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Jie Wen
Xi'an Jiaotong University, China, People's Republic of, jiewen@stu.xjtu.edu.cn

Chang Liu
Xi\'an Jiaotong University, Xi'an, China, justin1113@stu.xjtu.edu.cn

Xueyuan Peng
Xi'an JiaoTong University, China, People's Republic of, xypeng@mail.xjtu.edu.cn

Experimental Investigation of a Horizontal Hermetic Scroll Compressor with Novel Oil Circuit Design

Jie WEN, Chang LIU, Xueyuan PENG*

School of Energy and Power Engineering, Xi'an Jiaotong University,
Xi'an, Shaanxi, China

(+86 029 82663785, +86 029 82668724, xypeng@mail.xjtu.edu.cn)

ABSTRACT

Owing to its reliable operation and low maintenance requirement, the scroll compressor has a potential application for oil and gas industry, e.g. the natural gas production for gas wells with low production and boil-off-gas recovery for gasoline filling stations. Though millions of scroll compressors are put into the refrigeration and air conditioning market each year, a much smaller number of such equipments have been used in the field of oil and gas production. This should be attributed to much larger quantity of compression heat for the natural gas compressor due to higher pressure ratio and larger isentropic exponent, which can not be taken way from oil circulation with traditional oil circuit design typical of refrigeration application. This paper presents an experimental investigation of a horizontal hermetic scorll compressor with novel oil circuit design. The oil was not injected but carried into the compression chamber by the suction gas to remove the compression heat. The oil circuit was so designed that the high pressure oil from the oil-gas separator was cooled, throttled into low pressure, and then stored in the horizontal motor casing, where the oil together with the suction gas entered the compression chamber. Owing to self-balancing, the oil level in the casing was kept constant whatever the operating conditions could be. Based on the novel oil circuit design, a vertical scroll compressor for commercial refrigeration was modified into a horizontal prototype compressor for natural gas compression. The prototype compressor was validated under a wide range of operating conditions in the closed loop test system. Its thermodynamic performances including flow rate and power consumption were tested under various working conditions. The results showed that the compressor could work reliably as the suction pressure ranged from 0 MPa (Gauge) to 0.25 MPa, and with one stage compression the maximal discharge pressure reached 3 MPa as the suction pressure was kept at 0 MPa.

1. INTRODUCTION

Energy is the important material basis for the survival and development of human society. As one of the three largest energy sources in the world, natural gas has a wide application in the basic energy facilities, and it is more and more important to be efficient in the exploitation of oil and gas fields [1].

In the process of natural gas extraction, the reservoir products can flow from the high-pressure reservoir direction to the low-pressure wellhead direction, due to the pressure difference between reservoir pressure and wellhead pressure. And when the pressure difference is greater, the flow rate will be the faster. But as gas fields are exploited, the reservoir pressure begins to fall so that there is not enough pressure to send the gas into the pipeline. This will reduce natural gas production [2]. In general, we cannot change the inherent reservoir pressure in the gas field and pipe network pressure, because the natural gas from gas wells still need to through a long gas pipeline that need to have enough pressure to overcome the resistance of the conveying process losses to the user side. But the wellhead pressure can be controlled, we can use the compressor to reduce the wellhead pressure and to ensure that there is sufficient pressure difference to send gas to the wellhead, as shown in Figure 1.

In addition, as shown in Figure 2, when the storage tank of a gas station is loading or stowing, due to the change of temperature and pressure in the tank, a large number of hydrocarbon gas will be evaporated in the tank, which will increase the pressure inside the tank. And these gases are directly discharged into the atmosphere through the breathing valve on the top of the tank. On the one hand, it brings great security risks to the gas station, and even endangers the staff and customers on the safety of life and property. On the other hand, considering the use situation of oil in China and the current situation of import and export, the emission of these gases also caused great economic losses. The most important thing is that these gases are emitted directly into the atmosphere, causing serious pollution to our environment, increasing carbon emissions and contributing to the greenhouse effect [3].

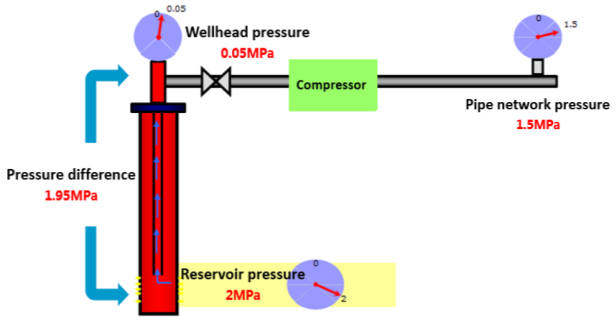


Figure 1: Natural gas fields using compressor

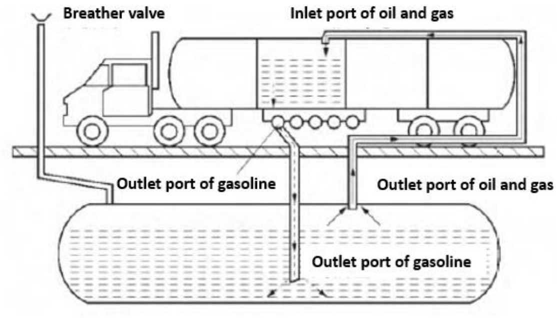


Figure 2: Gas station storage tank

For the above two cases, considering the remote production environment of oil and gas fields and the characteristics of small scale and wide distribution [4], we need a compressor with high reliability, high stability and long maintenance cycle, etc. At present, there are piston compressor and screw compressor in gas field in China. However, piston compressor has many vulnerable components and needs to be guarded. Besides, it is so bulky that is inconvenient to move [5]. Screw compressor has a limited pressure difference and the seal leakage problem. It is suitable for the situation where the flow is large [6]. Neither can meet the technical requirements of the site.

In this paper, a vertical scroll compressor for commercial refrigeration was modified into a horizontal prototype compressor for natural gas compression. For the characteristics of natural gas, such as poor intersolubility with lubricating oil and high isentropic index, a new type of oil circulation design is carried out. And the prototype compressor was validated under a wide range of operating conditions in the closed loop test system. Its thermodynamic performances including flow rate and power consumption were tested under various working conditions.

2. TECHNICAL ANALYSIS

2.1 Compressor Type Selection

Scroll compressor has the advantages of small volume, light weight, simple structure, less vulnerable parts, high operation reliability, small clearance volume and high efficiency. It has been widely applied in the field of refrigeration. At the same time, the scroll compressor is easy to make the whole sealing structure, which can guarantee the safety of the gas in the production process. In view of the above advantages and the more mature scroll compression technology, it is highly concerned to improve the pressure of natural gas, nitrogen and other gases by using scroll compression technology.

As shown in Figure 3, the compression chamber of the scroll compressor is composed of orbiting scroll and fixed scroll. In the process of suction, compression, exhaust work, the fixed scroll is fixed on the frame and the orbiting scroll, which is driven by eccentric shaft and is restricted by anti-rotation mechanism, is a plane swing around the center of the fixed scroll base. The gas is compressed in the crescent compression chamber which is formed by the meshing of orbiting scroll and fixed scroll, and then it is discharged from the axial hole in the middle of the fixed scroll.

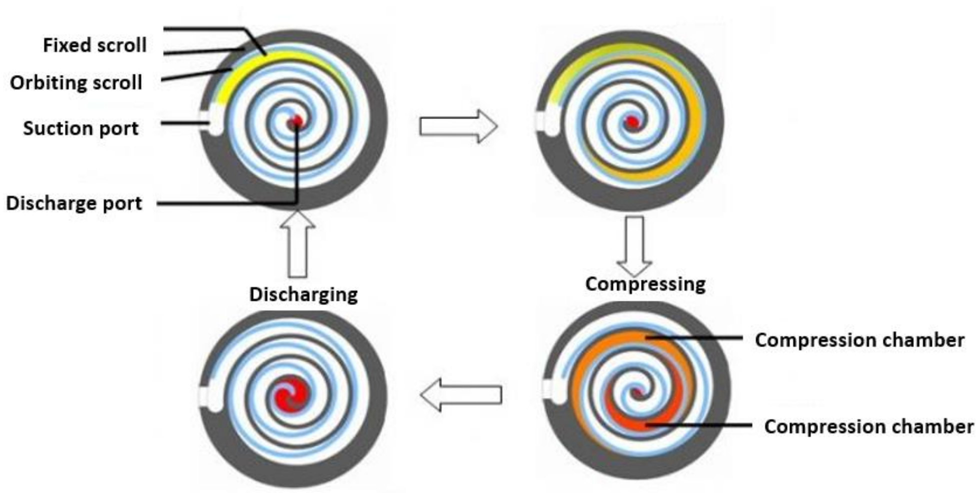


Figure 3: Scroll compressor work principle

2.2 The Reasons for Modification

Although the scroll compressor has many advantages, it cannot be used directly in the compression of natural gas. When the refrigerant enters the working chamber, the lubrication and seal can be satisfied by the lubricating oil carried by the refrigerant because of the good intersolubility between the refrigerant and the lubricating oil. In addition, the entropy index of refrigerant is low, so the temperature rise is not very significant in the compression process. However, such as natural gas and nitrogen, they have poor intersolubility with lubricating oil and have high entropy index. Therefore, a large amount of compression heat will be generated when the compressor works, and the compression chamber temperature rise is obvious. In order to achieve the purpose of lubrication, sealing and reducing the temperature of the compression chamber, the oil must be injected into the compression chamber.

At present, the scroll compressor with oil injection technology is mostly used in opened compressors. Leakage occurs frequently in the shaft seals. However, it is not allowed to leak when flammable and explosive gas, such as natural gas, is compressed. Therefore, it is necessary to adopt fully enclosed scroll compressor, which greatly increases the difficulty of oil injection technology. Moreover, the existing oil injection technology is mainly aimed at refrigerating scroll compressors using refrigerant [7, 8]. On the one hand, the lubricating oil circulation is small. On the other hand, it does not need to add lubricating oil, because the lubricanting oil is circulating in the refrigeration system with the refrigerant. It is different from the compressor that uses natural gas as the working medium.

External oil injection technology of scroll compressor can meet the requirements mentioned above, but it also need another set of oil circulation system which transports lubricating oil from the oil pool in the shell to the bearing lubrication surface. The structure of compressor oil circulation system is complex. And if two sets of oil circulation system is mismatch, it will lead to the level of oil pool gradually rise when a lot of lubricanting oil is injected into compression chamber and will reduce compressor efficiency or reliability. In addition, the heat generated by the compression process and motor can make the temperature of oil pool rising, it will lead to failure of lubricating oil and cause compressor efficiency lower and even burn out. So a novel oil circuit of scroll compressor is necessary.

2.3 The Novel Oil Circuit Design

2.3.1 Introduce: Based on the above considerations, this paper puts forward a novel oil circuit of fully enclosed horizontal injection scroll compressor. A vertical scroll compressor for commercial refrigeration, as shown in figure 4, was modified into a horizontal prototype compressor for natural gas compression, which combined the compression chamber injection circulation system and bearing lubrication system. The lubricating oil of the oil pool in the shell is involved in the circulation system of the lubricating oil. After passing the external heat exchanger, it returns to the compressor.

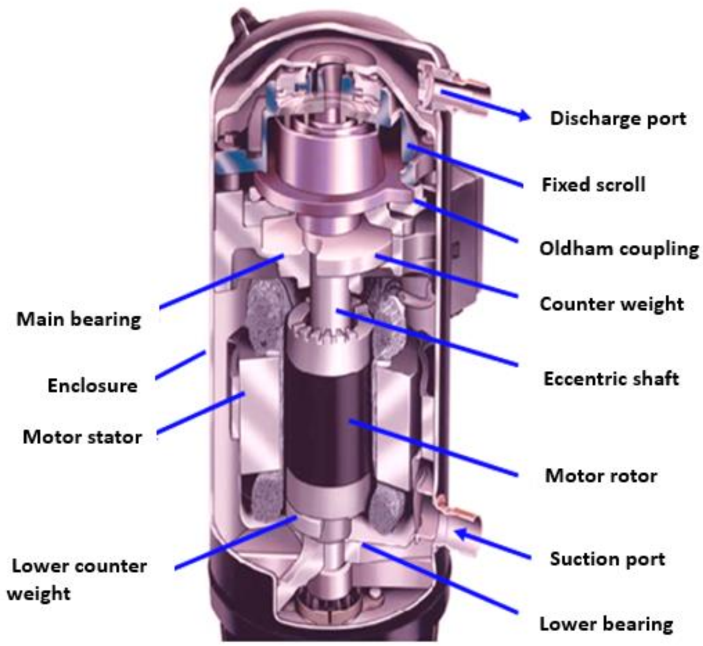
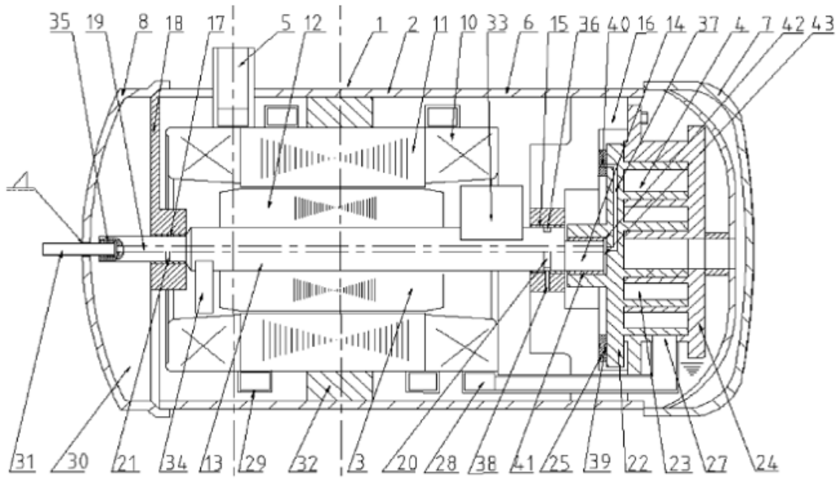


Figure 4: Primary vertical scroll compressor

2.3.2 Structure principle: A unified oil cycle system for bearing force surface lubrication and injection cooling of compression chamber is formed through pressure difference, while ensuring the sealing of the compressor and bearing force surface lubrication in the novel oil circuit.

As shown in figure 5, under pressure difference between suction pressure and exhaust pressure, lubricating oil into the oil hole in the rotating shaft through the injector tube. Then it was sent to the thrust surface of bearing, cross slip ring and the orbiting scroll thrust surface through the annular passage of the rotating shaft, oil duct of orbiting scroll and the annular passage formed on both sides of cross slip ring. Then lubricating oil falls into the oil storage tank at the bottom of the compressor shell. Meanwhile the excess lubricating oil in the oil hole is also discharged into the oil storage tank through the drain hole of the main bearing. The lubricating oil in the oil storage tank enters into the intake duct through inlet holes that set under the oil level of the storage tank. Next it is carried into the compression chamber by the suction gas to remove the compression heat and is carried out with exhaust gas. Last the lubricating oil back to the fuel injection pipe after the oil separator and the heat exchanger.

2.3.3 Self-balancing characteristic: The above structure can be used to self-adjust the gas flow according to the exhaust pressure and rotational speed of compressor. When the exhaust pressure becomes higher, the compression heat increases correspondingly, and the amount of oil injection also increases. Due to the pressure difference of suction pressure and exhaust pressure increases, the oil mass flowing into the shell from the injection pipe adds. Thus the oil pressure of the oil hole and each lubrication surface is high. It is helpful for the compressor to overcome the increased pressure of driving surface caused by the increase of exhaust pressure. At the same time, as the level of the oil pool rises, the oil content of the intake hole increases. So that the oil level in the air passage increases accordingly and the oil mass sucked into the compression chamber increases. It is beneficial to cool the compression chamber. In a similar way, when the compressor speed increases, the centrifugal force of lubricating oil in annular channel will increase. So there is sufficient lubricant to cool the compression chamber. When the exhaust pressure of compressor is reduced or the rotating speed is slow, we will obtain the opposite effect. Therefore, it can achieve self-balancing of oil mass.



1. Scroll compressor 2.Compressor shell 3.Motor 4.Compressing mechanism 5.Inlet pipe 13.Rotating shaft 15.Main bearing 19.Oil hole 22.Orbiting scroll 23.Compression chamber 24.Fixed scroll 25.Cross slip ring 26.Outlet pipe 27.Inlet hole of compression chamber 29.Oil drain hole 30.Oil storage tank 31.Injector tube 36.Annular passage 37.Oil duct

Figure 5: The internal structure of a self-balancing scroll compressor

3. EXPERIMENT

3.1 Experimental Setup

In order to obtain thermodynamic performances including massflow rate and power consumption of scroll compressor with the novel oil circuit under different working conditions, the test bench is seted up, as shown in figure 6. It is mainly composed of enclosed horizontal scroll compressor, oil separator, heat exchange, gas tank and nozzle flowmeter.

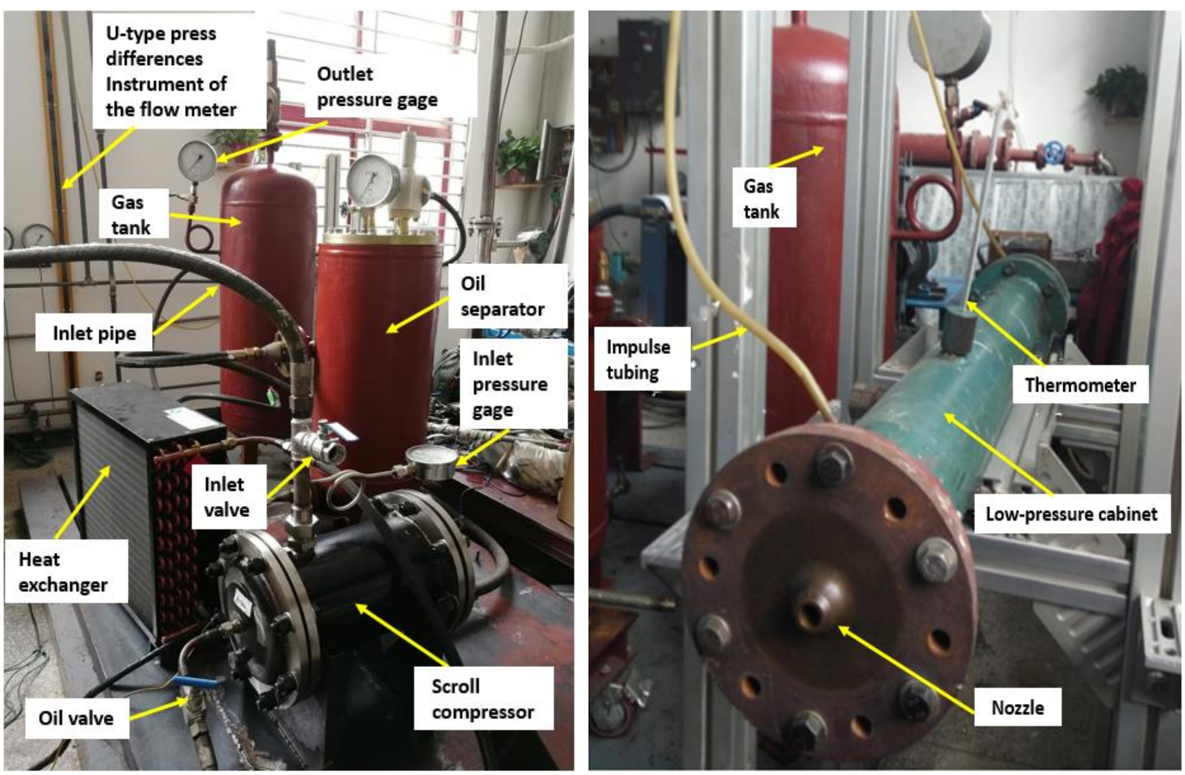


Figure 6: Experimental equipment

The flow calculation formula of nozzle flowmeter is based on the burr equation of compressible fluid [9].

$$Q = 3.53636 \times 10^{-3} \times C_1 d_m{}^2 T_0 \sqrt{\frac{H}{P_0 T_1}} \tag{1}$$

Where, Q is the massflow rate of the scroll compressor, C1 is the flow coefficient, d_m is the nozzle diameter, T_0 is inlet temperature, H is the water column height difference of U-type press differences instrument, P_0 is inlet pressure, and T_1 is the nozzle temperature. The figure 7 shows the experiment flow chart.

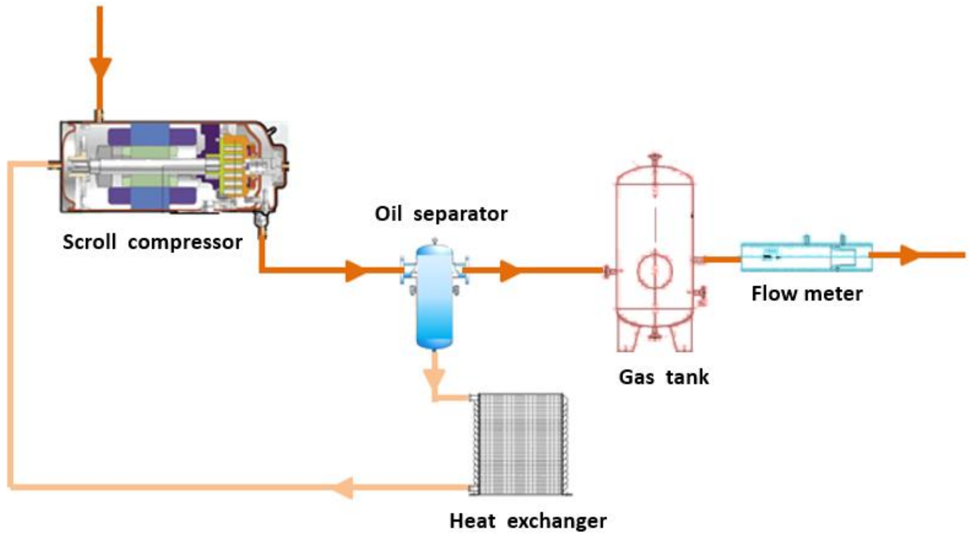


Figure 7: Flow chart of test bench

3.2 Result and Discussion

According to the experimental results, the massflow rate curve, power curve and specific power curve of the modified scroll compressor under different suction pressure and different exhaust pressure were plotted respectively.

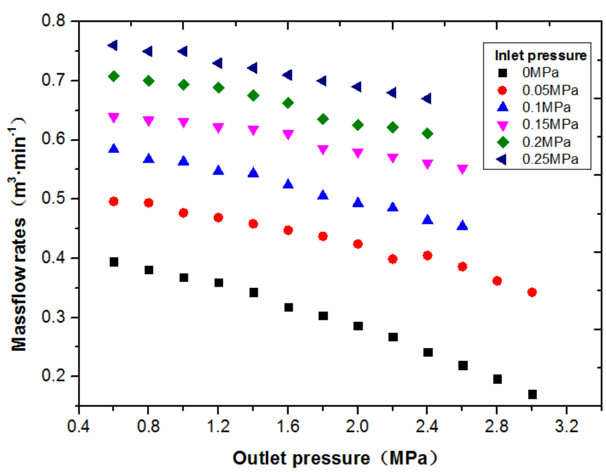


Figure 8: Massflow rate curve

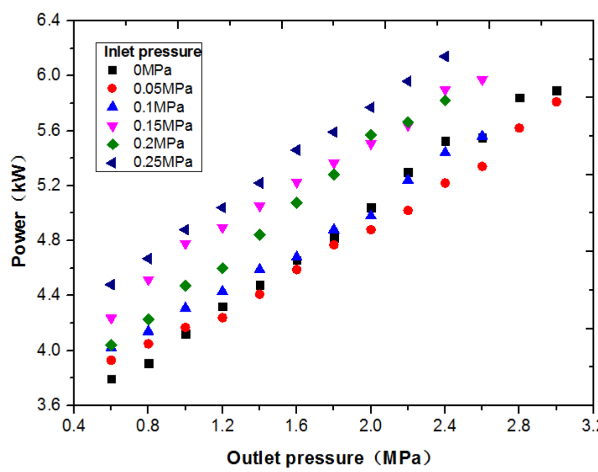


Figure 9: Power curve

Figure 8 shows the massflow rate change with the inlet pressure and outlet pressure. We can see that the massflow rate decreases with the increase of the outlet pressure at the same inlet pressure. The reason of this change is that the compressor leakage will increase with the high outlet pressure. Under the same outlet pressure, the massflow rate is greater corresponding with the rising inlet pressure. When the inlet pressure is 0MPa, the outlet pressure can reach up to 3MPa, and the maximum massflow rate is 0.4m^3/min. When the inlet pressure is 0.25MPa, the massflow rate can reach up to 0.75m^3/min, which can meet the needs of general oil field.

In the figure 9, we can see that the power increases with the increasing outlet pressure under the same inlet pressure. Under the common outlet pressure, the power grows with the increase of inlet pressure linearly in the same way.

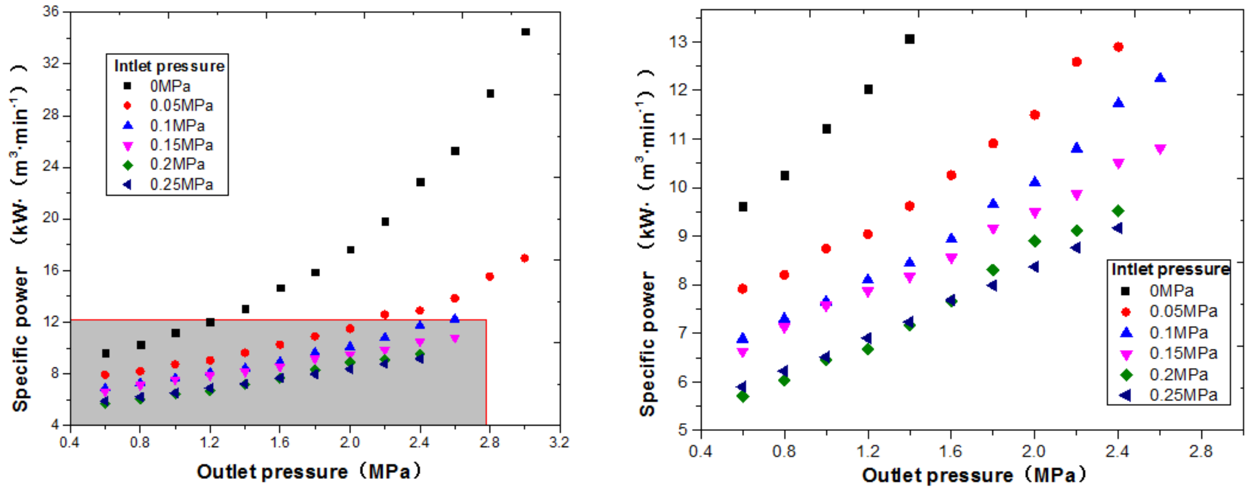


Figure 10: Specific power curve

Figure 10 shows the specific power change with inlet pressure and outlet pressure. Among them, the right picture is a partial enlargement of the left picture. As the picture displays, under the same inlet pressure, the specific power obviously increases with the rising outlet pressure. On the contrary, the specific power decreases with the increase of inlet pressure under the same outlet pressure. These mean that more power needs to be consumed in the larger pressure ratio.

4. CONCLUSION

Compressor is an important equipment in the gas production and the process of flash vapor recovery of gas station. However, there are a series of problems in the piston compressor and screw compressor which are adopted at present. In this paper, the fully enclosed scroll compressor with less moving parts and high reliability is adopted. Aiming at the characteristics of low solubility of natural gas and lubricating oil and high entropy index, a self-balancing oil circuit structure is proposed. The compressor adopts horizontal structure, which solves the problem of lubrication and cooling in the compression chamber, and can realize the automatic adjustment of the oil quantity with the change of the working condition. The prototype compressor was validated under a wide range of operating conditions in the closed loop test system. It can meet the demand of general oil field. The application of this structure to the recovery of natural gas in oil and gas fields not only improve the efficiency of natural gas production, but also bring considerable economic benefits.

REFERENCES

[1]. Li, X.D., Distribution characteristics and discovery prospect of giant oilfields in China. Shiyou Kantan Yu Kaifa/Petroleum Exploration and Development, 2006. 33(2): p. 127-130.

[2]. Pu, W., et al., A novel insight of laboratory investigation and simulation for high pressure air injection in light oil reservoir. JOURNAL OF NATURAL GAS SCIENCE AND ENGINEERING, 2017. 38: p. 333-344.

[3]. Hilpert, M. and P.N. Breysse, Infiltration and evaporation of small hydrocarbon spills at gas stations. Journal of Contaminant Hydrology, 2014. 170: p. 39-52.

[4]. Guifang, Y., et al., Distribution Characteristics of Shallow Natural Gas in China Oil Fields and Its Influence on Drilling. Procedia Engineering, 2011. 26: p. 1857-1863.

[5]. Liang, Y. and F. Zhou, Study on the Application of Large-scale Reciprocating Piston Compressor Installation Technology in Petrochemical Plant. Chemical Engineering Design Communications, 2017(11): p. 83.

[6]. Wang, Z., et al., Research of leakage characteristics of single screw refrigeration compressors with the Multicolumn Envelope Meshing Pair. International Journal of Refrigeration, 2015. 49: p. 1-10.
[7]. Ramaraj, S., et al., Experimental analysis of oil flooded R410A scroll compressor. International Journal of Refrigeration, 2014. 46: p. 185-195.
[8]. SAWAI, K., et al., Experimental Study for High Efficiency on R410A Scroll Compressor-2nd Report: Efficiency Improvement with New Oil Injection to Compression Chambers. Transactions of the Japan Society of Refrigerating and Air Conditioning Engineers, 2009. 26(4): p. 387-395.
[9]. Qu, Z., ed. Compression Test Technique. 1990, Weapon Industry Press: Beijing.