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Design and Development Waste Heat Recovery from Domestic Refrigerator

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Abstract- There is an economic reason to extend the useful life of the landfill because once the old landfill is filled, the new one can be found only at greater distance, and this increases remarkably the transportation cost. Therefore, waste has to be recovered as much as possible. To do this, in developing countries context, small scale composting promotion is widely accepted and the contribution of informal recycling is also widely recognized. The question remains to what extent composting and informal recycling contribute to the waste diversion. To create a platform for discussion and learning, a model is established. The model in this paper is based on the system dynamics (SD) approach. The simulation results with the data collected in Phnom Penh city, Cambodia, show that waste recovery through small-scale composting and informal recycling cannot contribute significantly to the waste diversion without other supporting policies.

Keywords: Solid waste management, waste recovery, informal recycling, waste pickers, system dynamics, developing countries, etc.

1. INTRODUCTION

1.1 Environmental Aspect of Air Conditioning Systems

Since 1987theMontreal Protocol controls the use and release of CFCs and has set a time-scale schedule for eliminating their production. This agreement is an historic step in the ongoing process of building consensus regarding environmental impacts of CFCs. One of the HCFCs, R-22, and one of theHFCs,R-134a are utilized as substitutes for CFCs, but the HCFCs and HFCs will face similar restriction for their high GWP (Global Warming Potential). For comparison, some of the working fluids ODP (Ozone Depletion Potential) and GWP are listed in Table 1.1

Table 1.1 ODP and GWP of common Refrigerants

Sr.No	Chemical	ODP	GWP	Estimated Atmospheric Life
1	CFC-12(CCl_2F_2)	0.93	3700	122

2	HCFC-22(CHClF2)	0.05	510	18
3	HFC-134a(CF3CH2F)	00	400	18
4	Carbon dioxide(CO2)	00	10	230
5	Ammonia(NH3)	00	00	-
6	Water(H_2O)	00	00	-

1.2 Vapour Compression System

Vapour compression refrigeration system is by far the most popular and widely used System in refrigeration and air conditioning both for industrial and domestic applications.

In this system the working substance is a refrigerant like A refrigerant readily evaporates and condenses depending upon the pressures and temperatures during the cycle, therefore, refrigerant undergoes a change of phase alternately between liquid and vapor phases without leaving the system. During evaporation, it absorbs latent heat from the brine or cold chamber and during the process liquid changes into vapor, hence, creates cooling effect in the cold chamber. During condensation, refrigerant rejects heat to external system like cooling water or to the atmosphere and the refrigerant converts from vapor to liquid. The schematic diagram of a vapor compression refrigeration system is shown in Fig. 1.2 the system mainly consists of a refrigerant compressor, a liquid receiver, a refrigerant control valve also called as expansion valve and evaporation.

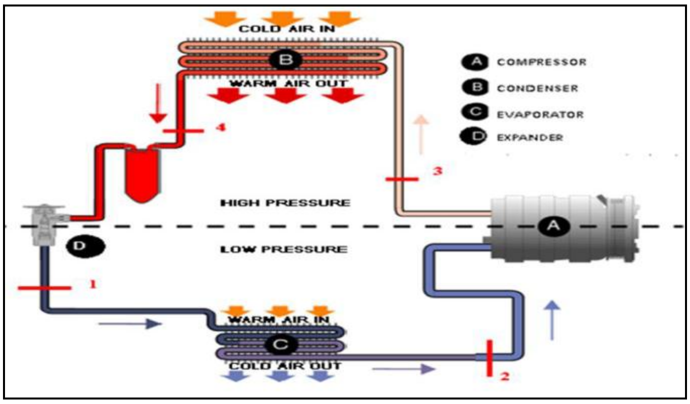

Fig-1.1 Vapour compression system

Working:

Compression refrigeration cycles take advantages of the fact that highly compressed fuels at a certain temperature tend to get cooler when they are allowed to expand. If the pressure change is high enough, then the compressed gas will be hotter than our source cooling and the expanded gas will be cooler than our desired cold temperature. In this case, fluid is used to cool a low temperature environment and reject the heat to high temperature environment. The vapour compression cycle uses energy input to drive compressor. When the compressor is started, it draws the low pressure vapour from the evaporator at state 1 and compresses it isentropic ally to a sufficient high pressure up to state 2 because a proportion of the energy put into the compression process is transferred to the refrigerant. Since the compression work is done on the vapour, its temperature also increases.

Hot vapour from compressor under pressure are discharged into the condenser where it is cooled at constant pressure by rejecting heat to condenser cooling medium usually water or surrounding air. This converts the hot vapour into liquid and the liquid is collected in the liquid receiver at the state. The liquid from the liquid receiver at high pressure is then piped to a refrigerant control valve which regulates the flow of liquid into evaporator. This control valve, while restricting the flow, also reduces the pressure of the liquid with the result the liquid change into vapour of low dryness fraction represented by During this process the temperature of the re refrigerant reduces corresponding to its pressure. There is no loss or gain of heat through the expansion valve.

Finally, the low pressure, low temperature refrigerant passes through the evaporator coil, where it absorbs its latent heat from the cold chamber or from the brine solution at constant pressure and converts into vapour at state 1.So during this process it changes its state from liquid to the gas. It is again supplied to the compressor. Thus, the cycle is completed.

1.3 The Effect of Sub Cooling

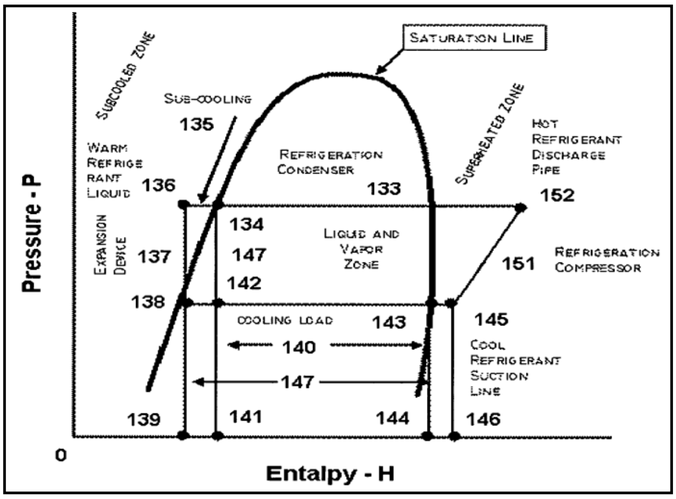

Fig 1.3-the effect of sub-cooling the liquid

On the p-h chart shown in fig. a simple saturated cycle has been compared with another cycle in which all other states are identical except that the liquid at the exit from the condenser is cooled below the saturation temperature. State3 is reached instead of state 3 in simple saturated cycle. Fig shows the sub-cooling on p-h chart for Freon-12(R-12),From 40 c to 30 c. Points 1-2-3-4 represent the simple saturated cycle and point 1-2-3'-4' represent the sub-cooled cycle. In order to appreciate the effect of sub-cooling better, numerical values have been labeled on p-h chart for both sub-cooled and simple saturated cycles.

A typical vapour compression system consist of four major components i.e. compressor, condenser, expansion device and an evaporator are depicted schematically in Figure 1.3 is a thermodynamic diagram of the process where the numbered points correspond to the numbered points in Figure 1.Theoperation cycle consist of compressing low pressure vapor refrigerant to a high temperature vapor(process 1-2); condensing high pressure vapor to high pressure liquid (process 2-3); expanding high pressure liquid to low pressured super cooled liquid (process 3-4); and operating low pressure liquid to low pressure vapor(processes4-1). The heat absorbed from evaporator in process 4-1 is rejected to outside ambient during condensation process 2-3 and is generally a waste heat.The condensation process can be divided in 3 stages viz. desuperheating2-2a Condensation and sub cooling. The saturation temperature by design is anywhere from ten to thirty degree above the heat sink fluid temperature, this ensure the heat sink fluid can extract heat from the refrigerant. The superheat can be as much as 100 F or more above the saturation temperature. This so-called superheat Isa part of waste heat that can be recovered for useful purposes through the use of a heat recovery unit is special purpose heat exchanger specifically designed to:

- Remove heat represented by 2-3 in figure 2.
- Improve overall system efficiency by using water cooled condenser.
- Use thermo siphon system to circulate water to minimize pumping cost.
- Protect against contamination of portable water via double wall construction.

The Heat Recovery Unit is installed on household refrigerator therefore there may be change in the applied load of the refrigerator. Therefore tests are carried out at different load conditions to measure COP and performance of Heat Recovery Unit i.e. temperature in water tank for 8 hours. From this data economy of the system will be decided.

2. LITERATURE REVIEW / RELEVANCE

Use of waste heat recovery from thermal system is not a new technique altogether. The focus is placed on a need to develop effective, less costly and maintenance free auxiliary integrated with main system to achieve waste heat recovery. Following research has been contributed to the area of waste heat recovery and performance enhancement of refrigeration systems.

A.S.Katkarand L. Dhale had constructed and tested an integrated heat recovery system which has been designed both to enhance the performance of a domestic refrigerator and simultaneously recovers heat using water heat exchanger. The performance has been monitored using instruments and results shows that the cop of the R134a system was improved by 9%. A spiral tube heat exchanger unit installed in parallel to air cooler condenser and experimental results are recorded and analysed [1].

T Patel et al have reviewed previous work in area of waste heat recovery from condenser of domestic refrigerator in terms of background, originally, current status, and researches [2].

Serenity K. et al have investigated the performance of household refrigerator using air-cooled and water-cooled condenser. The experiment was done using HFC 134a as the refrigerant and polios-ester oil (POE) as the lubricant. The

performance of the household refrigerator air-cooled and water-cooled condensers were compared for different load conditions. The result shows that there is reduced energy consumption for water cooler condenser up to 11%. About 200 litters of hot water at a temperature of about 58' cover a day can be collected from the system from igloo kelvinator refrigerator [3].
P. Elumalaietal investigated experimentally the heat recovery by using hot oven and heater of VCR system. The oven recover's the superheat of the refrigerant vapour and utilize it for heating space inside the hot oven. A juice chamber is designed to reduce its temperature by pumping it through heat exchanger attached to evaporator. The effectiveness of cooler as well as the effect of operating temperature has been studied. The result shows that temperature in oven is 48'c and 42'c in water. After a period of 30 minutes running of 165 liters, 124 watts R134a refrigeration system [4].
Y.A.Patiland H.A. Dange have published a research paper in which the authors have investigated a waste heat recovery system with thermo siphon and experimented to recover condenser heat from the household refrigerator of 200 liters. Tests are carried out at different load conditions to measure cop and performance of the system. It is observed that 100 liters of water in water tank gets heated up to 40'c within 8 hrs of average load conditions [5].
T.Agarwal et al installed a cabin at the top of domestic refrigerator with condenser coils inside the cabin for heating water. It was concluded that there is increase in cop of system up to 11% copper coils of diameter 4.36mm and length 620 cm were installed inside the cabin and average amount of heat added to water is calculated to be is 8 watts [6].
Raut D.M.et al described a multipurpose refrigerator with hot box and water heater. The discharge line of compressor is bypassed before air cooler condenser to water tank and hot box. The water tank of 1.5 litters capacity gets heated to 50'c in 35 minutes and hot box heats up to 45'c in same time when operated alone [7].
G.G.momin et al have done experimental on 17SL LG refrigerator and observed that 100 liters of waste water gets heated up to 60'c within eight hours at average load from the condenser waste heat recovery system. It consists of water tank of capacity 5 liters through which water is flowing and refrigerant tube is brazed helically on it [8].
Reny Varghese et al have done retrofitting of condenser of domestic refrigerator for heat recovery. The condenser coil is placed in a hot chamber and the evaporator is moved from top to the bottom chamber. The deep freezer is used as a hot chamber by replacing evaporator coil by condenser coil [9].
The performance analysis shows there is 9.92w heat recovered through water and a 12.26% increase in cop is achieved [10].
S.N.Vedil and A Kumar have proposed a combined VCR and VAR cycle in which waste heat of condenser is utilized to run a bottoming cycle I.e. VAR where generator gets the heat from condenser of VCR cycle as well as solar energy. a R12 VCR system performance is improved using NH3-H2O VAR system. Theoretical analysis indicates 10.5% increase in cop of system [11].
S.C.Walawade, B.R.Barve and P.R. Kulkarni have attempted to utilize waste heat from condenser of refrigerator. Two sections of air cooler condenser one at the bottom and one at the top of insulted cabin are mounted that there is improvement of 11.81% in cop of system by recovering 9.92w of heat by water [12].
N.B.Choudhari and P.N.Choudhar have designed a heat recovery system from the condenser of 145w Godrej refrigerator. A heat exchanger with 50 liters water tank is constructed for heat recovery using thermos siphon effect. Results indicate that 7.2 litre water at 51'c is available per hour [13].
S.B.Lokhande and Dr.S.B.Barve have done experiment on Godrej refrigerator with 165 litre capacity. A hot case on top side of refrigerator is installed with the system for food or milk heating purpose [14].
T.B.shinde et al have done experimentation and performance evaluations of a waste water heat recovery system by using a water tank for condenser heat absorption of 200 L LG refrigerator experiments were performed with and without heat recovery system and result shows that there is 10'c increase in water outlet temperature [15].
S.N.Sapali et al have investigated to utilize waste heat of condenser of a bulk milk cooler using shell and coil type heat exchanger. The result shows that complete superheat and 35% of latent heat is recovered and cop of the system is increased from 3 to 4.8. This hot water is utilized for cleaning equipment's by varying water circulation. The results are discussed which concludes that 53 to 65% of total heat lost is recovered in heat exchanger [16].
R.M.Slama coupled water heater and heating floor alternatively. The water in heater gets heated up to 60'c in a day and for heating floor 50'c with ambient temperature of 26˚C[

3. PROPOSED EXPERIMENTAL SETUP

3.1 Problem Statement

1. In refrigeration and air conditioning systems, heat removed from the controlled space and heat added in the compressor during compression is rejected in the condenser to the ambient; Also COP increases by involvement of another condenser or heat exchanger for sub cooling process (before throttling).
2. To recover this waste heat and to increase COP, an experimental setup is developed by fitting water cooled heat exchange to an existing refrigeration application.
3. Waste heat recovered will be used for water heating, which will be stored in an insulated tank, and can be used for various applications.

3.2 Objectives

1. To evaluate the performance of refrigeration system when combined with condensing heat recovery system.
2. The article includes a test procedure utilized to evaluate the condensing heat recovery system relevant experimental results, a detail analysis of the mechanisms, and improvement measure on such a system.

3. The experimental setup has been tested for various conditions like no load, full load and on seasons viz, summer, rainy and winter.
4. The experimental results indicate that the coefficient of performance system.
5. Thus, the average cooling coefficient of performance (COP) of system can be improved.
6. The value of COP, power consumption, temperature rise of water have been calculated

3.3Methodology

In the proposed work, heat lost in heat exchanger will be recovered by using water cooled heat exchanger unit, and there covered heat will be utilized for water heating. Effect of heavily. Recovery on total system will be analysed. For this investigation, an experimental setup is developed. As per the Energy balance equation, total heat added in the system is equal to total heat rejected in the water cooled heat exchanger (waste energy). In the experimental setup for removal of the waste heat, heat exchanger is used, which is fitted between Compressor and condenser in parallel Valves are used to bypass the heat recovery unit so that the system will work without the heat recovery unit.

3.4 The Proposed System:

The experimental setup shows the spiral tube heat exchanger unit installed in parallel to air cooled condenser with conventional refrigeration or air-conditioning system. Spiral tube type heat exchanger is designed and installed in the cycle for heat recovery as shown in the figure.Figure-4 shows the theoretical amount of waste heat available for recovery on p-h diagram. Experiments are carried out on the setup as per the methodology, and results are recorded and analysed.
Experiments are carried out with heat exchanger and bypassing the heat exchanger. Mass flow rate of water circulation is changed and its effect on system performance is by using water cooled heat exchanger in the cycle discharge pressure is reduced and work required to drive the compressor is reduced.
In the water cooled heat exchanger, the growth of the sub cooled region also contributes to the decrease in pressure drop, as previously discussed. In the evaporator, an additional contribution to the pressure drop reduction is given by lower inlet qualities to the coil. The performance of the water cooled heat exchanger in terms of saturation temperature is dramatically worsened with the increase in sub cooling because the sub cooled region introduces an area with lower temperature difference and heat transfer coefficient.

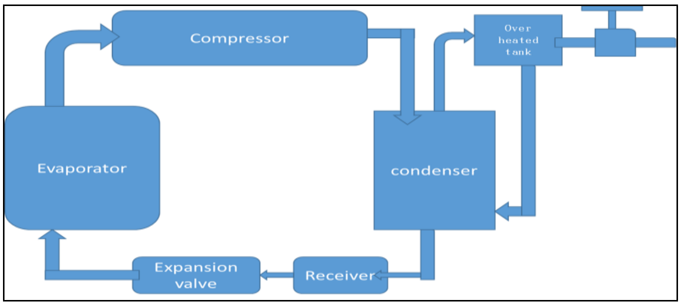

Figure 3.1 Vapour Compression Refrigeration Cycle

Process 1–2

Low-pressure liquid refrigerant in the evaporator absorbs heat from its surroundings, usually air, water or some other process liquid. During this process it changes its state from a liquid to a gas, and at the evaporator exit is slightly superheated.

Process 2–3

The superheated vapour enters the compressor where its pressure is raised. The temperature will also increase, because a proportion of the energy put into the compression process is transferred to the refrigerant.

Process 3–4

The high pressure superheated gas passes from the compressor into the condenser. The initial part of the cooling process de-superheats the gas before it is turned back into liquid. The cooling for this process is usually achieved by using air or water. A further reduction in temperature happens in the pipe work and liquid receiver, so that the refrigerant liquid is sub-cooled as it enters the expansion device. The condenser has to be capable of rejecting the combined heat inputs of the evaporator and the compressor. In other words: (1 – 2) + (2 – 3) has to be the same as (3 – 4).

Process 4-1

The high pressure sub-cooled liquid passes through the expansion device, which reduces its pressure and controls the flow into the evaporator. There is no heat loss or gain through the expansion device.

3.5 Advantage of Waste Heat Recovery

1. System Performance Improved
2. Hot water Output.
3. Efficiency of the process increases.
4. Decreases the cost of fuel & energy consumption.
5. Hot water output can be used for number of application

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