Performance Evaluation of Domestic Refrigerator with Waste Heat Recovery System

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Abstract. The objective of the article is to study the performance of domestic refrigerator with waste heat recovery system. The usage of domestic refrigeration systems are increasing every day due to the requirement. During the operation of domestic refrigeration system, heat is rejected through the condensing coil to the atmosphere and leads to thermal pollution. Hence this heat can be recovered by suitable waste heat recovery system and employed for useful domestic applications. Hot chamber box has been fabricated and assembled with the domestic refrigerator. Experimental analysis has been carried out under air cooled condenser and hot chamber condenser with different loading conditions like no load, 1 litre, 3 litres, 5 litres, and 10 litres of water in the evaporator unit. COP is calculated for all the loading conditions and compared with air cooled condenser and hot chamber condenser. COP of all the loading conditions is maintained almost in the same range value. COP value is obtained in the range of 5 to 5.5 for the air cooled and hot chamber condensation modes. Hence the performance of domestic refrigerator is not changed due to the running of hot chamber box. Due to installation of hot chamber box waste heat is recovered from the condenser coil. The maximum heat recovery is arrived in the range of 31.15 to 33.66 kJ/kg.

Key words: COP, Domestic refrigerator, Hot chamber box, Waste heat recovery.

1. INTRODUCTION

Refrigeration is the science of producing and maintaining temperature below that of the atmosphere temperature. This indicates that the removing the heat from a substance through a refrigeration cycle. Maintaining the low temperature in a space using refrigeration system could be employed for preservation of food materials, vegetables, fruits, medicines, etc. Heat always travels from higher temperature to lower temperature region. With help of external sources, heat can travel from lower temperature to higher temperature. Refrigerators are working based on the statement of second law of thermodynamics. Most of the domestic refrigerators are belongs to Vapour Compression Refrigeration System (VCRS) and the main components of VCRS are compressor, condenser, expansion device and
evaporator. The working fluid of the refrigeration system is termed as refrigerant which is defined as a substance that absorbs latent heat through vaporization and rejects the same during the condensation. During the condensation process, large amount of heat is released from the condenser coil of refrigerator to the atmospheric air. Hence the cooling effect is obtained in the evaporator of the VCRS. Heat rejected from the condenser coil can be recovered by a suitable waste heat recovery system. By retrofitting a waste heat recovery system, condenser heat can be recovered and can be utilised for various domestic applications like maintaining food items at warm condition. It is possible to improve the overall performance of the refrigeration system by utilizing the waste heat generated from the refrigerator. Development of such efficient methods can be employed for heating the food items which reduces the extra energy cost incurred to heat the food items separately.

Waste heat from the domestic refrigerator was utilized for water heating application which can be used for different applications in houses. Maximum temperature of 44.3°C for water is obtained from the refrigeration system with the domestic refrigerator capacity of 165 litres and overall performance of the refrigerator is also enhanced [1]. Domestic refrigerator with waste heat recovery system provides an increase in overall effectiveness of domestic refrigerator and provides energy saving. There is an improvement in COP of the domestic refrigerator and waste heat could be used for heating applications [2]. The use of waste heat recovery system in a domestic refrigerator is employed for water and air heating applications. Temperature gradient of 10°C between air inlet & outlet was achieved and water temperature has increased upto 46°C. COP of the domestic refrigerator is also enhanced without change of normal refrigeration effect [3]. Experimental study was executed on VCRS under different evaporator loads like 50,100,150,200 and 250 Watts. During the process, the heat rejected in the condenser was applied for sub cooling purpose of another refrigeration system. Results show that improvement in condenser heat rejection rate, refrigeration effect and COP of the system [4]. Condensing coil length plays an important role in the heat rejection rate from the condenser and variable lengths of condenser coil have executed in this study. Usage of condenser coil length about 9.75 m in domestic refrigerator offers 5.74% improvement in COP compared to the existing system. Net refrigeration effect is improved about 5.81% more than the existing system and the power consumption is about 5.48% less than the existing VCRS. Hence more heat rejection occurs in the condenser coil and improvement in heat rejection is about 4.85% more than the existing condenser [5].

Heat rejected from the condenser coil of 1 TR air-conditioning system was examined. Rejected heat was used for water heating applications and mass flow rate water was varied from 20 to 200 lph. At lower mass flow rate of water, the water temperature was achieved about 60°C. Cooling and heating effect are achieved by using air-conditioning system [6]. Waste heat recovery system has assembled with the refrigeration system to recovery the condenser heat and recovered heat was used for water heating application. Temperature gradient was obtained about 46°C [7]. Modified heat exchange has employed in air-conditioning system and the experimental results shows that the waste heat is recovered from the air conditioning system. Increase in COP is obtained about 13% from the analysis and thermal pollution is also reduced [8]. 165 litres capacity refrigerator has used and the condenser heat is recovered by the waste heat recovery system. Water temperature was reached about 50.6 °C in outside the cabin [9].

Water cooled condenser was assembled with the refrigeration system to receive the heat rejected from the condenser. Maximum water temperature is reached about 50°C in 3 hours of operation and average temperature was obtained about 40°C. Overall performance of the refrigeration system was enhanced without changing the normal cooling effect [10]. Water tank capacity of 100 litres has used to observe the heat rejected from the condenser of the refrigerator and the maximum temperature was achieved by 45°C under full load operation. Based on the quantity of water in the tank, the heating time has varied. This provides better performance of the refrigeration system and reduces the thermal degradation of the environment due to condenser heat [11]. Performance evaluation of vapour compression refrigeration system was completed under different loading conditions in the evaporator chamber [12].

In summary, VCRSs are widely used for domestic applications in present scenario. Hence the performance improvement of the refrigeration system should be concentrated by reducing the electricity consumption and also proper utilization of waste heat from the domestic refrigerator for different applications. Literature shows that most of the studies are carried out to improve the performance of the domestic refrigerator by utilizing the waste heat from the condenser coil effectively. Recovered waste
heat could be used for numerous applications like heating of food items, cookies, hot water, etc. Experimental study has carried out on a domestic refrigerator with a waste heat recovery system and discussed the practical feasibility.

2. MATERIALS AND METHODOLOGY

The main components of VCRS are compressor, condenser, expansion valve and evaporator. Experimental arrangement has been arranged with two modes of condensation namely air cooled condenser and hot chamber condenser. Figure 1 represents the experimental arrangement of the domestic refrigerator with the proposed condensation modes. The capacity of the domestic refrigerator is 195 litres. Existing air cooled condenser (copper) is having the dimensions of 0.005m in diameter and 8.40m in length with equally spaced aluminium fins. For the same area of the existing air cooled condenser, with the help of copper tube of 0.008m diameter a hot chamber box condenser has fabricated and the hot chamber condenser is assembly with the domestic refrigerator at the top. Pressure and temperature measurements are observed at different state points like 1, 2, 3 and 4 by pressure gauge and thermocouples respectively. Thermocouples are also used to measure the temperature inside the hot chamber box. Gate valves are mounted between the air cooled condenser and hot chamber condenser in order to bypass the flow of refrigerant in different modes. Photographic view of the experimental arrangement is shown in Figure 2.

Flow diagram of the experimental system is shown in Figure 3. Vapour refrigerant at low temperature and pressure (1) enters into the compressor where it is compressed isentropically. Subsequently its pressure and temperature increased (2). Then the high-pressure vapor state refrigerant enters into the hot chamber box from compressor and the heat available in the refrigerant is used to heat the hot chamber box. After the hot chamber box, vapour state refrigerant enters into the air cooled condenser coil where it is condensed into the high-pressure liquid state refrigerant (3). High pressure/low temperature liquid state refrigerant is expanded through the expansion valve (4) and allowed to flow inside the evaporator where the cooling effect is induced. Due to absorption of heat inside the evaporator chamber, the refrigerant is converted into low pressure/temperature vapour refrigerant (1) and the same cycle repeats.

Figure 1. Experimental arrangement of domestic refrigerator with hot chamber box condenser

Figure 2. Photographic view of the experimental arrangement
Figure 3 Flow diagram of the experimental system

A temperature controller unit is assembled with the experimental system and temperature is controlled in the hot chamber box by accepting signals from the temperature sensors through thermocouple. It compares the actual temperature which is produced in the hot chamber box with the desired control temperature or set point temperature. Based on the set point temperature limit, the exhaust fan will rotate automatically to drain the excess hot air which accumulated inside the hot chamber box. When the set point temperature is reduced inside the hot chamber box, the exhaust fan get stopped its operation and allows the hot chamber box to reach the required set point temperature. Temperature sensor is placed inside the hot chamber box and received input signals are given to the temperature controller. Measured temperature is indicated in digital temperature indicator and set point temperature is also arranged in the indicator. The photographic view of the temperature controller is shown in Figure 4.

Figure 4 Photographic view of temperature controller

3. EXPERIMENTAL ANALYSIS

Experimental analysis is executed in two modes of operations like air cooled condensation and hot chamber box condensation. In order to run the experimental system in the above modes, valves are employed at different locations of the experimental arrangement. By opening and closing of these valves, the experimental analysis has executed in air cooled condensation and hot chamber box condensation. These valves provide the change of circulation of refrigerant at the desired modes and bypass the flow of the refrigerant to the two different condensers. First the refrigerant is circulated to flow through existing air cooled condenser and the experimental analysis is completed with different loading conditions like no load, 1 litre, 3 litres, 5 litres, and 10 litres of water in the evaporator. For each loading condition, experimental system has been run for the time period of 100 minutes and each 10 minutes interval temperature and pressure measurement has noted at different locations like compressor inlet and outlet, condenser outlet and evaporator inlet. This experimental observations are repeated for the air cooled condenser and hot chamber condensation modes. During these modes of operation, hot chamber temperature is also noted in the middle and bottom positions. The temperature controller controls the temperature inside the hot chamber box according to the set point temperature. R134a is charged in the
VCRS. The following empirical correlations are used to calculate the various output parameters like work input supplied, condenser heat rejection rate, refrigeration effect and COP.

\[ W_{in} = m_r (h_2 - h_1) \]  
\[ Q_{rej} = m_r (h_3 - h_2) \]  
\[ RE = m_r (h_1 - h_4) \]  
\[ COP = RE/W_{in} = (h_1 - h_4)/(h_2 - h_1) \]

4. RESULTS AND DISCUSSION

Enthalpy values are calculated at different states like compressor inlet \((h_1)\) and outlet \((h_2)\), condenser outlet \((h_3)\) and evaporator inlet \((h_4)\) using the empirical relations. Based on the enthalpy values, the various output parameters like work input supplied, condenser heat rejection rate, refrigeration effect and COP are calculated at different loading conditions. COP is the prime parameter for any refrigeration system to identify its performance. Hence, COP has been calculated for the different loading conditions in evaporator for air cooled condenser and hot chamber condenser. The variation in COP is plotted with respect to experimental time. 100 minutes has been taken for each experiment in air cooled condenser and hot chamber condenser modes. The variation in COP with respect to experimental time for air cooled condenser and hot chamber condenser is represented in Figure 5, 6, 7, 8 and 9 for the different loading conditions like no load, 1 litre, 3 litres, 5 litres, and 10 litres respectively. The COP values are arrived about 5 to 5.5 for the both mode of condensations. Due to change in loading conditions in the refrigeration system, COP values are varied for the hot chamber condenser and air cooled condenser.
Experimental study has been executed for the period of 100 minutes under each loading conditions. When the time increases, the required cooling effect is also progressed in a increased mode. Hence, COP of the refrigeration system is decreased with increase in time under air cooled condenser and hot chamber condenser operations. Figure 10 represents the variation of waste heat recovered in the hot
chamber box at different loading conditions. Waste recovery rate is increased when the experimental time is increased for all the loading conditions. The maximum heat recovery is arrived in the range of 31.15 to 33.66 kJ/kg. Based on the different capacity of domestic refrigerators, hot chamber box can be designed and implementation of this concept in the domestic refrigerator increases the overall performance of the system. Cooling and heating effect are achieved by using the domestic refrigerator and holds economic feasibility for real time implementation.

![Waste heat recovered in the hot chamber box at different loading conditions](image)

Figure 10 Waste heat recovered in the hot chamber box at different loading conditions

5. CONCLUSION

Experimental analysis has been performed on domestic refrigerator with waste heat recovery system and the following points are noted based on the results obtained.

- Domestic refrigerator with waste heat recovery system was experimentally investigated at various load conditions like no load, 1 litre, 3 litres, 5 litres, 10 litres and the performance parameters are calculated and compared on each load conditions.

- Waste heat recovery system performs well along with the domestic refrigerator. Hence the condenser heat can be trapped and applied for various domestic applications like maintaining food at warm condition.

- The performance of domestic refrigerator is indicated by the term COP. COP of all the loading conditions is maintained almost in the same range value. COP value is obtained between 5 to 5.5 for the air cooled and hot chamber condensation modes respectively.

- Hence the performance of domestic refrigerator is not changed due to the running of hot chamber box.

- Waste heat recovery rate is increased when the experimental time is increased for all the loading conditions. The maximum heat recovery is arrived in the range of 31.15 to 33.66 kJ/kg.
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