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REFRIGERATION BY WASTE HEAT RECOVERY

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Abstract—One third of heat energy generated by the automotive internal combustion engine is wasted in the exhaust system. Heat energy that is wasted can be used to run the absorption refrigeration system. The engine exhaust system is connected to the generator of the refrigeration system to supply the input heat required for the refrigeration process. The temperature of the evaporator was measured for various loading condition of the engine. The result indicates that the performance of the refrigeration system increases with increase in the temperature of the exhaust gas. The temperature of the refrigeration system reaches the lowest value of 16^0C at 80% of loading condition.

Key Words: Vapour Absorption, waste heat, Refrigerant

1. INTRODUCTION

The higher the utilization of natural resources due toincrease in population and technology development leads to the depletion fuel resources. Increasing fuel cost and reducing petroleum supplies are forces to utilize the energy fully from the fuel. In energy conservation, use of IC engine is of special important, because the machineries use around 60% of petroleum derived fuels in worldwide. The major difficulty to overcome the development of internal combustion engine is the reduction of emission (such as CO_2, CO, N_2O and particulate matter); it is achieved by increasing the engine efficiency and the partial recovery of waste energy from the exhaust gases. The recovery of waste energy or waste heat recovery is heat, which is produced in a process by way of fuel combustion (or) chemical reaction and then dumped into the environment even through it could still be reused for some useful and financial resolution. In water cooled engine, the one third of the energy is wasted in engine cooling system and the one third of the energy is wasted in exhaust gases. For such cases, vapour compression air conditioning system is used for cooling the cabin and in goods carrying. Internal combustion engine efficiency can be increased by attaching absorption refrigeration system.

1.1 Needs for energy conservation in India

The increasing demand for power has led to considerable fossil fuels burning which has in turn had an adverse impact on environment. In this context, efficient use of energy and its conservation is of paramount importance. It has been estimated that nearly 25,000 MW can be saved by implementing end-use energy efficiency and demand side management measures throughout India. Efficient use of energy and its conservation assumes even greater importance in view of the fact that one unit of energy saved at the consumption level reduces the need for fresh capacity creation by 2.5 times to 3 times. Further, such saving through efficient use of energy can be achieved at less than one-fifth the cost of fresh capacity creation. Energy efficiency would, therefore, significantly supplement our efforts to meet power requirement, apart from reducing fossil fuel consumption.

1.2 Waste heat recovery

A waste heat recovery unit (WHRU) is an energy recovery heat exchanger that recovers heat from hot streams with potential high energy content, such as hot flue gases from a diesel generator or steam from cooling towers or even waste water from different cooling processes such as in steel cooling.

1.2.1 Waste heat recovery equipment's/ methods

Waste heat found in the exhaust gas of various processes or even from the exhaust stream of a conditioning unit can be used to preheat the incoming gas. This is one of the basic methods for recovery of waste heat.

1.2.2 Organic Rankin Cycle

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Waste heat recovery from internal combustion engines (ICE) is one of the opportunities for economizing of energy consumption. Fig 1.1 represents a typical a waste heat energy recovery system with ORC. In an ICE, a great amount of fuel energy is wasted in form of heat due to thermal limitations. Roughly one-third of fuel energy is converted to mechanical power and the rest is released to the ambient in form of heat. Waste heat recovery using ORC is an efficient method compared with the other techniques; so automobile manufacturers use this method to enhance the efficiency of their products. In 2007, Hountalas et al. investigated improving the efficiency of a heavy diesel engine using the methods of heat recovery from exhaust gas. These methods include mechanical turbo compounding, electrical turbo compounding and steam Rankine cycle.

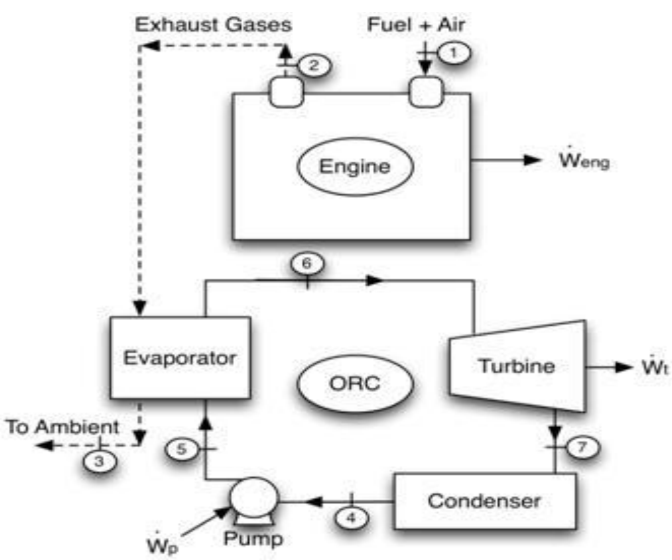

Fig. 1.1: A typical waste heat energy recovery system with ORC

1.3 Waste heat potential from engines

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. During engine run time, there are four sources of usable waste heat from a reciprocating engine: exhaust gas, engine jacket cooling water, lube oil cooling water, and turbocharger cooling are dissipated to the atmosphere. The single largest amount of unused heat from the engine is the exhaust heat, which contains about 30% of the fuel energy. It is evident that exhaust gases comes out from the exhaust port at a very high temperature, it has been seen that in diesel engines exhaust emission are at the high temperature of 250°C to 600°C (approx.) with high quality and quantity. Fig 1.2 shows the amount of heat dissipated from engines at same interval of time.

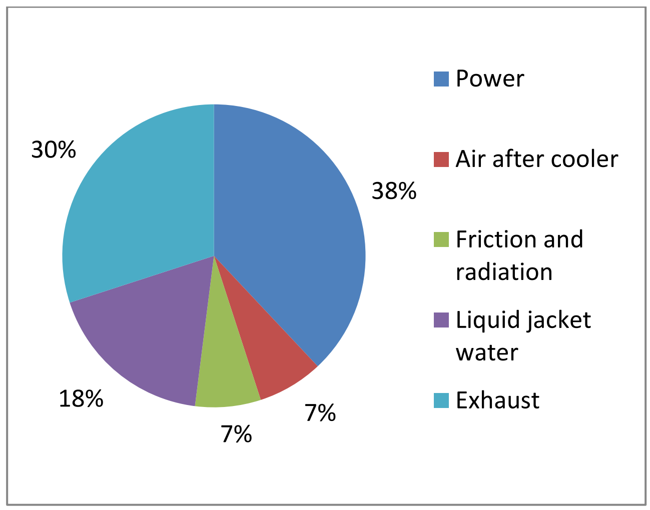

Fig. 1.2: Amounts of heat dissipated from engines

If the waste heat were put to appropriate use, there would be great energy or fuel savings. The engine exhausts gas can be applied directly for process drying. Generally, the hot water and low pressure steam produced by reciprocating engine system is appropriate for low temperature process needs, space heating, potable water heating, air conditioning or refrigeration and to drive absorption chillers providing cold water.

WHR system requires waste recovery equipment to recover heat from the streams and transform it into a useful form for utilization. This is done using energy conversion devices.

- Firstly, the waste heat energy is utilized to burn an additional amount of fuel.
- The second stage, a thermoelectric generator producing electrical energy by utilizing the heat of exhaust gases.
- The third stage energy recovery is done by coupling a compressor and an alternator.

1.4 Vapour Absorption Cycle

ISSN: 2455-1600

In the early years of the twentieth century, the vapor absorption cycle using water-ammonia systems was popular and widely used. It's also used in industrial environments where plentiful waste heat overcomes its inefficiency. Fig 1.3 shows the block diagram of Vapour Absorption refrigeration system.

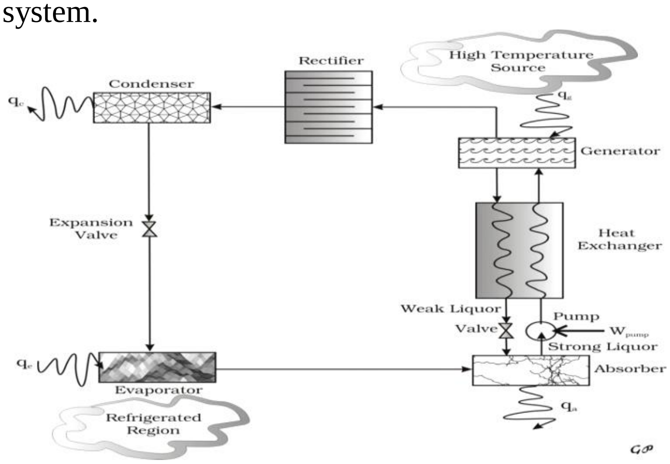

Fig. 1.3. Block diagram of Vapour absorption refrigeration system (VARS)

In the absorption system, the compressor is replaced by an absorber which dissolves the refrigerant in a suitable liquid, a liquid pump which raises the pressure and a generator which, on heat addition, drives off the refrigerant vapor from the high-pressure liquid.

The refrigerant used in vapour absorption system is ammonia, water and hydrogen. Ammonia is widely used as a refrigerant in industrial systems for food refrigeration, distribution warehousing and process cooling.

Moreover Ammonia can be used as a Household ammonia that can be used on many surfaces. Because ammonia results in a relatively streak-free shine, one of its most common uses is to clean glass, porcelain and stainless steel also it can be used as a vehicle fuel Ammonia has been proposed as a practical alternative to fossil fuel for internal combustion engines. The calorific value of ammonia is 22.5 MJ/kg (9690 BTU/lb) which is about half that of diesel.

1.5 Role of water in vapour absorption system

Ammonia is readily miscible in water. Ammonium Hydroxide on slight heating easily liberates ammonia gas. The reaction of ammonia with water is exothermic and the engine energy from this exothermic reaction is used for the circulation of hydrogen in the system.

1.6 Role of hydrogen in vapour absorption system

Hydrogen is used to reduce the partial pressure of ammonia in the evaporator. Also it keeps the total pressure of the system constant. Hydrogen doesn’t reacts with water and with ammonia. Hydrogen critical temperature is very low; it can be easily used for very low evaporator temperature.

2. LITERATURE REVIEW

The number of authors discussed about the amount of energy wasted in internal combustion exhaust gas heat. From their study they agree with the fact that the sufficient energy is available in the engine exhaust to power absorption refrigeration system. A.T.Rego et al [16], who designed and tested a prototype for an absorption refrigeration system, powered by the exhaust gas heat of a 260 kW diesel engine. Performance of the system is evaluated at constant engine speed and various engine speeds. The authors revealed that the quantity of exhaust gas energy is sufficient to power the 0.215m^3 refrigerator. They take the reference operation parameter system indicates typical values ranges between 180-250^{0}C.
Andre Aleixo Manzela et al [4] designed and tested a prototype for an absorption refrigeration system, powered by the exhaust gas heat of a 260 kW diesel engine. The authors showed that the engine speed over 2000rev/min, the temperature inside refrigerator is increased and they used fixed engine speed of 1500rev/min. absorption refrigeration system is run by giving the engine exhaust by opening the throttle value for 25%, 50%,75% and wide opening. Their experimental results shows, temperature inside the refrigeration system is dropped faster when throttle value opened widely. Steady state relative humidity is 29% for 25% of throttle opening and 35% for wide opened throttle value. When throttle value is opened for 25% lowest cooling capacity is achieved and COP

ISSN: 2455-1600

increases and for wider opening of throttle value cooling capacity increases and COP decreases. Andy Pearson et al [5], in their review paper assesses the reasons why ammonia is so popular in industrial schemes, the reasons why it is thought less suitable for other applications and the possible profits at local, national and international levels that might be gained by more general acceptance of ammonia as a refrigerant.

Dolz et al [10], in their paper they described the study of different bottoming rankine cycles using water stream and innovative steps for waste heat recovery in heavy duty diesel engine. They divided the work into two parts. In the first part detailed study of HDD engine is made and available waste energy from the engine. A detailed study of waste heat energy source is made to determine the appropriate for the application in bottoming cycle to reduce the external irreversibility. In the second part will analyse the various innovative processes in HDD engine to fit with refrigeration system.

Charles Sprouse and Christopher Depcik [8], in their review organic rankine cycle works effectively with waste heat recovery from internal combustion engine, because organic rankine cycle works well with medium grade energy from engine exhaust. The main aim of the review focus on selection of working fluid and cycle expander, hence both of this has larger impact on system performance. Their result showed fuel economy is improved to 10% with modern refrigerants and expander technology.

3. SCOPE OF THE PRESENT WORK

The project consists of an Absorption refrigeration system using heat engine energy as input. The principle behind absorption refrigeration is that it uses three gases to accomplish its cooling effect namely ammonia (refrigerant) water (absorbent) and hydrogen. Ammonia is used as the refrigerant as it is easily available, environmentally friendly and can produce a better cooling effect. Hydrogen is used to reduce the partial pressure of ammonia vapour in the evaporator chamber so that more ammonia evaporates yielding more cooling effect. Heat input is required at the generator where aqua ammonia is heated to get ammonia vapors. In this project, an experimental setup for Absorption refrigeration is made using heat engine energy to supply input heat.

4. SYSTEM ANALYSIS

The unit charge consists of a quantity of ammonia, water and hydrogen at an enough pressure to condense ammonia at the room temperature for which the unit is designed. Fig 4.1 shows the basic layout of the absorption refrigeration system using waste heat from IC engine. When heat is supplied to the boiler system, bubbles of ammonia gas are formed which rise and carry with them quantities of weak ammonia solution. This weak solution passes into the tube, whilst the ammonia vapour passes into the vapour pipe and on to the water separator. Here any water vapour is condensed and goes back into the generator system leaving the dry ammonia vapour to pass to the condenser. Air flowing over the fins of the condenser removes heat from the ammonia vapour to cause it to condense to liquid ammonia in which state it flows into the evaporator. The evaporator is delivered with hydrogen. The hydrogen permits across the surface of the ammonia and lowers the ammonia vapour pressure sufficiently to allow the liquid ammonia to evaporate.

The evaporation of the ammonia extracts heat from the food packing space, as defined above, thereby lowers the temperature inside the refrigerator. The mixture of ammonia and hydrogen vapour passed from the evaporator to the absorber. Inflowing the upper portion of the absorber is a continuous trickle of weak ammonia solution fed by gravity from the tube. This weak solution, flowing down through the absorber comes into contact with the mixed ammonia and hydrogen gases which readily absorbs the ammonia from the blend, exit the hydrogen free to rise through the absorber coil and to return to the evaporator. The hydrogen thus flows continuously between the absorber and the evaporator. The strong ammonia solution formed in the absorber flows down to the absorber vessel and thence to the boiler system, thus finishing the full cycle of operation. The liquid flow of the unit is purely gravitational. Heat is produced in the absorber by the process of absorption. This heat must be degenerate into the surrounding air. Heat must also be degenerate from the condenser in

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order to cool the ammonia vapour sufficiently for it to liquefy. Free air flow is therefore necessary over the absorber and condenser. The whole unit functions by the heat applied to the boiler system and it is of paramount importance that this heat is kept within the necessary limits and is properly applied.

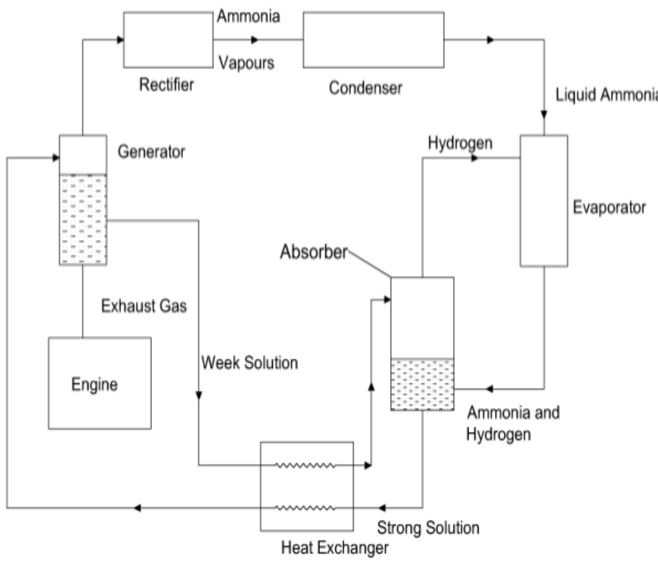

Fig 4.1 Schematic of the absorption refrigeration system using waste heat from IC engine

The coefficient of performance of the absorption system is given by the ratio of instantaneous cooling capacity and instantaneous heat transfer to the energy source to the refrigeration system

$$COP = \{Q_E/Q_G\} \quad (1)$$

$$Q_C = Q_G+Q_E \quad (2)$$

Where, Q_G is the heat supplied to the refrigerant in the generator, Q_C is the heat discharged to the atmosphere or cooling water from the condenser and absorber, Q_E is the heat absorbed by the refrigerant in the generator.
T_G is the temperature at which heat Q_G is given to the generator, T_C is the temperature at which heat Q_C is discharged to atmosphere or cooling water from the condenser and absorber and T_E is the temperature at which heat Q_E is absorbed in the evaporator.

$$\{Q_G/T_G\}+\{Q_E/T_E\} = \{Q_C/T_C\} = \{(Q_G+Q_E)/T_C\} \quad (3)$$

$$Q_G=Q_E\{(T_C-T_E)/T_E\}*\{T_G/(T_G-T_C)\} \quad (4)$$

Maximum coefficient of performance of the system is given by

$$COP = \{Q_E/Q_G\}$$

$$COP=\{T_E/(T_C-T_E)\}*\{(T_G-T_C)/T_G\} \quad (5)$$

5. EXPERIMENTAL PROCEDURE

A commercial $0.08424m^3$ refrigerator which using an ammonia-water as refrigerant in the absorption refrigeration system which actually run by the heat produced from the LPG burner was modified to use the heat from the engine exhaust. The engine used in this experiment is 10 HP COMET twin cylinder diesel engines. The engine is coupled with electrical loading. Temperatures are measured by using a k type thermocouple and evaporator temperature is measured by using digital sensor. Engine speed and load signals are monitored in all tests.

Testing Parameter involved for determining the refrigeration performance is shown in Table 5.1 and Table 5.2 for the duration of 1 hour, where $T_{Exhaust}$ refers exhaust gas temperature and T_E for evaporator (refrigerator) temperature.

Table 5.1 Evaporator temperature with brake power

Brake power(kW)	2.9	3.6	4.4	5.2	5.9
$T_E(^0C)$	29	25	21	18	16

Table 5.2 Evaporator temperature with exhaust gas temperature

$T_{Exhaust}(^0C)$	290	320	349	360	370
$T_E(^0C)$	29	25	21	18	16

ISSN: 2455-1600

6. RESULTS AND DISCUSSION

Experiments are performed for different exhaust gas temperature and brake power (load) which provides the required heat to the generator to produce the better cooling in refrigeration system. From the experiments the refrigeration effect is noticed between 260 ^{0}Cto 370^{0}C of the exhaust gas. The test was conducted by setting the temperature 260,300,340,360 and 370^{0}C.At 260^{0}C, no refrigeration effect is found. For temperature 300^{0}C, the refrigeration system starts cooling and produces the lowest cooling.

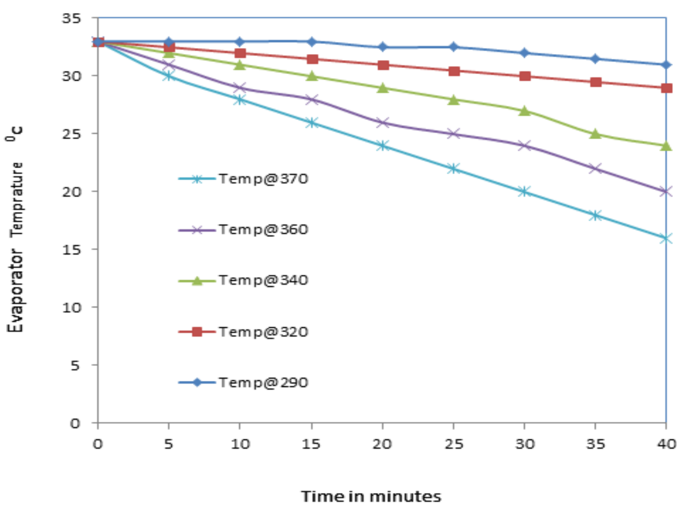

Fig 6.1: Variation of evaporator temperature with respect to exhaust temperature

At 340^{0}C, the temperature inside the refrigerator reduces and produces the cooling effect inside the refrigerator. For 360^{0}C, produces the better cooling. At 370^{0}C, the maximum cooling capacity of 16^{0}C is achieved in the evaporator.

Fig. 6.1 shows the variation in refrigerator temperature with respect to time for a range of exhaust gas temperature from 260^{0}C to 370^{0}C. The continuous reduction in refrigerator temperature is noticed when the duration increases. For 300^{0}C, 26^{0}C reduction in refrigerator temperature is noticed for the duration of 1 hr.

At elevated exhaust gas temperature the reduction in refrigerator temperature is more. 16^{0}C reduction in refrigerator temperature is observed at the maximum exhaust gas temperature of 370^{0}C for the same duration of 1 hr.

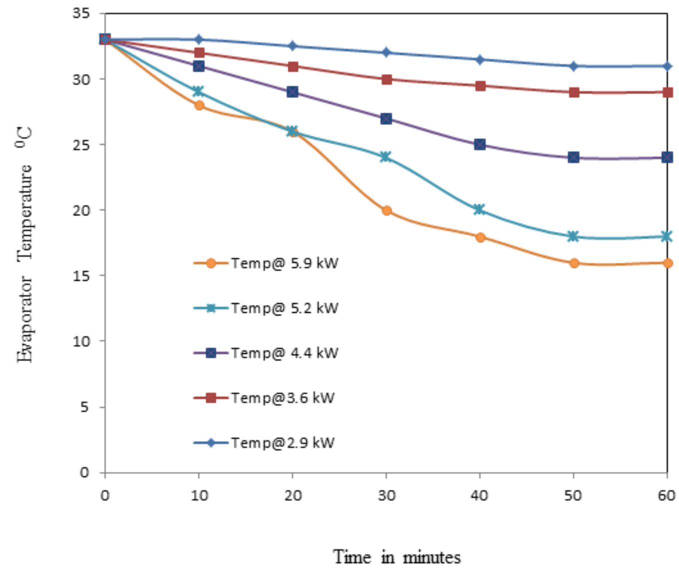

Fig 6.2: Variation of evaporator temperature with respect to brake power

Tests were conducted at different engine brake power to determine the performance of the refrigerator. Engine brake power is the important parameter which determines the temperature of the exhaust gases. The results are shown in Fig. 6.2 .The similar trend is noticed for different break power as that of exhaust temperature. The maximum reduction of 16^{0}C is noticed in 40 min at 5.9 kW. The various experimental values are given in Tables 6.1 and 6.2.

7. CONCLUSION

The heat energy from the exhaust gas is used as a source to run the absorption refrigeration system. The experiment was conducted with various exhaust gas temperature ranging from 260 to 370 ^{0}C and at different brake power from 2.9 kW to 5.9 kW. In this work, the maximum cooling of 16^0 C was attained for the exhaust temperature at 370^0 C in 40 min duration. Very low temperature can be achieved by the refrigeration system when coupled with high capacity multi cylinder engine. It is concluded that the heat energy available in the engine exhaust can be effectively used for refrigeration.

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