ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 7, Issue 8 , August 2020

Thermal Analysis of Hermetic Reciprocating Compressor: A Review

Avadhut Anant Kulkarni, Nitin VasantSali

Research Scholar,Department of Mechanical Engineering,Government College of Engineering, Karad,Maharashtra, India
Associate Professor, Department of Mechanical Engineering,Government College of Engineering, Karad,Maharashtra, India

ABSTRACT: The effective design of a thermal component needs sound heat transfer analysis. The heat transfer analysis gives an idea of the thermal behavior of that component. The compressor is one of the essential parts of the VCRS system, on which most refrigerators and AC's work. The airtight and compact structure of the compressor makes the heat transfer analysis complex. The overheating of the compressor causes inefficiency. The main purpose of the study of heat transfer is to reduce overheating.

This paper is a small review of the work devoted to the area of heat transfer of the hermetic compressor. The study includes a description of the methods used, solution methodology, and various tools used by the researchers. Every method has some advantages and disadvantages but also fits best based on the purpose of the analysis.

KEYWORDS: Hermetic Compressor, Reciprocating compressor, Heat transfer, Thermal analysis.

I.INTRODUCTION

The HVAC industry is one of the fastest-growing and rapidly changing industries in the world. The refrigeration and air conditioning is an integral part of it. The refrigeration can be achieved by various means, among which the mechanical vapor compression refrigeration system (VCRS) is employed in all domestic, commercial, and industrial refrigeration system as well as in automotive climate control systems.[1]

Among the four major components of the VCRS system power requirement is mostly related to the compressor. The major compressors used for refrigeration are either semi-hermetic or fully hermetic compressors. In hermetic compressors, the motor and the compressor are enclosed in the same housing and they are airtight. This setting avoids refrigerant leaks, as leaks from compression are retained inside the compressor and are constantly incorporated into the system. This makes heat transfer analysis of the hermetic compressor a complex phenomenon.

According to Prasad [2], the heat transfer in compressor not only affect the efficiency but also the design, operation, and reliability of the compressor. Overheating of the compressor is nothing but unwanted temperature rise before actual compression. This leads to inefficiency because it reduces the volumetric efficiency of the compressor. This heating also ensures the entry of fully vaporized gas within the compressor. To reduce overheating one must know the temperature distribution. The prediction of temperature distribution is only possible with good heat transfer analysis. The various tools and techniques used by the researchers are explained in upcoming sections.

II. THERMAL ANALYSIS

A. Experimental Method

The experimental method is the first method used for the thermal analysis of the compressor. Instead of the development of new methods of thermal analysis, this method is widely used for the quick solution. The temperature measurement tool is used widely for the study of superheating in compressors. One more important use of this method is for the validation of simulation data.

In this method, thermal analysis is done by measuring temperature using temperature transducers, measuring the heat flux using heat flux sensors, pressure-volume measurement using an optical encoder, etc. These transducers are placed at different locations of the compressor. From the measured temperature values, the enthalpies at inlet and outlet are calculated and from these enthalpy values, the heat absorbed or released is calculated using the formula of the advective energy transfer.

$$Q = m\,(H_i - H_o)\;(1)$$

Then from the energy balance equation, it's a straightforward task to determine the heat transfer coefficient (U) from eq. (2).

$$Q = UA\,(T_g - T_s) \qquad (2)$$

The temperature measurement also enables us to know the hot and cold sources within the compressor.

The very common and easy method of temperature measurement is using thermocouples. Hence, from Meyer and Thompson [3] to Zhou et.al. [4] many researchers used thermocouples for temperature measurement as shown in Fig 1. The thermocouples are placed at different locations of the compressor like muffler, motor, shell, cylinder head etc.to measure the temperature either to study the overheating phenomenon or for experimental validation of the analytical results. Ooi et. al. [5] and Pizzaro [6] also did temperature measurement using thermocouple in different regions of the compressor for validation of their simulation models. The thermocouple wires are placed at different locations of compressors such as on inner parts like a muffler, cylinder head, etc. and outer shell. Dutra [7] used heat flux sensors and thermocouples for experimental investigation of heat transfer. The internal and external surfaces of the shell are divided into small regions and each region is instrumented with a heat flux sensor. Silva et. al. [8] used Heat flux sensors for investigation of heat transfer at on-off conditions as shown in fig. 2.

Fig1. Thermocouples mounted on the shell

Fig 2. Thermocouples mounted on the shell

Due to similarities in geometry and operation, many of the results applied to the compressor are from internal combustion engines. A similar methodology was used by Adair et. al. [9] in 1972. He used fast response thermocouples for evaluation and modification of correlations originally developed for I. C. Engines. Morrison [10] conducted an experimental study of heat transfer and flow in compressor by instantaneous temperature, pressure, and velocity measurement using a cold wire sensor used widely for measurements in I. C. Engines.

Dutra [11] used a technique of infrared thermography to find out the temperature distribution in the compressor. This technique gives the results with different colour bands and value. He also uses a heat flux sensor for calculation of heat transfer rate. Dincer et. al. [12] used pressure transducers and optical encoders for getting a time-dependent pressure-volume diagram. The compressor work is calculated from this diagram and given as a boundary condition to simulate transient heat flow.

B. Numerical Method

There is a lot of research carried out in the open literature regarding the prediction of temperature within the compressor using numerical analysis. This research involves mainly three types of models namely integrated model, differential model, and hybrid model.

1. *Integrated Model*

a) Lumped Model

In this model, the whole domain is divided into a small number of control volumes. The heat transfer coefficient is calculated experimentally in this model but some researchers also used correlation for that. The objective of this method is to study of overheating of suction gas and prediction of temperature distribution.

Todescat et.al. [13] developed a model for forecasting of temperature distribution in the small hermetic compressor. The compressor was divided into 4 control volumes and the first law energy balance was applied to each control volume. The heat conductances were calculated experimentally and overall heat balance was put forth by equating heat transfer from the gas inside the shell to the shell is equal to heat transfer from shell to the surrounding. The differential governing equations were solved using numerical methods through the simulation program.

Dutra et. al. [14] adopted the lumped model for heat transfer analysis of R134a based hermetic reciprocating compressor. The whole domain is divided into 8 control volumes including an electric motor. The heat transfer coefficient is obtained from experimental results. The model is divided into three sub-models: 1) Thermodynamic model 2) Thermal model for temperature forecasting 3) Electrical model for the motor. The model is solved by information exchange between these models using a coupled simulation program. The thermodynamic model gives mass flow rate, the electric model gives losses and this data is transferred to the thermal model to get the temperatures.

Zhou et. al. [4] presented the simplified lumped model for R290 commercial compressor. The model has only six control volumes as shown in Fig. 3 and the equation set is solved after one complete cycle of the crankshaft. The mass flow rate is also integrated over a 360-degree crank angle. The heat transfer coefficient is calculated from correlations. The results show good agreement with test results.

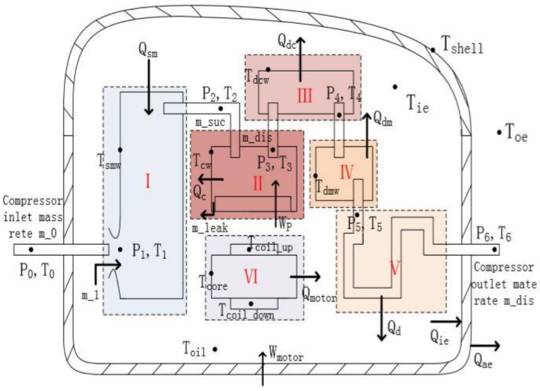

Fig 3. Lumped model of Zhou[4].

C) Thermal network method

The thermal network model is very similar to the lumped model conceptually. In both models, energy balance equations are formed using the first law of thermodynamics, governing equations solved numerically to get temperatures. The main difference between the Thermal network model and the lumped model is that the heat transfer coefficients are obtained from heat transfer correlations in the thermal network model instead of the experimental method. As correlations used for heat transfer calculations, this model considers the contribution of oil flow, radiation heat transfer from the motor, and all convective heat transfers. To get accurate results from the model it generally uses a large no. of elements to predict temperature distribution.

Ooi et. al. [5] presented a numerical model based on the thermal network method for R134a hermetic compressor. The computational domain is discretized into 46 thermal elements and thermal interaction between each element is modelled. The heat transfer correlations for different flow conditions within the compressor are studied and the geometry of compressor components is simplified for best fit to correlations. The set of equations is represented in matrix form and solved numerically using Gauss- Jorden method.

Haas [15] proposed a steady-state thermal network model for a hermetic compressor. The model has 3 main computational domains solid elements, fluid flow within control volume, and lubricating oil. All modes of heat transfer are taken into consideration. The whole compressor is divided into 63 control volumes. The motor losses and friction losses are obtained from experiments and taken as a heat source for the analysis. The results obtained from the model show a maximum deviation of 7 ^{0}C.

The integrated model is easy to adopt and usually adopted for simple and less expensive analysis. The main difficulty is to find the exact correlation for the calculation of the heat transfer coefficient. The temperature distribution in the solid component is also difficult to calculate by this method. Hence some studies in the literature are carried out by using differential methods.

2. *Differential Model*

This model has an objective to predict the fluid flow and heat transfer involved within the compressor. This model gives detailed behaviour of flow and interaction with different components of the compressor. This is done by discretizing the domain in thousands or millions of control volumes and solving the differential equations of mass, momentum, and energy for each element. It provides a detailed analysis of flow behaviour within components of a compressor at a faster rate and lowest cost than experimental methods. As this model involve the use of computers, it provides accurate and quick solution even for complex geometries.

Raja et. al. [16] presented a differential model for simulation of the household compressor. The model solves the computational domain using commercial CFD code and finite volume method. The domain is divided into four sub-domains: 1) Refrigerant 2) Lubricating oil 3) Stator and rotor and 4) Compressor block. The methodology used is the first refrigerant flow path is solved giving predicted temperatures and calculated heat transfer coefficients as input and secondly, the solid domain is solved by giving gas temperatures as input. The maximum deviation for the rotor is 7.8%and for the motor block it’s 8%.

Chikurde et. al. [17] and Birari et. al. [18] used commercial CFD code Ansys Fluent for the steady-state heat transfer analysis of the hermetic reciprocating compressor. The heat generated from motor losses, mechanical losses are calculated and given as a volumetric heat source boundary condition. The solid and fluid domain of [17] is shown in fig. 4. The simulation was divided into two steps, the first step is for the suction system and other for the discharge system. The dynamic mesh is used for compression process simulation. The motor and friction losses are calculated from the dynamometer test and taken as a heat source. The model is tested for R22 and R404C compressor. The results show a maximum 16^{0}C difference with the test result.

Wu et. al. [19] proposed a 3D simulation model to study temperature distribution in the motor of the R32 hermetic rotary compressor. The computational domain is divided into three sub-domains: i) Refrigerant gas model ii) Stator iron model iii) Stator winding model. Rotor losses are calculated from Anisoft software. The discharge temperature is given as an inlet boundary condition for simulation. The results of the simulation show good agreement with experimental results with variation less than 5^{o}C. According to the author integral approach to stator winding is sufficient for the thermal study of the motor.

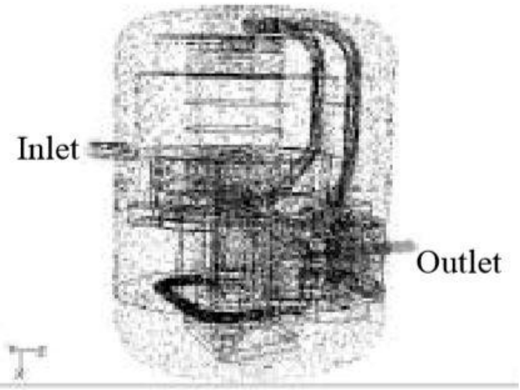

Fig 4. Computational domain of Chikurde et. al. [17]

This modelling method provides flexibility in compressor heat transfer analysis as it solves both fluid and solid domains. But, this model requires high computational time and optimization is also difficult. Complex phenomena like dynamics of refrigerant in the compression chamber, lubrication dynamics are still difficult with this technique.

3. *Hybrid Model*

The hybrid model combines an integrated model with a different model to solve complex heat transfer problems. The heat transfer in solid components, refrigerant heat transfer, and heat transfer related to oil can be easily solved by this model. It simply combines the simplicity of the integration model and the accuracy of the differential model.

Sanvezzo and Deschamps [1] developed a hybrid simulation model for heat transfer analysis. The temperature of the refrigerant at a different location is found using an integrated model similar to Todescat et. al. [13] and the solid temperatures are calculated using differential models. The heat transfer coefficients for heat transfer between solid components and refrigerant are calculated from correlations available in the literature. The author taken lubrication oil as a subdomain and correlations for oil heat transfer are also taken into considerations. The two models are solved simultaneously by exchanging the information. The results show good agreement with experimental results. The simulation results are shown in fig. 5.

Posch et. al. [20] presented a hybrid simulation model consist of three main parts. The refrigerant in the shell is considered as one control volume and the oil domain is divided into three control volumes. The solution algorithm starts with an initial guess of temperature in all parts, gas, and refrigerant oil. The commercial CFD code used is Ansys Fluent. All three domains are solved iteratively till the convergence criteria is reached. The models show the maximum difference of 4.2^{0}C with test results.

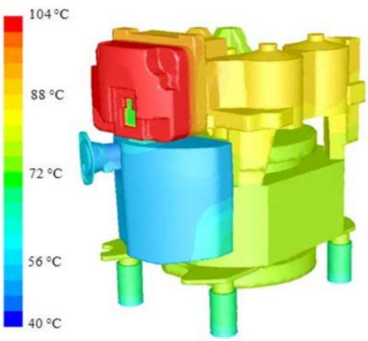

Fig 5. The temperature distribution of the gas path.

III. CONCLUSION

In order to design a more efficient and reliable compressor heat transfer analysis is an important step. Each method of analysis has its application area and differs from other methods in accuracy and complexity. The integration model is good for optimization, quick simulation, and approximate results at the lowest cost. Conversely, a different model can be easily adopted for complex parts and drastic changes, it also gives detailed temperature distribution but needs special skills and high cost of computation. The hybrid model is a compromise between the above two, it gives solid heat transfer along with better refrigerant heat flow at the lowest cost. The choice of the numerical method is based on the need for accuracy and complexity of the model.

REFERENCES

[1] Sanvezzo Jr.J, Deschamps. C.J. "A Heat Transfer Model Combining Differential and Integral Formulations for Thermal Analysis of Reciprocating Compressors", International Compressor Engineering Conference, July 16-19, 2012, paper 2210.
[2] Prasad B.G. Shiva. "Heat Transfer in Reciprocating Compressors - A Review",International Compressor Engineering Conference,1998, paper 1349
[3] Meyer W.A., ThompsonH. D."An Analytical Model of Heat Transfer to the Suction Gas in a Low-Side Hermetic Refrigeration Compressor",International Compressor Engineering Conference,1990, Pg. no: 898-907.
[4] Zhou R.,Guo B., Chen X., Tuo J., Wu R., Fagotti F., Zhao Y., Yang S., Xu B."Heat Transfer Simulation for Reciprocating Compressor with Experimental Validation", 10th InternationalConference on Compressors and their Systems, 2017, paper 012011.
[5] OoiK. T."Heat Transfer Study of a Hermetic RefrigerationCompressor", International Journal of Applied Thermal Engineering, 2003,Vol. 23,Pg. no: 1931-1945.
[6]Pizzaro R. "Influence of lubricating oil on transfer heat in an alternate airtight compressor",Dissertation of Master's degree- Federal University of Santa Catarina, Florianópolis, Brazil, 2007.
[7]DutraT., DeschampsC.J. "Experimental Investigation of Heat Transfer in Components of a Hermetic Reciprocating Compressor",International Compressor Engineering Conference, 2010, paper 2002.
[8]SilvaG., DutraT., DeschampsC.J. "Experimental Investigation of Heat Transfer in Components of a Hermetic Reciprocating Compressor under Thermal Transient",International Compressor Engineering Conference, 2016, paper 2464.
[9]AdairR.P., QvaleE. B., PearsonJ. T. "Instantaneous Heat Transfer to the Cylinder Wall in Reciprocating Compressors",International Compressor Engineering Conference, 1972, Pg. no: 521-526.
[10]MorriesenA."Experimental Investigation of Temperature Transients in Hermetic Reciprocating Compressors",Dissertation of Master's degree- Federal University of Santa Catarina, Florianópolis, Brazil, 2009.
[11]DutraT."Heat Flux Measurements in Reciprocating Compressors",Dissertation of Master's degree- Federal University of Santa Catarina, Florianópolis, Brazil, 2008.

[12] DincerM.O., SariogluK., KerpiciH. “Experimental and Numerical Heat Transfer Analyses of Exhaust Region of Reciprocating Compressor”, International Journal of Materials, Mechanics and Manufacturing, 2015,Vol.3, Pg no: 13-16.
[13]Todescat M.L.,Fagotti F., Prata A.T., Ferreira R. T.“Thermal Energy Analysis in Reciprocating Hermetic Compressors”,International Compressor Engineering Conference, 1992, Pg no: 1419-1428.
[14] Dutra T., Deschamps C.J.“A Simulation Approach of Hermetic Reciprocating Compressors Including Electrical Motor Modelling”, International Journal of Refrigeration, 2015,Vol. 59,Pg. no: 168-181.
[15]Haas D.A. “An equivalent thermal circuit model for the forecasting of temperature distribution alternative refrigeration compressors”,Dissertation of Master's degree- Federal University of Santa Catarina, Florianópolis, Brazil, 2012.
[16] RajaB., ShekharS.J., LalD.M., KalanidhiA. “The numerical model for thermal mapping in a hermetically sealed reciprocating refrigerant compressor”, International Journal of Refrigeration, 2003,Vol.26,Pg. no: 229-236.
[17]Chikurde R.C.,Loganathan E., Dandekar D.P“Thermal Mapping of Hermetically Sealed Compressors Using CFD”,International Compressor Engineering Conference, 2002, paper C-64.
[18]Birari Y.V.,Gosavi S.S., Jorawekar P.P.“Use of CFD in Design and Development of R404a Reciprocating Compressor”,International Compressor Engineering Conference, 2006, paper C-072.
[19]Wu J., Hu J., Chen A., Mei P., Zhou X., Chen Z.“Numerical Analysis of Temperature Distribution of Motor-Refrigerant in an R32 Rotary Compressor”,International Journal of Applied Thermal Engineering, 2016, Vol. 95,Pg. no: 365-373.
[20]Posch S., Hopfgartner J., Heimel M., Berger E., Almbauer R., Stangl S.“Thermal Analysis of a Hermetic Reciprocating Compressor Using Numerical Methods”,International Compressor Engineering Conference, 2016, paper 1215.

AUTHOR’S BIOGRAPHY

Avadhut A. Kulkarni is currently the research scholar at Government College of Engineering, Karad. He received his B.E. in Mechanical Engineering from Shivaji University, Kolhapur, India in 2017. Currently, he is pursuing M.Tech in Heat Power Engineering from at Government College of Engineering, Karad.

Nitin V. Sali is currently the Associate professor at Government College of Engineering, Karad. He received his B.E. in Mechanical Engineering from Shivaji University, Kolhapur, India in 1991. He received his M.E. in Heat Power Engineering from Shivaji University, Kolhapur, India in 1995. He has a total of 26+ years of teaching experience and published many research papers in national and international conferences and journals. He is a member of the Indian Society for Technical Education, New Delhi, and e-Journal of International Fluid Power System Association.