FLEXIBLE HEAT EXCHANGE SOLUTIONS FIT FOR LIFETIME OPERATION OF OIL & GAS PRODUCTION FACILITIES

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ABSTRACT

Oil and gas production facilities will experience many changes in the operating conditions during the life of the facilities. It would be advantageous if the equipment installed within the process would incorporate an inherent capability to adept to the various changing process conditions and still provide the desired process and mechanical functions.

This paper describes flexible heat exchange solutions fit for lifetime operation of oil and gas production facilities. This flexibility includes the ability to handle changes in flow rates, relative concentrations of oil, gas and produced water as well as changes in the physical and thermal properties of the bulk fluids.

This paper is based on several years of active participation in oil and gas facility conceptual evaluations, detailed designs, redesigns, debottle-necking studies as well as feed back from operating facilities.

The plate and frame heat exchanger concept provides many benefits for the facility operator; besides the direct weight and space savings, the exchanger concept also provides process flexibilities in that the plate and frame heat exchanger can be re-sized several times during the life of a facility for various process situations and thus assist in providing a better quality crude oil, using less utilities and requiring less maintenance.

INTRODUCTION

As illustrated in Fig. 1, the crude oil and produced water flow rates will vary during the various phases of the life of an offshore or onshore oil production facility.

During the early production the crude oil will be very dry with only a small amount of produced water. Later on, produced water will break through and the water cut (% of produced water by volume in the crude oil) in the incoming well streams will increase. During the latter phase, the water rate may far exceed the crude oil rate. Besides the changes in the relative concentrations of oil, water and gas, the total fluid flow can also change.

It is more or less impossible to accurately size the production facility to perform at its optimum at every time period during the life of the facility with a single set of process equipment. Most equipment will need to be sized for a number of cases, such as max flow, min flow, max viscosity and for heat exchangers also max and min duty.

Heat is added, removed and / or interchanged at various places within the process. The heat exchange demand will also vary during the life of the offshore facility and thus the duty of the individual heat exchangers will also vary with time.

Utilizing the inherent flexibility of a plate and frame heat exchanger, the heat transfer area can be adopted to new or unexpected conditions. Plates can be added, removed or replaced with plates with a different pattern. If required, plates can be swapped between different plate and frame heat exchangers in different locations at the same facility or between different facilities. All process connections are located at the front side of the heat exchanger and thus it is very easy to resize the heat exchanger 'in-place', without changing the footprint of the exchanger.

Fig. 2 shows two plate and frame heat exchangers installed in crude oil service at an offshore platform in Louisiana, USA. As can be seen, the frames include space for future expansion of the heat exchanger size.

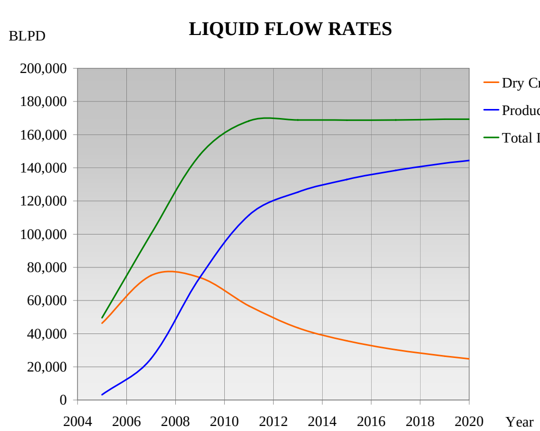

Fig. 1 Example of oil and produced water profiles

Fig. 2 Heat exchanger offshore installation

FLOW RATE PROFILES

As shown in Fig. 1, the crude oil and produced water flow rates will change considerably during the life of an offshore or onshore facility.

The liquid flow rates are often expressed as 'barrels oil per day' (bopd) or 'barrels liquid per day' (blpd). The first expression is the net amount of oil produced from the facility and the latter is the amount of liquid (oil plus produced water) required to be handled by the facility in order to produce the net crude oil flow rate. The following listing includes some specific examples of the changes that can be encountered:

- change in the total volume of fluids produced
- change in the water cut of the incoming crude oil
- change in the gas / oil ratio
- change in the API gravity of the oil and / or produced water salinity, due to different flow rates from different formations (wells)
- change in the process temperature and pressure, as different parts of the formation is depleted and / or new wells added

Since the Free Water Knock Out vessel becomes much more effective for higher water cuts (above the inversion point for heavier oils), the relative flow rates within the facility will also change.

A different way of looking at Fig. 1 would be to look at the total flow rate and the water cut of the incoming crude oil as illustrated in the Fig. 3 below.

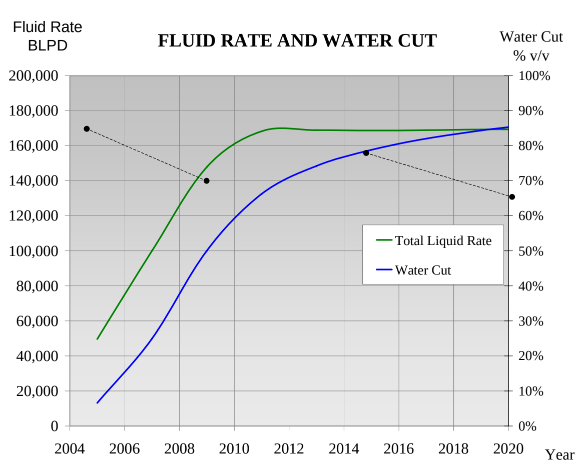

Fig. 3 Examples of water cut variations

The main function of an offshore platform is to lift the crude oil and gas to the surface facility and to deliver a dry oil / dry gas into the export pipeline / export tanks. Secondary functions are produced water deoiling, power generation, fresh water generation and providing a habitat for the crew that operates the facility. If the crude oil and the associated gas came out of the ground in a dry state forever, the offshore facility could be eliminated.

CRUDE OIL EMULSION PROPERTY CHANGES

Since water has much higher heat transfer properties than crude oil, it is important to know the crude oil emulsion properties in order to correctly size the individual heat exchangers. The wet crude oil contains associated gas and produced water, and thus the fluid properties to apply during the heat exchanger design will require some consideration. The output from simulations like HYSIS, provide the properties for the aqueous, hydrocarbon and vapor phases separately. To correctly size the heat exchanger, the oil / water emulsion properties should be considered as well as any remaining free water, the vapor fraction and the gas release due to decrease in process pressure and sometimes increased temperature.

a) Crude oil emulsion viscosity

Most of the time, the heat exchanger data sheets provide the viscosity data for the crude oil and the produced water separately. By using the crude oil viscosity directly, the emulsion viscosity can be grossly underestimated. Fig. 4 shows crude oil emulsion viscosity variations as a function of the crude oil water cut at a specific temperature and gas / oil ratio.

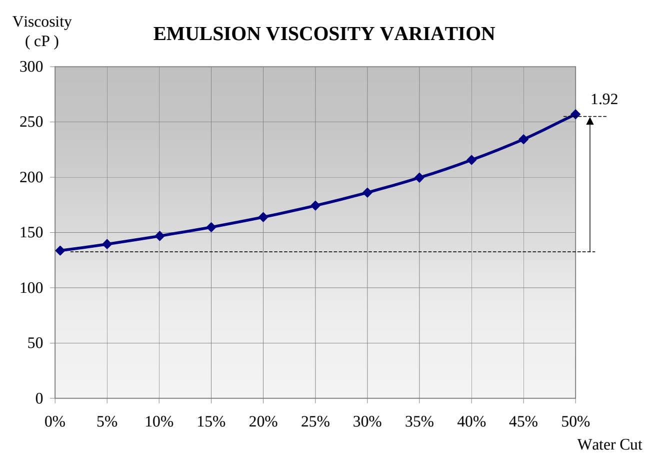

Fig. 4 Crude oil emulsion viscosity variation as a function of water cut

The emulsion viscosity at 50% water cut is 92% higher than the dry crude oil viscosity in the example shown. This will have a drastic effect on the heat exchanger design; both on the required surface area and also on the pressure drop across the exchanger.

The viscosity increase would be further accentuated by the presence of small produced water droplets in the emulsion from artificial lift like electric submersible pumps or gas lift.

b) Crude oil emulsion specific heat

The specific heat of the emulsion would be expected to increase with increased water cut, since the produced water has almost twice the specific heat compared with the crude oil. This is confirmed by the curve in Fig. 5. The specific heat for the emulsion is 52% higher at 50% water cut, compared with 'dry oil' (0.5% water cut). In this case, the increase in specific heat is almost proportional to the water cut of the emulsion.

Crude oil emulsions with lower produced water salinity have a higher increase in specific heat, since it is primarily the water and not the salt in the produced water that provides the heat transfer.

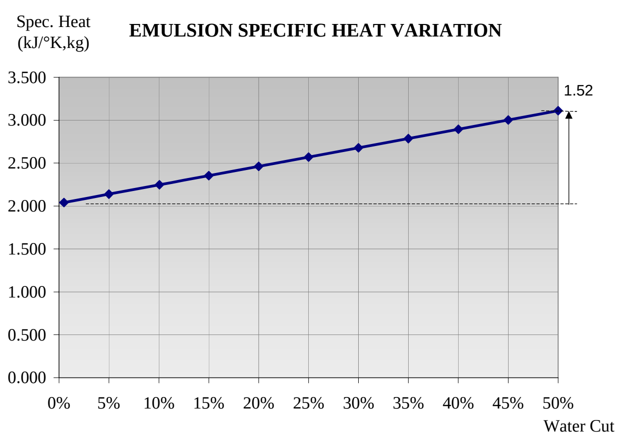

Fig. 5 Crude oil emulsion specific heat variation as a function of water cut

c) Crude oil emulsion thermal conductivity

The thermal conductivity of the emulsion is also likely to change with the water cut, since the produced water has much higher thermal conductivity than the crude oil.

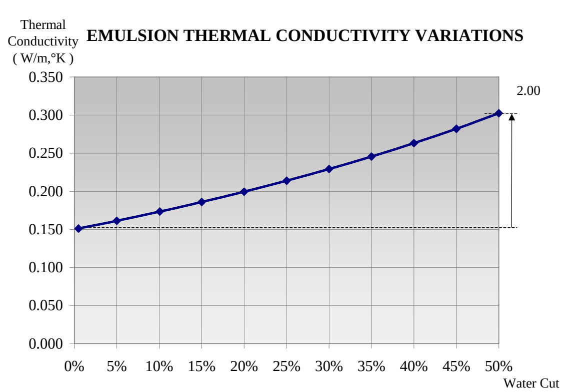

Fig. 6 Crude oil emulsion thermal conductivity variation as a function of water cut

In this example, the thermal conductivity doubled for 50% water cut, compared with dry oil.

d) Crude oil emulsion density

The emulsion density is a linear function of the crude oil and produced water ratio.

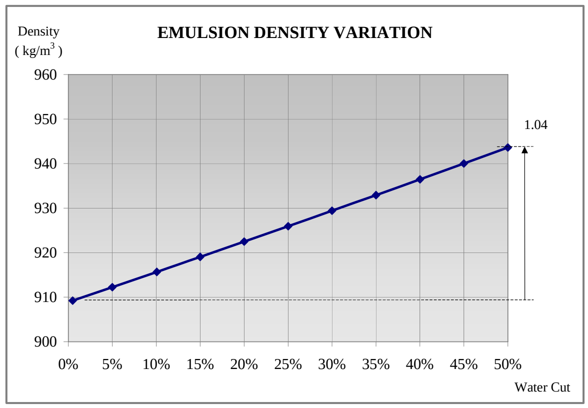

Fig. 7 Crude oil emulsion density variation as a function of water cut

Since the crude oil and produced water densities are relatively close to each other for crude oils with an API gravities below 40, the emulsion density does not change much with increased water cut for. In this example, the emulsion density increased by 4% when the water cut increased from 0.5% to 50%.

e) Free water in the crude oil emulsion

Produced water that is not bound in the emulsion will retain its normal physical properties. These will have to be considered together with the emulsion properties to make up the total liquid phase physical properties.

f) Associated gas and gas release

Associated gas will influence the pressure drop across the heat exchanger significantly, since the pressure drop is a function of the volumetric flow. A reduction of pressure inside the heat exchanger may lead to additional gas being released and heating may result in partial vaporization. This is normally not a linear effect, a simulation program will provide the heat release curve, from which data can be used to calculate the effect of gas release and partial vaporization.

The gas / oil ratio normally varies during the life of the field and also depending on whether all gas is exported or a fraction is reinjected to assist retaining the reservoir pressure.

HEAT EXCHANGER POSITIONS

The heat transfer needs within the primary crude oil production process are:

- heating the crude oil emulsion to improve the oil / water separation process
- cooling the dehydrated crude oil to stabilize the oil

In a highly effective heat exchanger as the plate heat exchanger, it is normally justified to combine the heat transfer needs by introducing an interchanger where the incoming crude oil emulsion is heated by means of cooling the export crude oil. If the water cut is very high, a second interchanger can be used, where the crude oil emulsion is further heated by means of cooling the produced water. Since the plate and frame heat exchanger can be operated in a pure counter current flow, it will be very efficient as an interchanger as crossing temperatures are allowed.

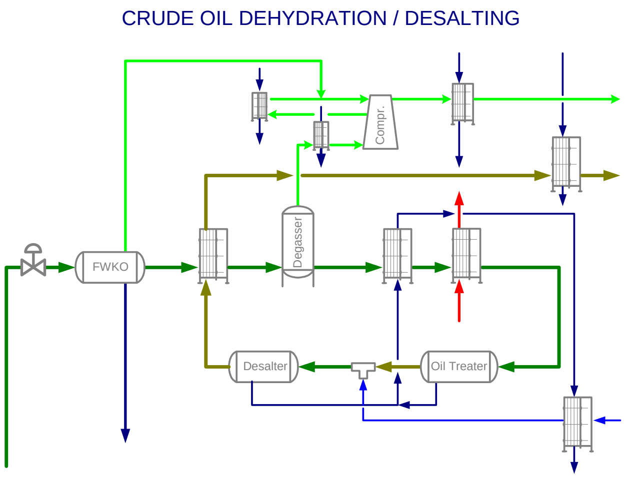

Fig. 8 Heat exchanger positions within a typical crude oil production process

THE EXPANDABLE HEAT EXCHANGER

As described in the previous sections, the offshore and onshore oil production facilities will experience large variations in the:

- total liquid volumes produced
- relative production volume of oil, produced water and associated gas
- fluid physical and thermal properties

over the life of the facilities. It is common that the facilities will have to undergo 'debottle-necking' exercises several times after the facility has been commissioned, in order to further optimize the process based on the present process conditions.

The above criteria puts variable design demands on the heat exchangers installed. Thus the process demands for the heat exchangers during the first two years of operation may be drastically different than the process demands five – six years later.

Compact gasketed and semi-welded plate and frame heat exchanges offer flexible solutions to the above problem, since the heat exchangers can be opened and additional plates be added to an existing frame. This is not the case for conventional shell and tube heat exchangers.

The plate heat exchangers are very compact due to their high thermal efficiency. This can be attributed to the thin plate thickness, narrow channels, turbulent like flow inside the exchanger, higher shear stress and the enlarged surface area due to the corrugation of the plates. The countercurrent flow within the exchanger allows for very narrow temperature approaches and also crossing temperatures. This results in fewer plate and frame heat exchangers would be required, compared with heat exchanger solutions using shell and tube type heat exchangers.

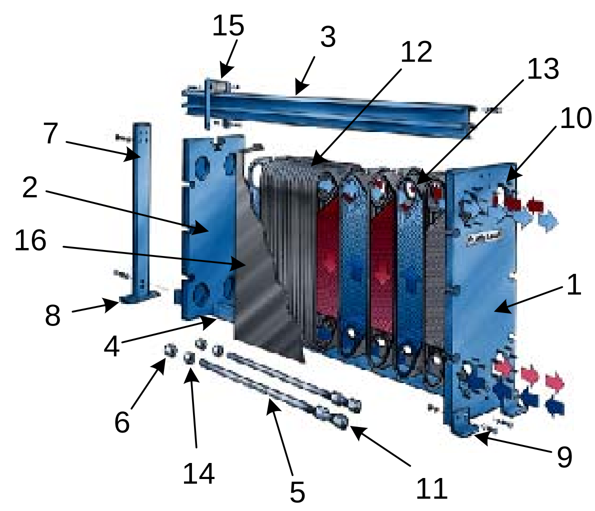

Fig. 9. Plate and frame heat exchanger design

The design of the plate and frame heat exchanger is depicted in Fig. 9. The heat exchanger is made of a series of thin corrugated alloy plates, which are gasketed and compressed together in a carbon steel frame, to create a series of parallel flow channels where the heat transfer takes place. The stiffness of the fixed and movable covers provide a uniform compression of the interplate gaskets, through the tightening rods acting on the outside of the covers. The 5-point guide system also assures that the plates are properly aligned. The ports at the four corners of the plates act as fluid distribution headers and the interplate gaskets direct the fluid flow in addition to provide the primary seal for the exchanger. The hot and the cold fluids will travel in the odd and even number channels respectively.

As a result of the high thermal efficiency, the plate heat exchanger will occupy less footprint and weigh much less than a conventional shell and tube heat exchanger. This is very important as the oil and gas industry is moving into deeper waters and use ballasted facilities. The topside process facility can thus be made much smaller through the use of compact heat exchangers and other compact process equipment, with obvious savings in costs and weights / required foot print. Similarly, an existing process facility can be expanded to higher production capacity through the use of compact process equipment, without the need to add additional deck space and / or structural reinforcements.

Table 1. Heat Exchanger Parts

1. Fixed Cover	9. Frame Foot
2. Movable Cover	10. Stud Bolt
3. Carrying Bar	11. Bearing Box
4. Guide Bar	12. Plate Pack
5. Tightening Bolt	13. Gasket
6. Tightening Nut	14. Lock Washer
7. Support Column	15. Roller Assembly
8. Support Foot	16. Shroud

Fig. 10 shows two different sets of heat exchangers for the same duty. As can be seen, the facility savings of using a plate and frame type heat exchanger solution would be:

- 86 % less operational weight
- 87% less installation footprint
- 89% less installation and maintenance footprint

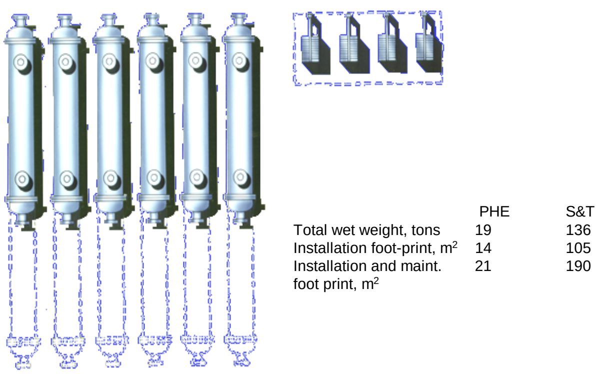

Fig. 10 Two sets of exchangers with identical duty, but very different size and weight. Crude oil coolers for North Sea project, from the early 80's.

The plates inside the plate and frame exchanger are normally made of stainless steel or Titanium, but can be made of other materials, such as high Nickel alloys. The specific material is selected to prevent corrosion. By avoiding corrosion and also by maintaining a high shear stress, the plate and frame heat exchanger is very resistant to fouling. The design also allows for quick and efficient cleaning, either mechanical or chemical.

The plate types can further have different pressing patterns and pressing depths.

The plates are currogated to:

- make the plate rigid
- promote turbulent like flow
- create contact points for strength
- provide more heat transfer area

The turbulent like flow inside the heat exchanger is caused by the fluid being deflected each time it encounters another corrugation. This has two benefits for the heat exchanger:

- increased heat transfer rate, since the boundary layer is minimized
- self cleaning effect, since the turbulent like flow will help preventing deposits on the plates

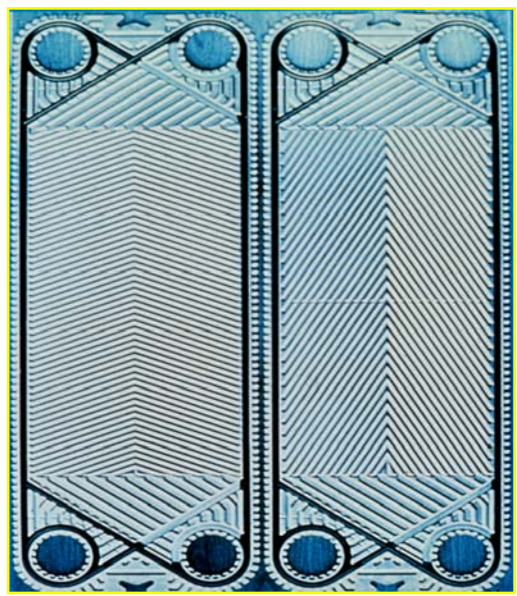

Fig. 11 Heat transfer plates

Fig. 11 shows two different plate pressing patterns for less viscous and for more viscous fluids. The plate on the left provides better heat transfer and a higher pressure drop. The plate on the right is used where more viscous fluids require a low pressure drop. Note the different angles for the Chevron patterns.

Fig. 12 illustrates how a single heat exchanger can be optimized for flow rates between 60,000 and 180,000 blpd, by simply adding additional plates to the same heat exchanger frame.

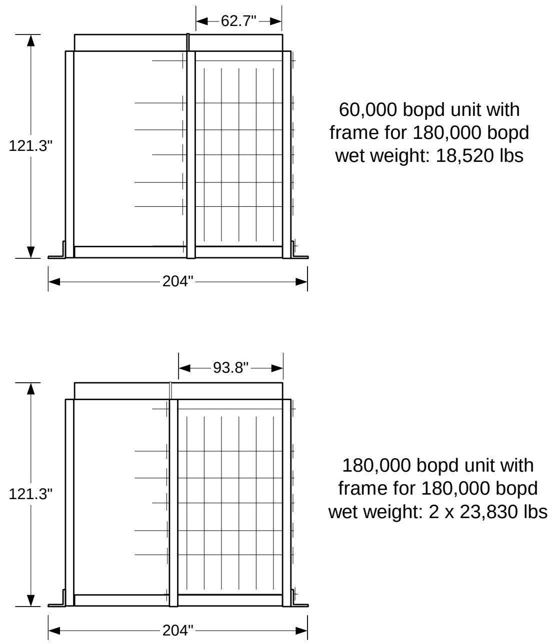

Fig. 12 Variable heat exchanger design

The initial exchanger was 5.2 m long and had a wet weight around 8,000 kg, for a total flow of 60,000 bopd during phase one. Two identical exchangers were installed for 100% duty / stand-by operation.

During phase two the production would expect to increase to 180,000 bopd. The first exchangers could be reused with an addition of 50% plates, in addition to one identical exchanger added. Thus three identical exchangers would be installed for 2 x 50% duty and 50% stand-by.

The heat exchanger could thus handle three times higher flow rate, with the investment of only 50% more deck space on the offshore facility.

SIZING FOR VARIOUS WATERCUTS

In the below analysis, the physical properties from Fig. 4 through Fig. 7 have been used together with flow rates and water cuts from Fig. 3. The resulting heat exchanger demand can be viewed in Table 2.

The duty for this exchanger position is heating a crude oil emulsion from 59.3°C to 79.4°C using a Glycol solution with 90°C temperature. The LMTD is 16.6°C.

Table 2 summarizes the heat exchanger details. Typical overall heat transfer coefficient is 890 W/m^2,°C for this exchanger, with 100 kPa pressure drops.

Table 2 – Heat Exchanger Details

Total Fluids blpd	Water Cut %	Heat Load MW	Heat Transfer Area m^2	Model & No. plates
75,000	15	6.07	416	1 x PH14 226 pl.
125,000	37.5	13.11	905	1 x PH14 492 pl.
150,000	60	17.54	1468	1 x PH14 798 pl.
150,000+	The emulsion downstream the FWKO is assumed to have constant composition, once the FWKO influent is above the inversion point.			

In the above example a single plate and frame heat exchanger can be used, possibly with 100% back-up, with the addition of more heat transfer plates during the shut-downs of the summers of 2008 and 2010.

It is assumed that the emulsion downstream of the FWKO (Free Water Knock Out) vessel remains relatively constant with regard to fluid properties, once the FWKO incoming emulsion has exceeded the inversion point, which for this particular crude oil is around 60% v/v.

This shows that the heat exchanger position can be optimized several times during the operational life of this facility. This will have the following benefits for the operator:

- reduced consumption of heat media, since the exchanger always operates at its optimum point
- deferred capital expenditure, since most of the heat exchanger plates can be purchased later
- better heating of the crude oil and better performance of the downstream separators
- less maintenance, since the heat exchangers will operate at their design shear rates and stable wall temperatures, resulting in less fouling

In most installations that don't use compact heat exchangers for this service the exchangers are typically excessively oversized, so that they rarely operate at design conditions and thus have higher fouling rates than would normally be experienced.

FEEDBACK FROM OPERATING EXCHANGERS

The plate and frame heat exchangers shown in Fig. 2 are part of a group of four exchanger positions operating on medium API gravity crude oil (heating, interchange and cooling), installed in 1994 / 1998 at EW-873A in the Gulf of Mexico. Each exchanger position was designed for 100% duty and 100% stand-by operation. All units have Titanium plates and hydrogenated Nitrile gaskets. All units have operated continuously since they were installed, without any need to open and clean the units. The design includes pre-strainers with a max opening smaller than 40% of the gap inside the channels between the plates. The original design was for 35,000 bopd and peaked above 80,000 bopd in 1999. To cope with this higher flow rate, both exchangers were operated in parallel in addition to an upgrade in the heat media system.

The plate and frame heat exchangers depicted in Fig. 10 were installed on three concrete deepwater platforms in the Norwegian sector in the North Sea in the early 80's. Originally the Alpha platform was fitted with shell and tube heat exchangers, but these were retrofitted in 1984 with AX30's plate and frame heat exchangers (3 x 884,000 kg/hr of crude oil). These heat exchangers cool the crude oil using seawater before the oil is transferred to the storage cells within the substructure of the platforms. The exchangers were selected for their small size, low weight and high efficiency. The crude oil flow rates and water cuts have varied over the years, as has the fluid properties due to a number of tie-backs to the original process. The plate and frame heat exchangers have been extended and the plate grouping changed several times to adjust the exchanger characteristics to the current heat exchange demands. The original frames and plate packs are still in place and service and working well according to the customer.

Plate and frame heat exchangers are also used for heating very heavy crude oil (API 11.3) in Midway Sunset, California (land based application, west of Bakersfield). The plate and frame exchangers were selected since they provide better heat transfer due to higher turbulence and also due to the fact that the plate and frame heat exchangers require less maintenance. Three exchangers in parallel heat approximately 50,000 blpd of wet crude oil emulsion (20 – 25% water cut) to approximately 200°F, using low pressure steam as heat media. The initial installation included 2 x 190 plates, which was later expanded to 3 x 295 plates. The use of Titanium plates has proven to be a good protection against aggressive water, where 316 type plates would corrode. The exchangers have been operating since the late 1980's and have been in continuous duty for five years since the last overhaul.

CONCLUSIONS AND OBSERVATIONS

The plate and frame heat exchangers can be optimally sized during the different operational phases of an offshore or onshore facility. The benefits for the facility are:

- better heat transfer and improved heating of the crude oil
- reduced weight load on the facility structure
- less footprint required for installation and maintenance of the heat exchanger
- optimally sized heat exchangers based on actual production data rather than early production forecast
- utility heat media savings
- reduced maintenance
- deferred capital costs

since the heat exchangers do not have to be over-sized.

The fact that the plate and frame heat exchanger only weighs a fraction of a conventional heat exchanger and requires much smaller footprint makes the plate and frame heat exchanger ideal for offshore facilities and especially ballasted deepwater offshore platforms.

REFERENCES

J. Marriott, 1971, *How and Where to use Plate and Frame Heat Exchangers*, Chemical Engineering

B. Magnusson, 1985, *The Origins & Evolution of the Alfa Laval Plate and Frame Heat Exchanger*, Nortstedts Tryckeri, Stockholm

S. Sjögren and I. Svensson, 1988, *Reliability of Plate Heat Exchangers in the Power Industry*, ASME/IEEE Power Generation Conference, Philadelphia, PA

J. Burley, 1991, *Don't Overlook Compact Heat Exchangers,* Chemical Engineering

N. Dhuldhoya & M. Mileo, Texaco E & P Inc., M. Faucher & E. Sellman, Alfa Laval Inc., 1998, *Dehydration of Heavy Crude Oil using Disc Stack Centrifuges*, SPE-49119.

C.Haslego & G.Polley, 2002, *Designing Compact Plate and Frame Heat Exchangers*, CEP Magazine