Electrostatic Separation Technology for Water-in-Oil Dispersions / Emulsions

by Ir. Dr Eow John Son

THE COMPACT CENTRIFUGAL ELECTROCOALESCER-SEPARATOR

In the oil and gas industry, mining and extraction industries, chemical process industries, and biomedical and pharmaceutical industries, there are many processes where water drops are finely dispersed in an oil phase to enhance mass transfer of chemical species. Subsequently, the water drops may have to be separated from the oil for the downstream operation. A number of separation methods may be used such as gravitational settling, centrifugation, hydrocyclones, membrane filtration and electrostatic separation, depending on the size of the water drops and the properties of the two phases [1, 2, 3].

Gravitational sedimentation has a wide range of applications, such as the removal of solids from liquid sewage wastes, the settling of crystals from liquor, and the separation of a liquid-liquid mixture in solvent extraction [1]. However, gravitational separation usually becomes difficult when the density difference between the two phases is very small, when the continuous liquid is highly viscous, and when the dispersed phase is of very small drops. The separation can also becomes highly complicated when the very small dispersed drops are covered by layers of impurities such as surface active agents, asphaltenes and resins, making the drops repel each other and thus remaining stable in the dispersions [4, 5, 6].

In the oil and gas industry, a separation method based on the different electrical properties of the two phases is employed to separate water-in-oil dispersions [7, 8]. The underlying mechanisms of the electro-separation technique are summarised in Figure 1 [9], and its practical aspects used in the oil and gas industry are summarised in Figure 2 [2].

Electrostatic separation of water-in-oil dispersions has a number of advantages, such as low power consumption due to very low electrical current used, no addition of chemicals is required, and the method is free from mechanical break down as no moving parts are involved [8, 10]. In this article, a compact electrocoalescer-separator [11], together with the electrical effects that enhance the separation of water-oil dispersions, are highlighted.

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The design and performance of a compact centrifugal electrocoalescer-separator [11] combined electrocoalescence with centrifugal forces to separate dispersed water drops from the flowing viscous oil, with the two liquids having a very small density difference.

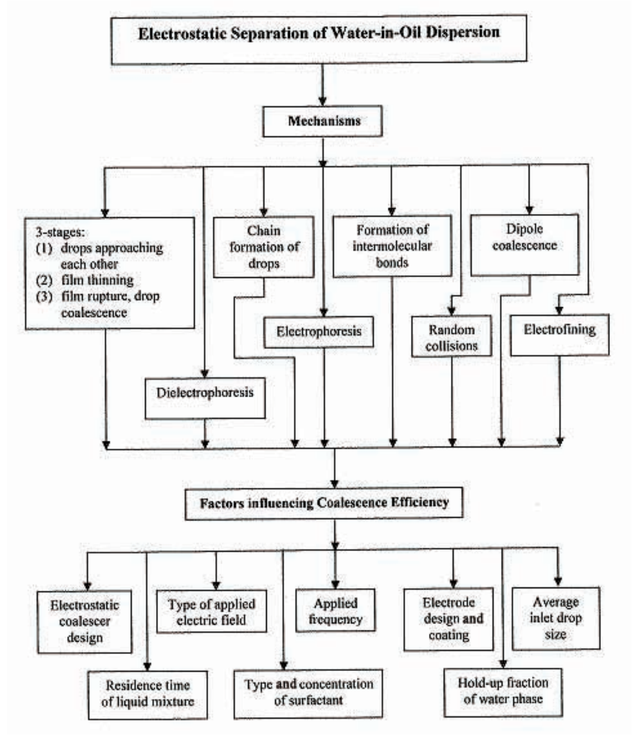

Figure 1: Mechanisms and factors influencing the electrostatic separation performance [9]

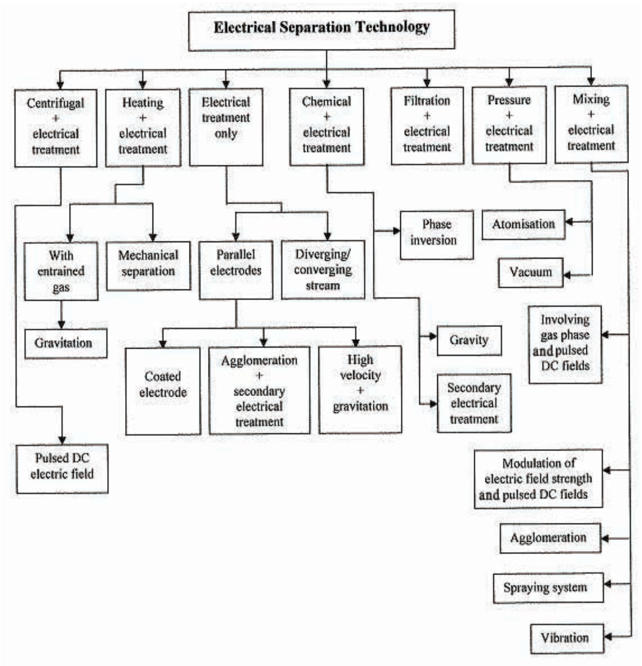

Figure 2: Various combinations of electrical separation technology [2]

Figure 3 shows the water-oil separator based on the centrifugal action and equipped with electrodes to enhance the separation [11]. The brass cone is connected to a high voltage supply with positive polarity, while the brass strip and the brass shaft are grounded. There are a number of regions of high electric field intensity: (i) between the brass cone and the middle shaft, (ii) between the cone and the copper strip, and (iii) between the base of the cone and the accumulated water layer at the bottom of the separator. The water-in-oil dispersion enters the upper part of the cylindrical section tangentially, causing centrifugal or swirling motion, therefore forcing the heavier water drops to move to the cylinder wall where they coalesce rapidly under the influence of the pulsed DC electric field. Drop-interface coalescence also takes place in the bulk water phase at the bottom of the separator. As there are no moving parts in the system, the necessary vortex motion is performed by the liquid itself.

The fundamental mechanisms in the electrocoalescer-separator are drop charging and drop-drop coalescence, followed by drop-interface coalescence [9, 10, 13, 14]. The height of the accumulated water layer at the bottom of the separator can be controlled by a valve to facilitate the investigation of the effect of *H* (*i.e.* the distance between the oil-water interface and the bottom of the brass cone) on the efficiency of the separation of water drops from the flowing oil. The accumulated water phase, which is more conductive than the oil phase, at the bottom of the separator acts as a grounded 'electrode'; it also facilitates drop-interface coalescence for the removal of the dispersed water drops from the flowing oil. A pulsed DC electric field can be applied to the brass cone. Square pulses of different frequencies are shown in Figures 4(a, b, c and d).

The separation efficiency of the electrocoalescer-separator can be defined as:

$$\text{Separation efficiency (\%)} = \frac{W_{retained}}{W_{in}} \times 100 \qquad (1)$$

with W_{in} as the inlet flow rate of the water drops, and $W_{retained}$ is the amount of water phase retained by the separator per unit time.

Figure 5 illustrates schematically the movement of water drops in the centrifugal electrocoalescer-separator. The water/oil dispersion enters the separator tangentially, inducing a swirling flow. However, if the drops enter near the cylindrical wall, they could be dispersed radially inwards due to the high turbulent mixing in the feed section. Away from the feed section, as the water drops are denser than the oil, they move towards the wall due to the centrifugal effect.

In the absence of an applied electric field, a water drop within the flow is basically exposed to (i) gravitational and centrifugal forces, and (ii) the drag exerted on the water drop by the flowing oil. In the presence of an electric field, water drops coalesce rapidly and become larger, and at the same time, deviate more than in the previous case from the fluid stream line. In Region A, some of the drops are charged by contacting the high voltage brass cone, while other drops are polarised. Under a suitable electric field, drop-drop coalescence takes place in this region, and some drops that go into Region B are significantly larger than the average inlet drop size.

In Region C, a water drop either moves towards the oil-water interface or moves upward to the inside of the brass cone. This depends largely on the flow rate, the applied electric field, and the drop size. If the flow rate is too high, most of the water drops will flow with the continuous oil

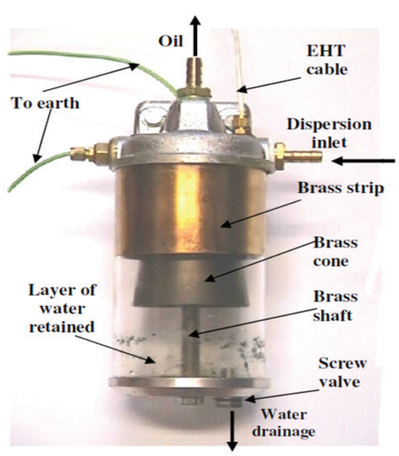

Figure 3: The centrifugal electrocoalescer-separator that combines electrostatic and centrifugal separation forces [11]

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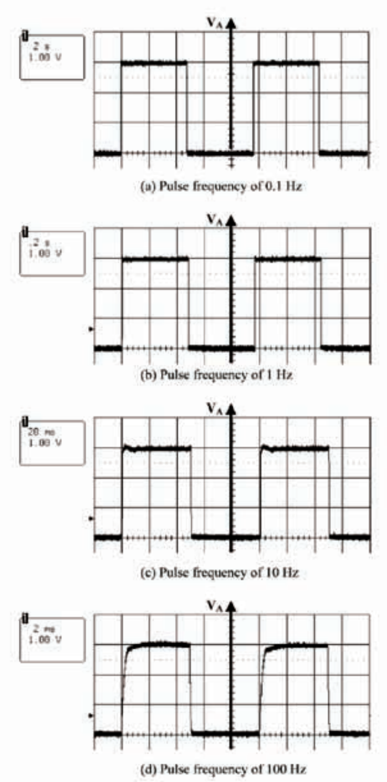

Figure 4: The shape of the applied pulses at the applied potential of 3 k

phase into the cone. By increasing the applied electric field strength, it has been observed that more water drops tend to move to the oil-water interface due to an increase in the electrical-induced attractive force between the drops and the interface. Rapid drop-interface coalescence then takes place. The distance, *H*, between the bottom of the brass cone and the oil/water interface can be controlled by the valve at the bottom of the separator. Drops that do not coalesce with the oil/water interface will flow into the brass cone in a swirling motion. Drop-drop coalescence may also occur in the Regions D and E, as a number of drops in the outlet have been observed to be larger than the drops entering the bottom of the cone.

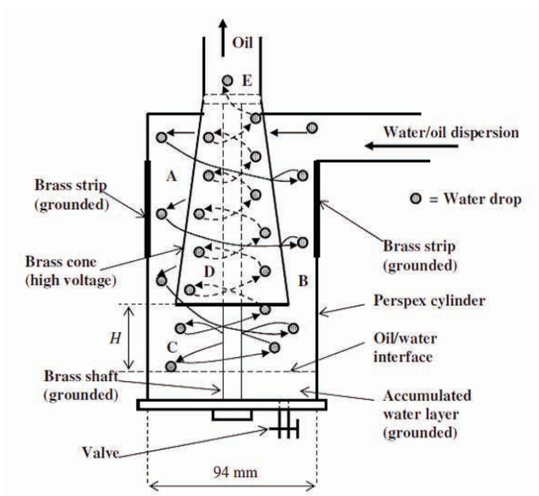

Figure 5: Movement of the water drops in the electrocoalescer-separator

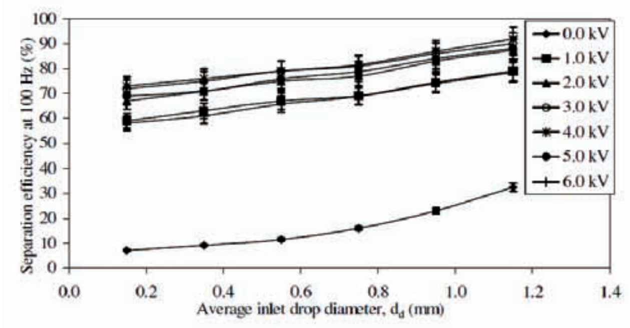

Figure 6: The grade efficiency curve at pulsing frequency of 100.0 Hz and H = 15 mm for the electrocoalescer-separator

Generally, decreasing the *H* will increase the separation efficiency. For inlet water drops of 0.55mm diameter and *H* = 15mm, the optimum separation efficiency is about 65%, which occurs at the applied potential of about 3 kV. When *H* is increased to 55 mm, the optimum efficiency reduces to a maximum of about 40%, which occurs between the applied potential of 4 kV and 5 kV. However, when the magnitude of the applied electric potential is further increased beyond these values, the separation efficiency is observed to decrease. This might be due to the fact that high electric field can deform and finally break up aqueous drops into smaller drops [15].

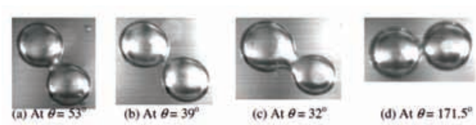

Figure 7: Attraction leading to coalescence between two water drops at θ = 53°, 39°, 32° and 171.5°, and applied electric field of 1 kV/cm

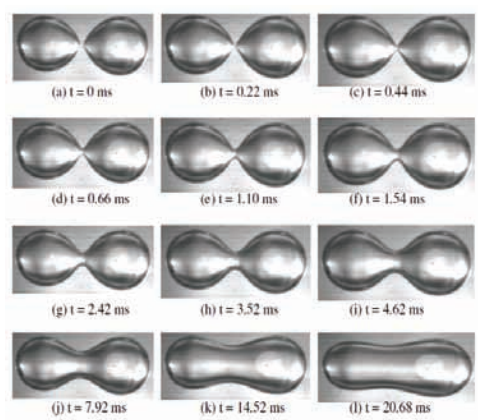

Figure 8: Attraction leading to coalescence between two water drops at θ = 0.5°, and applied electric field of 1 kV/cm

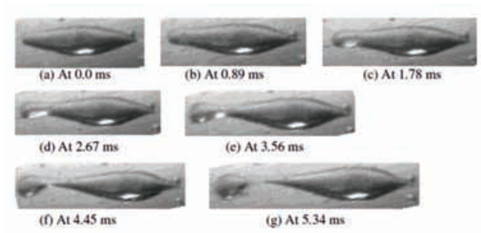

Figure 9: Deformation and break-up of a water drop at applied potential 4.5 kV

When the pulsing frequency is further increased from 50 Hz to 100 Hz, there is very little change in the observed grade efficiency, as shown in Figure 6 at H = 15 mm. At the applied pulsing frequency of 100 Hz, for the inlet drop size of 0.15 mm and the applied potential of 1 kV, the separation efficiency is about 58 %, compared to that of about 55% for the applied frequency of 50 Hz. As for the pulsing frequency of 50 Hz, the separation efficiency for the frequency of 100 Hz has also been shown to increase with the applied potential until 4 kV, beyond which the efficiency of the separator decreases. At the optimum applied potential of 4 kV, the maximum separation efficiency is about 93% when the average inlet drop diameter is 1.15 mm, for the pulsing frequency of 100 Hz. The separation efficiency is about 90% under the same conditions but with the pulsing frequency of 50 Hz. At the applied frequency of 100 Hz, the grade efficiency at the applied potential 6 kV is very similar to that at 1 kV for the various inlet drop sizes. Moreover, the applied potential of 5 kV produces similar separation efficiency to that produced by the potential of 2 kV for the inlet drop sizes shown in Figure 6.

DROP-DROP COALESCENCE PROCESS

It has been shown that the applied electric field will enhance drop-drop coalescence, provided that the field is applied in a certain direction to the flow direction of the drops [12]. To achieve maximum force of attraction between adjacent water drops, the electric field should be applied in such a way that it makes a 0° angle with the line joining the centres of the drops. When the two water drops become very close together, drop-drop coalescence occurred, as shown in Figures 7 (a to d) at different angles at an applied field strength of 1 kV/cm.

For water drops dispersed in viscous oil, the drainage of the film separating the two drops is the bottle-neck of the overall coalescence process. Once this film is broken, drop-drop coalescence can then occur rapidly, as illustrated in Figures 8 (a to l).

DEFORMATION AND BREAK-UP OF WATER DROPS

The separation of a water drop from the oil depends on the drop's trajectory and the deviation from its original trajectory due to external forces. However, deformation and break-up of a water drop can occur under a very high electric field, as shown by Figures 9 (a to g). The time required for complete detachment of a droplet from a 1 mm water drop in sunflower oil under an electric field of 4.5 kV/cm is about 4.45 ms. Before the droplet is detached, the main drop is stretched by the electric field into a prolate body, forming an elongated end [15]. The breakage occurs at the weakest point of the elongated end, as shown by Figure 10 (f), producing a smaller droplet, whose size depends on the breaking point of the elongated end [15, 16]. This could be due to the overwhelming electrical-induced stresses at the water drop-oil interface, thereby diminishing the force balance between the interfacial tension and the electrical-induced stresses.

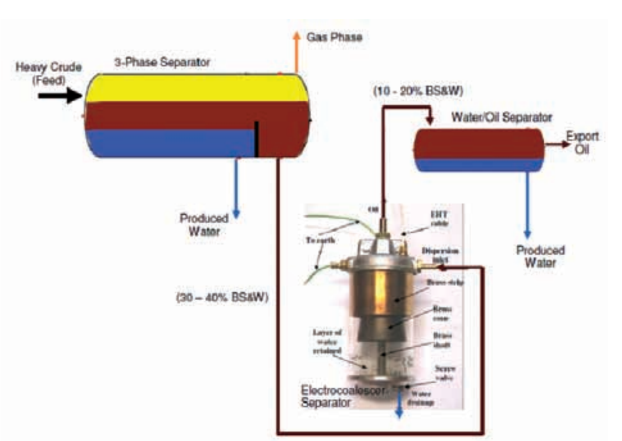

Figure 10: Application of Electrocoalescer-Separator in treating heavy crude oil

Besides the electrostatic effect, the flow in the separator may have the potential for breaking the suspended drops due to: (1) transient shear and local pressure fluctuations caused by turbulence, and (2) viscous shear as a result of time-average velocity gradients. Possible turbulent shear stress and energy dissipation in the entry can affect the size of the drops, with large drops stretched by turbulent vortices and broken up into smaller drops. High turbulence can also cause diffusion and modify the ideal settling motion of small drops within the separation region, with turbulent diffusion having a significant effect in liquid-liquid dispersions as compared to solid-liquid dispersions [17]. This is because the inertia of a drop is smaller than that of a similar size solid particle, due to the small density difference of the liquids. A drop will therefore be more sensitive to the turbulent motion of the continuous liquid.

APPLICATION IN THE OIL AND GAS INDUSTRY

The electrocoalescer-separator can be further developed as a high-performance compact solution to treat heavy crudes into export-quality oil. This will have the advantages of lower chemicals consumption, power consumption and operating temperature, and better safety towards short-circuiting. The specific application is as illustrated in Figure 10.

The crude oil (containing 30 to 40% BS and W) from the conventional 3-phase separator will flow into the compact Electrocoalescer-Separator, which will take out a major portion of the water content. As a result, the treated oil exiting the Electrocoalescer-Separator will only contain 10 to 20% BS and W. Moreover, the remaining water droplets in the treated oil are charged / polarised by the applied pulsed DC electric field, enhancing drop-drop and drop-interface coalescence in the downstream water/oil separator. As such, a lower retention time is required, resulting in the smaller water/oil separator. This directly reduces the footprint, weight and capital costs of the equipments.

CONCLUSION

The compact electrocoalescer-separator, with an optimum electric field, has been proven to produce good separation efficiency for water drops dispersed in flowing viscous oil. The swirling motion distributes the dispersed water drops uniformly within the separator. Moreover, the water drops, having larger centrifugal forces due to the swirling effect, move rapidly towards the grounded brass strip, facilitating drop-drop coalescence and water-oil separation.

The separation efficiency increases with the applied electric field strength until a certain limit. Above this critical electric field strength, drop deformation and break-up occurs, generating smaller drops, and thus reducing the separation efficiency. An optimum electric field strength and an optimum pulsing frequency have been observed to exist with pulsed DC electric field for the enhancement of drop-drop and drop-interface coalescence in the compact electrocoalescer-separator.

The inlet drop size has a significant influence on the separation efficiency. Above a certain inlet drop size (>1.2-mm), the separation efficiency will be very high even in the absence of electric field. However, for small inlet drops (< 0.8-mm diameter), the applied electric field plays a significant role in the separation process. The layer of the water phase accumulated at the bottom of the separator plays a vital role in capturing the dispersed water drops from the flowing oil.

The compact electrocoalescer-separator can be further improved for offshore and onshore installations to reduce the water content of crude oil, especially in the crude oil dehydration and desalting process. Moreover, the separator can be easily installed into existing process lines to separate water drops from flowing oil, in other industries, such as biodiesel production, palm oil refining, oleochemical processing, *etc*.

For more information on the electrocoalescer-separator technology, the author can be contacted by email at *johneow@hotmail.com*. ■

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