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Performance Analysis And Experimental Investigation On Exhaust Gas Heat Recovery For IC Engines Using Shell And Tube Heat Exchanger

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Abstract— **Increase in energy demand results in shortage of energy. Many effective means were under research to overcome shortage of energy. Recent trend researchers focussing on cogeneration and waste heat recovery in order to improve the efficiency of existing system as well as to avoid energy wastage.**

In this work waste heat from the exhaust gas is recovered by means of shell and tube heat exchanger to convert cold fluid in to hot fluid. In this system water is used as a working fluid. Water extracts thermal energy to estimate the exhaust heat obtainable from the engine exhaust gases. The exhaust gases which is passed through the tube side of the heat exchanger is obtained from the existing four stroke single cylinder diesel engine whereas water is passed through the shell side of the heat exchanger. The counter flow type heat exchanger arrangement is considered for the analysis. Therefore, the heat transfer characteristics of a system combining compression ignition engine and heat exchanger which recover waste heat from exhaust gas. Performance improvement in this type heat exchanger gives the better usability of low grade heat energy.

Index Terms— **Energy, WHR, Shell and Tube, Counter etc.....**

I. INTRODUCTION

The main reason to convert deployable sources of energy into useful work is to reduce the rate of consumption of fossil fuel. Waste heat can be reused for some useful and economic purpose. Internal combustion engines are major source of fossil fuel around the globe. Nearly half of the energy is converted into useful work in those engines.

II. HEAT EXCHANGER

Heat exchanger transfers thermal energy from hot fluid to the cold fluid as it passes through the walls and tubes. Constructional features, physical state of fluids, design and fluid motion are used to classify the types of heat exchangers.

III. SHELL AND TUBE HEAT EXCHANGER.

In this heat exchanger one of the fluids flow through the bundle of tubes and other fluid is forced through the shell. The reliability and heat transfer effectiveness are important hence shell and tube heat exchanger is used in this project. The typical layout of shell and tube heat exchanger is shown below

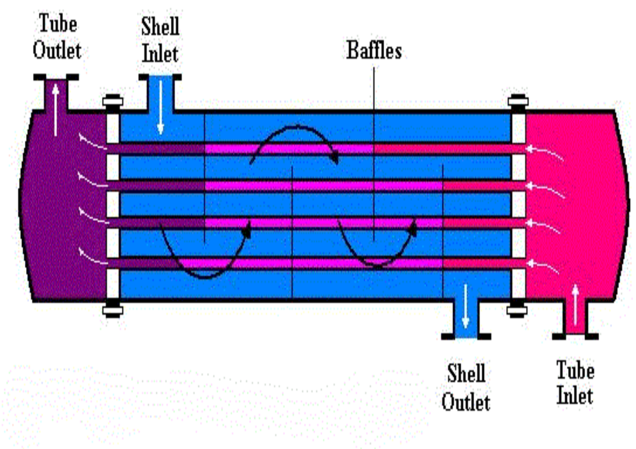

Fig no 1. Shell and Tube heat exchanger

IV. LITERATURE REVIEW

Junjiang Bao, Li Zhao [1] explained how to effectively utilize low and medium temperature energy which is one of the solutions to alleviate the energy shortage and environmental pollution problems. They considered organic Rankine cycle is the important reason for the extraction of thermal energy because of the feasibility and reliability. Selection of working fluids and its thermodynamic and physical properties, performance, suitable expansion machine are reviewed in their paper.

Sipeng Zhu, Kangyao Deng, Shuan Qu [2] studied on the thermodynamic processes of a bottoming Rankine cycle for engine waste heat recovery and on the viewpoints of energy balance and exergy balance. A theoretical formula and exergy distribution map for qualitative analyses of the main operating parameters were presented under simplified conditions when exhaust gas is selected as the only heat source. Their results show that the working fluid properties, evaporating pressure and superheating temperature are the main factors influencing the system design and performances. They suggested that the global recovery efficiency does not exceed 0.14 under typical operating conditions

Hua Tian, Gequn Shu, Haiqiao Wei, Xingyu Liang, Lina Liu [3] proposed an Organic Rankine cycle system in the internal combustion engine exhaust heat recovery and techno-economically analyzed on various working fluids. They signified that ICE exhaust heat (about one third of energy generated from the fuel) can be recovered by ORC

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system. The cycle parameters, including the thermal efficiency, expansion ratio, net power output per unit mass flow rate of hot exhaust, ratio of total heat transfer area to net power output and electrical production cost were analyzed and optimized.

H.G. Zhang, E.H. Wang, B.Y.Fan [4] analyzed the performance of finned-tube evaporator for engine exhaust heat recovery. A mathematical model of the evaporator was created based on the detailed geometry and the specific ORC working conditions. The heat transfer of the evaporator was estimated from the diesel engine and suggested that exhaust temperature of the gas increases with engine speed and engine load. They concluded that the heat transfer area for a fined tube evaporator should be selected carefully based on the engine's most typical operating region.

Iacopo Vaja, Agostino Gambarotta [5] described a specific thermodynamic analysis in order to efficiently match a vapor cycle to that of stationary Internal Combustion Engine. A parametric analysis was conducted in order to determine optimal evaporating pressures for each fluid. They considered three simple cycles: a simple cycle with the use of only engine exhaust gases as thermal source, a simple cycle with the use of exhaust gases and engine cooling water and regenerated cycle.

Jian Sun, Wenhua Li [6] presented a detailed analysis of an ORC heat recovery plant using R134a as working fluid. Mathematical models for the expander, evaporator, air cooled condenser and pump are developed to evaluate and optimize the plant performance. The effects of controlled variables, including working fluid mass flow rate, air cooled condenser fan air mass flow rate, and expander inlet pressure, on the system thermal efficiency and system net power generation were investigated.

E.H. Wang, H.G. Zhang, B.Y. Fan, M.G. Ouyang, Y. Zhao, Q.H. Mu [7] analyzed the performance of different working fluids operating in specific regions using thermodynamic model built in Mat lab together with REFPROP. The results were compared in the regions with fixing the net power output at 10kW. They indicate that R11, R141b, R113 and R123 performed slightly better than others.

M. Hatami, D.D. Ganji, M. Gorji-Bandpy [8] shortly reviewed the waste heat recovery technologies from diesel engines, the heat exchangers which re the common way to use in the exhaust engines. They evaluated and completely reviewed the different Heat Exchangers that are previously designed for increasing the exhaust waste heat recovery.

Tianyou Wang, Yajun Zhang, Zhijun Peng, Gequn Shu[9]reviewed on the basis of various researches on thermal exhaust heat recovery with Rankine cycle and concluded that Rankine cycle has been the most favourite basic working cycle for thermodynamic HER systems. They show that for increasing the total efficiency and reducing CO2 emissions Exhaust heat recovery based on thermoelectric and thermal fluid systems have been explored in the past decade.

Antonio Domingues, Helder Santos, Mario Costa [10] evaluated the vehicle exhaust WHR potential using a RC. The thermodynamic analysis was performed for water and revealed the advantage of using the water as the working fluid in applications of thermal recovery from exhaust gases of vehicles equipped with a spark ignition engine. For the shell and tube heat exchanger, their simulations reveled that an increase of 0.85%-1.2% in the thermal efficiency and an increase of 2.64%-6.94% in the mechanical efficiency for an evaporating pressure of 2 MPa.

Alberto Boretti [11] conducted the research on recovery of exhaust and coolant heat on hybrid passenger car with a 1.8L naturally aspirated gasoline engine. Their ORC configuration fitted in exhaust and coolant permitted an increase in fuel conversion efficiency by up to 6.4% and 2.8% individually and 8.2% combined.

Steven Lecompte, Henk Huisseune, Martijn van den Broek, Bruno Vanslambrouck, Michel De Paepe [12] presented an overview of ORC architectures, performance evaluation criteria and boundary conditions and also the overview of experimental data had given.

Charles Sprous III, Christopher Depcik [13] reviewed the history of internal combustion engine exhaust waste heat recovery focusing on thermodynamic cycle which works well with medium grade energy of the exhaust. They focused primarily on the expander and working fluid to increase the system performance. Their results showed that 10% improvement with modern refrigerants and advancements in expander technology.

Sylvain Quoilin, Sebastien Declaye, Bertrand F. Tchanche, Tchanche, Vincent Lemort [14] proposed a sizing model of waste heat recovery application which are capable of predicting the cycle performance with different working fluids with different component sizes. For the same working fluid, the objective functions such as economics, profitability, thermodynamic efficiency leads to different optimal working conditions in terms of evaporating temperature and fluid density.

V. EXPERIMENTAL DESIGN

The newly designed shell and tube heat exchanger is integrated with existing diesel engine . Such that the complexity of the analysis is reduced to concentrate on higher heat transfer optimization.

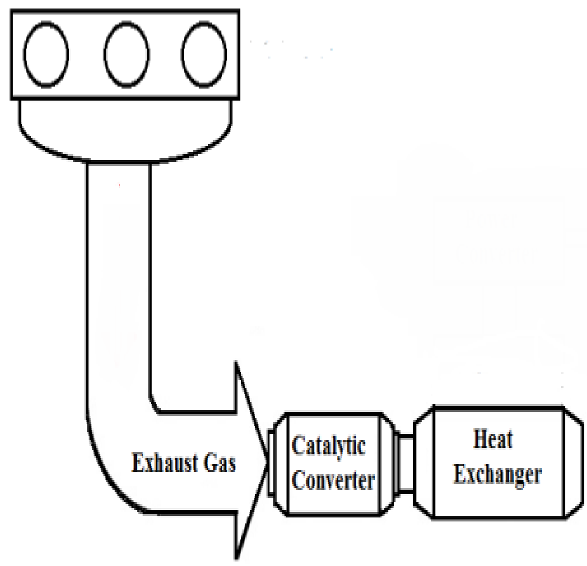

Fig no 2:Engine and heat exchanger layout

VI. TECHNICAL SPECIFICATION OF HEAT EXCHANGER

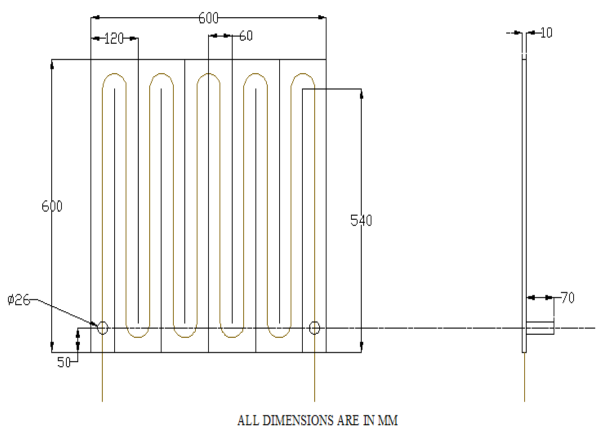

Fig no 3. Specification of heat exchanger

HEAT EXCHANGER:

Length -- 600m

Width -- 600mm

Thickness -- 10mm

Baffle spacing –60mm

Inlet and outlet pipe diameter – 26mm

Inlet and outlet pipe length – 70mm

PIPE SPECIFICATION:

Pipe material -- copper

No of pipes – 1

Pipe length – 6 m

Pipe diameter – 6mm

ENGINE SPECIFICATION:

Type – Four stroke single cylinder diesel engine

Output power – 15 bhp

Speed – 1500 rpm

VII. EXPERIMENTAL SETUP

The exhaust pipe of the engine is connected to the shell inlet tube of the heat exchanger where the gasses are allowed to pass over the copper tubes and the shell outlet tube is made to pass through the atmosphere. The water is passed through the tube side of the heat exchanger which is then heated by the exhaust gas of the engine.

One side of the heat exchanger has exhaust gas inlet and water outlet and other side of the heat exchanger has exhaust gas outlet and water inlet thus the setup is considered to be the counter flow type arrangement.

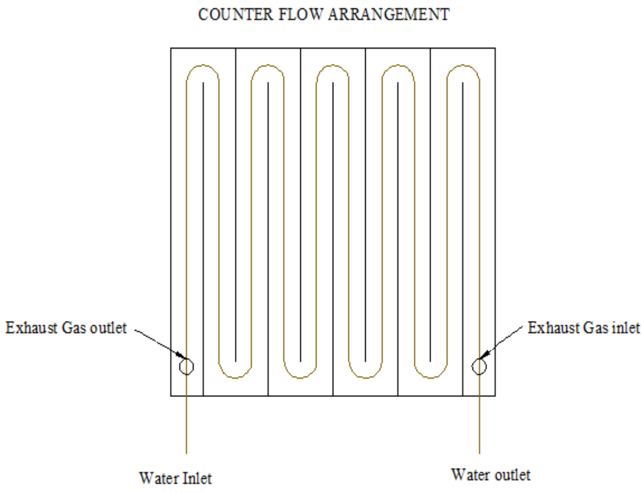

Fig no 4. Counter flow arrangement of the experiment.

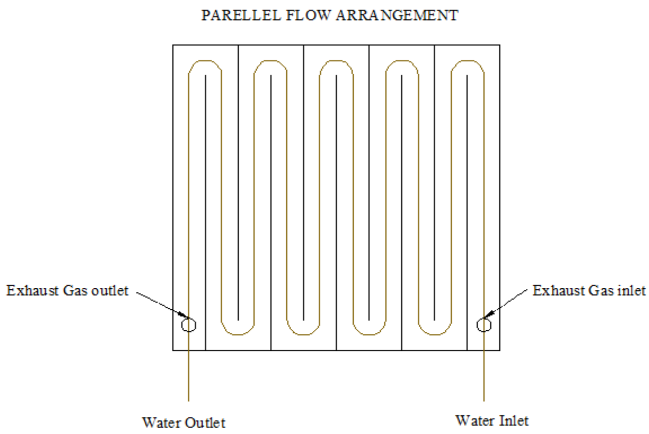

Fig no 5: Parallel flow arrangement of the experiment

In parallel flow arrangement also the exhaust pipe of the engine is connected to the shell inlet tube of the heat exchanger where the gasses are allowed to pass over the copper tubes and the shell outlet tube is made to pass through the atmosphere. The water is passed through the tube side of the heat exchanger which is then heated by the exhaust gas of the engine. The difference from the parallel flow arrangement is that the one side of the heat exchanger has exhaust gas inlet and water inlet and other side of the heat exchanger has exhaust gas outlet and water outlet thus the setup is considered to be the parallel flow type arrangement.

VIII. FORMULAS

Heat tranfer rate from exhaust gas = $m_h C_{ph}(T_{hi} - T_{ho})$ in watts.
Heat transfer rate from water = $m_c C_{pc}(T_{ci} - T_{co})$ in watts.
Effectiveness = $q_{act} / q_{max} = m_c C_{pc}(T_{ci} - T_{co})(mC_p)_{min}(T_{hi} - T_{ci})$.
m_h , m_c= mass flow rate of hot fluid and cold fluid (kg/s).
C_{ph} , C_{pc} = specific heat capacity of hot and cold fluid (kj/kgK).
T_{hi} , T_{ho} = Temperature of hot fluid inlet and outlet (K).
T_{ci} , T_{co} = Temperature of cold fluid inlet and outlet (K).

IX. READINGS AND TABULATION:

Counter flow type arrangement:

S.NO	Mass flow rate	Time	Manometer difference		Temp of exhaust gas inlet	Temp of exhaust gas outlet	Temp of water inlet	Temp of water outlet
			H_1	H_2				
	(sec/kg)	(Minutes)	(cm)		(Celsius)	(Celsius)	(Celsius)	(Celsius)
1	24	5	2.8	26.5	58	36	33	44
2		10			64	46		49
3		15			68	48		50
4	32	5			59	43		49
5		10			63	45		50
6		15			69	48		51
7	58	5			71	51		52
8		10			75	53		54
9		15			79	56		56

Orifice diameter = 10mm

Mass flow rate of air in the engine = 21.49 m3/hr = 26.325 kg/hr

Load on the engine = 9kg

Heat transfer rate from exhaust gas == 885 watts

Heat transfer rate from water = 755 watts

Effectiveness = 0.26

Parallel flow type arrangement

S.NO	Mass flow rate	Time	Manometer difference		Temp of exhaust gas inlet	Temp of exhaust gas outlet	Temp of water inlet	Temp of water outlet
			H1	H2				
	(sec/kg)	(Minutes)	(cm)		(Celsius)	(Celsius)	(Celsius)	(Celsius)
1	24	5	2.8	26.5	54	44	32	36
2		10			60	50		40
3		15			62	51		41
4	30	5			53	45		40
5		10			65	52		43
6		15			67	57		47
7	56	5			73	63		45
8		10			73	63		50
9		15			76	66		50

Orifice diameter = 10mm

Mass flow rate of air in the engine = 21.49 m3/hr = 26.325 kg/hr

Load on the engine = 9kg

Heat transfer rate from exhaust gas = 885 watts

Heat transfer rate from water = 755 watts

Effectiveness = 0.26

VIII. RESULTS

1. Thus the experiments were conducted using hell and tube heat exchanger to extract heat from engine exhaust gas with parallel and counter flow arrangement.

2. In case of parallel flow arrangement temperature of exhaust gas is reduced from 76 degree Celsius to 66 degree Celsius. In counter flow arrangement the temperature reduced from 79 degree Celsius to 56 degree Celsius.

3. Experimental results were compared and verified with theoretical reviews. Performance of counter flow arrangement is greater than parallel flow arrangement.

IX. CONCLUSION

The above result shows that effectiveness of shell and tube heat exchanger is increased by employing more contact area between the surface of shell and tube inside the heat exchanger.

X. PHOTOGRAPH

PIPES AND BAFFLES ARRANGEMENT

Fig no 6. Pipes and baffles

HEAT EXCHANGER COUPLED WITH DIESEL ENGINE

Fig no 7. Expermental setup

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