EXPERIMENTAL STUDY OF KALINA CYCLEAND ITS EFFECT ON EXHAUST EMISSION FROM MULTI-CYLINDER 1196 CC PETROL ENGINE

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ABSTRACT

The increasingly worldwide problem regarding rapid economy development and a relative shortage of energy, the internal combustion engine exhaust waste heat and environmental pollution has been more emphasized heavily recently. The total amount of energy supplied to engine, out of which only 30% to 40% is convert into useful work while rest of energy is expelled to the environment which causes serious environment damage. Therefore it is required to utilize this waste energy to improve thermal efficiency of engine and also to reduce greenhouse effect. This paper focuses on waste heat recovery of 1196cc multi-cylinder petrol engine with the help of Kalina cycle. In order to investigate the effect of Kalina cycle, an experimental set-up has been developed. For the experimental purpose, Kalina cycle is connected to exhaust ofengine have been tested for different mass flow rate and rpms. This paper also covers the analysis of exhaust emissionwith and without Kalinacycle. The waste heat of small car engine doesn't find use due to its minimum quantity of heat availability. Due tohigh thermal efficiencyofKalina cycle, it is suitable for waste heat recovery from small car engines. In the present work, optimum mass flow rate ofKalina Cycle and turbine pressure ratio effect is experimentally studied for waste heat recovery from 1196cc multi-cylinder petrol engine.For maximum turbine power of 41.98 W, the optimum mass flow rate is found to be 0.29LPM. From comparative analysis of exhaust gas emission from engine, CO2, NOx and HCemissions reduces due to use of Kalina cycle.

Keywords: Ammonia-Water Mixture, Exhaust Heat Recovery, Separator, Waste Heat

I. INTRODUCTION

With the increasingly prominent problem regarding rapid economy development and the graduallyserious environmental pollution, the waste heat recovery and waste gas pollution processing have receivedsignificant attention. Waste heat recovery is the system in which waste heat of different application such as internal combustion engines, turbines, industries, small power plants etc. are converted into useful mechanical or electrical energy. There are various direct and indirect technologies by using which heat can be recovered.Out of which, the organic Rankine cycle and Kalinacycle is the good choices for electricity generation, as they operates at low-temperature heat sources.

With automobile industrial revolution, the manufacturing and sales of small vehicle increases drastically. Each small vehicle engine loses a large part of the fuel energy to the environment, most importantly with the exhaust gasses which can contain about 25% of the input energy [1].Hence it is required to reduce this wastage in small vehicle. Main problem in heat recovery from such system is its small amount of heat availability.

Dr. Alexander Kalian proposed waste heat recovery cycle which give high thermal efficiency than Organic Rankine Cycle. This cycle is known as Kalina Cycle or Ammonia-Water bottoming cycle. The mixture of Ammonia-water of different concentrations are used as working fluid. Because of non-isothermal phase change behaver of Ammonia-Water mixture, Kalina Cycle can extract low temperature heat effectively. Thus Kalina Cycle is suitable for waste heat recovery from light duty engine.

Fromexisting literatureview reveals that,very little research has been done on waste heat recovery on multi-cylinder petrol engine with the help of Kalina cycle.Experimental studies have done for ORC and Kalina cycle on heavy duty engines like truck, marine, small power generation plant, industrial waste heat etc.Most of experimental studies focused on how effectively power produce by ORC or Kalina cycle with low exhaust emission.It is found that the Kalina cycle can produce minimum power at 53 ºC temperature. Inadequate implementation of Kalina cycle on four cylinder light motor vehicle engine. Hence, it is clear that with the help of Kalina, Rankine and Breton cycle, waste heat from exhaust gas can be recovered to produce power. Up till now, Kalina cycle is studied on heavy duty engines, turbines, geothermal sources etc. Hence it is required to study and investigate the performance of Kalina cycle on multi-cylinder petrol engine.

This experimental study is carried out on 1196 CC multi-cylinder petrol engine of Maruti Suzuki Eeco and the Kalina cycle is used with 0.6% ammonia-water mixture. The objective of the study is to find the mass flow rate of ammonia-water mixture in Kalina cycle to produce maximum turbine power and study the behaviour of turbine pressure, with comparative analysis of exhaust emission from engine with and without Kalinacycle.Theresultsobtained from this experimental study will help to decide the feasibility of Kalina cycle on small cars.

II. THEORETICAL HEAT LOSS THROUGH THE EXHAUST EMISSION

Engine specification is given in Table I.

Table 1 Engine Specification

Manufacture	Maruti Suzuki (Eeco)
Engine	4 Cylinder, 4-Stroke, S.I. Engine
Bore	0.071m
Stroke	0.075m
Sp. Fuel Combustion	270gm/kw.hr
Capacity	1196CC
Maximum Power	73BHP @ 6000rpm
Maximum Torque	101Nm @ 3000rpm
RPM	6000rpm
Cooling System	Water Cooled

Heat loss through the exhaust gas from multi-cylinder petrol engine is calculated as follows. Assuming,

Volumetric efficiency is 0.8 to 0.9

Specific gravity of fuel is 0.85 kg/lit

Calorific value of petrol is 44 MJ/kg

Density of air fuel is 1.167 kg/m3

Specific heat of exhaust gas is 1.1-1.25 KJ/kg°K

Exhaust heat loss through multi-cylinder petrol engine Mass flow rate of air in suction,

$m_a = \eta_v \times \rho_a \times n \times V$ 1

$m_a = 0.9 \times 1.16 \times \frac{3000}{2} \times 1196 \times 10^{-6}$

$m_a = 31.2$ gm/sec

Mass flow rate of petrol fuel,

$m_f = (SFC \times POWER)$ 2

$m_f = 270 \times 36$

$m_f = 2.7$ gm/sec

Heat avalable at exhaust gas

$Q = (m_a + m_f) \times C_p \times \Delta T$ 3

$Q = 33.9 \times 1.2 \times (400 - 40)$

$Q = 14.6$ KW

Therefore the total energy loss by Multi-Cylinder SI-Engine is 27.12%. Hence the loss of heat energy through the exhaust gas exhausted from I.C. engine into the environment 27.12% energy.

III. EXPERIMENTAL TEST FACILITY

3.1 Experimental Set Up

In this experimental setup of given dissertation work, Kalina cycle performance will be tested on multi-cylinder petrol engine. In this setup, all essential measuring instruments will be calibrated and connected as per recommended standards. The schematic view of experimental set up to study the performance of Kalina cycle on multi-cylinder petrol engine is shown in figure 2.

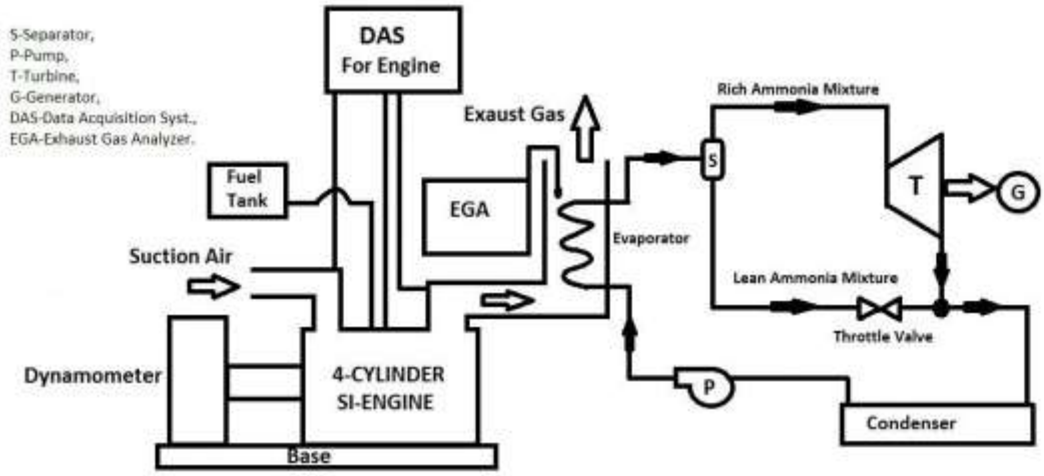

Figure 2 Experimental setup

Experimental set up consist of multi-cylinder SI-Engine with Kalina cycle as shown in figure 2. The dynamometer, exhaust gas analyzer and data acquisition system are connected to multi-cylinder engine. The dynamometer is used to provide different load to engine. Data acquisition system is provided to analysis the change in different parameter of engine during experimentation such as suction temperature, exhaust temperature, brake power of engine, rpm etc. At the exhaust of engine as shown in fig. exhaust gas analyzer is fixed to study the variation in exhaust emission coming from engine during experimentation.

Figure 3 Photographic Image of the experimental setup

Heat required for driving the Kalina cycle is taken from exhaust heat of engine by using evaporator. The high pressure ammonia-water mixture is collected in separator out of which high pressure vapour rich mixture is used to drive turbine and liquid lean mixture is used to increase the condensation temperature by using throttle valve as shown in fig. The rich and lean mixture are mixed before condenser and cooled in condenser by using water. The condensed ammonia-water mixture is supplied to evaporator by recirculation, using pump as shown in fig. the photographical view of experimental setup is shown in figure 3.

Present experimental setup consists of four main components which are necessary for performance analysis of kalian cycle. Specifications of each components of present experimental set-up are given as following

The experimental setup used Maruti-Suzuki Eecomulty-cylinder petrol engine. It is small 1196 CC engine with MPFI system. This engine is inline type four cylinder four stroke petrol engine which produce 73bhp at 6000rpm.The detail specification is given as follows

The water cooled eddy current dynamometer is used to change the load on engine to study the engine performance. Eddy-Current Brake Dynamometers are ideal for applications requiring high speeds and also when operating in the middle to high power range. Eddy-Current Brakes provide increasing torque as the speed increases, reaching peak torque at rated speed. The dynamometers have low inertia as a result of small rotor diameter. Brake cooling is provided by a water circulation system, which passes inside the stator to dissipate heat generated by the braking power. The dynamometers have accuracy ratings of ± 0.3% to 0.5%. The detail specification is given as follows

Table 2 Dynamometer Specifications

Weight	560 kg
Inertia	0.093 kg.m^2
Maximum Power	150 kW (200 bhp)
Maximum Torque	500 Nm
Maximum Speed	12000 rpm
Operating Temperature	10ºC to 60ºC
Minimum water mass Flow rate	20 LPM
Accuracy	± 0.3% to 0.5%

Use of a five Gas Exhaust Analyser can be helpful in troubleshooting both emissions and driveability concerns. The five gasses measured by the latest technology exhaust analysersfor petrol emissions are HC, CO, CO2, O2 and NOx.We can use clues and patterns of exhaust readings to figure out if we have a problem in Combustion, Ignition and exhaust emission etc.

Figure 4 Photographic Image of Kalina Cycle System

The photographical view of system is shown in fig 4.6. Kalina cycle have two heat exchangers, pump, Turbine, separator and mixing-chamber. The spiral tube heat exchangers have 10mm Aluminium spiral tube diameter and 140mm shell diameter. The diaphragm pump used in this system which gives 5.5 bar pressure and 4LPM mass flow rate at 30 W. The turbine used is centrifugal type with 55mm impeller diameter. The separator is cylinder of diameter 30mm and length 40mm with one inlet and two outlets. The mixing-chamber is cylinder of diameter 30mm and length 50mm with two inlets and one outlet.

Table 3 shows variation in turbine power for different mass flow rate of ammonia water mixture and for different turbine pressure ratio at respective RPMs.

N(rpm)	MFR (LPM)	TPR	TP (W)
1400	0.15	1.55	22.32
1400	0.22	1.94	27.94
1400	0.29	2.54	36.58
1400	0.36	1.73	24.91
1400	0.43	1.46	21.02
1600	0.15	1.62	23.00
1600	0.22	2.02	29.90
1600	0.29	2.56	37.89
1600	0.36	1.78	26.34
1600	0.43	1.46	21.61
1800	0.15	1.59	24.17
1800	0.22	2.02	30.70
1800	0.29	2.55	38.76
1800	0.36	1.82	27.66
1800	0.43	1.47	22.34

N(rpm)	MFR (LPM)	PR	TP (W)
2000	0.15	1.67	25.38
2000	0.22	2.06	31.38
2000	0.29	2.58	39.91
2000	0.36	1.88	29.04
2000	0.43	1.52	23.49
2200	0.15	1.65	26.05
2200	0.22	2.04	32.14
2200	0.29	2.62	40.81
2200	0.36	1.92	29.89
2200	0.43	1.54	23.99
2400	0.15	1.76	27.86
2400	0.22	2.10	34.44
2400	0.29	2.56	41.98
2400	0.36	1.88	30.83
2400	0.43	1.52	24.93

3.2 Experimental Results

All the measured parameter for different mass flow rate and speeds are listed in table3. First the engine rpm is made constant like 1400rpm then change the mass flow rate of ammonia-water mixture from 0.12lpm to 0.42lpm and note down the turbine pressure ratio and turbine power. Repeat same process for different rpms from 1400rpm to 2400rpm. From experimental values find mass flow rate which give maximum turbine power.

For comparative exhaust gas analysis first engine is run without Kalina cycle at different rpm from 1200rpm to 2400rpm and second time engine is run with Kalina cycle. Five gas analyser is used to note down the CO, CO2, NOx, HC and O2 emission for respective rpms.The results obtained from experimentation is shown in table 4.

Table 4 Shows Exhaust Emission from Engine at Constant Load one Kg For Different Speeds

RPM	O2 with KC	O2 with KC	CO2 with KC	CO2 with KC	CO with KC	CO with KC	Nox with KC	NoxwithKC	HC with KC	HC with KC
1200	19	19.17	7.225	6.658	141	143	149.1	139.9	133.0	118.4
1400	18.94	19.08	7.326	6.744	159	162	166.9	158.7	154.8	137.6
1600	18.99	19.1	7.583	6.983	180	186	165.3	160.7	149.3	133.1
1800	18.86	18.99	8.29	7.595	243	245	171	163.1	156.2	143.7
2000	18.83	19	8.486	8.186	261	263	176.4	169.1	190.8	179.5
2200	18.81	18.88	8.682	8.478	327	328	201.7	193.3	257.4	249.3
2400	18.77	18.86	8.902	8.779	391	392	222.2	217.5	293.6	285.9

V. REASULT AND ANALYSIS

After the extensive experimentation at different speeds and loads of engine, results obtained are broadly discussed hear. The optimum mass flow rate of ammonia-water solution and optimum turbine pressure ratio results are discussed. Then comparative experimental results of exhaust emission with and without Kalina cycle is describe in table 3.

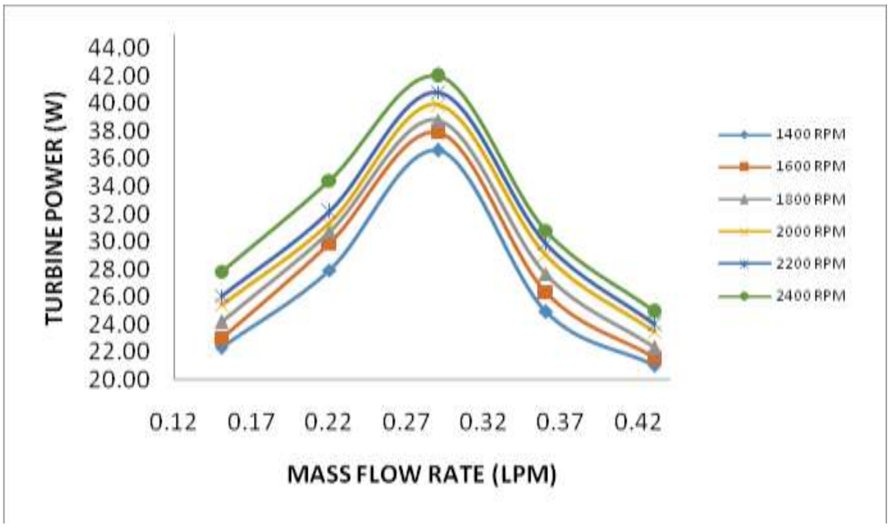

Figure 5 Turbine Power Variations with Mass Flow Rate

It is required to find the mass flow rate for which Kalian cycle shows maximum output power to fix the optimum mass flow rate in Kalina cycle for maximum efficiency. The figure 5 shows turbine power variations with mass flow rate.The load on engine is kept constant at 10kg and at different engine speeds from 1400RPM to 2600RPM and for respective different mass flow rate of ammonia-water mixture solution from 0.12LPM to 0.42LPM the variation in turbine power is experimentally studied.A results show continues increase in turbine power then it riches to its maximum power and start decreasing with increase in mass flow rate at constant load and respective RPM. The maximum turbine power shows 36.58W, 37.89W, 38.76W, 39.91W, 40.81W and 41.98W at 1400RPM, 1600RPM, 1800RPM, 2000RPM, 2200RPM and 2400RPM with optimum mass flow rate of 0.29LPM. At the begging mass flow rate is minimum and enthalpy difference is maximum but its product give minimum value until it riches to that point where both achieve such a value that their product should be optimum as we continue to increase mass flow rate then enthalpy difference start decreasing and again their product start decreasing.

To study the behaviour of turbine in Kalina cycle, the outlet and inlet pressure ratio of turbine is experimentally studied with respect to turbine power at different mass flow rate from 0.12LPM to 0.42LPM at different RPM from 1400RPM to 2400RPM as shown in figure 6.A results show continues increase in turbine power as pressure ratio increases up to optimum pressure ratio which is achieve at optimum mass flow rate. At the same time turbine power also increases with RPM too. The maximum turbine value is 36.58W, 37.89W, 38.76W, 39.91W, 40.81W and 41.98W for pressure ratio 2.54, 2.56, 2.55, 2.58, 2.62 and 2.56. The pressure at inlet of turbine is going to increase as mass flow rate of ammonia water mixture increase up to its optimum value and the pressure at outlet almost remains constant. Hence the pressure ratio increases with mass flow rate and the turbine power too.

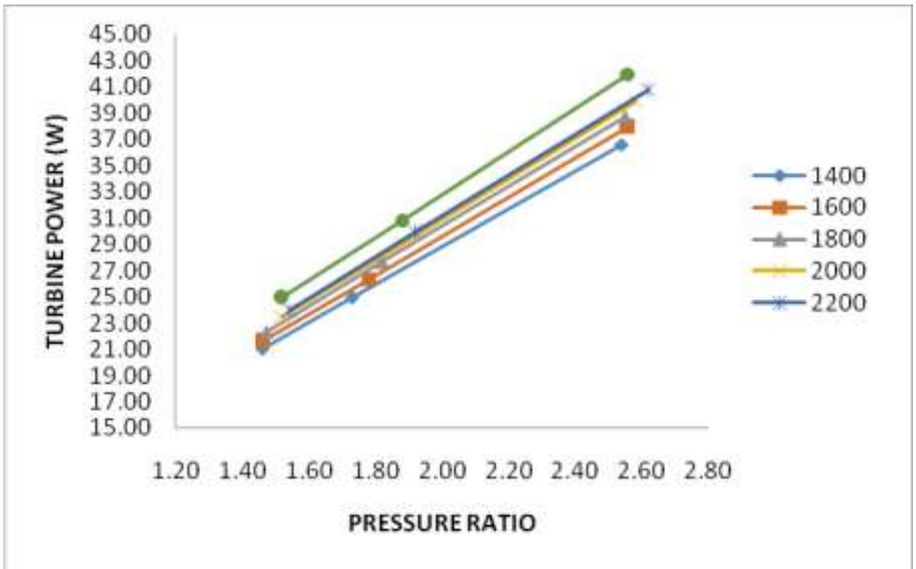

Figure 6 Turbine Power Variations with Pressure Ratio

In IC-Engine the intake is taken as HC, N_2 and O_2 and after combustion at outlet there is CO, CO_2, NO_x, HC, O_2 and H_2O. It is required to study behaviour of exhaust emission with and without Kalina cycle.

Following figure 7 shows the effect of Kalina cycle on the amount of oxygen emitted from the engine. It shows that the highest amount of oxygen 19.2% is emitted from the engine when the speed is between 1200-2400 RPM while the exhaust system is attached with Kalina cycle system. Again from this figure the amount of oxygen emitted from the engine without Kalina cycle has been reduced significantly while the best possible amount of oxygen is 18.1% which occurred around 1400RPM of engine speed. The amount of oxygen emitted from engine stabilizes while the engine speed increases with the absence of catalytic converter but the amount is still lower than the condition while the exhaust system. The amount of oxygen increases in exhaust with Kalina cycle because the extra amount of oxygen present at exhaust not chemically react with nitrogen, carbon monoxide to produce NO_X and CO_2, because for this reaction high temperature is required.

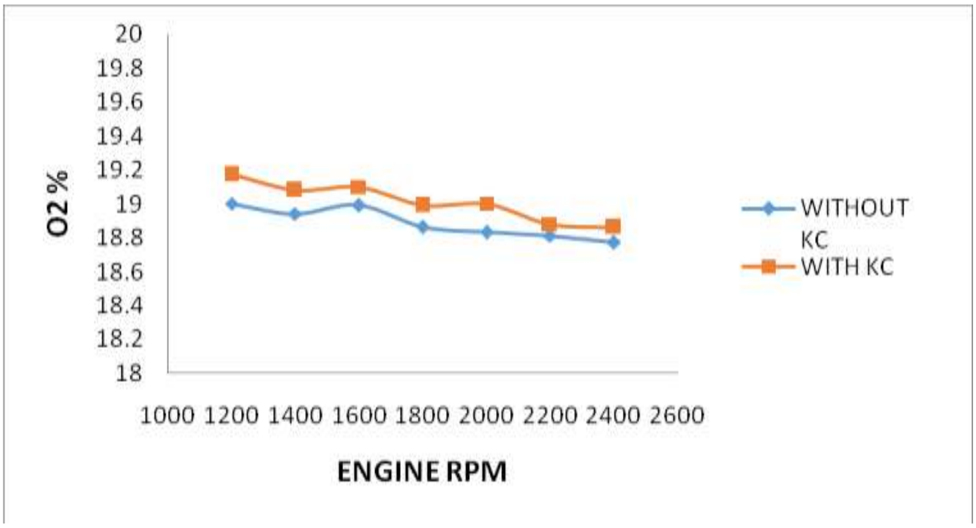

Figure 7 Oxygen Emission Variations with Engine RPM

From figure 8 CO2 emitted from the engine is always less than 7ppm while the minimum amount of CO2 emission from engine without Kalina cycle is greater than 7ppm. This implies a quite good improvement in reduction of CO2 presented in the exhaust gas. In both the cases the amount of CO2 increases constantly with increase in speed. Highest speed causes to emit the highest amount of CO2 from the engine exhaust. After 1600 RPM the CO_2 emission is above 7ppm for exhaust with Kalina cycle. The amount of CO_2 emission reduces in engine with Kalina cycle because at low temperature CO to CO_2 conversion rate is reduced.

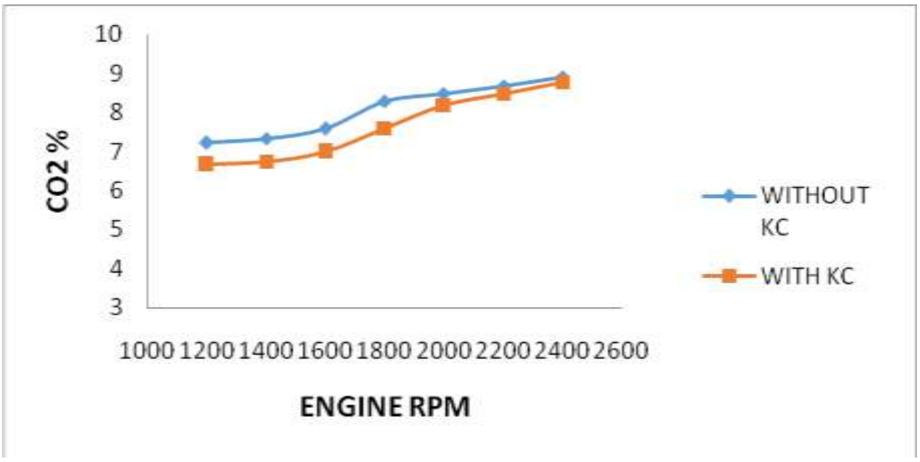

Figure 8 Carbon Dioxide Emission Variations with Engine RPM

The figure 9 shows the linear characteristic of CO emission with the change of engine speed. In both the cases the amount of CO increases with the engine speed. But with the use of Kalina cycle the CO emission increases as compare to CO emission without Kalina cycle. At 1200RPM to 2400RPM CO emission for without are 141ppm, 159ppm, 180ppm, 243ppm, 261ppm, 327ppm and 391ppm and with Kalina cycle are 143ppm, 162ppm, 186ppm, 245ppm, 263ppm, 328ppm and 392ppm. The CO emissions which produce during combustion react with excess oxygen and produce CO_2. CO to CO_2 conversion rate is minimum with use of Kalina cycle because of low temperature.

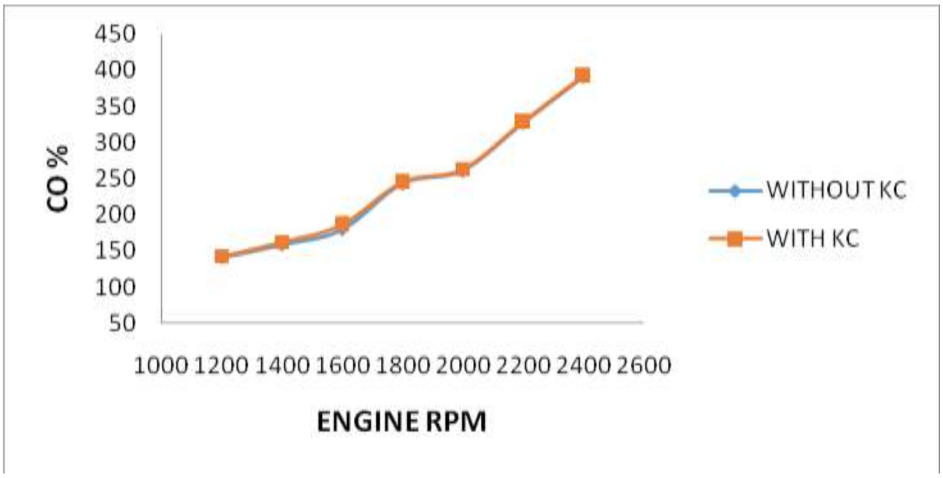

Figure 9 Carbon Monoxide Emission Variations with Engine RPM

Oxide of nitrogen are NO and NO_2 which produce by chemical reaction between nitrogen and excess oxygen present at exhaust gas at high temperature. From following figure 10 it is found that as engine speed increase from1200 RPM to 2400 RPM then NO_x emission increase drastically for both with and without Kalina cycle. The NO_x emission for engine without Kalina cycle is 149.1ppm, 166.9ppm, 165.3ppm, 171ppm, 176.4ppm, 201.7ppm and 222.2ppm and with Kalina cycle is 139.9ppm, 158.7ppm, 160.7pp, 163.1ppm, 169.1ppm, 193.3ppm and 217.5ppm. The NO_x emission of engine exhaust with Kalina cycle shows minimum emission than engine without Kalina cycle because lower temperature exhausts produce due to evaporator of Kalina cycle. In pure combustion process engine exhaust contains CO_2 and H_2O. Hydro-carbon present in exhaust explains the incomplete combustion process. Kalina cycle system not going to reduce the HC contain by any reaction. So to reduce the HC in exhaust the baffles and winded tubes act as filter and some of hydro-carbon get deposited on that which reduces HC contain at exhaust during draining to atmosphere.

With increase in speed of engine from 1200 RPM to 2400 RPM then amount of HC emission at exhaust also get increase for both with and without Kalian cycle. At 1200 RPM HC emission for with and without Kalina Cycle is 118.4ppm and 133ppm. As we move to maximum 2400 RPM the HC emission for with and without Kalina Cycle shows small variation as 285.9ppm and 293.6ppm.

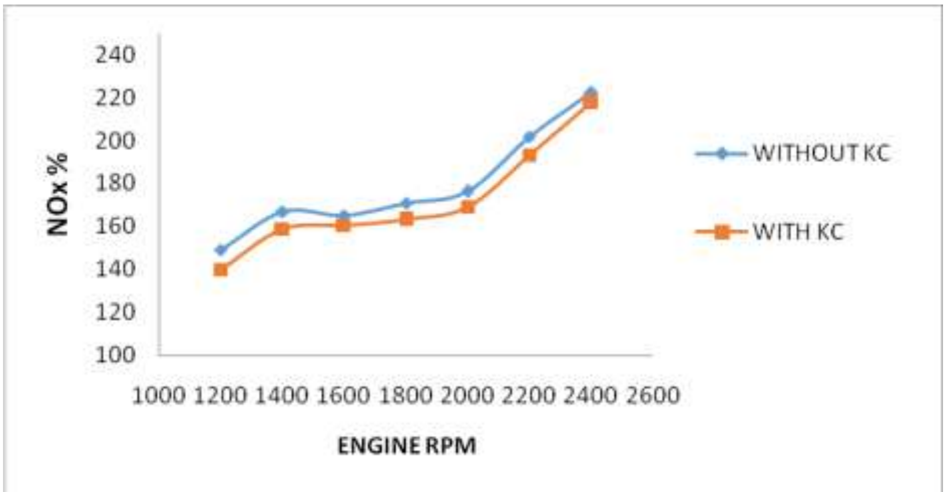

Figure 10 Oxides of Nitrogen Emission Variation with Engine RPM

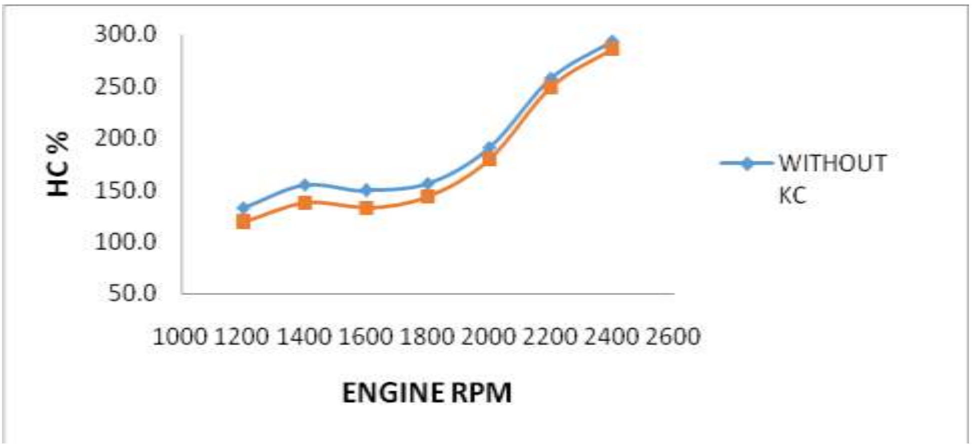

Figure 11 Hydro Carbon Emission Variations with Engine RPM

V. CONCLUSION

Power cycles with ammonia-water mixtures as the working fluid are well suited for utilization of waste heat from multi-cylinder petrol engines. The 1196CC multi-cylinder petrol engine losses 27% of its energy in exhaust gas. This waste energy not only increases entropy but also causes other environmental damages. This waste energy can be utilize with the help of Kalina cycle. From given experimental study it is found that at different speeds optimum mass flow rate of ammonia-water mixture is found to be 0.29LPM. At different speeds, as turbine pressure ratio increase then the turbine power also increases. From exhaust analysis it is found that, Oxygen emission at exhaust of engine enhanced due to use of Kalina cycle with engine exhaust. Carbon dioxide emission at exhaust of engine reduces due to use of Kalina cycle with engine exhaust. There is very small decrease in carbon monoxide with the help of engine with Kalinacycle. Oxides of nitrogen emission decreases due to use of Kalina cycle with engine exhaust. Hydro carbon emission at exhaust reduces with the help of engine with Kalina cycle.

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