

Flow assurance conceptual design involves multi-disciplinary integrated work that often requires co-operation and co-ordination among various disciplines/teams. However, as discussed in this article, an attempt is made to define the minimum conceptual analysis requirements for the emulsion based flow assurance problems. A comprehensive check list has been developed based on the experience.

An emulsion is a heterogeneous system that consists of at least one immiscible liquid intimately dispersed in another in the form of droplets. The droplet size can vary from one to several hundred microns. Although there are several classifications of

A comprehensive

CHECK LIST



B. Chandragupthan, PL Engineering Ltd, and Girish Babu Nounchi, Wood Group Kenny, Abu Dhabi, give an overview on emulsion based flow assurance solutions that aid in eliminating potential threats.

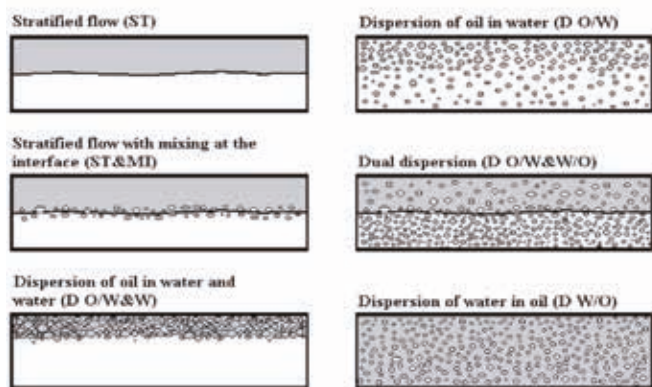


Figure 1. O/w dispersion flow patterns.

Table 1. Dosing rate of the demulsifiers

Light crudes	10 - 50 ppm (with respect to dry crude)
Heavy crudes	up to 150 ppm
Deoilers	10 ppm (maximum)

emulsions, there are fundamentally two types: normal emulsion, which is water dispersed in oil (water-in-oil, w/o); and reverse emulsion, which is oil dispersed in water (oil-in-water, o/w). Based on stability, emulsions are also classified as stable, meso-stable and unstable emulsions. Multiple emulsions are complex dispersion systems known as 'emulsion of emulsions'. The most common multiple emulsions are the water-oil-water (w/o/w) type.

Emulsion stability

The factors that usually favour emulsion stability are low interfacial tension, high viscosity of the bulk phase and relatively small volumes of dispersed phase. A narrow droplet distribution of small size is also advantageous, since polydisperse dispersions will result in a growth of large droplets on the expense of smaller ones, an effect termed Ostwald ripening.

Particles (for example, polymers, surfactants or adsorbed particles) that are oil-wet tend to stabilise w/o emulsions while those that are water-wet tend to stabilise o/w emulsions. In order to stabilise the emulsions, the particles should be at a sufficiently high concentration and at least one order of magnitude smaller in size than the emulsion droplets.

Effect of pH

To minimise emulsion formation the crude oil should not make contact with high or low pH water; since the interfacial tension between the oil and water droplets is relatively low at either end of the pH scale, thus will enhance the emulsion stability.

Effect of salt content

In general, increasing the salt content lowers the interfacial tension. However, as it has been noticed in many cases, because of high separation (due to higher water density), the stability of o/w emulsions decreases with increasing salt content of the water phase.

Temperature effects

An increase in temperature results in a decrease in emulsion stability. The changes in temperature have a significant effect on interfacial tension, solubility of surfactant, brownian motion, viscosity of liquid and phases of interfacial film.

Effect of density

The density ratio in liquid-liquid systems usually varies between 0.7 - 1.1. Hence, the separation of the two phases due to gravity is much slower in liquid-liquid systems. The density differences between two liquids have a substantial effect on flow pattern. Generally, it is more difficult to produce a dispersed flow regime when the density difference is high.

Effect of viscosity

The viscosity ratio's for liquid-liquid systems is higher than that of gas-liquid systems. Due to the large variety of liquids produced, the viscosity ratio can vary significantly. Normally, viscosity ratio varies in the ratio of 0.3 - 10⁴ for liquid-liquid systems and 10⁻² for gas liquid systems. The result of this difference in viscosity ratio is that in liquid-liquid flow, dispersions of the droplets of one phase into another. The drag between two phases and the slip velocities are larger than the gas liquid system due to interaction between liquids, surface tension, wetting properties of pipe material, inversion point and surfactant effects. In general viscosity has a dual effect on flow.

Increase in viscosity can increase instability due to difference in velocity profiles at the interface. At the same time it helps to dissipate the energy that causes instability. The viscosity of w/o emulsions is generally higher than that of crude oil at the same test conditions, which results in higher pressure drop along the pipeline and is difficult to separate the water from the emulsions. The viscosity of w/o emulsions can be reduced by adding some emulsifier, and its inner and outer phases can be inverted top form an o/w emulsion with lower bound water content. Rules of thumb:

- For oil-water systems, the maximum effective viscosity of liquid occurred at the phase inversion point. The effective viscosity at inversion point is directly proportional to the mixture velocity.
- In general, an increased viscosity will cause hold up to become greater. Within 30 - 70% water cut range, inversion of the emulsion can be expected and the effective viscosity can increase to a high value.
- Higher viscosity of one phase will favour it to be the continuous phase.
- In pipelines more viscous oils tend to be dispersed.
- The emulsion viscosity is proportional to the continuous phase's viscosity, but it also depends on the dispersed phase's volume fraction, the droplet diameter, the dispersed phase's viscosity and the shear rate and the temperature.
- When approaching phase inversion conditions, emulsions behave as Non Newtonian Pseudo Plastic fluids. This gives the emulsions the remarkable property that they become less viscous as the shear rate increases. No reliable,

general correlation for predicting this effect for emulsion exists.

Effect of surface tension

It is believed that an increase in surface tension reduces the unstable growth of the short waves at the interface and decreases droplet generation. In addition, if the generated droplets are larger it is difficult for the turbulent forces to keep the droplets dispersed. In this case, the breakup of droplets is more difficult due to its higher surface tension.

Effect of interfacial tension

Interfacial tension can affect the phase inversions, since it affects the drop size and interfacial area. A decrease in interfacial tension will lead to an increase in drainage time for the film between the drops, leading to higher drop breakage and lower drop coalescence and as much smaller drop size. A higher dispersed phase fraction will thus be required for inversion to occur. It was also found that lowering the interfacial tensions will lead to reduce the wettability of the containing surfaces. Rules of thumb:

- In the absence of other forces the interfacial tension will cause inversion to occur at 50% volume fraction.
- Decreasing the interfacial tension widens the ambivalent region and makes it more difficult to cause and appearance of phase inversion.
- The initialisation of the dispersion has a strong effect on phase version.

Effect of high strength interfacial film

The main factor affecting the stability of the emulsion is the high strength interfacial film, which hinders the coalescence of water droplets

Effect of inlet design and wetting properties

Different inlet devices, such as static mixtures (or) nozzle configuration, can influence flow pattern and pressure gradient in oil water flow. The degree of wetting of the wall surface depends on wall materials and the history of the fluid dynamics at the pipe wall surface. This can have significant effect on the flow pattern as the liquid with higher wetting properties can spread around pipe surface.

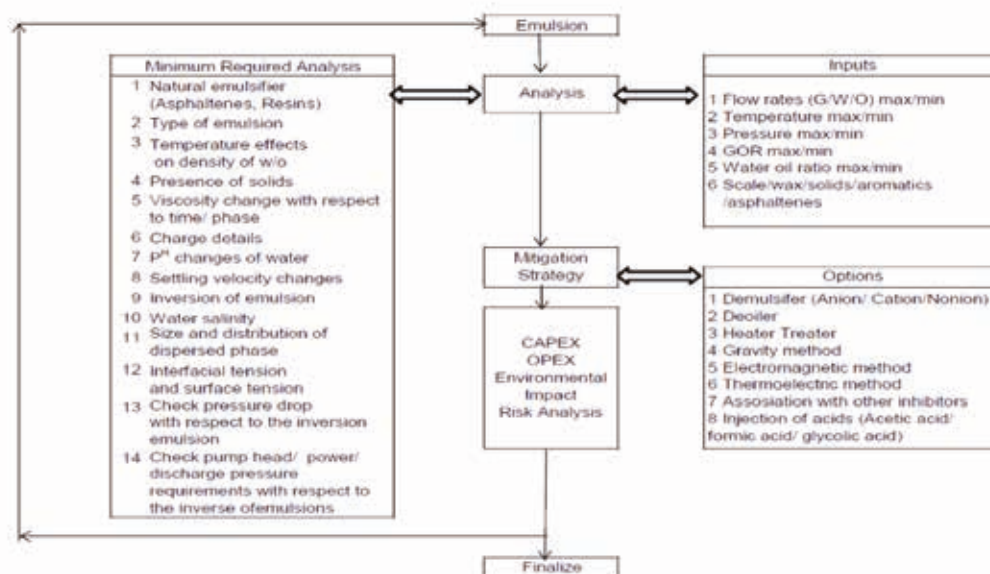


Figure 2. Emulsion-decision making tree.

Inversion of emulsion

Inversion of emulsion refers to a process in which emulsion suddenly changes from w/o to o/w or vice versa by increasing the disperse phase volume to around 0.7. High water cut emulsions are usually strong shear thinning and may even possess visco-elastic properties. The viscosity of w/o emulsion is always higher than that of the oil, even if the oil has much larger viscosity than water. In fact, the viscosity of the emulsions as functions of water cut are sometimes refers to the point of maximum water uptake as the inversion point. This suggests that the w/o emulsions turn into an o/w emulsion.

Demulsifiers & deoilers

The emulsion breakers for w/o emulsions are called demulsifiers. The emulsion breakers for o/w emulsions are known as deoilers. These are surface active agents which diffuse through the continuous phase of the emulsion to the oil-water interface where they deactivate the emulsifying compounds. There are different classifications of the demulsifiers. Based on the charge they are classed into anionic, cationic and non-ionic. Another classification is based on the response time of the demulsifiers. They are fast acting demulsifiers (generally used in off shore) and slow acting demulsifiers (usually used in onshore). Rules of thumb:

- No single demulsifier can be applied to break all kind of crude oil emulsions.
- Interaction with other chemicals such as corrosion inhibitor/ hydrate inhibitor to be checked.

Demulsifier efficiency is affected by the water/oil ratio, surfactant concentration, surfactant molecular weight, alkyl chain length, asphaltene content and aromaticity.

Dosing rate

The general dosing rate of the demulsifier is given below. These are based on the experience, but subject to the expert opinion. Emulsion treating chemicals are generally available as 25 - 50% solution of the active material in alcohol/aromatic solvents (Table 1).

Heater-treater/electric & magnetic treaters/ gravity separators

Process engineer shall check the additional requirements of heater treater/electric treater/magnetic method and gravity separator for successful transportation/handling of the emulsions. A feasibility study has to be conducted for all the options.

Oil line water slugs

Free water will tend to be collected at all low points in the line at which the velocity of the water phase is less relative to that of the oil phase. This holdup principally occurs under conditions of stratified flow where the water forms a distinct layer at the bottom of pipeline. Where the concentration of water is relatively low, the separated water resides primarily within the pipe boundary layer. As a result, its average velocity is less than that of the overlying oil. This velocity difference is further increased by greater inertial stresses acting on the water phase. The presence of uphill sections within a pipeline will further enhance the velocity differences, whilst downhill sections will reduce them. The water holdup fraction is influenced by the density and viscosity of the both liquids, flowing water fraction, the pipe diameter, mixture flowrate and the pipe inclination. Water holdup increases with the flowing water fraction and the pipe inclination. The water cut of the liquid has some effects in the transition from stratified to slug flow. Increasing the water cut results in the transition occurring at higher liquid velocity at the same gas velocity. Rules of thumb:

- When the flowing water fraction increases over 10% the flow regime is no longer stratified and it hold up will tend towards the flowing water fraction. Water slugs will be created by accumulation and sweep out, the size of which will mainly depends on the geometry of the line.
- In case of two phase (oil-water) lines, the pressure drop will be higher at 40 - 60% water concentration and was independent of the volumetric flowrate of oil.
- At moderate and low mixture velocities of say less than 4 m/s, water and hydrocarbon liquid, say oil, stratify into layers but occasionally tend to alternate to a series of successive "Plugs" of water/oil/water etc within the stratified liquid layer.
- Homogeneous approach is acceptable only when the mixture flow velocity is above 5 m/s and there are no emulsions.
- At moderate and low mixture velocities of say less than 4 m/s, water and hydrocarbon liquid, say oil, stratify into layers but occasionally tend to alternate to a series of successive "plugs" of water/oil/water etc within the stratified liquid layer.

Temperature effects

Generally at the elevated temperatures, the destabilising efficiency of the demulsifier is high. But it has to be studied.

Flow pattern classification

Widely used flow patterns are given below.

- Stratified flow (SF).
- SF with mixing at the interface.
- SF with a free liquid and dispersion of another fluid (D o/w & W).
- SF with a free liquid and dispersion of another fluid (D w/o & W).
- W/o dispersion above o/w dispersion.
- W/o dispersion above o/w dispersion with pure oil at the top and pure water at the bottom.
- Full o/w dispersion.
- Full w/o dispersion.
- Core annular flow (viscous oil in core and water in annulus).
- Core annular flow (water in core and oil in annulus).
- Core annular flow (dispersion of w/o in core and water in annulus).
- Core annular flow (dispersion of o/w in core and oil in annulus).
- Core annular flow (dispersion of one phase in core and dispersion of another in annulus)
- Intermittent flow.
- Elongated or spherical bubbles of one phase in a continuum of another phase.

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