Pedro Cruz Alcantar, et. al. International Journal of Engineering Research and Applications
www.ijera.com
ISSN: 2248-9622, Vol. 14, Issue 1, January, 2024, pp 58-64

RESEARCH ARTICLE OPEN ACCESS

Design, Construction, and Evaluation of a Reverse Cycle Machine for Educational Use

Pedro Cruz Alcantar[1], Isaac Compeán Martinez[1], Horacio Bautista Santos[2,3], Rafael Figueroa Díaz[4], Ambrocio Loredo Flores[1], Héctor Arturo Álvarez Macias[1], Josefa Morales Morales[1]*

[1]*Unidad Académica Multidisciplinaria Región Altiplano, Universidad Autónoma de San Luis Potosí UASLP–UAMRA, Carretera Cedral Km, 5+600 Ejido San José de las Trojes, Matehuala, San Luis Potosí 78700, México*
[2]*Tecnológico Nacional de Mexico/ Instituto Tecnológico Superior de Chicontepec, Calle Barrio Dos Caminos No. 22. Colonia Barrio Dos Caminos, Chicontepec, Veracruz 92709, México*
[3]*Tecnológico Nacional de México/ Instituto Tecnológico Superior de Tantoyuca, Desviación Lindero Tametate S/N, Colonia La Morita, Tantoyuca, Veracruz 92100, Mexico; horacio.bautista@itsta.edu.mx*
[4] *Departamento de Ingeniería Eléctrica y Electrónica, Instituto Tecnológico de Sonora, ITSON, 85130. Cd Obregón, México*

ABSTRACT

This article presents the design and construction of a reverse cycle machine for educational purposes. The first stage focused on the conceptual design, defining the essential components of a thermal machine and their interconnection to create a conceptual prototype. Subsequently, a complete machine was built using recycled materials, which was capable of performing the proposed refrigeration and heating cycles. In the final stage, the thermal efficiency of the machine was evaluated. To do this, temperatures and pressures were measured at key points, allowing the creation of thermodynamic diagrams of the cycles and determining the thermal characteristics of the machine. This approach not only demonstrates the feasibility of building educational thermal machines with second-hand materials but also emphasizes the importance of efficiency evaluation in thermal systems.

Keywords - Cooling systems, Educational , Refrigeration cycle, Reversed cycle, Thermal characterization

Date of Submission: 09-01-2024 Date of acceptance: 23-01-2024

I. INTRODUCTION

The training of new engineers in the field of energy, particularly thermal energy, is crucial in the current context marked by increasing pollution, global warming, and climate change. Thermal energy focuses on studying the thermodynamic relationships between heat and work in refrigeration systems or power generation, making it a vital field for various industrial applications such as conservation, process cooling, and space conditioning.

Universities play a key role in training these engineers, providing education in the design, installation, commissioning, and efficiency analysis of thermal equipment. A current trend in this field is the use of reversed cycle machines for space conditioning, which combine refrigeration and heating in a single unit, providing significant economic benefits [1-2].

In-depth knowledge of these machines is essential for newly trained engineers to be competitive in the job market and potentially create their own employment. This practical approach is particularly relevant for students in Administrative Mechanical Engineering (IMA) and Mechatronics Engineering (IMT), as it directly impacts their training in areas such as thermodynamics, thermal machines, heat transfer, and mechanical-mechatronic design. Practical learning about the operation of components such as compressors, heat exchangers, valves, expansion elements, instrumentation, and control is invaluable.

In summary, education in thermal energy, particularly through practical application in the design and construction of reversed cycle machines, is crucial for preparing engineers for current and future challenges in the field of engineering [3-4].

II. METHODOLOGY

Vapor Compression Refrigeration

A real vapor compression refrigeration cycle differs from an ideal one in several aspects, mainly due to irreversibilities occurring in various components. Two common sources of irreversibility are fluid friction (which causes pressure drops) and heat transfer to or from the surroundings. The T-S diagram of a real vapor compression refrigeration cycle is shown in the following Figure 1.

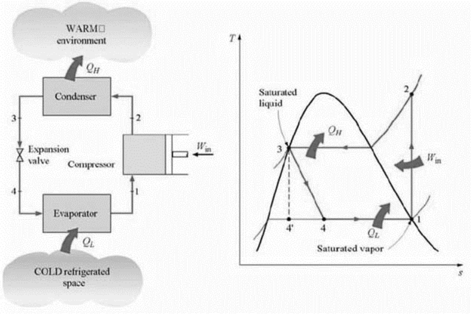

Fig. 1. Schematic and T-S diagram for the ideal vapor compression refrigeration cycle [5].

In the ideal cycle, the refrigerant leaves the evaporator and enters the compressor as saturated vapor. However, in practice, it's not possible to control the state of the refrigerant with such precision. Instead, it's easier to design the system so that the refrigerant slightly overheats at the compressor's inlet. This slight overheating ensures that the refrigerant is completely evaporated when it enters the compressor. Also, the line connecting the evaporator with the compressor tends to be very long; therefore, the pressure drop caused by the fluid's friction and the heat transfer from the surroundings to the refrigerant can be very significant. The result of the overheating, the heat gain in the connecting line, and the pressure drops in the evaporator and the connecting line, is an increase in the specific volume and, consequently, an increase in the compressor's power input requirements since the work of steady flow is proportional to the specific volume. The compression process in the ideal cycle is internally reversible and adiabatic, and therefore isentropic. However, the actual compression process will include friction effects, which increase the entropy and heat transfer, which may increase or decrease the entropy, depending on the direction. Consequently, the refrigerant's entropy may increase or decrease during an actual compression process, depending on the predominance of the effects. The compression process may even be more desirable than the isentropic compression process because the refrigerant's specific volume and, consequently, the work input requirement are smaller in this case. Thus, the refrigerant should be cooled during the compression process whenever it is practical and economical to do so. In the ideal case, it is assumed that the refrigerant leaves the condenser as a saturated liquid at the compressor's exit pressure. In reality, some pressure drop in the condenser is inevitable, as well as in the lines connecting it with the compressor and the throttling valve. Also, it's not easy to execute the condensation process with such precision as to have the refrigerant as a saturated liquid at the end, and it is undesirable to send refrigerant to the throttling valve before it is fully condensed. Consequently, the refrigerant is slightly subcooled before entering the throttling valve. Despite all this, it should be kept in mind since the refrigerant enters the evaporator with a lower enthalpy and therefore can absorb more heat from the refrigerated space. The throttling valve and the evaporator are located very close to each other, so the pressure drop in the connecting line is small.

Heat Pump System

Heat pumps are generally more expensive than other heating systems, but when purchased and installed, they save money in some areas because they reduce the heating bill. Despite their relatively higher initial costs, the popularity of heat pumps is increasing. About a third of all homes built for small families in the United States in the last decade of the 20th century were heated with heat pumps. The most common energy source for heat pumps is atmospheric air (air-to-air systems), although water and soil are also used. The main problem with systems that use air as a source is frost formation, which occurs in humid climates when the temperature drops below 2 to 5ºC. Frost accumulation on the evaporator coils is quite undesirable as it interrupts heat transfer. However, the coils can defrost it when the heat pump cycle is reversed (operating it as an air conditioner). This causes a reduction in system efficiency. Systems that use water as a source typically use groundwater at depths of up to 80 m in the temperature range between 5 and 18ºC, and do not have frost formation problems. They usually maintain higher COPs, but are more complex and require installations to reach a large water reservoir, like groundwater. Systems that use soil as a source are also few, as they require large piping located under the ground at a certain depth where the temperature is relatively constant. The COP of heat pumps almost always varies between 1.5 and 4, depending on the particular system used and the source temperature. A new class of pumps recently developed, powered by a variable speed electric motor, is at least twice as efficient as its predecessors. Both the capacity and efficiency of a heat pump decrease significantly at low temperatures. Consequently, most heat pumps that use air as a source require a supplementary heating system such as electric resistance heaters, or a gas or oil furnace. Considering that the temperatures of water and soil do not vary much, perhaps supplementary heating is not required in systems that use water or soil as a source. However, heat pump systems must be sized sufficiently to meet the maximum heating load. Heat pumps and air conditioners have the same mechanical components. Therefore, it is not economical to have two separate systems to cover the heating and cooling requirements of a building. A system can be used as a heat pump in winter and as an air conditioner in summer. This is achieved by adding a reversing valve to the cycle, as shown in Figure 2. As a result of this modification, the heat pump's condenser (located indoors) functions as the air conditioner's evaporator in the summer. In addition, the heat pump's evaporator (located outdoors) serves as the air conditioner's condenser. This feature increases the competitiveness of the heat pump. Such dual-purpose units are frequently used in motels [5].

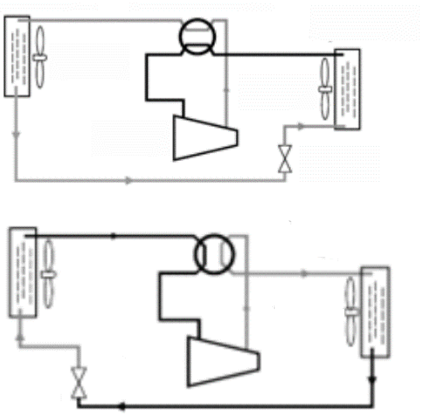

Fig. 2. Schematic diagram of a heat pump operation in winter and summer

III. DESIGN AND CONSTRUCTION OF THE REVERSE CYCLE MACHINE

The components of a compression refrigerator are as follows.

- Heat Exchanger 1.
- Compressor.
- Heat Exchanger 2.
- Expansion valve or expansion element.
- 4-way valve.
- Fan.
- Filter.

Figure 3 shows the CAD design of the reverse cycle machine that was designed."

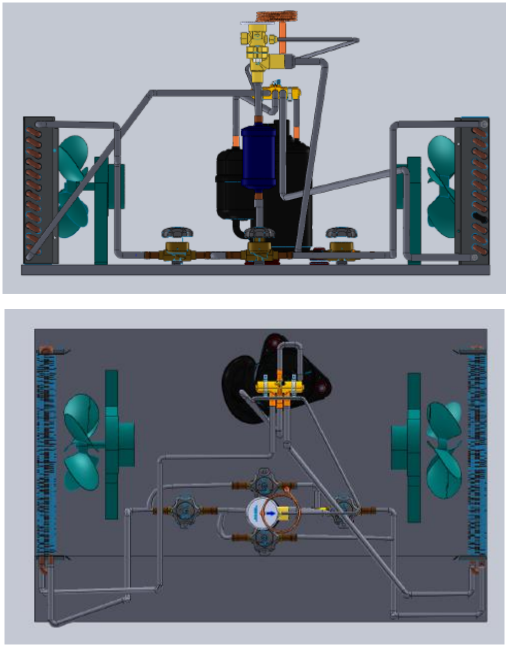

Fig. 3. Solidworks model of the reverse cycle machine design.

Figure 4 shows the final construction of the machine, where all the components and their assembly can be seen.

Fig. 4. Final construction

IV. EXPERIMENTATION

This section discusses the electronic elements and devices used in the thermal characterization of the reverse cycle machine, such as data acquisition modules, and devices for measuring temperature and pressure. Finally, the strategy for locating temperature measurement points in the system is presented, along with the results of implementing instrumentation in the system. The points where it was considered important to measure the temperatures of the hybrid system in order to obtain the thermodynamic cycle efficiency of the system and express it in the Mollier diagram are:

- Evaporator output.
- Condenser output.
- Compressor input.
- Compressor output.
- Expansion valve output.
- Ambient Temperature

Additionally, an extra thermocouple was added to monitor changes in ambient temperature. Figure 5 shows the location of the installed thermocouples, and Figure 6 shows the reverse cycle machine with instrumentation.

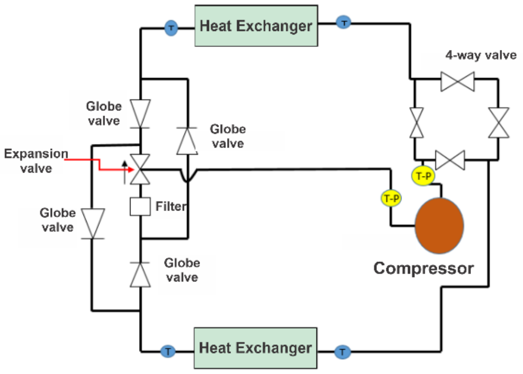

Fig. 5. Location of thermocouples in the system.

Fig.6. Instrumented reverse cycle machine.

V. RESULTS

The temperatures and pressures of the cycles were measured on several days, the following figure shows the most representative results obtained. For the characterization of the reverse cycle machine.

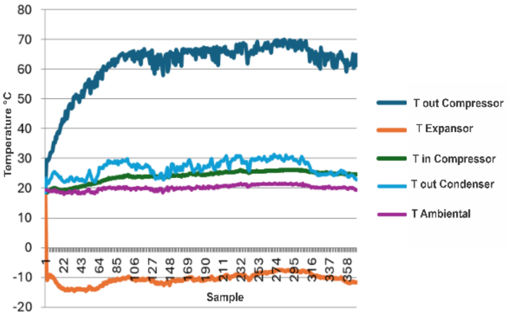

Fig.7. Test of the system temperature measurement system

The experimental test method was based on the ISO/WD 9806-1 standard and specifically on the input-output method. The method consists of measuring the thermodynamic input and output state of the working fluid to estimate the energy gained by the same, as an intensive variable the enthalpy of the coolant is used.

Energy Performance of the Reverse Refrigeration Cycle

The Coefficient of Performance is the ratio between the useful energy (heat removed by the evaporator) and the energy consumed (the energy to operate the compressor). This is related in the following equation:

$$\boldsymbol{COP = \frac{Q_{Evap}}{W_{comp}}}$$

Where:

COP is the system performance, Q_Evap is the heat in the evaporator (KJ/Kg), W_(comp) is the work in the compressor, and Q_col is the heat in the solar collector. One of the most practical ways to obtain the necessary parameters to estimate the COP is to use the Mollier diagram of the working fluid. For the system under study, the working fluid corresponds to refrigerant 22. Therefore, the Mollier diagram of the refrigerant was used to graphically obtain the intensive properties to determine the COP. It is important to highlight that the Mollier diagram for refrigerant 22 relates enthalpies, entropies, pressures, temperatures, quality, specific volume, among others.

Thermodynamic diagrams for cycle 1(cooling)

Two points were taken from the data measured during the experimentation. The thermodynamic properties of the states to be plotted are as follows:

Table 1. Thermodynamic properties for the refrigeration cycle

	Process 1
Point 1	P=8.9bar , T=57°C
Point 2	P=6.5 bar , T=25°C
Point 3	P=2 bar- T=-12°C
Point 4	P=1.2 bar, T=22°C

Diagrams for process 1

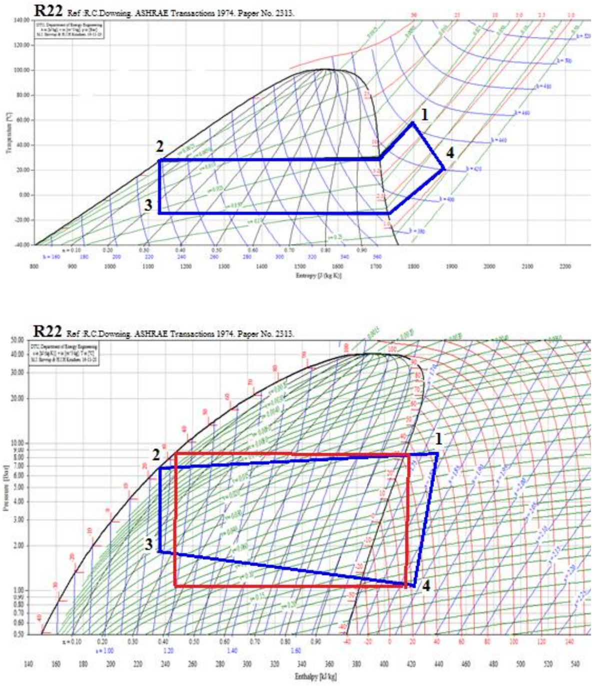

Fig. 8. P-h and T-S diagram for the refrigeration cycle

The heat input Q_e :

$$Q_e = h_4 - h_3$$

$$Q_e = (421.1 - 231.2)kJ/kg = 189.9\ kJ/kg$$

Compressor work:

$$W_c = h_1 - h_4$$

$$W_c = (440.2 - 421.1)kJ/kg = 19kJ/kg$$

Heat output:

$$Q_s = h_1 - h_2$$

$$Q_s = (440.2 - 234.9)kJ/kg = 205.2\ kJ/kg$$

With the above results, the operating coefficient of the compression refrigeration system is:

$$COP = \frac{h_4 - h_3}{h_1 - h_4}$$

$$COP = \frac{421.16 - 231.26}{440.22 - 421.16} = 9.9$$

Thermodynamic diagrams for cycle 2 (heating)

Two points were taken from the data measured during the experimentation. The thermodynamic properties of the states to be plotted are as follows:

Table 2. Thermodynamic properties for the refrigeration cycle

	Process 2
Point 1	P=8.9bar , T=66°C
Point 2	P=7 bar y T=27°C
Point 3	P=2 bar y T=-10°C
Point 4	P=1.2 bar y T=25°C

Diagrams for process 2

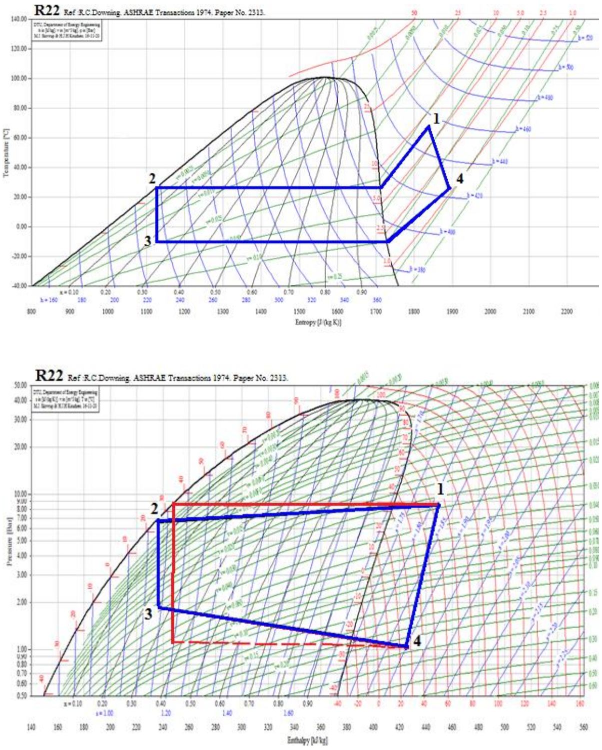

Fig. 9. P-h and T-S diagrams for the heating cycle

The heat input Q_e :

$$Q_e = h_4 - h_3$$

$$Q_e = (424.1 - 233.2) kJ/kg = 190.87\ kJ/kg$$

Compressor work:

$$W_c = h_1 - h_4$$

$$W_c = (449.6 - 424.1) kJ/kg = 25.5\ kJ/kg$$

Heat output:

$$Q_s = h_1 - h_2$$

$$Q_s = (449.6 - 237) kJ/kg = 212.6\ kJ/kg$$

With the above results, the operating coefficient of the compression refrigeration system is:

$$COP = \frac{h_4 - h_3}{h_1 - h_4}$$

$$COP = \frac{424.1 - 233.2}{449.6 - 424.1} = 7.4$$

The previous results show that the efficiencies for the refrigeration cycle and the heating cycle are similar and with acceptable values for such systems. The cycle change for the machine is efficient even though its components are made of recycled materials. For the system studied in this work, coefficients of 7.4 to 11.6 were obtained.

VI. CONCLUSIONS

Based on the results obtained throughout the presented work, the following conclusions are drawn:

- The reverse cycle machine designed and built with recycled material works correctly for both refrigeration and heating cycles.
- Comparing the performance coefficients, it can be observed that they are very similar, indicating that the machine performs well for each cycle.
- The prototype of the reverse cycle machine is operational and in conditions suitable for use in training new engineers.

REFERENCES

[1] Barrón, R. T., Castro, A., Morales, F., Rojas, D., Torres, M. (2001). Manual de prácticas e implementación de un banco de pruebas de laboratorio para sistemas de refrigeración por compresión (tesis de licenciatura). Universidad veracruzana. Poza Rica Veracruz.

[2] López, A. (2011). Instrumentación y puesta a punto de un sistema de refrigeración solar por

absorción intermitente (tesis de licenciatura). Universidad veracruzana. Coatzacoalcos, Veracruz.

[3] Moreno, L. F., López, A., Guerrero, E. D., Martínez, J. M. (2004). Monitoreo en tiempo real de las variables físicas de un panel solar a través de LabView. Instituto tecnológico superior de Zacapoaxtla. La Mecatrónica en México, Vol. 3, No. 2, páginas 27 – 34. Zacapoaxtla, Puebla.

[4] Bolaños, A., Vargas, A. (1999). Análisis experimental del refrigerante R134a en el banco de refrigeración del laboratorio de conversión de energía (tesis de licenciatura). México D.F.

[5] Yunes A. Çengel y Michael A. Boles. (2012). Termodinámica, 7ª edición, México, D.F., México.: Mac Graw Hill1.