Mixing in the Oil and Gas Industry

Preface:

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Introduction

The oil and gas industry includes the processes of exploration, extraction, upgrading, refining, transporting and marketing oil products. The largest volume products of the industry are fuel oil, <gasoline> and feedstock for bulk and fine chemicals [1]. There are two types of crude oil: one is <conventional> and the other is <unconventional> to which oil sand resource belongs. There are an estimated 1.5 and 170.4 billion barrels of established conventional and bitumen crude oil remaining as of 2009 in Alberta [2]. A typical production flow of conventional oil is shown in Figure 1. The extraction of heavy oil (bitumen) from oil sands conserves is shown in Figure 2; the rest of the flow is the same as the conventional crude oil.

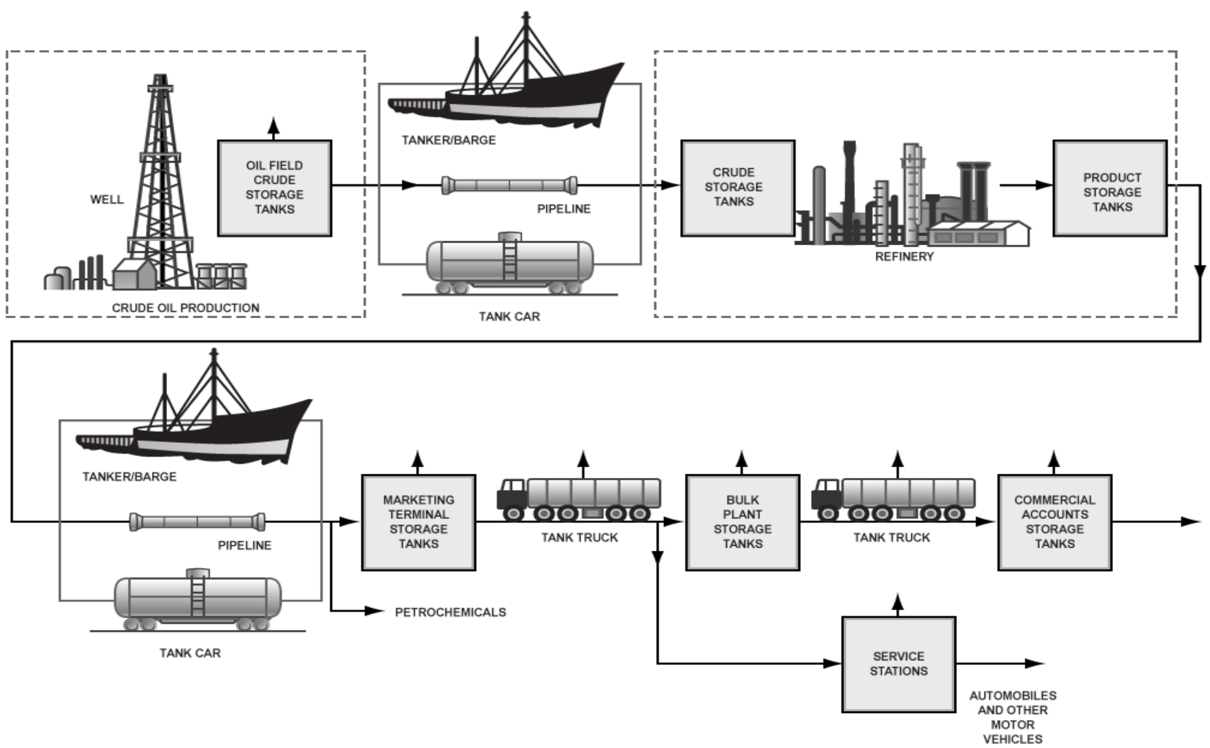


Figure 1 Product Flow of Crude Oil [4]

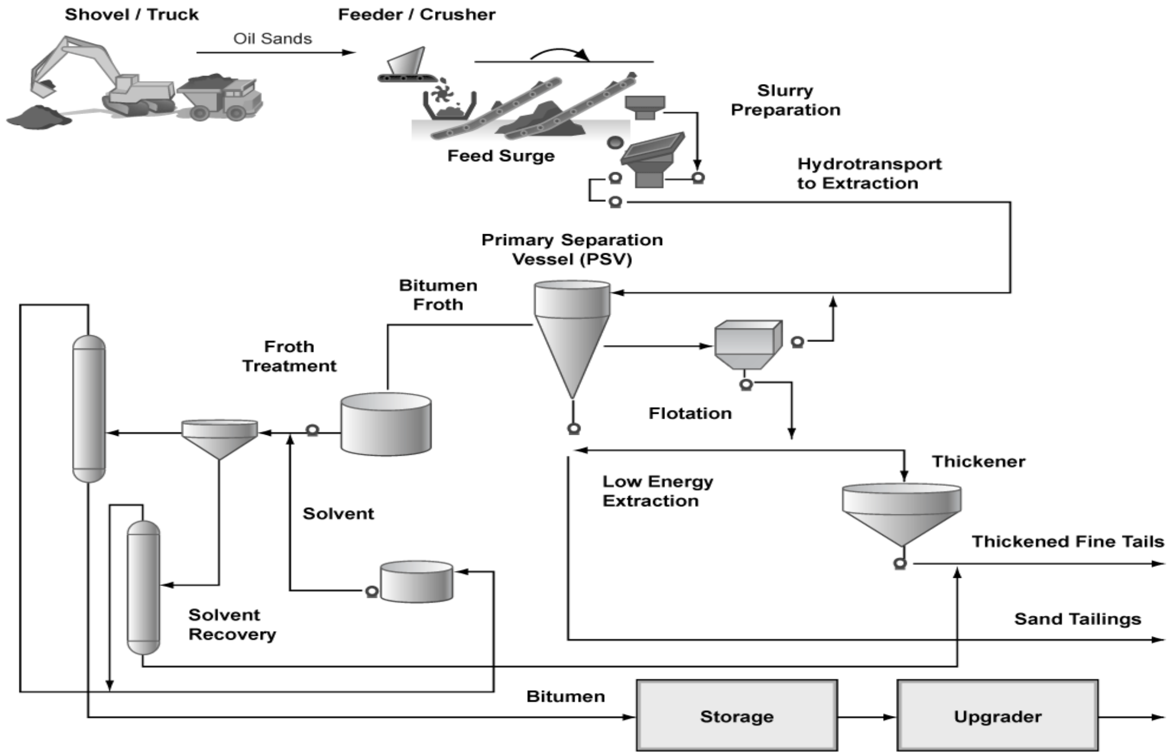


Figure 2 Mining and Extraction of Bitumen from Oil Sands [9]

Mixing is involved in every step of the oil industry from exploration to marketing products. While drilling oil and gas wells, drilling fluid is applied**.** The fluid consists of a mixture of clay and a stabilized water-in-oil emulsion. The emulsion is prepared batchwise by dispersing water in oil in agitated tanks. The main functions of drilling mud include providing hydrostatic pressure to prevent formation fluids from entering into the well bore, keeping the drill bit cool and clean during drilling, carrying drill cuttings out of the well and suspending the drill cuttings while drilling is paused and the drilling assembly is brought in and out of the hole. Thus, mixing technology plays an important role in the exploration stage [3].

Meanwhile, mixing is important for product sampling in the pipeline transport. When crude oil is sampled to determine its water content before its custody is transferred to refineries, the water has to be uniformly dispersed across the cross-section of pipes. Thus, a mixer system has to be installed upstream of the sampler. Adequate mixing should create a good dispersion but still allow water to easily settle in downstream storage tanks. Optimum mixing can add a high value for refineries as even a sampling error of 0.1% can cost refineries about $250, 000 per medium-sized tanker [4].

Viscous crude oil has become an increasingly important source of hydrocarbons around the world. Transportation of these viscous crudes from the source to the refinery is a challenge because existing pipelines were designed for less viscous crudes. One available technology is to mix crude oil into water with an emulsifier to form high oil content oil-in-water emulsions with a dramatic decrease in viscosity and pressure drop. The pumping cost for these emulsions is similar to the lower viscosity conventional crude oils [5, 6].

Mixing is used control sludge accumulation in crude oil storage tanks. Crude oil usually carries a certain amount of bottom sludge and water. As this sludge is heavier than crude oil, it settles in storage vessels at terminals and refineries. Excessive sludge accumulation can occur in tanks with poor mixers and at low ambient temperatures. Once the sludge is settled on the tank floor, it hardens and cannot be removed by normal pumping. The tank has to be taken off-line and cleaned, which is hazardous, expensive, time consuming and requires sludge disposal [4].

Furthermore, mixing is extensively used in unit processes of gas treating, extracting, upgrading and, refining. <Natural gas> often contains a high concentration of <CO_2> and <SO_2> which make it unsuitable for direct use as fuel gas. Conventional processes reduce these concentrations by absorbing CO_2 and SO_2 in an amine solution in a packed bed contactor. Although these towers provide the maximum driving force for <mass transfer>, they are very large. Therefore, on <offshore platforms> <static mixers> can be the favored choice because they provide perfect <plug flow>, a large number of stages, good radial mixing, high mass transfer coefficient, and are smaller in size and weight [4].

<Propane> deasphaleting is another example of solvent extraction. In this case a static mixer is employed to mix <asphaltene> and part of propane before feeding into the extractor; it significantly reduces the size of the extractor.

Desalting, the first step in refineries, removes salt from crude oil before it is sent to the downstream units. This is carried out by first mixing a demulsifier in the pipe followed by emulsifying fresh water in an in-line mixer. The water-in-oil emulsion is broken in an electrostatic separator to produce oil with negligible salt and water. Optimum mixing of fresh water is desired for satisfactory desalting. Poor mixing can lead to carry over of salt in the crude; over mixing can result in the formation of a stable emulsion and poor separation [4].

In many process units with a <continuous stirred-tank reactor (CSTR)>, such as fluid coking (Figure 3), visbreaking, <fluidized catalytic cracking> and ebullated bed hydroconversion, mixing plays a vital role. For example, the yield of products is determined by the feed properties, the temperature of the fluid bed, and the residence time in the bed. The fluid bed reduces the residence time of the vapor-phase products and provides excellent heat transfer that allows the reactor to operate at higher temperature. These factors generally give a lower yield of coke and high yield of gas oil and olefins [8].

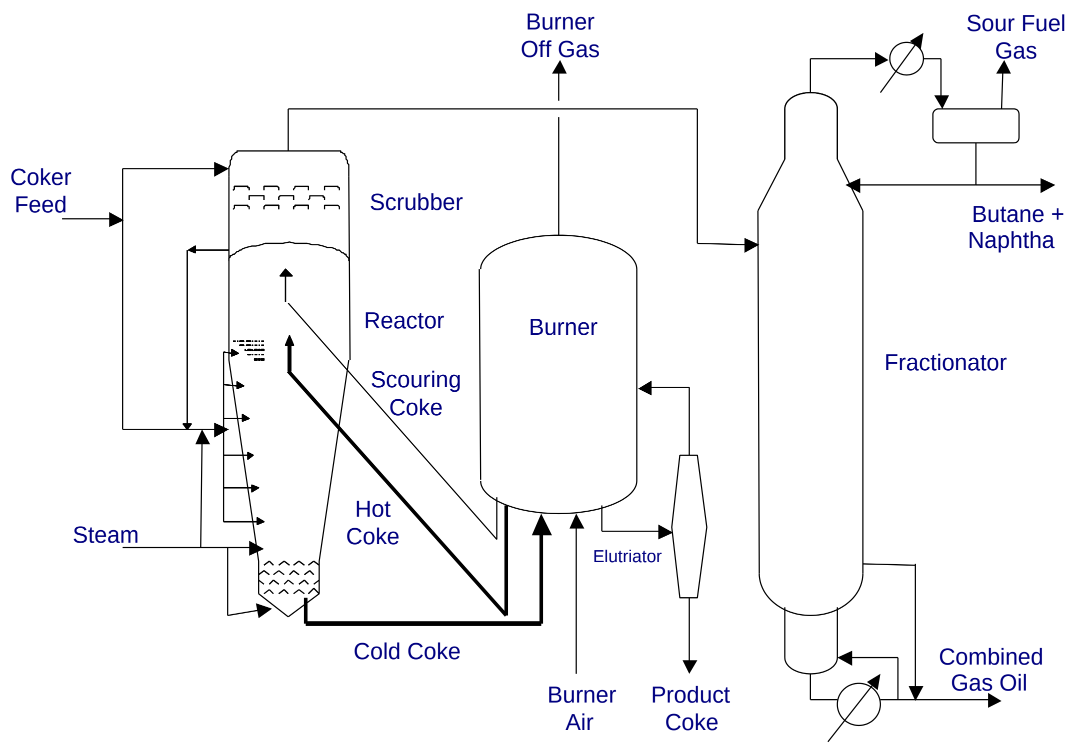


Figure 3 Process Schematic of Fluid Coking [8]

Most products of refineries need to be blended with additives prior to marketing. Base lube oils are fed to a tank with agitators or blenders with additive concentrations prescribed by the formula for each product and are mixed according to the precise weight prescription in order to achieve the required properties (Figure 4) [10, 11].

Mixing systems used in the oil and gas industry play very important roles. However, they are often designed based on limited data and experience and may be inadequate. Design guidelines are needed to achieve good process performance and reliability [4].

Figure 4 Lube Oil Bleeding [10]

Mixing in crude oil storage tanks

Crude oil storage is problematic in that it usually carries with it an amount of sludge. This can cause problems in storage of the crude oil because the sludge will usually settle to the bottom of the tank. Proper mixing is therefore required to stop this from happening. Sludge is generally made up of organic and inorganic materials in many forms. It is heavier than crude oil and if not mixed, it will settle and solidify on the bottom of the tank. This solidification causes the oil to become extremely hard to pump out of the tank. Without proper mixing, sludge accumulation can become a serious problem.

The mixing solutions that are currently applied in industry are:

- Side entering propeller mixers
- Rotating submerged jet nozzles

Side entering propeller mixers are mounted horizontally on the sides of the tank, near the bottom. These mixers produce spiraling circulation patterns as shown in Figure 5. Side entering

<propeller> mixers need to be designed to provide the suspension velocities at the opposite wall for their operation. These mixers can also be designed to be more flexible if sludge control is a major problem. The propellers can be made to swivel as they operate, covering a larger surface area on the bottom of the tank. Multiple units are often used in a single tank because of the limited power capacity of these types of propellers. These mixers can be configured in a clustered formation or distributed formation as shown in Figure 6.

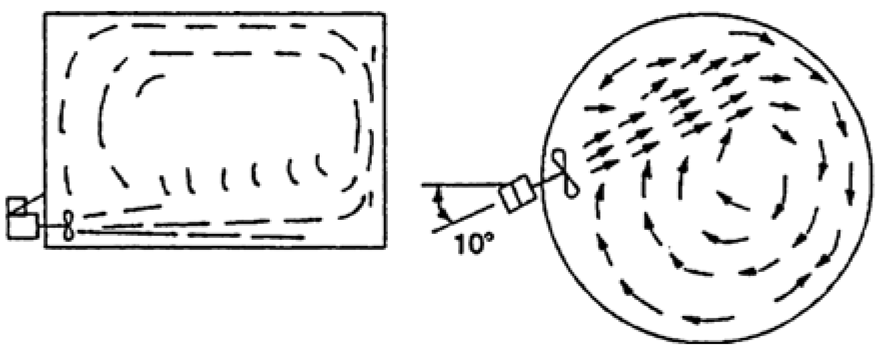


Figure 5 Possible flow patterns of a side entering propeller mixing application [4]

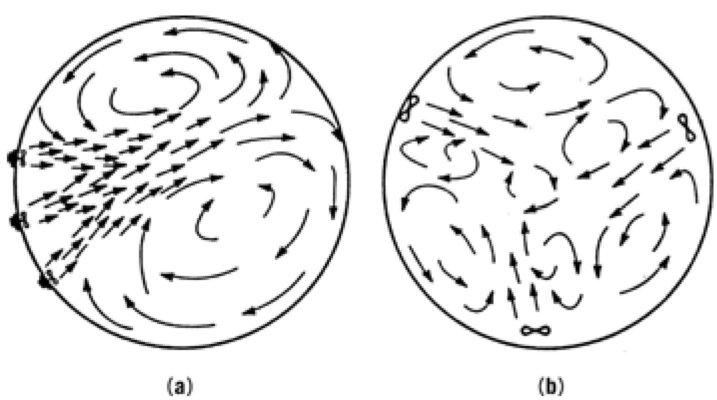


Figure 6 Flow patterns of different formations of side entering propeller mixers [4]

(a) A clustered formation; (b) a distributed formation

As long as adequate power is supplied to the tank, either mixing configuration will do. The number of mixers used to mix the tank depends on the diameter of the tank. The following table can be used as a rule of thumb [12].

Table 1

Tank diameter, *m*	<30	30-45	45-60	>60
Number of mixers	1	2	3	4 or 5

Tests have been performed to determine the minimum energy required to mix a tank containing sludge. At colder temperature sludge build-up becomes a larger problem. It was determined that mixers should be designed at 0.4 hp/kbbl to minimize sludge formation [4].

Rotating submerged jet nozzles are designed to deliver a constant force on the tank floor to dislodge any settled sludge. Since the storage tanks used are usually quite large, the jet nozzles need to rotate to apply this force to the entire tank floor. Single jets can be used, but it is more common to see double jets because the force balance on the mixer tends to be more stable. Figure 6 shows common rotating jet mixers used in industry.

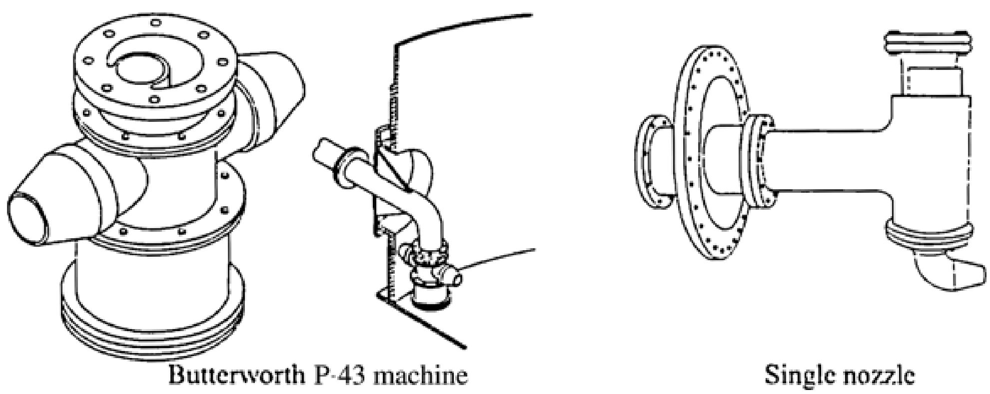


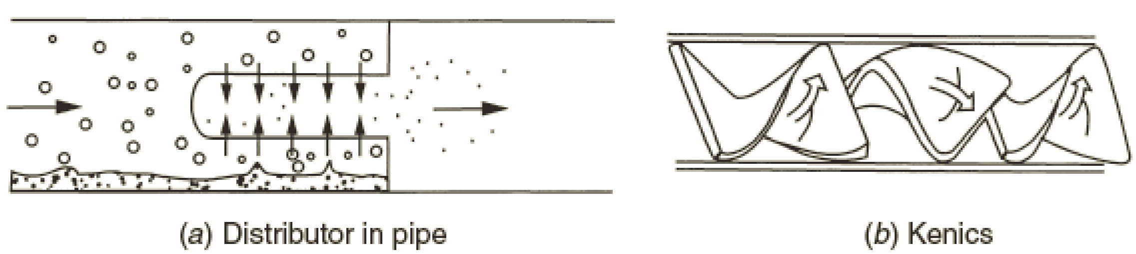
Figure 7 Common rotating jet apparatus used in industry [4]

P43 nozzle operation consists of pumping crude oil though the jet nozzle, either though receipt or by recirculation [4]. The nozzle is designed to provide suspension velocities at the furthest point in the tank. The P43 can be operated in a central position, or as shell mixers on the sides of the tank. The central position allows only one jet mixer to be used, while multiple mixers are often used in the shell configuration. Side entering mixers are not expected to re-suspend sludge, while rotating jet mixers are expected to prevents settling and suspend settled sludge.

The paraffin-based sludge that forms on the bottom of the tank is traditionally removed by: manual cleaning, robotic methods, chemical cleaning, or resuspension by jets [16]. The sludge is mainly composed of long chain hydrocarbons held together via <Van der Waals forces> and behaves as a thixotropic <non-Newtonian fluid>. Thus, it is a shear thinning fluid. For a jet to suspend the deposited particles, the entering kinetic energy must overcome the Van der Waals forces. The energy required to prevent sludge formation in medium and heavy crudes is 0.6 to 0.8 hp/kbbl. It has been found that the critical velocity of typical crude oil required to maintain sheared sludge particles in suspension is approximately 0.6 to 1.2 m/s [17].

Mixing in pipeline transport

Crude oil usually contains a certain amount of water. When crude oil is transported via pipeline, it is essential that the water is uniformly dispersed across the pipe cross section. In the absence of good mixing, water can be stratified and flow near the pipe bottom and escape from crude oil. Before the custody of the crude oil is transferred to the refineries, it needs to be sampled to determine the water content. Therefore, mixing systems should be installed just upstream of the sampler. Adequate mixing has to be provided to create good dispersion; however, the resulting emulsion may not be stable, because afterwards water must settle easily in downstream storage tanks. The type and design of such a mixer depends on the length of the pipe, upstream/downstream sections, and pressure drop. The most frequently used mixers are fixed geometry static mixers (Figure 8), variable geometry in-line mixers, rotary in-line blenders and recirculating jet mixers (Figure 9) [4].



When the crude oil is viscous, transportion from the source to the refinery can be a tremendous problem since existing pipelines were designed for less viscous crudes. By heating, diluting with lighter fractions, or thermal viscosity breaking, the viscosity of the crude oil can be decreased making it possible to transport heavy crudes in existing pipelines; however, all of these techniques are expensive and are not practical in all situations. Techniques are required to reduce the pumping costs without significantly increasing the handling costs at either end of the pipeline. Dispersing the oil in water with a surfactant to form an oil-in-water emulsion is a viable alternative. The viscosity of crude oil can be lowered to the order of 50 mPa·s (about 50 times the viscosity of water) while transporting a fluid which has an oil content of 70% or greater [5, 6].

Figure 8 Fixed Geometry Static Mixers [4]

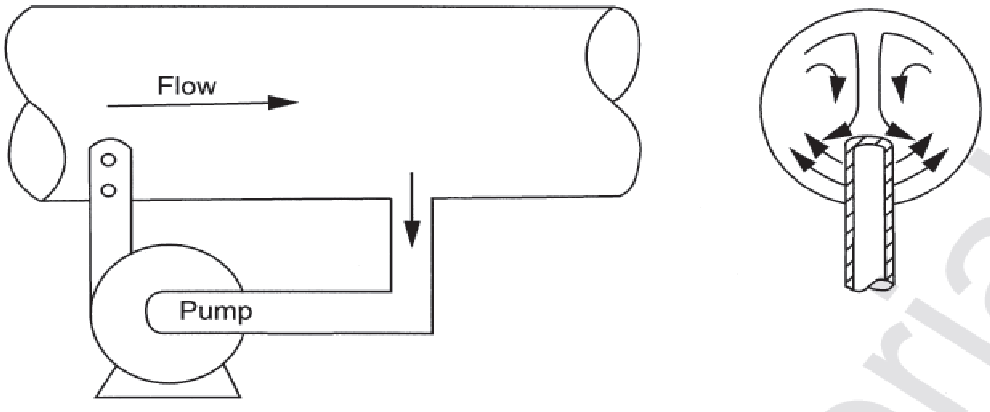


Figure 9 Recirculating Jet Mixer [4]

In another pipelining transport application, the dry oil sand ore is crushed, and then introduced into a cyclo-feeder (Figure 10), which is a simple bowl of swirling slurry, where it is mixed with hot water. After adequate mixing of the dry lumps with water in the cyclo-feeder, the slurry is introduced to the hydrotransport pipeline with entrained air and a <surfactant>. Travelling down the pipeline, the oil is liberated from the ablated oil and sand lumps. Consequently, the mixing efficiency directly affects the oil recovery from the oil sands ore and the extraction operation [7, 8, 9].

Figure 10 Swirling Action in a Cyclone Feeder [8, 9]

Mixing in downstream processes

Fluid catalytic cracking

<Fluid catalytic cracking (FCC)> remains the primary means of converting heavy hydrocarbon feeds into lighter products with more value. In order to achieve high gasoline selectivity, minimize waste products, and increase octane number, additives are added to the catalysts. In the FCC process, catalyst particles, hydrocarbon feedstock, and steam are combined and passed through a reactor with residence times on the order of 5 to 8 seconds. In order to perform effectively, the additives in the catalyst must be evenly dispersed [13]. The zeolite support, active matrix, and clay (serves as a heat sink and transfer medium) are mixed with a binding agent. These components are suspended in slurry, and then spray dried. Micro-scale homogeneity is required for optimal catalyst activity, chemical stability, and mechanical stability. In order to obtain consistent catalyst properties, the catalyst is produced continuously [14]. Several means can be employed to achieve good mixing in a continuous process: <t-mixers>, <static mixers>, and <mixing tanks>.

Fuel Additives

Many types of fuels require additives. Aviation turbine fuels are an example of fuel additive blending. Turbine-powered aircraft have been used since the Second World War. Each country sets the guidelines of required additive concentration levels that are acceptable for use in specific aircraft types. Fuel additives include: oxidation inhibitors, metal deactivators, corrosion inhibitors, lubricity improvers, static dissipater additives, anti-icing additives, biocides, and thermal stability additives [15]. As the guidelines for each country vary, the amount of each additive added needs to be adjusted, while remaining well mixed. Thus, continuous addition with a <static mixer> and/or <t-mixer> is required.

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