CHEMICAL ENGINEERING TRANSACTIONS, Volume 12, 2007
Edited by Jiri Klemeš

Evaluation of Surface Roughness on the Fouling of Surfaces

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Fouling takes place as the result of a series of complex reactions that cause deposits to form on surfaces. This process begins immediately upon contact and is diverse in both time and space. It causes annual losses in the billions of dollars. Parameters that influence fouling include: flow velocity, surface temperature, surface material/finish, roughness, surface geometry and fluid properties. In this study, roughness is under review.

In general, the surfaces studied were exposed to untreated lake water for various time periods and configured either horizontally or vertically. Several materials with different surface finish are examined. Results are presented that compare the change in surface roughness, over time, for the variety of conditions considered. Observations include: visible film, color change, corrosion, deposit characteristics, weight change, etc. Considerations in choosing a material for a process surface in a fouling condition include the total amount of fouling and rate of fouling.

1. Introduction

The accumulation of scale, organic matter, corrosion products, coke, particulates or other deposits on a process surface is considered to be fouling. Fouling is complex, costly, and affects many different industries. Its development is more rapid in systems where adequate nutrients are available. In systems with high shear forces, the deposits may grow only to a few micrometers, while in low flow systems; deposits can reach the thickness of several centimeters (Heitz et al. 1996). Nesta and Bennett (2005) note that fouling "costs industry billions of dollars each year". This paper will examine how several types of materials, with various finishes, foul when exposed to untreated lake water.

Fouling can be categorized into biofilms and macrofoulers. Biofilms (microfouler) are bacteria, while algae, slime; hard species, such as barnacles and mussels are considered macrofoulers. Either type of deposit growth will cause process efficiency or product quality to be reduced.

Flow rate, temperature and chemical composition of the liquid all influence the formation of a deposit. Surface roughness also impacts the formation of a deposit with smooth surfaces not allowing the growth to adhere as easily as does a textured surface. Although different from industry to industry, most deposits are unwelcome and have the potential to cause severe problems. Hays et al. (2005) presents a discussion of biofouling in enhanced heat exchanger tubes. Webb and Li (2000) report that enhanced tube fouling is related by several variables including surface roughness.

Callewaert et al. (2005) presents a discussion on the treatment of stainless steel surfaces with polymers to limit fouling. Beuf et al. (2003) and Kim et al. (2003) discuss other surface treatments including coatings (silica,SiOX, Ni-P-PTFE, Excalibur®, Xylan®); ion implantations (MoS2, SiF+); and optimum plasma zone (OPZ) processes.

Everaert and Baeyens (2004) review the effect of heat transfer surface temperature, roughness, and fluid shear on fouling deposits. Studies by Jones et al. (1999) and Holah and Thorne (1990), observe that surface defects are closely associated with significant fouling increases and deposits returned more rapidly after repeated cleaning. Zettler et al. (2005) investigated the influence of surface properties, fluid temperature, fluid composition and fluid velocity on fouling deposits. Malayeri and Müller-Steinhagen (2003) discuss surface finish and the importance of early identification of conditioning films. Mott (1991) concludes that smooth materials (glass and electropolished 316 stainless steel) had 35% fewer deposits than a corresponding "as received" sample of 316 stainless steel. Design approaches to overcome fouling include treatment, design and over design.

2. Experiment

Several commercially available materials (Copper, Brite Aluminum, 1020 Cold-Rolled Carbon Steel, glass, concrete and Stainless Steel) with typical finishes were tested. Plates (0.5 ft x 0.5 ft) were placed in tanks (see Figure 1) at the Great Lakes Research Center (State University of New York College at Buffalo) for various amounts of time with surface water from Lake Erie supplied at a flow rate of 6 liters/min. The inlet hose was placed opposite the drain on the bottom of the tank to create a cross flow over the plates. Tanks were monitored during the experiment to ensure the conditions and plates were kept constant. After the prescribed time, the tank was drained and the samples were dried, examined; with surface roughness measurements and photographs then taken.

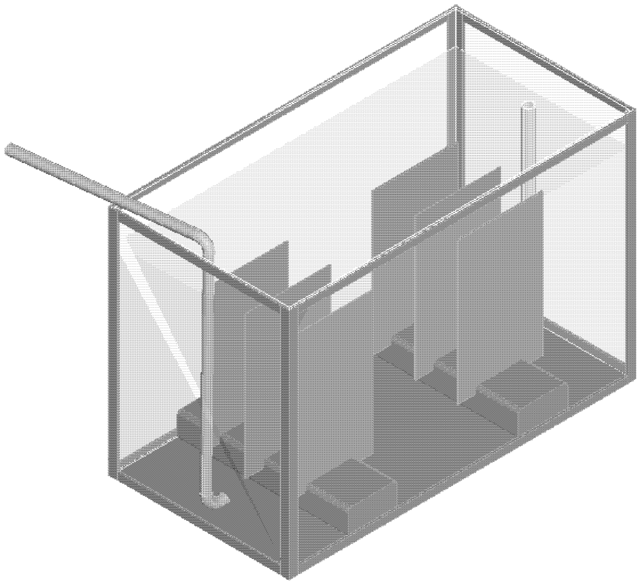

Figure 1 Tank with Positioned Plates

More precisely, the first step after drying was to observe and photograph the surface appearance of each plate. Each sample was photographed using an Olympus microscope, Model SZX12, which was mounted with a Hitachi Digital Camera. The next step was to obtain surface roughness measurements. Measurements were taken using PocketSurf I, a portable surface roughness gage with a traverse speed of 0.2" (5.08mm) per second and a probe radius of 0.0004" (10μm).

3. Results

As each set of plates was removed from the medium, observations about the conditions of each plate were made. These observations included: visible film, color change, corrosion, deposit characteristics, etc. Table 1 provides observations of the various plates studied for the range of conditions considered. Figure 2 provides a comparison of surface roughness measurements for copper plates with different initial surface roughness values. It shows transient surface roughness measurements of copper plates exposed to once through lake water. Since three measurements were taken for each plate sample, the data points are average surface roughness values for a particular time period. The best fit curve was then drawn between the plotted points. Each material showed an increase in the surface roughness from the original values.

Comparing the surface roughness values over the time period shows a gradual increase in the roughness values with increasing immersion times. When taking measurements for some tests, a large amount of error can be assumed since the probe was not able to record the measurements properly because of the high surface variation across the traversed area. This partially accounts for the highly irregular data in Figure 2.

There are two distinct groups of data in Figure 2. The bottom group consists of data collected from initially smooth copper plates. These plates would represent typical material shipped from the factory. As can be seen from this data, fouling rates are regular. The second group of data (upper) is more random. Some of the slopes are rather steep, while others are more gradual. This data represents data of copper plates that started the experiment with an initial roughness. In examining this figure, one sees larger rates of fouling that are not as predictable as the lower group of data. Initial surface roughness provides many sites for fouling to be initiated.

In general, for short time periods, roughness develops at a faster rate than the rates found for long test periods. In tests of 30 days, the slope is 0.78 for smooth surfaces as compared to 1.19 for an initially rough surface, giving an average 30 day run value of 0.99. In looking at the 60 day sample, the slope drops to 0.43 for smooth plates and 0.70 for rough surfaces, giving an average value of 0.56 for the 60 day case. Finally for the 90 day sample, both tests yield a slope of 0.33. For long runs it is reasonable to assume that you are in the steady state period of fouling in Figure 3, while for short run periods (<75 days) you are in the accumulation phase.

This study showed the thickness of the deposit became more visible the longer the plate was exposed to lake water and is correlated through the use of the surface roughness measurements. A more detailed transient examination of other materials/surfaces, coatings and different geometries is currently being studied.

Table 1. Surface Observations of Copper Plates Exposed to Once Through Lake Water for Various Immersion Times.

Material	*30 Days*	*60 Days*	*90 Days*
Copper	Uneven discoloration-very slight tan deposits unevenly spaced-slight green aging lower area.	Uneven discoloration-very slight tan deposits lower area , left side & top slight green aging.	Uneven discoloration-more tan deposits and green aging than 60 day.
	30 Days	***60 Days***	***90 Days***
Textured Copper	Uneven film-slight dusting tan deposits-concentrated lower ½-uneven discoloration	Overall film-discoloration- slight green aging-dusting tan deposits (more than 30 day) concentrated lower	Overall heavier than 60 day film-more than 60 day dusting tan deposits-some green aging

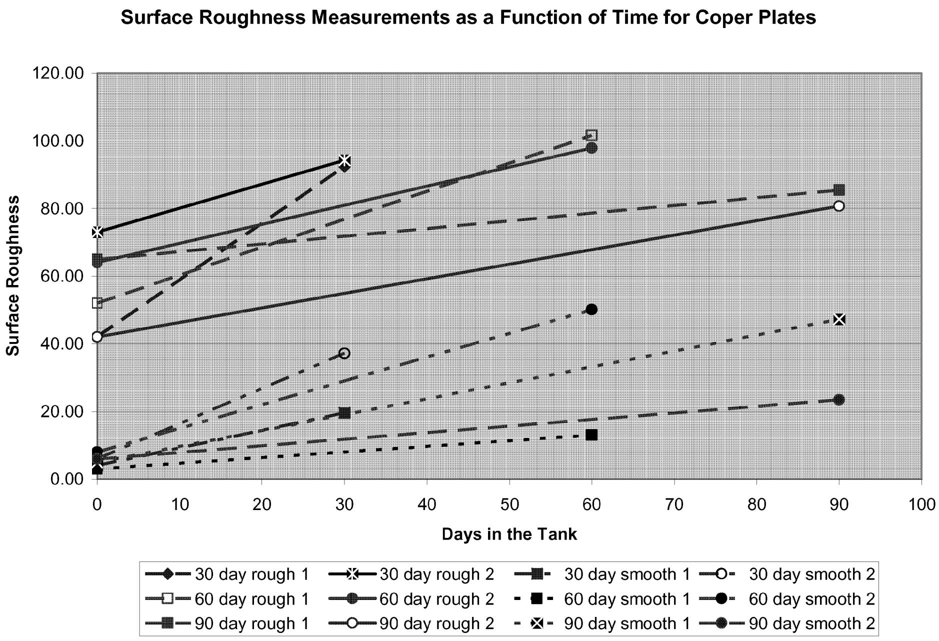

Figure 2. Transient Surface Roughness Values of Vertical Copper Plates Exposed to Once Through Lake Water for Smooth and Textured Plates.

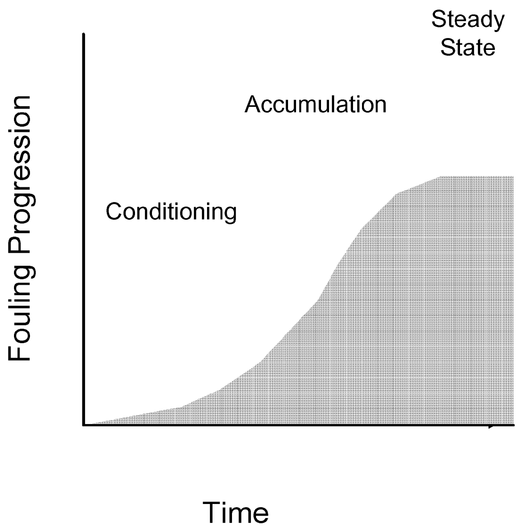

Figure 3. The Progression of Fouling Described by Three Periods; Conditioning, Accumulation and Steady State.

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