Study on the Gas-Liquid Mixing System by Using Ejector
이젝터를 사용하는 기-액 혼합시스템에 관한 연구

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Key Words : 혼합 시스템(Mixing System), 기-액 이젝터(Gas-Liquid Ejector), 전산유체역학(CFD)

Abstract : 산업공정에서 널리 사용하는 반응기는 성질이 상이한 물질을 혼합하는 시스템으로서 본 연구에서는 이젝터(ejector)에 의한 반응기의 개발을 수행하였다. 액체-가스 이젝터는 구동유체에 의하여 기체가 흡입되면서 각종 유해가스를 제거하는 목적 또는 기체와 액체의 혼합 등 목적으로 사용된다. 본 실험에서 액체구동 가스혼합반응기의 실험 장치를 구축하고 이젝터 내부의 유동패턴과 기체용해도 자료를 도출하며 고효율 이젝터 설계를 위한 진공도 측정과 디퓨저 각도가 다른 이젝터의 실험 및 수치해석을 수행하였다. 이젝터의 성능은 흡입 측에서의 진공압력으로 평가되며 이 진공압력은 이젝터의 노즐 설계 및 유동조건에 의하여 결정되므로 이에 대한 기본적인 특성 도출이 선결되어야 한다. 순환유체의 유량이 70LPM, 80LPM 90LPM조건에서 두 가지 디퓨저에 대하여 비교실험을 수행하였다. 실험적 연구와 수치해석연구를 통하여 혼합성능과 이젝터의 내부유동특성에 대하여 고찰한 결과 디퓨저의 각도가 5.0도일 때 진공도가 더욱 높으며 구동액체의 유량이 작을 때는 진공도차이가 크지만 유량이 증가함에 따라 진공도 차이가 감소된다. 구동액체의 유량이 증가할수록 용존산소농도는 증가하며 디퓨저의 각도가 5.0도일 때는 용존산소농도가 더 높게 나타나는 것을 확인할 수 있었다.

1. 서 론

In chemical process industry, efficient gas-liquid contacting is essential in processes such as hydrogenation, chlorination, etc. Gas-liquid interfacial mass transfer often controls the overall production rate of gas-liquid reactor. High intensity gas-liquid mixers, like static mixers, rotor stator and ejector are increasingly used as a primary gas dispersion device in gas-liquid reactor. These high intensity mixers can improve the mass transfer rates by generating small bubbles, which are then injected into a reaction vessel, thereby improving the mass transfer characteristics of the entire system.

A typical example of such a gas-liquid reactor is the Loop Venturi Reactor. In this reactor type the gas phase is initially dispersed in the ejector section. These reactors have frequently been recommended for processes where gas-liquid interfacial mass transfer was the rate-controlling step of the process. Due to their favorable mass transfer and mixing characteristics, ejectors are being increasingly used in the chemical and biochemical industries[1~2].

Many multiphase contacting devices have been described. They can be roughly classified into three groups: Mechanically stirred tanks or columns in which a phase is dispersed using the mechanical power supplied by one or several impellers; gas-driven reactors in which power is mainly by the gas phase; these include first pneumatically-agitated reactors, such as bubble columns and airlift reactor in which the liquid is the continuous phase and for which power from gas compression, expansion; they include also packed columns in which the gas constitutes the continuous phase and for power supply derives

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from the kinetic energy of the gas; liquid-driven reactors in which the mechanical for dispersion is obtained from the kinetic of the liquid phase[3].

Loop reactors represent a very attractive alternative technology for gas-liquid system. A typical loop reactor consists of a vessel, an ejector and a circulation loop equipped with a pump. The benefit of the loop reactor is efficient gas-liquid mass transfer which is accomplished with the ejector. Typically no mechanical agitation is needed.

In order to achieve the best performance of the reactor system, mathematical modeling is necessary. An appropriate model for the loop reactor should be fulfill at least the following requirements: the reaction kinetics should be described in a realistic, the non-idealities of the flow pattern should be included and the dynamic characteristics of the reactor should be a vital part of the model[4].

Jet loop reactor with two phase flow has found various applications within areas such as fermentation and wastewater treatment or chemical reaction. In this research we focus on the effective gas-liquid mixture. The dissolved oxygen concentration will be reach to saturated state so when circulate it continuously is insignificant. Therefore, set the initial condition at 0.1 ppm by put some Na_2SO_3 in the working fluid.

To reach high efficiency it is necessary to establish quantitative relationship between geometry of the ejector, the operating conditions and the performance of the ejector.

Ejector is a device utilizing the kinetic energy of a high velocity liquid jet in order to entrain and disperse the gas phase. In the gas-liquid reactor the main part is ejector. A standard ejector consists of a nozzle, throat, gas suction chamber, mixing tube and diffuser. Liquid is supplied to the ejector via nozzle and the fast liquid jet produced by the nozzle entrains and disperses the gas.

The reactor simple in design and requires no extra compression device for dispersion of the gas dispersion as the gas phase is sucked in and dispersed by the high-velocity liquid jet discharging through the ejector. The beneficial use of an ejector as a gas distributor in aerated towers has been highlighted the literature. The ejector provides high shear between the phases creating a fine gas-liquid dispersion, thereby giving smaller bubbles. In a word, ejector is a simple pump or compressor without moving parts.

The diffuser have influence on vacuum pressure and also significant for mechanical equipment convert the kinetic energy to the pressure energy. Many researchers had been trying to investigate about ejector performance with experimental and numerical analysis.

According to Witte[5], a so-called mixing shock occurs in the mixing tube. In the region of this mixing shock, the two-phase flow changes from jet flow into a homogeneous bubble flow and this flow pattern transition is accompanied by a sudden pressure build up. Behind this mixing zone both phases flow through the remaining part of the ejector homogeneously. When the gas-liquid flow stream leaves the ejector, a secondary dispersion of bubbles is obtained in the bulk fluid of the reactor vessel. According to Cunningham and Dopkin[6], the location of the mixing shock zone is a key point for the ejector performance. The optimum dispersion efficiency is achieved when the liquid jet breaks up just at the end of the mixing tube. If the jet disintegration occurs earlier, the flow of the homogeneous gas-liquid mixture through the remaining part of the mixing tube results in excessive friction losses. In the other hand, the mixing tube is too short, the jet does not break up and accordingly the momentum transport between the phases does not occur. As a result, the ejector efficiency in such a case strongly decreases. The occurrence of the jet break up and the position of the mixing shock zone in the mixing tube depends generally on the gas and liquid flow rates, on the ejector pressure drop and on its geometrical parameters (nozzle, diameter and length of the mixing tube, angle of diffuser). For given flow conditions, ejector design has to be optimized to provide maximum dispersion efficiency. Due to the sensitivity of the location of the mixing shock region to the flow conditions, the dispersion efficiency decrease significantly with the variations of the liquid flow rate. Numerous attempts have been reported in the literature at facilitating the jet disintegration and stabilizing the position of the mixing shock zone within a wide range of flow conditions, with the ultimate purpose of making the dispersion efficiency of ejectors less dependent on their working conditions[7,8].

In this research we focus on the effective gas-liquid mixture characteristics. Consider the dissolved oxygen concentration will be achieve to saturated state when circulate it continuously Therefore, we set the mass transfer at the initial concentration of oxygen at 0.1ppm according put some Na_2SO_3 in the working fluid. The same procedure was followed for different liquid volumetric flow rate and diffuser angles.

This paper conducted to investigate performance and mass transfer in the mixing system. Also investigate the hydrodynamics and mass transfer characteristics of gas-liquid ejector using CFD analysis. In order to approach optimize the geometry of gas-liquid ejector and other operating condition.

2. Experimental setup and method

A schematic diagram of the ejector and the experimental facility used is show in Fig. 1. As the working fluids used in this research were water and air as the secondary fluid, the gas and liquid phases mixing and dispersion created by mixing shock, resulted into much smaller bubbles. It will contribute to enlarge the contact area so that obtain expectative dissolution. The flow rate was controlled by the Rota meter. As the working fluids used in this research were water as motive fluid and air as secondary fluid, the assumption of incompressible flow was seems to be appropriate. The experiments were carried out in an acrylic column of 0.2m in diameter and 0.475m in height.

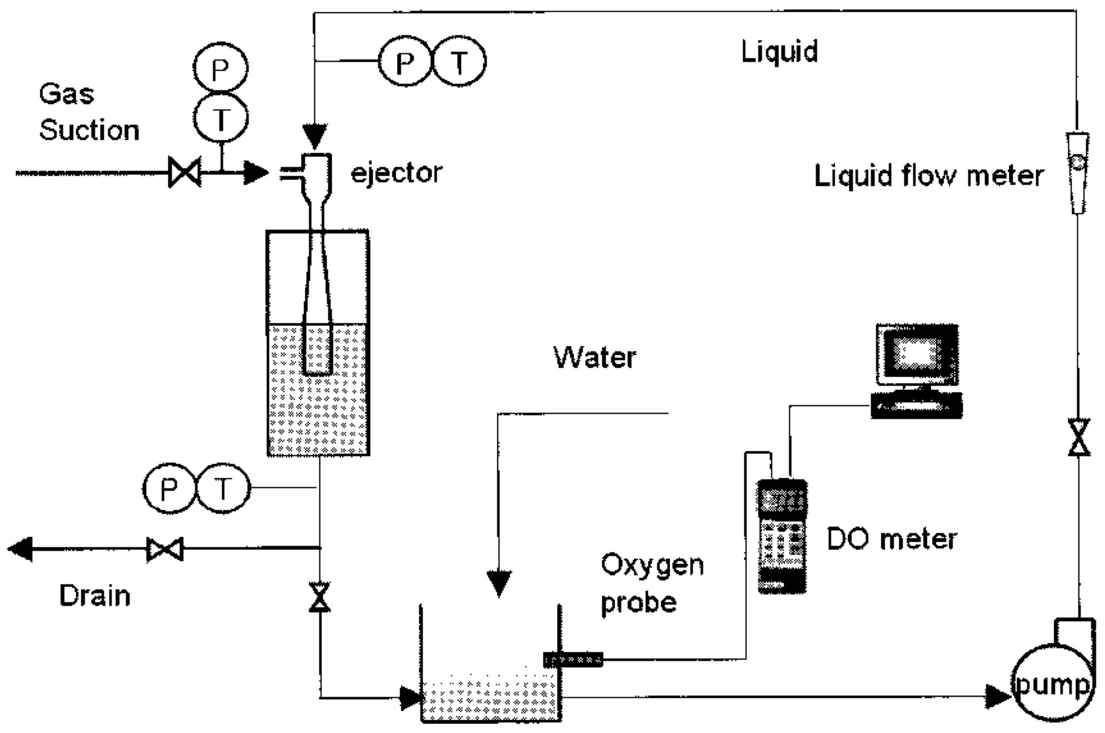


Fig. 1 Schematic diagram of mixing system

The volumetric gas-liquid mass transfer rates were calculated from the oxygen concentration in the liquid phase. Make following assumption. The gas flow is considered to be constant and a pure gas is supplied.

3. Experimental results and discussion

Fig. 2 shows the vacuum pressure for different diffuser angle. When diffuser angle is 5.0degree the vacuum pressure is higher and when the flow rate of liquid is low, the vacuum difference is large but the vacuum difference came to narrow with the flow rate increases. Therefore, it was meant that the flow rate increasing insignificant on vacuum pressure.

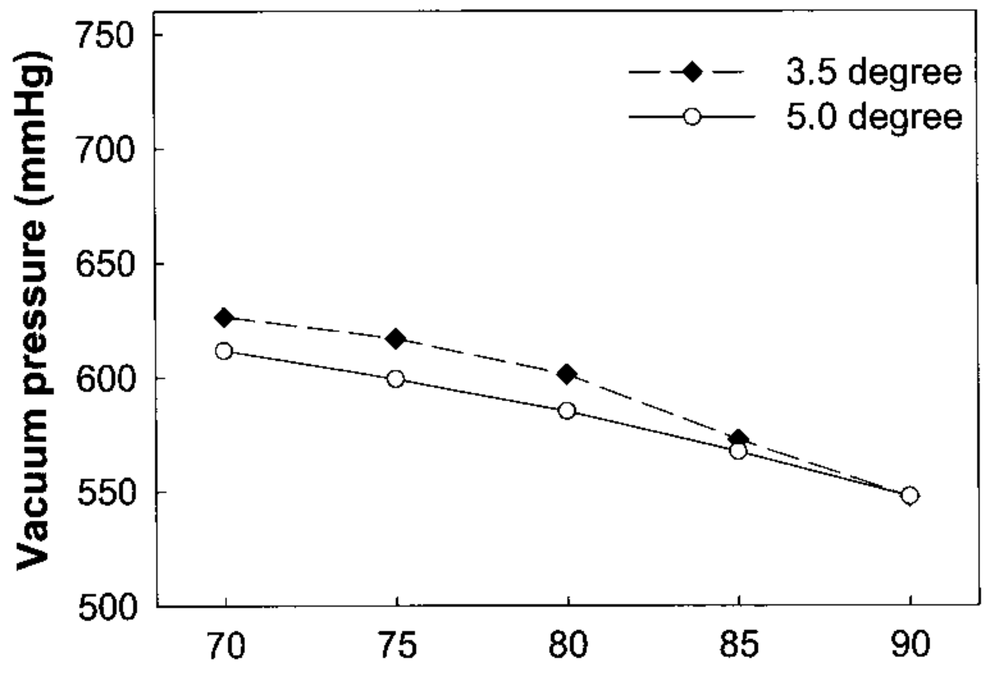


Fig. 2 Distribution of vacuum pressure for different diffuser angle

Fig. 3 and Fig. 4 shows the effect of flow rate and diffuser angle on the two phases mixing. Compare the results at various flow rate of operating condition, it can be seen that the dissolved oxygen is quite high with increasing of flow rate at the both case. However at the same flow rate of working fluid, the dissolved oxygen is higher when diffuser angle is 5.0degree but the difference is decreasing.

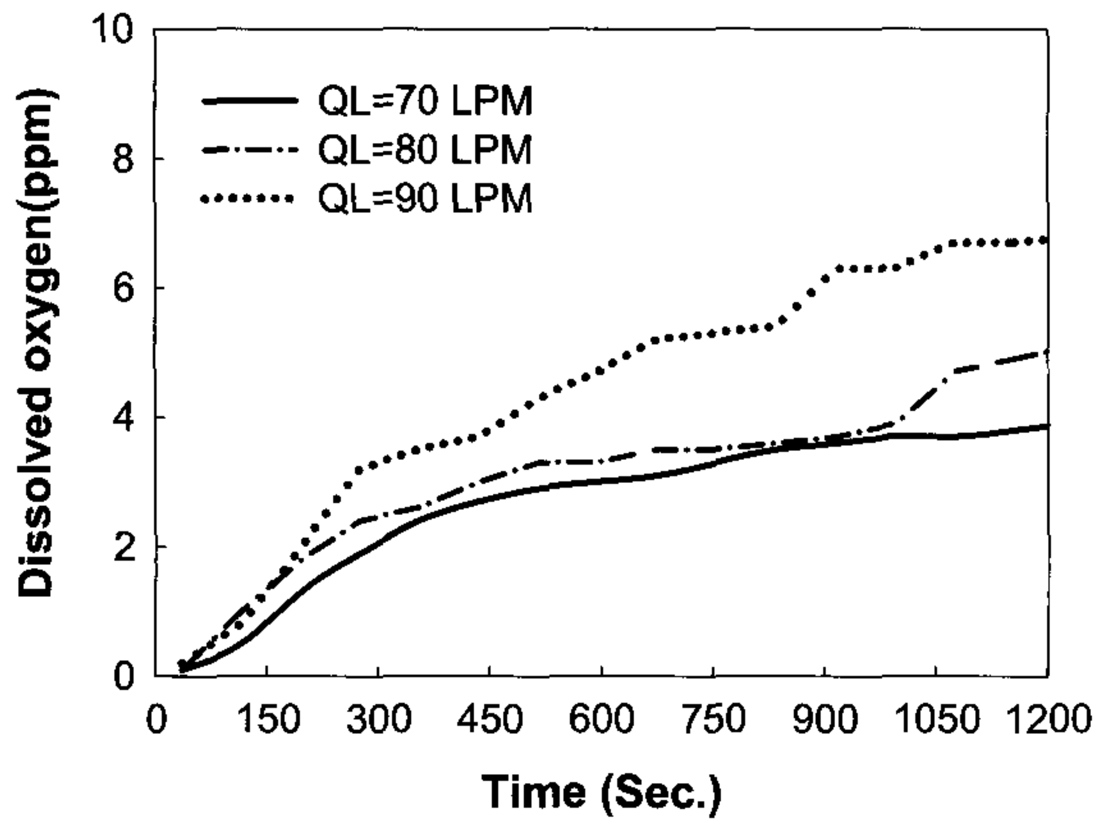


Fig. 3 Variation of dissolved oxygen at Θ=3.5°

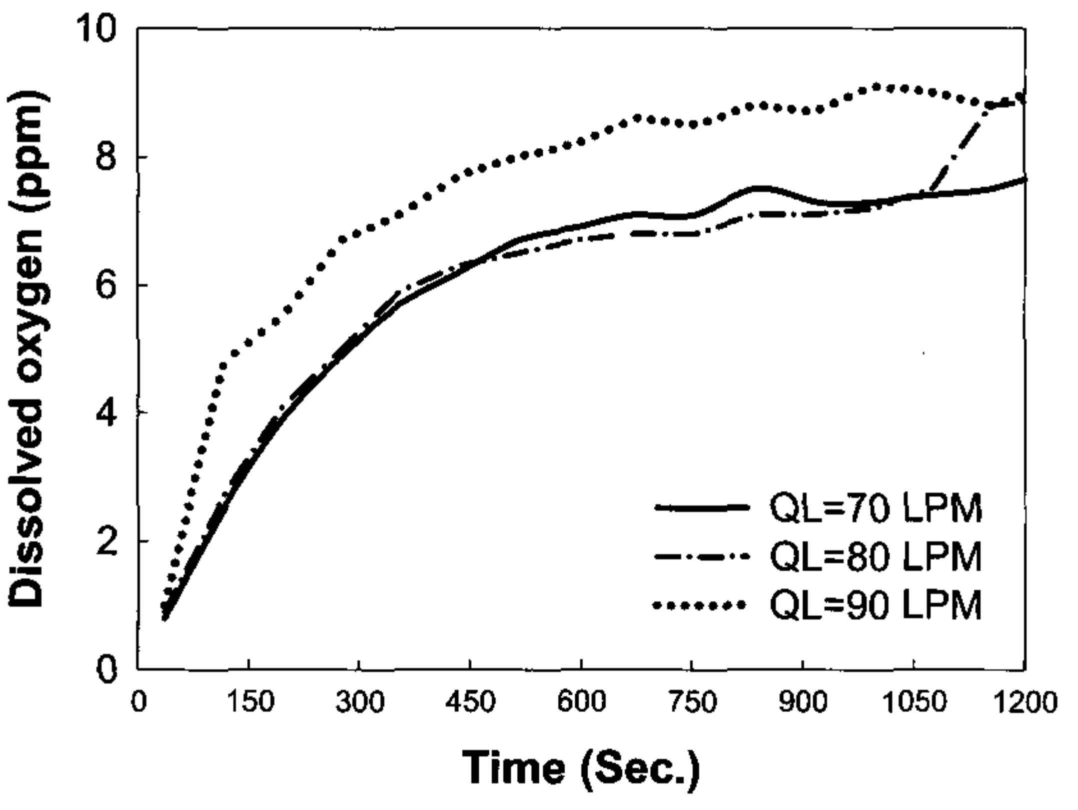
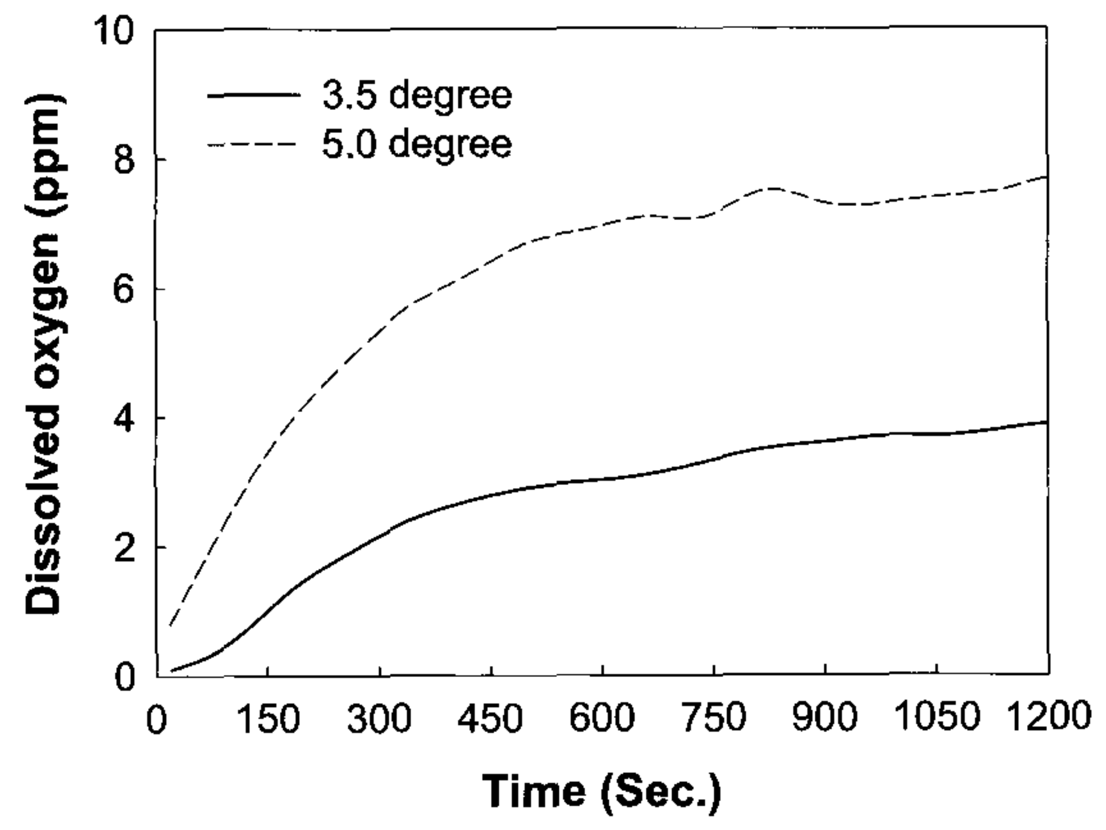


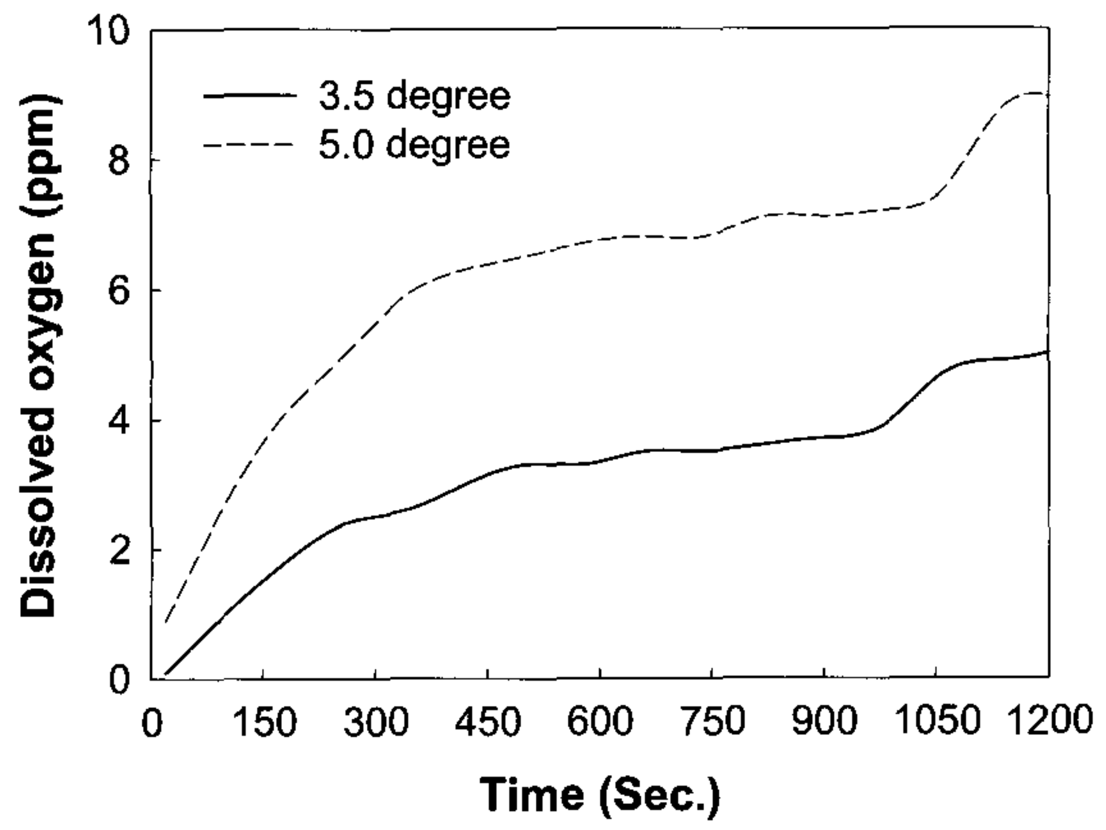
Fig. 4 Variation of dissolved oxygen at Θ=5.0°

Fig. 5 shows the influence of diffuser angle on the two phases mixing at the same flow rate of working fluid. It can be seen that, the dissolved oxygen is higher with increasing of diffuser angle in each case.

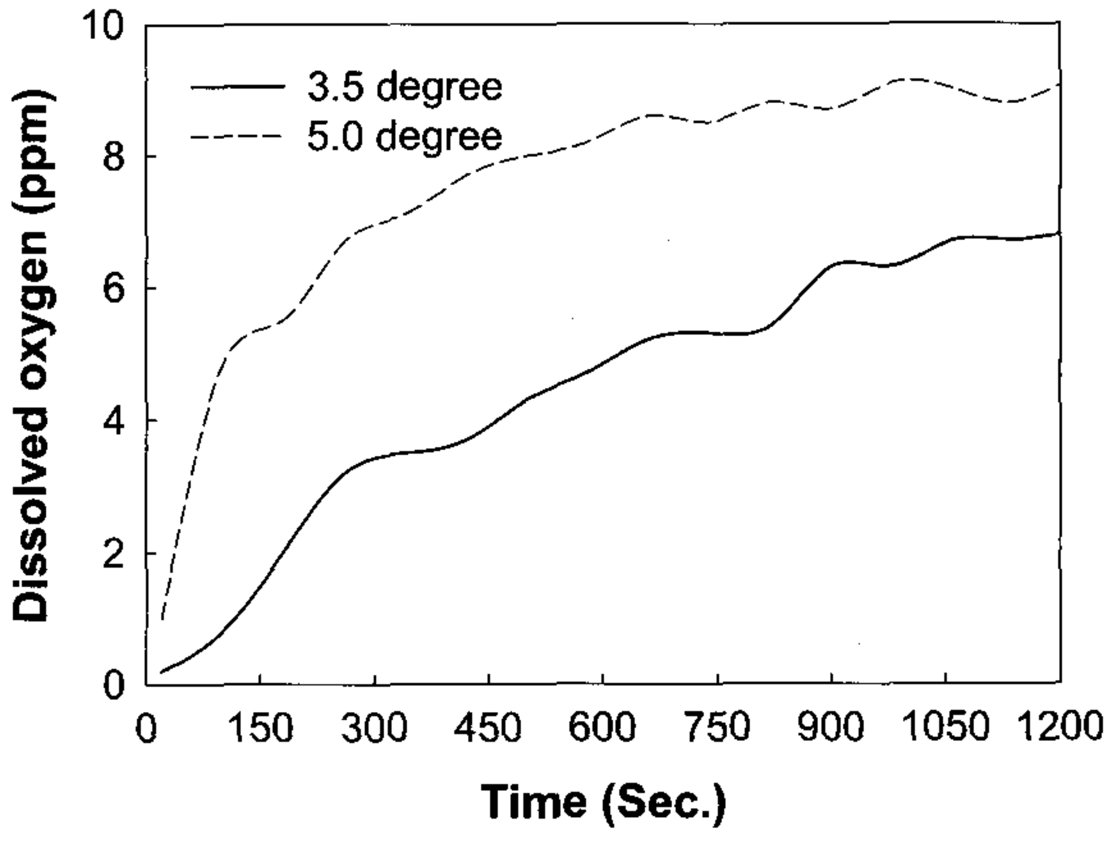
As we know pressure and temperature is significant parameter on the dissolved oxygen rate. The dissolved oxygen decreases with increasing of temperature and increase with increasing of pressure. The reason is water have regular molecular structure so if the temperature is rising will be resulted in vivacious molecular motion. Consequently the oxygen went out from water then the oxygen quantity decreasing. Therefore for each test the experiment were started at the initial condition of 293K of ambient temperature and atmosphere pressure.



(a) Q_L=70LPM



(b) Q_L=80LPM



(c) Q_L=90LPM

Fig. 5 Distribution of dissolved oxygen for various flow rates

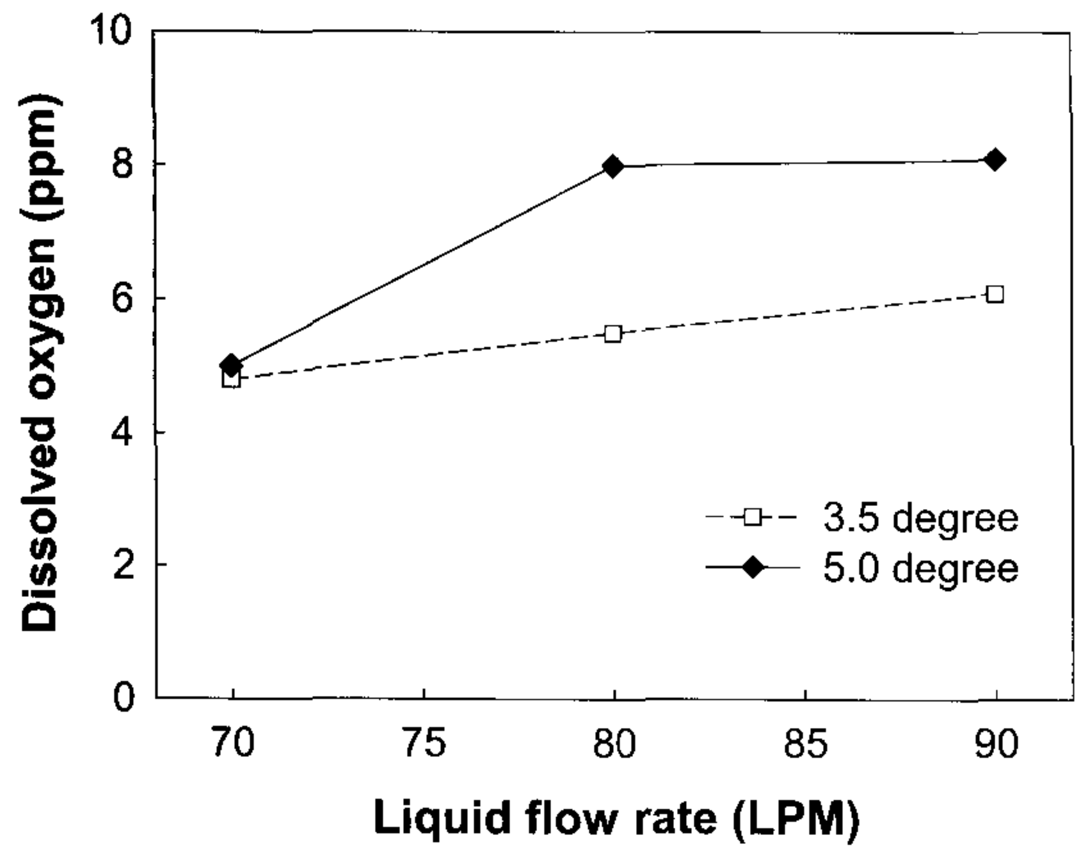


Fig. 6 Comparison of the DO between two models

Fig. 6 shows the ultimate dissolved oxygen concentration in the working fluid. It seems clearly that the performance of diffuser angle is 5.0 degree is better. However at the lower flow rate the concentration is similar but with increasing of flow rate the difference will came to large. In the 5.0degree case with increasing of flow rate the difference of DO did not have influenced much by flow rate.

As shown above the results indicate that the dissolved oxygen gradient was increase with increasing of flow rate of working fluid and diffuser angle.

4. Numerical analysis

Recently, with the rapid development of numerical solution method, many researchers attempted to apply Computational Fluid Dynamics (CFD) in modelling the flow in the ejectors. The merits of using CFD approach is the capability on producing details the flow field and at any given operating conditions or model geometry can be simulated for extensive analysis of the flow related properties.

If the research only depends on experiment the setup was too expensive considering the cost and it will be take long time also, so that some times it is inefficient for research. In the other hand, the numerical analyses enable to predict and provide data that is difficult to obtain in experimental method.

Anyone wish to use CFD in a serious way must realistically that it is no substitute for experiment, but a very powerful additional problem solving tool. Validation of a CFD code requires highly detailed information concerning the boundary conditions of problem. To validate these in a meaningful way it is necessary to produce experimental data of similar scope.

4.1 Model and boundary conditions

The numerical analysis directed towards modelling the same ejector geometry used in experiments in order to compare results. Fig. 7 shows the basic shape of ejector used in CFD analysis. The grid generate shown in Fig. 8.

The governing equations are solved using the commercial CFD (Computational fluid dynamics) program STAR-CD. Atmosphere state was applied into initial pressure condition and flow split applied to diffuser outlet. Pressure boundary conditions were applied to experimental pressure value.

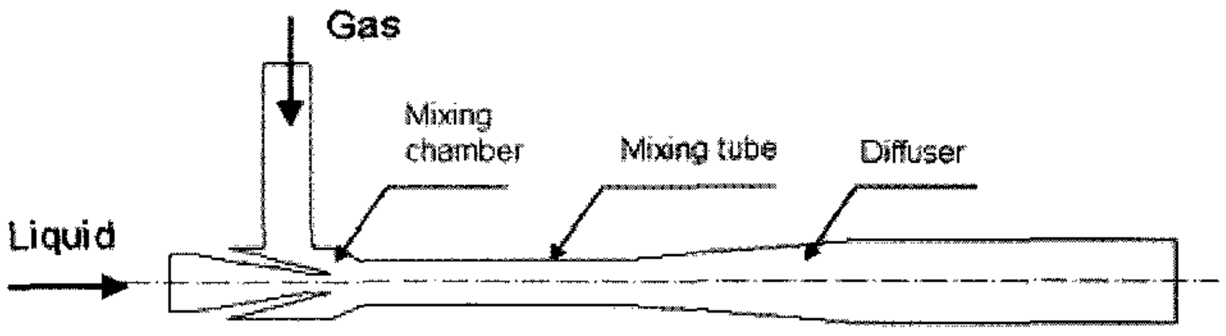


Fig. 7 Schematic diagram of ejector model for numerical analysis

The terms of computation were steady state and incompressible flow. Turbulent model was use standard $k-\varepsilon$ High Reynolds Number model. Use SIMPLE algorithm and upwind scheme. Maximum residual tolerance was set under 0.0005.

Fig. 8 Grid generation of ejector model

The ejector configuration used in the present study had a mixing tube diameter of 22mm and diffuser outlet diameter of 40mm (i.e. diffuser angle of 3.5 and 5.0degree). The nozzle diameter used was 8.5 mm. The mixing tube lengths were varied 70 LPM, 80 LPM, 90 LPM, respectively.

Table 1 Analysis conditions

Parameter	Value
Mixing tube length	120 mm
Mixing tube diameter	22 mm
Diffuser angle	3.5°, 5.0°
Nozzle size	Φ 8.5
Volumetric flow rate(Q_L)	70LPM, 80LPM, 90LPM

4.2 Results and discussion

Fig. 9 shows the pressure along the centerline of ejector for various flow rates. For pressure boundary conditions were applied to experimental pressure value. With an increase in the flow rate the two phase pressure drop decreases. It was obviously at the nozzle can get lower pressure with higher flow rate. Fig. 10 shows the comparison between two ejector models when flow rate was 90LPM.

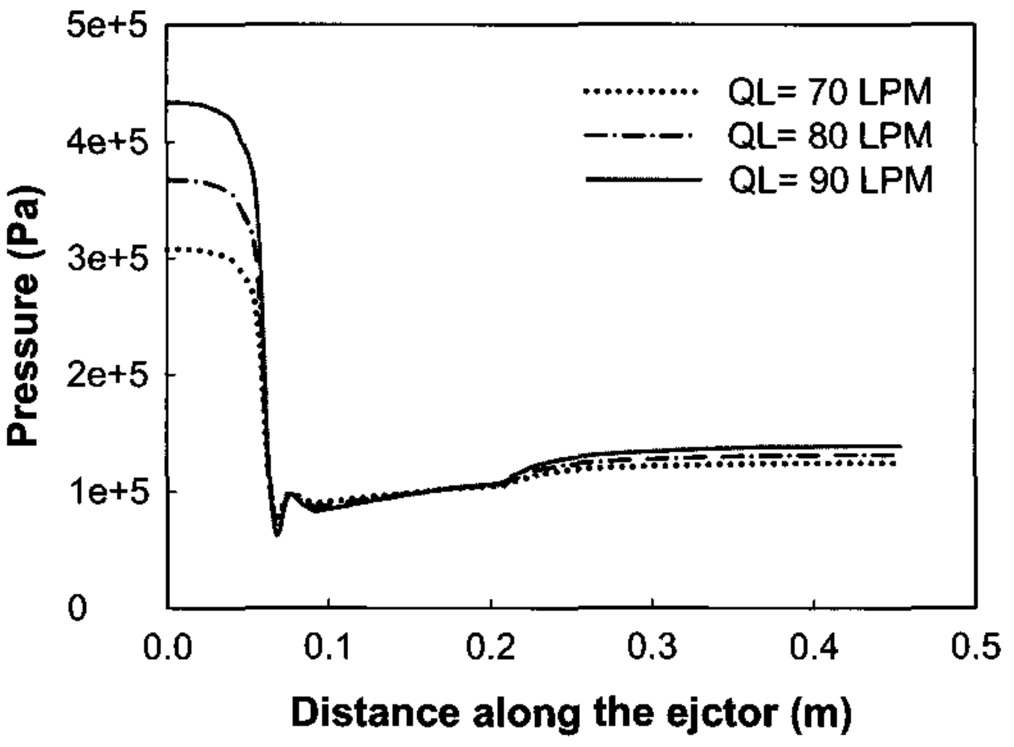


Fig. 9 Pressure along the ejector for various flow rate

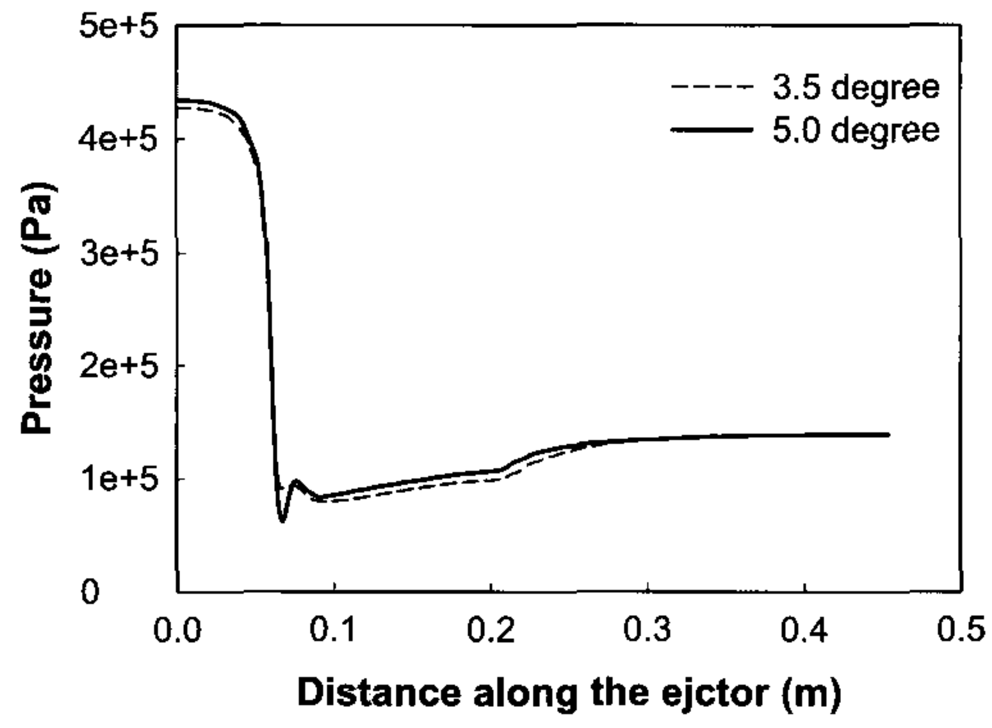
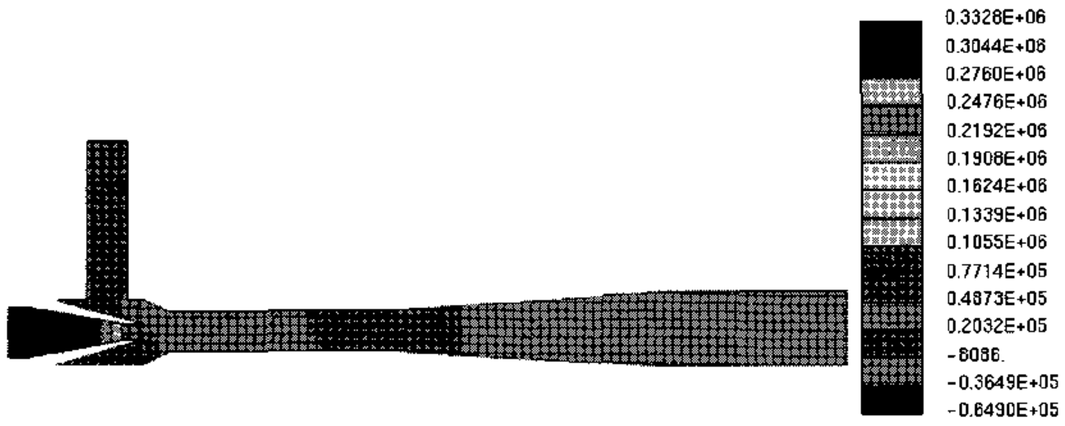
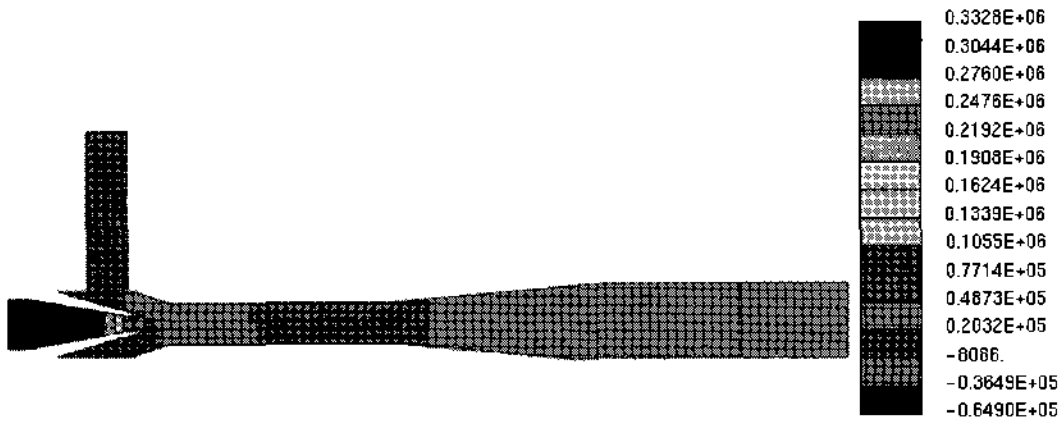


Fig. 10 Comparison of pressure between two models Q_L=90LPM

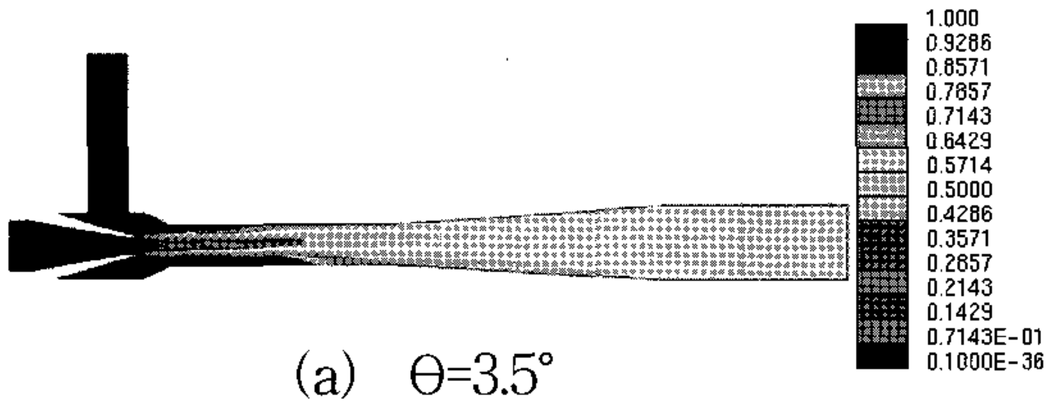


(a) Θ=3.5°

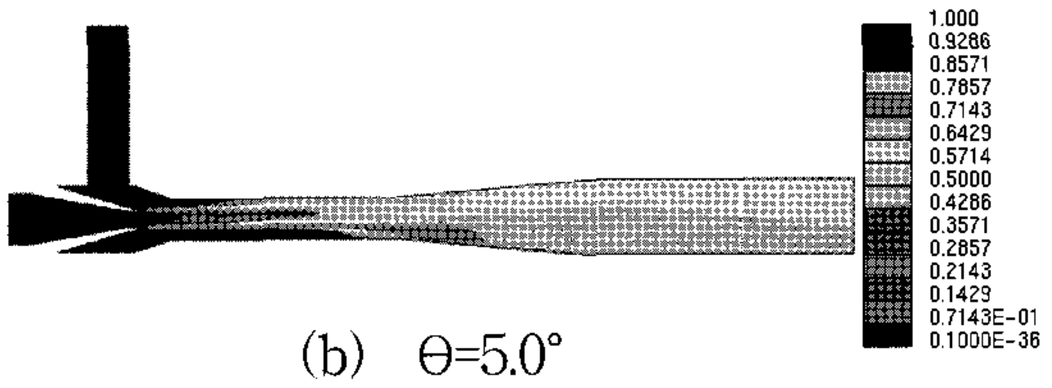


(b) Θ=5.0°

Fig. 11 Contour pressure along the ejector at Q_L=90LPM



(a) Θ=3.5°



(b) Θ=5.0°

Fig. 12 Air fraction along the ejector at Q_L=90LPM

Fig. 11 shows the contour pressure along the ejector by numerical process. Fig.12 shows the air fraction along the ejector when the high kinetic energy produces local low pressure zones resulting in entrain and disperse gas phase. Red color means air and blue means water. Two phase flow through the nozzle, mixing tube and diffuser get mixed.

5. Conclusions

This paper describes a basic background and development of a gas-liquid ejector and its application in the reactor system. At this moment, it can be said that the understanding in gas-liquid reactor system theory has not been completely cleared. Now many researchers try to make new assumptions on mixing and flowing characteristic and applied on the computer simulation analysis. Also try to compare with experimental results then investigate the mass transfer flow characteristics and characteristics of the reactor so that improve the efficiency.

Gas-liquid ejector is the critical component of reactor system. The system efficiency is not only depends on the system operating conditions, but also the ejector configuration has a significant effect. From experiment and numerical analysis results can be summarized as follows:

When diffuser angle is 5.0degree the vacuum pressure is higher and when the flow rate of liquid is low the vacuum difference is large but the vacuum difference come to narrow with the flow rate increases. The dissolved oxygen is increases by increasing of flow rate at the both case. However, at the same flow rate of working fluid, The dissolved oxygen concentration is higher when diffuser angle is 5.0degree but the difference is decreasing. With an increase in the flow rate, it reached lower pressure at the nozzle.

The major purpose of using gas-liquid ejector is to increase mass transfer and efficiency. It is most desirable to design a device or select an operating condition. For this object more of knowledge and reasonable estimates are needed.

According to the results of the numerical analysis and experiment we can expect approach to more excellent mixing performance due to use bigger vessel to extend the contact time of gas-liquid two phases. In addition, we have plan try to approximate from other way, for instance import other geometrical parameters and operating conditions such as nozzle diameter, flow rate.

It is suggested that further studies should focus on quantitative study of the bubble size, bubble breakup and coalescence mechanisms in gas-liquid mixing system.

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