AN ANALYSIS OF MIXING PROCESS IN A STATIC MIXER

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Summary In the present study flow mixing process in a static mixer for two immiscible viscous fluids has been treated numerically. A comparison of numerical results and measured data for flow mixing process in circular duct has been made to check the results of numerical simulations. The mixing efficiency function has been proposed to performed process optimisation and obtain most efficient conditions for industrial mixing process.

Introduction

In many industrial applications static mixers are easy used for homogenisation of different liquid, gas or grain components. Advantage of this mixing technology is very small maintenance, which is a result of the absence of any dynamic devices. Despite the numerous applications of static mixers, the fundamental understanding of the process is so far described insufficiently (Godfrey 1992). Some researchers have reported pressure drop data (Chen 1973, Shah&Kale 1991, Fasol 1997), resident time distributions (Nauman 1991, Fasol 1997, Li 1998), friction factor (Moranicais 1999), mixing pattern "frieze" by solidification of coloured components. Recently computational investigations of mixing analysis have been carried out for different mixers. Byre&Sawley[1] and Muzzio performed three-dimensional analysis; however those studies did not provide detailed analysis of mixing performance. Also comparisons of computed mixing pattern with experimental one have not been reported. A prediction or calculation of quality of mixing process of two streams with different viscosities, densities and phase ratios which are homogenised in a static mixer do not have been reported in open literature. This study presents results for a SMX (and SMR) static mixer and compare mixing pattern with experimental visualisation. The paper focus on the mixing quantities In the mixing process of two different flow streams with similar or different properties as well as flow rates.

Formulation of the problem

Geometries of SMX and SMR static mixers used in analysis are shown on Fig.1. Geometrically the Sulzer SMX and SMR mixers are very similar in design, and main differences are in the shape of inserts - round or rectangular cross-section duct. Detailed information can be found in Sultzer, Chemtech.

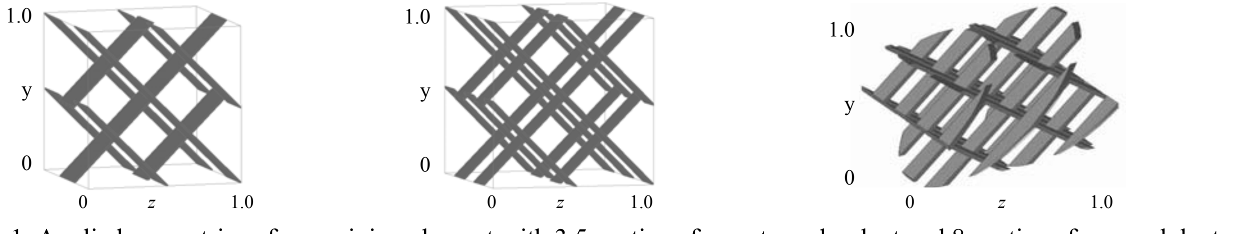

Fig.1. Applied geometries of one mixing element with 3,5-sections for rectangular duct and 8-sections for round duct.

The mathematical model for the flow mixing processes of n-fluids is given by the continuity and momentum equations. Assumed the fluid is considered to be incompressible, Newtonian and properties (for each fluid) are constant these equations are as follows:

$$\nabla \cdot V = 0 \quad (1) \qquad \frac{\mathrm{D}\boldsymbol{V}}{\mathrm{D}t} = -\frac{1}{\rho}\nabla P + \frac{\mu}{\rho}\nabla^2 \boldsymbol{V} + \boldsymbol{F} \quad (2) \qquad \frac{\partial f_n}{\partial t} + \nabla \cdot (f_n V) = 0 \quad (3)$$

Equation (3) has been used for analysis mixture of more than one fluid with different properties. Function f_n has been used in VOF (Volume of Fluid) method to specify amount of n-th fluid mixture in each computational control volume. For two different fluids mixture $f_1+f_2=1$. Base on that information fluid properties in each CV can be easily calculated as follows: $\rho=f_1*\rho_1+f_2*\rho_2$ and $\mu=f_1*\mu_1+f_2*\mu_2$ where subscript (1) and (2) denote constant properties of fluids at duct inlet. For constant mesh (Fig.2) geometrical approximation has to be introduced also. Proposed method was adopted from phase-change solidification problems on constant grid.

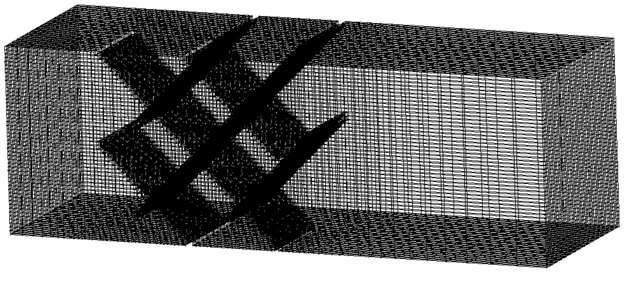

Fig.2. Simplify grid for square cross-section duct with one mixing element with 2-sections.

The flow in mixing process was calculated numerically by the control volume method, solving the finite-difference equivalent of equations (1)-(3). Staggered grids were used for the velocity components. The SIMPLE-C algorithm was used to solve the pressure. The central finite-difference approximation was applied for the diffusion terms while, for the convection terms the QUICK scheme was used. The present scheme was based on fully implicit discretisation schemes taking into account the unsteady terms of governing equations. The grid points were non-uniformly allocated and total number of grids was 50x50x200 up to 100x100x400. Properties of a working fluid was based on water properties but in same cases the density and viscosity was set one order higher to analyse mixing process of fluids with different properties. A condition examined here was determined by Re number (base on duct diameter). At the duct inlet one fluid entrance was located in the upper half of the cross-section and second one in lower half. To investigate mixing properties a total 250.000 massless passive tracers was distributed uniformly located in the upper or lower half cross-section.

Results

The evolution of the mixing pattern in the SMX static mixer for different cross-section and Re=1 for each fluids has been compared with experimental visualisation form Sulzer (Chemtech)

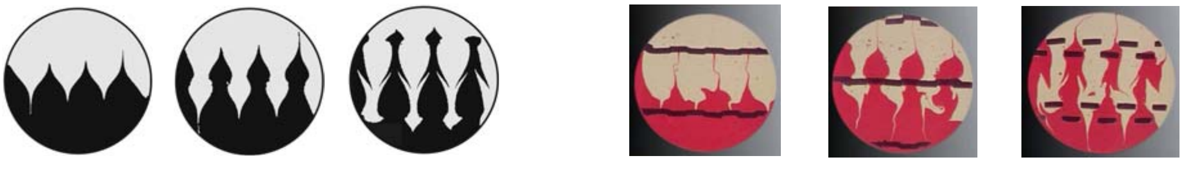

Fig.3. Computed and observed mixing pattern for Re=1 and mixing element length z*=0.25, 0.5, 0.75

One of the most important parameter in mixing analysis is segregation, pressure drop and particles resident time. In present work two primary parameters segregation [2] and pressure drop (with reference to pressure in empty duct) has been link to one parameter mixing efficiency $E = \frac{-\log(S)}{Z}$. Examine of that parameter E allow us to obtain most efficient conditions for mixing process.

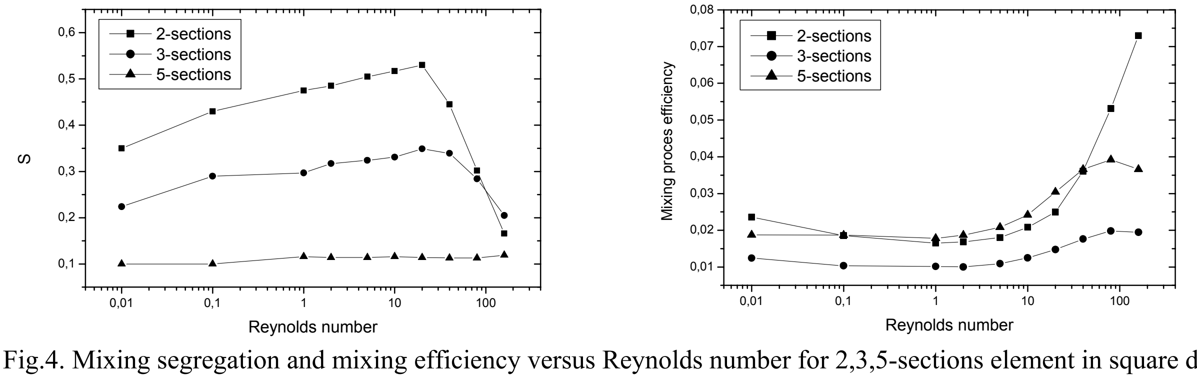

Fig.4. Mixing segregation and mixing efficiency versus Reynolds number for 2,3,5-sections element in square duct

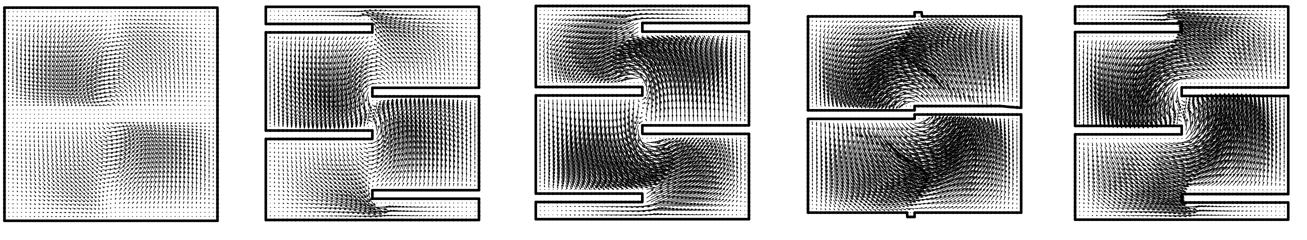

Fig.5. Velocity vectors for 2-section mixing element and Re=10 (for XY plane and z*=0.0; 0.2; 0.4; 0.5; 0.6)

Fig.5 shows velocity components (u,v) of the flow fields in XY cross-section planes. It can be seen big differences in velocity magnitude at points near to the element wall and wall of a duct. In configuration with 3,5-sections element velocity magnitude is more uniformly distributed over XY duct cross-section.

Conclusions

Flow characteristic in SMX static mixer agree well with experimental visualisation. The effect of Re number on segregation and mixing efficiency was analysed. It has been found that irrational increasing of flow rate (Re number) can decrease mixing segregation .i.e. higher flow rate produce less effective mixing but required energy is very high.

References

[1] Byre O., Sawley M.: Parallel computation and analysis of the flow in static mixer, *Chem. Eng. J.*, 70, 93-104,1998.
[2] Bednarz T., Analiza numeryczna procesu mieszania płynów newtonowskich w mikserze statycznym, proc. of XV KKMP, Augustów,PL, 2002.