

AN OVERVIEW OF FOULING

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Summary

Fouling, the unwanted accumulation of generally solid material on heat exchangers interferes with efficient operation. Foulants vary widely in character ranging from deposits of previously suspended particulate matter, previously soluble salts, living matter in the form of micro or macroorganisms or products of corrosion. The presence of the deposit increases the pressure loss through the exchanger and restricts heat transfer. Unless the problem is controlled, severe malfunction of the equipment may be experienced and the associated additional costs may be high, including lost production, extra energy and maintenance costs. Techniques employed for control may be physical or chemical.

1. Introduction

The term "fouling" usually refers to the accumulation of unwanted, generally solid material on surfaces. In many industrial situations these deposits interfere with the operation of the particular process plant in which the fouling occurs. In some operations the deposit may be of benefit. In the biological treatment of waste water, for instance, where the accumulation of biofilms on the surfaces of an inert medium is essential for effective treatment, the establishment of the "fouling" layer is actively encouraged. In most industrial processes however, the presence of deposits represents a problem ranging from a simple nuisance to a serious operating difficulty. Deposit formation can occur from a fluid, whether flowing or stagnant, dependent on the conditions prevailing in the system. The possibility of fouling therefore, has to be recognized and suitable mitigation opportunities taken to alleviate any detrimental effect that may result, in order to maintain satisfactory performance.

Fouling is in general, related to the processing of fluids either liquid or gas, and the origins of the associated foulant (or foulants) are diverse. Suspended matter, dissolved solids, breakdown of the fluid being processed, chemical reactions, the presence of living entities such as bacteria, fungi or algae on the microscale, or much larger creatures such as mussels and barnacles, may, depending on the system, contribute to the growth of deposits on surfaces. The deposit itself will often consist of a complex

heterogeneous mass, difficult to define in a comprehensive way. The character of the deposit may change as the accumulation process continues, so that the outer layers are quite different from those directly attached to the surface.

In water systems fouling may result from the precipitation of dissolved solids (scaling), deposition of suspended solids, corrosion of metal surfaces or the accumulation of micro or macroorganisms. There may be some synergism between two or more fouling effects, for instance corrosion may be encouraged below biofilms, where the pH level is more aggressive, due to the biological activity, than in the bulk.

Precipitation of dissolved salts may occur in evaporators in desalination plant, that restricts heat transfer, reducing evaporation rates, with a general detrimental effect on thermal efficiency. Corrosion can occur in almost any part of a process plant, particularly in equipment fabricated from mild steel, due to the presence of aggressive components in the water. The resultant corrosion layers may restrict flow through pipes and valves and give rise to particulate matter that is carried forward in the water flow. Suspended particulate solids, either corrosion products or material introduced with the water feed, are likely to accumulate in stagnant regions or where velocities are low. Eventually this may present severe restrictions on flow and may even block valves. The performance of reverse osmosis membranes in desalination plant may be affected by the presence of deposits of particles originally suspended in the water. Biofouling can occur in almost any location in a water circuit having conditions that sustain primitive life, e.g. availability of nutrients, oxygen, temperatures in the region of 30-40°C and pH around 7. The performance of cooling towers, water coolers, e.g. steam condensers, is likely to be affected by reduced heat transfer. Flow restrictions in ducts and pipe lines will also be apparent. Membrane surfaces in reverse osmosis units may provide suitable habitat for microorganisms so that the efficiency of the process is adversely affected.

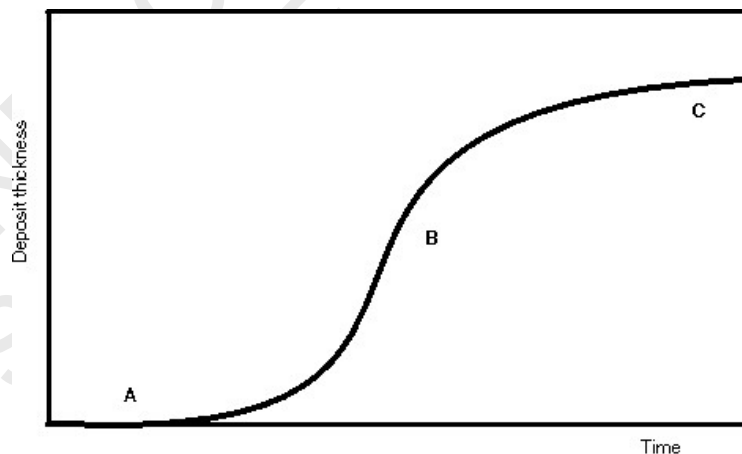


Figure 1. An idealized representation of deposit development with time.

The thickness of a foulant layer on a surface in a flowing system will increase over a period of time. The rate of growth will depend on the prevailing conditions and in particular the magnitude of the velocity in flowing systems. An ideal curve for the development of a deposit with time is shown in Figure 1. Essentially it consists of three

regions:

1. A period of time when little or no deposition occurs (labeled A in the diagram). Often this region is referred to as the "initiation" or "conditioning" time. It ranges from minutes to months. In many examples of fouling the conditioning of the surface is not fully understood, but it would seem that in most examples of fouling surface effects are necessary before fouling can commence at a measurable rate. In biofouling, for instance, it is understood that an adsorbed conditioning layer of organic macromolecules on the surface, is required before microorganisms can attach. The function of this adsorbed layer is not clear but it may well be that in natural conditions, the quantity of organic breakdown products is large compared with the concentration of microorganisms, and therefore these macromolecules are first to attach. Under these circumstances, it would be expected that bacteria for instance, will have adapted so that they require the presence of this conditioning layer before attachment is possible. It is entirely possible also that this organic conditioning layer represents a nutrient source, which further encourages the microorganisms to the surface.

Once deposition begins, provided the foulant or precursors are present in sufficient quantity, the foulant layers may be laid down quite rapidly, in relative terms (see section of the curve labeled B in Figure 1).

After a period of time the rate of growth of accumulation slows down and may even cease altogether (region C in Figure 1). The usual explanation for this observation is as follows: The laying down of the deposit is a dynamic process so that removal of foulant from the surface and deposition are occurring at the same time. In the initial stages, the rate of deposition far exceeds the rate of removal, but as the deposit grows the rate of removal increases until the plateau, or equilibrium, condition is reached and the two rates are the same, thereby giving a constant thickness. This is brought about by the fact that as the flow area reduces due to the presence of the deposit, for a given flow rate, the velocity increases. As a result the shear forces acting on the deposit surface increase and the rate of removal increases.

It has to be stressed that this is an ideal representation of the fouling process (see Figure 1), many variations may be observed in practice. Some fouling processes may show a straight line relationship with time (this implies a tenacious deposit), while others show a falling rate but never reaching a constant deposit thickness.

Under static conditions, such as might occur in a tank, the presence of a deposit is more likely to represent a contamination risk to the fluid as it is used from the tank, rather than interference with operations associated with fluid movement. Where a fluid is flowing in pipes and ducts, the effect of deposits is felt in terms of increased pressure loss through the system. There are a number of reasons for this effect, but principally it results from the reduction of flow area due to the presence of the deposit. As the flow area becomes restricted for a given volumetric flow rate, the velocity is increased. As the pressure loss is proportional to the square of velocity, a small reduction in cross sectional area can represent a relatively large increase in pressure required to drive the fluid through the system. As an example, if a deposit of 1 mm thickness resides on the

inner surface of a 20 mm I.D. pipe the flow area is reduced by a factor of $18^2/20^2 = 0.81$. If a fluid flows at 1 m s^{-1} in the clean pipe, in order to give the same volumetric flow in the fouled pipe the velocity has to increase to 1.23 m s^{-1} , i.e. the pressure loss is increased by a factor of $(1.23)^2 = 1.51$ or over 50 per cent.

Reduction in flow area is not the only result of the presence of deposit on the pipe surface that affects pressure loss. In general, the surface topography of deposits is rough. An example is given in Figure 2 which shows the rippled surface of a deposit formed by the precipitation of silica from flowing geothermal water. The effect of increased roughness is to increase frictional losses still further, with an accompanying additional pressure loss through the system. It is very possible that the frictional pressure loss could be more than doubled as a result.



Figure 2. A rippled silica deposit on the inside of a heat exchanger tube.

Apart from roughness, the energy absorbed as a result of the presence of the foulant, can be increased by other deposit characteristics. For instance, a biofilm which in general terms is a matrix of microorganisms, extracellular organic material, debris and water filled interstices, is flexible, so that under the influence of flowing water, it deforms thereby absorbing energy from the system.

The increased energy demand in a flowing system can be considerable, but there are further energy implications where heat exchangers are subject to deposit accumulation. The purpose of a heat exchanger is to transfer heat effectively between two streams.

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