**International Journal of Energy Science and Engineering**
Vol. 4 No. 2, 2018, pp. 29-33
http://www.aiscience.org/journal/ijese
ISSN: 2381-7267 (Print); ISSN: 2381-7275 (Online)

# Empirical Study of Fouling Rate in the Heating Devices in Oil Companies

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## Abstract

The insolubility number is the y-axis intercept of a line drawn through the two points. The solubility blending number is calculated by the equation given in obtained results. In other words; Determination of $I_N$, insolubility number, and $S_{BN}$, solubility blending number, for Forties and Souedie crude oils is investigated in this paper. The objective of the research is to represent a novel arrangement of conical three dimensional rough tubes (FS3D) for heat transfer coefficient enhancement. Experiments were performed with 316 stainless steel tubes of FS3D roughness and hot crude oil was circulated in constant heat flux condition in the related set up. The pressure drop is measured in this set up and compared with the pressure drop in a smooth tube with the same operating conditions. The heat transfer coefficient is one of essential parameters for design of heat transfer equipment's and in this experimental work this is investigated for an Iranian crude oil in the FS3D rough tube.

## Keywords

Fouling, Oil, Solid, Refinery, Asphaltene

Received: June 28, 2018 / Accepted: July 23, 2018 / Published online: September 4, 2018



## 1. Introduction

While the general fouling mitigation strategy will solve any refinery fouling problem, it makes sense to keep in mind the most common causes. Since 90% of refinery fouling is caused by only six basic causes, most fouling causes can be quickly identified by using tests or indicators for the diagnosis and investigation steps. Although some of these tests and indicators are proprietary, examples will be discussed among those that are not proprietary. The most common causes of refinery fouling are: A). Inorganics, B). Oil Incompatibility on Mixing, C). Coke from over thermal treating crude/resid/oil, D). Oil-water emulsions, E). Polymerization of olefins after thermal conversion, F). Insoluble asphaltenes on cooling after conversion. The diagnosis is arrived from three sources of evidence: 1. Process conditions/history, 2. Analysis of Foulant, 3. Analysis of oil flowing through fouling unit. The process conditions/history should include the range and average conditions (temperature, pressure, flow rate, and feeds) and should include upstream units as well as the fouling unit [1]. What is most revealing is determining the difference in conditions when the unit was not fouling and when the unit was fouling. Can the initiation of fouling be correlated with a particular incident, such as a process upset, a contaminant (slop or sludge) addition, or a new feed? The analysis of the foulant usually reveals the most information about the cause. As a result, the foulant sample should be taken with care while recording information as to its location, amount, and exposure to cleaning liquids prior to sampling. Pictures of the foulant in the unit prior to sampling are very revealing. If the foulant is a solid, it should be ground and mixed to homogenize to obtain an average sample [2]. The sample should be washed with a solvent, like methylene chloride or toluene, to remove the oil and then dried. If the foulant is

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soluble in the solvent, like an asphaltene sediment, a different sample should be washed with heptane. The first foulant analysis should be to determine how much is inorganic. An ash test, thermal gravimetric analysis (TGA), or elemental analysis may be used. If it is determined to be over 10 wt% inorganic, this cause should be determined, traced to the source, and mitigation action implemented before acting on the organic portion of the fouling. Often the inorganic fouling adsorbs organics out of the oil and elimination of the inorganic deposit also eliminates the organic portion of the fouling. Common inorganic fouling are iron sulfide, rust, sea salts, catalyst fines, clays or dirt, and ammonium chloride [3]. Iron sulfide and rust are corrosion products [4]. Therefore, they should be traced to the corrosion source or determined if they arrived in the crude oil. Iron sulfide is a black, granulated, insoluble solid that is often misidentified as coke. Iron sulfide can form directly from hydrogen sulfide reacting with iron or steel surfaces. Alternatively, iron naphthenate can form as an oil soluble salt by naphthenic acids in the oil reacting with steel surfaces and then reacting with hydrogen sulfide that is released when oil is thermally cracked [5]. If sea salts, sodium, calcium, and magnesium chlorides, are not removed in the desalter, they can deposit wherever the water is evaporated in the preheat train [6]. Since calcium and magnesium chloride are not thermally stable, they can decompose in resid conversion units, hydro conversion or coking, to form hydrogen chloride and react with ammonia released by the conversion to form the solid, ammonium chloride [7]. This salt can be washed out of the unit, such as a coker fractionator, with water or caustic can be injected after the desalter to convert calcium and magnesium chloride to sodium chloride. However, the preferred solution is to correct the desalter operation to more effectively remove the sea salts from the crude oil [8]. Oil incompatibility is discussed in a separate paper [9]. However, coke forms from the thermal cracking of oil when asphaltenes become insoluble at thermal cracking temperatures[4]. The mechanism is as is shown in Figure 1. Asphaltenes in the oil contain thermally stable, polynuclear aromatic cores with pendant groups connected to the core by thermally unstable bonds. When exposed to high temperatures (above 350°C), these bonds break to form free radicals [10]. As long as the asphaltenes are dispersed in the rest of the oil, they abstract hydrogen from hydroaromatics and terminate the free radicals [11]. However, the loss of pendant groups makes the asphaltenes less soluble. Eventually, the converted asphaltenes become insoluble and undergo a liquid-liquid phase separation [12]. This asphaltene rich phase has little or no abstractable hydrogen. As a result, the asphaltene free radicals combine to form high molecular weight and insoluble coke [13]. However, before coke is formed, the polynuclear aromatics in the converted asphaltenes tend to orient with the large flat aromatics parallel to each other. This orientation can be detected by observing the coke with an optical microscope under crossed polarized light where ordered structures show up as bright while unordered (amorphous) structures are dark. Figure 2 shows coke formed from thermally cracking Cold Lake vacuum resid and dispersed in quinoline, an excellent solvent. The particles under normal light are spheres or agglomerate of spheres because of surface tension when it was a second liquid phase. Part of it is bright under cross polarized light because of the aromatic orientation. This is a liquid crystalline coke or the carbonaceous mesophase [14]. Therefore, we use the presence of the carbonaceous mesophase in a foulant as an indicator to show that the fouling is coke that was formed by the asphaltene phase separation mechanism during thermal cracking. If the coke was formed by oil incompatibility on mixing and the insoluble asphaltenes were later thermally cracked, no carbonaceous mesophase would be observed. The majority of the available literature is related to the issue concerning distillation, and they are heavily concentrated in the atmospheric and vacuum columns [15]. I bet you know the reason. Future solutions for improving energy efficiency in separation processes in oil refineries are basically related to: A). Membrane technology. B). Fouling mitigation. C). Optimization and “advanced” process control. D). Heat integration. E). Design of efficient separation systems. F). What follows are mostly on the drawing board, i.e., no real-world implementation. For Membrane technology; researchers discusses that membrane technology is still an infant in the world of grown-up inefficient processes in the oil industry. Its main application is in hydro desulfurization processes in catalytic hydro treating units, replacing existing separation processes with energy savings up to 20%. Nevertheless, Scientific’s claimed a fuel reduction of 36,000 bbl./year (or 20% w.r.t. the conventional process) by adding a membrane unit in the dewaxing unit to recover part of the solvent stream. The membrane is selective to the solvent from the solvent/oil/wax mix [16]. According to literatures, further research is needed to develop appropriate membrane materials that can withstand the harsh conditions in petroleum refining processes [17]. In addition, researchers presented a performance monitoring via an Excel® spreadsheet of the preheat train for a crude distillation unit [18]. The authors claim that by using their technique the energy loss in a period of 2 years can be reduced by almost 60% [19]. Also, Scientific’s proposed a model of crude oil fouling in preheat exchangers with the aim of better controlling fouling formation. In contrast with other models, the one proposed by the authors consider the mechanisms of formation and natural removal [20]. In addition, researchers presented the application of existing fouling models to maximize heat recovery in the preheat train of the crude oil distillation [21]. The authors' conclusion was that designing for maximum heat recovery results in a less efficient system over time due to fouling effects [22]. However, Scientific's states that the very complex mechanisms which lead to fouling are still not properly understood to the extent they can be safely used for fouling mitigation techniques (anti-fouling agents and coatings) [23-25].

## 2. Investigation of case study

Totally, the determination of $I_N$, insolubility number, and $S_{BN}$, solubility blending number, for Forties and Souedie crude oils is investigated in this paper. In addition, the calculation of the solubility blending number of blends of the two crude oils is shown in the obtained results.

## 3. Results and Discussion

As shown in Figure 1, the volume percent toluene in the test liquid is plotted versus 100 times the volume ratio of oil to test liquid. The insolubility number is the y-axis intercept of a line drawn through the two points. The solubility blending number is calculated by the equation given in Figure 1.

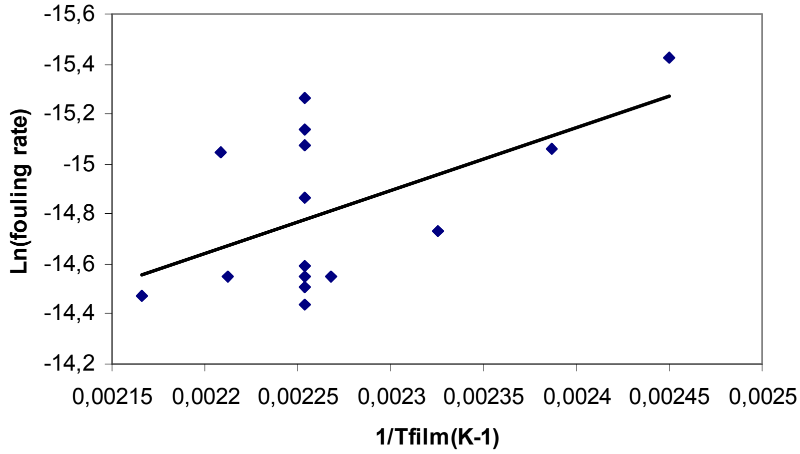


**Figure 1.** Determination of fouling versus inversion of film temperature.

The helical tubes and three-dimensional roughness tubes are 2 famous types of enhanced tubes to augment heat transfer in heat exchangers. Although studies show the benefits of 3D roughness tubes such as increasing flow turbulence and heat transfer coefficient, there is not a unique equation to define the heat transfer parameters for all of types of these tubes. Considering this, the authors investigated the newly proposed FS3D tube to find the heat transfer factors. The inner arrangement of such tubes should be designed to augment heat transfer coefficient without any malfunctions. The FS3D arrangement prepares high heat transfer coefficient for rough tubes and also experimental results show that the fraction of obtained pressure drop of this tube over the pressure drop of a smooth pipe is 1.41. This fraction is relatively low compared with reported values for other rough tubes.

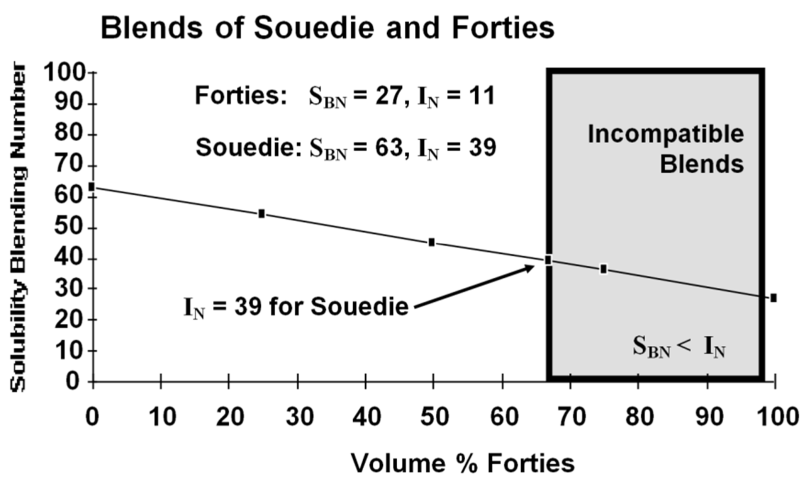


**Figure 2.** Blends are compatible when the volumetric average solubility blending number is greater than the insolubility number of any component oil.

## 4. Conclusion

The study points out that the novel arrangement of 3D rough tubes which is called FS3D type, enhances the heat transfer coefficient and augments the rate of heat transfer in laboratory scale rough tubes containing an Iranian crude oil. To aim this purpose an experimental apparatus was built. This set up contains a novel arrangement of conical 3D rough tubes which is equipped with pressure, flow and temperature gauge instruments, centrifugal pump, storage tank. The novel rough tube is emerged by constant heat flux and the fluid flow regime is turbulent and the pipe segment is insulated. Experimental results show the fraction of obtained pressure drop of this tube over the pressure drop of a smooth pipe is 1.41. This fraction is relatively low comparison with reported values for other rough tubes. Although studies show the benefits of 3D rough tubes such as increasing flow turbulence and heat transfer coefficient, there is not a unique equation to define the heat transfer parameters for all types of these tubes. Considering this, in this work, authors proposed a new represented type of rough tube, FS3D rough tube to augment the heat transfer coefficient which is beneficial in cost and energy savings.

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