Reeder M.F., Bakker A., Janz E., Myers K.J. (1997) Experimental Investigation of Viscosity Ratio Effects on the Performance of Kenics Static Mixers. Presented at Mixing XVI, June 22-27, 1997, Williamsburg VA, USA.

Experimental Investigation of Viscosity Ratio Effects on the Performance of Kenics Static Mixers

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Abstract submitted to the 16th Biennial North American Mixing Forum
1 December 1996

A number of studies have shown that blending two fluids becomes increasingly difficult as their respective viscosities become increasingly disparate. In industry, such high viscosity ratio applications are commonly encountered, especially in the areas of polymer processing and waste water treatment. Kenics static mixers have successfully been used for blending in many of these situations, but relatively little quantitative data relating to the effect of viscosity ratio has been documented. This is partly due to the relatively difficult nature of performing experiments, which have generally been limited either to qualitative visualizations using colored dye or to invasive pointwise measurements.

In light of this, the present study has been undertaken to quantify the adverse effect of increasing viscosity ratio on the mixture quality of two miscible fluids blended by Kenics static mixers. Laser induced fluorescence (LIF) coupled with image post-processing has proven to be an extremely useful method for investigating this issue. The advantage of this approach is that both qualitative images and quantitative information about the flow field and mixing characteristics may be obtained non-intrusively as long as the experimental fluids are clear. Our results indicate that there is a strong interaction between the effects of viscosity ratio, flow rate ratio, and the ratio of the velocities of the main flow and the addition. As a result, the design of the injector can have a significant effect on the rate of mixing.

This paper will discuss both the application of LIF and how the mixing performance can be improved by proper injector design.

Experimental Investigation of the Effects of Viscosity Ratio on the Performance of Kenics Static Mixers

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Acknowledgements

Dave Ryan

James Nordmeyer

Aaron Thomas

Reasons for Studying Viscosity Ratio Effects

- Many relevant industrial applications
- High viscosity ratios lead to difficult mixing applications
- Reliable experimental data is relatively scarce

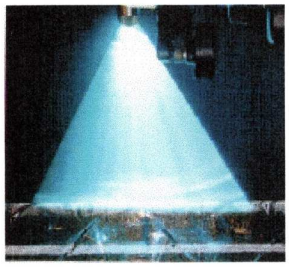
Complications of High Viscosity Ratio Experiments

- High viscosity test fluid properties
  - How quickly does it thin with water addition?
  - Non-Newtonian and viscoelastic effects?
- Effect of injection
  - Single-point vs. multi-point
  - Velocity ratio
- How to calculate the Reynolds number
- How to quantify mixedness

Experimental Outline and Methods

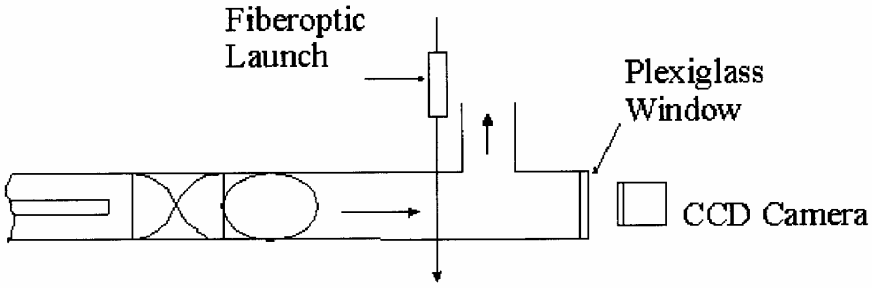
- Injecting CMC (high viscosity) into water
  - Laser Induced Fluorescence (LIF)
- Injecting water into high viscosity fluid
  - Using rhodamine dye with CMC
  - Using LIF with CMC
  - Using rhodamine dye with corn syrup

Laser Induced Fluorescence

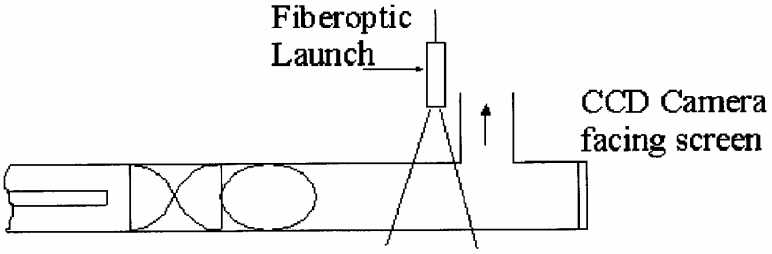


- Laser sheet projected through pipe wall
  - Recorded with a CCD camera (8-bit resolution)
  - Intensity varies linearly with dye concentration
- Image analysis can be used to determine COV
- Minimally intrusive and non-destructive
- Requires clear fluids with similar refractive indices

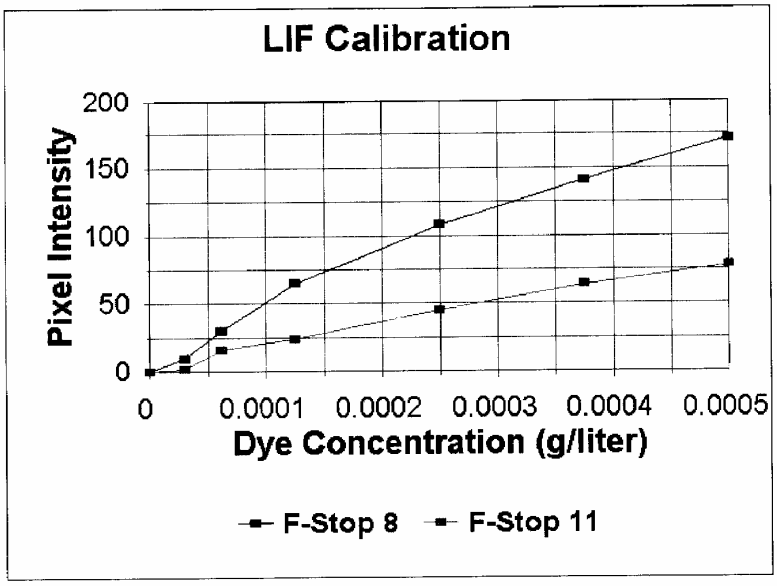
LIF "Front View" Experimental Setup



LIF "Side View" Experimental Setup



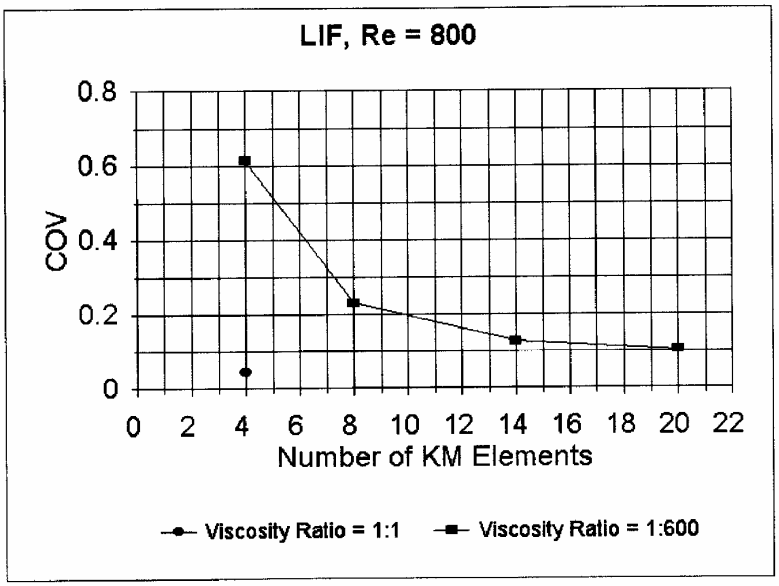
Calibration



Typical Applications for Mixing High Viscosity Fluid into Low Viscosity Fluid

- Wastewater Treatment
  - Polyelectrolytes into water
  - Usually high Reynolds numbers (> 20000)
- Food Processing

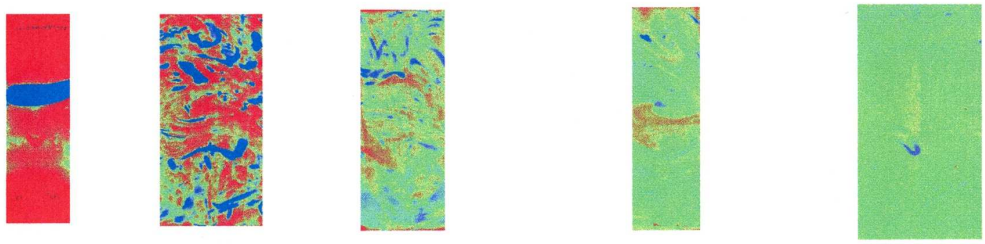
COV Calculations for Re = 800



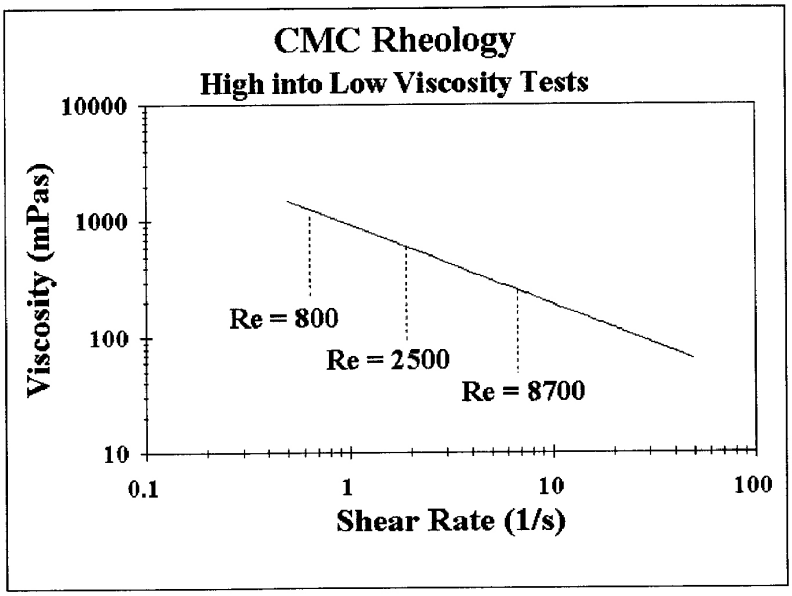
Typical Images for Re= 800

Raw

Processed

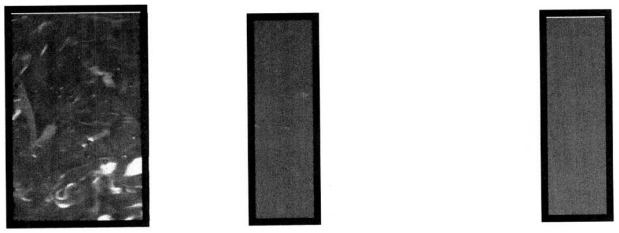


Use of Shear Thinning Material Complicates Results

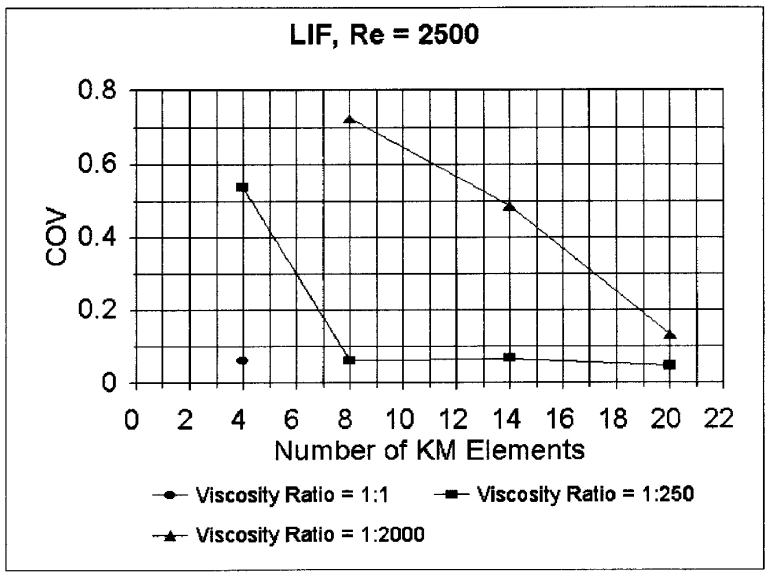


Typical Images for Re = 2500

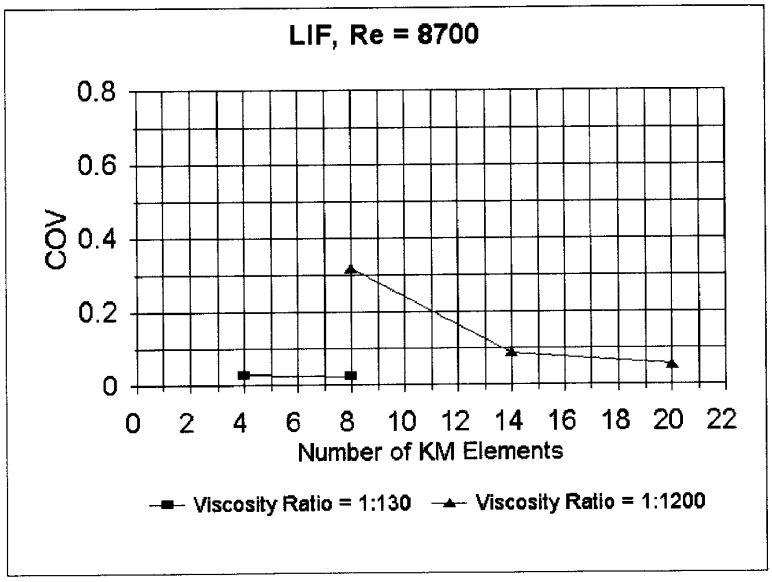
KM-4 KM-8 KM-14



COV Calculation for Re = 2500



COV Calculation for Re = 8700

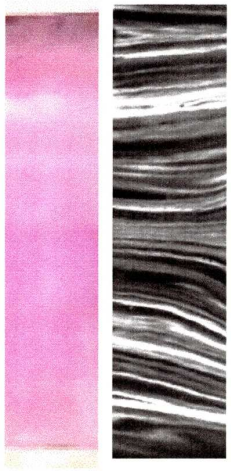


Typical Applications for Mixing Low Viscosity Fluid into High Viscosity Fluid

- Polymer Processing
- Polystyrene
- Silicones/Caulkings and Colorants

Comparison of Colored Dye Visualization and LIF images

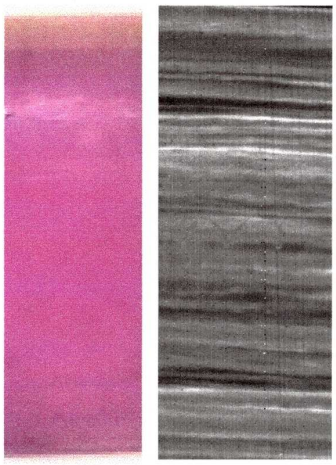
14 KM



10 percent water addition to CMC

Viscosity ratio = 2000:1

20 KM



Front View LIF

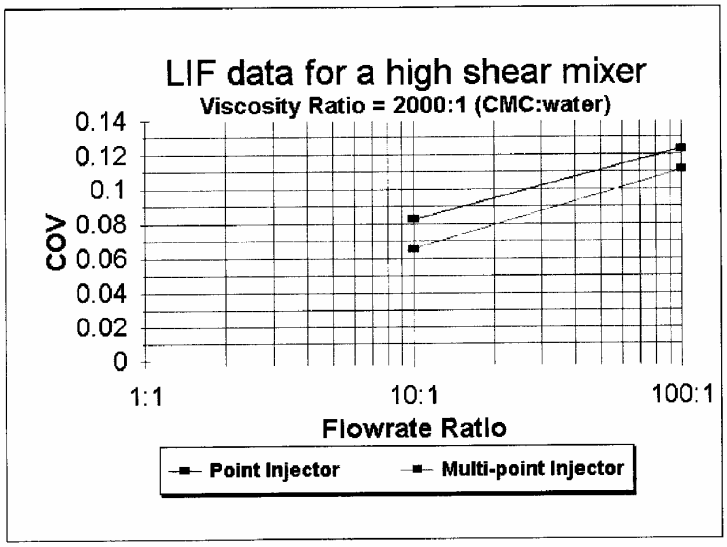
Viscosity Ratio = 2000:1

Water addition = 10 percent

Re = 1

After 20 Kenics elements

Effects of Flowrate Ratio and Injector Style on a Mixer's COV



Injecting Water into Corn Syrup

- Newtonian fluids
- Viscosity ratio varied up to 500000:1
- Ten percent water addition leads to an order of magnitude drop in the outlet viscosity
- Refractive index difference prevents good image quality for LIF

Effect of Injection Velocity for a Viscosity Ratio of 100000:1

KM-26

Injectant velocity = 100 * main flow velocity
Flowrate ratio = 1:1
(Channeling, poor mixing)

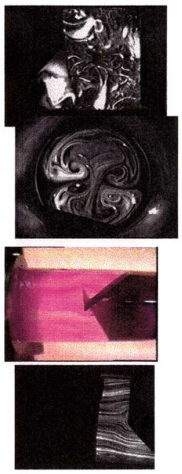
Injectant velocity = 10 * main flow velocity
Flowrate ratio = 10:1
(Much better mixing)

Chemineer High Shear Mixer

- A new "High Shear" mixer design gives better mixing per unit length than the helical element mixer
- Higher pressure drop per unit length than the helical element mixer
- High shear mixer is well-suited for mixing low viscosity fluid into high viscosity fluid

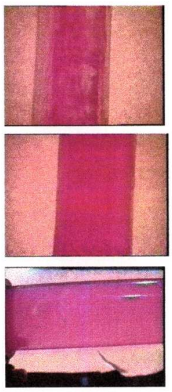
Video Chronology

- Injecting CMC into water
  - LIF, side views, steady state, Re = 800
  - LIF, front views, at initial injection to steady state for Re = 800 and 2500
- Injecting water into CMC
  - Flow visualization with red dye
  - LIF for same fluids and flow conditions



Video Chronology

- Injecting water into corn syrup
  - 53000:1 viscosity ratio, KM-20
  - 53000:1 viscosity ratio, high shear mixer
  - 300000:1 viscosity ratio, high shear mixer



Conclusions

- Laser induced fluorescence can be used to investigate high viscosity ratio mixing.
- The LIF technique is extremely sensitive to concentration differences and its spatial resolution is quite high.
- Injector design can play a critical role in mixer performance.
- A new Chemineer static mixer design can be used for extremely high viscosity ratio mixing.