Experimental Investigation of Heat Recovery from Engine Exhausts Gas Using in Electrolux Refrigeration System

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ABSTRACT

Efficiency of diesel engine is about 35-40 % remaining energy go waste. Maximum energy wastes in exhaust. In diesel engine 30-32% energy go waste in exhaust. So it is important to recover energy from exhaust. Approximately 15% of all the electricity produced in the whole world is employed for refrigeration and air conditioning system. During recent years research aimed at the development of technologies that can offer reductions in energy consumption. By reason that absorption refrigeration technologies have the advantage that the peaks of requirements with the availability of the waste heat. My aim is to recover heat from exhaust gas and use it for absorption refrigeration system (Electrolux refrigeration system).

Keyword*:* *Heat recovery, Absorption refrigeration system, Electrolux refrigeration.*

1.INTRODUCTION

It is well known that energy shortage and environmental pollution have become global issues of common concern. As the most widely used source of primary power for machinery critical to the transportation, construction and agricultural sectors, engine has consumed more than 60% of fossil oil. On the other hand, the amount of CO2 gas released from engine, just for transportation applications, makes up 25% of all human activity related CO2 emissions. Thus, energy conservation on engine is one of best ways to deal with these problems since it can improve the energy utilization efficiency of engine and reduces emissions [1].
Waste heat recovery technologies in engines: In this section, a short review of the technologies for heat transfer from engines is presented. In the current status of the world the requirement of energy is increasing especially for transportation applications, so the usage of fossil fuels and consequently harmful green house gases (GHG) will increase. Researchers attempt to reduce the need of fossils fuels by using the waste heat recovery from engines. Also now, six technologies are presented for engines waste heat recovery of which Saidur et al. [2] have performed a complete review of four of them. These six technologies are thermoelectric generators (TEG), Organic Rankine Cycle (ORC), six stroke engines, turbo charging, exhaust gas recirculation (EGR) and exhaust heat exchangers (HEXs).
Given the importance of increasing energy conversion efficiency for reducing both the fuel consumption and CO2 gas emissions of engine, scientists and engineers have done lots of successful research aimed to improve engine thermal efficiency, including supercharge, lean mixture combustion, etc. However, in all the energy saving technologies studied, engine exhaust heat recovery (EHR) is considered to be one of the most effective means and it has become a research hotspot recently [1].

1.1 Diesel engine

A diesel engine is an internal combustion engine which operates using the diesel cycle. Diesel engines have the highest thermal efficiency of any internal or external combustion engine, because of their compression ratio. The diesel internal combustion engine differs from the gasoline powered Otto cycle by using a higher compression of the air to ignite the fuel rather than using a spark plug for this reason it is known as compression ignition and the petrol engine is referred as spark ignition engine. In the diesel engine, only air is introduced into

the combustion chamber.
Fig.1 sankey diagram of diesel engine

The air is then compressed with a compression ratio typically between 15 and 22 resulting into a 40 bar pressure compared to 14 bar in the gasoline engine. This high compression heats the air to 550 °C. At about this moment, fuel is injected directly into the compressed air in the combustion chamber.

The efficiency of such an IC engine is 35–40%, meaning that only about one-third of the energy in the fuel used is converted to useful work. This means that the remaining 60-65% of the primary energy is rejected to the environment by cooling water/lubricant losses of approximately 28-30%, exhaust gas losses of approximately 30–32%, and the remainder by radiation, etc. The same is true for the considerably more powerful main propulsion engines of the road vehicle.

1.2 Refrigeration

The production of cold has applications in a considerable number of fields of human life, for example the food processing field, the air-conditioning sector, and the conservation of pharmaceutical products, etc. The conventional refrigeration cycles driven by traditional vapor compression in general contribute significantly in an opposite way to the concept of sustainable development.

During recent years research aimed at the development of technologies that can offer reductions in energy consumption, peak electrical demand and energy costs without lowering the desired level of comfort conditions has intensified. By reason that absorption refrigeration technologies have the advantage of removing the majority of harmful effects of traditional refrigeration machines and that the peaks of requirements in cold coincide most of the time with the availability of the waste heat, the development of absorption refrigeration technologies became the worldwide focal point for concern again. Waste heat energy can be transformed either to electricity or to heat to power a refrigeration cycle.

1.3 Electrolux refrigeration system

In the system shown in figure 2 Model of NH3-H2O single effect refrigeration is shown. In this system evaporator and absorber is maintained at lower pressure level and generator and condenser at higher pressure level. Let's start from absorber, saturated vapour of pure NH3 at state 5 enters into absorber where ammonia which is working as refrigerant absorbed by solution and refrigerant releases the heat absorbed inside evaporator which is removed by continuous circulation of cooling water and comes out at state 7 then strong solution at state 7 is passed through pump and pumped to generator pressure at state 9 through liquid-liquid heat exchanger. Inside generator solution absorb heat from the waste heat coming out of diesel engine's exhaust, causing refrigerant to vaporize and separate refrigerant from absorbent solution and solution having less concentration of refrigerant returns back to absorber through liquid-liquid heat exchanger. As in case of NH3-H2O system vaporize refrigerant contains water along with it so it passes through dephlagmator ,After dephlagmator pure ammonia comes out at state 1 and then it enters into condenser where it rejects heat and condenses and comes out at state 2 then through expansion valve it comes to evaporator at state 4 where it absorbs heat i.e. called refrigerating effect then its converts into vapour and exits at state 5 lower pressure and enters into absorber this process repeats again and again in absorption refrigeration cycle

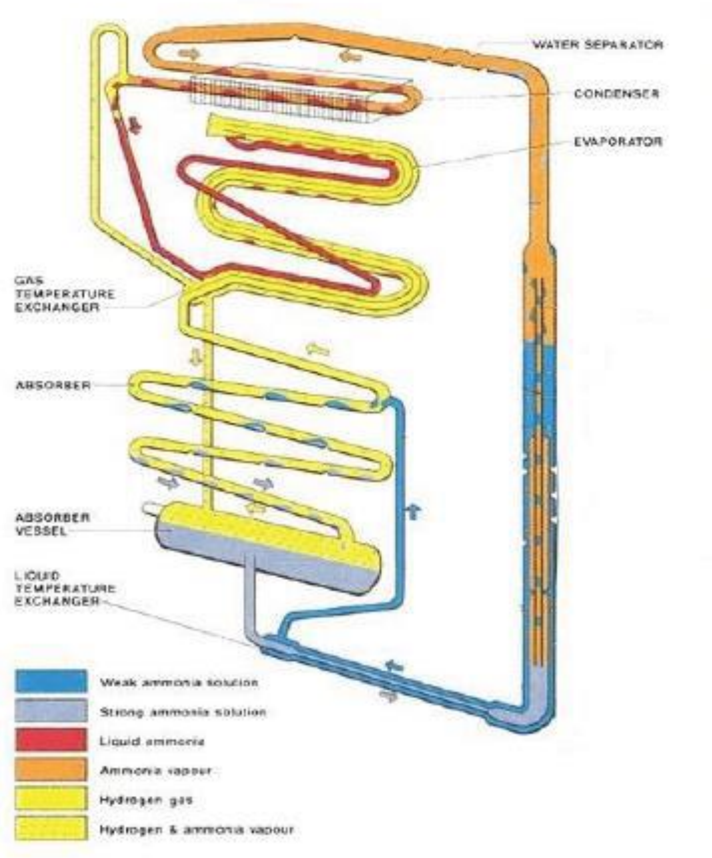
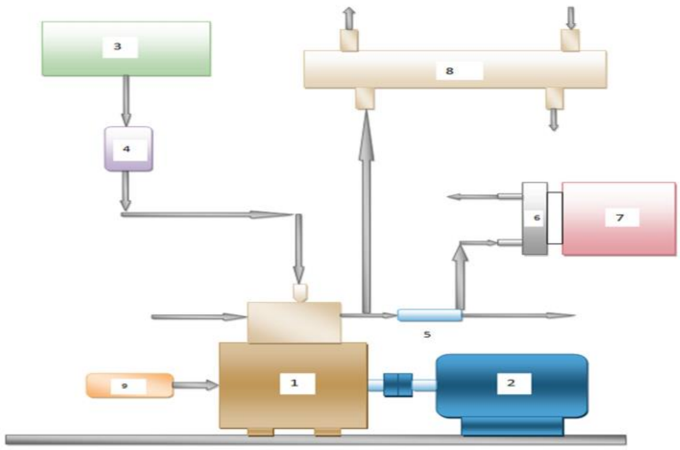


Figure 2 Electrolux Refrigeration system



1. Engine , 2. AC Dynamometer, 3.Fuel tank, 4.Burette, 5.Bypass valve, 6. Heat exchanger, 7.Electrolux refrigerator, 8.Calorimeter, 9.Tachometer

2. Experimental Setup

Table 1. Of Engine Specification

No. of cylinder	Single cylinder
No. of strock	4
Cylinder dia.	87.5 mm
Stroke length	110 mm
C.R. length	234 mm
Fuel	Diesel
Power	3.5 kw
Speed	1500 rpm

Table 2. Of Specification of Electolux Refrigerator

ELECTROLUX	
Ser. No.	92503617
Model	EA 0600 C
Prod. No.	921150150
Type	E 30/60 Absorption system
Gross Volume	60 L
Refrigerant NH3	0.55 kg
Nominal voltage	230 V 50-60 Hz
Nominal Current	0.41 A
Nominal Input	95 W

3.Sample Calculation

For Diesel Engine, at full load condition
Load=9 kg,Brake power =2.64 kW, Speed = 1500 rpm
Time for consumption of 10ml fuel = 33.35sec

Calculation of energy analysis at Compression Ratio 17 and Injection Pressure 180 bar is given below:

Mass flow rate of engine cooling water $(m_w)_{en}$ = 250 LPH(litre per hour)

$$= 250 \times 10^{-3}/3600 \ m^3/sec$$

$$=(250 \times 10^{-3}/3600)\times \text{density of water}$$

$$= (250 \times 10^{-3}/3600) \times 1000 \ kg/sec$$

$$= 0.06944 \ kg/sec$$

Mass flow rate of calorimeter water $m_{wcal} = 80\ LPH$

$$= (80 \times \frac{10^{-3}}{3600}) \times 1000$$

m_{wcal} = 0.02222 kg/sec

Mass of fuel consumed per unit time $\dot{m}_f = \frac{volume\ of\ fuel\ consume}{time\ taken} \times density\ of\ fuel$

$$= \frac{10 \times 10^{-6}}{33.35} \times 834$$

$$=2.5007 \times 10^{-4} \ kg/sec$$

$$= 0.000252 \ kg/sec$$

$$\dot{m}_a = c_d \times \frac{\pi}{4} \times d^2 \times \sqrt{2 \times 9.81 \times h_w \times \rho_{water}/\rho_{air}} \times \rho_{air}$$

Where ρ_{water}= 1000 kg/m^3

ρ_{air}= (P/ R T) kg/m^3

= 1.013×10^5 / {287× (25+273)}

= 1.184 kg/m^3

c_d= co-efficient of discharge of orifice=0.6

d= diameter of tube orifice=20mm

hence mass of air consumed per unit time

$$\dot{m}_a = 0.6 \times \frac{\pi}{4} \times (20 \times 10^{-3})^2 \times \sqrt{2 \times 9.81 \times 0.06258 \times 1000/1.184} \times 1.184$$

= 0.007183 kg/sec

Mass of exhaust gases per unit time $\dot{m}_{ex} = \dot{m}_a + \dot{m}_f$

= 0.007183+ 0.000252

= 0.007435 kg/sec

Heat supplied to the engine per unit time

$\dot{Q}_{in} = m_f \times LCV$

= 0.000252× 42850

= 10.79 kW

Brake power of the engine

$\dot{W}_{sp} = 2\pi NT/60{,}000$

= $2\pi \times 1545 \times (9 \times 9.81 \times 0.185)/60000$

= 2.6415 kW

Heat carried away by cooling water of the engine

$\dot{Q}_{CW} = m_{cw} \times C_{pw} \times (T_2 - T_1)$

= $0.02222\times 4.187 \times (313 - 304)$

= 0.8373 kW

Heat carried away by exhaust gases

First of all exact specific heat of exhaust gases is not known hence it can be found out by heat balance in calorimeter.

Heat gain by water in calorimeter = Heat loss by exhaust gases in calorimeter

$\dot{m}_{wcal} \times C_{pw} \times (T_4 - T_3) = \dot{m}_{ex} \times C_{pex} \times (T_5 - T_6)$

$0.02222\times 4.187 \times (310 - 304) = 0.007183 \times C_{pex} \times (633 - 563)$

C_{pex} = 1.1101 kJ/kg.k

Heat carried away by exhaust gases is now calculated as

$\dot{Q}_{ex} = \dot{m}_{ex} \times C_{pex} \times (T_5 - T_0)$

= 0.007183× 1.1101 × (633-298)

= 2.6712 kW

Unaccounted losses

$\dot{Q}_u = \dot{Q}_{in} - (\dot{W}_{sp} + \dot{Q}_{cw} + \dot{Q}_{ex})$

= 10.71-(2.6415 + 0.8373 + 2.6712)

= 4.56 kW

Brake thermal efficiency(BTHE)

$\eta_{bth} = \left\{\frac{\dot{W}_{sp}}{\dot{Q}_{in}}\right\} \times 100\%$

= 24.44%

Heat energy available in exhaust gas = mg. x Cp x ΔT

= 0.043× 1.3 × (360- 42)

= 17.77 kW

Heat gain by Heat exchanger = $mg \times CP_g \times (1\text{-bypass factor}) \times \Delta T$

$= 0.043 \times 1.3 \times (1 - 0.6) \times (323 - 305)$

= 402.48 W

Heat gain by generator =

$Heat\ gain\ by\ Heat\ exchanger \times Effectiveness\ of\ Heat\ Exchanger$

= 402.48× 0.5

= 201.24 W

Water volume = 5 liter

Time = 110 min

Temperature , Ta=37°C & Tb = 6.5°C

Cooling effect = 4.187 $\times\ water\ volume\ \times (T_a - T_b)$

= 4.187 $\times 5 \times (37 - 6.5)$

= 638.52

Cooling effect in watt = $\frac{Cooling\ Effect \times 1000}{Time\ Duration\ \times 60}$ W

$= \frac{638.52 \times 1000}{110 \times 60}$ W

= 96.74 W

COP of refrigeration = $\frac{cooling\ effect}{heat\ gain\ by\ generator}$

$$= \frac{96.74}{201.24}$$

= 0.4807

Percentage of heat recovers $= \frac{Heat\ gain\ by\ generator}{Heat\ energy\ available\ in\ exhaust\ gas \times (1-0.6)}$

$$= \frac{201.24}{17770 \times (1-0.6)}$$

= 0.0283

= 2.83%

4. Table 3. Of Performance readings:

Sr No.	Load (kg)	Brake power (kw)	Mass flow rate of exhaust gas (kg/s)	By pass factor	Heat gained by Heat Exchanger (W)	Effectivnes s of Heat Exchanger	Heat gained by Generator	Cooling effect (W)	COP of refriger ator	% of heat recovery
1	1	0.31	0.040	0.3	124.8	0.5	62.4	64	1.0325	0.015
2	5	1.48	0.041	0.3	214.4	0.5	107.3	77.29	0.342	1.72
3	9	2.64	0.043	0.6	402.7	0.5	201.2	96.79	0.4809	2.83

5. Result and Discussion

5.1Heat loss in exhaust gas

The experimental results were analyzed and the data has been summarized in graphical form. From the experimental data the heat loss in exhaust gas has been determined and has plotted as function of brake power.

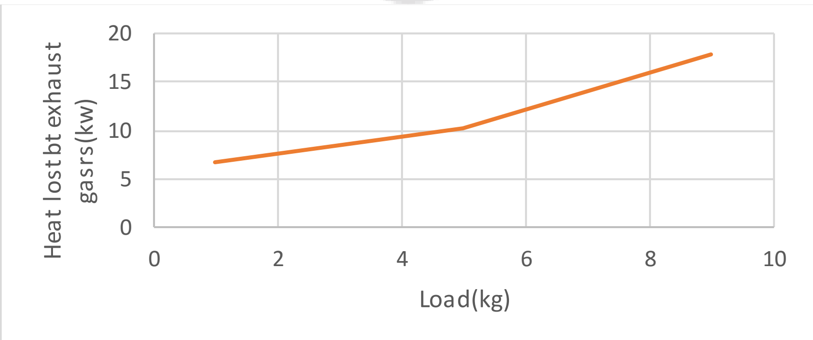


Chart 1: Variation in heat loss by exhaust gas with Load

Chart 1 shows graph for variation of load with respect to Heat loss for naturally aspirated engine. For all the cases tested, Heat loss is found to increase with increase in the Load. It can be seen that as the load increases, heat loss increases to the maximum at full load.

5.2 Heat recover

Chart 2 shows graph for variation of Energy recover with respect to brake power, with naturally aspirated engine. For all the cases tested, Energy recover is found to increase with increase in the brake power. It can be seen that as the load increases, Energy recover increases to the maximum at full load for all the cases tested.

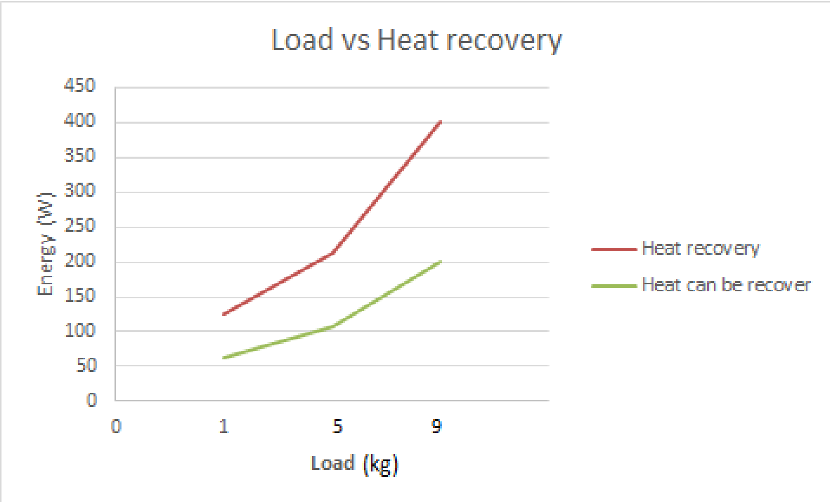


Chart 2 Variation in heat loss by exhaust gas with load

5.3 COP of refrigerator

Chart 3 shows graph for variation of COP with respect to Exhaust gas temperature, with naturally aspirated engine. For all the cases tested, COP is found to increase with increase in exhaust gas temperature. It can be seen that as the exhaust gas temperature increases, COP of refrigerator increases to the maximum at full load for all the cases tested.

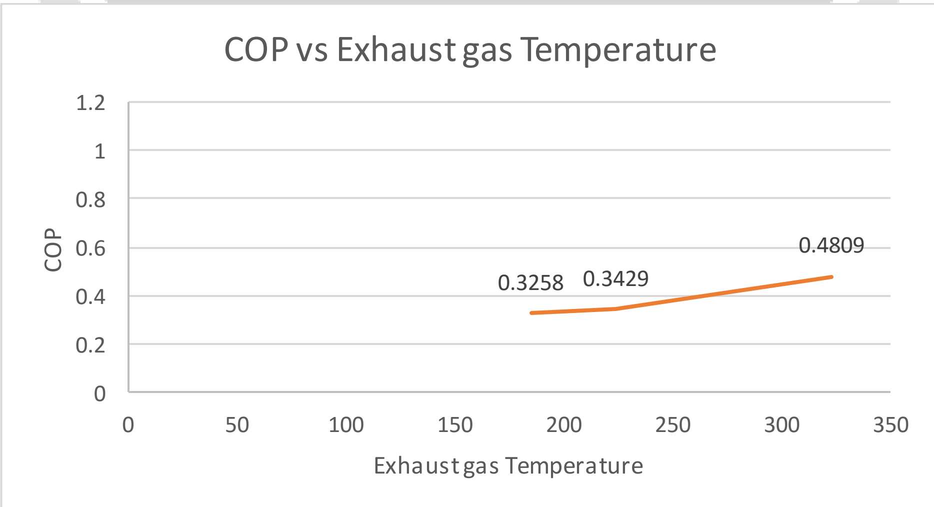


Chart 3 COP vs Exhaust gas temperature

6. Future Scope

As the system used in experiment is small capacity, it can be replace by system of higher capacity which can extract large amount of heat of exhaust gas.

Heat exchanger of anti-corrosive material with good design can improve rate of heat transfer.

7. Conclusion

The absorption refrigeration system is a feasible alternative to the traditional vapour compression system for automotive case. The absorption refrigeration systems use an eco-friendly refrigerants and consume very little power for operation when compared to traditional vapour compression systems. The reduction in power is achieved because the system can be operated using the waste heat rejected from exhaust gas and because no compressor is required.

From experiment, it is concluded that about 2 to 3 % of heat is recovered using Electrolux refrigeration system.

As the load on the engine is increased, amount of heat utilisation is increased.

This is because the temperature of exhaust gas is increased with increase in load.

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