NOTE TO THE EDITOR

An Observation of Microbial Cell Accumulation in a Finned Tube

M. TURAKHIA and W. G. CHARACKLIS

Institute for Biological and Chemical Process Analysis, Montana State University, Bozeman, MT 59717

Biofouling in heat exchange equipment results in significant energy loss by increasing heat transfer resistance and fluid frictional resistance. This paper compares the deposition and distribution of attached microbial cells on a smooth tube and a tube with inner fins after 100 hours exposure. Preliminary results suggest a significantly different distribution of attached microbial cells on the finned tube.

Le bio-encrassement de l'équipement d'échange de chaleur produit une importante perte d'énergie en augmentant la résistance au transfert de chaleur et de quantité de mouvement des fluides. On compare, dans le présent travail, le dépôt et la distribution de cellules microbiennes adhérant sur un tube lisse et un tube pourvu d'ailettes intérieures, après une exposition de 100 heures. Des résultats préliminaires portent à croire qu'il existe une distribution bien différente des cellules microbiennes adhérant sur la tube à ailettes.

Biofouling is a general term referring to undesirable attachment of microorganisms on surfaces. These microorganisms are entrapped in a polymer matrix of their own making. These extracellular polymer substances (EPS) are presumed to be largely composed of polsaccharides along with glycoprotein, and sometimes nucleic acids. The composite of microbial cells and EPS will be termed *biofilm.*

Fouling biofilms impair the performance of process equipment. They can impede the flow of heat across the surface, increase the fluid frictional resistance at the surface, and increase the rate of corrosion at the surface. Fouling of heat exchange equipment was estimated to cost the United States billions of dollars annually (Lund and Sandu, 1981).

The need for high performance, compact, heat exchange equipment has led to the development of many types of surfaces that enhance heat transfer performance of smooth tubes. Enhanced performance over smooth tubes is achieved by providing inner fins or using indented or fluted tubes. These tubes increase the heat transfer rate by modifying the flow pattern and increasing the surface area for heat transfer. The modified flow pattern in enhanced heat transfer tubes also increases the convective heat transfer. However, enhanced convective heat transfer suggests that convective mass transfer is also increased. Increased mass transfer leads to increased transport of potential fouling materials to the surface. Most of the work on fouling of enhanced heat exchange tubes (Watkinson et al., 1974; Watkinson and Martinez, 1975) has focused on inorganic deposits. No such systematic work has been done with biofouling.

This communication compares the deposition and distribution of microorganisms on a smooth tube and a tube with inner fins in a controlled laboratory system.

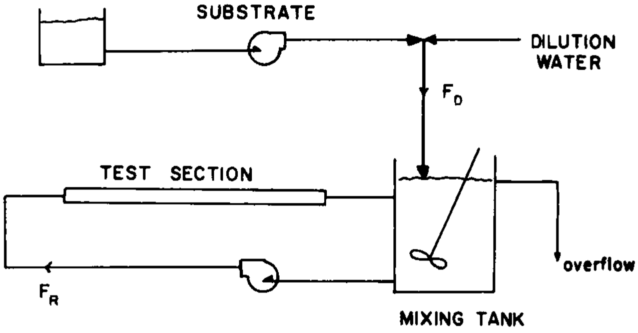

Figure 1 — Schematic diagram of the Experimental system.

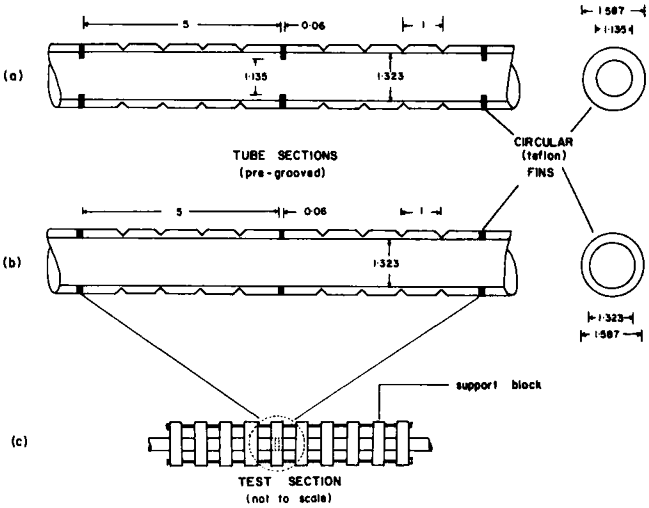

Figure 2 — Details of tube section and test section assembly.

Experimental system and methods

The experimental results were obtained by measuring the number of bacterial cells attached on a tube section within a recirculating tubular reactor system. The system consists of a mixing tank and an external recycle loop (Figure 1). The recycle loop was made up of 1.587 cm O.D., 70:30 Cu/Ni heat exchange tubing with a wall thickness of 0.132 cm. The dilution rate, F_D, (0.027 l/min) was much smaller than the recycle flow rate, F_R, (7.5 l/min). At this high recycle rate, the entire system behaves as a continuous stirred tank

---

*Correspondence: W. G. Characklis, Director, Institute for Biological and Chemical Process Analysis, Montana State University, Bozeman, MT 59717.

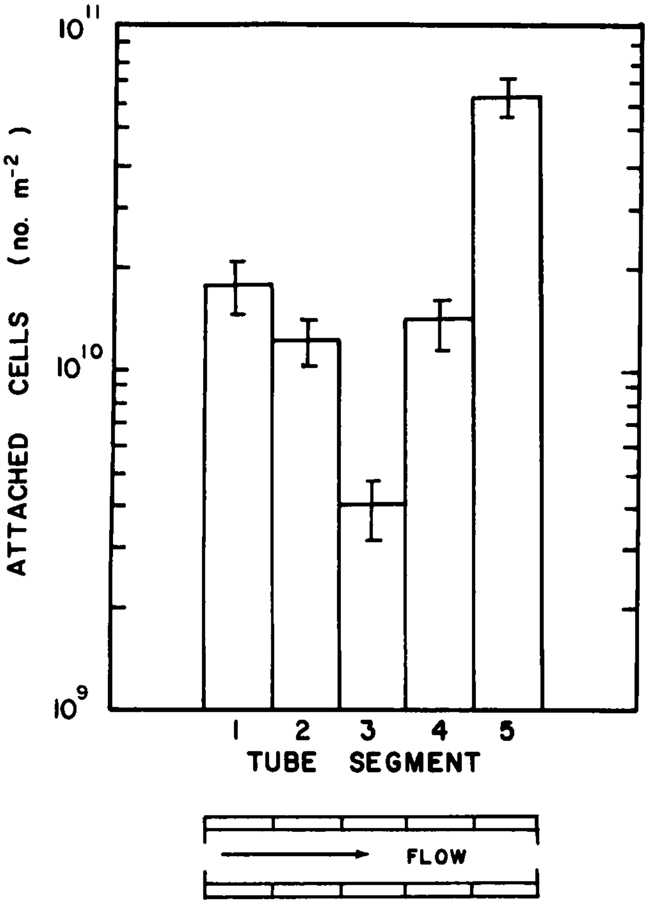

Figure 3 — Distribution of attached microbial cells on a tube section between two circular fins separated by a distance of 5 cm (fin height = 0.094 cm) at the end of 100 hours.

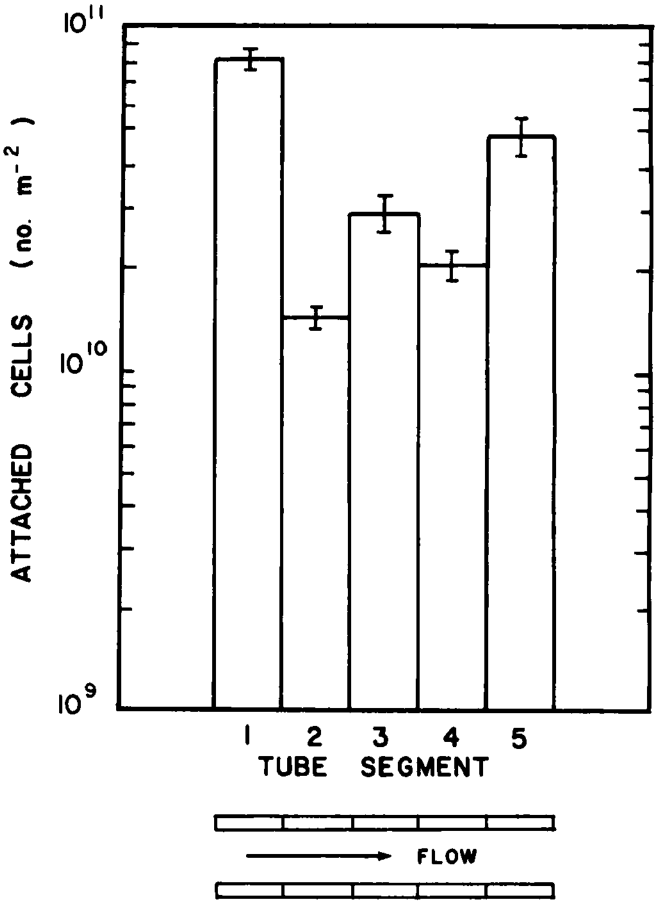

Figure 4 — Distribution of attached microbial cells on a 5 cm smooth, 70:30 Cu/Ni tube at the end of 100 hours.

reactor (CSTR). The Reynolds number in the recycle loop based on smooth tube diameter was 16600. A detailed description of the experimental system is presented elsewhere (Characklis, 1980). The experimental system includes a test section (Figure 2c) which consists of a series of removable tubes (5 cm long) which are held in place, between teflon gaskets (fins) whose I.D. and O.D. are the same as that of tube material, to form a continous tube (Figure 2b).

The same test section was used to form a continuous tube with circular inner fins (height of the fin = 0.094 cm) which were placed 5 cm apart (Figure 2a). The circular fins were 0.06 cm thick teflon rings (I.D. = 1.135 cm, O.D. = 1.587 cm).

The experiment was initiated by inoculating a mixed population of microorganisms and operating the reactor in a batch mode (as opposed to continuous flow) for 8 hours. The test sections were not exposed to the test fluid during this period. The dilution feed consisted of a substrate solution, dilution water, and micronutrients. The substrate was composed of glucose (10 mg/l) as the sole carbon and energy source. The temperature inside the reactor was maintained at 30 C and pH 8−8.2. The mean fluid velocity was 0.91 m/s.

Each tube section was machine grooved on the outside so that the tube could be broken into five (5) segments easily. The tube segments were numbered for identification. At the end of 100 hours, a tube section from the smooth tube and another from the finned tube were removed from the reactor. The tube sections were broken into five segments. The biofilm from these segments was scraped into 5 ml of 2% filtered (average pore size 0.002 cm) formalin. The total number of cells on these tube segments were measured by acridine orange direct count (AODC) epifluorescence microscopy (Hobbie et al., 1977).

Results

Experiments were conducted to compare the distribution of attached bacteria on a 5 cm smooth tube section and a section of tube between two circular fins separated by a distance of 5 cm. The total number of attached cells at the end of 100 hours was measured by AODC epifluorescence microscopy.

The following observations are noteworthy:

1. There exists a significant difference in the distribution of attached cells in a tube section with two inner circular fins (Figures 3 and 4) as compared with a smooth tube section. The height of the fin protruding in the flowing fluid (7.5 l/min) was 0.094 cm. The minimum amount of attached cells was found at the center of the tube. In general, the flow pattern in the finned tube will influence the distribution of attached cells.
2. The extent of fouling in the finned tube section was somewhat less than that of the smooth tube (Figures 3 and 4).

If mass and heat transfer rates are greater in finned tube, why are fewer cells observed on the finned tube? The reported data reflect net accumulation of microbial cells. Consequently, increased turbulence in the region between the two fins may decrease attachment rate or increase detachment rate or both. The results after 100 hours can only suggest a decreased *sticking efficiency* for microbial cells under experimental conditions.

Summary

Finned tubes, by the virtue of modified tube geometry and/or additional available surface area, exhibit heat transfer coefficients (based on plain tube surface area) typically twice those of plain tubes at clean conditions. Hence, the required surface area in a heat exchanger is significantly reduced and more compact and lightweight heat exchangers result. No systematic studies of biofilm accumulation in enhanced heat exchange tubes have been performed in the past. Preliminary results obtained suggest that a significantly different distribution of attached microbial cells will form on finned tube surfaces. This single observation at the end of 100 hours cannot be extrapolated to all alloys, geometries, and operating conditions such as flow velocity and water quality. Our results suggest that more defined studies should be pursued with enhanced heat transfer surfaces to determine their performance in environments with high potential for fouling. Such studies may lead to a geometry which maximizes heat transfer while minimizing fouling.

Acknowledgement

The authors gratefully acknowledge partial financial support from the National Science Foundation (CPE 80-17439), Office of Naval Research (N00014-80-C-0475), Calgon Corporation, and Montana State University Experiment Station.

Tina Baril helped machine the sample tube sections.

References

Characklis, W. G. "Biofilm Development and Destruction. Final Report." Electric Power Research Inst., RP902-1, (1980)

Hobbie, J. E., Daley, J. E., and Jasper, S. "Use of Nucleopore Filters for Counting Bacteria by Fluorescence Microscopy." Appl. Environ. Microbiol. **33**, 1225–1228 (1977).

Lund, D. B., and Sandu, C. "State-of-the-art of Fouling: Heat Transfer Surfaces." *Proc.* International Workshop on Fundamentals and Application of Surfaces Phenomena Associated with Fouling and Cleaning in Food Processes, Tylosand, Sweden, p. 27–56 (1981)

Watkinson, A. P., Louis, L., and Brent, R. "Scaling of Enhanced Heat Exchange Tubes." Can. J. Chem. Eng. **52**, 558–562 (1974)

Watkinson, A. P., and Martinez, O. "Scaling of Spirally Indented Heat Exchange Tubes." Trans. ASME J. of Heat Transfer. **97**, 490–492 (1975).

Manuscript received April 19, 1983; revised manuscript reviewed July 7, 1983; accepted for publication July 13, 1983.