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CFD MODELING OF MIXING PROCESS IN PUMP FOR TWO LIQUIDS WITH DIFFERENT TEMPERATURES

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ABSTRACT
The mixing of two or more liquids is very common in many industrial applications. In some cases the liquids are set on the pump inlet. The mixing process of two non-isothermal fluids in a pump is investigated in the presented work. Different pump geometries have been studied with comparison steady state and averaged transient results.
Presented work considers the influence of the difference in temperatures of two mixing liquids on the mixing process.
The pump model consists of suction, impeller and discharge parts which were meshed and calculated together. This, for instance, naturally permits the effects of non-uniformity of velocity and liquids concentrations distribution on the impeller eye and on the inlet of the discharge segment to be taken into account.
Dependence of the density of liquids on the temperature is taken into account.
Results of previous work with isothermal liquids demonstrated significant change in the mixing uniformity coefficient γ depending on where on the inlet the injected fluid is located and effect of very fast fading oscillations of concentration with blade passing frequency. For injection with angular symmetry on the pump inlet, γ is close to 1 (ideal mixture) on the outlet compared with γ less than 0.9 for strong angular asymmetry injection on the pump inlet, which is not sufficient for some applications.
Results of presented work show the small, but visible, difference in the mixing uniformity coefficient for isothermal and non-isothermal liquids with the same flow rates on the inlet. Temperature uniformity coefficient is very close to the mixing uniformity coefficient, which is obvious, because of closeness of turbulent diffusivity and thermal conductivity coefficients.

Keywords: pump, CFD, concentration, mixing, oscillations, uniformity, transient, non-isothermal.

INTRODUCTION
In a large variety of areas, from airspace technologies to food production, the mixing process plays an important role. Therefore, many efforts are made to understand the mechanisms and principals of mixing processes. One of the main efforts is CFD modeling [1 – 3]. Usually, a special mixer is used to help mixing. In this paper, however, a natural mixing process is investigated.
The mixing process of two non isothermal fluids in a pump is investigated in the presented work. The mixing process of two isothermal fluids was studied in the work [3].
Liquids are set on the pump inlet without any mixer involvement, so the pump itself is used as a mixer.
This work investigates the influence of the secondary liquid injection location on an inlet. Centrifugal and vertical pump geometries have been studied. As shown in the works [4, 5], the oscillations may have a significant effect on the parameters of the flow performance. Therefore, oscillation behavior of the concentration of secondary liquid has been studied.
Due to the fact that the calculations required a large computation capacity, transient pump 3D simulations have been provided for only one case to illustrate the problem.

MODELS
One of the pumps is a centrifugal double suction pump. Therefore, due to the symmetry of pump geometry, only half of the real domain is considered. The other pump is a vertical pump, and full geometry has been considered, due to different numbers of vanes on the impeller and bowl.
Due to the turbulent character of flow, the exact value of laminar diffusion coefficient is not so important.
Commercial code Fluent 12.0.16 was used for CFD computations.

The flow is incompressible. Steady and unsteady Reynolds averaged Navier – Stokes equations (RANS) and k-ω turbulence closure models have been applied.

Time step has been chosen so the impeller would turn on 1/175 of its full revolution in one time step.

The mesh near the pump walls was prepared so the value of Y^+ would be in the range of $20 < Y^+ < 400$, especially on the impeller walls.

Fick's law with the following form:

$$\boldsymbol{J_i} = \mu_{eff}/Sc_t \nabla C_i \tag{1}$$

(where index $i = (1, 2)$; $\mu_{eff} = \mu + \mu_t$)

has been used to describe the diffusion flux of a species.

Only one diffusion equation for C_2 has been calculated. Water concentration is $C_1 = 1 - C_2$.

γ definition is:

$$\gamma_X = \int_A [1 - \mathrm{abs}\,(X_{id} - X)/2X_{id}]\rho \mathbf{U} d\mathbf{S} \Big/ \int_A \rho \mathbf{U} d\mathbf{S}$$

Where A is an area of section on which γ is calculated and X_{id} is variable X in ideal mixture, X is the actual value of X (liquids concentration or temperature). In the case of $\gamma_x = 0$ when two fluids are not mixed yet, weight coefficient α in the γ_x definition is $\alpha = 1$ if $C_{id} = 0.5$ and $\alpha \approx 2$ if $C_{id} << 0.5$. Therefore, in the present work $\alpha = 2$ was chosen.

The pressure-based coupled solver has been applied.

Sliding mesh for transient calculations and MRF for steady state calculations has been used.

Hexahedral mesh has been used for vertical pump. Centrifugal pump has been meshed with hexahedral mesh for impeller and tetrahedral mesh with prism layers for other parts of the pump. The total number of cells varied from four to eight millions.

The geometry of the inlets is shown on Figure 1.

On the suction part we have two inlets; water goes in trough inlet 1 and the second liquid gets

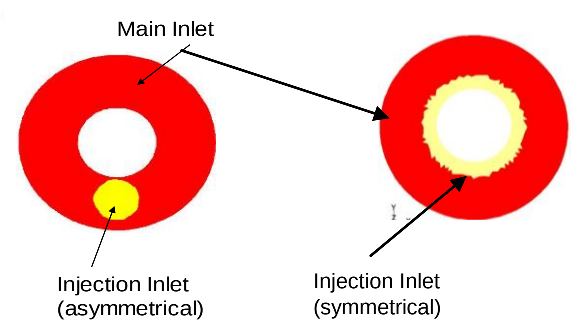

Figure 1. The Geometry of Inlets

Two types of injection inlets for the second liquid were studied. First is an annular (symmetrical) inlet and second is an asymmetrical inlet.

The boundary conditions types are the same for vertical and centrifugal pumps.

RESULTS

Steady state calculations of γ for vertical pump geometry show that mixing is very good even after first impeller, and have relatively weak dependence on the ρ_2.

The results in the case of the asymmetrical injection inlet show qualitatively similar X distribution with different X_{id}. Therefore, there is a significant difference between the X distribution for the annular injection inlet and the X distribution of the asymmetrical injection inlet.

The monotonic dependency of γ_X from X_{id} on the outlet needs to be noted.

Comparison of the temperature distribution on the impeller blades for asymmetrical and annular injection inlet (figures 2 and 3) demonstrate significant difference, even in quality point of view.

For injection with angular symmetry on the pump inlet, γ is close to 1 (ideal mixture) on the outlet compared with γ less than 0.9 for strong angular asymmetry injection on the pump inlet, which is not sufficient for some applications.

Results of the presented work show the small, but visible, difference in the mixing uniformity coefficient for γ_T and γ_c with the same flow rates on the inlet. For instance, for $C_{id} = 0.143$ we have $\gamma_T = 0.911$, $\gamma_c = 0.928$. Inlet temperature for hot liquid is 364 K^o, for cold liquid it is 274 K^o.

The results of the transient calculations of γ_c for the centrifugal pump on the section surface that crosses the impeller with the asymmetrical location of the second liquid inlet are shown on the figure 4.

The oscillations with blade passage frequency dissipate completely on the outlet. Only low frequency oscillations with period ~ 3 revolutions and very small amplitude are observed.

The time-averaged γ on the outlet for the transient calculations and the γ received from steady state calculations are different.

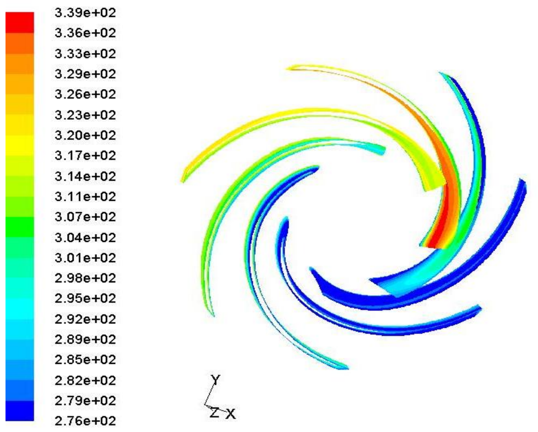

Figure 2. Temperature (K^0) distribution on the impeller blades (asymmetrical injection case)

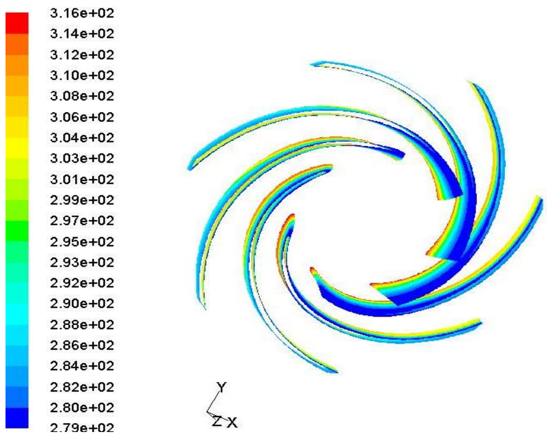

Figure 3. Temperature (K^0) distribution on

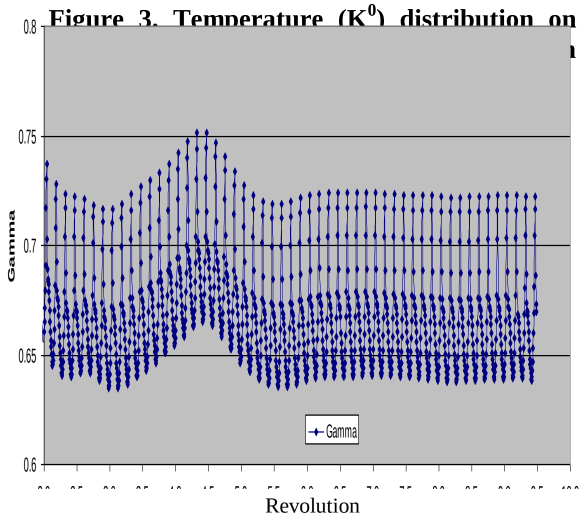

Figure 4. The oscillation behavior of γ_c on the section surface crossed the impeller (centrifugal pump) with the asymmetrical injection inlet.

DISCUSSION AND CONCLUSIONS

The coefficient γ reaches regular oscillation amplitude with *w* frequency after six revolutions. This means that initial conditions have no influence on γ at that time.

The difference between steady state and transient γ calculations may be caused by the transient nature of pump flows, which can not be perfectly resolved by the MRF model.

Temperature uniformity coefficient is very close to the mixing uniformity coefficient, because of closeness of turbulent diffusivity and thermal conductivity coefficients ($Sc_t \approx Pr_t$). The difference can be explained by different walls boundary conditions for concentrations (zero flux on the all walls) and for temperature (which is adiabatic on the impeller blades only) and some dependence of density of mixture on the temperature.

The difference between temperature distribution on the pump blades for symmetrical and asymmetrical injection inlet may have large influence on the inception of cavitation in the pump.

This work demonstrates promising results for the successful mixing of two liquids directly in the pump.

The future development of this work requires the following: an increasing number of transient calculations, considering effects of cavitation (especially for high temperature of injection liquid), and significant experimental work.

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