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REVIEW PAPER ON SIMULATION & DEVELOPMENT OF HIGHER EER FOR OIL FLOODED ROTARY SCREW COMPRESSOR

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ABSTRACT

Their most common mode of operation is as oil-flooded machines when delivering air and gases at moderate pressures and flow rates. In order to achieve the best performance, it is essential to be able to predict the optimum amount of oil, required for the oil injection process, accurately. Analytical procedures for the design and performance estimation of twin screw compressors are well developed. The Air-Oil separator (AOS), which is part of oil flooded rotary screw compressor, is modelled and CFD simulation is performed with the help of ANSYS Fluent. For the simulation of AOS finite volume discretization method is used. In case of highly swirling flow, the Reynolds Stress Model is used for better predictions. The results produced by this simulation are compared with existing AOS whose experiment data is collected. After validating the existing system, system is modified. The modification is done on geometrical parameter. CFD of the modified system is performed to predict flow behaviour, primary separation efficiency and pressure drop. The predicted values from CFD modelling are compared with experimental data. For different geometrical parameter, equation of primary separation efficiency in terms of pressure drop and angular position is formulated which is key outcome of this work.

Keywords: CFD, OFRSH, AOS, Simulation, Liquid-Gas, Compression

1. INTRODUCTION

The machines that take in air or any other fluid at lower pressure and compress it to higher pressure are called compressors. The compressor is power consuming machine in which mechanical work is converted into the pressure energy of fluid. They are also considered as reverse heat engine. Generally, the compressors are driven by electric motors, I.C. (Internal combustion) Engines or gas turbines. A compressor used for increasing the pressure of air is called air compressor. The gases or vapors can be compressed from one state to another state at constant temperature (isothermally) or by an adiabatically or by a polytropic process (pressure, temperature and volume varies during compression process and there is an exchange of heat energy between the system and the surroundings). The constant temperature (isothermal compression) and adiabatic compression are very difficult to achieve in practice. Therefore, the compression of gases or vapors is always polytropic. Among the various types of compressors, the rotary screw compressors are the focus point of the present research. Rotary, helical screw, oil injected, positive displacement compressors are constant-volume, variable-pressure machines. They are available in a range from 25 to 3000 cfm at pressures up to 600 psig (41 bars) in single, two and three- stage designs [1]. Rotary screw compressor consists of two rotors, one male rotor which contains number of helical lobes and one female rotor which contains number of corresponding grooves. Air is compressed between cavities which are formed by meshing of rotors. The cylinder consists of two rotors called as air end in which air is compressed in presence of oil [1]. In air end oil flow is there whose function is to liberate the heat which is generated because of compression and provide lubrication between two rotors. This oil is mixed with the compressed air so from compressed mixture oil must be removed which can be done by Separator

Fig.1 Construction of an air-oil separator

There are many components involved in screw compressor and each of them have its own significant which affect the performance of the compressor (refer Fig. 1). Mainly Screw compressor consist of air filter, air end (rotor assembly), separator tank, air cooler, oil cooler, oil filter and moisture separator. Air filter is provided to capture impurities like dust particles present in atmospheric air. Filtered air comes from air filter is entered into airend assembly which consist of two rotors in which air is compressed. Simultaneously oil is entered in air end to provide lubrication between rotors and to liberate the heat which is generated due to compression. In air end both oil and air mixed. At exit of airend non return valve is provided through which air-oil mixture is entered into separator tank. Flow at inlet of the separator tank is highly dispersed. Function of Separator tank is to separate oil from mixture. Separation process is done in two stages. First stage is called mechanical separation also called as primary separation and second one is called as secondary separation which is done by passing remaining mixture through porous material. At the end of secondary separation, remaining air has a notable quality. This air is passed through MPCV (Minimum Pressure Check Valve) and entered air cooler where it is cooled by air cool heat exchanger. At the exit of the air cooler air having moisture content which needs to remove from air in dry air application so this air passed through moisture separator after that air is delivered to the desired application. Oil which is separated primarily is passed through temperature control valve (TCV). Function of the TCV is to guide the oil flow according to its temperature. If the temperature is lower than specified limit oil is diverted towards oil filter otherwise it goes into oil cooler which is air cool heat exchanger and after passing through oil cooler oil is entered into oil filter where impurities present in oil is cured and it moves further to airend. As shown in figure 2.

Fig.2. Schematic depiction of the components of an oil-flooded rotary screw compressor

2. LITERATURE REVIEW

Dusane et al. (2023) investigated the pressure drop and efficiency of oil separator in the multi heat pump system. By varying the diameter and height of the separator, five different types of separators were observed for efficiency and pressure drop (refer Fig. 2.12). The mass flow rates of the working fluid, in this case refrigerant, were recorded. As the mass flow rate increase, the system efficiency initially decreases while showing upward trend afterwards. Under the low flow rate conditions, the decrease in oil droplet size affected the efficiency of separator. For high mass flow conditions, the ride in centrifugal force affected efficiency of separator. **[1]**

Kim et al. (2020) By varying the diameter and height of the separator, five different types of separators were observed for efficiency and pressure drop. The mass flow rates of the working fluid, in this case refrigerant, were recorded. As the mass flow rate increase, the system efficiency initially decreases while showing upward trend afterwards. Under the low flow rate conditions, the decrease in oil droplet size affected the efficiency of separator. For high mass flow conditions, the ride in centrifugal force affected efficiency of separator. **[2]**

S. Rane et al. (2019) presented their work on the customization of the mesh generation for CFD analysis in the rotor pairs of the twin screw type rotary compressor. The grids were developed for different types of meshing namely diffusion smoothing (SH) and key-frame re-meshing (KR) along with a used defined cycle (UH); all three by considering 3 different scenarios. Hence, total nine cycled were studied with different number of cells and nodes for the identification of errors in pressure, mass and temperature. However, the attempts to solve the flow inside the rotors were not successful by KR meshing method due to the numerical mesh complexity. Hence, it was suggested to develop and used customized mesh generation CFD tools for the complex rotary compressor systems. Moreover, a simplified flowchart depiction of the mesh generation was also presented, which added a significant value to the work and to the existing literature. **[3]**

Tang et al. (2020) studied the effect of main geometric characteristics such as compression volume curve, sealing line length, flute area, wrap angle and blowhole area. Mathematical models of these parameters were formulated to develop the manufacturing software. Tang and Fleming studied the effect of relative blowhole area and relative contact line length on performance and suggested some methods for geometrical parameter optimization. **[4]**

Sjoholm et al. (2019) examined the effect of some of the geometrical parameters like number of lobes, wrap angle, L/D ratio and opening of discharge port early for a particular profile shape. The authors focussed more attention on fundamental aspects of the design process. Number of designs was created and their dimensions were normalized to male rotor diameter of the 5/6 profile to get identical displacement per unit revolution in all types of rotors. The authors applied generalized mathematical modelling to calculate the geometrical characteristics and presented the results. It has been observed from the results that the contact or interlope sealing line length increases strongly with the number of lobes, which has an adverse effect on performance at low male rotor tip speeds and high-pressure ratio. **[5]**

Singh et al. (2019) presented a general algorithm for generation of screw rotor profile and related machine geometry. The method is convenient for the design of screw rotors as well as for improvement of existing rotors. A rack-based procedure, capable of generating modern screw rotor profiles has also been included. The main advantage of the algorithm lies in its simplicity, and its capacity to enable ordinary mechanical engineers to create a variety of profiles, a privilege which was previously shared only by a limited number of exclusive specialists. The conjunctive condition has been solved numerically, thereby introducing a variety of primary arc curves. The approach has simplified the design procedure since only primary arcs need to be given, the secondary arcs being automatically generated. **[6]**

C.X You et al. (2018) developed a rapid, flexible and comprehensive computer assisted technique to analyze twin-screw rotor profile generation methods. The strength of this method lies in the reduction in time taken by the whole process from profile generation to performance prediction. This powerful profile generation tool can be used in many ways. It has been instrumental in inventing and analyzing entirely new profiles and modifying existing profiles to match particular applications, optimizing geometrical parameters of machines and understanding the importance of different leakage areas and power loss. It has also been used for generating input data such as contact line length and blowhole area for performance prediction programmes. The flow chart of program sequence used for profile generation is shown in Figure 2.2. The model has been used several times successfully for all 26 kinds of applications including analysis and evaluation. The profile types investigated had a wide range of shapes, number of male/female lobes (3/4 to 6/8 and in between), wrap angles (150 to 3500), L/Dm ratios (0.8 to 2) and built in pressure ratios (4 to 10). **[7]**

M. Azadia 2018 In their experimental investigations, various reciprocating and rotary compressors of comparable capacities have been analyzed on the basis of their thermodynamic and mechanical losses. The authors have explained the differences and have concluded that that both types of positive displacement compressors have their own merits, and that they complement each other to the extent that they may often be combined in one plant to obtain the most energy efficient installation under variable operating conditions. **[8]**

K. Willenborg et al. (2018) The authors have concluded that 4/6 and 5/7 profile combinations are the better choices for high pressure applications. Also, the 5/6 combination showed relatively higher isentropic indicated efficiency for L/D ratios up to 1.7. The 5/7 combination showed that the performance of this combination is very close to that of the 5/6 combination for L/D ratio above 1.7, and that their deflections are much smaller as shown in Figure 2.1. It has been concluded that the 5/6 combination is more appropriate for L/D ratio above 1.7, particularly for high pressure ratio applications. **[9]**

Y. Zhu and K.W. Lee (2018) have published a paper that describes the development of two highly efficient oil free screw compressors designed for dry air delivery. Their design is based on the use of rack generated 3/5 rotor profiles. The optimum rotor size and speed, together with the shape and position of the suction and discharge ports, were determined by mathematical modelling. The model took full account of the limitations imposed by selection 27 of bearings and seals required to maximize endurance and reliability. Xing et al developed a software package to design twin-screw compressors. The package was used to calculate the rotor profile, geometrical characteristics, thermodynamic performance, and forces on rotor teeth, rotor shape and cutter shape. A user-friendly interface and some powerful post processing programs were also included in the package. The same package has been used for improving the performance of an existing machine. **[10]**

Research Gaps

Based on the literature survey conducted as elaborated earlier, there are few research gaps has been identified as listed below.

- An explanatory methodology for achieving near to class zero quality air in contact cooled rotary screw compressor is not found in the literature.
- The methods of enhancing the efficiency of contact cooled rotary screw compressor by reduce the pressure drop in the compressor sub system have not been studied.

3. OBJECTIVES

The aim of the present work is focused on the evolution of the design of air-oil separator for the performance enhancement of the oil-flooded rotary compressor. Based on the identified research gaps, the objectives of the present work are defined as listed below:

- To improve the air oil separation efficiency.
- To reduce the pressure, drop across the separation sub-system.
- To provide energy efficient power saving solution to industries.

4. METHODOLOGY

The present study of enhancing the performance of the air-oil separator (AOS) in terms of separation efficiency and reduced pressure drop has been conducted by designing different sets of system combination. These diverse system configurations consist of altering air-oil mixture inlet tilt angle and the porosity of the porous medium used inside AOS system. The entrance tilt angle is investigated at the values of -10°, 5°, 0°, 5°, and 10°, while the porosity values were varying as 0.8, 0.85, 0.9, and 0.95. The pressure drop and separation efficiency are computed for the different combinations of these parameters and the most energy efficient solution has been identified. The computation has been conducted through the Computational Fluid Dynamics (CFD) analysis and then validated by means of experimental observations.

Air Oil separator used in Rotary screw compressor to separate the oil from the compressed air-oil mixture. Construction of Air-oil separator and separator element is shown in Fig. 4.1. It is also called as separator tank. Separation process occurs basically in two steps. Primarily, oil is separated because of density difference and swirling motion of the mixture. Secondary separation is done by porous media. The Location and perform criteria of separator we discuss in the present study. With mixture volume fraction it depends which method we use for partial tracking separation if the it is less than 10% than we use DPM and or if more than 10% we us VOF in our case it is 1 to 2%so we used DPM for this. Again, the flow of oil which is very less compared to air so in CFD first continuous phase simulation is performed and then in post processing see the behavior of oil particle that travel along the flow and how much of them are trapped in wall. Compressed air-oil mixture is entered from the inlet is provided to make tangential inlet for the tank. Tangential inlet creates swirling motion of mixture. Primarily oil is separated because of this swirling motion of the mixture which is called mechanical separation or primary separation. After primary Separator element consists of porous material whose porosity is 0.8 with in exit system in this porous material is made of fiber glass which works on principle of coalescence. According to principle of coalescence small droplets of oil particles are collected and form large droplets. Large droplet having higher density is settled down at bottom curvature plate of the element.

5. CONCLUSIONS

The current study focuses on the examination of the air-oil separation device for improving the performance of an oil-flooded air compressor. The investigation was carried out using CFD analysis, and the results were compared to the experimental data collected for the traditional system. The CFD findings agreed well with the experimental data.

swirling flow in AOS, and hence RNG may be considered the optimum technique for swirling flow applications.

Additionally, the system is suited for DPM implementation since the oil volume part, or VOF, is less than 10% AOS and provides relatively accurate performance forecasts. DPM was used to follow each individual particle through the continuous fluid in order to calculate the particle paths inside the flow.

6. FUTURE SCOPE

The current work has concentrated entirely on reducing the contamination of oil particles during the filtering process using CDF modeling and experimental investigation. Through study of the porosity of the air-oil separator filter element, the inquiry has successfully decreased the oil incursion from the standard 5 PPM value to 1.34 PPM, which is a significant step towards converting an oil-flooded system to an oil-free system. There is a good chance that the earlier detected 1.34 PPM contamination will be reduced to completely zero contamination as a future scope to the current activity. For industrial applications, this is quite desired. Additionally, the absence of oil penetration opens up several additional economic applications.

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