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THERMAL ANALYSIS OF RECIPROCATING COMPRESSORS PARTS

Mahir Hussain*

*Assistant Professor,
Department of Mechanical Engineering, Faculty of Engineering,
Teerthanker Mahaveer University, Moradabad, Uttar Pradesh, INDIA
Email id: mahir.engineering@tmu.ac.in

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ABSTRACT

The paper provides a comprehensive examination of various approaches to thermal analysis of reciprocating compressors. It is generally known that a significant portion of the inefficiency in small reciprocating compressors used for residential refrigeration is due to thermal effects, which are primarily manifested as superheating. As a result, being able to tune the compressor's thermal behaviors is critical for increasing its efficiency. In fact, it is widely assumed that the effectiveness with which the thermal issue is addressed will have a significant impact on future compressor improvements. The purpose of this work is to provide an overview of the various computational and experimental approaches for compressor thermal design that are currently used in the industry. Each methodology is briefly described, along with prospective applications for compressor analysis, as well as its key benefits and limitations. Finally, some new information concerning recent developments in this field is shared. The purpose of this research is to determine the temperature distribution on the piston's upper surface. Because damaged or broken parts are so expensive to replace, it is predicted that the top surface of the piston will be damaged or broken owing to temperature weather during operation.

KEYWORDS: *Air Compressor, High-Pressure Cylinder, Thermal Analysis.*

1. INTRODUCTION

Refrigerators and freezers account for about 8% of domestic electric energy consumption in the United States, according to recent estimates. One of the key reasons for the growing need for high-efficiency cooling systems is this. The compressor[1] is one of the most energy-intensive components of a vapor-compression refrigeration system[2]. The overall efficiency of a compressor is determined by three factors:

- Electrical efficiency[3], which is linked to the driving motor and its start-up auxiliary device;
- Mechanical efficiency[4], which is linked to the bearing system; and
- Thermodynamic efficiency[5], which is linked to irreversibility in the suction, compression, and discharge processes. a device that turns potential energy into power typically from an electric motor, diesel engine, or gasoline engine) by compressing air into a smaller volume and therefore increasing its pressure.

While the air stays pressured, the energy in the form of compressed air can be stored in the tank. These energies can be exploited for a variety of purposes, including harnessing the kinetic energy of depressurized air [8].

According to a basic analysis of current efficiency levels of state-of-the-art domestic reciprocating compressors, electric efficiency ranges from 87 to 88 percent. The use of synchronous motors might improve this efficiency even more; however such options are not always used due to cost concerns. The efficiency levels of the mechanical system are also fairly high, reaching up to 92 percent in some cases. It's worth noting that linear compressors and variable-speed compressors operating at lower speeds can provide even better mechanical efficiency. Temperature influences the material qualities, as well as the component's dimensional stability and integrity. The fact that the exit valves atop the High-Pressure Cylinder fail is a source of concern. The problem with the valve must be fixed right away. When a compressor's valve or valve plate breaks, serious damage might occur. Low-Pressure Cylinder features two suction valves and two delivery valves in the Air Compressor. High-Pressure Cylinder has one suction valve and one delivery valve at the same time. All valves are found in the Low- and High-Pressure Cylinder Heads, respectively.

Thermodynamic efficiency is substantially lower, ranging between 80 and 83 percent in most cases. As a result, it is evident that future increases in compressor efficiency will almost certainly be linked to lower thermodynamic losses. Figure 1 depicts the sources of thermodynamic losses in a high-efficiency compressor working with R134a and a capacity of 900 BTU/h. As shown in Fig. 1, the suction and discharge operations account for the majority of the thermodynamic losses due to viscous losses in the vapour route from the suction line to the cylinder and from the cylinder to the discharge line, respectively. Much effort has gone into reducing energy losses in the suction and discharge systems, primarily through the reduction of flow limitations.

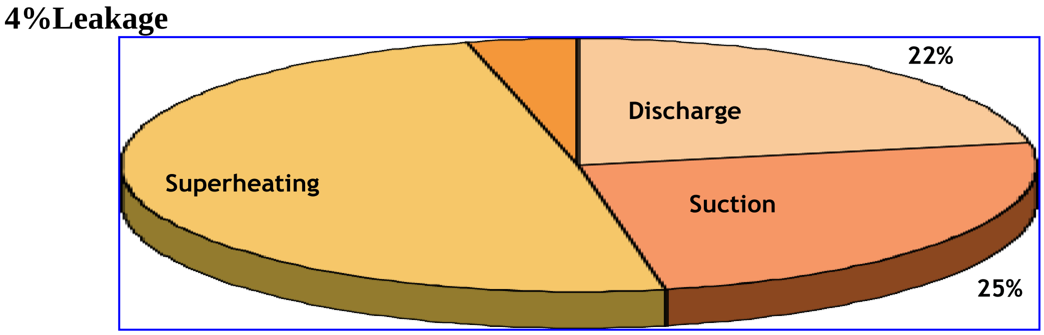


Figure1: Sources of thermodynamic losses in a900BTU/h compressor, operating with R134a.

Superheating[6] is a large contributor to thermodynamic losses, but it has gotten far less attention throughout time. According to research (1998) provided an excellent summary of research on this topic up to 1998, including an assessment of important breakthroughs in theoretical, computational, and experimental approaches. The author stated that more work remains to be done in order to fully comprehend the heat transfer phenomenon in compressors, as well as to build numerical models and experimental approaches to account for this in compressor design. He came to the conclusion that the heat transfer phenomenon in reciprocating compressors was misunderstood as a technology problem. Superheating affects the compressor volumetric efficiency in addition to the thermodynamic efficiency, because the gas density in the compression chamber is directly related to the gas temperature. As a result, the lower the gas temperature, the lower the volumetric efficiency.

Suction and discharge losses and superheating losses are two separate phenomena. The losses caused by viscous effects may be easily isolated in the former, and then proposed methods to reduce them, such as modifying the geometric characteristics of acoustic filters and valves. Superheating losses, on the other hand, are influenced by a variety of factors that might combine in complex ways. For example, in the suction process, gas heating might occur at the muffler walls, which are warmed by the gas inside the compressor shell. However, heat is released through hot sources, such as the gas discharge tube, and through the shell wall to the external ambient, resulting in the temperature of the gas inside the compressor shell.

Since of the aforementioned reasons, thermal analysis of compressors is a tough undertaking because the complexity of compressor geometry precludes simple modeling approaches. Understanding all essential parameters operating on gas heating during its passage from the suction line up to the compression chamber is critical in order to discover alternatives to reduce superheating losses. The current work provides a comprehensive overview of existing experimental techniques and numerical methodology for analysing compressor thermal behavior. Each technique is described briefly, along with its key benefits and downsides. The most recent breakthroughs in this field are also discussed. The authors sincerely apologise for the lack of any linked work in this study area, as a review is a very lengthy activity that is always bound to be incomplete.

2. ANALYSIS:

The use of thermocouples[7] to characterize the thermal behavior of compressors is arguably the most traditional and well-established technique. This is an intrusive technique in which several wires are placed inside the compressor shell to carry the thermocouple signal to the data acquisition system, as shown in Fig. 2. As a result, proper wire positioning is critical to avoid any significant changes in the gas dynamics inside the compressor. The use of thermocouples, in addition to being a fairly simple technique, allows for energy balances in numerous compressor components by assessing the gas enthalpy fluctuation between the entrance and departure sections, as shown in Fig. 3. As a result, the thermal energy, $\dot{Q}_W$, being emitted or absorbed in each component of the compressor can be estimated as follows:

$$\dot{Q}_W \square (\dot{m}h)_{in} \square (\dot{m}h)_{ou} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(1)$$

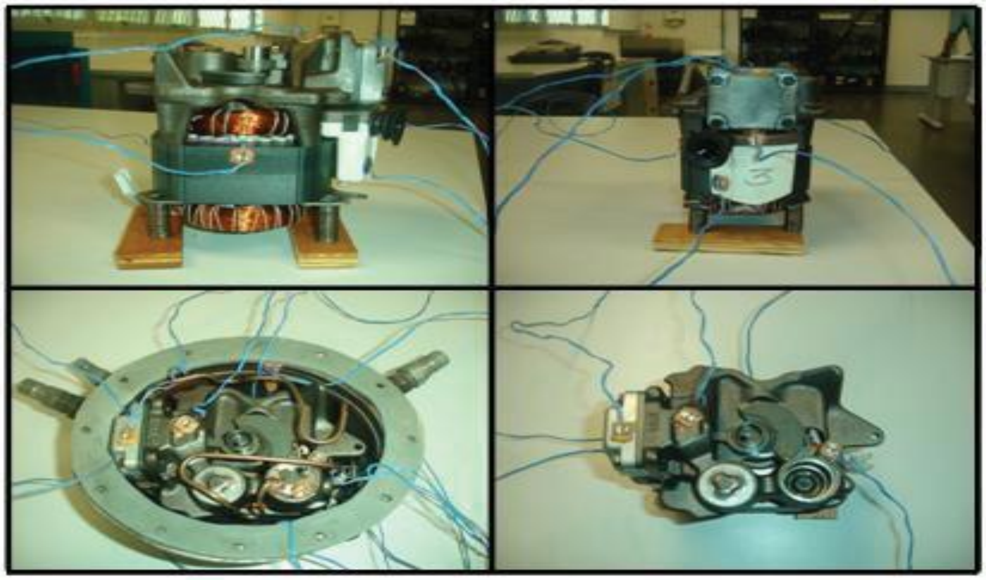
Then, it is as straight for ward task to character rize the heat transfer process at the component wall through the concept to fan equivalent thermal conductance(UA):

$$\dot{Q}_W \square UA \square (T_{gas} \square T_{amb}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots.(2)$$

Naturally, in equation (1), the values of enthalpy at the entrance and exit sections of the component can be estimated from the temperature measurements at the same locations.

Therefore, with temperature measurements also for the gas in side the component, T_{gas}, and for the gas in the surrounding ambient, T_{amb}, the equivalent conductance (UA) can be found from equation (2).

Figure2: Typical Arrangements of Thermocouples for Thermal Analysis of Compressors.



Temperature measurements can also reveal the presence of hot and cold sources in the compressor, allowing for the identification of components that have a significant impact on the superheating process. The following are the primary disadvantages of utilising thermocouples to investigate compressor thermal dynamics:

- The data is limited to temperature, preventing a comprehensive investigation of the heat transfer[8] between compressor components. This is a significant disadvantage since understanding this thermal interaction is necessary for innovative layout concepts that reduce the amount of heat transported to the suction gas.
- The response time of thermocouples is substantially faster than that necessary to register the gas temperature fluctuations that occur inside residential refrigeration compressors. This is due to their thermal inertia, which can be reduced significantly with the use of micro-thermocouples.

Heat flux sensors[9], as illustrated in Fig. 3, are another option for characterizing the heat transfer dynamics inside the compressor. Although heat flux sensors have been employed in other applications, such as the thermal mapping of household refrigerators, their usage in hermetic compressors is significantly more problematic due to the limited space available internally. Furthermore, the compressor's interior atmosphere, which is made up of lubricating oil and refrigerant, is particularly harsh on some of the materials used to build such sensors on the walls. Other challenges include thermal contact resistance between the sensor and the surface, as well as thermal radiation characteristics discrepancies between the sensor and the wall surfaces. Regardless of how these issues are resolved, heat flux may be directly measured, and thermal analysis is significantly improved. Heat transfer coefficients in some compressor components can be obtained by combining heat flow and temperature measurements, which can be utilised as input data for numerical simulation models or as information to assist understand the prevalent heat transfer mechanism in each component.

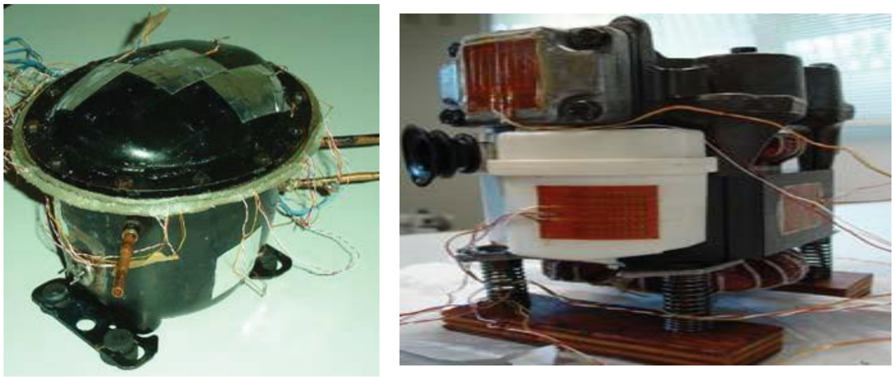


Figure3: Use of Heat Flux Sensors in Refrigeration Compressors.

Because compressor temperatures are relatively low, thermal radiation emissions are concentrated in the infrared band. As can be observed in Fig. 3, infrared thermograph[10] is a suitable additional tool for investigating the compressor temperature profile. Temperature data are typically made accessible on some part of the surface in such devices in order to determine the surface emissivity and, ultimately, the temperature field. An infrared camera can provide far more information than thermocouples, as well as a visual image that allows temperature comparisons over a vast region. In addition, because it functions in a non-contact mode, infrared thermograph has relatively little impact on the heat transfer process itself, unlike thermocouples. However, some scenarios, such as the existence of no uniform surface emissivity and measurements for internal components, may make infrared thermograph challenging, necessitating the use of infrared transparent windows to provide access.

Designers have started looking for energy reductions at any cost, as the compressor's efficiency is approaching its limitations and energy shortages are looming on the horizon. This has prompted experts to reexamine the impact of heat transport on performance and reliability. Compressors efficiency[11] The early phases of such efforts were marred by disagreements between different organizations, and it wasn't until the 1980s that the impact of heat transfer on compressor performance was recognized.

3. NUMERICAL ANALYSIS:

The development and implementation of numerical approaches to forecast the thermal behavior of refrigeration compressors has been the subject of a number of studies in the literature. In general, such approaches can be classified into three categories, as outlined below. Integral Numerical Model:

From the analysis developed a numerical model in which control volumes are linked by equivalent thermal conductance calibrated using experimental data for the compressor thermal profile at a given operating condition. At each point throughout the working cycle, the energy balance for the refrigerant inside the cylinder is calculated, taking into consideration time fluctuations in mass and energy fluxes. The numerical model can anticipate various complicated processes inside the compressor thanks to the experimental calibration. However, this limits the model's flexibility in terms of precisely predicting the compressor thermal profile caused by changes in compressor layout. In addition, if the compressor operating condition differs significantly from the reference condition used to calibrate the model, modifications to the conductances are required.

Hybrid Numerical Model:

Differential and integral formulations are integrated in this method to address a conjugate heat transfer problem, which is usually for isolated components like suction and discharge mufflers, cylinder head, and compression chamber. The hybrid model has a number of advantages over the pure integral model, including the ability to resolve conduction heat transport in solid domains. The hybrid model, on the other hand, must be calibrated using experimental data as well.

Differential Numerical Model:

This type of modeling aims to solve both conduction heat transfer and gas fluid flow in compressor components at the same time. The major goal is to forecast fluid flow and heat transfer in a certain design, allowing for a more cost-effective and faster study of components than is possible with experimental methods. The rise in popularity of this sort of compressor simulation approach is linked to the fact that computers are getting more powerful and less expensive, making simulations of very big issues possible. However, because the governing equations must be solved using numerous numerical approximations and physical models, simulation approach is currently lagging behind experimental analysis as a design tool.

4. LITERATUREREVIEW:

- Almbauer et al. (2006) combined three approaches to numerically simulate the temperature field of a compressor cylinder-piston system: I a one-dimensional differential formulation for the fluid flow conservation equations; ii) a three-dimensional formulation for conduction heat transfer in the cylinder-piston solid domain; and iii) a lumped formulation for the thermal energy ballast. The deduction of heat transfer correlations between particular masses, according to the authors, is a disadvantage of the generally utilised Thermal Network (TNW) calculation.
- Ribas Jr. (2007) devised a methodology for solving three-dimensional heat transfer by conduction in the compressor crankcase, using an integral experimentally calibrated numerical method comparable to Todescat et al. (1992) to account for convective heat transfer between the gas and the crankcase. Although the model is largely based on experimental data, it enables for component thermal optimization because the conduction heat transfer interaction between the components is precisely defined. As a result, the temperature distribution in solid components is better understood.
- Using a commercial CFD code, Chikurde et al. (2002) numerically studied the fluid flow and heat transport processes in a 1.5 tonne A/C hermetic compressor. The simulation was run under a steady-state condition, with the mass flow rate and suction gas temperature set at the inlet. The numerical results were found to be quite close to the experimental results.
- Abidin et al. (2006) provided a computational model for simulating the solid and fluid domains of a compressor piston-cylinder system, as well as the domain change caused by piston motion. The decision to use only a portion of the compressor domain was made to save money on computational processing. Separately from the solid domains, the fluid domain was simulated. The heat flux boundary conditions at the interfaces between the solid and fluid domains are evaluated using the temperature results from the transient fluid

simulation. New values for the interface temperature are acquired after solving the energy equation in the solid domain and passed as a boundary condition to the fluid.

5. CONCLUSIONS:

Gas superheating can account for up to half of the thermodynamic losses in a small reciprocating compressor, as illustrated in this research. As a result, gaining a better understanding of the compressor's thermal dynamics is essential. for further tuning and the creation of a family of high-efficiency compressors For this thermal characterization, there are a variety of experimental and numerical methodologies with varying degrees of precision and complexity. In terms of experimental methodologies, in addition to thermocouples, some attempts to incorporate more sophisticated devices to characterize the heat transfer phenomenon inside the compressor, such as infrared cameras, heat flux sensors, and temperature sensors with fast response times, have been observed. Several new strategies for numerical simulation techniques have been proposed in recent years, including improvements to integral models based on lumped energy conservation equations and differential models to solve three-dimensional conduction heat transfer in the solid domain, as well as to resolve thermal coupling between the solid domain and the fluid flow. Naturally, each numerical modelling method has its own set of benefits and drawbacks. Integral models, for example, are computationally cheap and an excellent choice for compressor optimization, but they can't account for the effects of severe changes in compressor layout. The most comprehensive models, on the other hand, provide a very detailed representation of the compressor thermal profile at a significantly greater computational cost. The environment in which the thermal analysis is to be applied determines the numerical simulation model to be used. The optimum method for compressor design, according to experience, is to integrate numerical models with experimental techniques, so that each can complement the other. This enables for more accurate results and a better physical knowledge of the compressor's thermal dynamics, as well as the investigation of ways to reduce superheating losses. Based on the findings of this study, more research will be conducted at both the fundamental and application levels to improve the current ability to address the impact of heat transfer on compressor performance.

REFERENCES:

1. H. Sixmith and H. Altmann, “A regenerative compressor.” 1976.
2. A. M. A. Soliman, S. H. Taher, A. K. Abdel-Rahman, and S. Ookawara, “Performance enhancement of vapor compression cycle using nano materials,” 2015, doi: 10.1109/ICRERA.2015.7418526.
3. J. G. Koomey, S. Berard, M. Sanchez, and H. Wong, “Implications of historical trends in the electrical efficiency of computing,” IEEE Ann. Hist. Comput., 2011, doi: 10.1109/MAHC.2010.28.
4. P. Zamparo, A. E. Minetti, and P. E. Di Prampero, “Mechanical efficiency of cycling with a new developed pedal-crank,” J. Biomech., 2002, doi: 10.1016/S0021-9290(02)00071-4.
5. Å. Jernqvist, K. Abrahamsson, and G. Aly, “On the efficiencies of absorption heat pumps,” Heat Recover. Syst. CHP, 1992, doi: 10.1016/0890-4332(92)90015-A.

6. R. Balasubramanian, “Superheating of liquid alkali metals,” Int. J. Thermophys., 2006, doi: 10.1007/s10765-006-0098-2.

7. SMITH CP, “THERMOCOUPLES,” Eng Matls Des., 1969, doi: 10.1049/pbce033e_ch3.

8. R. D. Jackson and S. A. Taylor, “Heat transfer,” in Methods of Soil Analysis, Part 1: Physical and Mineralogical Properties, Including Statistics of Measurement and Sampling, 2015.

9. O. V. Lobach and V. A. Gridchin, “Smart wireless heat flux sensor,” 2015, doi: 10.1109/APEIE.2014.7040854.

10. R. Usamentiaga, P. Venegas, J. Guerediaga, L. Vega, J. Molleda, and F. G. Bulnes, “Infrared thermography for temperature measurement and non-destructive testing,” Sensors (Switzerland). 2014, doi: 10.3390/s140712305.

11. M. Yang, “Air compressor efficiency in a Vietnamese enterprise,” Energy Policy, 2009, doi: 10.1016/j.enpol.2009.02.019.