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Comparative Study of Crude Oil Dehydration Equipments

Enas Abu Obieda Abd El Gadir Hilal[1], Taj Alasfia Mubarak Barakat[2]

[2]Department of Chemical Engineering, Faculty of Engineering University of Khartoum Sudan (E-mail: tmbarakat@uofk.edu)

Abstract: The present study addresses all facets of an efficient, compact and environmentally acceptable crude oil dehydration operation based on three different equipments. The equipments considered for the purpose of this research are a gravity settler (liquid-liquid) separator, heater-treater system and electrostatic coalescer. Case studies present the effect of crude oil properties and operating conditions on the right decision of equipment selection. The selection is based on mathematical equations that characterize the choices of the separation system through the determination of the required size and expected efficiency. The results of this study showed that the gravity settler is most suitable for dehydration of light density (less than 850 kg/m3) and low water-cut (less than 40%) crudes. The heater-treater system is found to be most suitable when dehydration of viscous and high water cut crudes is considered. Furthermore the study concludes that the electrostatic coalescer is most suitably used for dehydration of crude oil with water cut 20% or less, as expected, because short circuiting occurs above this limit; In the cases where crude water cut is less than 20%, the electrostatic coalescer showed the highest expected efficiency with the lowest equipment size requirements.

1. INTRODUCTION

During the operation life of a petroleum production well, dry oil is produced initially followed by the onset of water, the amount of which will generally increase with time with processing reservoir depletion. This water can cause many problems in the oil processing units such as corrosion and plugging problems and increase the cost of oil processing operations. Furthermore it reduces the selling price of the crude oil. Crude oil needs to be dehydrated to a certain level to meet purchaser's limits.

In general, a dehydration process consists of the initial removal of the (often larger) part of the produced water which is not emulsified ('free' water) followed by the subsequent further treatment of the emulsified part of the oil/water mixture.

This research aims to study an oil water separation system and the most appropriate separation procedure. This study will focus on the comparative analysis between different dehydration equipments and procedures for an efficient and cost-effective operation.

2. BACKGROUND

Probably the simplest way of separating a (destabilized) crude oil/water mixture is to route it directly to storage tanks and allow the water to settle out whilst the crude is awaiting shipment. For example: settling tanks. As the water cut increases, it becomes more attractive to remove water in a continuous process rather than in a batch dehydration process. The following types of continuous dehydration equipment are commonly being used:

- Dehydration tanks.
- Coalescers.
- Centrifuges.

These equipments have different operating principles such as: gravity difference, application of heat, application of electric charge and application of centrifuge force (see table 2.1). In general, the following process steps can be distinguished in a typical oil field dehydration system.

i) Destabilization of the emulsion by injection of chemicals.
ii) Degassing in a separator and/or degassing boot.
iii) Heating (especially for heavy, viscous crudes).
iv) Coalescence of small water droplets into larger ones.
v) Settling of water.

Table 2.1 Dehydration equipment selection guidelines [1]

Equipment	Application	Particulars
Free water knockout (FWKO)type separator	For high water cut crudes where the bulk of the water separates quickly	Final crude polishing to export quality can be carried out using other methods
Dehydration type separators	For low water cut crudes where dehydration to about 1-5%water is required	Usually located downstream of FWKO separators in offshore applications
Heater-treater	Considered for dehydration of difficult emulsions or very viscous crudes	Choice based on economic arguments. can be operated at higher temps than 100C
Wash tanks	General purpose. particularly useful with higher water cut crudes	Careful design of internals required to avoid channeling
Settling tanks	General purpose. use especially where plenty of tankage is available	Not a good choice for high water cut crudes
Electrostatic coalescers	Considered when deep dehydration is required (to about 0.5% water)	More sophisticated, hence more potential problems. short-circuiting problems
Centrifuge	Suitable for deep dehydration and solid removal compact size potential for offshore application	Field tested. Cost saving. More trials required.

3. MATERIALS AND METHODS

This section focuses on the equipment selection and design/sizing guidelines for oil-water separation processes. Details of the liquid-liquid separator, heater-treater and electrostatic coalescer as described by empirical relations are given next. Furthermore efficiency calculations for each equipment will be outlined. These equations are used to evaluate the different separation systems considered to allow for the appropriate decision to be made regarding the best possible choice for a given oil-water mixture.

Empirical relations were established in equation (3.1) between two of the terms in Stokes' Law, Q/A (= flow /horizontal cross-sectional area) and $\Delta\rho/\mu$ (= density difference / (oil/water) viscosity of the continuous phase). These empirical relations [1] are in the following form:

$$(Q \div A) = a \times (\Delta\rho \div \mu)^{b} \qquad (3.1)$$

The coefficients (a) and (b) depend on the type of liquid and the dehydration performance. The above relationship forms the basis for the sizing methods for dehydration equipment.

In order to arrive at an optimum design and sizing of dehydration equipment, a number of general considerations need to be taken into account:

- Design conditions which include the flow rate and temperature.
- Nature of the feed which include density, viscosity, Emulsion stability, Droplet size distribution and gas fraction.
- Product specification which include Oil quality and Water quality.

3.1 liquid-liquid separators (gravity difference)

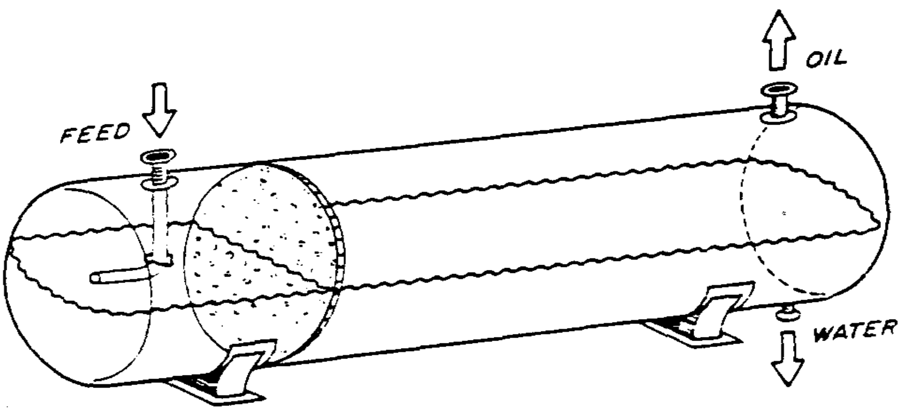

Figure 3.1 liquid-liquid separator [1]

The following data are required at the minimum operating temperature, Net oil flow q_o m^3/s, total liquid flow q_1 m^3/s, oil density ρ_o kg/m^3, water density ρ_w kg/m^3, oil viscosity μ_o Pa.s and water viscosity μ_w Pa.s

The sizing routine is as follows:

Step 1

Calculate the density difference and the ratio of density difference to oil and water viscosity [1].

$$\Delta\rho = \rho_w - \rho_o \quad (3.2)$$

$$\Delta\rho \div \mu_o \text{ and } \Delta\rho \div \mu_w \quad (3.3)$$

Step 2

Find the maximum allowable flux rates $(q_1/A)^*$ and $(q_o/A)^*$ in term of (m/s).

Liquid flux rate=1.25×10^-8 × (Δρ÷μ$_w$)

Oil flux rate=1.4×10^-6× (Δρ÷μo) ^0.6

Step 3

Calculate the minimum required horizontal cross-sectional area [1] in square meter of the separation compartment:

$$A_{h\,min} = q_1 \div (q_1/A)^* \quad (3.4)$$

$$A_{h\,min} = q_o \div (q_o/A)^* \quad (3.5)$$

Select the highest value for $A_{h\,min}$.

Step 4

Select a vessel with suitable dimensions to satisfy $A_{h\,min}$ requirement. The L/D ratio should be in the range 3 to 5 [1].

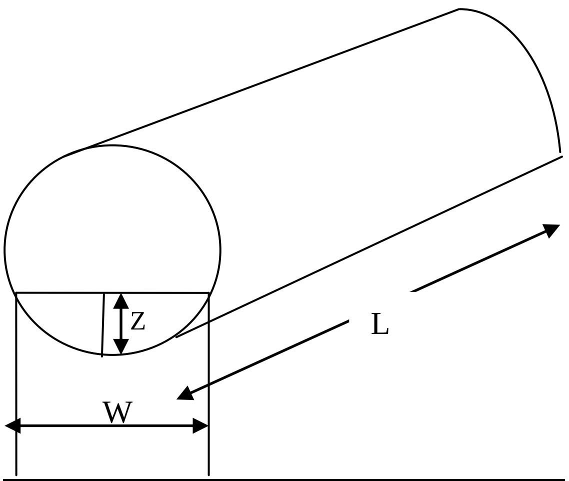

Figure 3.2 Illustration of drum critical dimensions

Step 5

Calculate the efficiency of the separation unit from the following equations.

Calculate the settling velocity of the water droplets

$$U = d^2 \times g \times (\rho_w - \rho_o) \div 18 \times \mu_o \quad (3.7)$$

Calculate the interface area, dimensions are illustrated in figure 3.2

$$A_{int} = W \times L \quad (3.8)$$

$$W = 2 \times (D \times Z - Z^2)^{0.5} \quad (3.9)$$

$$Z = 0.15 \times D \quad (3.10)$$

Calculate the amount of water settled in the equipment

$$q_{ws} = U \times A_{int} \quad (3.11)$$

Calculate the efficiency of the equipment

Efficiency= separated water ÷ water entering the system

$$E = q_{ws} \div q_w \quad (3.12)$$

3.2 Heater-treater (heat application)

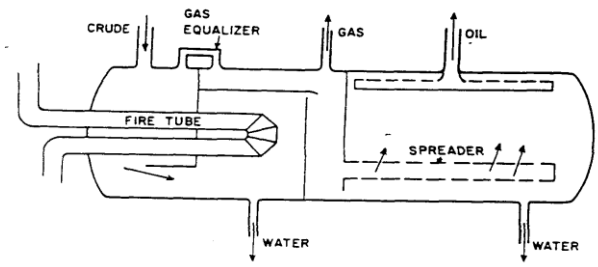

Figure 2.2 - Horizontal heater-treater [1]

In addition, the following data are also required.

Inlet temperature: t_i (°C), operating temperature: t (°C) and specific heat of crude: C_p (kJ/kg °C)

The sizing routine is as follows:

Step 1

Calculate the density difference and the ratio of density difference to oil and water viscosity [1]

$$\Delta\rho = \rho_w - \rho_o \quad (3.13)$$

$$\Delta\rho \div \mu_o \text{ and } \Delta\rho \div \mu_w \quad (3.14)$$

Step 2

Find the maximum allowable flux rates $(q_1/A)^*$ and $(q_o/A)^*$ in term of (m/s) and calculate the required horizontal cross-sectional area for the separation compartment as described in Section 3.1 for a liquid-liquid separator in dehydration service.

Step 3

Select a vessel size which satisfies the $A_{h\,min}$ requirement. The L/D ratio should be in the range 3 to 5 [1].

Step 4

Calculate the required heat input [1]

$$H = q_o\, \rho_o\, C_p\, (t - t_i) \text{ kJ/s} \quad (3.15)$$

C_p values for crude oil are given in Figure A.3

Step 5

Calculate the efficiency of the separation unit from the following equations [4]:
Calculate the settling velocity of the water droplets
$U=d^2\times g\times (\rho_w-\rho_o) \div 18\times\mu_o$ (3.17)
Calculate the interface area
$A_{int} = W\times L$ (3.18)
$W=2\times (D\times Z - Z^2)^{0.5}$ (3.19)
$Z=0.15\times D$ (3.20)
Calculate the amount of water settled in the equipment
$q_{ws} = U\times A_{int}$ (3.21)
Calculate the efficiency of the equipment
Efficiency= separated water ÷ water entering the system
$E= q_{ws} \div q_w$ (3.22)

3.3 Electrostatic coalescer (electrical charge)

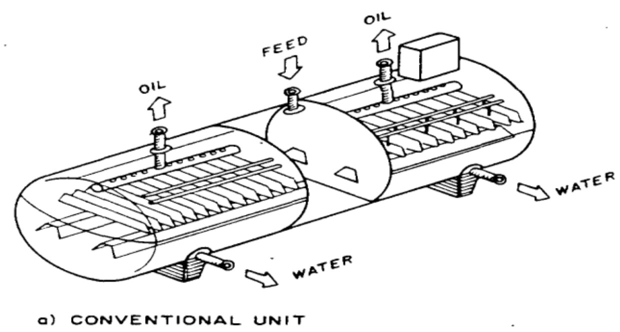

Figure 2.3 electrostatic coalesce [1]

Feed inlet water cut is usually restricted to 20% for AC and AC-DC units, and 10% for bi-electric units [2]. Otherwise short circuiting of the grids may occur. It is not usual to consider water flux rates since these are nearly always satisfied.
The following data are required at the minimum operating temperatures:
$q_o, \rho_o, \rho_w, \mu_o$
The sizing routine is as follows:

Step 1

Calculate the density difference and the ratio of density difference to oil viscosity [1]
$\Delta\rho= \rho_w - \rho_o$ (3.23)
$\Delta\rho\div\mu_o$ (3.24)

Step 2

Find the maximum allowable oil flux rate (q_o/A) in terms of (m/s).

Oil flux rate=2.3×10^-6 × (Δρ÷μo)^0.6

Step 3

Calculate the minimum required horizontal cross-sectional area in terms of square meter of the separation compartment:
$A_{h\ min} = q_o \div (q_o/A)$ (3.25)

Step 4

Select a suitable electrostatic coalescer to satisfy $A_{h\ min}$. Suitable standard sizes are given in figure A.5.

Step 5

Calculate the efficiency of the separation unit from the following equations [4]:
Calculate the settling velocity of the water droplets
$U=d^2\times g\times (\rho_w-\rho_o) \div 18\times\mu_o$ (3.27)
Calculate the interface area
$A_{int} = W\times L$ (3.28)
$W=2\times (D\times Z - Z^2)^{0.5}$ (3.29)
$Z=0.15\times D$ (3.30)
Calculate the amount of water settled in the equipment
$q_{ws} = U\times A_{int}$ (3.31)
Calculate the efficiency of the equipment
Efficiency= separated water ÷ water entering the system
$E= q_{ws} \div q_w$ (3.32)

4. RESULTS AND DISCUSSION

From the sizing routines mentioned in chapter three it is clear that the selection of appropriate dehydration equipment for a particular case depends on three principal factors:
i) The density of the crude oil.
ii) The viscosity of the crude oil.
iii) The water cut.
To study the effect of these factors on the selection of the appropriate equipment it is necessary to make the above sizing routines for the three types of the separation equipments in different ranges of oil density, oil viscosity and water cut.
The oil density ranges varies from (700-850) kg/m^3 for light crudes, from (850-900) kg/m^3 for medium crudes and from (900-970) kg/m^3 for heavy crudes [1].
The oil viscosity range selected for the purpose of this study varies from (0.009-0.05) pa.s which is expected to be low viscosity, (0.05-0.1) pa.s which is expected to be medium viscosity and from (0.1-0.5) pa.s which is expected to be high viscosity.

The water range selected for the purpose of this study varies from (5%-20%) which is expected to be low water cut crudes, (20%-40%) which is expected to be medium water cut crudes and from (40%-60%) which is expected to be high water cut crudes.

Table 4.1 Oil-water properties at minimum operating temperature 50°C [6], [7]

Oil-water Properties	Value
Total liquid flow q_1	20 m^3/hr =0.00556 m^3/s
Net oil flow q_o	0.00445 m^3/s
Oil density ρ_o	832.01 kg/m^3
Water density ρ_w	988.0 kg/m^3
Oil viscosity μ_o	0.018836 Pa.s
Water viscosity μ_w	0.000547 Pa.s
Water droplet diameter	200 μm
Water droplet diameter after the effect of electric charge (in the electrostatic coalescer)	320 μm

Table 4.2 Oil-water properties at heating temperature 70°C [6], [7]

Oil-water Properties	Value
Oil density ρ_o	812.19 kg/m3
Water density ρ_w	978.0 kg/m^3
Oil viscosity μ_o	0.009503 Pa.s
Water viscosity μ_w	0.000404 Pa.s
Specific heat of crude C_p	2.125 kJ/kg °C
Water droplet diameter	210 μm

Using MATLAB to solve the set of equations from (3.2) to (3.32) to calculate the area and the efficiency of each equipment in the different ranges of oil density, oil viscosity and water-cut.
A case study for the oil density range (700-850) kg/m^3 showed that the liquid-liquid separator has the highest area and the efficiency (figure 4.1 and 4.2). The heater-treater resulted in a lower area, higher efficiency than the liquid-liquid separator. The electrostatic coalescer showed to require the least equipment area and the highest efficiency. In this case it is better to use multistage separator to increase the separation efficiency and to eliminate the annual cost of heating and electricity needed in the case of heater-treater and electrostatic coalesce.

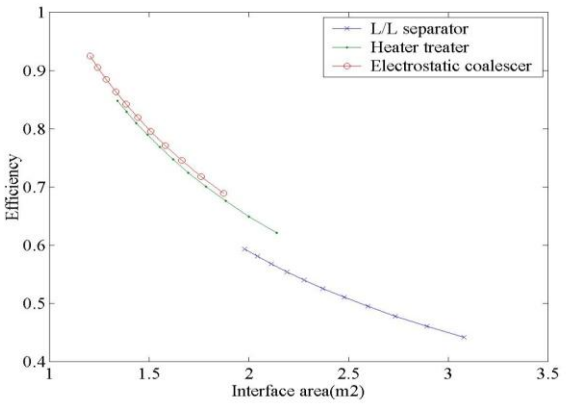

Figure 4.1 the efficiency of the separation units in the density range (700-850) kg/m^3

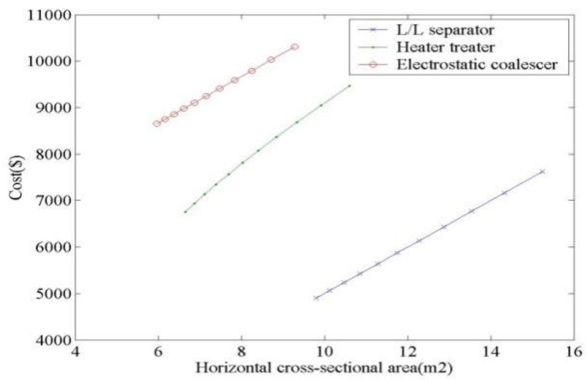

Figure 4.2 the horizontal area of the separation units in the density range (700-850) kg/m^3

5. CONCLUSIONS

The study concludes that the separator is suitable for low density, low viscosity and low and medium water cut crudes.
The heater-treater considered for dehydration of heavy or viscous crudes and also it can be used for the dehydration of different types of crude oil but the choice here depends on the economical aspect since it needs additional cost for heating.
The electrostatic coalescer considered when deep dehydration is required because it gives high efficiency but this restricted to maximum water cut 20% since short circuiting occurs above this limit.

6. RECOMMENDATIONS FOR FUTURE WORK

6.1 Detailed process design

The study focused only on the liquid phase separation of the crude oil-water mixture. The effect of gas phase generation by heating is not considered. Detailed design and analysis of these equipments is necessary in order to consider all aspects of equipment design and operation.

6.2 De-oiling of water

The study did not consider the effluent of the crude oil-water separation systems wich will always contain some remaining oil. This produced water will require de-oiling process prior to disposal or further processing in order to minimize the environmental impact.

REFERENCES

[1] Karl Mess, PETRONAS TECHNICAL STANDARDS, Design and engineering practice, Mohd Suradi Yassin, Manager (Standards), ESU. Kuala Lumpur, April 1993.
[2] SHELL DEHYDRATION MANUAL, Shell International Oil Products B.V. Amsterdam, January 1999.
[3] Coulson and Richardson, Chemical engineering volume 6, Chemical engineering design, 4th edition,

RK Sinnott, Elsevier 2005.

[4] Francis S. Manning and Richard E. Thompson, OIL FIELD PROCESSING, Volume Two: crude oil, Penn well publishing company, Oklahoma, 1995.

[5] Ken Arnold and Maurice Stewart, Surface Production Operations, Volume 1, Design of oil handling systems and facilities, 2nd edition.

[6] http://www.engineeringtoolbox.com/water-thermal-properties-d_162.html, May 2011

[7] Petroleum Training Centre (Central Petroleum Laboratories), May 2011