CHEMICAL ENGINEERING TRANSACTIONS

VOL. 59, 2017

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Zhuo Yang, Junjie Ba, Jing Pan

ISBN 978-88-95608- 49-5; **ISSN** 2283-9216

DOI: 10.3303/CET1759003

On the Influence of Inlet Distortion on Syngas Compressor for Coal Chemical Industry

Yong Li, Hongtao Zhang

Zhengzhou Railway Vocational & Technical College, Zhengzhou 451460, China

767991413@qq.com

Based on numerical simulation and laboratory test, the radial distortion of air flow in a double inlet syngas compressor is analysed in this paper. The author also considers the compressor's mechanical response to homogeneous inflow, mixed inflow, and the length of mixing chambers. Finally, the feasibility of the numerical simulation is verified, drawing such conclusions: The efficiency and pressure rise of a compressor with distorted inlet will decrease by 6.1% and 210Pa, respectively, in the case of mixed inflow, indicating that the inlet flow field of the compressor and the one of subsequent fans match poorly, which is a direct cause to the degrade in overall compressor performance; the mixing speed is ascending from outer diameter to inner diameter at 90 degrees or above in the circumferential direction and descending at 270 degrees or above; the internal diameter velocity is higher than the external diameter velocity in the radial direction; the maximum flow rate measured by turbine flow meter is 0.201kg/s and the minimum one is 0.0256kg/s. The maximum inflow rate is 0.089kg/s and the minimum one is 0.064kg/s. The total pressure loss of compressor inflow is in positive proportion to the length of the mixing chamber. The longer the mixing chamber is, the greater the loss coefficient is. When the length of the mixing chamber is fixed, the loss coefficient is inversely proportional to Re.

1. Introduction

Coal resource is the principal energy source in China. With low production efficiency in the traditional coal chemical industry, coal burns incompletely and generates a huge amount of CO2 that pollutes environment severely. In this case, new coal chemical industry is of great practical significance. In the coal chemical industry, operating efficiency and equipment status directly affect the economic benefits of coal production.
High-pressure cycle technology is widely used to improve the synthesis efficiency of synthetic gas compressor. However, this approach has the disadvantages of large design error caused by the inhomogeneity of circulating inflow, lack of correlation parameter correction in the circulation section, and overall performance not good enough to meet the design requirements.

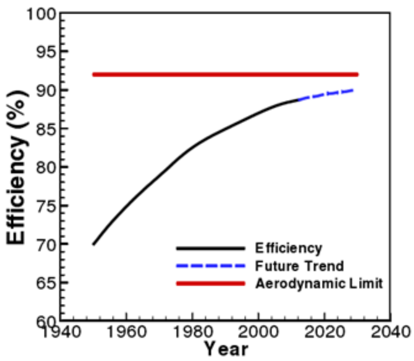


Figure 1: Trend of the centrifugal compressor efficiency

Please cite this article as: Yong Li, Hongtao Zhang, 2017, On the influence of inlet distortion on syngas compressor for coal chemical industry, Chemical Engineering Transactions, 59, 13-18 DOI:10.3303/CET1759003

To solve these problems, it has been a topical study to develop high-efficiency syngas compressor. The variation curve of the peak efficiency of compressors between 1950 and 2010 is shown in Figure 1, showing that most of the centrifugal compressors are 70%-75% efficient. With continuous technological update, the efficiency of centrifugal compressor can reach about 88% by the year 2010.
In order to further improve the operating efficiency of syngas compressors, researchers studied the mechanism of centrifugal compressors in the aspects of aerodynamic theories (Dowson, Walker and Watson, 2004; Denton and Horlock, 2005; Mitsuhashi, 2002), aerodynamic experiments (Boncinelli, 2007; Xie, 2005; Bulot and Trébinjac, 2009; Lee, 2013; Everitt and Spakovszky, 2011); manufacturing technologies (Boncinelli, 2007 (Wei and Jin, 2012; Li and Xi, 2007), etc. In recent years, syngas compressors have been developed and commercialized as a modified version of traditional synthetic gas compressors, whose structures are related to working pressure. Researchers analysed syngas compressors from different perspectives, achieving some positive outcomes (Rubechini and Boncinelli, 2004; Rubechini and Boncinelli, 2004; Pinto, 2016; Subramanian, Sekhar and Prasad, 2015; Rafiee and Sadeghiazad, 2016; Mahdy, 2009; Arabawy, 2009; Murgi et al., 2016; Freitas et al., 2016; Saebea et al., 2017; Tan et al., 2017; Herman et al., 2016; Chen et al., 2016; Lestinsky et al., 2016). Based on numerical simulation and laboratory test, the radial distortion of air flow in a double inlet syngas compressor is analysed in this paper. The author also considers the compressor's mechanical response to homogeneous inflow, mixed inflow, and the length of mixing chambers. Finally, the feasibility of the numerical simulation is verified.

2. Analysis of the influence of the inlet distortion of double inlet gas compressor

2.1 Test setup

At present, the common commercial gas compressor is double-cylinder with an average pressure of about 14MPa. In order to measure the internal flow field in the circulation section of the synthesis gas compressor, a circulating intake air ventilation test equipment is developed with a double inlet device, a centrifugal machine and a connecting pipe. There are 10 2mm-thick blades in front of the fan. The turbine is 50.6mm wide, and the inlet and outlet diameters are 230.5mm and 593.5mm, respectively. The inlet is composed of double pipes at the diameter of respective 100mm and 180mm. The field test device is shown in Figure 1.

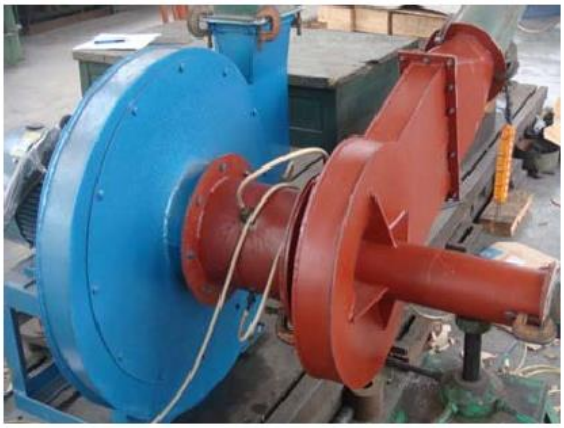
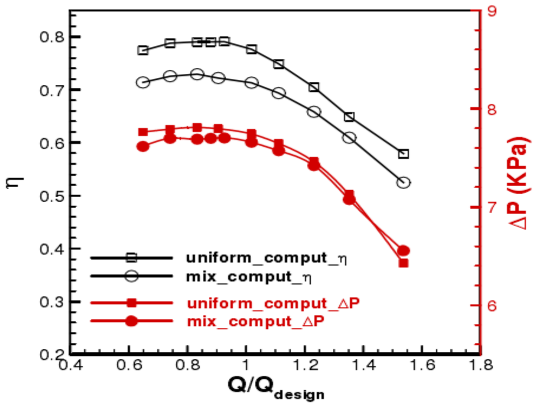


Figure 2: Field test graph of synthetic gas compressor

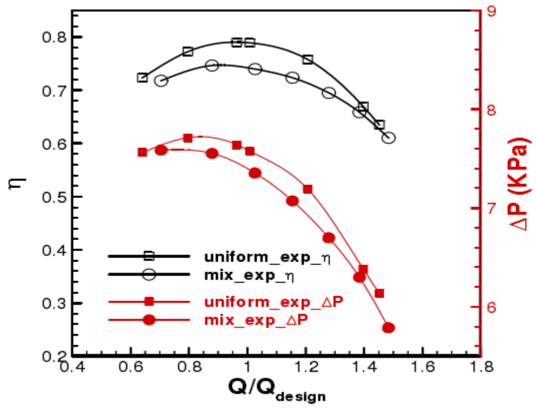
Our tests include the performance test of the synthesis gas compressor and the speed test of the mixing chamber in the compressor. The performance test mainly serves to monitor the fan performance in the conditions of homogeneous inflow and mixed flow. Pneumatic monitoring consists of static pressures in the inlet, in the mixing chamber and in the outlet.

2.2 The effects of homogeneous flow and mixed flow on compressor performance

The effect of mixed flow and homogeneous flow on the performance of the compressor was verified by numerical simulation and laboratory test. The length of the mixing chamber was set as 210mm. The test results are shown in Figure 3, where ΔP is the pressure rise, η is the efficiency, and the abscissa represents the ratio of the actual flow Q and the designed flow Qdesign. As can be seen from the figure, the change trend of numerical results is similar to that of experimental results, albeit different in the large volume side. When Q / Qdesign>1.2, ΔP (numerical simulation) is about 7% higher than ΔP (test). Their little difference in the small volume side is caused by the large value of ΔP obtained when the simulative turbulence intensity is ideally lower than the actual one. The two calculation results show that the efficiency and pressure rise of a compressor with distorted inlet will decrease by 6.1% and 210Pa, respectively, in the case of mixed inflow. This phenomenon indicates that the inlet flow field of the compressor and the one of subsequent fans match poorly, which is a direct cause to the degrade in overall compressor performance.



(a) Numerical Simulation



(b) Laboratory test

Figure 3: Performance comparisons of the centrifugal with numerical simulation and laboratory test

Figure 4 is the distribution of mass flow rates in every flow pass at the designed flow Qdesign. It can be seen from the figure that the maximum flow rate is 0.201kg / s in the No. 12 flow pass and the minimum flow rate is 0.0256kg / s in the No. 1 flow pass. The flow in No. 11 and No. 12 passes is relatively large while the flow in No.1 and No. 8 passes is relatively small, all of which are at the outlet of the vortex tongue. In the case of homogenous flow, different flow passes have similar flow rates, with the maximum one of 0.089kg / s in the No.9 flow pass and the minimum one of 12, 0.064kg / s in the No.12 pass. In the whole, the mass flow rate presents periodic distribution.

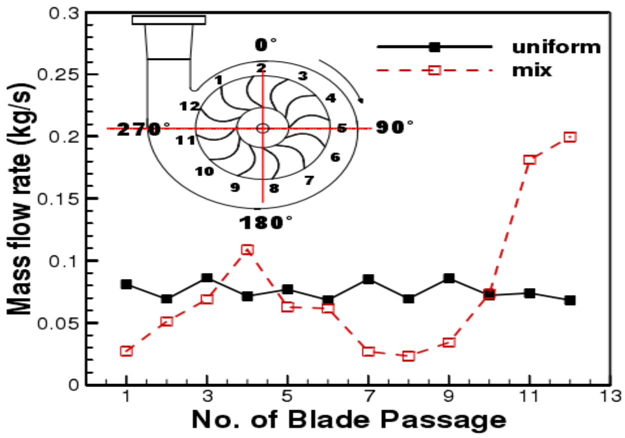
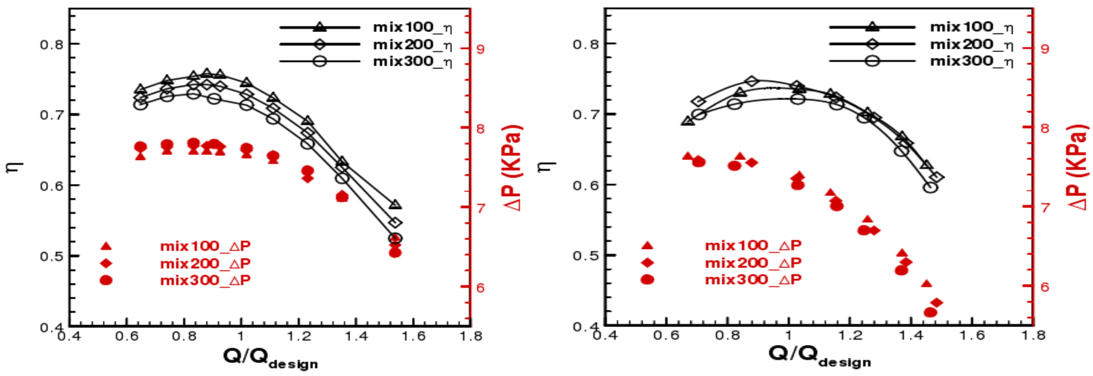


Figure 4: Mass flow distribution in blade passages at uniform and mixing inlet

2.3 Effect of mixing chamber length on compressor performance

The author compared the performance of the compressor when the mixing chamber was respective 100mm, 200mm and 300mm long. It can be seen from the figure that the numerical and experimental fan efficiencies decrease with the extension of the mixing chamber. However, when Q/Qdesign<1.1, the fan efficiency at the mixing chamber length of 200mm exceeds the one at the mixing chamber length of 100mm. Therefore, it can be seen that the length of the mixing chamber exerts some influence on fan efficiency, but not in terms of “the longer, the better”. We compared Figure 5 with Figure 3 and summarized that the influence of mixing chamber length on ΔP in the inlet and outlet is insignificant.



(a) Numerical Simulation (b) Laboratory test

Figure 5: Performance comparisons of the centrifugal with numerical simulation and laboratory test

On the basis of the test results, the inflow pressure loss at the three mixing chamber lengths is plotted in Figure 6. It can be seen from the figure that the total pressure loss in the three mixing chambers increases with the increase of Q/Qdesign, and the longer the mixing chamber is, the greater the total pressure loss becomes. This phenomenon is a reflection of the correlation between total pressure loss and route loss in the cavity and between total pressure loss and the inflow's impact loss on the cavity wall.

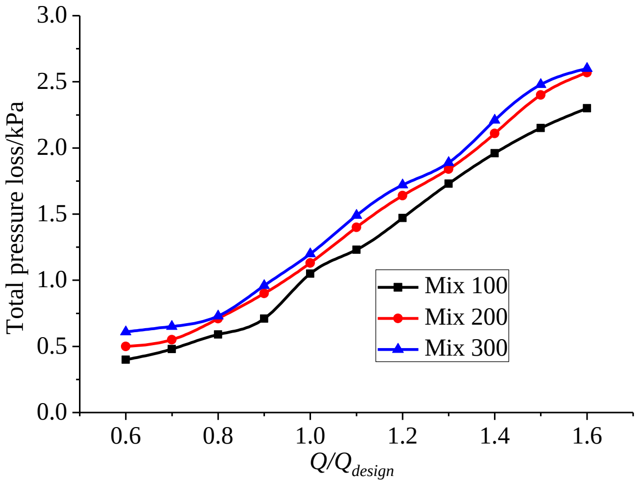


Figure 6: Comparisons of total pressure loss with different mixing length

We expressed the total pressure loss coefficient with F, which is equal to the ratio of the total pressure loss to 1 / 2ρvmix2. According to the statistical results, we determined the relationship formula of F:

$$F = 0.58\frac{l_{mix}}{d_h} + 49.4\,\mathrm{Re}^{-0.3747} \tag{1}$$

$$\mathrm{Re} = \frac{\rho_{mix} v_{mix} d_h}{\mu_{mix}} \tag{2}$$

Where Lmix is the length of the mixing chamber; vmix is the mixing speed; dh is the hydraulic diameter; and Re is calculated from vmix and dh. The loss coefficient curves at the three mixing chamber lengths are shown in Figure 7. As can be seen from the figure, the longer the mixing chamber is, the greater the loss coefficient is; and that when the length of the mixing chamber is fixed, the loss coefficient is inversely proportional to Re.

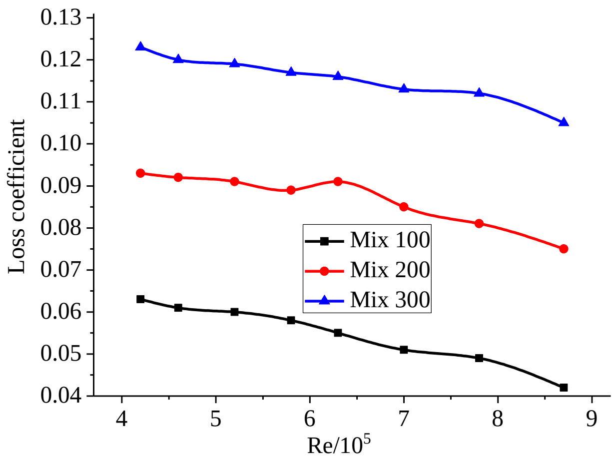


Figure 7: Reynolds number on import resistance coefficient with different mixing length

3. Conclusion

Based on numerical simulation and laboratory test, the radial distortion of air flow in a double inlet syngas compressor is analysed in this paper. The author also considers the compressor's mechanical response to homogeneous inflow, mixed inflow, and the length of mixing chambers. Finally, the feasibility of the numerical simulation is verified, drawing such conclusions:

The efficiency and pressure rise of a compressor with distorted inlet will decrease by 6.1% and 210Pa, respectively, in the case of mixed inflow, indicating that the inlet flow field of the compressor and the one of subsequent fans match poorly, which is a direct cause to the degrade in overall compressor performance.

The mixing speed is ascending from outer diameter to inner diameter at 90 degrees or above in the circumferential direction and descending at 270 degrees or above; the internal diameter velocity is higher than the external diameter velocity in the radial direction; the maximum flow rate measured by turbine flow meter is 0.201kg / s and the minimum one is 0.0256kg / s. The maximum inflow rate is 0.089kg / s and the minimum one is 0.064kg / s.

The total pressure loss of compressor inflow is in positive proportion to the length of the mixing chamber. The longer the mixing chamber is, the greater the loss coefficient is. When the length of the mixing chamber is fixed, the loss coefficient is inversely proportional to Re.

Reference

Arabawy H.A.M.E., 2009, Soret and dufour effects on natural convection flow past a vertical surface in a porous medium with variable surface temperature. Journal of Mathematics & Statistics, 5(3), 190-198. DOI: 10.3844/jmssp.2009.190.198.

Boncinelli P., Ermini M., Bartolacci S., Arnone A., 2007, Impeller-diffuser interaction in centrifugal compressors: numerical analysis of radiver test case. Journal of Propulsion & Power, 23(6), 1304-1312. DOI: 10.2514/6.2006-3453.

Bulot N., Trébinjac I., 2009, Effect of the unsteadiness on the diffuser flow in a transonic centrifugal compressor stage. International Journal of Rotating Machinery, 3, 380-387. DOI: 10.1155/2009/932593.

Chen P.-C., Chiu H.-M., Chyou Y.-P., Svoboda K., 2016, Warm syngas clean-up processes applied in synthetic natural gas (sng) production with coal and biomass, Chemical Engineering Transactions, 52, 469-474, DOI: 10.3303/CET1652079

Denton J.D., Horlock J.H., 2005, A review of some early design practice using computational fluid dynamics and a current perspective. Journal of Turbomachinery, 127(1), 5-13. DOI: 10.1115/1.1650379.

Dowson P., Walker M.S., Watson A.P., 2004, Development of abradable and rub-tolerant seal materials for application in centrifugal compressors and steam turbines. Sealing Technology, 12, 5-10. DOI: 10.1016/s1350-4789(04)00451-9.

Everitt J.N., Spakovszky Z.S., 2011, An investigation of stall inception in centrifugal compressor vaned diffusers. Journal of Turbomachinery, 135(1), 1737-1749. DOI: 10.1115/gt2011-46332.

Freitas A.C.D., Guirardello R., 2016, Predictive thermodynamic modelling of liquid-liquid-vapor-fluid (llvf) equilibrium in synthetic hydrocarbon synthesis from syngas, Chemical Engineering Transactions, 50, 313-318, DOI: 10.3303/CET1650053

Herman A. P., Yusup S., Shahbaz M., 2016, Utilization of bottom ash as catalyst in biomass steam gasification for hydrogen and syngas production, Chemical Engineering Transactions, 52, 1249-1254, DOI: 10.3303/CET1652209

Lee D.H., 2013, Numerical investigation on the effects of self-excited tip flow unsteadiness and blade row interactions on the performance predictions of low speed and transonic compressor rotors. Gynecologic Oncology, 110(2), 146-151.

Lestinsky P., Grycova B., Koutnik I., Pryszcz A., 2016, Microwave pyrolysis of the spruce sawdust for producing high quality syngas, Chemical Engineering Transactions, 52, 307-312, DOI: 10.3303/CET1652052

Li Z., Xi G., 2007, Numerical investigation of unsteady igv-impeller-diffuser interaction in a centrifugal compressor. Journal of Northwestern Polytechnical University, 22(10), 1715-1721.

Mahdy A., 2009, Mhd non-darcian free convection from a vertical wavy surface embedded in porous media in the presence of soret and dufour effect. International Communications in Heat & Mass Transfer, 36(10), 1067-1074. DOI: 10.1016/j.icheatmasstransfer.2009.07.004.

Mitsuhashi K., 2002, Pulsation analysis of reciprocating compressor piping system by convolution integral. Transactions of the Japan Society of Mechanical Engineers C, 68, 672, 2293-2300. DOI: 10.1299/kikaic.68.2293.

Murgi N., De Lorenzo G., Corigliano O., Mirandola F.A., Fragiacomo P., 2016, Influence of anodic gas mixture composition on solid oxide fuel cell performance: Part 1, International Journal of Heat and Technology, 34(S2), S303-S308, DOI: 10.18280/ijht.34Sp0216

Murgi N., De Lorenzo G., Corigliano O., Mirandola F.A., Fragiacomo P., 2016, Influence of anodic gas mixture composition on solid oxide fuel cell performance: Part 2, International Journal of Heat and Technology, 34(S2), S309-S314, DOI: 10.18280/ijht.34Sp0217

Pinto R.N., Afzal A., D'Souza L.V., Ansari Z., Samee A.D.M., 2016, Computational fluid dynamics in turbomachinery: a review of state of the art. Archives of Computational Methods in Engineering, 1-13.

Rafiee S.E., Sadeghiazad M.M., 2016, Three-dimensional numerical investigation of the separation process inside vortex tube using different operating conditions. Journal of Marine Science and Application, 15(2), 1-10. DOI: 10.1007/s11804-016-1348-8.

Rubechini F., Boncinelli P., 2004, Real gas effects in turbomachinery flows: a computational fluid dynamics model for fast computations (2003-gt-38101). Journal of Turbomachinery, 126(2), 268-276. DOI: 10.1115/1.1738121.

Saebea D., Authayanun S., Patcharavorachot Y., Soisuwan S., Assabumrungrat S., Arpornwichanop A., 2017, Performance analysis of solid-oxide electrolysis cells for syngas production by h2o/co2 co-electrolysis, Chemical Engineering Transactions, 57, 1627-1632, DOI: 10.3303/CET1757272

Subramanian S., Sekhar A.S., Prasad B.V.S.S.S., 2015, Influence of combined radial location and growth on the leakage performance of a rotating labyrinth gas turbine seal. Journal of Mechanical Science and Technology, 29(6), 2535-2545. DOI: 10.1007/s12206-015-0545-8.

Tan H.B., Ghani W.A.W.A.K., Hussian S.A., Ng D.K.S., 2017, Feasibility study of napier grass and oil palm frond blend pellets for syngas production, Chemical Engineering Transactions, 56, 1669-1674, DOI: 10.3303/CET1756279

Wei B., Jin D., 2012, Numerical simulation of impeller-diffuser interaction in centrifugal compressor. Journal of Turbomachinery, 122(4), 777-786. DOI: 10.1115/1.2841358.

Xie Y., Deng Q., Zhang D., Feng A., 2005, Strength design and numerical analysis of radial inflow turbine impeller for a 100kw microturbine. Proceedings of the Asme Turbo Expo, 881-888. DOI: 10.1115/gt2005-68302.