United States
Environmental Protection
Agency

Risk Reduction Engineering
Laboratory
Cincinnati OH 45268

Research and Development

EPA/600/S2-90/007 August 1990

EPA

# Project Summary

# Separated Flow Conditions at Pipe Walls of Water Distribution Mains

Lawrence S. Galowin

**The objectives of this research project were to develop and evaluate a method for determining residence times for separated recirculation cavity flow conditions, and to determine the rate of growth and surface ramp contours developed from particulate deposits at obstacles that induce separation and eddy formations in water mains used to distribute drinking water. Resulting biofilm formations contribute to accelerated corrosion rates, increased flow resistance, and the formation of encrustations and colonization that may lead to water quality deterioration. The dependency of conditions at the pipe wall on viscous flow parameters was identified from experiments and analysis of simulated biological growth and decay rates.**

***This Project Summary was developed by EPA's Risk Reduction Engineering Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).***

## Background

An increasing number of drinking water utilities in the United States are reporting persistent violations of the safe drinking water coliform maximum contaminant level (MCL). When the treated water leaving the plant is in compliance, the implication of such violations is that the water quality is deteriorating within the distribution system. Some of these utilities have also reported physical conditions that are consistent with biofilm formation on pipe walls—one possible reason for these occurrences. Biofilm formation also has some significant, negative impacts on the costs associated with distribution system operation. Biofilm layers contribute to increased corrosion rates, increased flow resistance, and formation of encrustations and colonization, anyone of which may lead to water quality deterioration. As a result, the Drinking Water Research Division of the U.S. Environmental Protection Agency's Risk Reduction Engineering Laboratory in cooperation with the National Bureau of Standards initiated a study to examine the hydrodynamic conditions that may affect the formation of biofilm layers on distribution system pipe walls. Research to evaluate the dependency of conditions at the pipe wall on viscous flow parameters was identified from experiments and analysis of biological growth and decay rates.

Past research recommended fluid dynamic investigations of those flow properties and transport coefficients in the water flow layers adjacent to the pipe wall that contribute to biological and chemical formations. Current physical and analytical models do not take into account the simultaneous processes of momentum exchange, diffusion mechanisms, distribution of chemical species concentrations and reactions, and the thermochemical state conditions that govern the corrosion and biological phenomena. Resistance to disinfection at pipe wall surfaces and in dead-end mains can exist even with the residual chlorine concentration levels (based on bulk flow conditions) normally applied to preserve water quality in the pipes. For EPA to recommend procedures for control and prevention of "biofouling," it is necessary to understand the wall phenomena and the flow parameters that govern the local pipe environment, which ultimately contributes to bioorganism colonization.

## Study Objectives and Scope

Fluid flow conditions influence, and may govern, the growth of pipe wall formations, colonization, propagation, and downstream reattachment/deposition locations of bioforms. The transport and distribution profiles of constituents and chemical concentrations or nutrients affecting growths are strongly coupled to the hydraulics. Extended time periods for bioform cell reproduction and life cycles result from separated flows with recirculation eddies or stagnant regions at the pipe walls, branch pipe fittings, dead-end branches, and flow obstacles.

The scope of this investigation included the following tasks. The experimental task was to determine upstream and downstream solid formations developed from small solids streaming toward and about obstacles at the pipe wall and the nearby recirculation patterns caused by the captured solids over a range-of-flow Reynolds numbers. The obstacle simulations represented partially open valves or reductions in pipe cross-sections. Solids captured from the flow at a junction fitting from a main to a dead-end branch were investigated to determine the extent of a separated recirculation flow condition at the dead-end branch inlet. The analytical task was to determine separation and recirculation flow regions at wall cavities and at steps in order to define the flow streamline paths, the motion of small particulates detained within the region, and extended residence times. The Navier-Stokes equations for steady flow in the viscous layer near the pipe wall in the vicinity of the disturbance were solved numerically through a finite difference method computer program.

## Water Main Distribution Systems

Flow conditions in water main distribution systems are highly variable. Design requirements for sizing pipe diameters are usually based on flow rates for fire fighting. As a result, the normal, potable-water flow rate conditions are below the design values. When high demand occurs, loosely bound sedimentary deposited materials, biofilm materials, and other aggregated substances are shed from the pipe wall and carried downstream.

To provide remedial procedures for control and prevention of corrosion/fouling, the complex mechanisms that cause these problems must be understood. Simple techniques, such as mechanical pipe wall cleaning, are unsatisfactory as a long-term solution for elimination of deposits and corrosion. Recurrence of corrosion and aggregate formations containing bioorganisms at the pipe wall indicates that the fundamental causes must be determined to effectively and permanently treat distribution mains to preserve water quality.

## Modeling Methods

Currently available biofilm models do not consider the simultaneous local processes and mechanisms of momentum exchange, chemical species distribution, and thermodynamic state. Global procedures lack accurate details of flow interactions in the biochemical/physical structure formations dependent on local conditions that control the processes. Corrosion and biofilm development depend on the kinetics and reaction rates among local constituents in the bulk flow and with the pipe wall as a source of solute materials. Locally, pH and chemical concentrations may differ from those in the bulk flow.

Flow velocity, chemical species concentrations, energy, nutrients, and biomass contributors that are close to the wall have profile distributions with large gradients. The local properties depend on the mass transfer exchange and mechanisms of mixing and chemical reactions in the region. Models to improve the determination of influencing factors near the pipe wall require consideration of the extent of coupling among: the fluid convective transport properties (turbulent energy fluctuations); diffusion (shear layer or laminar conditions modified with turbulent, bulk-flow eddy effects); chemical reactions and species concentration distributions (variations dependent on the bulk-flow viscous layer); chemical reaction rates in the solution involving the ionized states (as well as corrosion due to oxidation/reduction reactions coupled with electropotential differences of pipe wall material impurities/constituents); nutrients available with extended residence times (for enhanced bioorganism reproduction)

## Pipe Configuration Conditions

Stagnation, separation regions, and flow recirculation or eddies in pipe flow can occur at obstacles (fittings, bends, branch junctions, flanged connectors, valves) and at wall roughness sites (welds, pitting of surfaces, corrosion/encrustation locations) on irregularly coated manufactured pipe surfaces. Chemical reaction equilibrium conditions depend on both the pipe wall materials and state as well as on local flow conditions. Precipitate wall attachment and entrapment can also result in microscopic aggregation clusters that may unite or expand into larger formations on the wall. The constituent wall conditions can be significantly different from the bulk-flow properties because of foreign materials coming from biological cells.

When pipe flow velocities are very low, the sweeping velocities of the water can be insufficient to remove particulates from the pipe wall surface so that deposits formed on the wall can result in sheltered regions that promote bioform growths. Without the bulk-flow disinfectant penetration to the interior of wall formations, uninhibited growth can continue. Also, at all bulk-flow pipe velocities, the viscous wall effects result in vanishing velocities near the wall. Consequently, even under ideal conditions, the region at the wall is essentially slow moving, and transport phenomena considerations must include the diffusive transport mechanisms.

## Conclusions

Calculations illustrate that properties of separated flow conditions in cavities along the walls of water pipe systems can be determined from the governing equations of fluid dynamics. Capture of buoyant, neutral, and nonbuoyant particles, over a range of sizes, can occur in the circulation field of the separated flow. Particulate depositions at cavity wall corners are also possible. Extended residence-time periods can result in nucleation or incubation sites within local regions. Changes in the pipe flow conditions can purge the cavities and thereby become a method of propagating newly developed bioform colonies to other downstream locations along the pipe wall.

Modeling showed the self-purging of cavity particle constituents depend on diameter, specific gravity, and initial locations in the flow field. Also, it was shown that buoyant and nonbuoyant particle motions depend on the flow conditions. Therefore, the assumption that particle falling or rising conditions exist only because of specific gravity can be erroneous. The controlling processes for biocolonization, reproduction, and adhesion mechanisms govern the size of formations and their density. Changed mass groupings result in new particle track paths that increasingly depart from streamline motion as a function of the fluid forces and inertial properties.

Experimental results showed flow separation upstream and downstream of pipe wall obstructions that resulted from the formation of recirculating eddies within separated regions. As the velocity of the flow is reduced, the recirculating eddies have insufficient velocity to keep solids contained in the circulating motion and the larger solids aggregate at the pipe invert. The accumulation of solids become more extensive as the flow velocity is further reduced. The pattern of solids deposition depends on the strength and the position of the recirculating eddies.

In a dead-end branch pipe from a main, separated flow regions were created in the entry vicinity of the branch fitting, with recirculating eddies within the branch itself; these were noted at all pipe flow velocities. The eddies rotated in both horizontal and vertical planes. In the regions of solids deposition, it would be expected that conditions for the bioorganism colonization would be enhanced because of increased residence times. At higher flow velocities, the scale of containment of solids within the separated flow regions showed extended residence times and increased nutrient concentrations from sedimentary materials; contrary to the expectation that greater scouring would occur.

## Recommendations

The determination of the chemical species concentration distribution profiles in the vicinity of the pipe wall is necessary. The lack of free chlorine, as a disinfectant to attack colonies, at the pipe wall requires explanation. Research on the dependency of biofilm formations, limitations on growth depths because of the shearing action in the stream, and attachment mechanisms require further study with the use of experimental methods and extension of analytical techniques. The modeling methods of this study should be enhanced to include porous fiber structures of film layers on the pipe wall so that an accurate shearing flow interface model by a porous surface layer simulation can be established.

Experimental measurements need to be made for very fine particulates and sedimentary materials that appear on pipe walls and at obstacles. Since the shear and drag forces for creeping flow along the wall are generally linearly dependent on flow velocity, any differences in deposition formations from the flow wall would be shown. Chemical species concentration profiles need to be measured with various pipe wall materials, such as, inert glass, concrete, iron, and copper. These measurements would provide data to evaluate the interactions of different wall materials with flow constituents for the range of pH levels representative of water utility distribution systems.

The full report was submitted in fulfillment of Interagency Agreement No. DW13931205 between the U.S. Department of Commerce and the U.S. Environmental Protection Agency.



☆U. S. GOVERNMENT PRINTING OFFICE: 1990/748-012/20062

*Lawrence S. Galowin is with the U.S. Department of Commerce, National Institute of Standards and Technology, Gaithersburg, MD 28099 .*

*Richard G. Ellers is the EPA Project Officer (see below)*

*The complete report, entitled "Separated Flow Conditions at Pipe Walls of Water Distribution Mains," (Order No. PB90-188 897/AS; Cost: $23.00, subject to change) will be available only from:*

*National Technical Information Service*
*5285 Port Royal Road*
*Springfield, VA 22161*
*Telephone: 703-487-4650*

*The EPA Project Officer can be contacted at:*

*Risk Reduction Engineering Laboratory*
*U.S. Environmental Protection Agency*
*Cincinnati, OH 45268*

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati OH 45268

BULK RATE
POSTAGE & FEES PAID
EPA
PERMIT No. G-35

Official Business
Penalty for Private Use $300

EPA/600/S2-90/007