A Review on Exhaust Gas Heat Utilization for Air Conditioning

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Abstract - *This work presents a Vapor absorption refrigeration system using the exhaust gas heat of any prime source like Boiler, IC engine or Chimney as low grade energy source. In this project vas system runs on the heat supply from the waste heat gases. Vapor compression refrigeration system is replaced by the Vapor absorption refrigeration system. In any type of prime heat source almost 30% of heat is wasted in the form of exhaust gas to the surrounding atmosphere. So, this waste heat is used for the vas system to provide as energy source to Generator in system. Temperature of this exhaust gas should be more than 100 ºc and it should be provided in temperature range of 80-120 ⁰C to Generator. Ammonia-water mixture is used as refrigerant in this vas system. All the remaining parts of the system i.e. condenser, expansion device and evaporator will be same as that of simple vapor compression refrigeration system. This system of ammonia-water refrigerant can provide up to -5 ºc temperature but we can achieve nearly 5-6 ºc temperature range because of some losses. In this project our aim is to achieve the sufficient temperature range for the human comfort. Concentration of this project is to utilize the exhaust gas heat which is wasted to the surrounding and lead to the increase in temperature of atmosphere.*

Key Words: waste heat, exhaust heat temperature, vapour absorption refrigeration system, Vapour compression, aqua-ammonia refrigerant etc.

1. INTRODUCTION

The various energy sources is one of the main motivations for technological development. The increasing demand for energy involves the search for new sources of Energy or new processes to energy conservation. Internal combustion engines (ICE), mostly based on fossil fuels, are one of the most mature and widespread thermal engines. One of the Challenges of these engines is to reduce their emissions of greenhouse gases and which decrease their efficiency. Indeed, only one third of the energy supplied to the IC Engine is transformed into mechanical work, the rest is lost through the cooling and exhaust systems in the atmosphere. Thus, the development of absorption machines becomes important for saving the energy resources.

André Aleixo Manzela, Sérgio Morais Hanriot [1] this work presents an experimental study of ammonia water absorption system using the exhaust gas of internal combustion engine as an energy source. Introduction of the absorption refrigeration system in the engine exhaust system did not causes significant pressure drop in the exhaust flow, as the engine output power was increased and specific fuel consumption was decreased with removal of other exhaust system components. Overall, carbon monoxide emission was decreased when the absorption refrigerator was installed in the exhaust gas, while hydrocarbon emissions showed an increase **J.P. Yadav and Bharat Raj Singh [2]** In the study an experimental set up is designed and fabricated to use low grade heat energy i.e. exhaust gases as input heat to the system. This is a new technique to use in automobile air conditioning, industrial refrigeration and air condition system especially in food preservation. This experimental setup is based on use of waste exhaust heat of an automobile. The heat required in the generator can be saved up to 33 % by using hot exhaust gases as low grade energy source. Either the decrease in temperature of evaporator or the increase in the temperature of generator, COP of the system will decrease respectively. Using heat exchanger, analyzer and pre heater the COP of the system can be improved. **Mohamed Izzedine Serge, Ababacar THIAM [3]** this paper present an experimental study of H2O –NH3-H2O absorption refrigeration in the two type of energy sources that is the convectional electrical energy from grid an exhaust gas as a input from internal combustion engine. Dynamic method is used to evaluate the behavior of component of the system for both energy sources. . This analysis shows a difference in warm-up times and maximum temperatures reached between the two energy sources**. N. Chandana reddy, G. Maruthi Prasad Yadav [4]** this paper is presented on the waste heat from C. I engine is used as one of the alternative energy source for refrigeration system. In this paper, an overview of utilization of waste heat with a brief literature of the current related research is studied. This shows that deployable sources of energy and for developing techniques to reduce pollution of exhaust gas. This study shows interest in encouraged research and development efforts in the field of alternative energy sources, and the use of the exhaust wasted forms of energy.

2. Vapor Absorption Refrigeration System

The vapor absorption system uses heat energy as a input source to the generator instead of mechanical energy as in vapor compression systems, for to change the conditions of the refrigerant required for the operation. The function of a compressor in a vapor compression system, is to take the vapor refrigerant from the evaporator and then raises its temperature and pressure higher than the cooling medium in the condenser. The liquid refrigerant which is leaving the condenser is expanding in the evaporator. This system consist of all the component similar to that of vapor compression system except the generator. In this system compressor is replaced by other component such as generator, absorber, pump, heat exchanger etc. The process of working of this refrigeration system is that a mixture of refrigerant and an absorber that is strong solution is pumped from the absorber using a small pump to the generator to raise the temperature of the refrigerant. The generator is the main unit of this refrigeration system. The generator where heat is supplied to the strong aqua - ammonia solution. Due to the supplied heat to the strong solution in the generator the refrigerant is separated from the strong solution and forms vapor. The remaining weak solution flows back through a heat exchanger in to the absorber. The refrigerant is then passed through a condenser where the heat of the vapor refrigerant is extracted and the refrigerant temperature is cooled to room temperature. This cooled refrigerant is then passed through an expansion device where during expansion the temperature of the refrigerant falls below the atmospheric temperature. The cold refrigerant is then passed through the evaporator, where the heat is extracted and refrigerant effect is produced .Then the weak refrigerant from generator mix with refrigerant from the evaporator due high affinity between two liquids .Then the refrigerant is again passed in the generator and cycle is repeated.

2.1 Generator

Generator is simply one type of heat exchanger in which heat is transferred from exhaust gas to vaporize the ammonia from strong aqua-solution. During the heating the vapor is formed in the generator at high pressure and temperature. This vapor ammonia formed is then supplied to the generator. The weak solution flows back to the absorber at low pressure after passing through the pressure reducing valve. The high pressure ammonia vapor from the generator is condensed in the condenser to the high pressure liquid refrigerant. This liquid ammonia is passed to the evaporator through expansion valve

2.2 Absorber

In the absorber the low pressure ammonia vapor refrigerant leaving the evaporator which enters the absorber and is absorbed by the water which has the strong affinity. The water has the ability to absorb very large the ammonia vapor and the solution which is formed, is known as aqua-ammonia solution. Because of absorption capacity of water, which lowers the pressure in the absorber and hence more ammonia refrigerant comes inside the absorber. In the absorber strong solution of aqua–ammonia is formed and which being supplied to the generator to raise the temperature through heat exchanger which raises the temperature of the refrigerator.

2.3 Condenser

The fin type of condenser consist of coils of pipe in which high pressure and temperature vapor refrigerant is being cooled and condensed latent heat of refrigerant is removed . The refrigerant while passing through the condenser rejects its latent heat to the surrounding medium such as air or water. In the condenser the super heated vapor is formed into saturation temperature of refrigerant. The liquid refrigerant is passed to expansion valve to decrease the temperature of the refrigerant which is then passed to the expansion valve.

2.4 Expansion valve

It is also called as throttle valve or expansion valve. The high pressure and temperature of liquid refrigerant is being transformed from the expansion valve. Which allow the refrigerant to pass through the small coil which reduces the pressure and temperature of the refrigerant which is passed through the expansion valve.

2.5 Evaporator

Evaporator is simple a cooling chamber which consists of a coil of pipe in which the liquid vapor at low pressure and temperature is evaporated and change into vapor refrigerant at low pressure and temperature in the evaporator. In this liquid vapor refrigerant gain its latent heat of from the medium such as air, liquid brine etc.

2.6 Pump

Pump converts the mechanical energy from motor to the energy of a moving fluid which supplies to the generator. Some energy goes into the kinetic energy of fluid motion and some goes into fluid motion. Aqua-ammonia solution pumped at high pressure to the generator

3. Effect of exhaust gas

3.1 Environment Concern

There is a around 1,50,000 deaths per year around the world is due to Global warming .That is true! An article in 'Scientific American' published in the year 2009, states that a team of climate change researchers from the World Health Organization (WHO) confirms that around 1.5 lakh people lost their lives because of Global Warming, and it is feared to be doubled by the year 2030.

The National Climatic Data Centre (NCDC), which is part of the National Oceanic and Atmospheric Administration (NOAA), has been maintaining monthly and annual records of combined land and ocean surface temperatures for more than 130 years. According to these data, the temperatures have climbed above pre-industrial levels by 1^{o}C. The Intergovernmental Panel on Climate Change (IPCC), forecasts a temperature rise of 1.4 to 5.8 ^{o}C over the next century.

3.2 Effect on Global Warming

- The sea ice in arctic now covers 14.36 million square miles. This is the lowest area of ice on record.
- Since the year 2000, average mean sea level has risen almost 20 centimeters.
- This rising sea level is causing coastal flooding and storm surges.
- If all the ice sheets in Greenland and the Western Antarctic melted, the average sea level can rise by up to 13 meters. It can be a disaster of extinction level.
- Extreme weather was felt all over the globe. The polar vortex in North America, Heat waves in Australia, and the snow in Vietnam are some unusual weather experiences all over the world.

4. Experimental Setup

4.1 Electrolux Vapor Absorption System

The main purpose of this system is to avoid pump so that to avoid moving parts hence the machine becomes noise-less. This system is three fluid system ammonia, water and hydrogen etc. In this ammonia is used as a refrigerant and water is used as a solvent and hydrogen increases the absorption capacity of aqua-ammonia solution. The ammonia vapor which is in the condenser is converted into liquid ammonia, which flows to the evaporator under the gravity. The vaporization of ammonia in the evaporator produces refrigeration. If liquid ammonia is introduced at the top of the system it passes on to the evaporator and vaporizes. Hydrogen flows upwards in the evaporator counter - flows to liquid ammonia that falls from the top. The ammonia vapor and hydrogen leave the top of the evaporator and flow through the gas heat exchange getting warmed by the warmer hydrogen flowing through the evaporator. Both the gases ammonia and hydrogen flow to the absorber and Weak aqua ammonia solution enters at the top of the absorber and absorption of ammonia gas as it passes counter flow through the absorber. The strong aqua-ammonia solution from the bottom of the passed into the generator .Where in the generator strong aqua-ammonia solution is converted into vapor form. Vapor refrigerant is passed to the condenser through the separator to remove any moisture particles from refrigerant .The remaining weak solution from the evaporator is again supplied to the absorber through the heat exchanger.

4. Setup Diagrams

Fig(1) : Electrolux vapor absorption system

4.2 Working

1. This type of system is known as three fluid refrigeration system in which refrigerant is ammonia, water as solvent and third fluid is hydrogen as absorber

2 . Circulation of system is achieved by under gravity by providing high pressure condenser and generator and low pressure in the evaporator.

3. The liquid ammonia flows under gravity into evaporator of this system.

Fig (2) :Back view of the system

4. The strong solution of vapor and hydrogen vapor coming out of evaporator is passed to absorber.

5. The strong solution of aqua ammonia from the absorber enters into generator through heat exchanger where the strong solution is transferred into vapor form.

7. The strong aqua ammonia solution is heated by the generator by exhaust gas.

8. The weak solution is passed to the absorber and aanalyzer and rectifier remove moisture in ammonia vapor and dehydrated ammonia vapors are passed to condenser.

9. The advantage of Electrolux refrigerator is that it has no moving parts.

5. Calculation

5.1 Heat Loss through the Exhaust in Internal Combustion Engine

Engine and dynamometer specification is given in tables below. Heat loss through the exhaust gas from internal combustion is calculated as follows.

Assuming, *[5]*
Volumetric efficiency (η_v) is 0.8 to 0.9
Density diesel fuel is 0.84 to 0.85 gm/cc
Calorific value of diesel is 42 to 45 MJ/kg
Density air fuel is 1.167 kg/m^3
Specific heat of exhaust gas is 1.1-1.25 KJ/kg°K

5.2 Specification of engine

- Manufacture : Kirloskar Oil Engine Ltd. Pune
- Engine : Single Cylinder. 4-Stroke, Vertical Stationary C.I. Engine
- Bore : 87.5mm
- Stroke : 110mm
- Comp. Ratio: 17.5
- Capacity : 661cc (0.661 Liters)
- Power : 8 hp (5.9kW) at 1800rpm
- Sp. Fuel Combustion : 220gms/kW-hr
- RPM : 1800rpm
- BHP@1800 rpm : 5.9kW
- Cooling System : Water Cooled

5.2 Table Observation

T1 (°C)	T2 (°C) (Tg)	T3 (°C) (Te)	T4 (°C) (Tc)	T5 (°C)	T6 (°C)
68.8	83.8	6.4	53.1	37.4	33.3
63	83.2	-10.8	38.4	37.6	29.2
65.6	85.7	-10.8	36.6	37.8	28.9
62.8	82.2	-11.1	36	38	28.4

Heat loss in exhaust gas (Q_E)

$Q_E = m_E \times Cp \times \Delta T$

$= 8.9427 \times 10^{-3} \times 1.1 \times (450- 30)$

$= 4.13$ kJ/sec (or kW)

Therefore, the total energy loss by diesel engine is 29.21%. Hence the loss of heat energy through the exhaust gas exhausted from I.C. engine into the environment **29.21%** energy.

Above calculation is done using the four stroke single cylinder engine and the readings are taken from some amount of mass of this exhaust gas i.e. 0.144 kJ/sec. Only some amount of heat has been utilized because of the size of the Electrolux system

Theoretical COP = $\left(\frac{Te}{Tc-Te}\right) \times \left(\frac{Tg-Tc}{Tg}\right)$

Where,
Te = Evaporator Temperature (°K)
Tc = Condenser Temperature (°K)
Tg = Generator Temperature (°K)

Calculations for 1st reading,

$$COP = \left(\frac{279.4}{326.1-279.4}\right) \times \left(\frac{356.8-326.1}{356.8}\right)$$

COP = 0.515

From the calculations of the single cylinder four stroke CI engine we found that , exhaust gas contains nearly 4.14 KJ/Sec of heat which is nearly 25% of the total power generated by the engine. So we are using very small amount of heat energy for our project which is 80 watts that is 80 J/Sec. using this much amount of heat we got the above temperature ranges at the evaporator.

To find out the refrigerating effect generated inside the evaporator, we should consider the theoretical COP.

$$COP = \frac{\text{REFRIGERATING EFFECT GENERATED}}{\text{HEAT SUPPLIED TO GENERATOR}}$$

Heat supplied to the generator = 80 watts (J/Sec)

Calculations for 1st reading,

$$0.515 = \frac{Re}{80}$$

Re = 41.2 watts (J/sec)

$= 41.2 \times 10^{-3}$ KW

Calculating the average refrigerating effect generated by the input energy with 80 J/sec

$$\text{Avg. refrigerating effect} = \frac{41.2+53.6+60.56+57.84}{4}$$

= 53.3 watts

$= 53.3 \times 10^{-3}$ KW

So, in the Electrolux system if we supply 80 J/Sec amount of heat to the generator then we will get the average 53.3 J/Sec amount of refrigerating effect at the cabinet temperature of 28 ^{0}c.

6. Electricity Consumption analysis

To understand the electricity saving by the absorption system at the place vapor compression refrigeration system.

A 5 star air conditioning system have EER value 3.5.

EER = Energy Efficiency Ratio

$$3.5 = \frac{\text{heat to be extracted}}{\text{power consumption}}$$

$$\text{Power consumption} = \frac{53.3}{3.5}$$

= 15.23 watts

$= 15.23 \times 10^{-3}$KW

For the 8 hours run of the ac each day for 30 days electricity consumption,

$= 15.23 \times 10^{-3} \times 8 \times 30$

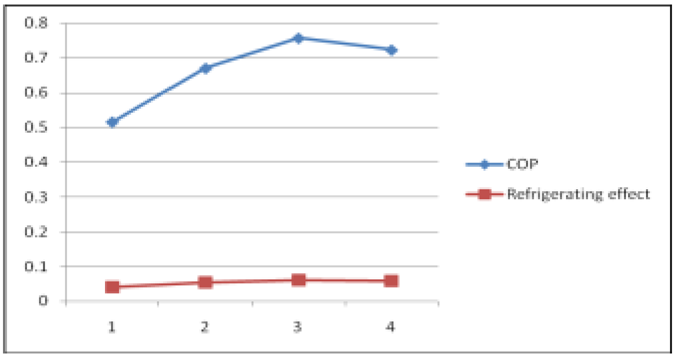
= 3.66 KW.hrs /month

So, from above electricity consumption calculations we can conclude that by using very small amount of exhaust gas heat, that is of 80 J/Sec , we can generate 53.3 J/Sec, and can save up to 3.66 units per month which is required for the vapor compression air conditioning system to generate the amount of refrigerating effect by using the electricity.

7. Results and discussion

- Relation between the Coefficient of Performance and the Refrigerating effect generated inside the cabin (KW)

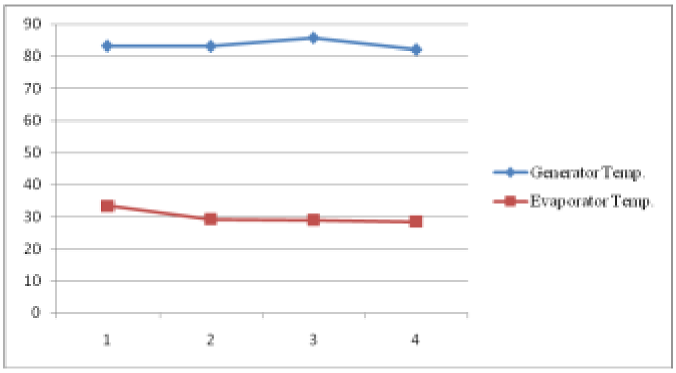
COP	Refrigerating effect (kW)
0.515	0.0412
0.67	0.0536
0.757	0.06056
0.723	0.05784



From above graph we can say that as the theoretical Coefficient of Performance goes on increasing the Refrigerating effect inside the evaporator goes on increasing. The theoretical COP is dependent upon the various temperature, so the refrigerating effect is dependent upon the temperatures inside the system.

- Relation between the Generator Temperature (^{0}C) and the Temperature inside the cabin (^{0}C)

Generator Temp. (^{0}c)	Evaporator Temp. (^{0}c)
83.3	33.3
83.2	29.2
85.7	28.9
82.2	28.4



This plot shows the impact of the generator temperature on the temperature inside the evaporator. As we supply the exhaust gas with high temperature the temperature inside the evaporator decreases or to achieve the low evaporator temperature we should supply the exhaust at the generator at higher temperature.

8. Conclusions

Based on the results, discussion and observation the following conclusions are made:

- This technique can be used in automobile air conditioning, industrial refrigeration and in food preservation.
- This system is based on utilization of waste exhaust gas as a low grade energy source at the generator.
- So, from above electricity consumption calculations we can conclude that by using very small amount of exhaust gas heat, that is of 80 J/Sec, we can generate 53.3 J/Sec, and can save up to 3.66 units per month which is required for the vapor compression air conditioning system to generate the amount of refrigerating effect by using the electricity.
- From above graph we can say that as the theoretical Coefficient of Performance goes on increasing the Refrigerating effect inside the evaporator goes on increasing. The theoretical COP is dependent upon the various temperature, so the refrigerating effect is dependent upon the temperatures inside the system.
- From generator temperature and evaporator temperature, we can say that, as we supply the exhaust gas with high temperature the temperature inside the evaporator decreases or to achieve the low evaporator temperature we should supply the exhaust at the generator at higher temperature.

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