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Heat Recovery and Storage from Vapour Compression Refrigeration Cycle

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ABSTRACT

Heat energy is the main source of life, using it in an economical way leads to a pollution free environment. Fossil fuels are the main source to produce heat energy in our day-to-day life which results in formation of greenhouse gases and global warming. In current situation we can't avoid it completely but reduce it in many areas. That's why we made a heat recovery system to from vapour compression refrigeration system, considerable amount of heat is waste sent to the atmosphere at a range of 30^0C to 50^0C. That heat will be used in the heating purpose due to this we can reduce the usage of external heaters and reduce the use of fossil fuels. Recovery is apart but storing of the recovered heat from the system is much use full by phase changing materials like paraffin wax. While using a combined waste heat recovery and heat storage system we recovered 32^0C to 43^0C of heat within 3 hours in domestic and commercial purpose vapour compression refrigeration system. This will considerably reduce the global warming and greenhouse gases forming, reduce the expenses for external heater's, highly use full in commercial areas require constant cooling and heating purpose.

KEYWORDS: Heat recovery, Heat storage, VCR, PCM

1. INTRODUCTION

Waste heat is heat, which is generated in a process by way of fuel combustion or chemical reaction, and then "dumped" into the environment even though it could still be reused for some useful and economic purpose. The essential quality of heat is not the amount but rather its "value". The strategy of how to recover this heat depends in part on the temperature of the waste heat gases and the economics involved. Large quantity of hot flue gases is generated from Boilers, Kilns, Ovens and Furnaces. If some of this waste heat could be recovered, a considerable amount of primary fuel could be saved. The energy lost in waste gases cannot be fully recovered. However, much of the heat could be recovered and loss minimized by adopting.

An attempt has been made to utilize waste heat from condenser of vapour compression refrigeration system. This heat can be used for number of domestic and industrial Purposes. The study has shown that such a system is Technically feasible and economically viable. Refrigerator an Air conditioner which is been previously made exert a lot of amount heat through condenser to overcome this wastage of heat. We decide to develop This machine this heat is utilized for heating water and collecting in box we have also taken review of Previous which help us to decide the work plan for This machine.

In this project waste heat energy is converted to useful source without disturbing refrigeration cycle. The refrigerator with hot box the discharge line of compressor is by passed before it goe;s to regular condenser, it passed through system (PCM and in insulated box known as hot box). After passing through system line is connected to evaporator then the compressor.

1.1 Heat Recovery Systems

Depending upon the type of process, waste heat can be rejected at virtually any temperature from that of chilled cooling water to high temperature waste gases from an industrial furnace or kiln. Usually higher the temperature, higher the quality and more cost effective is the heat recovery. In any study of waste heat recovery, it is absolutely necessary that there should be some use for the recovered heat. Typical examples of use would be preheating of combustion air, space heating, or pre-heating boiler feed water or process water. With high temperature heat recovery, a cascade system of waste heat recovery may be practiced to ensure that the maximum amount of heat is recovered at the highest potential. An example of this technique of waste heat recovery would be where the high temperature stage was used for air pre-heating and the low temperature stage used for process feed water heating or steam raising.

1.1.1 High Temperature Heat Recovery

The temperatures of waste gases from industrial process equipment in the high temperature range. All of these results from direct fuel fired processes.

1.1.2 Medium Temperature Heat Recovery

The temperatures of waste gases from process equipment in the medium temperature range. Most of the waste heat in this temperature range comes from the exhaust of directly fired process units.

1.1.3 Low Temperature Heat Recovery

The following Table lists some heat sources in the low temperature range. In this range it is usually not practical to extract work from the source, though steam production may not be completely excluded if there is a need for low-pressure steam. Low temperature waste heat may be useful in a supplementary way for preheating purposes.

Table 1.1 Temperature Range

SOURCE	TEMPERATURE (℃)
Furnace doors	32–55
Bearings	32–88
Injection molding machines	32–88
Air compressors	27–50
Pumps	27–88
Internal combustion engines	66–120
Air conditioning and refrigeration condensers	32–43
Liquid still condensers	32–88

1.1.4 Benefits Of Waste Heat Recovery

Benefits of 'waste heat recovery' can be broadly classified in two categories:

1.1.5 Direct Benefits:

Recovery of waste heat has a direct effect on the efficiency of the process. This is reflected by reduction in the utility consumption & costs, and process cost.

1.1.6 Indirect Benefits:

a) **Reduction in pollution:** A number of toxic combustible wastes such as carbon monoxide gas, sour gas, carbon black off gases, oil sludge, Acrylonitrile and other plastic chemicals etc., releasing to atmosphere if/when burnt in the incinerators serves dual purpose i.e., recovers heat and reduces the environmental pollution levels.

b) **Reduction in equipment sizes:** Waste heat recovery reduces the fuel consumption, which leads to reduction in the flue gas produced. This results in reduction in equipment sizes of all flue gas handling equipment’s such as fans, stacks, ducts, burners, etc.

c) **Reduction in auxiliary energy consumption:** Reduction in equipment sizes gives additional benefits in the form of reduction in auxiliary energy consumption like electricity for fans, pumps etc.,

1.1.7 Development Of A Waste Heat Recovery System

Understanding the process

Understanding the process is essential for development of Waste Heat Recovery system. This can be accomplished by reviewing the process flow sheets, layout diagrams, piping isometrics, electrical and instrumentation cable ducting etc. Detail review of these documents will help in identifying:

a) Sources and uses of waste heat

b) Upset conditions occurring in the plant due to heat recovery

c) Availability of space

d) Any other constraint, such as dew point occurring in an equipment etc.

1.1.8 Economic Evaluation of Waste Heat Recovery System

It is necessary to evaluate the selected waste heat recovery system on the basis of financial analysis such as investment, depreciation, payback period, rate of return etc. In addition, the advice of experienced consultants and suppliers must be obtained for rational decision. Next section gives a brief description of common heat recovery devices available commercially and its typical industrial applications.

1.2 HEAT STORAGE

Heat or cold in the physical sensei's a form of energy and can be stored in various ways and for many different applications. There are various ways to classify thermal energy storage (TES) materials and systems. Most commonly three types of TES systems are distinguished:

- **Sensible heat storage**- results in an increase or decrease of the storage material temperature, stored energy is proportional to the temperature difference of the used materials.
- **Latent heat storage**- is connected with a phase transformation of the storage materials (phase change materials - PCM), typically changing their physical phase from solid to liquid and vice versa. The phase change is always coupled with the absorption or release of heat and occurs at a constant temperature. Thus, the heat added or released cannot be sensed and appears to be latent. Stored energy is equivalent to the heat (enthalpy) for melting and freezing.
- **Thermochemical heat storage**- is based on reversible thermochemical reactions. The energy is stored in the form of chemical compounds created by an endothermic reaction and it is recovered again by recombining the compounds in an exothermic reaction. The heat stored and released is equivalent to the heat (enthalpy) of reaction.

1.2.1 Storage of latent heat

Materials for the storage of latent heat are also named phase change materials (PCM), because of the fact that they change their physical phase from solid to liquid and vice versa. The phase change is always coupled with the absorption of heat when the solid melts — heat of melting — and a heat release when the liquid solidifies. The phase change occurs at the melting temperature Tm. At that temperature, these materials melt when heat is added, but do not exhibit a rise in temperature. Thus, the heat added cannot be sensed and appears to be latent. The most prominent advantage of storage concepts using the latent heat is the option to store energy within a narrow temperature range close to the phase change temperature. A change of one crystalline form into another without a physical phase change may also be considered as storage of latent heat. The heat of solid-solid phase changes (rearrangement of crystalline forms) is typical smaller compared to the heat of melting and solidification. Although enthalpies are large, the liquid-gas phase change is not utilized for latent heat storage due to the large volume of the gas phase.

The development of a latent heat storage system starts with the selection of the PCM. The temperature of the phase change should correspond to the specific application. For the temperature range below 120 °C organic PCMs can be utilized. At temperatures above 120 °C, critical aspects of organic PCMs include the long-term thermal stability, the reactivity with oxygen and the high vapor pressure.

1.3 Refrigeration Cycles

Refrigeration is the science of producing and maintaining temperatures below that of the surrounding atmosphere. This means the removing of heat from a substance to be cooled. Heat always passes downhill, from a warm body to a cooler one, until both bodies are at the same temperature. Maintaining perishables at their required temperatures is done by refrigeration. Not only perishables but to-day many human work spaces in offices and factory buildings are airconditioned and a refrigeration unit is the heart of the system.

In simple, refrigeration means the cooling of or removal of heat from a system. The equipment employed to maintain the system at a low temperature is termed as refrigerating system and the system which is kept at lower temperature is called refrigerated system. Refrigeration is generally produced in one of the following three ways:

- By melting of a solid.
- By sublimation of a solid.
- By evaporation of a liquid.

Most of the commercial refrigeration is produced by the evaporation of a liquid called refrigerant. Mechanical refrigeration depends upon the evaporation of liquid refrigerant and its circuit includes the equipment naming **evaporator, compressor, condenser** and **expansion valve.** It is used for preservation of food, manufacture of ice, solid carbon dioxide and control of air temperature and humidity in the air-conditioning system.

1.3.1 Important Refrigeration Applications:

- Ice making
- Transportation of foods above and below freezing
- Industrial air-conditioning
- Comfort air-conditioning
- Chemical and related industries
- Medical and surgical aids
- Processing food products and beverages
- Oil refining and synthetic rubber manufacturing
- Manufacturing and treatment of metals
- Freezing food products
- Miscellaneous applications

1.3.2 Refrigeration Systems

The various refrigeration systems may be enumerated as below:

- Ice refrigeration
- Air refrigeration system
- Vapour compression refrigeration system
- Vapour absorption refrigeration system
- Special refrigeration systems

(i) Adsorption refrigeration system (ii) Cascade refrigeration system

(iii) Mixed refrigeration system (iv) Vortex tube refrigeration system

(v) Thermoelectric refrigeration (vi) Steam jet refrigeration system.

1.3.3 Air Refrigeration System

Introduction

Air cycle refrigeration is one of the earliest methods of cooling developed. It became obsolete for several years because of its low co-efficient of performance (C.O.P.) and high operating costs. It has, however, been applied to aircraft refrigeration systems, where with low equipment weight, it can utilize a portion of the cabin air according to the supercharger capacity. The main characteristic feature of air refrigeration system, is that throughout the cycle the refrigerant remains in gaseous state.

1.3.4 Reversed Carnot Cycle

If a machine working on reversed Carnot cycle is driven from an external source, it will work or function as a refrigerator. The production of such a machine has not been possible practically because the adiabatic portion of the stroke would need a high speed while during isothermal portion of stroke a very low speed will be necessary. This variation of speed during the stroke, however is not practicable.

p-V and T-s diagrams of reversed Carnot cycle are shown in Figs. 14.1 (a) and (b). Starting from point l, the clearance space of the cylinder is full of air, the air is then expanded adiabatically to point p during which its temperature falls from T1 to T2, the cylinder is put in contact with a cold body at temperature T2. The air is then expanded isothermally to the point n, as a result of which heat is extracted from the cold body at temperature T2. Now the cold body is removed; from n to m air undergoes adiabatic compression with the assistance of some external power and temperature rises to T1. A hot body at temperature T1 is put in contact with the cylinder. Finally, the air is compressed isothermally during which process heat is rejected to the hot body.

1.3.5 Reversed Brayton Cycle

An air refrigeration system working on reversed Brayton cycle. Elements of this systems are:

1. Compressor 2. Cooler (Heat exchanger) 3. Expander 4. Refrigerator.

In this system, work gained from expander is employed for compression of air, consequently less external work is needed for operation of the system. In practice it may or may not be done e.g., in some aircraft refrigeration systems which employ air refrigeration cycle the expansion work may be used for driving other devices. This system uses reversed Brayton cycle which is described below:

(a) and (b) shows p-V and T-s diagrams for a reversed Brayton cycle. Here it is assumed that (i) absorption and rejection of heat are constant pressure processes and (ii) Compression and expansion are isentropic processes.

1.3.6 Simple Vapour Compression System

Introduction

Out of all refrigeration systems, the vapour compression system is the most important system from the view point of commercial and domestic utility. It is the most practical form of refrigeration. In this system the working fluid is a vapour. It readily evaporates and condenses or changes alternately between the vapour and liquid phases without leaving the refrigerating plant. During evaporation, it absorbs heat from the cold body. This heat is used as its latent heat for converting it from the liquid to vapour. In condensing or cooling or liquifying, it rejects heat to external body, thus creating a cooling effect in the working fluid. This refrigeration system thus acts as a latent heat pump since it pumps its latent heat from the cold body or brine and rejects it or delivers it to the external hot body or cooling medium. The principle upon which the vapour compression system works apply to all the vapours for which tables of Thermodynamic properties are available.

1.3.7 Simple Vapour Compression Cycle

In simple vapour compression system fundamental processes are completed in one cycle. These are:

1. Compression 2. Condensation 3. Expansion 4. Vaporization.

The vapour at low temperature and pressure (state ‘2’) enters the “compressor” where it is compressed isentropically and subsequently its temperature and pressure increase considerably (state ‘3’). This vapour after leaving the compressor enters the ‘‘condenser” where it is condensed into high pressure liquid (state ‘4’) and is collected in a “receiver tank”. From receiver tank it passes through the “expansion valve”, here it is throttled down to a lower pressure and has a low temperature (state ‘1’). After finding its way through expansion “valve” it finally passes on to “evaporator” where it extracts heat from the surroundings or circulating fluid being refrigerated and vapourises to low pressure vapour (state ‘2’).

1.3.8 VAPOUR ABSORPTION SYSTEM

Introduction

In a vapour absorption system, the refrigerant is absorbed on leaving the evaporator, the absorbing medium being a solid or liquid. In order that the sequence of events should be continuous it is necessary for the refrigerant to be separated from the absorbent and subsequently condensed before being returned to the evaporator. The separation is accomplished by the application of direct heat in a ‘generator’. The solubility of the refrigerant and absorbent must be suitable and the plant which uses ammonia as the refrigerant and water as absorbent will be described.

1.3.9 Simple Vapour Absorption System

The solubility of ammonia in water at low temperatures and pressures is higher than it is at higher temperatures and pressures. The ammonia vapour leaving the evaporator at point 2 is readily absorbed in the low temperature hot solution in the absorber. This process is accompanied by the rejection of heat. The ammonia in water solution is pumped to the higher pressure and is heated in the generator. Due to reduced solubility of ammonia in water at the higher pressure and temperature, the vapour is removed from the solution. The vapour then passes to the condenser and the weakened ammonia in water solution is returned to the absorber. pumping a liquid requires much less work than compressing a vapour between the same pressures) but a heat input to the generator is required. The heat may be supplied by any convenient form e.g., steam or gas heating.

1.3.10 Practical Vapour Absorption System

Although a simple vapour absorption system can provide refrigeration yet its operating efficiency is low. The following accessories are fitted to make the system more practical and improve the performance and working of the plant.1. Heat exchanger. 2. Analyzer. 3. Rectifier.

2. LITERATURE REVIEW

Romdhane ben slama developed a system that can recover heat from the condenser of the refrigerator. In this work air-cooled conventional condenser is replaced by another heat exchanger to heat water. The results show that water at a temperature of 60ºC was produced by the system. This paper also analyzed the economic importance of the waste heat recovery system from the energy saving point of view.

Jarag Sachin, Ghutukade S T et el Potential Estimation of Waste Heat Recovery from Window Air Conditioner. they analyses, it has been understand that by replacing the normal Air Conditioner by this system will help to save numbers of LPG gas cylinders per year. This not only saves the cost but also it protects the environment by reducing the global warming engendered because of LPG gas. By extracting heat from the Air conditioning unit which are going to the environment, we are able to lower Global warming considerably. If this system is established all over world, excessive amount of LPG gas gets saved.

Shinde, V. Dhanal et el presented a case study on Super Heat Recovery Water and It can be concluded that the system, as in while operating under full load condition gives a better COP as compared to no load condition. Hence if the system continuously operates under full load, the COP can be improved. The heat absorbed by water has been observed to be highest during full load. The heat recovery technique, which can be applied to a refrigeration system, provides a compound air-cooling and water-cooling. The use of heat recovery system illustrates the improvement in COP and also the reduction in power consumption. The temperature difference obtained between the water inlet and outlet exceeds 10o C.

Patil and Dange modified a domestic 190 liter refrigerator to recover the waste heat by installing a water tank containing the condenser coils of refrigerator. Experiment showed that maximum temperature increment was up to 40 degree centigrade. But major drawback with this type of arrangement was that it had no mobility and cannot be used for domestic purposes.

N. B. Chaudhari discussed Heat Recovery System from the Condenser of a Refrigerator. The quantity of heat to be recovered from the condenser of a domestic refrigerator was theoretically calculated. It is in the range 375 Watt to 407 Watt. The quantity of heat recovered from the condenser of a domestic refrigerator I is found experimentally and found as 202 Watt to 410. This depends on the flow rate of water circulated. In this case the water flow rate range is wide. Therefore, there is a wide variation in the results.

M. Joseph Stalin et al. designed a prototype efficient usage of waste heat from air conditioner. In this experimental analysis, it has been perceived that by supplanting the normal Air Conditioner by this system will vanguards to rescue 4 numbers of LPG gas cylinders per year. This not only saves the cost but also it bulwarks the environment by truncating the global warming engendered because of LPG gas.

Kaushik et.al. The studypresented effect of operating temperature in condenserand evaporator. Withvarying temperature and mass flow rates for different working fluids. It also claims that 40%of heat can be recovered from condenser through CHE.

Abu-Mulaweh describes athermo siphon heat recovery system. Throughexperimental setup, rejected heat from air conditioner wasrecovered to obtain hot water for free on account of cost ofsmall heatexchanger.More close to our focused subject, removing thecondenser from backside of refrigerator andinstalling awater heater in place of the former, resulted in waterreaching a temperature of 60 oC.

RamadhanBen Slama encourages use of such system for economicbenefits in household utilization. In other studies the sameresearcher showed coupling of water heater and heatingfloor can save energy in an effective manner.

Y.A. Patil et. al. made an effort to improve theperformance of household refrigerator through heatrecovery from condenser. In that study 50 liter of waterwas heated to 45 oC in 5 hours. Regular continuous flow ofwater was needed in order to improve the overallperformance.

Sreejith K. et. al. found out that withwater cooled condenser refrigerator performanceimproved as compared to air cooled condenser. For whichthey performed an experimental investigation of watercooled condenser on household refrigerator. In their otherstudies relating to the same field of interest

Sreejith K. et.al. made a waste heat recovery unit which allowed the

system to run as both, a refrigerator and a geyser. system was developed and

S.C. Walawade et.al. which also talks aboutthe practicality of such systems.

G.G.Momin et.al. concluded to have enhanced the COPof refrigerator when it is run with their heat recovery unit.The study shows they were able to achieve 60Octemperature of water at average load.

Tarang A. et. al.worked on enhancement ofCOP of household refrigerator. By using convectioncurrent of heat from condenser they were able to achieve

11% improvement. A simulation study conducted by

S.C.Kaushik et. al. on industrial refrigeration systems byemploying Canopus heat exchanger. The study proved toimprove overall COP of the system, thus a prospect forindustrial refrigeration.

M. Joseph S et. al. did atheoretical analysis of hot water production from waste heat of air conditioner.Implementation of a heatexchanger in the system has a potential for saving LPG gas.

R.B.Lokapure et. al. found out thatthe COP of air conditioning system with heat exchanger forheat recovery increased about 13 percent. Acomprehensive research on heat recovery systems

3. OBJECTIVES

3.1 Objectives

- To recover and store considerable heat energy
- To reduce the usage of fossil fuels
- To reduce the usage of external domestic heating equipment
- To increase the C.O.P of the system

4. FABRICATION AND WORKING

4.1 Experimental Setup Specification

Domestic refrigerator selected for the project has following specifications:

Refrigerant used: R134a refrigerant

Capacity of the refrigerator: 65 litres

Compressor capacity: 0.16 hp

Condenser sizes

Length – 8.5m

Diameter -6.35m

Evaporator

Length- 7.62m

Diameter- 6.4mm

Capillary

Length- 3.6m

Diameter- 0.9mm

The following procedure is adopted for experimental setup of the vapour compression refrigeration system

4.2Working Procedure

- Refrigerator setup is connected to power supply
- Back pressure of compressor set to 60 kgf/cm^2
- Setup is turned on
- Temperature and pressure of the system were noted at compressor, condenser, evaporator, expansion valve
- Reading was taken in equal intervals
- System is turned off and the Hot Box is fixed to the condenser coil
- Now the setup is turned on
- Again, the pressure and temperature were noted from the same points and the temperature in hot box and the PCM also noted
- Test is repeated in different conditions

Fig 4.1 Experimental setup

5. RESULTS

- Temperature in the hot box after 3 hours is 30^0C to 43^0C which can be useful for low temperature heating like food and snacks warming purposes
- Temperature of the hot box will increase in time
- The C.O.P of the system nearly remains same
- The C.O.P of the system is low because of the setup we used it can be increased in case of real domestic purpose setup
- The temperature recovered can also be high if we use domestic or commercial purpose refrigerators and air conditioner

6. CONCLUSION

“Waste heat recovery system” is an excellent tool to conserve available energy. An attempt is made to recover the waste heat from 165 L refrigerator used for domestic purpose. As indicated in this paper, recovered heat can be utilized as food and snacks warmer, water heater, grain dryer. So, one can save lot of time and energy also. Suitable heat recovery system can be designed and developed for every household refrigerator.

The experimentation has shown that such a system is practically feasible. Technical analysis has shown that it is economically viable. If this can be started from individual level then it can sum up and enormous effect can be obtained. Thus, with small addition in cost if we recover and reuse the waste heat, then definitely we can progress towards energy conservation and simultaneously achieve our day today function. In present situation where everybody in a home is moving out, this combination of refrigerator and food warmer is definitely a boom.

It is evident from above investigation that the machine called as Refrigerator with Hot Box performs the best up to 40-50℃,maintain temperature up to 35-45 ℃ in Hot Box. The amount of heat absorbed by the PCM is 31J. The refrigerator that we use in our daily routine release lot of heat which goes waste but as per the accessories that attached, we have used i.e., Hot Box used above heat and fulfill the purpose. After the attachment of Hot Box, the efficiency of refrigerator is not affected. The machine fabricated has good utilization in hotels, dairy, industry and also useful for domestic purpose. The serving cooling and heating both the purpose.

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