

# FUNDAMENTALS OF LIQUID-LIQUID SEPARATION VIA COALESCENCE



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## **Abstract**

There are many technologies designed to separate multiple liquid phases. Although the principles discussed in this technical report apply to most of them, the focus of this paper is on high-efficiency liquid-liquid coalescer systems. Properly designed liquid-liquid coalescing systems efficiently separate the emulsified or dispersed liquid from the continuous phase of the process stream to prevent downstream contamination or to recover valuable product. The process is complex, with many factors to consider. Creating a system for efficient separation requires technical expertise acquired from years of experience and understanding of the science and parameters affecting the process. This technical report presents a high-level understanding of the fundamental principles, design considerations, and equipment required for successful liquid-liquid separation.

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## 1. Need for Liquid-Liquid Separation

Liquid separation applications are concerned with the separation of two immiscible phases, typically aqueous and hydrocarbon phases. In some applications, the aim is to separate the less-concentrated aqueous phase from the hydrocarbon phase, while in others, the target is to separate the less-concentrated hydrocarbon phase from the aqueous phase. The ability to separate a mixture of two liquid phases is critical to the successful operation of many industrial, chemical, and refining processes.

Process complications caused by emulsions can include equipment fouling, reduced production output, off-spec product, environmental discharge violations, increased operating costs, and unscheduled shutdowns that can lead to production and revenue losses. Emulsions can form during different stages of a process due to mechanical energy input and/or chemical component interactions. It can occur in mechanical devices like pumps and other high shear process equipment, or while flowing through pipelines.

Inability to deal with the emulsion can have adverse effects on the downstream equipment and process. Following is a short list of the possible effects of emulsions on the downstream equipment/process:

- ▶ Corrosion
- ▶ Low-quality downstream products
- ▶ Equipment plugging or fouling
- ▶ Environmental discharge beyond the regulated limits
- ▶ Bacterial growth
- ▶ Clogging of injector tips
- ▶ Foaming

### a. The importance and applications of a liquid-liquid coalescer

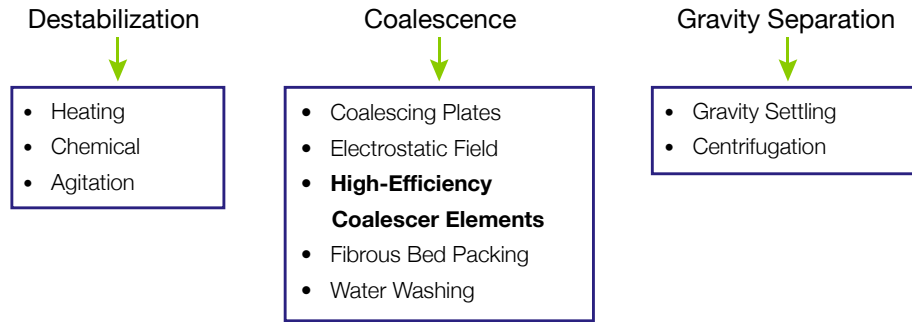
Coalescing filters are typically used to separate fine emulsions of a dispersed liquid component from a continuous phase (e.g., water from oil, oil from water, among others). Generally speaking, coalescence filtration is a process in which immiscible droplets carried by a flowing liquid are captured by the fibers of a filter medium, grown, and released to enhance separation rates of the droplets from the liquid stream.

More specifically, liquid-liquid coalescers are used to accelerate the merging of many droplets to form droplets of greater diameter so they can be separated out of the continuous phase. Increasing the diameter increases the buoyancy or gravitational forces, and hence floating or settling, respectively, of the droplets downstream, requiring considerably less residence time. The reduction in residence time reduces the size of the vessel and thereby reduces the capital expense. To separate a dispersed phase, techniques like gravity settling, adsorbent filters, and hydrocyclones, among other techniques, are used. Gravity settling is primarily used in case of large-size droplets (> 250 to 300 microns) in the dispersed phase. By comparison, liquid coalescers are typically the only cost-effective or reliable solution when the size of the dispersed droplets is under 20 to 30 microns where other technologies may be ineffective at separation.

**b. Conventional methods and technologies used for liquid-liquid separation**

Different techniques are applied to different processes to achieve the desired separation. Selecting the process for liquid-liquid separation depends on a number of factors.

An emulsion treating unit or system uses one or more of the following methods to aid separation:



**Table 1**  
*Common methods available for treating an emulsion*

**I. Gravity settling and Stokes law**

Gravity settling is one of the oldest and simplest methods used for separating emulsions and works on the basis of difference in density between the two phases. It is heavily used in treating emulsions with large droplet sizes needing limited residence time. The gravitational force is resisted by the buoyancy force and a drag force from the movement of drops through the primary phase. When an equilibrium is considered, a constant velocity is reached that can be computed from Stokes law.

According to Stokes law:

The force of viscosity on a small sphere moving through a viscous fluid is given by:

$$F_d = 6\pi\mu Rv$$

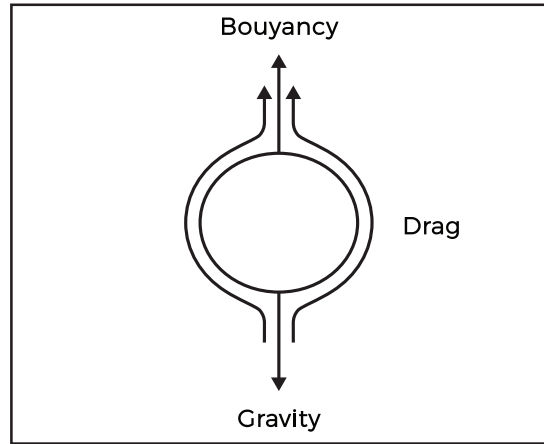
where:

$F_d$  is the frictional force - Stokes drag - acting on the interface between the fluid and the particle

$\mu$  is the viscosity

$R$  is the radius of the spherical object

$v$  is the flow velocity relative to the object



**Figure 1**  
***Forces on a liquid droplet<sup>1</sup>***

At terminal (or settling) velocity, the excess force,  $F_g$ , due to the difference between the weight and buoyancy of the sphere (both caused by gravity) is given by:

$$F_g = (\rho_p - \rho_f)g \frac{4}{3}\pi R^3$$

with  $\rho_p$  and  $\rho_f$  the mass densities of the sphere and fluid, respectively, and  $g$  the gravitational acceleration. Applying the force balance  $F_d = F_g$  and solving for the velocity,  $v$ , gives the terminal velocity,  $v_s$ . If a particle only experiences its own weight while falling in a viscous fluid, then a terminal velocity is reached when the sum of the frictional and the buoyant forces on the particle due to the fluid exactly balances the gravitational force. This velocity is given by:

$$v = \frac{2gr^2(\rho_p - \rho_f)}{9\mu}$$

where:

$v$  = settling velocity for a liquid droplet in a liquid

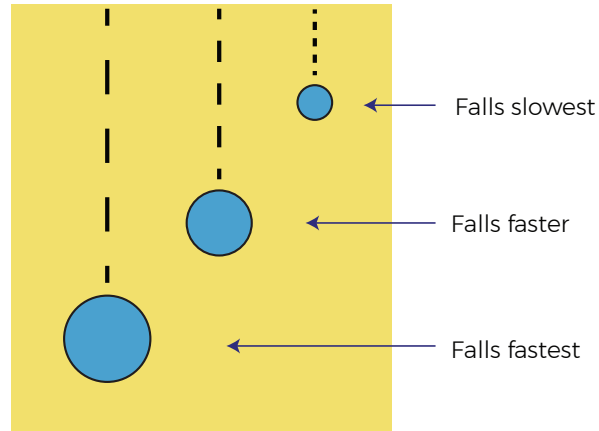
$g$  = gravitational force

$\mu$  = dynamic viscosity of continuous phase

$\rho_p$  = density of liquid droplet

$\rho_f$  = density continuous phase

$r$  = radius of the sphere/droplet



**Figure 2**

***Schematic of water drop falling into an oil bath at different time intervals***

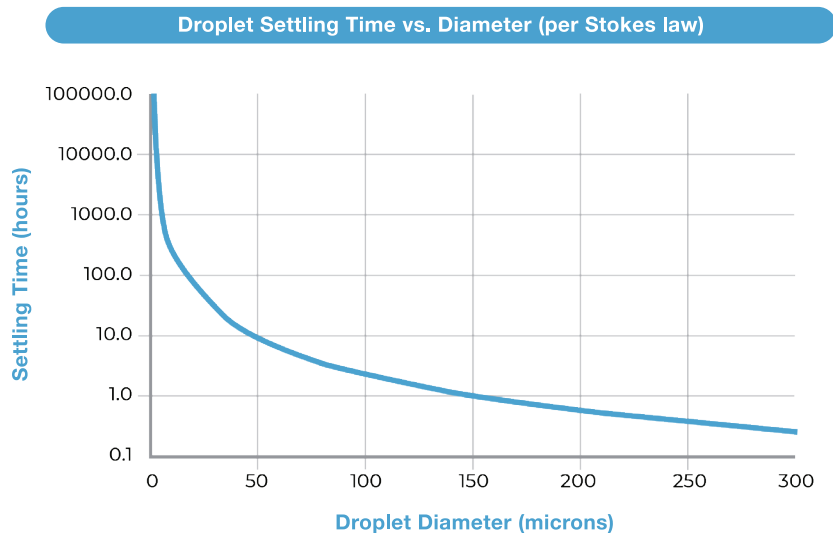
Stokes law makes the following assumptions for the behavior of a particle in a fluid:

- ▶ Laminar flow
- ▶ Spherical particles
- ▶ Homogeneous (uniform in composition) material
- ▶ Smooth surfaces
- ▶ Particles do not interfere with each other

In the actual process, not all droplets are spherical, the flow is not always laminar, and particles do interact, therefore Stoke's law is typically used as a guiding principle and adjustments are to be made to account for these unknowns.

Gravity settling works well for the dispersed phase droplets to settle out of the primary phase fluid only when the droplet sizes are large enough. For smaller droplets, the settling time needed can be quite long, needing very large disengagement (separation) zones – and make gravity settlers by themselves expensive or even impractical. In these cases, droplet interception and coalescence would be preferred to facilitate droplet growth and thereby reduce droplet settling times.

**Figures 2 and 3** illustrate the effect of drop sizes on settling times.



**Figure 3**  
*Estimated separation time vs. droplet diameter using Stokes law, assuming settling time of 15 minutes for a 300 micron droplet*

As per Stokes law, when droplet diameter reduces, the settling velocity reduces by the square of the droplet diameter, and the settling time for the droplet across a set distance increases significantly. For example, while a 300 micron-size droplet may need a gravity settling time of 15 minutes, a 10 micron-size droplet would need 225 hours to traverse the same settling distance by gravity alone!

The larger the droplet diameter of the dispersed phase and the greater the density difference between the droplets, greater is the separation rate. At high temperatures, reduction in the viscosity of the continuous phase will result in an increase in the separation rate. Gravity settling can be used alone to treat emulsions with large droplet sizes only. Therefore, high-efficiency coalescers are used to increase droplet size to resolve slow gravity settling when residence times, footprint, and capital cost considerations result in more favorable economics.

**c. Liquid-liquid separation using high-efficiency coalescers**

The actual coalescence of the dispersed droplets occurs inside the coalescing elements through a three-step process. First, the process is initiated with the interception of the dispersed liquid droplets in the stream by the microfiber matrix. Subsequently, the small droplets effectively coalesce within the fiber matrix to form larger droplets. Finally, in the drainage phase, the large liquid droplets are released from the coalescing element.

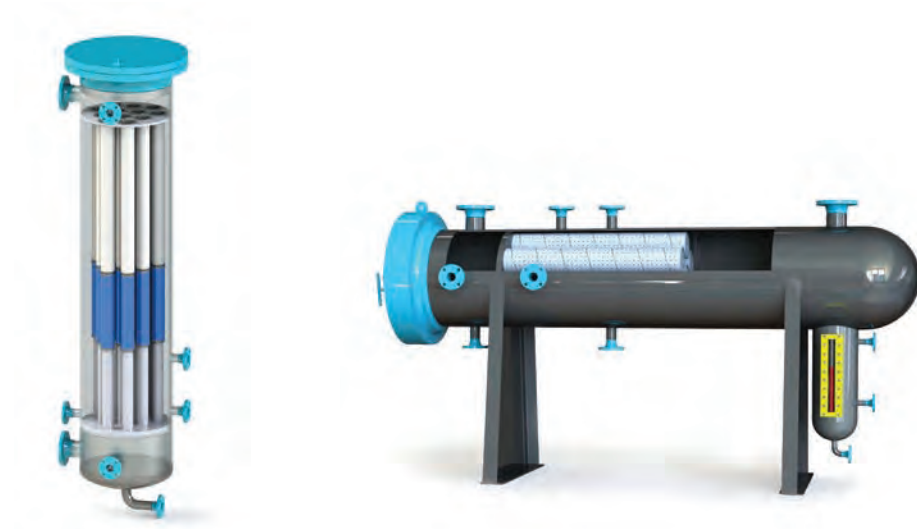
The larger droplets exiting the coalescer elements enter the disengagement phase where they separate from the continuous phase more rapidly due to increased droplet size and gravitational or buoyant forces. The continuous phase exits through its designated outlet, and the discontinuous phase is drained from a collection boot. Vessel design is critical to complement the coalescer element performance for efficient separation of the discontinuous phase from the continuous phase.

These coalescer systems can be configured either vertically or horizontally.



*The horizontal configuration* is the most common. In this configuration, the coalescer consists of a horizontal coalescer cartridge stage, followed by a settling zone that relies on the density difference between the dispersed phase and the bulk phase to separate the coalesced droplets. The length of the settling zone is commonly referred to as the 'disengagement length' indicating the distance needed by droplets to disengage from the primary phase and move to the intended collection zone.

*The vertical configuration* can be modified to use a similar coalescer stage and a secondary separation stage utilizing a separator cartridge with hydrophobic barrier capabilities to allow a hydrocarbon stream to go through while retaining the coalesced aqueous droplets.



**Figure 4**

***FTC Strata Series high-efficiency liquid-liquid coalescer system in vertical and horizontal configuration***

Following is a list of common applications for liquid-liquid coalescers:

- ▶ Water removal from refined fuels (diesel, gasoline, kerosene, and others)
- ▶ Hydrocarbon removal from quench water
- ▶ Oil removal/recovery from aqueous streams
- ▶ Hydrocarbon removal from amines
- ▶ Amine removal from hydrocarbons
- ▶ Caustic removal from fuels
- ▶ Water removal from LPG and NGL
- ▶ Water removal from chemicals
- ▶ Water removal from animal and vegetable oils

Prior to understanding the process of liquid-liquid separation using a high-efficiency coalescer, it is important to understand the characteristics of emulsions that need separation.

**d. An overview of the emulsion in the system**

An emulsion is a mixture of two or more liquids that are normally immiscible (unmixable or unblendable). Emulsions are part of a more general class of two-phase systems of matter called colloids. The phase that is present in the form of droplets is the dispersed phase, and the phase in which the droplets are suspended is called the continuous phase.

Some emulsions break easily when the source of the mixing energy is removed. However, any natural and artificial stabilizing agents can keep the fluids emulsified. The final droplet size of the emulsion is dependent on not only the chemistry but also the amount of energy.

Common examples of emulsified fluids include mayonnaise, salad dressing, butter, vinaigrettes, and some cutting fluids for metal working.

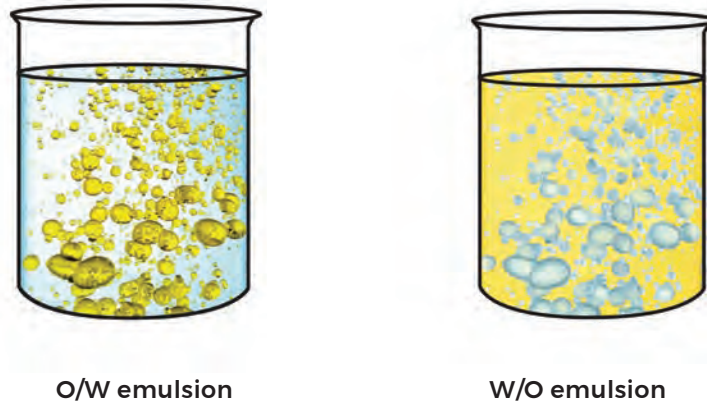


**Figure 5**

***Photograph of oil-in-water emulsion with (left to right) mineral oil, emulsified mineral oil in water, and water***

Types of emulsions include:

- ▶ Simple emulsions
  - Oil-in-water (O/W)
  - Water-in-oil (W/O)
- ▶ Multiple emulsions
  - Oil-in-water-in-oil (O/W/O)
  - Water-in-oil-in-water (W/O/W)



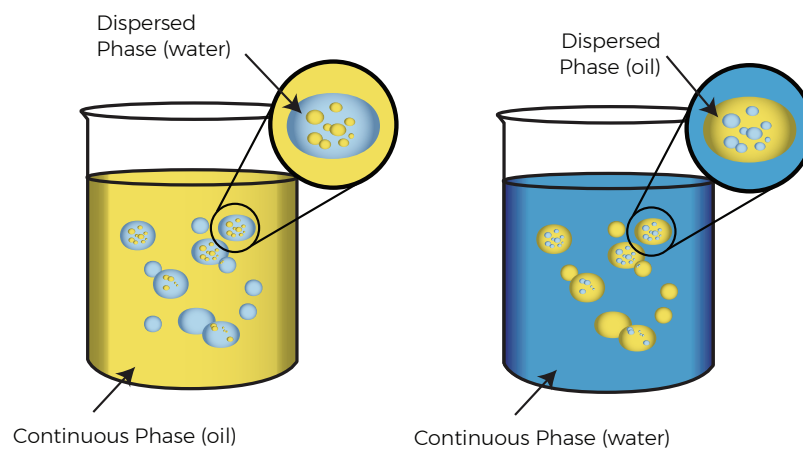
**Figure 6**  
*Schematic representation of oil-in-water and water-in-oil emulsions*

Emulsions can be further classified according to droplet size into three categories:

- ▶ Conventional emulsions ( $d > 200 \text{ nm}$ )
- ▶ Nanoemulsions ( $d < 200 \text{ nm}$ )
- ▶ Microemulsions ( $d < 100 \text{ nm}$ )

The extent of emulsion stability is determined by factors such as:

- ▶ Droplet size distribution
- ▶ Density difference between the dispersed and continuous phase
- ▶ Chemical makeup of the dispersed phase



**Figure 7**  
*Examples of multiple emulsions*

**e. Surfactants (surface active agents)**

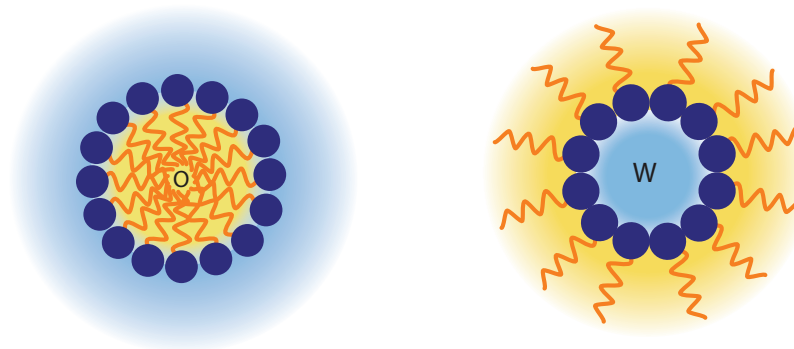
Surface active agents, called surfactants, are organic molecules that consist of two parts: polar portion (hydrophilic) and the non-polar portion (hydrophobic). Surfactants are essential materials and are very commonly used in most industries. Surfactants are used in everyday products, including chemicals, soaps, shampoos, detergents, cosmetics, lubricants, and paints, as well as others. Consequently, it is necessary to understand the physical and chemical characteristics of surfactants and phase behavior.



**Figure 8**  
*Schematic of the surfactant chemical structure*

**Figure 8** shows the two parts of a surfactant molecule.

When two immiscible liquids are stirred, the emulsion is formed. When a surfactant is added to a two-phase system, emulsions are stabilized due to the slowdown of emulsion breaking.<sup>2</sup> The interfacial tension is decreased with the adsorption of more surfactant at the interface, and droplet coalescence is consequently made challenging. Stability of the emulsion is determined by different factors such as the nature of the interfacial film, continuous phase viscosity, oil-water ratio, mixing time, and temperature.<sup>3</sup> Lowering of interfacial tension will result in lowering of interfacial energy, thus increasing the stability of emulsion.



**Figure 9**  
*Schematic of surfactant in emulsion*

Different types of both natural surfactants and artificial surfactants can be present in a fluid system. They can exist in solid or liquid form. For example, asphaltenes are considered as the primary parameter in stabilizing water in oil emulsion, even with low content in petroleum industries. Other solids that stabilize emulsions include iron sulfide, paraffin, sand, silt, clay, scale, and corrosion products.

The amount of mixing and the presence of emulsifier including surfactants critically influence the formation of an emulsion. The amount of mixing depends on several factors and can vary within the process. In general, the greater the mixing, the smaller the dispersed phase droplets. Emulsion studies have shown that the droplets can vary in size from less than 1  $\mu\text{m}$  to more than 1000  $\mu\text{m}$ . The presence, amount, and nature of the emulsifier determines, to a large extent, the type and stability of an emulsion.

## 2. What is Coalescence?

### a. Stages and factors involved in coalescence process

Coalescence is a complex concept, and below is a stepwise explanation of the various steps that result in coalescence.

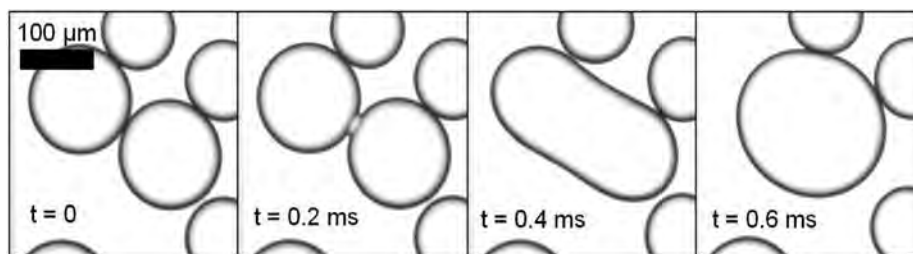
Before the coalescence of two drops can occur, the two droplets have to collide and come into contact with each other. The collision between two droplets is induced by different drop velocities compared to the surrounding continuous flow field, resulting in a relative velocity between the droplets. In actual applications, a broad variety of flow regimes can be found from stagnant continuous phase to fully turbulent flows.

The collision between two droplets can subsequently result in coalescence, agglomeration, or repulsion of the drops.

Coalescence involves the following stages:

- ▶ Approach
- ▶ Contact and deformation
- ▶ Drainage of continuous film trapped between drop interfaces
- ▶ Coalescence via film rupture, forming of coalescence bridge, and confluence

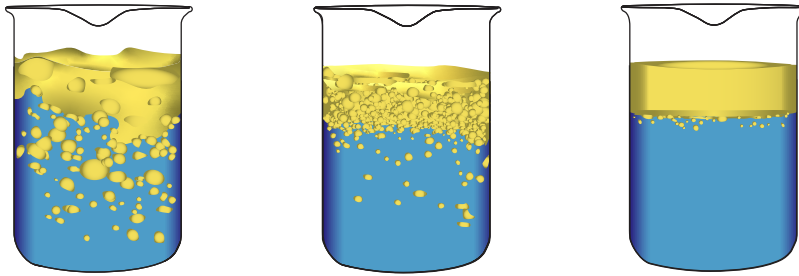
The four stages of droplet coalescence can be observed during every collision, but the occurrence and their time span may differ significantly with chemical and process conditions. There are numerous influencing factors that determine if the collision between two drops results in coalescence, agglomeration, or repulsion.



**Figure 10**

*The process of two drops coalescing with the time frame<sup>4</sup>*

There are a number of influencing factors that affect the continuous phase, interface, and the dispersed phase.



**Figure 11**  
***Phase separation of oil and water***

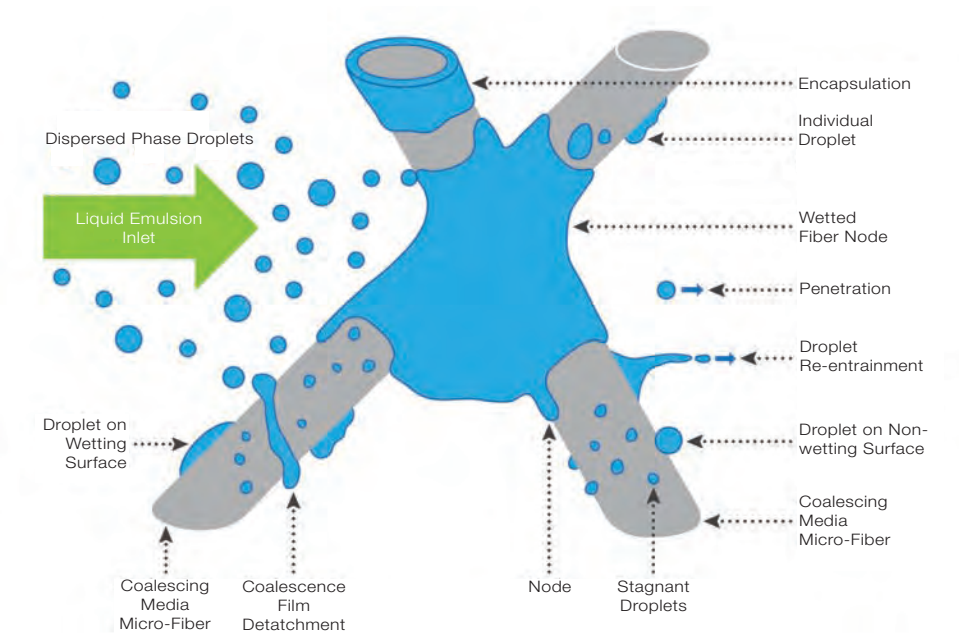
Coalescence is an interfacial phenomenon, as it is driven by the minimization of interfacial area/energy. Consequently, factors influencing the interface have the most significant impact on coalescence. Apart from surfactants, fine solid particles also can adsorb at the interface, stabilize it, and hinder coalescence.

Concerning the properties of the dispersed phase, the drop diameter is probably the most important influencing factor on coalescence. For finely dispersed droplets, the drops stay in spherical shape, and coalescence time generally diminishes with increasing drop diameter.

As the dispersed droplets intercept the fibers of the coalescer filter medium, they coalesce and grow in size within the filter medium until hydraulic drag forces of the continuous phase or the gravity/buoyancy force are strong enough to cause the enlarged drops to release from the coalescer. The critical size of the drop after which it detaches from the fiber also depends on the local velocity, fiber size, interfacial tension, and contact angle. It has also been observed that if the contact angle of the drop on the fiber is small, the drop does not break away from the fiber but is conducted along the fiber in the direction of fluid stream.<sup>5</sup> The separation efficiency depends on the feed drop sizes, dispersion composition and density, liquid viscosity, pressure, temperature, structure of the filter medium (e.g., fiber diameter, fiber orientations, pore structure, and packing density), and surface properties of the fibers, binder content, and filter thickness. The surface tension of liquid and emulsion flow rate also have significant influence on performance of the filter media. Saturation and pressure drop of the filter media are important parameters that need to be controlled to optimize performance. These parameters are important in designing the coalescing filter media.

- ▶ Pore size – Coalescers perform well with optimal fiber sizes and a graded pore structure.
- ▶ Face velocity – The velocity of the fluid across the media surface area controls the capture mechanism and probability of droplet capture. Coalescers have higher performance at optimized face velocities.
- ▶ Droplet size of dispersed phase – The mechanism of droplet capture is dictated by the size of the droplets, their flow pattern within the continuous phase, and the fiber and pore sizes.
- ▶ Interfacial tension (IFT) – Emulsions with higher interfacial tensions are less challenging than those with lower IFTs.
- ▶ Viscosity – Lower viscosity of continuous phase helps in reducing film drainage time and facilitates coalescence.
- ▶ Solid contamination – Fine solids particles can alter properties like interfacial tension and emulsion stability.

**b. Coalescence process within high-efficiency coalescing elements**



**Figure 12**

***Coalescence process second phase: the combination or aggregation of captured droplets***

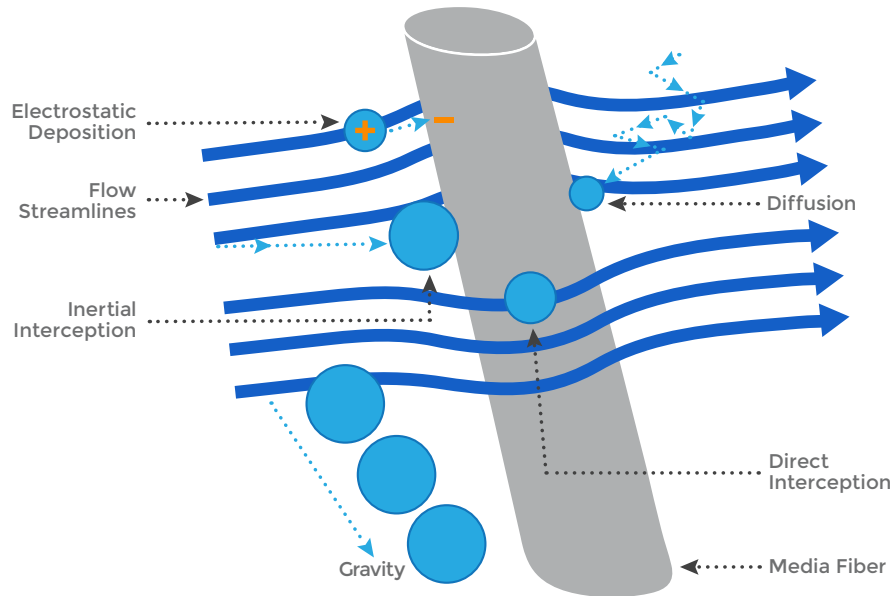
The entire mechanism illustrated in **Figures 12, 13 and 14** can be summarized by the following steps:

1. Droplet contact with fiber
2. Translation of droplets to fiber intersections by bulk flow
3. Coalescence of droplets to form larger droplets
4. Repeated coalescence of small drops into large droplets at fiber intersections and along the fiber surface
5. Release of the droplets from the fiber intersections due to increased drag or gravitational/ buoyancy forces

Droplet capture of the fibers of the filter medium proceeds by way of the following primary mechanisms, as illustrated in **Figure 13**.

- ▶ Diffusion deposition - The trajectories of individual small droplets do not coincide with the streamlines of the fluid because of Brownian motion. With decreasing droplet size, the intensity of Brownian motion increases, as does the intensity of diffusion deposition.
- ▶ Direct interception - Under this mechanism, a droplet is intercepted as it approaches the collecting surface at a distance equal to its radius.

- ▶ Inertial impaction - The presence of a body in the flowing fluid results in a curvature of the streamlines in proximity to the body. Because of their inertia, individual droplets do not follow the curved streamlines but are projected onto the body and may deposit there. The intensity of this mechanism increases with increasing droplet size and velocity of flow.
- ▶ Gravitational deposition - Individual droplets have a certain settling velocity due to gravity. Consequently, the droplets deviate from fluid streamlines and may contact a fiber.
- ▶ Electrostatic deposition - Both droplets and fibers in the filter typically carry electric charges. Deposition of droplets on the fibers may take place because of the forces acting between charges or induced forces.

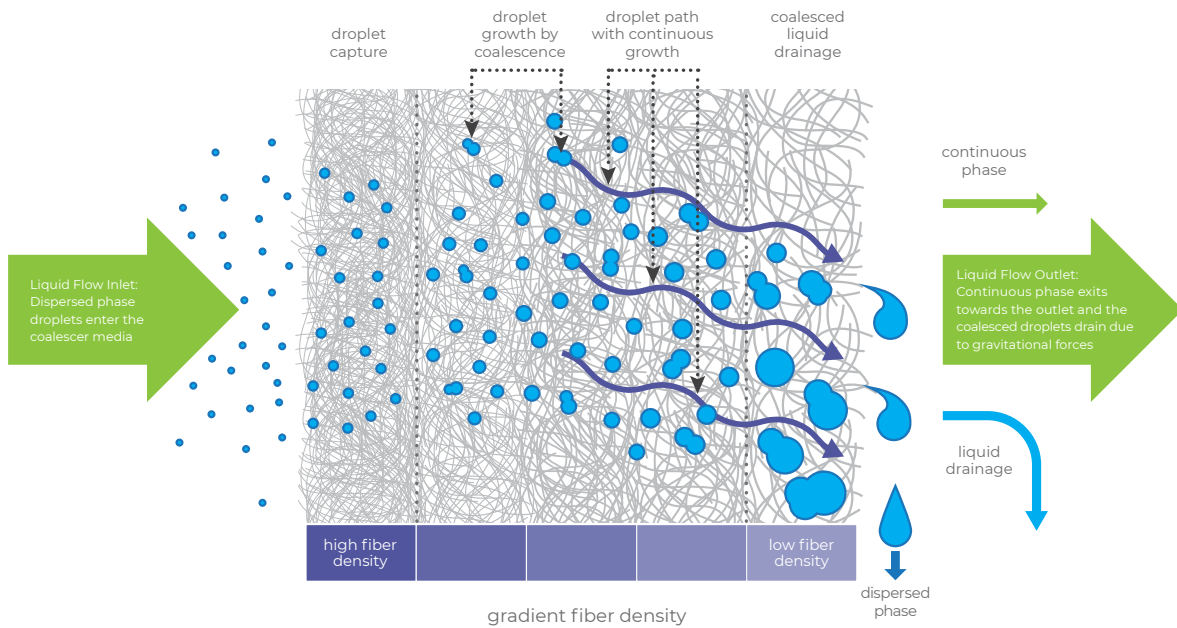


**Figure 13**

***Droplet capture mechanisms***

The second phase in the coalescence process is the combination or aggregation of the captured droplets. Increasing the tendency for droplets to adhere to a medium increases the chance of subsequent droplets striking and coalescing with those already retained. Whether a coalescing medium is hydrophilic (affinity for water) or oleophilic (affinity for oil) depends on the solid/liquid interfacial tension and the chemical nature of the dispersed phase. This wetting property helps in the coalescence step as the droplets adhere to the coalescing medium longer. Coalescing medium with a finer fiber matrix and increased surface area yield more contact sites, specifically fibers and nodes, for coalescing. Once several droplets are collected on the solid media (fiber), they tend to combine while minimizing their interfacial energy. Coalescers work better with optimal residence time in the media and with better droplet-to-fiber impact, droplet-to-droplet collision, and drainage.





**Figure 14**

***Three steps in liquid-liquid separation using a filter media***

As droplets move through the depth of the media, they coalesce and grow in size. Accordingly, the pores of the media need to be larger in order to accommodate the larger drop size, as illustrated in **Figure 14**. For an effective coalescer, the pore sizes grow from the inlet to the outlet side of the media. Without this gradient in pore sizes, the coalescer risks shearing back any droplets it manages to grow.

As the liquid droplets are captured in the void space of the filter, the filter media loads up, and the liquid needs to be drained to make the pore volume available for continued coalescence. A drainage layer is incorporated in the filter media to enhance drainage.

**c. Factors affecting liquid-liquid separation in high-efficiency coalescers**

Now that we have provided an overview of the mechanisms of successful coalescence using high-efficiency coalescers, it is important to be aware of the common factors that present challenges to successful liquid-liquid separation.

A number of factors like interfacial tension, wettability, pore size, flux rate, pre-filtration, and surfactants affect the liquid-liquid separation efficiency. **Table 2** provides a summary of the properties that impact coalescence by phase.

Continuous Phase	Liquid/Liquid Interface	Dispersed Phase	Liquid/Solid Interface
Viscosity	Interfacial Tension	Viscosity	Contact Angle
Density	Surface Potential	Density	Fiber Surface Roughness
Energy Input/Velocity	Surface Active Components: Surfactants, Particles, Ions	Drop Diameter	Fiber Surface Energy
Flow Pattern/Regime	Mass Transfer/Solubility in Continuous Phase	Ionic Strength, pH (if aqueous)	Wettability
Ionic Strength, pH (if aqueous)		Number Population	Hydro- or Oleophobicity
<b>Ambient and System Conditions</b>			
Temperature, pressure, geometry, surface wetting, electrostatic field, microwaves, ultrasound			

**Table 2**  
***Influencing factors on the coalescence process***

Following is a more detailed description of the important factors that affect liquid separation.

### **I. Interfacial tension**

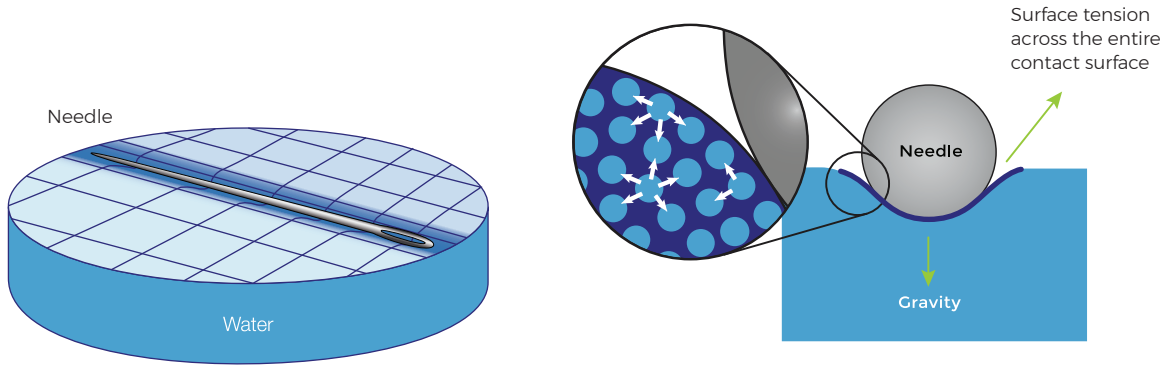
Higher interfacial tension between the droplets and the primary fluid results in a more stable emulsion as the droplets are stabilized by their surface energies.

Surface tension is a property of liquid arising due to cohesive forces between molecules of liquid. When the surrounding medium is air, it is called surface tension; when the surrounding medium for molecules is any other liquid, this phenomenon is called interfacial tension.

Liquid-liquid coalescer cartridges can be designed to enable the separation of low interfacial tension (IFT) emulsions that are challenging to separate by conventional technologies. High-efficiency coalescers can be formulated with special media materials, layering, or treatments to increase separation of more complex emulsions.

### **II. Surface tension and wettability**

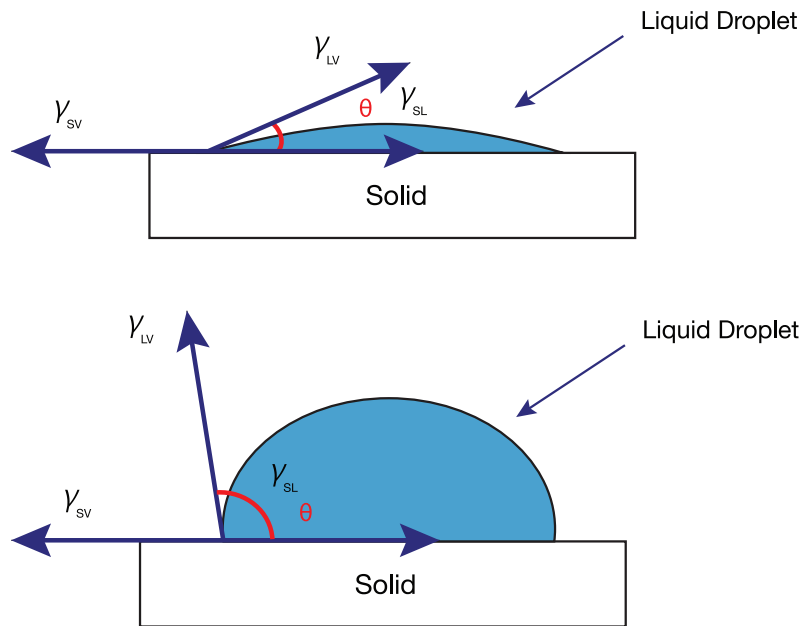
Surface tension is a property of a substance where the molecules of the substance at the surface experience unbalanced intermolecular forces. The shape of a liquid at the interface highly depends on the surface tension of the liquid and the solid with which it is in contact (e.g., media fibers). The liquid tends to minimize the surface free energy by minimizing the surface area. This is the reason why water droplets take the spherical shape when they detach from the liquid stream.



**Figure 15**

*Surface tension depicted by a needle floating on water*

Wetting depends both on the surfaces on which the liquid makes contact and the intrinsic characteristics of the liquid.



**Figure 16**

*A schematic of the contact angle and free energies acting on a liquid droplet where  $\gamma_{sv}$  is the solid-vapor interfacial energy,  $\gamma_{lv}$  is the liquid-vapor interfacial energy,  $\gamma_{sl}$  is the solid-liquid interfacial free energy, and  $\theta$  is the contact angle*

Wettability describes the preference of a droplet to be in contact with one phase over another phase. The discontinuous phase droplets come in contact first with the fibers of the coalescer media, and the grown

droplets come in contact with the fibers within the drainage layer. Therefore, wettability is instrumental in determining the correct media and type of drainage layer when designing a coalescer. Coalescers can be designed with enhanced surface properties to influence the adsorption of droplets and the ultimate release of coalesced droplets.

### **III. Surfactants**

Surfactants affect the liquid-liquid separation in more than one way. Surfactants can affect the emulsion by having an effect on the drop size and stability of the dispersed phase. The type of surfactant determines the stability of the emulsion. It can also interfere with the functioning of the coalescer by depositing itself on the interface between the fiber and the liquid.

Surfactants are responsible for a number of problems affecting adhesion, cohesion, and contact angle between the liquid drop and the coalescing fiber surface. The interfacial tension is decreased with the adsorption of more surfactant at the interface, and droplet coalescence is consequently delayed.

### **IV. Dispersed phase concentration**

Cartridge coalescers can accommodate relatively high (i.e., up to 5% typically) and fluctuating inlet dispersed phase concentrations. Highly concentrated emulsions increase the chances of droplet-droplet interactions improving coalescence. An increase in concentration also leads to faster saturation of the filter element. However, if the coalescer element is challenged with a concentration exceeding its liquid loading capacity, such as slugs, it can lead to less-efficient removal of the dispersed phase. Accordingly, a coalescer element needs careful design and testing to determine optimal liquid loading.

### **V. Flux rate and flow rate**

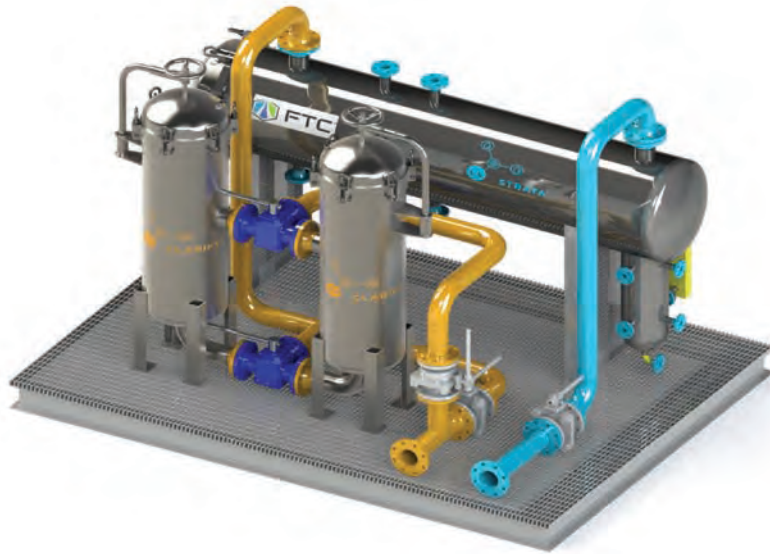
Flux is flow rate per unit area. This property applies to the system flow rate in relation to the available coalescing media surface area. Flux rate must be optimized to enhance the performance of a coalescer element by way of improving droplet interception, droplet growth, and eliminating carryover of the dispersed phase droplets.

As saturation progresses, droplets on the surface will eventually coalesce and grow large enough, such that gravity becomes the dominant force and, accordingly, they drain off the surface. But increasing the flux beyond a certain limit might cause the droplet to exit without reaching the maximum size possible.

### **VI. Solids contamination**

To operate at their highest efficiency, coalescers must be free from solid contaminants. Installing the correct pre-filtration system upstream of the coalescing unit is critical for proper functioning and operating efficiency. Solid contaminants can plug coalescer media, which can lead to more frequent changeouts and less-efficient performance. A frequent replacement of coalescer cartridges is not cost effective due to the costs of changeout, maintenance, and used cartridge disposal. So, it is usually recommended that a separate pre-filter be installed upstream of the coalescer to remove particulate matter, as shown in **Figure 17**.

Pre-filtration involves the use of a filter designed to remove particulate matter (e.g., dirt, sediment, and other particulates) from fluid prior to further treatment. The removal rating of the pre-filter should be selected according to the pore size structure of the coalescer medium, as well as according to the size distribution of the solid contaminants. The particulate pre-filter increases the investment cost of the cartridge coalescer solution but reduces overall operation costs of the coalescer assembly through significantly improved online life of coalescer cartridges. Typically, a coalescer can offer online life of one year or longer without changeouts if the solids are managed adequately.



**Figure 17**

*FTC Strata Series high-efficiency liquid-liquid coalescer and pre-filter packaged system*

### **3. Design Considerations for High-efficiency Liquid-Liquid Coalescer Systems**

This section addresses the various design considerations for high-efficiency liquid-liquid coalescing systems.

Liquid-liquid coalescer vessels can be designed vertically or horizontally. Separation of coalesced droplets is facilitated by settling along the disengagement length within the vessel. In vertical configuration, hydrophobic media can aid separation from oil without the need for vessel disengagement length. In the horizontal configuration, a settling zone achieves separation by gravity.



**Figure 18**

*FTC Strata Series high-efficiency liquid-liquid coalescer system in vertical and horizontal configuration*

Characteristics of the flow stream will greatly affect the design and operation of a coalescer. The following factors must be determined before designing the coalescer:

- ▶ Fluid composition of each phase.
- ▶ Flow rate (total) – operating and maximum design
- ▶ Discontinuous phase inlet concentration and droplet size
- ▶ Presence, concentration, and particle size of solid contaminants
- ▶ Operating pressure and temperature
- ▶ Density of each phase at operating conditions
- ▶ Viscosity of each phase at operating conditions
- ▶ Liquid-liquid interfacial tension
- ▶ Allowable pressure drop/loss – clean and dirty
- ▶ Effluent quality requirements (e.g., desired maximum discontinuous phase dispersed in the effluent)
- ▶ Vessel materials of construction and Non-Destructive Examination (NDE) requirements

With the above information, an experienced engineer can properly design a reliable liquid-liquid coalescer system.

A properly designed high-efficiency coalescer must satisfy several criteria for good operation.

- ▶ Designed to allow the dispersed phase droplets to separate from the continuous phase
- ▶ Designed with proper materials of construction for chemical and thermal compatibility
- ▶ Designed with proper media and velocity profiles to allow for the droplet interception, coalescence, and drainage
- ▶ Provide sufficient disengagement space for the coalesced droplets to rise and/or fall to their collection boot
- ▶ Provide protection of the coalescer from premature plugging from solid contamination
- ▶ Have appropriate ports, port locations, and instrumentation to aid operations in the ability to effectively operate the equipment
- ▶ Allow for variation in the flow rates and concentration, within reason, without adversely affecting separation efficiency

#### 4. Conclusion

As discussed herein, there are several technologies that can be used in case of liquid-liquid separation: gravity settling, centrifugal technologies, distillation, and using high-efficiency coalescers, among others. The choice of technology for the separation is crucial for the success of the process. This choice is determined by considering factors such as effluent quality needed, flow rate, type of contamination, and economics. The initial capital, operating, waste disposal, and maintenance costs must all be considered, along with the economic impact of lack of performance of a lower-efficiency system.

Advantages of liquid-liquid coalescer elements include low capital and operational costs, minimal maintenance, and low energy consumption. In addition, properly designed coalescers provide a high efficiency of separation. They can be used when the drop size of the dispersed phase is relatively small. They can be included in batch or continuous processes, and the size of the unit is relatively compact.

Liquid-liquid coalescer elements can be used independently or in series with another separation technology, with a view to grow droplets large enough and aid in the secondary stage separation. High-efficiency coalescers could significantly reduce the size and impact the economics of the secondary separator.

Technical expertise and expert understanding of the science and parameters affecting the process in tandem with testing abilities is a realistic need for the design of a reliable, efficient separation solution.

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