Determination of mixedness characteristics in Kenics Corporations static mixer
by William Bennington Fyock

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE in Chemical Engineering
Montana State University

Abstract:
The Static Mixer, as developed by Kenics Corporation, is a new type of mixing device that, with, no-moving parts, combines materials pumped' into it; the only power requirements are those involved in pumping the components to be mixed through, the device.

Previous work has indicated that the Static Mixer may be useful in combining fluids of highly different viscosities. It was the purpose of this research to quantitatively measure the mixing performance of the device when several sets of components of varying viscosity ratios were combined in the mixer, Various concentrations and flow rates of sodium carboxymethylcellulose (CMC), an ionic polymer, and water were the components combined; either CMC or water was used during the mixing runs as the main-stream component, with the remaining component injected into the main stream in the center of the inlet pipe to the mixer. Quantitative conductivity measurements were taken with a conductivity probe and wire mesh electrode. Well-mixed solutions of the same overall polymer concentrations found in the mixing runs were also analyzed, and the maximum concentration deviations observed were used in setting the boundary for the region of high mixedness in analyzing concentration deviations during mixing runs.

Based on measurements of mean, standard, and maximum deviation and on the percentage of run time that polymer concentrations fluctuated outside of the well-mixed region, it was concluded that 1%-by weight CMC solutions (viscosity ratio ~l500/l) are combined with a relatively high degree of mixedness, 2% solutions (viscosity ratio ~3,000/l) are combined with a high-degree of mixedness at low polymer flow rates, but with a much lower degree at high, polymer flow rates, and k% solutions . (viscosity ratio 30,000/1) are combined with a very low degree of mixedness. Also from measurements taken across the tube cross-section, it was concluded that polymer concentrations are higher at the tube walls than in the tube center during mixing runs.

Statement of Permission to Copy

In presenting this thesis in partial fulfillment of the requirements for an advanced degree at Montana State University, I agree that the Library shall make it freely available for inspection. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by my major professor, or, in his absence, by the Director of Libraries. It is understood that copying or publication of this thesis for financial gain shall not be allowed without my written permission.

Signature William B Jyock

Date 8/29/73

DETERMINATION OF MIXEDNESS CHARACTERISTICS IN KENICS CORPORATION'S STATIC MIXER

by

WILLIAM BENNINGTON FYOCK

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree

of

MASTER OF SCIENCE

in

Chemical Engineering

Approved:

Head, Major Department

Chairman, Examining Committee

Graduate Dean

MONTANA STATE UNIVERSITY
Bozeman, Montana

December, 1973

ACKNOWLEDGMENT

The author wishes to thank the staff of the Chemical Engineering Department of Montana State University, and in particular, Doctors W. E. Genetti and G. R. Cokelet, the directors of this research, for their help and suggestions with this project. A special thanks goes to Mr. J. Tillery and Mr. A. Huso for their assistance in equipment manufacture and repair.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The Static Mixer, as developed by Kenics Corporation, is a new type of mixing device that, with no moving parts, combines materials pumped into it; the only power requirements are those involved in pumping the components to be mixed through the device.

Previous work has indicated that the Static Mixer may be useful in combining fluids of highly different viscosities. It was the purpose of this research to quantitatively measure the mixing performance of the device when several sets of components of varying viscosity ratios were combined in the mixer. Various concentrations and flow rates of sodium carboxymethylcellulose (CMC), an ionic polymer, and water were the components combined; either CMC or water was used during the mixing runs as the main-stream component, with the remaining component injected into the main stream in the center of the inlet pipe to the mixer. Quantitative conductivity measurements were taken with a conductivity probe and wire mesh electrode. Well-mixed solutions of the same overall polymer concentrations found in the mixing runs were also analyzed, and the maximum concentration deviations observed were used in setting the boundary for the region of high mixedness in analyzing concentration deviations during mixing runs.

Based on measurements of mean, standard, and maximum deviation and on the percentage of run time that polymer concentrations fluctuated outside of the well-mixed region, it was concluded that 1%-by weight CMC solutions (viscosity ratio ∿1500/1) are combined with a relatively high degree of mixedness, 2% solutions (viscosity ratio ∿13,000/1) are combined with a high degree of mixedness at low polymer flow rates, but with a much lower degree at high polymer flow rates, and 4% solutions (viscosity ratio 30,000/1) are combined with a very low degree of mixedness. Also from measurements taken across the tube cross-section, it was concluded that polymer concentrations are higher at the tube walls than in the tube center during mixing runs.

I. INTRODUCTION

A. Theory of Operation

The Static Mixer, as designed by the consulting firm of Arthur D. Little, Inc. and further refined and marketed by Kenics Corporation, is a continuous, in-line mixer that combines materials with no power requirements other than those necessary to pump the materials to be mixed through the unit. The mixer is constructed of a series of short right and left-hand helices welded together such that the trailing edge of one element is rotated 90 degrees in relation to the leading edge of the next element (10).

Materials are mixed in the Static Mixer as a result of four processes (3):

(1) Flow Division: As the flowing material contacts the leading edge of each element, it is divided in two. Thus, the total number of divisions increase exponentially according to equation (1), where S is the number of divisions and n the number of elements.

$$S = 2^n \quad (1)$$

In this way, twenty helical elements produce over one million divisions, while thirty elements produce over 1,000 million.

(2) Flow Reversal: Because the mixer elements are right and left-handed, circular material flow alternates to the right and to the left. This alternation of flow constantly changes the

orientation of material presented to each new element, resulting in cumulative rather than repetitive mixing action.

(3) Flow Inversion: Within ten elements, a slug or particle of material travels from the center of the tube to the outer wall and back again. This has the effect of increasing the heat transfer efficiency of the mixer from 60 to 300 percent over straight tubing.

(4) Back Mixing: As each new element is encountered, the profile of maximum flow velocity changes, with the result of thorough axial mixing.

B. Applications

As a mixing unit, the Static Mixer is applicable to processes involving conventional mixing operations, and in the production of dispersions, emulsions, and slurries. Due to the flow-inversion and flow-reversal mixing actions, the unit also finds application in the area of increasing heat transfer efficiencies. Grace (6) provides heat transfer correlations, experimental heat transfer coefficients, and pressure drop correlations for Static Mixer systems in laminar flow; he goes on to describe existing and possible uses of the Static Mixer when both mixing and heat-transfer processes are in operation. Examples include the application of the unit in catalytic reformers, polymerization processes, the heating and cooling of viscous liquids, and in laminar flow reactors. The usefulness of the Static Mixer in these processes is dependent upon

the ability of the unit's unique mixing actions to increase the internal heat transfer coefficient and eliminate channeling. This serves to (1) prevent hot spots and catalyst deterioration in catalytic reformers, thus allowing the process to be carried out at higher temperatures with improved yields, (2) provide better temperature control in polymerization processes, thus eliminating hot spots and overcoming the control problems caused by the high heats of polymerization and low thermal conductivities of monomer and polymer slurry, (3) decrease the energy consumption and lessen the danger of thermal damage in the heating and cooling of viscous liquids, expecially those that are temperature-sensitive, and (4) improve the yields and decrease by-product losses in laminar flow reactors, since with the use of a Static Mixer a high proportion of the reaction mass is at reaction temperature for the optimum period.

Especially in the area of laminar flow reactors, Grace makes an important assumption, that being that the mixing performance of the Static Mixer is independent of velocity or viscosity.

Chen and Macdonald (4) further explore the possibilities of using the Static Mixer in polymer processing. Their work deals especially with the mixing of such materials as antioxidants, flame retardants, colorants, plasticizers, pigments, and light and heat stabilizers intimately into the polymer stream. As stated in their article, the mixing of such additives "often involves additive ratios of 1 to 2%, and viscosity ratios of several orders of magnitude between constituents. Achieving a terminal

blend under these adverse conditions poses a serious problem to the process engineer" (4). Here again, an understanding of the actual mixing characteristics of the Static Mixer, especially in the area of intimately combining fluids of highly different viscosities, is crucial if the unit is to find applications in the field of polymer processing.

Although Chen, Fan, and Watson (5) have studied the mixing mechanisms of solid particles in the Static Mixer, no quantitative studies have been done to determine the mixing characteristics and limitations of the unit in the area of combining fluids of highly different viscosities. It was for this reason that the present project was undertaken.

II. RESEARCH OBJECTIVE

The objective of this research was to determine quantitatively the mixing characteristics of Kenics Corporation's Static Mixer when fluids of varying viscosity ratios and flow rates were combined in the unit.

III. EXPERIMENTAL APPARATUS AND PROCEDURE

A. Method of Mixedness Analysis: Comparison of Indices of Refraction of Solution Samples

In the initial phase of mixedness testing, pure glycerin and distilled water were the components to be combined in the Static Mixer. After several trials, the flow system shown in Figure 1 was adopted; the mixer and entrance and exit tubing were assembled vertically to minimize flow complications caused by the density difference between glycerin and water. Distilled water, the main-stream component, was pumped by means of a Vibrostaltic pump from a large holding tank through Tygon tubing to a flowmeter; from the flowmeter the water was pumped through more Tygon tubing to the entrance section of plastic piping (inside diameter: 1/2"). Glycerin, the high-viscosity component in this case, was pumped by means of another Vibrostaltic pump through Tygon tubing to another flowmeter; from the flowmeter the glycerin proceeded through more Tygon tubing to an inlet nozzle positioned at the base of the entrance section of plastic piping at a point two inches above the fitting at the entrance to the Static Mixer. The inlet nozzle, as shown in Figure 2, was constructed of a Swagelok fitting into which a segment of rigid plastic tubing (inside diameter: 3/32 inch) was inserted. The end of the tubing positioned inside the entrance section of the flow system was filled with epoxy, and a downward-facing hole, 1/8 inch in diameter, was drilled in the plastic tubing to serve as the actual entrance port for the glycerin. During this and all other phases of the research, the entrance port of the inlet nozzle was positioned at the center of the entrance piping.

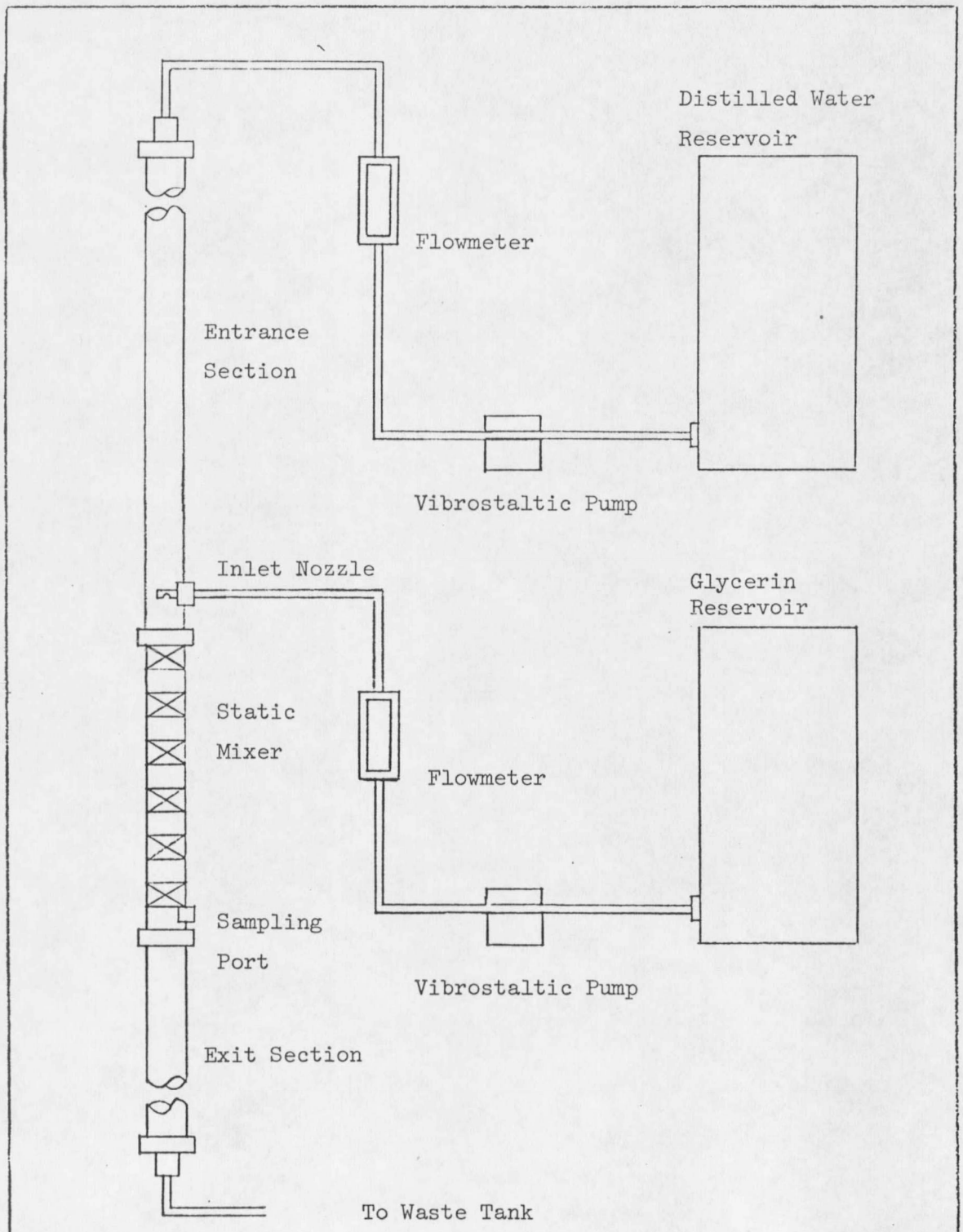

FIGURE 1: Glycerin-Water Schematic Flow System