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반대방향 충돌제트에 의한 원형 챔버 내 혼합거동에 대한 전산가시화

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Numerical visualization of mixing in a circular chamber by two opposite impinging jets

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Abstract In this study, the mixing process of two distinct flow is numerically investigated. Two flow with different physical properties (resin and hardener) are mixed through the opposing mixing jets. At a high pressure mixing process, the high speed flow is provided by two in-line nozzles. In the case of numerical modeling, Reynolds-Averaged Navier-Stokes Equations (RANS) is conducted to model the flow pattern inside the chamber. Additionally, SST k-omega turbulence model is selected to predict the kinetic energy of flow in impingement zone. The results show that mixing of two distinct flows would be efficient if the velocity of jet is high enough and nozzle diameter is a predominant parameter. Also, this velocity would create higher shear stress between two distinct flows which increases the mixing quality as well as strength of formed vortices. Eventually, the histogram of concentration fraction of resin is examined in order to show the quality of mixing and the range of concentration fractions in the output of chamber.

Key Words : Opposing impinging jets, mixing process, mixing chamber, numerical visualization

1. Introduction

Opposing impinging jets provide a simple in-line mixer configuration with potential industrial applications for rapid mixing of viscous fluids. Single or two-phase impingement of two opposing jets has been studied for its applications in such processes as reaction injection molding (RIM), thermal drying of solid particles with high water content, fuel combustion, gas or liquid mixing, pharmaceutical crystallization, absorption, catalytic reactions[1].

Although opposing jets have been proven useful in a number of industrial applications, fundamental research on opposing jets is still very limited. Devahastin and Mujumdar [2] extended their study of flow and mixing behavior of two-dimensional confined impinging streams to the turbulent flow regime. Using a newly proposed turbulence model

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they found that as the jet Reynolds number increased mixing was improved until some specific values of the dimensionless axial distance were reached. These critical values depended on both the operating conditions as well as the geometry of the system. This behavior was quite different from what was observed in laminar impinging streams of similar geometries[3]. For turbulent impinging streams increasing of the jet Reynolds number led to higher levels of the turbulence kinetic energy, especially in the impingement zone.

The objective of this study is to model the mixing process of two distinct flows in a high pressure mixing chamber. The model is three-dimensional with high pressure inlet. To increase the quality of mixing, two distinct flows are passed through distinct nozzles with cone angle of 180^o.

2. Methodology

The numerical simulation is conducted to study the flow pattern during the mixing process. A mixing chamber is considered in order to mix two different flows with different fluid properties. The simulations are carried out in Ansys-Fluent 16.0 (academic version). Finite Volume Method (FVM) is used to discretize the Navier-Stokes Equations with second order accuracy (second order upwind) based on the RANS approaches. To predict turbulence properties, the SST *k*-omega is also selected as turbulence model. For modeling of mixing of two different fluids, the mixture model is selected to examine the results in the output of chamber. The mixing flow rate is 40 gr/s and the density of resin and hardener are 1024 kg/m^3 and 940 kg/m^3, respectively. The mixing ratio in this study is also selected 100:100 and the diameter of nozzles in discharge area is 0.0003m. Figure 1 shows the computational domain used for the simulation. The combination of structured and unstructured mesh is used to improve the quality of simulation. Three different computational domains with different number of nods were selected. The coarse mesh (I), fine mesh (II) and very fine mesh (III) consist of 4×10^5, 8×10^5 and 1.6×10^6 nodes, respectively. The errors for total velocity and total void fraction in outlet between mesh (I) and (II) were 11.4% and 7.4%, respectively. With increasing of nodes in mesh, especially in mixing zone, the errors for the remarked values between mesh (II) and (III) were reduced to 0.97% and 0.46%, respectively. Finally, it is decided to select mesh (II) as a basic computational domain for the rest of investigations. On the point of runtime, all residuals were set to 10-5 and all of them should reach a stable trend without any notable dispersion.

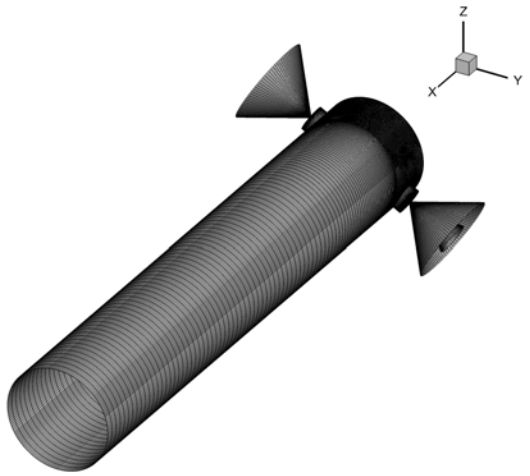

Figure 1. Overall view of computational domain. Two distinct nozzles are connected to a chamber.

As it is shown in Figure 1, the chamber was designed based on the structured mesh in order to obtain the better velocity profile near the wall regions. The importance of boundary layer mesh is a challenging issue in simulation of flow in nozzles. Therefore, appropriate boundary layer mesh is also conducted to minimize the numerical errors. Because of complexity of geometry, it is expected to used fine unstructured mesh just in one part of computational domain, where the nozzles are connected to chamber.

Figure 2 shows the nozzle geometry and structured mesh used to model flow with better concentration.

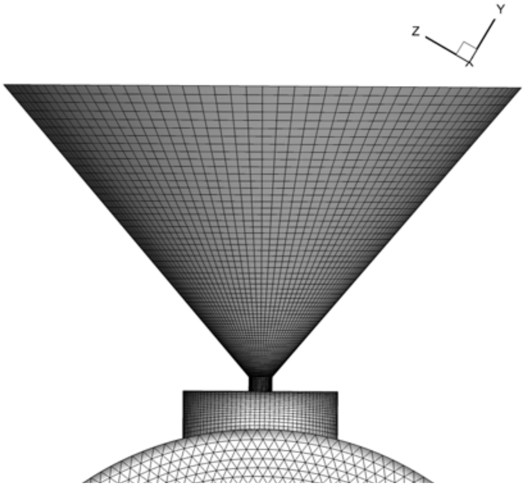

Figure 2. Nozzle geometry and structure mesh.

3. Results and Discussions

In this section, the numerical results are presented and significant features are discussed. Figure 3 shows the streamline for both resin and hardener. The red, blue and green colors signify the resin, hardener and mixture of them, respectively. This kind of opposite impinging jets leads to blending of distinct fluids appropriately, while vortex dynamics are the positive point. The vortices increase the turbulence and hence, the boundary layer mixing would be promoted. It is worthy being mentioned that the shear force in the stagnation point (where two impinging jet collide) is also responsible for blending of two distinct fluids, where the turbulence kinetic energy is maximum.

For inerpreting the mixing quality, the histogram of void fraction at output is provided in Figure 4. As seen from Figure 4, the range of void fraction for resin is approximately between 0.4 and 0.5. It is shown that the mixing process is done appropriately, while some techniques should be applied to reach the ideal value of 0.5.

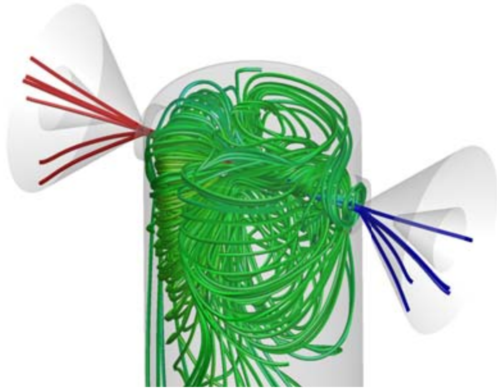

Figure 3. Streamline of resin and hardener flow inside the mixing chamber (The red, blue and green color signifies the resin, hardener and mixture of them, respectively).

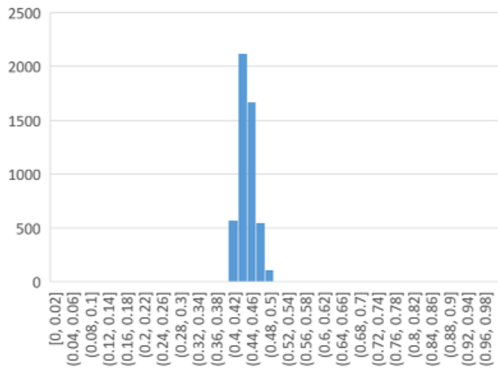

Figure 4. Histogram being related to concentration fraction of resin in the output of chamber.

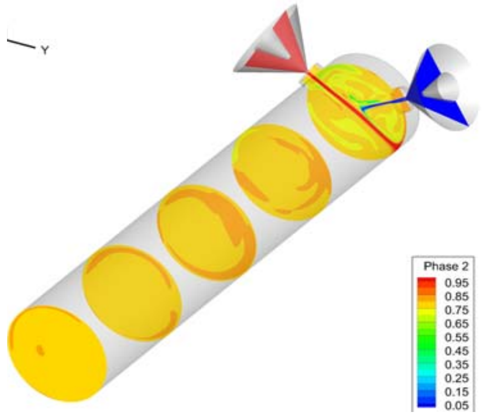

Figure 5. Contours of void fraciton for resign phase (Phase 2) in differetn position in mixing head; Mixing ratio and nozzle diameter are 100:35 and 0.3mm, respectively.

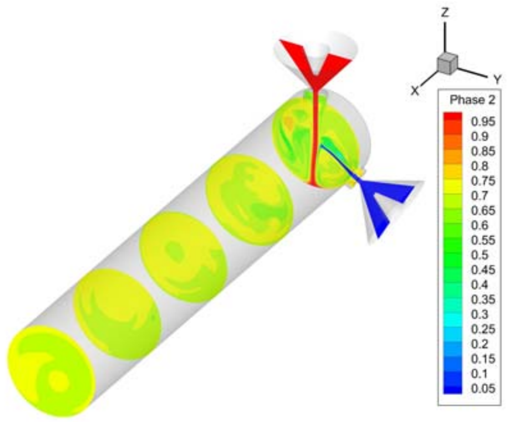

Figure 6. Contours of void fraciton for resign phase (Phase 2) in differetn position in mixing head; Mixing ratio and nozzle diameter are 100:35 and 0.45mm, respectively.

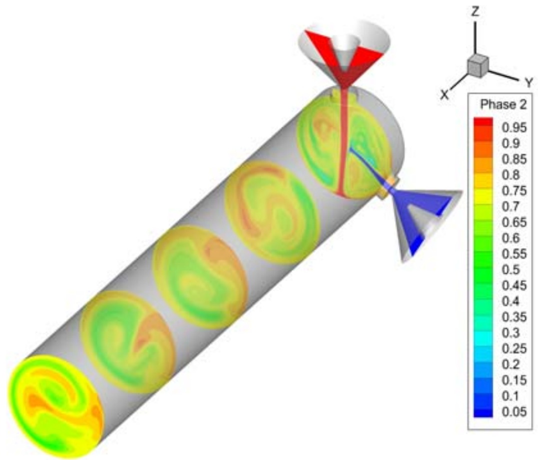

Figure 7. Contours of void fraciton for resign phase (Phase 2) in differetn position in mixing head; Mixing ratio and nozzle diameter are 100:35 and 0.6mm, respectively.

To focus more on the effect of nozzle diameter on mixing quality, three nozzles with different diameters are counsidered. The diameters are 0.3mm, 0.45mm and 0.6mm, respectively. Figure 5 shows the void fraction of resin in different positions in mixing head for nozzle with diameter fo 0.3mm. In this case the mixing ratio is 100:35. As it is shown, the the mixing process is done well and at the outlet we can see approximately homogenious mixing. For the case with nozzle diameter of 0.45mm, Figure 6 is provided. As it is shown, the quality of mixing decrease and at the end of mixing head, the mixture is not homogeneous. With increase og nozzle diameter to 0.6mm, the mixing quality reaches a poor point and the inhomogenious mixing covers the outlet. This fact is obvious in the results of Figure 7.

The nozzle size has a great effect on the mizing quality. Because the with decreaseing of nozzle diameter, the jet velocity increases and shear stress in mixing layer increases notably. Furthermore, the strength of vortices in mixing head will be more dominant and it is expeted to have a appropriate mixing quality at the outlet of mixing head. To illustrate the mixing process quantitavely, Figure 8, Figure 9 and Figure 10 are provided. These figures show the histogram of volum fraction at the outlet of mixing head for nozzle diameter of 0.3mm, 0.45mm and 0.6mm, respectively. As it is shown in Figure 8, the concentration of histogram is in a thin range (~0.78-0.8) and it shows the uniformity of mixing at this section.

However, with increasing of nozzle diameter to 0.45mm (Figure 9) the range of histogram extends, which shows the loss of homogenious in mixing fluid. Also, Figure 10 shows the range of mixing is between 0.48 and 0.86. This represents the poor quality of mixing for this case of study and a wide range of void fraction would be available in the outlet of mixing head.

4. Conclusion

In this study, the mixing process of two distinct flow was numerically modeled. Two flow with different physical properties (resin and hardener) were mixed through the opposing mixing jets. The RANS was applied to model the flow inside the chamber. Furthermore, SST *k*-omega turbulence model was chosen to predict the kinetic energy of flow in impingement zone. The results illustrate that mixing of two distinct flows would be efficient if the velocity of two jet is quite high. This can be achievable by decreasing of nozzle diameter. Finally, the histogram of void fraction of resin was considered in order to show the quality of mixing and the range of void fractions in the output of chamber.

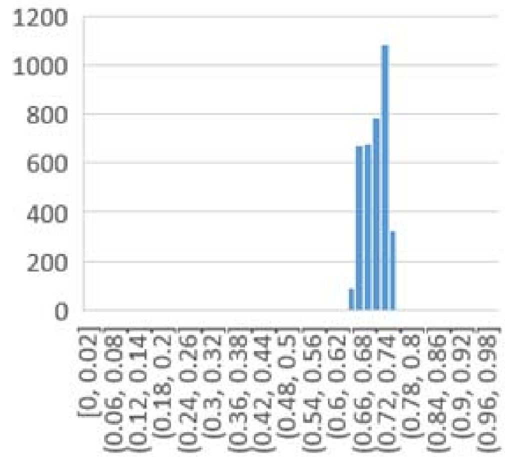

Figure 9. Histogram of void fraciton for resing ar the outlet of mixing head; the mixing ratio and nozzle diameter are 100:35 and 0.3mm, respectively.

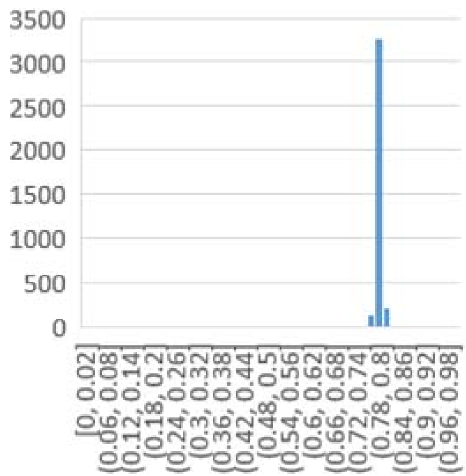

Figure 8. Histogram of void fraciton for resing ar the outlet of mixing head; the mixing ratio and nozzle diameter are 100:35 and 0.3mm, respectively.

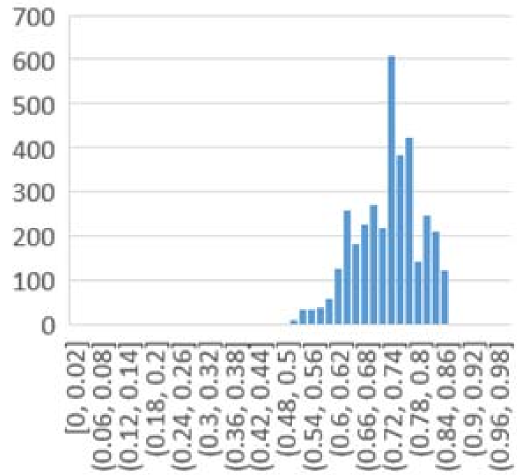

Figure 10. Histogram of void fraciton for resing ar the outlet of mixing head; the mixing ratio and nozzle diameter are 100:35 and 0.3mm, respectively.

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