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CFD Simulation for Compact Inline Contactor for Separation of CO_2 from Natural Gas

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Abstract: An investigation of the selected geometry for Compact Inline Contactor (CIC) has been carried out to study the effect of geometry on the pressure drop and mass transfer rate. Ejector type geometry has been selected and two-dimensional (2D) surface has been created for gas-liquid study using CFD approach. Operating condition is maintained by using constant value for inlet pressure and flow-rate for both gas and liquid. The length of diameter ratio of mixing tube (L_m/D_m) was varied from 5, 6 and 7. At L_m/D_m = 7, pressure recovery is found to be faster than other L_m/D_m ratios. However, at L_m/D_m = 5, mass transfer rate profiles is better than others.

Key words: Natural gas, offshore operating, gas-liquid ejector

INTRODUCTION

Natural gas has played a vital role in the world's energy supply and it has contributes in many applications. Natural gas is considered as the cleanest, safest and most useful energy sources as compared to other fossil fuels. It emits lower level of potentially harmful unwanted by-products when burned to form energy (Faiz and Al-Marzouqi, 2011). However, natural gas found from reservoir is not necessarily clean and free from impurities. It contains largely methane (CH_4) as a main component but it also contains considerable amount of light and heavier hydrocarbon as well as contaminating compound of carbon dioxide (CO_2), nitrogen (N_2), mercury (Hg), helium (He), hydrogen sulfide (H_2S), etc.

The natural gas obtained from the well have different range of composition depending on several factors such as type, depth and geographical location of the underground reservoirs of porous sedimentary deposit and the geology of the area (Shimekit and Mukhtar, 2012). In Malaysia, most natural gas reserves contain 50-74 mol% of CO_2 which is very high and has posed great challenge to the application of CO_2 separation technology at offshore operation (Ahmed and Ahmad, 2011).

CO_2 need to be removed from Natural Gas (NG) to protect the natural gas pipeline and maintain the heating value for NG. Due to limited space available at offshore environment, conventional separation approaches (e.g., cryogenic distillation, absorption, etc.,) are inappropriate to be employed at this condition. Hence, compact technology is substantial to remove CO_2 from NG at minimum footprint.

Various technologies have been applied in the downstream gas processing plant to remove CO_2 from natural gas. However, for offshore operation, the conventional absorption and adsorption technologies are found to be unsuitable since these technologies require significantly larger footprint and tonnage (Darman and Harum, 2006). Besides, substantial power consumption required by cryogenic separation also hinders the employment of this technology in offshore CO_2 separation. For CO_2-NG membrane separation, the utilization has been limited by the issues related with significant hydrocarbon losses and high pre-treatment requirement (Davison and Thambimuthu, 2004).

Thus, a new hybrid solution, namely Compact Inline Contactor (CIC), is proposed to enhance the absorption process of CO_2 from natural gas. CIC study, similarly as a gas-liquid ejector, can provide interfacial area and mass transfer coefficient at least one or two orders of magnitude higher than conventional gas liquid contactor (Yue *et al*., 2007; Stone *et al*., 2004).

The overall process of CIC is illustrated in Fig. 1. CIC allows CO_2-natural gas mixture to pass through the contactor with CO_2 lean solvent. The CO_2 in the natural gas will be absorbed in the CIC while producing a CO_2 rich solvent stream and a CO_2 lean natural gas stream. The CIC offers sufficient surface area and residence time for mixing and adsorption process while maintaining lower pressure drop and footprint.

CIC is better than conventional tower absorption process since it requires smaller footprint and tonnage, contributed by its higher surface area per volume design. In addition, it can also be applied at offshore

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operating pressure (up to 70 bar) whic avoids the reduction of feed pressure as required by membrane contactor.

CFD modeling: Many of studies have been conducted by researchers in order to find new technology for CO_2 and natural gas separation. Some of them are involved in simulation using Computational Fluid Dynamics (CFD). CFD is an efficient tool for calculating flow conditions, pressure drop and temperature profiles for single phase or multiphase. Several commercial programs are being used for absorption and desorption studies such as Fluent ® and CFX®. An optimistic aim for CFD modelling at absorption and desorption is to contribute to a complete detailed and quantitative description of the absorption and desorption process in self constructed geometry (Oi, 2010).

In this study, improvement in absorption technology for CO_2-natural gas is studied. ANSYS Fluent is chosen to use in this study and it is very helpful and provides low cost study of optimization work for absorption CO_2-natural gas process.

Geometries and mesh: Compact Inline Contactor (CIC) is basically designed according to the geometry of gas-liquid ejector as its capability to produce higher mas transfer rates by generating small droplets of the dispersed phase, thereby, will improve the contact area between phases (Balamurugan *et al*., 2007). Ejector type configuration has capability to process in co-current flow system. Thus, simultaneous aspiration and dispersion of the entrained fluid takes place.

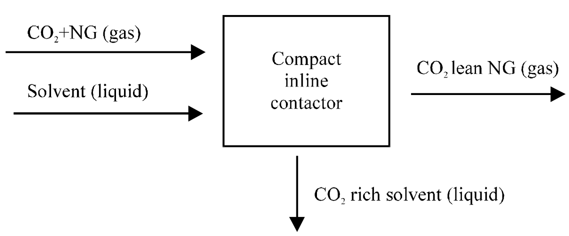

Fig. 1: Process of Compact Inline Contactor (CIC)

Gas-liquid ejector is operated according to the Bernoulli's principle. The motive liquid flows through the nozzle at high velocity and created a low pressure region just outside the nozzle. This phenomenon causes the second fluid get entrained into the ejector through this low pressure region (Balamurugan *et al*., 2007). Therefore, the dispersion of the entrained fluid in the mixing area of the ejector with the motive fluid jet flows simultaneously, lead to intimate mixing of the two phases.

Compared to other gas-liquid contacting systems like bubble columns and stirred tank, ejector provides higher values of volumetric mass transfer coefficient. Thus, ejector type contactor enables a substantial reduction in the size and has a great potential to form a compact system for absorption.

In this study, three different geometries of gas-liquid ejector were developed with different ratio of mixing tube length to diameter of mixing tube. The length of mixing tube is varied to 100, 120 and 140 mm while, the diameter of mixing tube is held constant at 20 mm. The ejector geometry is modeled using Design Modeler. Geometry of CIC is shown schematically in Fig. 2, which consists of nozzle, mixing tube, suction chamber and diffuser.

Case setup: The working fluids used in this study are water as primary fluid and mixture of methane and carbon dioxide as secondary fluid. The mixture gas is set to be in real gas condition at high pressure. The standard k-ε is used for turbulence model and the near wall treatment is set to the standard wall function.

Boundary condition: Boundary condition for liquid entering a primary nozzle and gas at gas inlet at the bottom and top of CIC were set as velocity inlets. The outlet face was set as pressure outlet. Velocity inlets were set at constant value and turbulent kinetic energy and dissipation rate were specified.

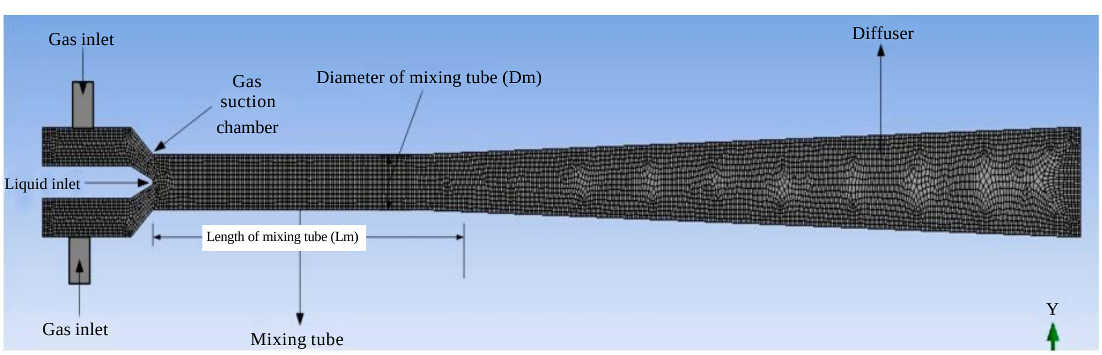

Fig. 2: Geometry and mesh of Compact Inline Contactor (CIC)

Calculation of mass transfer rate: Mass transfer rate is modeled and derived from the following equation:

$$W\left(\frac{mol}{s}\right) = \frac{4\pi D_{AB} P.r_s}{RT} \ln \frac{P - P_{A\infty}}{P - P_{AS}}$$

where, W is mass transfer rate for single droplet, D_{AB} is diffusivity coefficient for dilute liquid solution CO_2 in water, P is pressure of the system, r_s is the droplet radius, $P_{A\infty}$ is the pressure at bulk gas and P_{AS} is pressure at the surface of droplet.

RESULTS AND DISCUSSIONS

Influence of mixing tube length: Pressure distribution along the centerline of CIC at different L_M/D_M ratios: 5, 6 and 7 are shown in Fig. 3.

Figure 3 shows the pressure distribution at the centerline of CIC for different L_m/D_m ratios: 5, 6 and 7 at constant pressure and flow rate. Pressure started at high pressure and sudden pressure drop happened at the throat of the tube which is at the inlet of mixing tube. Pressure is slightly increases when the mixture flows along the tube. Pressure profiles are almost the same for any L_m/D_m ratios and only small difference existed between profiles. However, at L_m/D_m = 7, pressure recovery happened faster than other profiles. This may due to the less of mixing shock and flow is more stable in the longer tube. Therefore, the mixing tube length has some effects toward pressure distribution inside the tube (Fig. 4).

Figure 5 shows the profiles of mass transfer rate at the centerline of CIC for different L_m/D_m ratios: 5, 6 and 7 at constant pressure and flow rate. It is clearly illustrated that the mass transfer profile for all L_m/D_m ratios are almost

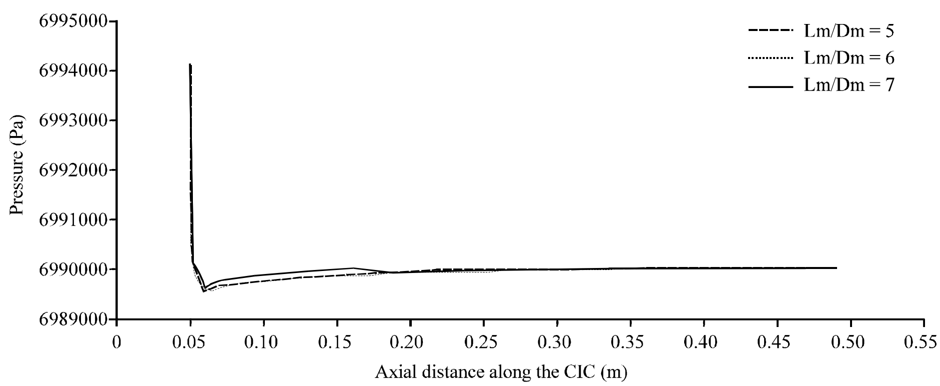

Fig. 3: Pressure profile along the centerline of CIC

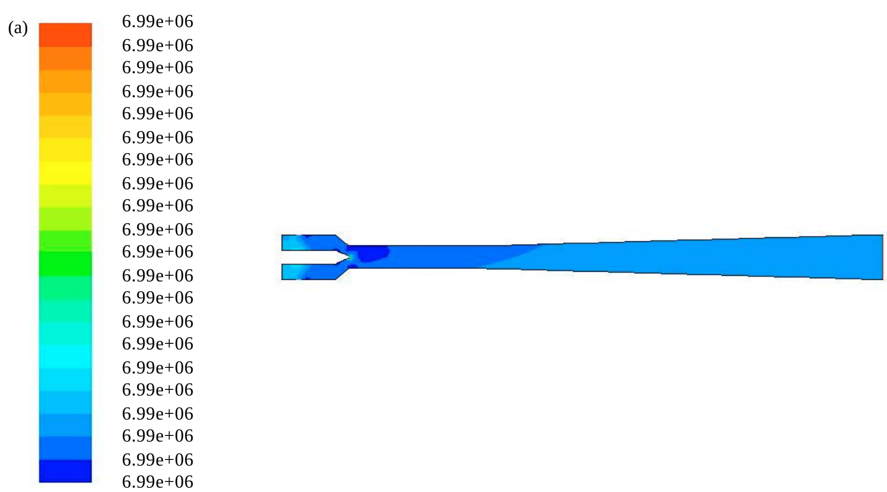

Fig. 4(a-c): Continue

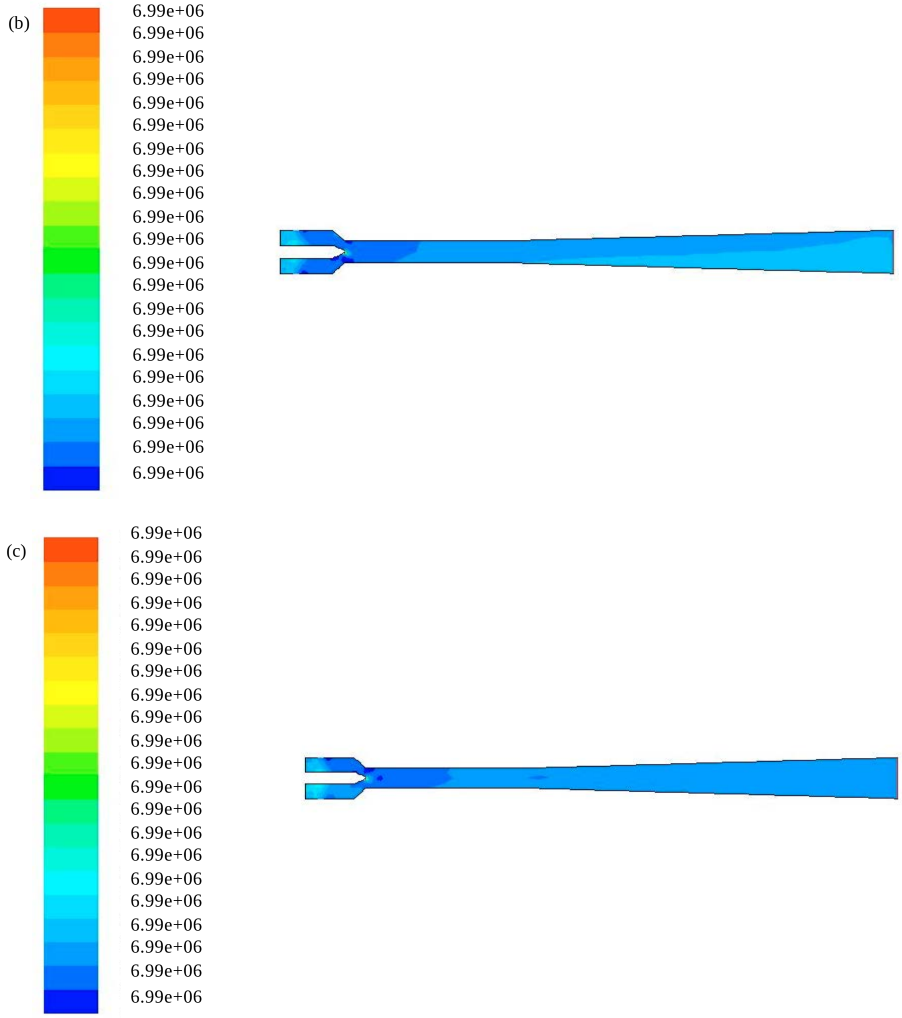

Fig. 4(a-c): Mass transfer rate at the centerline

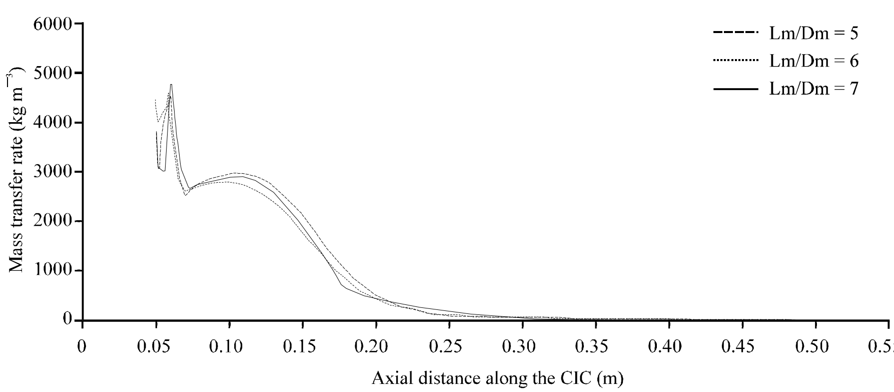

Fig. 5: Contours of pressure distribution inside CIC at different L_m/D_m ratios

similar. However, at $L_m/D_m = 5$, mass transfer rate is higher than other ratios starting from the entrance of gas and liquid mixture into the mixing tube (Fig. 6). This may be due to the better contact between phases and high

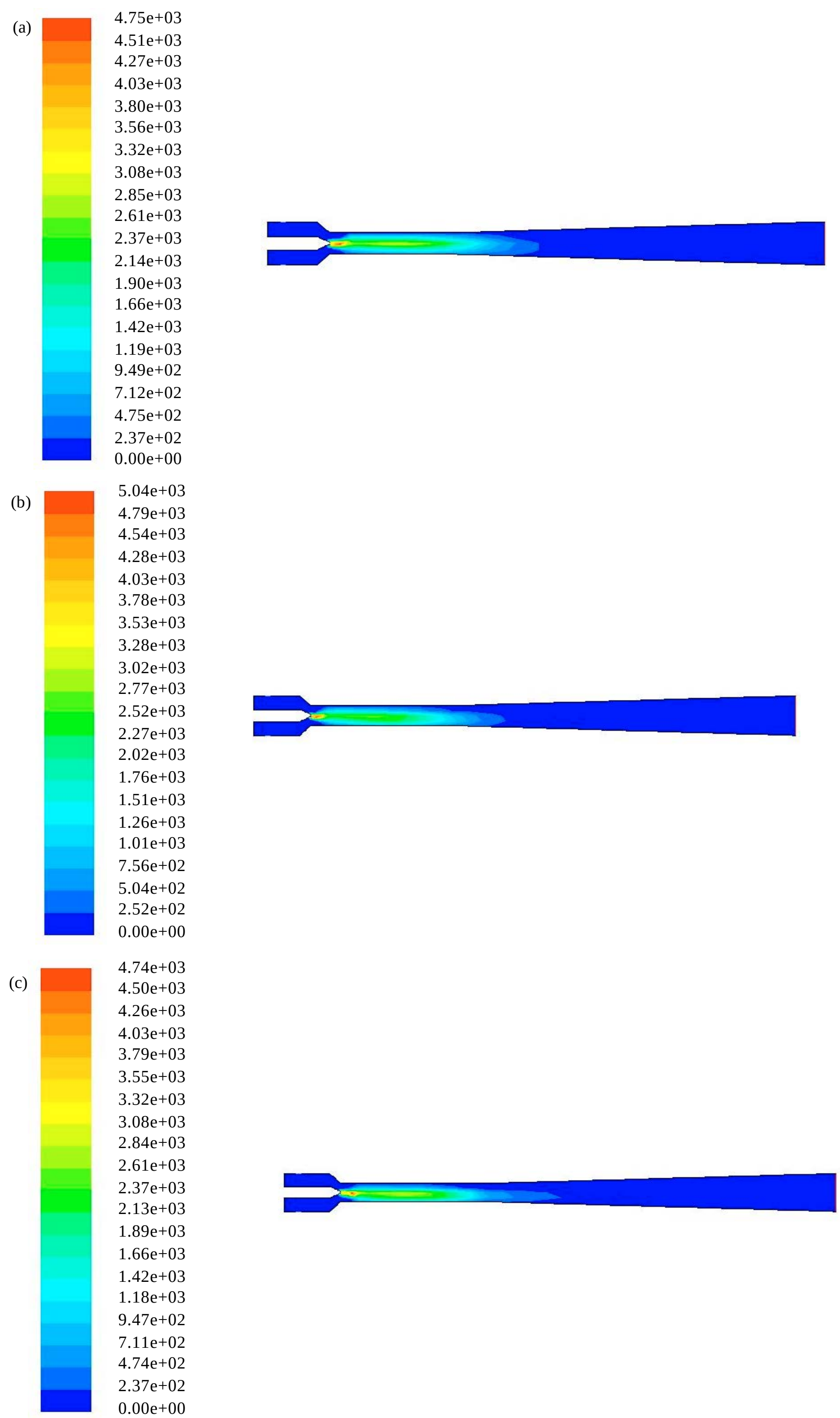

Fig. 6(a-c): Contours of mass transfer rate inside CIC at different L_m/D_m ratios dispersion energy at shorter mixing tube length. As the profile of shorter tube ends, the mass transfer rate profile for longer mixing tube will dominate. Mass transfer mostly happened at the mixing tube, thus the longer mixing tube give better continuity of mass transfer.

CONCLUSION

The present study shows that the length of mixing tube has some affects on the pressure profile and mass transfer rate along the tube. At L_m/D_m = 7, pressure recovered faster than other ratios due to less in mixing shock, more stable and smooth flow in longer mixing tube length. However, tube with L_m/D_m = 5 gives better mass transfer rate along the mixing tube due to better contact between phases and high dispersion energy at shorter mixing tube length. On the other hand, longer mixing tube length gives better profile in term of continuity of mass transfer process.

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REFERENCES

Ahmed, T.Y. and M.M. Ahmad, 2011. Flowsheet development and simulation of off-shore carbon dioxide removal system at natural gas reserves. Int. J. Chem. Environ. Eng., 2: 20-26.

Balamurugan, S., M.D. Lad, V.G. Gaikar and A.W. Patwardhan, 2007. Hydrodynamics and mass transfer characteristics of gas-liquid ejectors. Chem. Eng. J., 131: 83-103.

Darman, N.H. and A.R.B. Harum, 2006. Technical challenges and solutions on natural gas development in Malaysia. Proceedings of the 4th Workshop of the China-Sichuan Basin Case Study, May 30-June 3, 2006, Beijing, China.

Davison, J. and K. Thambimuthu, 2004. Technologies for capture of carbon dioxide. Proceedings of the 7th International Conference on Greenhouse Gas Control Technologies, September 5-9, 2004, Vancouver, Canada.

Faiz, R. and M. Al-Marzouqi, 2011. Insights on natural gas purification: Simultaneous absorption of CO_2 and H_2S using membrane contactors. Sep. Purif. Technol., 76: 351-361.

Oi, L.E., 2010. CO_2 removal by absorption: Challenges in modelling. Math. Comput. Modell. Dyn. Syst., 16: 511-533.

Shimekit, B. and H. Mukhtar, 2012. Natural Gas Purification Technologies-Major Advances for CO_2 Separation and Future Directions. In: Advances in Natural Gas Technology, Al-Megren, H.A. (Ed.). Chapter 9, InTech Publisher, Rejika, Croatia, ISBN: 978-953-51-0507-7, pp: 235-270.

Stone, H., A. Stroock and A. Ajdari, 2004. Engineering flows in small devices: Microfluidics toward a lab-on-a-chip. Annu. Rev. Fluid Mech., 36: 381-411.

Yue, J., G. Chen, Q. Yuan, L. Luo and Y. Gonthier, 2007. Hydrodynamics and mass transfer characteristics in gas-liquid flow through a rectangular microchannel. Chem. Eng. Sci., 62: 2096-2108.