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Investigation of Micromixing in Viscous Liquids

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Contents.

1. Introduction.

This dissertation treats the effects of laminar mixing of incompressible, Newtonian fluids of $Sc \gg 1$ (liquids) in single phase isothermal systems on the course of homogeneous chemical reactions. The considered liquids are completely miscible, but can differ in viscosity. Chemical reaction is a molecular level process so in the dissertation are investigated those features of mixing that cause the attainment of homogeneity on the molecular level. The process of mixing on the molecular scale is called micromixing; micromixing theory is thus concerned with the reduction of the scale of unmixed lumps of fluid by viscous deformation followed by molecular diffusion.

The subject is interesting from two points of view: practical and theoretical.

In practice laminar mixing is of importance when highly viscous liquids are to be mixed. This happens in numerous industrial processes such as polymer processing and rubber, food, cosmetic or glass technology.

The main practical problems can be summarized as follows.

- Micromixing affects the course of chemical reactions. For single reactions there is an influence of micromixing on the time of reaction, conversion or reactor size; for multiple reactions which are combinations of simple reactions there can also be a much more important influence of micromixing on selectivity, weight distribution of polymer molecules and thus on the physical properties of polymers, etc.
- It is difficult to mix highly viscous liquids, specially when the liquids differ in viscosity; high inputs of mechanical energy or long mixing times are required.
- It is difficult to compare different systems (reactors, mixers) from the point of view of energetic efficiency of mixing; it would be desirable to develop a rigorous procedure based on experimental data and mixing mechanism leading to estimation of energetic efficiency which can be applied to compare the systems of different geometry. In relation to the concept of energetic efficiency it is essential to know if and how much the efficiency can be increased, how to perform this increase technically and how this increase affects the product quality.

From the theoretical point of view, micromixing investigations can supply new information about the mechanism of mixing and can be used to verify the existing and the proposed models of micromixing. The main problems here are as follows.

- Mixing mechanism is very complex and many aspects of mixing are still not completely understood.
- The theory of mixing is related to many branches of science, i.e.: fluid mechanics, theory

of stability, theory of deterministic chaos, theory of chemical reactors.

● Micromixing models available in the mixing literature are usually based on simplified mixing mechanisms. Application of those models is thus limited, but the limitations are usually not given explicit and often not known to the authors.

The literature says that the liquid elements deformation is the most important phenomenon in mixing of viscous liquids. Deformation reduces the scale of segregation, increases the intermaterial surface and increases gradients of concentration, accelerating finally molecular diffusion. However, to be efficient, deformation requires a proper orientation of liquid elements. The orientation of fluid elements in the deformation field and the deformation field itself can be strongly affected by instabilities of the flow.

In view of these remarks the main aims of the dissertation are:

- to identify the main aspects of mixing mechanism of very viscous liquids,
- to work out mathematical models of laminar micromixing,
- to apply the proposed models for interpretation of experimental data.

These aims should be achieved in the following scope:

- a literature review of mechanisms and models of mixing,
- an analysis of mixing phenomenon in simple flows, including a simple elongation and a simple shear,
- a stability analysis of a simple laminar flow of the completely miscible liquids differing in viscosity, using as an example a core-annular flow,
- presentation of mixing models describing different aspects of mixing with different accuracy including the author's proposed models,
- selection of complex test reactions and the viscosity increasing agent,
- experimental investigations of mixing with chemical reactions,
- interpretation of experimental data with the use of the micromixing models,
- proposition of methodology of determination of the energetic efficiency of mixing; the method should enable comparison of mixing efficiency in different systems and provide facilities for establishing hierarchy of reactors and mixers from the point of view of efficient mixing,
- discussion of the concept of degree of segregation - the classical and new definitions.