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Practical Engineering Guidelines for Processing Plant Solutions

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Kolmetz Handbook of Process Equipment Design

CRUDE UNIT DESALTER SYSTEM

Section Three – Refinery Systems Chapter – 3.03

(ENGINEERING DESIGN GUIDELINES)

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INTRODUCTION

Scope

Oil produced in most oil fields is accompanied by water in the form of an emulsion that must be treated. In addition, this water normally contains dissolved salts, principally chlorides of sodium, calcium, and magnesium. If crude oil is left untreated, when it is processed in a refinery the salt can cause various operating and maintenance problems.

This design guideline covers the basic elements of Crude Unit Desalter System design in sufficient detail to allow an engineer, operations or maintenance personnel to understand the design, operation and maintenance criteria for a crude unit Desalter system with the suitable water wash flow, injection water, and settling velocity.

The design of Desalter may be influenced by factors, including process requirements, economics and safety. In this guideline, there are tables that assist in making these factored calculations from the vary reference sources. Include in this guideline is a calculation spreadsheet for the engineering design. All the important parameters use in the guideline are explained in the definition section which help the reader understand the meaning of the parameters or the terms used.

The theory section explains the type of Desalter (single stage, two stage and dual polarity), troubleshooting and emulsion drop theory. The application section of this guideline with the examples will make the user understand a Desalter and its operation.

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General Design Consideration

Heavy crude oil is becoming an increasingly more important option in terms of crude oil refining due to the fact that this type of feedstock is generally cheaper in the international market. Crude oil production is usually associated with the co-production of varying amounts of water, formation solids, and corrosion products. The water frequently contains sizeable concentrations of dissolved salts with the chlorides, sulfates, and bicarbonates of alkali metals and in which alkaline earths predominate.

Separation processes are applied at the production site in order to minimize the unnecessary transportation costs and to prevent corrosion in the transportation system. When crude oil is processed in the refinery, salt can cause numerous operating and maintenance problems.

Salt occurs naturally in all crudes but can vary significantly in concentration and makeup between crudes. The salt content of crude oil is highly variable and results principally from production practices used in the field. Salt may be derived from reservoir, aboard tankers, ballast water of varying salinity, formation waters or from other waters used in secondary recovery operations. The bulk of the salt present will be dissolved in coexisting water and can be removed in Desalter, but small amounts of salt may be dissolved in the crude oil itself.

The salts that are most frequently found present in crude oil feed stocks are sodium, calcium and magnesium chlorides (NaCl, CaCl2 and MgCl2) although other forms of salt can be present in smaller quantities. If these compounds are not removed from the oil several problems arise in the refining process.

Figure 1 shows the relationship between total salt content lbs/1000 bbl, in the produced oil and the salinity of the remnant brine in the oil when 0.1 of 1% saltwater remains in the oil.

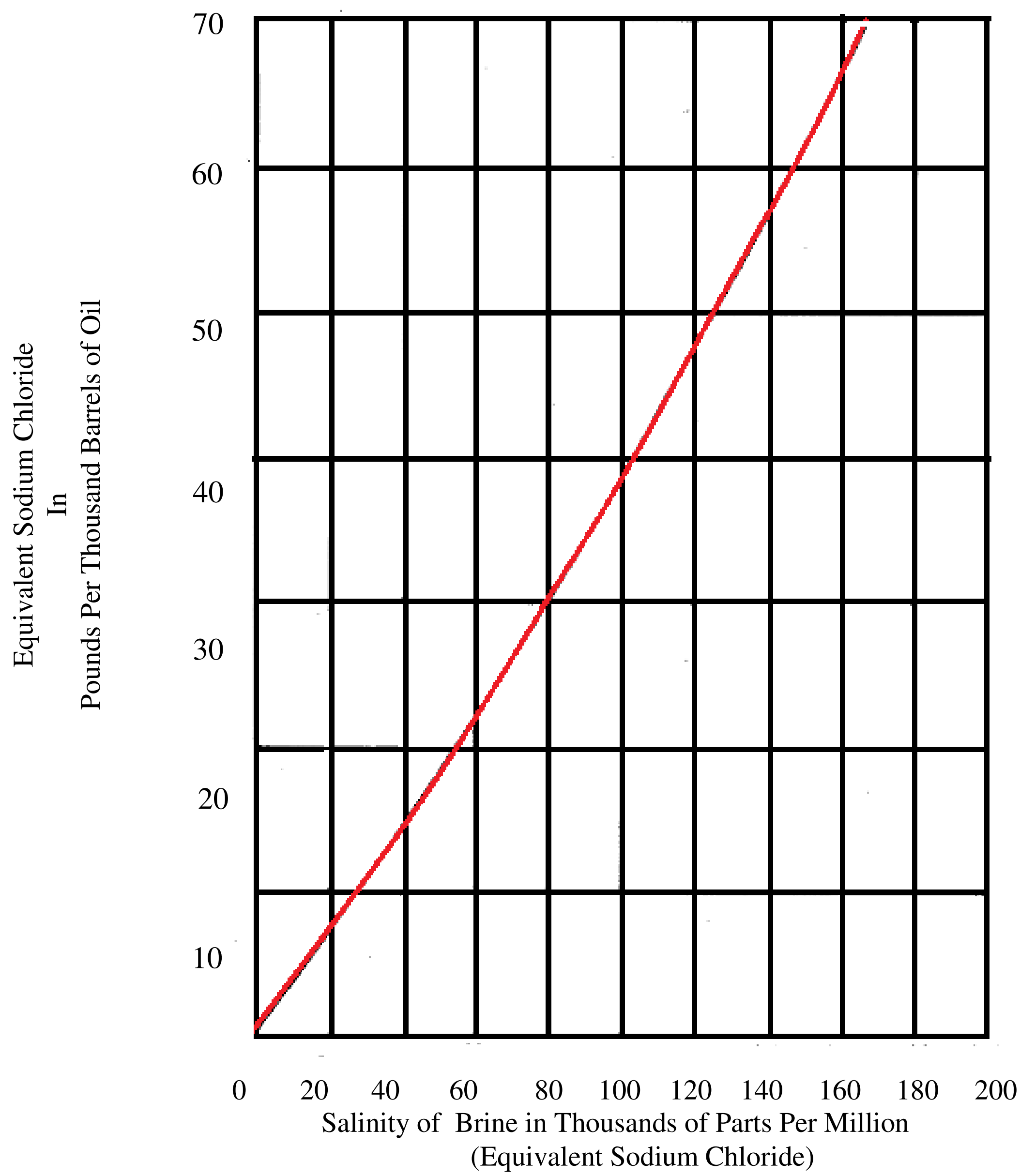


Figure 1: Relationship between salt content of oil to water salinity

Even in small concentrations, salts will accumulate in stills, heaters, and exchangers, leading to fouling that requires expensive cleanup. Below are some effects of salts.

1. During flash vaporization of crude oil certain metallic salts, the high temperatures that occur downstream in the process could cause water hydrolysis that can be hydrolyzed the metallic salts to hydrochloric acid which extremely corrosive. According to the following reactions:

   $$2NaCl + H2O \rightarrow 2\ HCl + Na2O$$

   $$MgCl2 + H2O \rightarrow 2\ HCl + MgO$$

   CaCl will typically hydrolyze first with MgCl requiring higher temperatures. NaCl on the other hand has a high hydrolyzation temperature not normally reached in a crude charge furnace. For this reason Caustic or NaOH can be injected into the Desalter crude stream to lower overhead chlorides. (3)

2. Salts and evolved acids can contaminate both overhead and residual products, and certain metallic salts can deactivate catalysts.

3. Salt cakes out inside equipment, cause poor flow and plugging

4. If a certain amount of salt remains it may cause fouling problems in pipes and reduces heat transfer rates in exchangers, and cause high heater tube-wall temperatures.

5. Plugged fractionators trays and burned-out fire tubes

6. Metals from salts can also cause catalyst deactivation and sintering which result in lower catalyst activity. Sodium has been found to be the most harmful metal for catalysts

Metals from salts can also cause catalyst deactivation and sintering which result in lower catalyst activity. Sodium has been found to be the most harmful metal for catalysts. This decrease in activity implies that used catalyst must be replaced more often to maintain a given activity level.

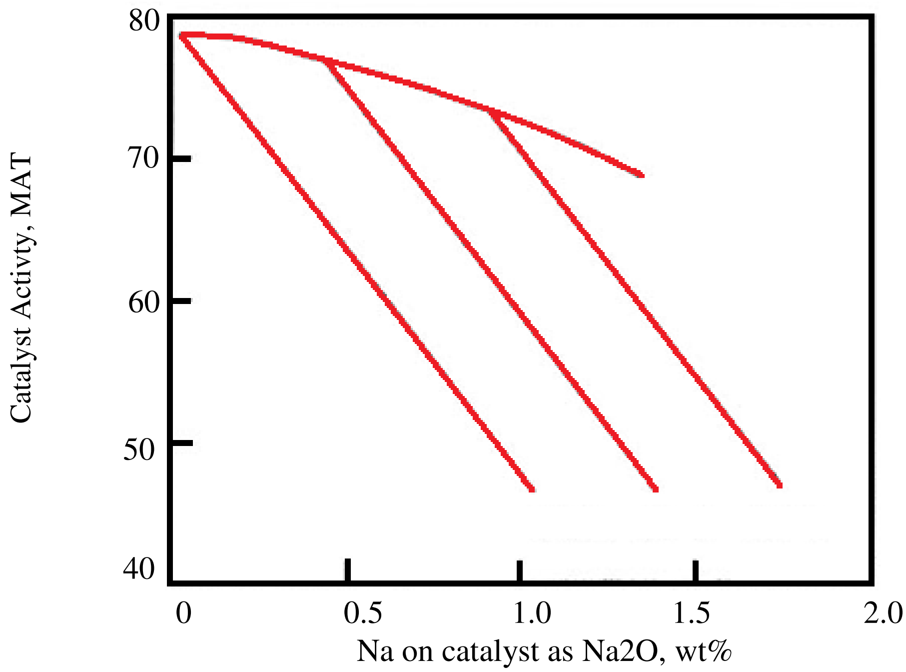


Figure 2: Catalysts activity loss from sodium contamination

Scale develops and accumulates by means of calcium sulphides precipitations. This accumulations takes place in heating tubes and may cause the following problems (2):

1. Reduction in heat transfer rate, which leads to more fuel consumptions and thus higher operating cost.
2. Creation of "Hot Spots" in heating tubes, which reduces tubes' operational expected lives.
3. Development of blockages inside tubes and thus lowering their capacities and efficiencies.

The amount of salt going into the charge furnace must be controlled to minimize corrosion in the downstream equipment. Since facilities are designed for a specific corrosion allowance it is critical that salt and corrosion to be controlled and to stay at or below the design limits.

The purpose of desalting is to remove contaminants from crude oil before it enters the processing units. By removing the contaminants at the onset it is possible to minimize corrosion and fouling in downstream units.

Refiners usually desalt the entering crude to less than 1 PTB (lb salt/1000 bbl) or the salt content on crude. Desalting in the field reduces corrosion downstream while the crude is transported either in pipelines or tankers. In addition the desalted water can, after suitable treatment, be re-injected back into the reservoir. This solves any environmental problems.

Desalting which follows the initial dehydration or emulsion breaking, consist of (4):

1. Adding dilution (or less saline) water to the crude
2. Mixing this dilution water with the crude to dilute the sediment and water (S&W) droplets in the crude
3. Dehydration (emulsion treating) to separate the crude oil and diluted brine (S&W) phases.

The result is to dilute the original S&W droplets and so reduce the salt content (PTB) for comparable levels of crude dehydration (remnant vol % S&W). Desalting can be performed in a single stage or in two stages, depending on the requirements of the refinery. Dehydration efficiency of a Desalter is usually 95% in a single stage and up to 99% in two stages (5).

The conventional equipment required for stage desalting includes:

1. A free-water knockout (FWKO) or heater treater for the initial brine removal or emulsion treating.
2. A tee for injecting the dilution water.

3. A mixing device to co-mingle the dilution water with the S&W drops entrained in the brine
4. A second treater (nearly always an electrostatic heater treater) to separate the crude and the dilution water.

When designing a Desalter, its type and size are all dependent on a number of operational factors such as required pressure, temperature, viscosity and flow rate, as well as user specification relating to maximum salt amount (PTB) allowed in the product oil stream. Figures 1 below shows a schematic of crude oil desalting respectively (6).

A typical process scheme is illustrated as follows:

1. Wet crude flow to wet tank.
2. Demulsifier / Chemical injection.
3. Crude flow to heat exchanger.
4. Flow to heater.
5. Wash water recycled from 2nd stage vessel.
6. Flow to 1st stage desalting mixing valve.
7. Mixed fluid to 1st stage vessel.
8. Flow to 2nd stage desalting mixing valve.
9. Fresh water from water-water heat exchanger originated from wash water tank.
10. Treated crude flow.
11. Effluent water from 1st stage Desalter vessel to water treatment plant and / or disposal pit.
12. BS&W Analyzer - A signal to diverting Valve.
13. Formation (free) water settled down at the bottom of wet tank, to water treatment plant and / or disposal pit

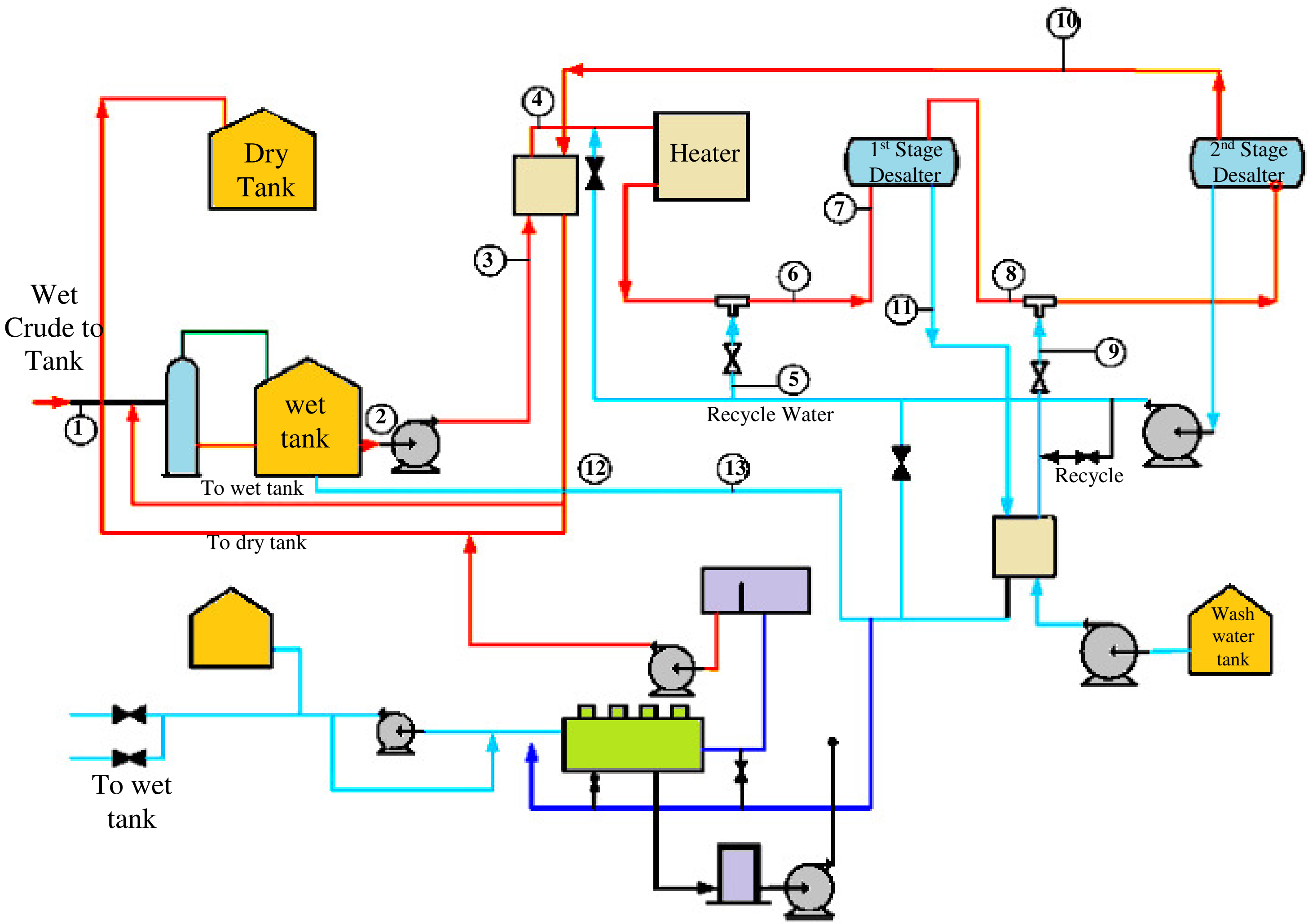


Figure 3: Schematic of crude oil desalting (7)

From figure 1 above, an emulsion comprises of water and oil flows to a wet tank. a common emulsion may contain up to 25% water cut. Water and salt of the crude must be reduced to 0.10% vol. and 5.0 PTB in typical Desalting/Dehydration Plant, respectively (TPL, 1992). A two-stage desalting system is used to remove such large quantities of water from the oil stream. The emulsion, leaves the wet tank, where the primary water separation takes place (stream 2). Chemical/demulsifier is injected into the stream prior to feed pumps. After settling for a period of several hours, formation water (stream 13) flows to waste water treatment plant or disposed to a designated disposal pit.

In stream 3, emulsion flow from the wet tank to a heat exchanger, where heat is recovered from the treated crude product stream 10. The emulsion then flows to a water-bath indirect heater, raising its temperature (stream 4). Water recycled from 2nd stage vessel (stream no. 5) injected into the emulsion flow coming out of the heater. At the mixing valve (no. 6), recycled water and emulsion agitated by an induced shearing force. The operation of a mixing valve is carried out by a simple globe valve where an operator would set the differential pressure across the valve to be as high as possible ensuring better mixing of the two fluids.

The mixing fluid enter to 1st stage Desalter where emulsion is exposed to a high voltage electrostatic field. the electrostatic field coalesces the dispersed water phase and gravity causes the enlarged water droplets to fall and collect in the bottom of the vessel then leaves the system to a wastewater treatment plant or the disposal pit (stream 11). This effluent water contains various impurities and salts removed from the water-in-oil emulsion.

Treatment of an emulsion (still contains salt water) is further enhanced in the second stage desalting vessel (stream 8) and mixed with fresh water (stream 9). treated emulsion is introduced near the bottom of the 2nd stage partially and travels upward through an electrical voltage grids. In this stage, water droplets are enlarged by means of high voltage electrostatic field and separated by gravity. The separated water is collected at the bottom of the vessel and recycled to the first stage Desalter (stream 5), while the treated crude flows from the top of the vessel (stream no. 10).

Desalter sizing is strongly influenced by viscosity which is dependent on the operating temperature. A Desalter feed temperature of at least 70˚C should be allowed in the design of very viscous oils. Higher temperatures will decrease the size of Desalter vessels, but is a trade-off of vessel cost versus heating costs.

Single Stage Desalter

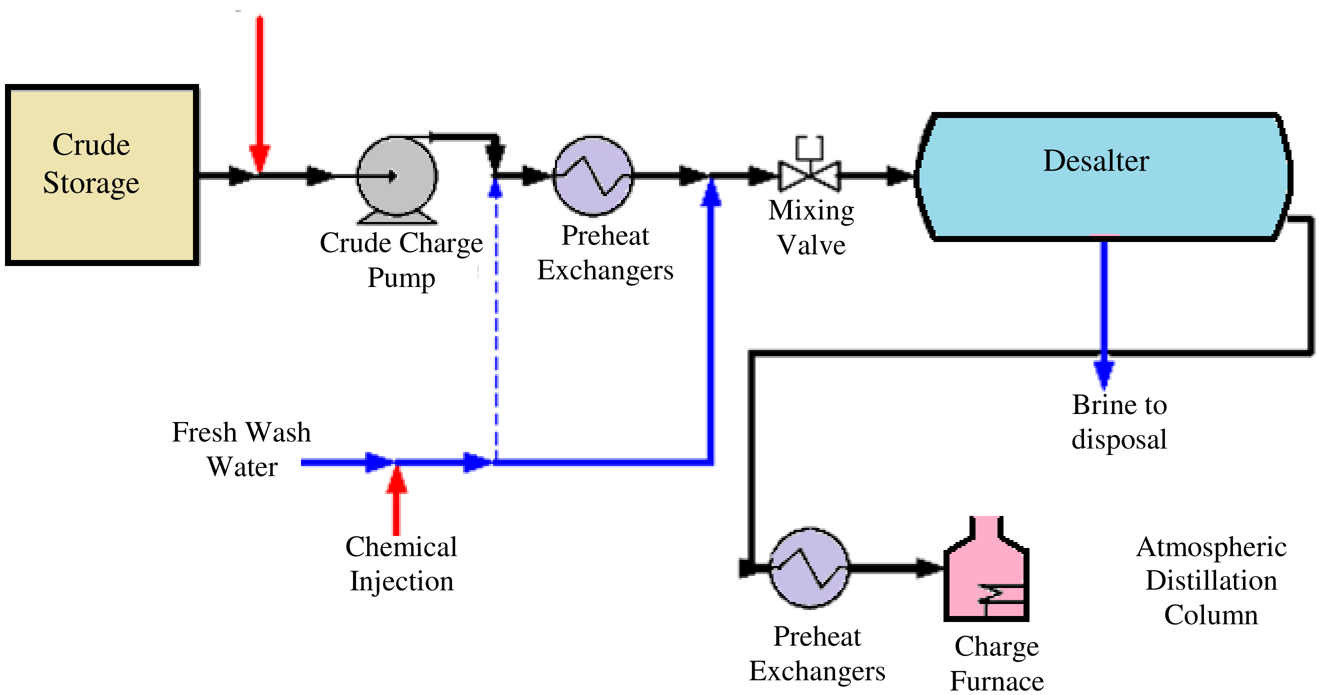


Figure 4: Typical Single Stage Desalter

Crude oil is typically brought into a refinery by pipeline and goes to the raw crude tanks. This can be a single tank or multiple tanks with various different crude blended together. Ideally the crude charge tanks will have continuous mixers but some facilities operate with static tanks which is not advisable since it does not allow for a fully blended feed.

The crude is then pumped to be heated into a series of heat exchanges against hot overhead and product side streams in the Crude Unit prior to entering the Desalter to a temperature of anywhere from 230-300F depending on the type of crude and the facility.

At a preheat temperature of about 200–250◦F water is injected into the crude to dissolve salt that is usually present. The mixture enters a Desalter drum usually containing an electrostatic precipitator. The salt water contained in the crude is separated by means of this electrostatic precipitation. The water phase from the drum is sent to a sour-water stripper to be cleaned before disposal to the oily water sewer.

The crude is then desalted and leaves the Desalter at 190 F then send through another set of exchanges, then into a crude charge furnace which is leaves at 600 F and finally into the crude unit distillation column.

The desalting process works by mixing raw crude oil with water in a mix valve with a high differential pressure. This causes the water and oil to form an emulsion with the salt mostly dissolved in the water phase. During mixing, salt content in oil is washed with the water and a W/O emulsion is formed. This emulsion is then broken in the Desalter by use of gravity, heat, electrical energy and chemical additives.

If mixing is good, dehydration efficiency can be compared with desalting efficiency as most of the salt passed from the organic phase into the water phase. In actual operation, water and oil are preheated and mixed in a 1:20 ratio.

It is common that a demulsifier substance is also added, usually 0.005 to 0.01 lb/barrel [6]. Mixture takes place in a mixing device, which is commonly a valve with a 5 to 20 psi pressure drop. It has been observed that good mixing allows for appropriate salt removal from oil.

Two Stage Desalting

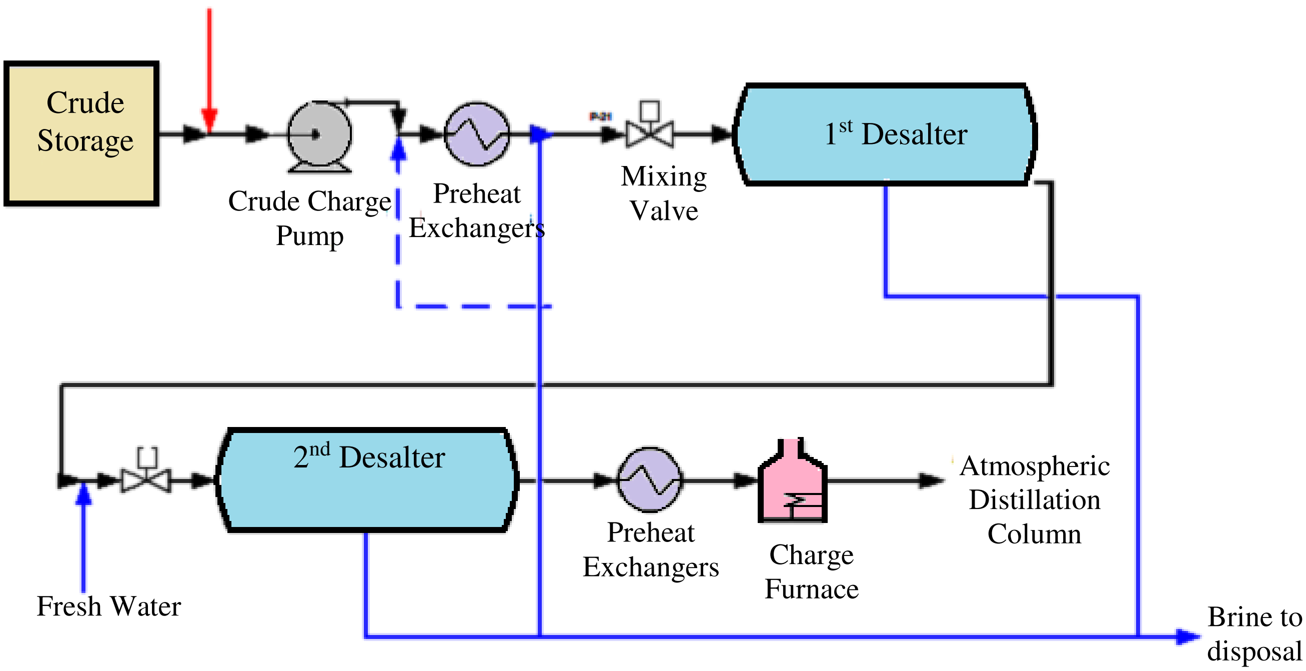


Figure 5: Typical Multi Stage Desalter

The techniques of emulsion breaking (demulsifier injection, heating, phase separation of any vapor or pressure stabilization, and electrostatic coalescence) may be required If co-mingling the crude and dilution water produces a stable emulsion

In single desalting, the required dilution water injection rate is usually 5-7% of the crude flow rate. Field desalting is often required in regions where fresh water is the scarcest. Two stage desalting usually reduces the dilution water required to 1-2%of the crude flow rate.

In two stage desalting the water leaving the second Desalter, while certainly more concentrated that the dilution water, is usually less saline than the brine drops entrained in the crude entering the first stage. Therefore, the dilution water required can be reduced further by injecting the second stage Desalter effluent water into the crude ahead of the first stage. In figure 6, the crude and dilution water streams contact the two Desalter counter currently. The level of the oil-water interface inside the treater can be raised by internally recycling some of the water leaving the Desalter as shown in figure 7. (5)

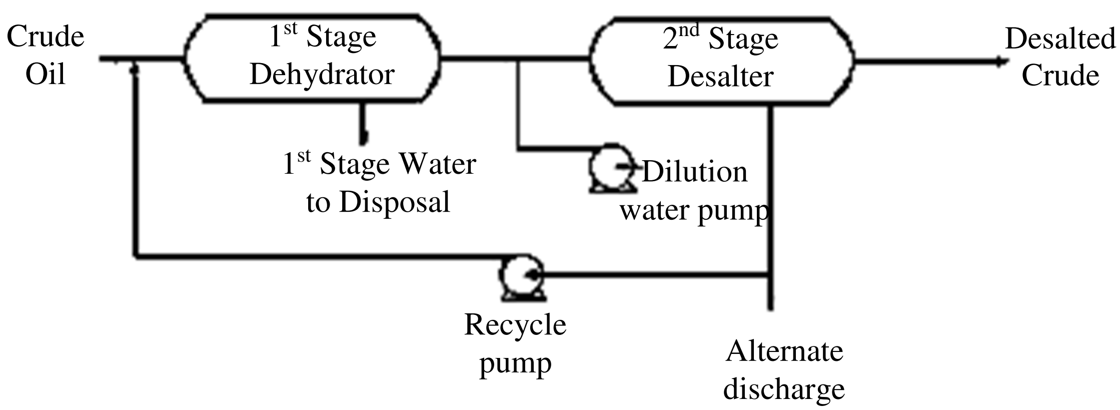


Figure 6: Two Stage Desalting with Recycle (9)

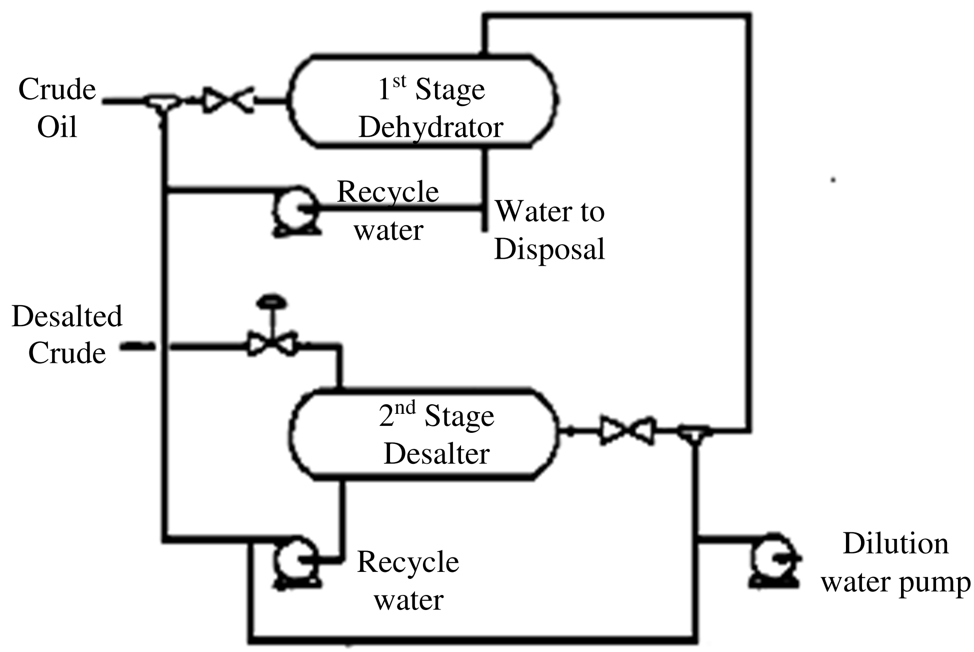


Figure 7: Two Stage Desalting with Recycle and Internal Recycle (9)

Electrostatic Desalter

The Electrostatic Desalter is a system consisting of electrostatic mixing, a control system for the composite electrodes, and countercurrent flow of the dilution water. Counter current flow is essential for realization of the full potential to be gained by multiple stages of mixing and coalescence. To achieve this benefit it is necessary to introduce dilution water above the electrodes in the zone of dry oil. The water must remain as coarse drops in this area to prevent carry-over. Uniform distribution is desired, although the electric field produces some amount of distribution and will overcome mild mal-distribution.

The simplest way of spreading the dilution water above the electrodes is through a system of laterals with orifices sized to produce a slight pressure drop at design flow rates. Orifices in the laterals produce a slight pressure drop at design flow rates and feed the dilution water into the Desalter as coarse drops. These dilution water drops must be large enough to fall and flow vertically down between the high voltage (HV) grid of electrodes. Small drops would be carried up by and leave with the upwardly flowing crude oil. Because of increased contact efficiency, less dilution water is usually required in this system.

The electrostatic desalting process removes water that is already present in crude oil as well as suspended solids. In the case of water removal, this allows a decrease in pumping costs. Also, if a considerable amount of water enters the preheat train it could vaporize and cause disturbances and vibrations due to high pressure. Such disturbances could be as mild as pipe vibration and noise or as serious so as to cause shut down (7).

Regarding suspended solids, their removal is important because such substances can go all the way through the refining processes to be expelled with the flue gas. This may cause that flue gas opacity to not comply with environmental requirements. In that event, the flue gas should receive additional treatment prior to being expelled.

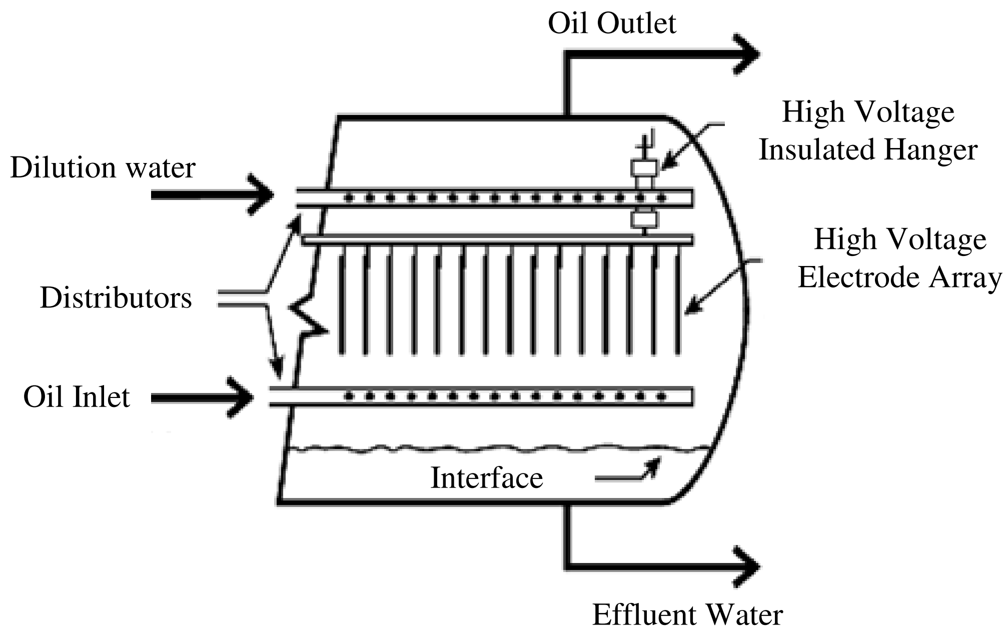


Figure 8: The Electrostatic Desalter System

The electrodes consist of vertical parallel plates of oppositely charged. Both diodes are connected to the same end of the transformer secondary winding, thus charging the plates on alternate half-cycles of AC power. This creates a DC field between the electrodes. The other end of the secondary winding is connected to ground; therefore, the electrode-to-vessel field is AC (10).

Because the plates can only charge on alternate half cycles, the current between them is limited to discharge of capacitively stored energy and is unable to produce significant electrolysis. These plates are also operating in relatively dry, non-conductive oil since the bulk dehydration has been accomplished in the AC field below the electrodes. This further limits DC current dissipation. This system is known as dual polarity. Both the vessel shell and the water phase are grounded to minimize corrosion. The upward flow of crude oil and the downward flow of dilution water result countercurrent contact.

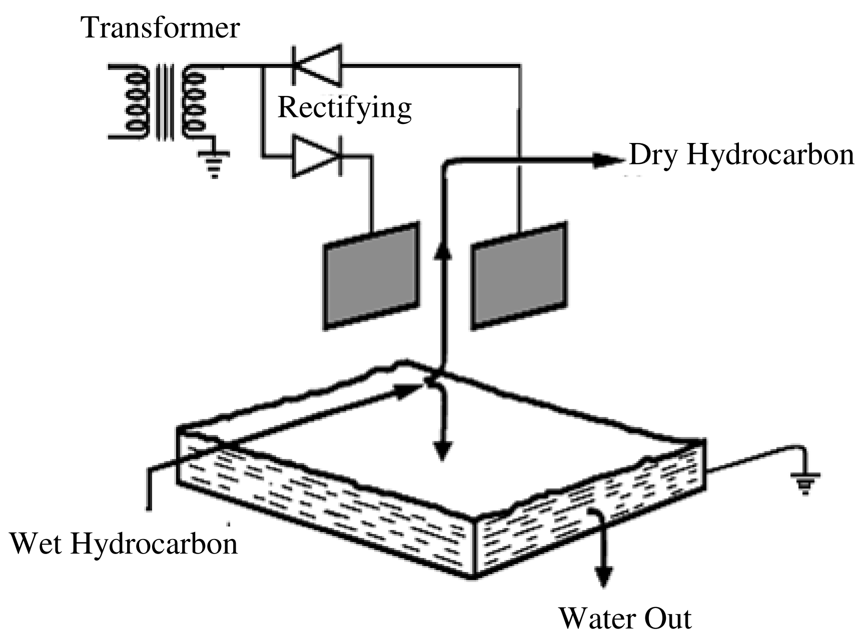


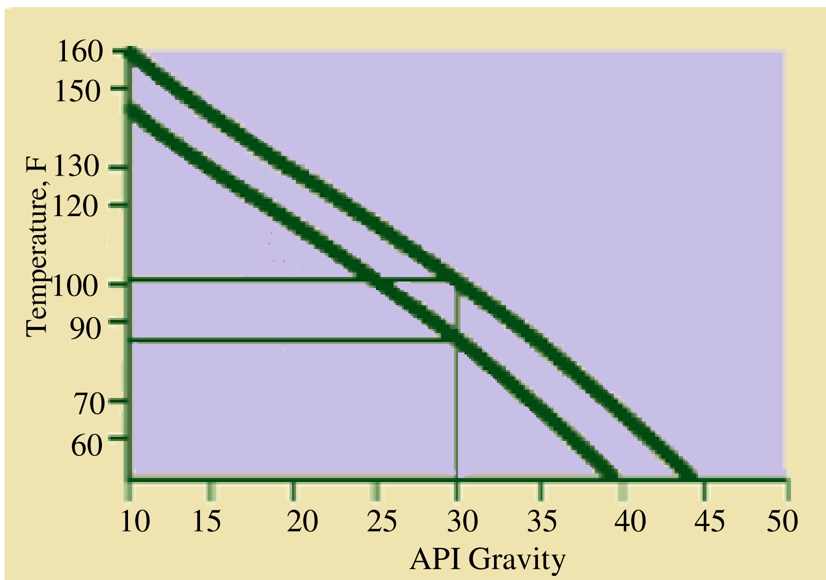
Figure 9: Dual Polarity AC/DC Field

Advantages of Dual Polarity

1. Lower operating temperatures mean lower fuel costs

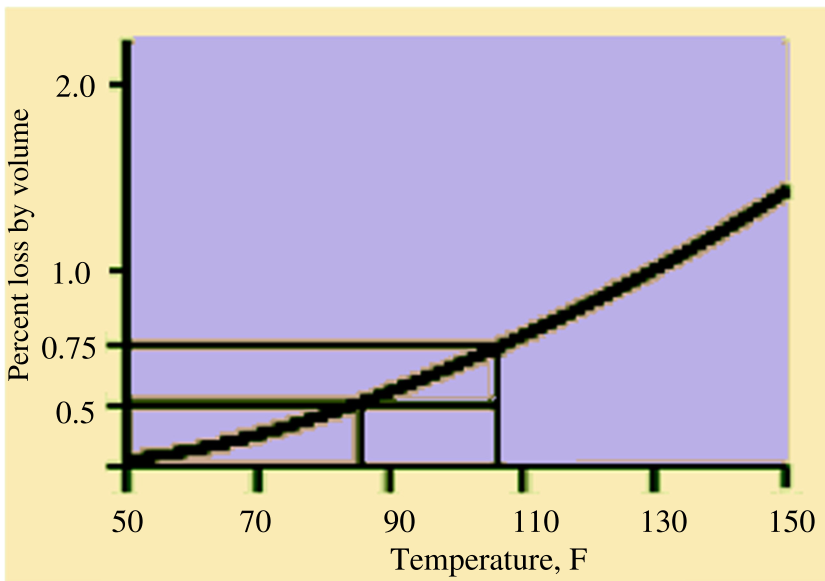
The dual polarity treater is designed to operate at temperatures 15ºF lower than a conventional electrostatic treater, and up to 60ºF cooler than ordinary heater treaters. The dual polarity electrostatics provide for more complete dehydration.

Consequently, it can process at higher viscosities, which means less heat is required to lower the viscosity of the oil at processing conditions. It provides sizeable savings in fuel costs for any gravity of crude oil.



2. Reduces volume loss, produces more oil to sales

The lower operating temperature of the dual polarity treater also results in less vaporization and loss of light ends from the oil.



3. Increased throughput rates

The dual polarity treater requires less space because the vessel can handle much higher flow rates than conventional treaters. The dual polarity process creates larger droplets than conventional AC units. These droplets fall through the opposing emulsion flow more easily so more oil can be processed in a given size vessel.

4. Under the same operating conditions, the power consumption of the AC-DC electrostatic desalting technology is only about 60% that of the AC electric desalting technology.

5. The AC-DC electrostatic desalting technology is widely applied to get rid of the salt in crude oil because of its character of dehydrating deeply rate. AC electric field is effective for big water droplets diameter over 30μm, while DC electric field has a preferable dehydrating effect for small water droplets diameter less than 30μm.

6. The electric field of the AC-DC electrostatic desalting technology is designed according to the distribution of electric conductivity of the crude oil. It has better adaptability to all kinds of crude oil and keeps the AC-DC electrostatic Desalter running smoother.

7. The AC-DC electrostatic desalting technology has more powerful demulsifying function. It has better adaptability to the crude oil with different water content from 1%~30%, especially for crude oil with different water content.

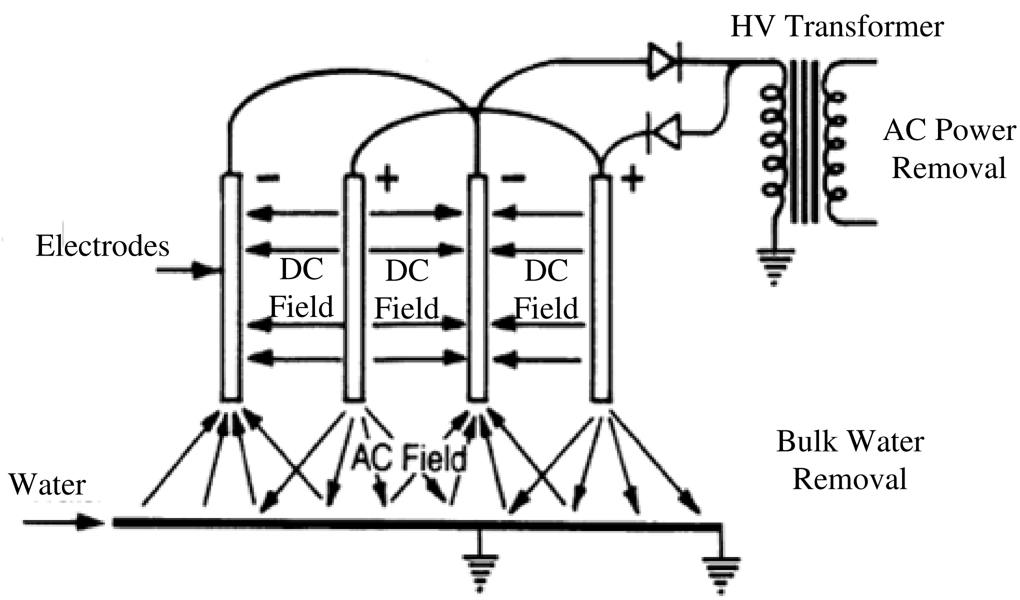


Figure 10: Combination AC/DC Electrostatic Fields

Desalting is achieved by varying the strength of the DC electric field between the electrodes. Four distinct stages have been identified in the mixing and coalescing process with unique field strength requirements for optimum performance of each stage (figure 11). These are as follows:

1. Dispersal: A fast ramp-up of voltage to the mixing voltage. Provides rapid reduction of the large drop population and coalescence of small drops.
2. Mixing: Sustained high intensity field for maximum drop subdivision and dispersal.
3. Coalescing: Voltage ramp-down to permit optimum drop growth. It is in this stage that most of the contact between the dilution water and the entrained brine occurs.

4. Settling: Sustained low intensity field for drop growth and sedimentation and to control aqueous phase hold-up between the electrodes.

Each of these stages can be adjusted for optimum intensity and duration using the modulating electronic controller.

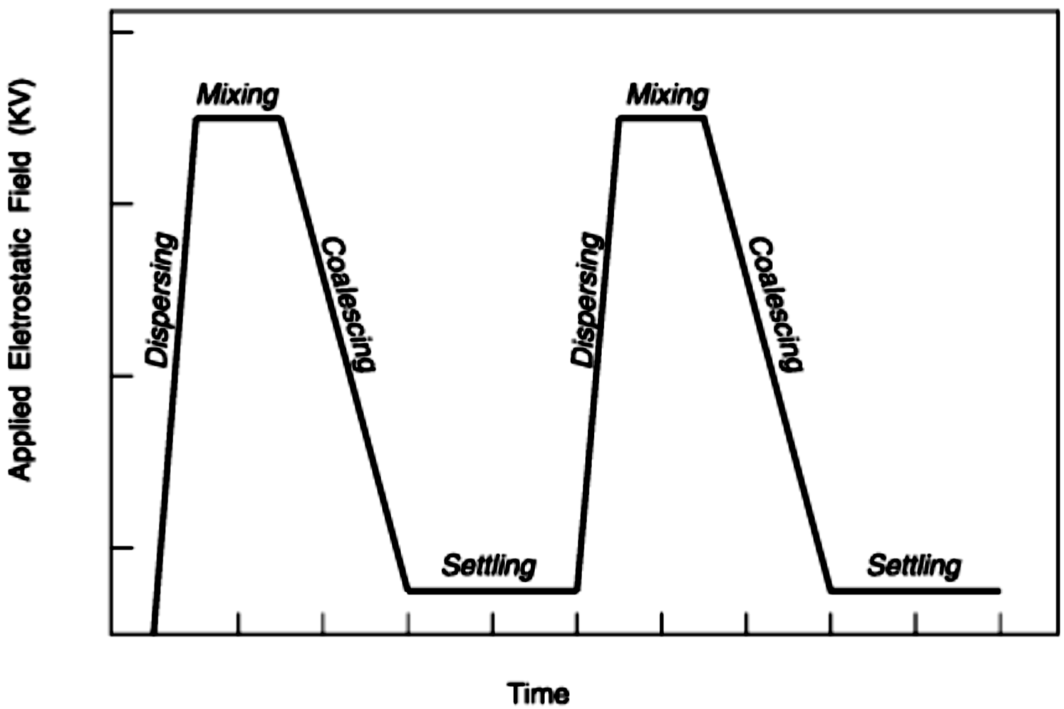


Figure 11: Voltage Modulation for Electrostatic Mixing/Coalescing

The use of an electrostatic-field Desalter is most effective whenever (11):

1. Difference in specific gravity between oil and water is greater than 0.001,
2. Fluid viscosity is less than 50 centipoises at separation temperature, and
3. Electrical conductivity of the oil phase does not exceed 10-6mho/cm.

Use of the electrostatic Desalter should be considered in any of the following circumstances:

1. Space is limited and more than one stage of desalting is required.
2. Outlet salt specifications are very low (less than one pound per thousand barrels of oil, PTB).
3. Dilution water quantity or quality is limited.
4. Minimization of wastewater is required.

The most important variables affecting desalting performance that have been studied and identified including; (1) settling time, (2) demulsifier injection, (3) heat, (4) freshwater, (5) mixing (emulsion, chemical, and the freshwater), and (6) electricity.

1. Settling time

Gravity differential is the scientific principle that forms the basis for all emulsion-treatment plants gravity to separate water droplets from the continuous oil phase because the produced formation water droplets are heavier than the volume of oil they displace. The produced water usually carries some salts and solids coated predominantly with a thin film of oil or just freely flowing along the emulsion stream (Lohne, 1994).

2. Demulsifier injection

Demulsifiers effect the water-oil interface. Demulsifiers act to neutralize the effects of emulsifying agents. The faster the demulsifier reaches to that interface, the better action would be accomplished. These surface-active chemicals adsorb to the water-oil interface, rupture the film surrounding water drops, and displace the emulsifying agents back into the oil. Breaking the film allows water drops to collide by the natural force of molecular attraction.

A rule of thumb used in the oil fields which states that the lower the water percentage in an emulsion the more difficult it is to treat. This rule is explained as such:

- ✓ Water drops distribution in the continuous phase depends on the water percentage.
- ✓ The higher the water percentage, the closer the proximity of water drops.
- ✓ Concentration of the emulsifying agents is more at the water-oil interface if the water percentage is small.
- ✓ Dispersed drops are difficult to coalesce compared to close by ones. Moreover, the rate, at which water drops will coalesce, is a function of the droplet radius.

3. Heating

Increasing emulsions temperature will decreases its viscosity, thickness and cohesion of the film surrounding water drops. Optimum temperature also reduces the continuous phase (oil) viscosity helping water drops to move freely and faster for coalescing. The following functions are accomplished by heating (12):

a. Dissolving the skin surrounding the water drops;
b. Spreading demulsifier throughout the continuous phase reacting with films;
c. Creating thermal current to collide water drops;
d. Melting the emulsifying agents.

Excessive heating leads to the following problems:

a. increase in fuel cost,
b. more maintenance problems and cost,
c. chances of scale development, and
d. increase in oil volume loss and API decrease.

4. Injection of freshwater

Some salts in emulsion come in solid crystalline form and should be dissolved by freshwater. Injection of fresh water is usually at a nozzle before heat exchangers to increase the mixing efficiency and to prevent scaling inside pipes and heating tubes. Freshwater is injected so that water drops in emulsions can be washed out and then drained off, hence the term ‘‘wash water.’’ The quantity/ratio of freshwater injected depends on the API gravity of the crude, but, generally, the injection rate is 3 -10% of the total crude flow, (3).

5. Wash Water Mixing

When dilution water (fresh water) is added to an emulsion, one needs to mix the phases so as to dissolve the salt crystals to aid in coalescing of finely distributed droplets. Mixing takes place in a mixing valve designed in a way that it provides a high shear force in the range of 10-25 psi of differential pressure. Mixing contributes to emulsion process in three steps:

- ✓ joins smaller drops together,
- ✓ mixes chemical / demuslifier with the emulsion, and
- ✓ breaks the free injected volume of wash water into emulsion sized drops and evenly distributes it.

6. Electric Field

The electric field help break the emulsions.

DEFINITIONS

Gravity separation - refers to the primary free settling of water and is related to the residence time that takes place in both settling tanks and desalting vessels.

AC – Alternating electrical current

Desalination - Process of removing salts from water sources

Fouling – The reduction in performance of process equipment (heat transfer tubing, membranes, etc.) that occurs as a result of scale buildup, biological growth, or the deposition of colloidal material.

Membrane – In desalting, used to describe a semipermeable film. Membranes used in electrodialysis are permeable to ions of either positive or negative charge. Reverse osmosis and nanofiltration membranes ideally allow the passage of pure water and block the passage of salts

Precipitate – A substance separated from a solution by chemical or physical change as an insoluble amorphous or crystalline solid.

Saline water – Water with dissolved solids exceeding the limits of potability. Saline water may include sea water, brackish water, mineralized ground and surface water, and irrigation return flows.

Salt diffusion – The movement of ions or molecules under influence of a concentration difference.

Solubility – A measure of the maximum amount of a certain substance that can dissolve in a given amount of water, or other solvent, at a given temperature.

Specific conductance (conductivity) – Quantitative expression for the capability of a particular solution to conduct electricity. It is defined as the conductance of a cube of that particular water that is 1 cm long and has a cross sectional area of 1 cm2. Conductivity is usually expressed in micromohos per centimeter.

Stage – A unit of desalting equipment capable of purification and separation of the feed water into product and concentrate. If separation is insufficient, more than one stage can be arranged in series

Turbidity – Opaqueness or cloudiness caused by the presence of suspended particles in water, usually stirred-up sediments. The turbidity of a water is measured by its capacity for absorbing or scattering light.

S&W content – Oil, as produces from the well and production equipment, may contain considerable amounts of brine, as well as solid materials. The water solids content is refferes to as sediment and water (S&W) or basic sediment and water (BS&W).

Demulsifier – or demulsifying chemicals are a mixture of chemicals used to break the emulsion by destroying a weakening the stabilizing film around the dispersed droplets.

Electrodes or grid – plates or rods used to establish the electric field in electrostatic treaters.

Electrostatic treater - treater using electric fields in the oil coalescing area.

Emulsifier - in addition to oil and water, a third substance called an emulsifier or emulsifying agent must be present for a stable emulsion to be produced. The emulsifiers usually exist as a film on the surface of the dispersed droplets.

Emulsion – a combination of two immiscible liquids. One liquid is broken into droplets and is known as the discontinuous, dispersed, or internal phase. The liquid that surrounds the drops is continuous or external phase.

Interface – the contact surface between the boundaries of the two immiscible liquids (e.g., the surface area between water droplets and the surrounding oil or the surface between separated crude and water in a vessel.

Water-in-oil (w/o) emulsion – Crude oil emulsions nearly always consist of water drops dispersed in a continuous oil phase. This type is also called a regular or normal emulsion

Desalting – Reducing the salt content of a crude oil by diluting the entrained/emulsified water and then dehydrating.

Dehydration – Removing water droplets or S&W or BS&W from crude oil (sometimes called treating)

Oil-in-water (o/w) emulsion – an emulsion consisting of oil drops disperse in a continuous water phase. This do-called reverse emulsion often occurs on waste waters and produced brines. The water content is generally greater than 85 volume percent.

Wetting – refers to the adhesion or sticking of a liquid to a solid surface. If the solid surface (grain of reservoir rock, fines, etc) is covered preferentially by oil, the surface is called oil wetted. Conversely, if water is preferentially attracted, the surface is water wetted.

NOMENCLATURE

A	Water in inlet stream, bbl
B	Water in clean oil, bbl
C	water to Desalter inlet, bbl
C_{so}	the salt content of the oil, lbm/1,000 bbl;
C_{sw}	the concentration of salt in produced water, ppm;
d	diameter of droplet
E	Mixing efficiency, %
E1	Mixing efficiency of V with A as fraction, %
E2	Mixing efficiency of Y with B as fraction, %
Ec	critical voltage gradient
E_f	electric field gradient, m
ε_o	permittivity of free space, farad/m
ε_{oil}	dielectric constant of crude oil
F_d	drop flow, m^3/s
F_d*	drop flow at current operating temperature, m^3/s
F_e	electrostatic force, N
$F_{O(in)}$	oil inflow, m_3/year
f_w	the volume fraction of water in crude oil.
$F_{W(in)}$	water inflow, m_3/year

$F_{W(out)}$*	water outflow at current operating temperature, m^3/ year
g	Gravity, m/s^2
h	distance covered by the drop, m.
K	Dielectric constant for the system
K1	Salt per barrel of water to facility, lb
K2	Salt per barrel of dilution water, lb
K3	Salt per barrel of water to Desalter inlet, lb
K4	Salt per barrel of water to second stage Desalter, lb
R	water to second stage Desalter, bbl
R_{WO}	water/oil feed ratio.
S	Water to first stage Desalter, bbl
SG_w	the specific gravity of produced water
T	Clean (water-free)crude volume, bbl
V	Recycle water to injection in first stage inlet line, bbl
V	Water to disposal, bbl
V_d	volume of water drop, m^3.
V_S	Settling rate, m/s
x	center-to-center distance drops, m
X1	fraction of water in produced oil stream
X2	Fraction of water in clean oil outlet
X3	Fraction of water in second stage outlet oil
Y	Injection water of lesser salinity than inlet water, bbl
Z	Salt in outlet clean oil/1000 barrels of net oil, lb

Greek Leters

η	dehydration efficiency
θ_d	drop’s residence time, s
ρ_O	density of oil, kg/m^3
ρ_W	density of water, kg/m^3
σ	surface tension
μ_O	dynamic viscosity of oil, kg/m s.

Superscript

A	Water in inlet stream, bbl
B	Water in clean oil, bbl
C	water to Desalter inlet, bbl
E	Mixing efficiency, %
Y	Injection water of lesser salinity than inlet water, bbl
Z	Salt in outlet clean oil/1000 barrels of net oil, lb