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Experimental Study on Diffusion Absorption System Using Engine Exhaust Gas Integrated With PCM

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ABSTRACT
A diffusion absorption refrigeration system is a thermal powered refrigeration system. Any low grade heat source can be used to run an absorption refrigeration system. In most of engine and industry large amount of heat is rejected as exhaust gas which is at low temperature. One of the efficient methods to utilize this energy is to convert it into cooling load by means of an absorption system. In this work exhaust gas of IC engine is used to power a commercial absorption system integrated with phase change material (PCM). PCM helps to control the generator temperature and also act as a constant temperature source whenever there is a fluctuation in the temperature. Experiment was conducted on single cylinder four stroke diesel engine exhausts coupled to a commercial 40L absorption system. PCM helps to increase the overall COP of the absorption system.

Introduction

In present scenario energy efficiency is a major topic of discussion. Large amount of fossil fuel is used in industry and automobile. In most of engine and industry huge amount supplied energy is wasted in the form of exhaust gas. If we utilize the energy from the exhaust gas we can increase the overall efficiency. Cogeneration is one of the methods to utilize the energy from exhaust gas. Temperature of exhaust gas has a great importance in the heat recovery. Gas turbine exhaust is at 600^0C which can be used effectively to produce power by means of Rankine cycle.

In cases of engine and industry, exhaust gas is at low temperature. So effective method to use this energy is to produce cooling load by means of an absorption system. Absorption system was developed by Nairn in 1777. By 19^{th} century system operating on ammonia and water had application in refrigerator. The system operating on lithium bromide and water were commercialized on 1940.The diffusion absorption refrigeration cycle was introduced around 1920 by Von Platen and Munters. It uses ammonia (refrigerant) and water (absorbent) as working fluids and hydrogen as auxiliary inert gas [1]. A diffusion absorption refrigeration cycle has no moving parts and is driven entirely by means of heat [2]. In this device, circulation of the working fluid is achieved by using a bubble pump where vapor, generated through heat input, this rises through a vertical tube under two-phase flow conditions.

Being quiet and reliable, this system is often popular in hotel rooms and offices. However, it has very low COP (coefficient of performance). The reasons of this disadvantage are; the presence of the auxiliary gas inside the evaporator, that reduces the refrigerant mass flow rate evaporating and thus the cooling capacity. The rectifier dissipates towards the ambient a not negligible amount of the supplied heat [3].

According to the estimation annually 15% of the total energy of world is consumed for air conditioning. Modern automobile air conditioning system is based on vapor compression system and R134a as refrigerant [4]. Vapor compression system works by the shaft power of engine .hence during air conditioning load on the engine increase. This will increase the fuel supply to the engine

When absorption refrigeration system is used, the exhaust energy is used to produce refrigerating effect. Thus the overall efficiency of the engine is increased. Diffusion absorption system has the ability to work by the energy from engine exhaust gas [5].

Diffusion Absorption System

The most economical and easy way to use the energy from exhaust gas is to convert it into cooling load by means of an absorption system. A diffusion absorption system doesn't need pump or any other mechanical device; it will run entirely on heat. This system consist of three working fluids ammonia as the refrigerant, water as the absorbent and hydrogen or helium as an inert gas which is used to regulate the partial pressure. The cyclic flow of working fluids occurs under the influence of gravity and heat. Diffusion absorption system consists of a generator, bubble pump, rectifier, condenser, evaporator and an absorber.

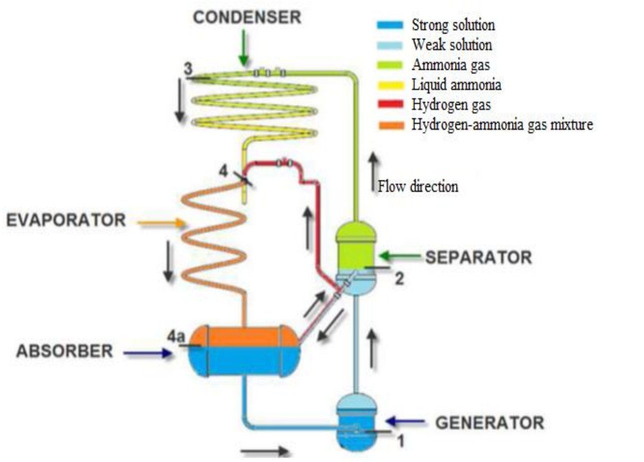

Figure 1. Schematic diagram of diffusion absorption system

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The strong solution from the absorber flows to the generator where it is heated to about 180^{o}C causing some of the ammonia to evaporate (1). The vapour forms bubbles that push columns of liquid solution in the bubble pump up to the liquid vapour separator in which ammonia vapour is separated out of solution and the week solution return back to the absorber via solution heat exchanger (2).

The vapour leaving the generator usually contains certain quantity of water; hence this vapour is purified at the rectifier where it is cooled down to 50^{o}C. Inside the rectifier the water vapour along with the ammonia condense and join with the poor solution and flow back to the absorber through the solution heat exchanger. The ammonia vapour leaving the rectifier is liquefied in an air cooled condenser (3). Now the liquid ammonia refrigerant passes to the evaporator. The evaporator is charged with inert gas hydrogen the presence of hydrogen gas reduce the partial pressure of ammonia. The partial pressure of ammonia and hydrogen in the evaporator will be at 2.5 and 16 bar respectively. At this condition ammonia evaporate at a temperature of -15^{o}C, since the ammonia continues to evaporate it partial pressure rises. This expansion lowers the temperature of the hydrogen-ammonia mixture, allowing it to absorb heat from the refrigerator compartment, which provides cooling. The density of ammonia is considerably greater than that of hydrogen. The vapour (ammonia and hydrogen) becomes heavier as ammonia continues to evaporate; therefore it drops from evaporator to the absorber. The hydrogen ammonia from the evaporator meets the week solution in the absorber. In the absorber, ammonia is absorbed by the week solution of ammonia and water. This cause the vapour (ammonia and hydrogen) lighter and thus it rise to the top of evaporator. This result in the circulation of hydrogen inside the evaporator and absorber. The hydrogen circulation has some effect on the evaporation rate in the evaporator and absorption rate in the absorber. Now the strong solution pass to the generator and cycle continues

Experimental Apparatus

In order to study the characteristics of cooling effect produced from waste heat, an experimental setup is designed and manufactured. The experiment setup is done on a single cylinder four stroke diesel engine exhausts coupled to a commercial 40L absorption refrigeration system.

In the experiment, inlet and outlet temperature of the generator, rectifier. the condenser, the evaporator, the absorber, the solution heat exchanger is measured. K-type thermocouple is used to measure the temperature. Refrigeration effect is calculated by the difference in temperature of water inside the refrigerator. The experiment was conducted on different engine loads and the corresponding data is obtained. PCM as table sugar was used to store the latent heat. Experiment was also conducted with and without PCM.

Table 1. IC Engine specification

Engine	Single cylinder Diesel engine
Power	6 hp @660 rpm
Bore diameter	139.7 mm
Stroke length	114.9 mm
Compression ratio	16

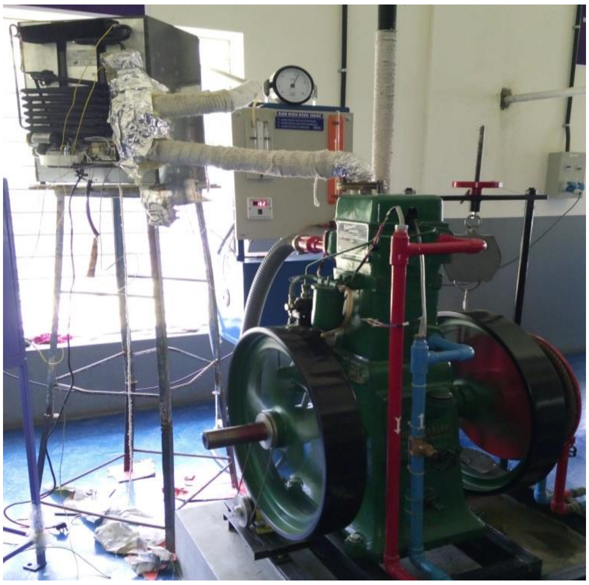

Figure 2. Experimental setup

Thermodynamic Analysis

In thermodynamic analysis mass and energy balance of each component of absorption system is studied

Generator and bubble pump

Heat input to the generator is supplied from the exhaust gas of engine, which vaporize and separate refrigerant from strong solution and is pumped through bubble pump

$\dot{m}_{1a}= \dot{m}_{3}+ \dot{m}_{2c}$ (1)

$\dot{m}_{1a}X_{1a}= \dot{m}_{3}X_{3}+ \dot{m}_{2c}X_{2c}$ (2)

$\dot{m}_{1a}h_{1a}+Qg= \dot{m}_{3}h_{3}+ \dot{m}_{2c}h_{2c}$ (3)

where $\dot{m}$ is the mass flow rate of the working substance, kg s^{-1}, h is the specific enthalpy, kJ kg^{-1}, Qg is the heat input in the generator, X is the mass fraction of the ammonia water mixture.

Rectifier

The vapour leaving the generator is not pure refrigerant; it contains yet a small amount of absorbent. It is purified a little more by a partial condensation in the rectifier so through this process the near-pure ammonia vapour is obtained. The absorbent richer liquid drops back to generator. The mass flow of the purified vapour and the heat rejected to the environment can be determined from the mass and energy balances expressed as follows:

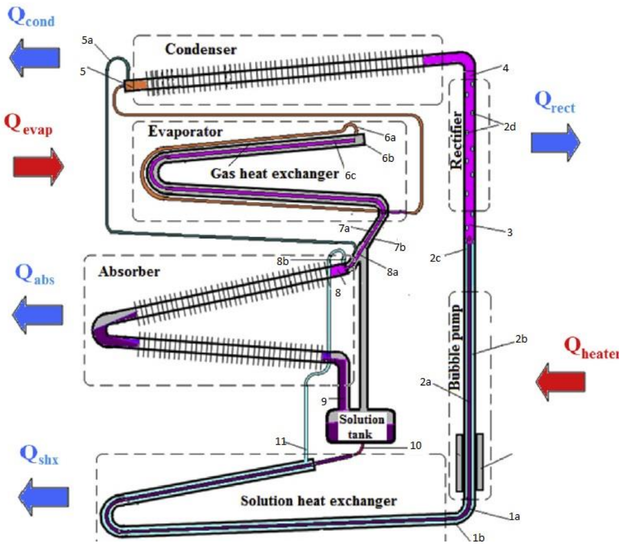

Figure 3. Practical diffusion absorption system

$\dot{m}_{3}= \dot{m}_{4}+ \dot{m}_{2d}$ (4)

$\dot{m}_{3}X_{3}= \dot{m}_{4}X_{4}+ \dot{m}_{2d}X_{2d}$ (5)

$\dot{m}_{3}h_{3}= \dot{m}_{4}h_{4}+ \dot{m}_{2d}h_{2d}+Qrec$ (6)

Condenser

The refrigerant vapour enters into condenser in which, it, with high-pressure, that is the same as operating system pressure, condenses into liquid. The mass and energy balances for condenser can be written as

$\dot{m}_4 = \dot{m}_5$ (7)

$\dot{m}_4 h_4 = \dot{m}_5 h_5 + Qcon$ (8)

Evaporator

The liquid refrigerant leaving the condenser at the operating system pressure reaches to the evaporator entrance where it mixes with the inert gas coming from the absorber through the gas heat exchanger. As a result, the partial pressure of the liquid refrigerant drops and it launches to evaporate at low temperatures. The mass and energy balances are shown as follows:

$\dot{m}_{6a} + \dot{m}_{ig} = \dot{m}_{7b}$ (9)

$\dot{m}_{6a} h_{6a} + \dot{m}_{ig} h_{ig} + Qevp = \dot{m}_{7b} h_{7b}$ (10)

Absorber

Here the refrigerant vapor is absorbed by the poor solution returning from the generator and rich solution flows down into the solution tank. Helium and ammonia residuals flow toward the evaporator.

The mass and energy balances, and the heat transfer rate rejected to the environment are calculated as follows:

$\dot{m}_9 + \dot{m}_{ig} = \dot{m}_{7b} + \dot{m}_{8b}$ (11)

$\dot{m}_9 h_9 + \dot{m}_{ig} h_{ig} + Qabs = \dot{m}_{7b} h_{7b} + \dot{m}_{8b} h_{8b}$ (12)

SHX (Solution heat exchanger)

In the SHX, the poor solution leaving the generator gives energy to the rich solution coming from the absorber with a lower temperature.

The mass and energy balances and heat transfer characterizing the SHX are given as follows:

$\dot{m}_{10} = \dot{m}_{1a} = \dot{m}_{rs}$ (13)

$\dot{m}_{1b} = \dot{m}_{11} = \dot{m}_{ps}$ (14)

$\dot{m}_{1b} = \dot{m}_{2c} + \dot{m}_{2b}$ (15)

$\dot{m}_{1b} X_{1b} = \dot{m}_{2c} X_{2c} + \dot{m}_{2d} X_{2d}$ (16)

$\dot{m}_{1b} h_{1b} = \dot{m}_{2c} h_{2c} + \dot{m}_{2d} h_{2d}$ (17)

$\dot{m}_{1b} h_{1b} + \dot{m}_{10} h_{10} = \dot{m}_{11} h_{11} + \dot{m}_{1a} h_{1a} + Qshx$ (18)

Coefficient of Performance (COP)

The coefficient of performance is defined as the ratio of the heat removed from the evaporator to that of heat supplied at the generator

$COP = \frac{Qevap}{Qg}$ (19)

Energy stored in PCM

The excess energy is stored in the PCM in form of latent heat and sensible heat. This energy is used to supply heat to generator during backup period

$Q\ stored = M_{PCM} \times Cp \times (T_m - 150) + M_{PCM} \times Lf$ (20)

Result and Discussions

The experiment were done from no load to full load on engine.as the load on the engine increase more amount of heat is supplied to the generator.

When the load on the engine increase the exhaust temperature were also increased. When the temperature is increased beyond certain limits, then the COP of the system will reduce.

The COP of the system will reduce as the generator temperature increase this is because as the temperature increase the concentration of the vapour reaching the rectifier will decrease. This will reduce the mass flow rate of refrigerant passing to the condenser and evaporator. The absorption system works efficiently in between temperature range 150°C-180°C

PCM is selected as table sugar because it has a melting temperature between 176°C-183°C and latent heat of fusion 135KJ/Kg. PCM helped to regulate the temperature with in the limit.

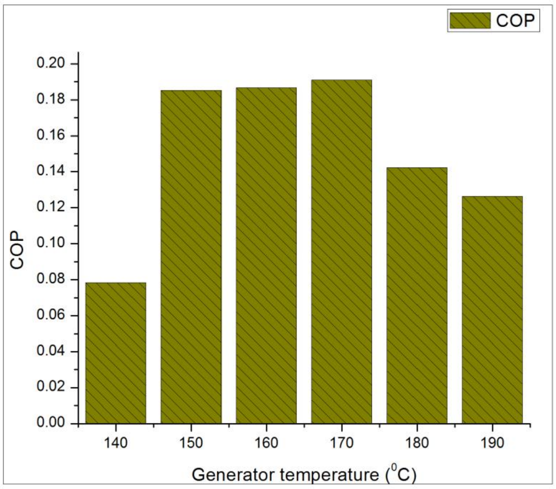

Figure 4. Variation of COP with generator temperature

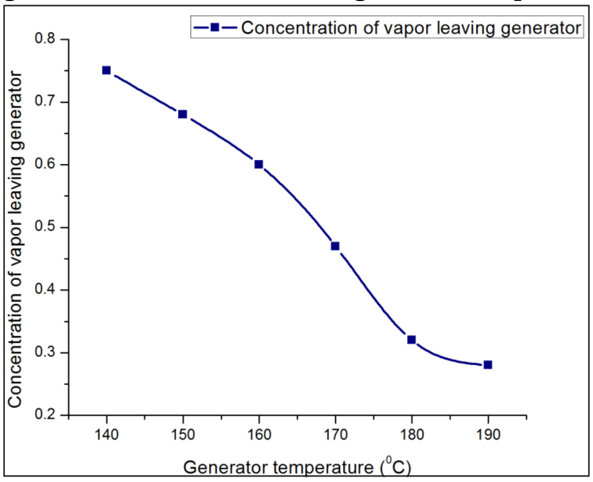

Figure 5. Variation of concentration of vapour leaving generator for different generator temperature

The above figure represents the variation of concentration of vapour leaving the generator corresponding to different generator temperature. When the generator temperature increase the concentration of vapour leaving the generator decrease. This is because as the generator temperature increase more amount of water in the solution is also get evaporated this will result in the decrease in the concentration of vapour.

Variation of generator temperature at various load

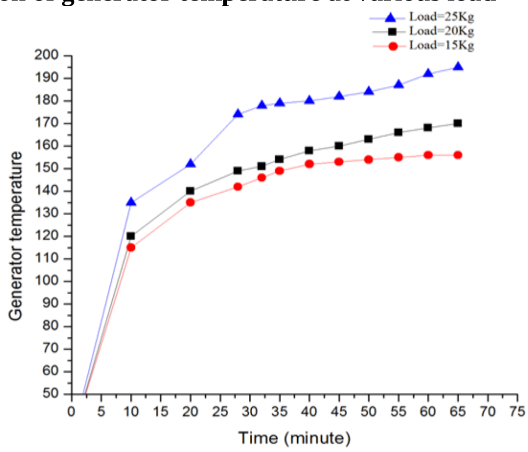

Figure 6. Variation of generator temperature at various load

The figure represents the variation in the generator temperature of absorption system with respect to the load on the engine.

Table 2. Therotical value for various generator temperature

T g ^oC	Qg kW	X_3	Q evp kW	COP
140	0.055	0.75	0.004308	0.078327273
150	0.055	0.68	0.010184	0.185163636
160	0.055	0.6	0.01026675	0.186668182
170	0.055	0.47	0.01051144	0.191117091
180	0.055	0.32	0.0078225	0.142227273
190	0.055	0.28	0.0069546	0.126447273

When the load on the engine increase the temperature of the exhaust gas is increased, as a result the generator temperature rises corresponding to the load on engine. The refrigeration effect of the absorption system is also increased with increase in the load; this is due to the rise in heat input to the generator of the absorption system.

Variation of evaporator temperature with load on engine

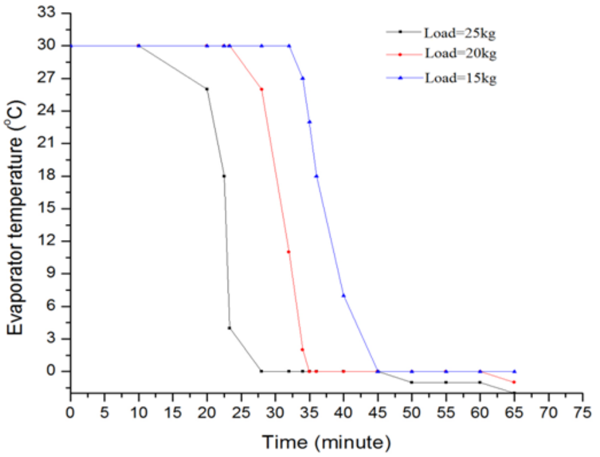

Figure 7. Variation of evaporator temperature with load

From the above graph it is seen that at high load the evaporator temperature reduce at a fast rate. This is due to the increase in the refrigeration effect produced due to increase in heat input to the generator, solution temperature will rises rapidly. When the load on the engine is decreased the system will require more time to produce the refrigeration effect. This is because of reduction in the amount of heat supplied to the generator.

Variation of refrigeration effect and COP with load

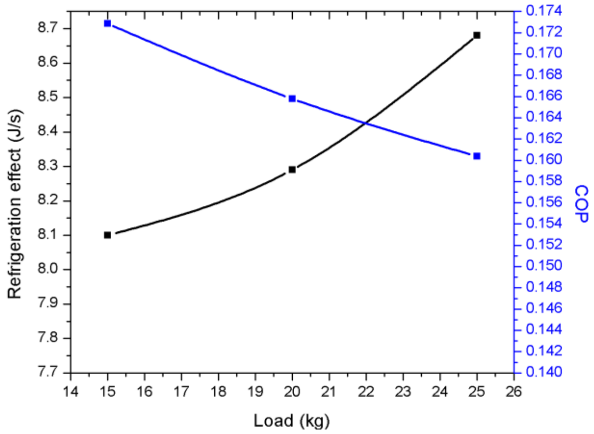

Figure 8. Variation of refrigeration effect and COP with load

From the above graph we can infer that in actual case as the load on the engine increase heat input to the generator increase hence the refrigeration effect also increase. But the rise in refrigeration effect is not linear, because some amount of supplied energy is lossed and due to increased mass flow rate the condensation becomes partial. Thus we can clearly observe a reduction in the COP due to the non-linearity in refrigeration effect. That is as the load increase the refrigeration effect increase but the COP of the system decrease.

Effect of PCM in absorption system

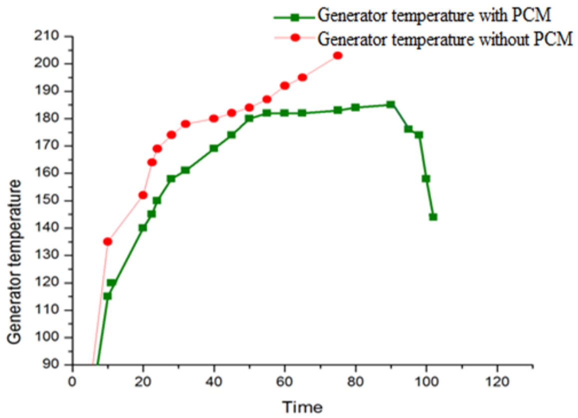

Figure 9. Effect of PCM in absorption system

The figure represents the variation of generator temperature with and without PCM. In the system without PCM the generator temperature increase rapidly and reach above 180^{o}C within 60 minutes. Futher rise in temperature is not desirable for absorption system. In the case of system with PCM, the generator temperature is maintained within the prescribed limit by means of heat absorbed by the PCM in form of latent heat. The stored energy in the PCM also act as a backup energy source whenever there is a reduction in the amount of heat to the generator.

Theoretically refrigeration effect was obtained 10.5J/s but in actual case it was obtained only 8.68J/s this is due heat loss by means of conduction and convection

COP theoretically obtained was .19 and in actual case it was obtained 0.16 and when the absorption system was integrated with PCM, overall COP of the system has increased to 0.167.

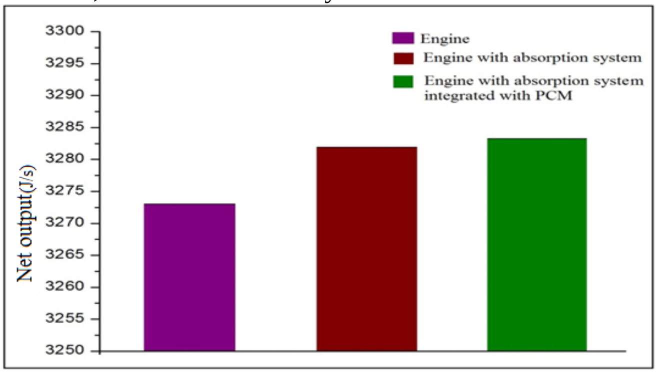

Figure 10. Represents net output of various systems

Figure represents the variation of net output of various systems. The first bar represent the out produced when the engine runs alone. Then the brake power produced by the engine is the only output we obtained.

But when the engine coupled to the absorption system the net output is increased that is engine produce the brake power and also act as a source of energy to the absorption system which produces refrigeration effect. Then the net output obtained will be the sum of brake power of engine and the cooling effect developed. This result in increase in net output and thus it help to increase the efficiency of the system

When the PCM was integrated to absorption system, then the overall COP of the absorption system was increased due to the regulation in the generator temperature which result in increase in the cooling load produced, and there by net output and the efficiency is further increased.

Conclusion

It has been seen that diffusion absorption system has the potential ability to produce refrigeration effect from the energy of exhaust gas. Hence it can replace the conventional vapour compression system in automobiles. PCM helps to increase the overall COP by regulating temperature of generator and act as a backup source whenever there is reduction in the amount of heat to the generator.

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