11. Conclusions.

Three main objects have been achieved in this dissertation. First, the mechanisms governing laminar micromixing of very viscous, Newtonian and incompressible fluids of $Sc \gg 1$ (liquids) were identified. Second, two mathematical models of laminar micromixing were constructed. Third, the proposed models were successfully applied to interpret the experimental results.

These aims were carried into effect in the following way.

- A literature review was performed including:
- definitions of mixing indices commonly used,
- existing knowledge of mechanisms of laminar mixing,
- the models of laminar mixing avaible in the literature,
- various approaches to the problem of efficiency of mechanical mixing,
- studies of stability of laminar flows,
- chemical test reactions to investigate mixing.

- The mixing phenomena in simple laminar flows were analyzed. This study explained the role of deformation of fluid elements in mixing on the molecular scale:
- decreasing of segregation scale,
- generation of a contact area between mixed fluids,
- increasing of concentration gradients in the direction of contraction and their decline in the direction of stretching.

The analysis also showed the role of orientation of fluid elements in deforming flows, presented effects of physical properties of mixed media on the course of mixing and provided some useful guidelines for modelling of micromixing in very viscous liquids, for example:

- deformation of fluid elements tends to stabilize the penetration distance of diffusive solutes in the direction of contraction
- mixing with deformation, molecular diffusion and chemical reaction can be considered as one-dimensional process.

- The stability of a simple, core-annular flow of completely miscible liquids (no interfacial tension) was examined. This study provided a unique experimental evidence showing that a considerable difference in viscosity of the mixed liquids can result in instabilities of deforming flows and retard the process of mechanical thinning by formation of periodic segregated structures. The theory of hydrodynamic stability was successfully applied to explain the observed phenomena and to find regions of stability of the considered flow. These regions are

presented as wavelengths of disturbances which are damped.

● Two mathematical models of laminar micromixing were constructed by applying two distinct integral transforms to differential material balances describing in the Largangian frame of reference the processes of mass transfer in a reaction zone. The first model correctly describes mixing of a small volume of concentrated solution of one reactant with a large volume of diluted solution of other reactants. The second model can be used provided that reactants concentrations are initially not very different.

The models enable prediction of the effects of: agitation speed, feeding rate, volume and stoichiometric ratios on the course of mixing with chemical reaction.

● The system of two competitive-parallel reactions and the viscosity increasing agent, suitable for experimental study of micromixing in very viscous liquids, was worked out. This included establishing of:

- the kinetics of the test reactions
- the properties of test reactants and the viscosity increasing agent, which can influence the course of the test reactions,
- the analytical method for determination of the product distribution.

● The experimental investigations of laminar mixing were carried out, with the use of the test reactions and the viscosity increasing agent, in two different systems - the semi-batch reactor (a cylindrical tank reactor with a pitched-blade impeller and baffles) and the batch reactor (a concentric cylinder system). These experiments revealed that the final product distribution depends on: agitation speed, volume ratio and viscosity ratio of the substrates solutions. The character of these relations was found to be similar in both reactors. Additionally, it was determined that it may be difficult to avoid completely the influence of the feeding rate on the product distribution in the semi-batch reactor, even for extremely long feeding times. It was also found that mixing in an unidirectional or a periodic Couette flow created in the batch reactor can be improved by a local flow disturbance.

● The experimental results obtained in the semi-batch and batch reactors were interpreted by means of the micromixing models developed in this dissertation. The models, in the region of their validity, were capable of explaining the effects of feeding rate, agitation speed and initial volume ratio on the product distribution of the competitive-parallel reactions.

● The procedure of determination of the energetic efficiency of mixing, enabling a comparison of different geometrical systems from the point of view of efficient mixing was proposed. The method was based on the test reaction system and the micromixing models developed in this dissertation.

● The effects of operating conditions and a system geometry on the course of simple and complex chemical reactions performed in very viscous liquids and in on-line reactors were studied using CFD methods. The results of the numerical simulations (conversion and selectivity of chemical reaction) were compared with the values of degree of segregation. The classical as well as new definitions of degree of segregation proposed in this thesis were used. The comparison showed that the choice of the degree of segregation definition should be related to the character of an investigated process.