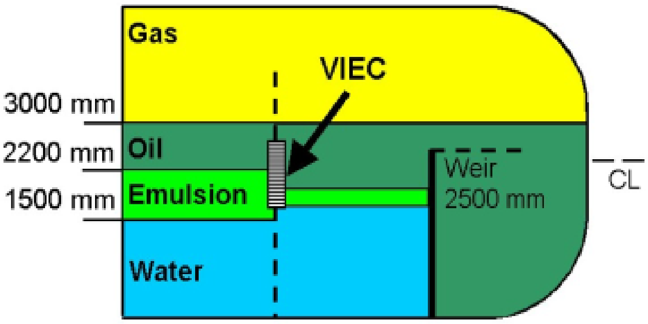

**Figure 1** Position of the VIEC, flow from left to right

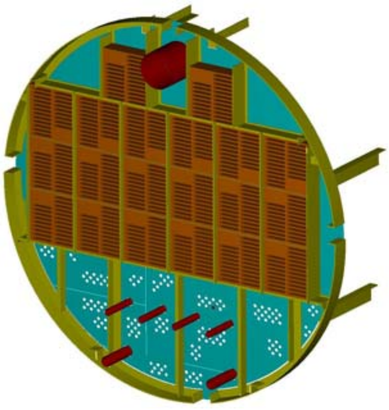

**Figure 2** VIEC elements with supporting frame installation, perforated plates above and below

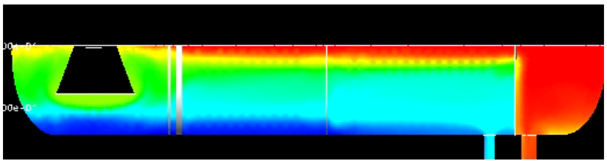

**Figure 3** Separator flow before coalescence (VIEC), red=pure oil, blue=pure water

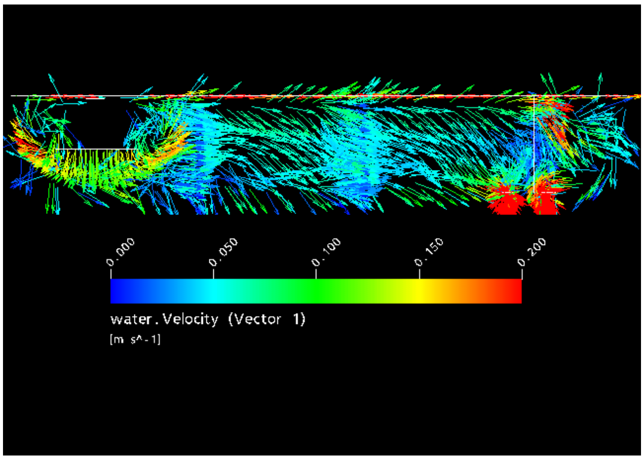

**Figure 4** Water velocities before the VIEC is switched on

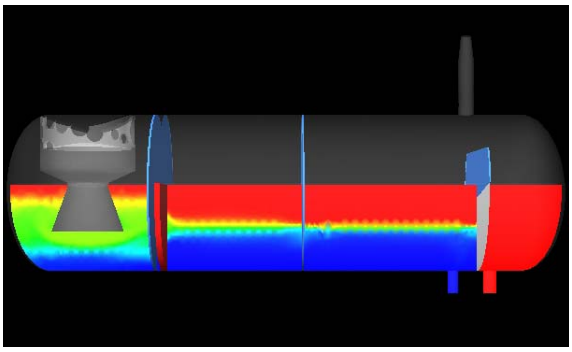

**Figure 5** Separation after the VIEC has been running for some time

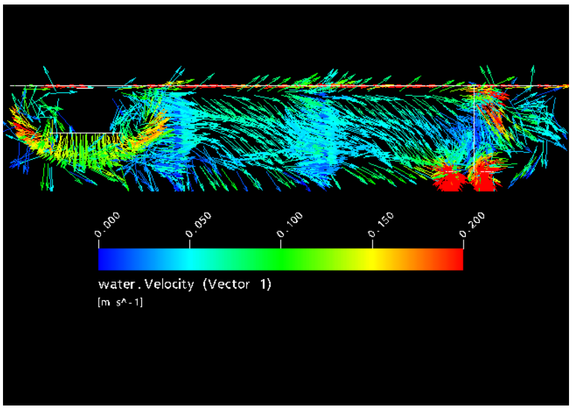

Figure 6 Water velocities after the VIEC is switched on

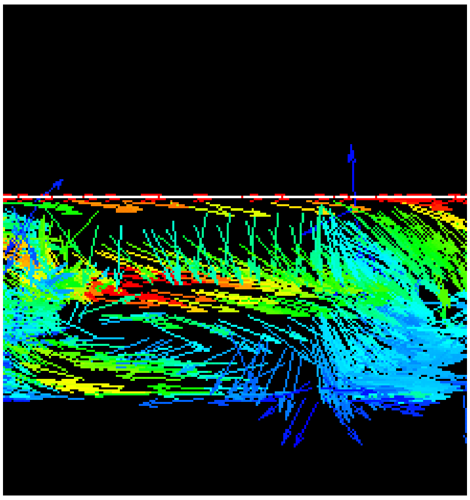

Figure 7 Backflow after the VIEC

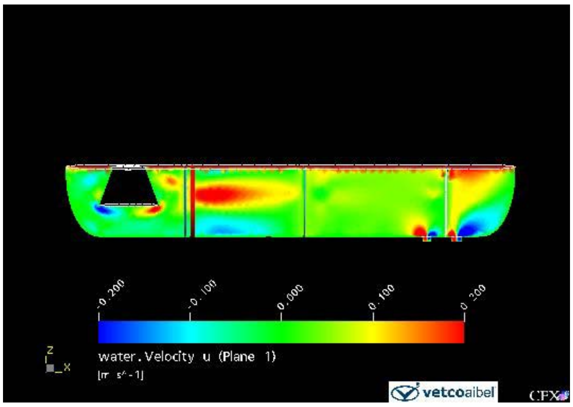

Figure 8 Horizontal velocity with the VIEC. Red=flow from left to right, Blue=flow from right to left

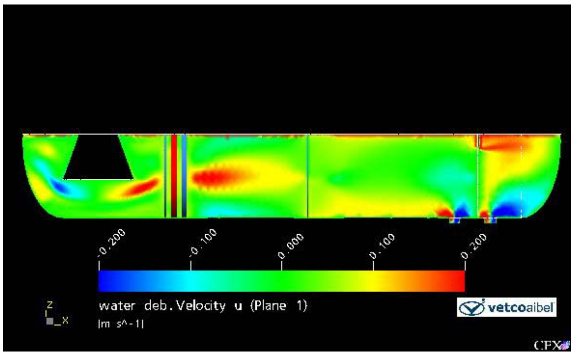

Figure 9 Horizontal velocity with the VIEC and extra plate. Red=flow from left to right, Blue=flow from right to left

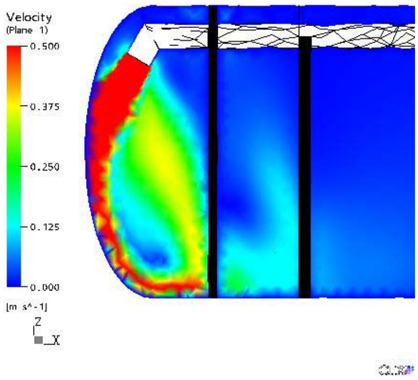

Figure 10 Velocity magnitude near inlet for FPSO Munin separator with new inlet

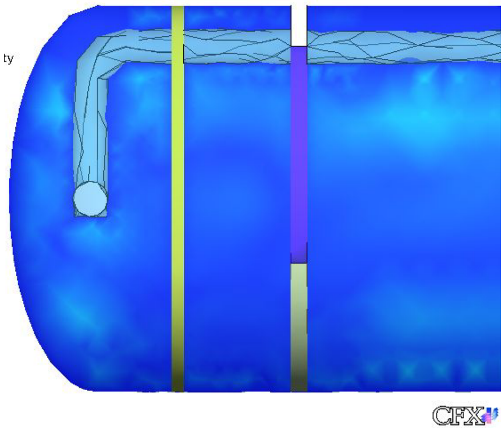

**Figure 11 Velocity magnitude near inlet for FPSO Munin separator**

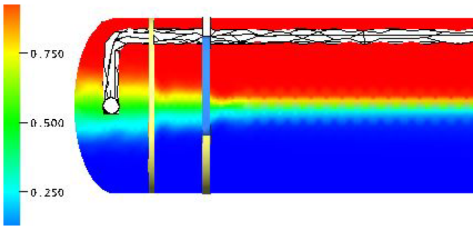

**Figure 12 Phase distribution in FPSO Munin separator with VIEC installed**