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Decade Developments of Rotary Compressor

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ABSTRACT

Compressor is the single largest consumer of primary energy (usually electricity) in an industrial refrigeration system and often become a focal point for energy efficiency improvement strategies. This is achieved either through the improvement of existing compressor designs, or by the introduction of new designs that is expected to overcome the drawbacks of existing compressors. This paper presents the summery of development and innovations made in rotary compressors used in refrigeration industry by the researchers in respect to performance, compactness, vibration, method of injection and losses.

Keywords: *Refrigeration; Rotary compressor; Development; Review*

1. INTRODUCTION

In refrigeration and air-conditioning systems, recent trends in compressor usage have elucidated the preferment of rotary type compressors over the veteran reciprocating piston cylinder type, mainly due to more noise and vibration disturbances exhibited by the latter. Rotary machines such as the rolling piston and scroll compressors do indeed not only feature a quieter and smoother operation, but are also simpler and more compact in their overall construction. Furthermore, rotary compressors are also shown to have achieved good reliability and efficiency. Due to these advantageous features, the uses of rotary compressors have been increasing over the years. As with the operation of all mechanical systems and machinery, one of the crucial factors affecting the performance of a refrigeration compressor is mechanical efficiency. Mechanical losses not only deteriorate the overall efficiency of the compressor, but also at times give rise to reliability problems due to wear and tear caused by the friction. In rotary compressors, as parts in sliding contact usually possess high relative velocities, frictional losses are predominant which have limited their performance despite their advantages mentioned earlier.

The scroll compressor is one of the rotary compressors used for compressing air or refrigerant, which was originally invented in 1905 by French engineer named Le'on Creux. The device consists of two nested identical scrolls constituted in the classical design by involutes of circle. The main advantages of the scroll compressor are the small number of moving parts, a high efficiency and a low level of noise and vibrations. However, one of the main problems when developing scroll compressors is the design of the scroll profile, which plays a key role in their performance. Most of the models of the scroll compressor are based on a geometrical description which develops a relationship between the volumes and the leakage areas as a function of the orbiting angle. The computation of the geometry allows pressure, temperature and mass flows to be computed in each chamber of the compressor.

The other type of rotary compressor such as screw refrigeration compressor is widely used in various refrigeration systems which have gradually replaced the reciprocating refrigeration systems employed in small cooling capacity systems and part of centrifugal refrigeration systems adopted in large cooling capacity systems. Many mathematical models have described the working process of screw compressors with focus on different processes or characteristics, such as oil injection, flow and heat transfer characteristics, internal leakage, p-V indicator diagram, and super feed process.

2. INNOVATIONS IN SCROLL COMPRESSOR

Scroll type compressors have become increasingly popular in refrigeration and air conditioning systems because of their high efficiency, low noise, fewer components, low vibration, light weight and small size compared to other types of compressors. **Chen et al. (2002a) [1]** discussed the development of a comprehensive simulation model of a horizontal scroll compressor, which combines a detailed compression process model **[2]** and an overall compressor model. In the overall model, compressor components are analyzed in terms of nine different elements. Steady state energy balance equations are established by applying the lumped capacitance method. In combination with detailed compression process model, these equations were implemented into computer code and solved recursively. In this way, the temperature and pressure of the refrigerant in different compressor chambers, the temperature distributions in the scroll wraps, and the temperatures of the other compressor elements can be obtained.

Lebrum and Winandy (2002) [3] published results of experimental analysis and modeling of scroll compressors using gas and liquid injection. The experimentation is based on hermetic scroll compressors using different methods of injection such as without injection, vapor injection and liquid injection. The analysis reveals the influence of these methods on the compressor behavior. A simplified model of the scroll compressor is then proposed that takes into account not only the different internal processes but also the refrigerant injection.

Winandy et al. (2002) [4] carried out the experimental investigation of a hermetic scroll compressor equipped with internal sensors. The analysis reveals the main process affecting the refrigerant mass flow rate as well as the compressor power and the discharge temperature .Based on the experimental results, a simplified model of the scroll compressor is proposed. It assumes that the refrigerant mass flow rate is affected by a suction temperature increase due to heat gained from a uniform wall temperature. This imaginary wall is supposed to gain heat from the electromechanical losses and from the discharged gas and to give heat to the ambient. The compression process is considered to be isentropic up to the adapted pressure and then isochoric until the discharge pressure. The model is able to compute variables of primary importance, like mass flow rate, the electric power and discharge temperature as well as secondary variables such as suction heating-up, discharge cooling down, and ambient losses.

The design and manufacturing of scroll compressors is not easy as their key parts have complex shapes with involute curves. A high degree of accuracy in assembling is required which encounters difficulties in the manufacturing cycle. **Jiang et al. (2003) [5]** presented the integration of constructive solid geometry (CSG) modeling and Computer Aided Manufacturing in the design in general, scroll compressors in particular. The approach is based on concurrent engineering. The involute scroll curve is created from equations. Designers can transfer the model to a manufacturing engineer for process planning. The manufacturing engineer can also advise the designer if some revisions are needed. Experts can check the models and processes of design and manufacturing. Thus, solid modeling and machine tool path simulation can bridge the gap between design and manufacturing which is essential for concurrent engineering. With this approach, a correct and precise solid model can be achieved, which leads to an optimal design in terms of quality, delivery time and cost.

Tseng and Chang (2006) [6] proposed a systematic design method for developing a family of scroll-type compressor (STC). Except of using general design optimization, model includes multi-variable, direct search, inequality constraints, both interactive session and discrete variable design optimization skills have also been employed in this study. Comparisons between calculated and measured results show that the maximum deviation of cooling capacity and coefficient of performance based on electrical power input are below 2.53% and 1.69%, respectively.

Wang et al. (2008) [7] concentrated on the numerical research on the scroll compressor with refrigeration injection. The model can be used to predict the macro performance and inner compression process of the injected scroll compressor. A series of experiments are conducted to validate the accuracy of the model. The results show that the model can precisely predict not only the general performance of the compressor but also the inner compression with or without refrigerant injection.

Blunier et al. (2009) [8] simulated the new analytical and dynamic model of scroll compressor. By using a novel reference frame, it proposes an original way of describing the geometry of the scroll wraps (represented as circle involutes) in which the symmetries are exploited in order to establish a thermodynamic model of the scroll compressor. This approach allows the chamber volumes to be analytically described without any special assumption and takes into account the discharge as a non-symmetrical process.

Cuevas and Lebrum (2009)[9] tested the variable speed scroll compressor .Variable speed compressors offer continuous control, low noise level, reduced vibration, low-start current, rapid temperature control, by operating the compressor at higher speeds initially, and observed better COPs than the conventional on/off control. However, there are some drawbacks concerning the inverter efficiency, the effect of the inverter on the induction motor and the effect of variable speed on the compressor isentropic and volumetric efficiencies. This study gave some experimental results as to inverter and compressor performances: it was observed that the inverter efficiency varies between 95% and 98% for compressor electrical power varying between 1.5 and 6.5 kW. Compressor efficiencies are not enormously influenced by compressor supply frequency, but depend mainly on compressor pressure ratio, except the tests developed at 35 Hz and one test at 40 Hz, for which the difference is attributed to the compressor internal leakages due to a lack of lubrication at low speeds.

Cuevas et al. (2010) [10] examined the characterization of scroll compressor under extended operating condition. Refrigeration and air-conditioning compressors are designed to work under well-defined conditions. In some applications it is interesting to observe their performances beyond these conditions, for example in the case of a high temperature two-stage heat pump or of a cooling system working at high temperature. In this study a compressor is characterized experimentally with refrigerant R134a and through 118 tests at condensing pressures varying from 8.6 up to 40.4 bar and evaporating pressures varying from 1.6 up to 17.8 bar. Under these conditions the compressor motor was pushed at its maximal current in several tests. This compressor performance is mainly characterized by its isentropic and volumetric efficiencies.

Duprez et al. (2010) [11] notified an improvement of the scroll compressors model. This improved model allows the calculation of refrigerant mass flow rate, power consumption and heat flow rate that would be released at the condenser of a heat pump equipped with the compressor, from the knowledge of operating conditions and parameters. Both basic and improved models have been tested on scroll compressors using different refrigerants. This study is limited to compressors with a maximum electrical power of 14 kW and for evaporation temperatures ranging from -40 to 15°C and condensation temperatures from 10 to 75°C. Using a global parameter determination (based on several refrigerants data), this model can predict the behavior of a compressor with another fluid for which no manufacturer data are available.

Yangguang et al. (2010) [12] compared the involute of circle with variable radii in a scroll compressor. A geometric model of scroll profiles, constructed from an involute of circle with variable radii, has been developed by using the theorem of planar orbiting mechanisms. Parametric studies have also been investigated in this study. When compared to the conventional scroll profile with the same suction volume, volume ratio and housing size, this new model demonstrates better reliability and efficiency because of a lower wrap height. Alternatively, a scroll type compressor with a more compact housing size can be achieved by using this new profile but keeping its wrap height the same as the conventional one. Furthermore, arc and line modifications have been built to provide wider design varieties. These are used to avoid interference at the center of the scroll pair and to boost the volume ratio of this new scroll profile.

Dutta et al. (2011) [13] analyzed the performance of scroll compressor under liquid refrigerant injection. In this study, fundamental and practical influence of liquid refrigerant injection on the performance of a refrigerant scroll compressor has been investigated experimentally and theoretically. In the theoretical analysis, a compression model of vapor / liquid mixture is developed by taking account of heat transfer from the cylinder wall to suction, compression and injection refrigerant. An experiment has been performed under the condition of keeping the oil temperature constant in order to investigate the fundamental influence of the liquid refrigerant injection on the compressor performance, and the results were compared with the theoretical ones.

Yoon et al. (2011) [14] investigated oil discharge ratio at inverter – driven high shell pressure scroll compressor using R410. In this study, the oil discharge characteristics of a high shell pressure scroll compressor, which uses R410A as the refrigerant and Poly Vinyl Ether as the oil, were measured according to the conditions for oil management. The measurement of oil discharge ratio (ODR) in the system is very important to secure the operational reliability. It was made in real time through the refractive index sensor. ODR was greatly influenced by the mass flow rate and the dynamic viscosity of the refrigerant. As the rotation frequency of the compressor became higher, ODR increased rapidly.

3. ENHANCEMENT IN SCREW COMPRESSOR

Twin screw compressors are rotary positive displacement machines of simple design capable of high speed operation over a wide range of operating pressures and flow rates with high efficiencies. Moreover, they are both reliable and compact. So screw compressors have recently found a broad application in the industry taking into account their advantages, such as in industrial refrigeration and central air-conditioning applications.

Suh and Lee (2001) [15] discussed the manufacturing concepts of composite screw rotors for air compressors by RTM (Resin Transfer Molding) process. Screw rotors, the key parts of screw compressors, are widely used in compressing air and refrigerant due to their high productivity, compact size, low noise and easy maintenance. In general, a screw compressor unit is composed of female and male rotors of complex geometric shape. The manufacturing cost and time of the screw rotors are high because the complicated helical shapes of the screw rotors are manufactured usually by dedicated machine tools. To reduce the production cost and weight of screw rotors, the screw rotors for air compressors were manufactured with chopped carbon fiber epoxy composite materials by the RTM (resin transfer molding) process using separable four –piece molds for easy demolding of helical shape screw rotors.

Yang (2002) [16] developed the mathematical model of the rotor profile of the single screw compressor. This paper presents a method for determining the basic profile of a single-screw compressor including a gate rotor and a screw rotor. The inverse envelope concept for determining the cutting-edge curve of the gate rotor is presented. Based on this concept, the required cutter for machining the screw rotor can be obtained by an envelope of the one-parameter family of obtained screw rotors. The obtained screw rotor is an envelope of the family of gate rotor surfaces. Let the obtained envelope of the one-parameter family of gate rotor surfaces become the generating surface. The inverse envelope can be used to obtain the envelope of the family of generating surfaces. Then, the profile of the gate rotor with the cutting-edge curve can be easily obtained. The proposed method shows that the gate rotor and the screw rotor are engaged along the contact line at every instant. This is essential to reduce the effect of leakage on compressor performance.

Reindl et al. (2003) [17] has discussed about the selection of screw compressors for energy efficient operation. Although numbers of alternative compressor technologies are available including reciprocating and rotary vane, many refrigeration end-users are inclined toward installation of screw compressors. The unique characteristics of screw compressors and criteria for selection to yield energy efficient operation when integrated into a built-up industrial refrigeration system with a brief overview of screw compressor technologies, methods of capacity control, and volume ratio concepts has been investigated. Energy efficiency aspects of screw compressor technologies are discussed for both fixed and variable volume ratio configurations. Guidelines for screw compressor selection are also outlined.

Stosic et al. (2003) [18] optimized the screw compressor on the basis of rotor profile. Increasing demands for more efficient screw compressors require that compressor designs are tailored upon their duty, capacity and manufacturing capability. A suitable procedure for optimization of the screw compressor shape, size, dimension and operating parameters is described here, which results in the most appropriate design for a given compressor application and fluid. It is based on a rack generation algorithm for rotor profile combined with a numerical model of the compressor fluid flow and thermodynamic processes. Some optimization issues of the rotor profile and compressor parts are discussed, using 5 to 6 screw compressor rotors to present the results. It is shown that the optimum rotor profile, compressor speed, oil flow rate and temperature may significantly differ when compressing different gases or vapors or if working at the oil-free or oil-flooded mode of operation. Compressors thus designed achieve higher delivery rates and better efficiencies than those using a traditional approach, which is illustrated in an example of the 3 to 5 screw rotors designed for a family of dry air compressors.

The theoretical and experimental study on indicator diagram of twin screw compressor published by **Wu et al. (2004) [19]** A new mathematical model for calculating the indicator diagram of twin screw refrigeration compressor is presented. The geometric parameters related to the rotation angle of male rotor are used in the model such as groove volume, suction and discharge port area, slide valve bypass port area, leakage area etc. The effects of internal leakage through five paths, oil injection, gas–oil heat transfer, refrigerant property and partial loading etc. are taken into account simultaneously and separately in the theoretical study. To verify the model and p–V indicator diagram, experimental recording of p–V indicator diagram of twin screw refrigeration compressor is carried out.

Numerical investigation of heat transfer on screw compressor rotors carried out by **Stosic et al. (2005)[20]**. Since dry screw compressor rotors and housing are subjected to high temperatures which cause their deformation, they either may not operate at high pressure ratio, or they must be cooled. However, the gas temperature is high only in the high pressure region of the screw compressor, therefore, the domain where the heat is transferred to the rotors is limited to only a small portion of the rotors and housing. Also, since the rotor revolve at high speeds while residing only briefly within areas of different gas temperatures during one cycle, the rotor temperature becomes virtually uniform across any cross sectional area perpendicular to the rotor axis and its value is somewhere between the highest and lowest gas temperature at that cross section area. At the same time, due to the relatively high thermal conductivity of the compressor components, which are made of metal, heat transfer by conduction is considered substantial and the rotor body temperature attained is a result of a balance between the heat received from the gas and its dissipation in regions of lower gas temperature. Consequently, it appears that rotor cooling is required only in the compressor high temperature region to keep rotor temperatures at a reasonable level. Therefore, an effective means of cooling the rotors could be to inject a small quantity of flashing liquid, preferably water into the casing, at the high pressure port end in any circumferential position.

Seshaiah et al.(2007) [21] developed the mathematical model of the working cycle of oil injected rotary twin screw compressor .Mathematical analysis of oil injected twin-screw compressor is carried out on the basis of the laws of perfect gas and standard thermodynamic relations. Heat transfer coefficient required for computer simulation is experimentally obtained and used in performance prediction, when the working medium being air or helium. A mathematical model has been developed for calculating the compressor performance and for validating the results with experimental data. The flow coefficients required for numerical simulation to calculate leakage flow rates are obtained from efficiency verses clearance curves. Effect of some of the compressor operating and design parameters on power and volumetric efficiencies have been analyzed and presented.

Wu et al. (2007) [22] carried out research on the working process of screw refrigeration compressor under super feed condition. To increase the refrigeration capacity and improve the coefficient of performance (COP), an economizer is used in the refrigeration system with screw refrigeration compressor. In this system, the mid-pressure refrigerant gas from the economizer is injected in the screw compressor. The p-V diagrams (pressure volume diagrams) of screw refrigeration compressor under different super feed pressures with economizer are recorded successfully by making use of a micro-type pressure sensor that embedded into the groove at the root of the female rotor on the discharge side.

Profiling of screw compressor rotors by use of direct digital simulation investigated by **Stosic et al. (2008)[23]**. A standard feature of AutoCAD software enables a rotor to be 'cut' from a given blank and then generate a meshing rotor profile from a given primary profile template for practically all existing screw compressor rotor profiles. Three examples are presented, namely, a roots blower to demonstrate two-dimensional meshing, a twin screw compressor to demonstrate 'two and one half' dimensional generation and a single screw compressor rotor and hobbing tool to show full three-dimensional profile generation. Rotor profile points can be generated by this procedure from which the compressor displacement, the sealing line points and the blow-hole area can be estimated.

Wu and Fong (2008) [24] has presented improved rotor profiling based on arbitrary sealing line for twin-screw compressors. A design method for the rotor profile of twin-screw compressor from an arbitrary sealing line is presented. The sealing line is divided into several functional segments that control the high-pressure side and the low-pressure side performances independently. Each functional segment is fitted by cubic spline and the shape of the segment can be adjusted by moving the control points of the cubic spline. Based on the shape of the sealing line, the performance of the compressor can directly be calculated and the corresponding rotor profiles are derived considering the non-undercutting condition. A numerical example which considers the geometric constraints of rotor profiles is presented to demonstrate the flexibility and stability in parametric study of the rotor design.

Wu and Fong (2009) [25] has optimized design of an explicitly defined rack for the generation of rotors for twin-screw compressors. In conventional rotor profile generation for the twin-screw compressor, the designed parameters are often decided by trial-and-error method and cannot distinctly predict the changed difference when adjusting one of parameters. Refer to previous rack-generated rotor profiles, explicit equations of the rack with two specific normal-equidistant trochoids are replacing the implicit form. The feasible parameters are designed on the rack in order to more instinctively and flexibly adjust each compound curve. The parametric study and non-undercut limits are presented for the rotor profile optimization with SUMT (sequential unconstrained minimization technique) method. A numerical example is presented to show the validation of the proposed optimization model and a practical experiment is conducted to test the excellent compressor performance.

The experimental study on oil injected twin-screw air compressor when compressing different light and heavy gases carried out by **Seshaiah et al. (2010)[26]**. Oil injected twin-screw compressors are widely used for medium pressure applications in many industries. Air compressors can be used for compression of helium and other gases, leading to significant cost saving. The efficiency, delivery rate and the heat of compression of the compressors (medium and small size) are analyzed. To generate experimental data, two similar compressors with different capacities are used to test the performance of air compressors when applied to compress nitrogen, argon and helium gases apart from air. This paper also describes the gas delivery rate and heat of compression (temperature) on volumetric and power efficiency.

Chen et al. (2011)[27] reported about the theoretical and experimental investigation on the performance of screw refrigeration compressor under part-load conditions Slide valve is normally employed in screw refrigeration compressor to meet the cooling capacity demanded by the load variation. A mathematical model describing the working process of screw refrigeration compressor with a slide valve assembly under part-load conditions is established based on the calculation of the effective by-pass area and radial discharge area. Experimental investigation on a screw refrigeration compressor under part-load conditions with several evaporation and condensation temperatures is also carried out. Simulation results are in good agreement with the experimental ones.

Hsieh et al. (2011)[28] had shown the temperature distributions in the rotors of oil-injected screw compressors. A mathematical model and a calculation procedure are proposed to effectively calculate the temperature distributions in the male and female rotors of the oil-injected screw compressors. The solution of the transient heat conduction problem of the rotors, which is subjected to a periodic convective boundary condition and five steady boundary conditions, is obtained by solving the set of Helmholtz equations derived from the partial differential equations for transient heat conduction without internal heat. This analysis show that the three empirical constants that were used to calculate the heat convection between the screw and the compressed air, the heat transfer between the rotor and the bearing at the inlet shaft of the rotor and the heat transfer between the rotor and the bearing at the outlet shaft of the rotor, have a stronger impact on the outputs of the mathematical model than the other three empirical constants. The reduced mathematical model, using only the three empirical constants with the strongest impact, can be used in the studies of the temperature distribution in the rotor. The calculated temperature distributions in the screws can be used to estimate the approximate thermal deformation of the screws and thereby improve the screw profiles and the design of the oil-injected screw compressor.

4. REVOLVING VANE AND ROLLING PISTON TYPE COMPRESSOR DEVELOPMENTS

Kim (2005)[29] examined the lubrication oil pumping by utilizing vane motion in a horizontal rotary compressor .For a horizontal rotary compressor which utilizes reciprocating motion of the vane for oil supply into lubrication elements, an analytical study has been carried out on the oil pumping mechanism. Energy equation has been applied to the oil flow inside the oil-conveying pipe with oil feeding hole in the middle. Oil distributions into individual lubrication elements such as various bearing elements have also been analyzed by applying electric circuit network theory to the oil flow network. Fairly good agreement between calculations and experiments for the oil pumping rate has been obtained in a wide range of compressor speed.

The performance of a rolling piston compressor is optimized by **Ooi (2005) [30]** under preset operational conditions and design constraints by employing a multi-variable, direct search, constrained optimization technique. A mathematical model for the compressor was first formulated. The model accounts for geometrical configuration, thermodynamic effects, valve dynamics, flow and mechanical considerations. The accuracy of the model was verified by comparing its prediction with measured results. The model was then linked with an optimization algorithm to search for a combination of some six design dimensions and seven sets of design constraints, for an optimum compressor performance with minimum mechanical losses.

A new rotary type compressor, named 'Revolving Vane (RV) compressor', in which frictional losses are effectively reduced through the radical use of a rotating cylinder, has been developed by **Teh and Ooi (2009a)[31]**. The friction at various contact regions are formulated and analyzed, after which a parametric study is conducted to reveal configurations of the compressor that achieves high mechanical efficiencies. A new gas compression mechanism named the 'Revolving Vane (RV) compressor' **(Teh and Ooi 2009b) [32]** has been invented and theoretically shown to achieve improved mechanical, volumetric and compression efficiencies over existing compressor designs. The experimental investigation of the RV compressor, primarily in validating the operational principle of the new mechanism by adopting it as an air compressor has been provided. In these tests, the basic functionality of the new design has been proven by operating at shaft speeds of 600–1200 rpm and attaining pressure ratios of more than 8:1. In addition, measured values of the average torque, mechanical power, volumetric flow rate and transient pressure variations in the suction and compression chambers are shown to be in good agreement with theoretical predictions.

Teh and Ooi (2009c) [33] compared the leakage loss of the revolving vane compressor and rolling piston type compressor. The efficiency of the RV compressor, alike other refrigeration compressors, is primarily affected by mechanical and leakage losses. The leakage loss in the RV compressor which mainly occurs at the radial clearance between the rotor and the cylinder is analyzed theoretically. In comparison with the rolling piston type, the leakage loss at the radial clearance in the RV compressor is typically found to be 40% lesser than that of the former. Furthermore, the leakage loss can be significantly reduced by selecting a shorter configuration of the compressor, which is anticipated to yield good volumetric efficiencies of more than 95%.

For a first time in refrigeration compressors, a rotating discharge valve is employed in the RV compressor mainly due to the rotation of the entire cylinder **(Teh et.al.2009d) [34]**. Under the application of the Euler–Bernoulli beam theory, a mathematical model of the rotating valve is formulated and the transient response of the valve under centrifugal loads in addition to pressure forces is analyzed. Results have shown that under careful design considerations, the performance as well as the reliability of the rotating discharge valve can be enhanced as compared to a non-rotating valve that is used in all refrigeration compressors currently.

Yang et al. (2009)[35] investigated experimentally the internal working process especially the internal leakage of a rotary vane expander prototype, which was developed to replace the throttling valve to improve the Coefficient of Performance (COP) of the transcritical CO2 refrigeration cycle. The pressure diagram as a function of the rotation angle (p–ϴ diagram) was recorded by two pressure sensors arranged within the expansion chamber, based on which the features of the working process were analyzed and effects of the some improvement measures on the internal leakage were discussed. Compared with the ideal p–ϴ diagram, the recorded diagrams presented more rapid decrease in the pressure during expansion process, which was attributed to serious leakage within the expander.

Park (2010) [36] concentrated on transient analysis of a variable speed rotary compressor. A transient simulation model of a rolling piston type rotary compressor is developed to predict the dynamic characteristics of a variable speed compressor. The model is based on the principles of conservation, real gas equations, kinematics of the crankshaft and roller, mass flow loss due to leakage, and heat transfer. For the computer simulation of the compressor, the experimental data were obtained from motor performance tests at various operating frequencies.

Subiantoro and Ooi (2010) [37] has done the design analysis of the novel revolving vane expander in transcritical carbon dioxide refrigeration system. Four possible design variants of the Revolving Vane expander have been examined in relation to their application when using CO2 as the working fluid in a refrigeration cycle. The detailed examination of design components and illustrations are presented and discussed. The study shows that the Revolving Vane expander design configuration with the vane attached to the rotor and in which the rotor is also used as the driving component is the most superior design. It is found to have the highest mechanical efficiency and the most desirable variation of the power produced.

Okur and Akmandor (2011) [38] investigated hinged and spring loaded rolling piston compressors pertaining to a rotary engine. Hinged rolling piston compressor promises high performance figures such as single stage high compression levels and higher volume flow discharge with competitively low input power and torque. The pumping characteristic of the present engine compressor unit has been increased by the implementation of a spring less vane configuration. The reciprocating vane which is usually operated by spring compression in air conditioning and refrigeration unit has been replaced by a hinge vane mechanism. At high speeds, the conventional spring loaded vane which is forced against the eccentrically moving rotor periphery disconnects and starts rocking.

The design improvements in a Revolving Vane (RV) compressor which significantly reduce the frictional losses presented by **Tan and Ooi (2011) [39]**.The original RV compressor has a vane that swivels during the operation. Though in general, the frictional losses of the RV compressor are significantly lower than most currently available rotary compressors, this swivel vane design has a disadvantage of relatively high vane side friction loss. The latter is caused by a high vane-side and slot contact force due to a high gas pressure differential force across the vane. The new design concept has been introduced to totally eliminate the vane side friction loss caused by the gas pressure differential force across the vane. This is achieved by rigidly fixing the vane onto the rotor or the cylinder.

Leakage study via radial clearance in a novel synchronal rotary refrigeration compressor published by **Yang et al. (2011) [40]**.The leakage flow characteristics at the radial clearance between the rotor and the cylinder in a novel synchronal rotary (SR) refrigeration compressor were analyzed, and the oil refrigerant two-phase leakage flow model was established. The leakage at different temperatures caused by wall velocity and pressure difference was calculated, and their influence on the total leakage analyzed. The leakage caused by wall velocity has great influence on the total leakage, especially when the radial clearance is small.

5. CONCLUSION

In well-established designs such as the reciprocating piston-cylinder compressor, rotary vane compressor, screw compressor, rolling piston compressor and scroll compressor, much progress has been done in the past few decades. It is now need to innovate a new compressor design, which reduces the friction, leakages and discharge losses. Efforts are made in this direction by the authors. New rotor geometry has been developed, which leads to significant improvements in efficiencies of compressor and it enhances the coefficient of performance of refrigeration cycle. The information regarding this development will be discussed in near future.

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