# Theoretical Analysis of Heat Pipe Heat Exchanger for Waste Heat Recovery from Diesel Engine Exhaust

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**Abstract**: The diesel engine is a primary power source of fuel for automobiles mainly due to its high operational reliability and excellent thermal performance. The energy consumption in automobiles has increased rapidly in recent decades. Also in diesel engine, large amount of energy is lost through the engine exhaust gas. It means a large fraction of the fuel energy remains untapped and gain of energy by waste heat is appreciable. For this purpose, use of heat pipe heat exchanger is most economical, highly reliable and effective method to recover waste heat. A heat pipe is a simple heat transfer device that can transport large quantities of heat with a very small difference in temperature between the two fluids. This study focuses on heat recovery from diesel engine exhaust to improve overall efficiency of diesel engine using Heat Pipe Heat Exchanger and to study the effects of various parameters that influence the performance of heat pipe heat exchanger. The objective of the study is to analyze theoretically the effect of exhaust gas flow rate and cooling air flow rate on the performance of heat pipe heat exchanger. To recover heat from exhaust gas the theoretical analysis was carried out for design of heat pipe heat exchanger using actual engine conditions and the effect of influence of gas flow rates on overall heat transfer co-efficient, heat rate, condenser outlet temperature, LMTD and effectiveness are studied. With these theoretical understanding experimental setup was developed to recover heat from engine exhaust at various gas flow rates using optimized heat pipe heat exchanger

**Keywords** : Heat pipe heat exchanger, Waste heat recovery, automobile exhaust gas.

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|---|---|
| $\dot{m}_e$ | mass flow rate of air in evaporator (kg/s) |
| $\dot{m}_c$ | mass flow rate of air in condenser (kg/s) |
| $p_e$ | Specific heat of air in evaporator (kJ/kg K) |
| $Cp_c$ | Specific heat of air in Condenser (kJ/kg K) |
| $Ce$ | Heat Capacity of air in Evaporator (kJ/K s) |
| $Cc$ | Heat Capacity of air in Condenser (kJ/K s) |
| $C_{min}$ | Minimum Heat Capacity of air (kJ/K s) |
| $T_{e,i}$ | Inlet Temperature at Evaporator (˚C) |
| $T_{e,o}$ | Outlet Temperature at Evaporator (˚C) |
| $T_{c,i}$ | Inlet Temperature at Condenser (˚C) |
| $T_{c,o}$ | Outlet Temperature at Condenser (˚C) |
| $Qe$ | Heat transfer rate in Evaporator (kW) |
| $Qc$ | Heat transfer rate in Condenser (kW) |
| Q | Theoretical Heat transfer rate of heat Exchanger (kW) |
| $Q_{max}$ | Maximum Heat transfer rate of heat Exchanger (kW) |
| $A_t$ | Total Area of Heat Pipe Heat Exchanger ($m^2$) |
| $U_t$ | Total Area of Heat Pipe Heat Exchanger ($m^2$) |
| LMTD | Logarithmic Mean Temperature Difference of Heat Exchanger |
| NTU | Number of transfer units |
| lpm | liters per minutes |
| $\varepsilon$ | Effectiveness of Heat Exchanger |

## I. INTRODUCTION

The rapid increasing rate of modernization has led to increase in demand of fossil fuels in the transportation sector over the past few years. This has caused many growing concern about the depletion of energy and the greenhouse effect. Many stringent laws had been put up in the developing country to overcome the problems related to emissions. There are various techniques to overcome these problems, but the heat recovery techniques are the best of all as it involves optimizing the heat which is released in the environment directly. The paper focuses on the waste heat recovery techniques using heat pipe heat exchanger.

The Heat Pipe Heat Exchanger was first proposed and patented by Gaugler of the general motors corporation, Ohio, USA in 1942 [1]. Then Grover rediscovered the heat pipe and carried out a theoretical and experimental analysis using a stainless-steel pipe and wire mesh wick material and using sodium, lithium and silver as working fluid [2]. With advent in the research the heat pipe has been used in various application viz. Space application, Waste heat recovery in automobiles [3]. latent heat storage device, Nuclear react0ors [4], electronics cooling applications, Air conditioners [5], etc. Investigation was carried out between the two heat pipes i.e. Thermosyphon heat pipe and screen mesh heat pipe. The results showed that at same orientation (900) the screen mesh heat pipe gives better wettability around the circumference and can be operated at any orientation as not in case of thermosyphon which is operated at only 900 from the horizontal. [6] and [7]. The effect of mass flow rate in condenser and evaporator section and their temperature difference had been investigated and it was found that these parameters have no effect on the effectiveness of heat exchanger if the input power to the evaporator had reached its maximum value [8]. the effect of mass flow rate ratio between evaporator and condenser sections on the effectiveness of air to air THE had been studied and per ($\varepsilon$ − NTU) method by using methanol as working fluid the results concluded that the effectiveness and heat transfer rate increased when the mass flow rate ratio (m e/m c) increased. [9]. This paper focuses on the use of heat pipe for waste heat recovery as it is highly reliable and economically viable.

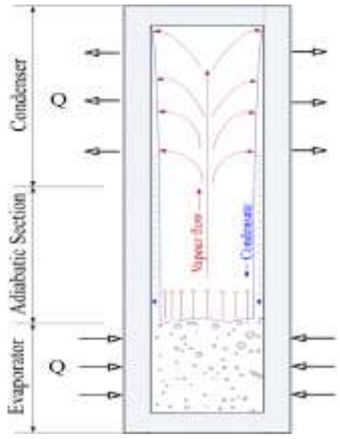


FIGURE 1 SCHEMATIC REPRESENTATION OF HEAT PIPE

## II. MATERIALS AND METHODS

The primary sizing had been done and the material selection and sizing had been done. Aluminum is selected as the pipe material as it has less resistance to corrosion from the exhaust gas than copper for a long service period. The wick material is made up copper of 100 wire mesh. And the working fluid is taken as distilled water with a filling ratio of 75 % the volume of the evaporator section. The heat pipes are arranged in staggered form. The design of experimental setup is designed to study the effect of various parameters that affects the performance of heat pipe heat exchanger using exhaust gas as a hot fluid and air as a coolant.

## III. EXPERIMENTAL SETUP

For conducting the experiment the engine specifications is given in Table 1 and the setup consists of heat pipe heat exchanger with staggered arrangement of tube. Thermocouples are used to measure the temperature at various points. The design parameters of heat pipe heat exchanger are provided in table 2.

The exhaust pipe of engine exhaust will be directly coupled to the evaporator end of the heat exchanger. Whereas the flow rates of the ambient cooled air will be varied though the help of mini-exhaust fan.

TABLE 1DIESEL ENGINE SPECIFICATIONS

| Sr. No | Description | Data |
|---|---|---|
| 1 | Name of the Engine Manufacturer | Kirloskar Engine |
| 2 | Type of the engine | 4-Stroke, Single Cylinder, Vertical, C.I Engine |
| 3 | IS Rating | 5 H.P at 1500 rpm |
| 4 | Bore X Stroke | 80mm X 110mm |

| | | |
|---|---|---|
| 5 | Cubic Capacity | 552.64 cc |
| 6 | Lubrication | Splash Type |
| 7 | Starting | Hand Cranking |
| 8 | Fuel Used | Diesel |
| 9 | Capacity of Diesel Tank | 7 Liter |
| 10 | Cooling | Water Cooling |

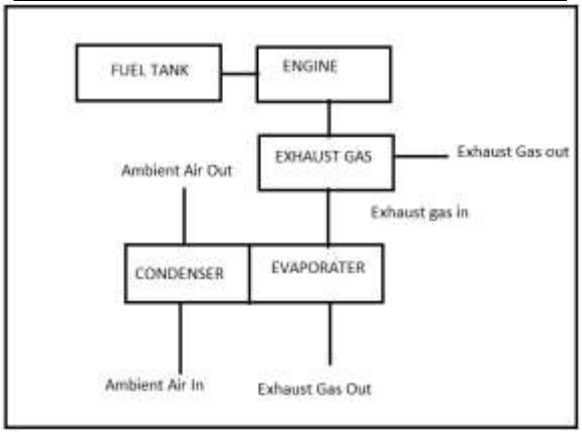


FIGURE 2 LINE DIAGRAM OF EXPERIMENTAL SET-UP

TABLE 2 DESIGN PARAMETERS OF HEAT EXCHANGER

| Parameters | Dimensions |
|---|---|
| Diameter of each tube | 2.54 cm |
| Length of each tube | 65 cm |
| Number of Tubes | 5 |
| Length of the Evaporator | 30 cm |
| Length of the Condenser | 30 cm |
| Baffles Spacing | 7.5 cm |
| Pitch | 5.6 cm |

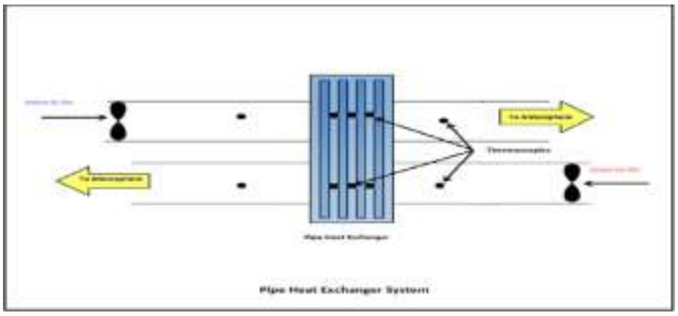

FIGURE 3 EXPERIMENTAL SET-UP OF HEAT PIPE HEAT EXCHANGER

BASIC EQUATIONS

**Heat balance**

Heat lost by exhaust gas = Heat gain by cooling air

$\left(\dot{m}_e * Cp_e * (T_{e,i} - T_{e,o})\right) = \left(\dot{m}_c * Cp_c * (T_{c,o} - T_{c,i})\right)$[10]

The heat capacity rates for evaporator and condenser,

$Ce = \dot{m}_e Cp_e$

$Cc = \dot{m}_c Cp_c$

The heat transfer rates for evaporator and condenser

$Qe = C_e\,(T_{e,i} - T_{e,o})$

$Qc = C_c\,(T_{c,o} - T_{c,i})$

The effectiveness of heat exchanger is given by,

$$\varepsilon = \frac{Q}{Q_{max}}$$

Where,

$$Q = \frac{Q_e + Q_c}{2}$$

$$Q_{max} = C_{min}\,(T_{e,i} - T_{c,i})$$

The overall heat transfer co-efficient of the heat exchanger is given by,

$$U_t = \frac{Q}{A_t\, LMTD}$$

The log mean temperature is given by,

$$LMTD = \frac{(T_{e,i} - T_{c,o}) - (T_{e,o} - T_{c,i})}{\ln\left(\frac{T_{e,i} - T_{c,o}}{T_{e,o} - T_{c,i}}\right)}$$

## RESULTS AND DISCUSSIONS

The theoretical results were obtained by using the above formulae.

**Figure 4** illustrates that there is increase in Overall Heat Transfer Rate when the volume flow rate in Evaporator is varied from from 200 lpm to 500 lpm and the volume flow rate of condenser is varied accordingly keeping the outlet temperature same.

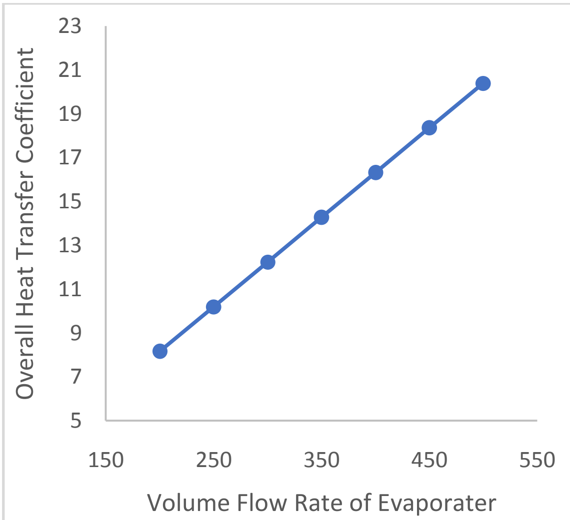


FIGURE 4 THE EFFECT OF VOLUME FLOW RATE OF EVAPORATOR ON THE OVERALL HEAT TRANSFER RATE WHEN THE CONDENSER VOLUME FLOW RATE IS ALSO VARIED

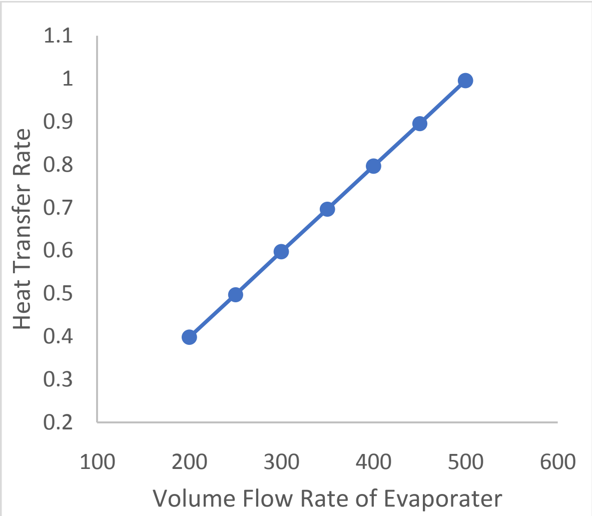


**FIGURE 5 THE EFFECT OF VOLUME FLOW RATE OF EVAPORATOR ON THE HEAT TRANSFER RATE WHEN THE CONDENSER VOLUME FLOW RATE IS ALSO VARIED**

**Figure 5** illustrates that there is increase in Heat Transfer Rate when the evaporator Volume Flow Rate is varied from 200 lpm to 500 lpm. Hence higher the volume flow rate in the condenser, higher the values of heat transfer rates.

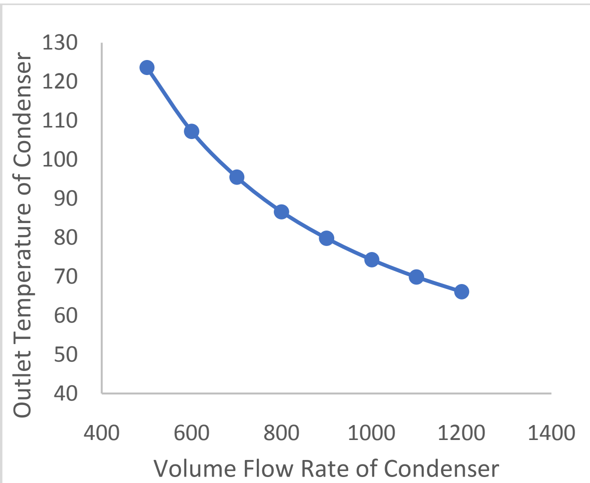


**FIGURE 6 THE EFFECT OF VARIOUS CONDENSER FLOW RATE ON THE OUTLET TEMPERATURE OF CONDENSER WHEN THE VOLUME FLOW RATE OF EVAPORATOR WAS KEPT CONSTANT AT 500 LPM**

**Figure 6** shows the results of outlet temperature of condenser when of the evaporator was kept at 500 lpm and the volume flow rates of Condenser section was varied from 500 lpm to 1200 lpm. The results showed that for the same heat transfer capacity the Outlet Temperature was reduced with increase in the volume flow rate temperature of the condenser section.

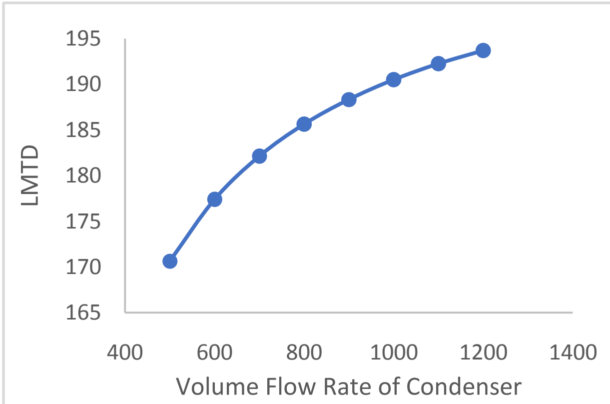


**FIGURE 7 THE EFFECT OF VARIOUS CONDENSER FLOW RATE ON THE LOG MEAN TEMPERATURE OF HEAT EXCHANGER WHEN THE VOLUME FLOW RATE OF EVAPORATOR WAS KEPT CONSTANT AT 500 LPM**

**Figure 7** shows the results of log mean temperature difference of heat exchanger when the volume flow rate in the evaporator section was kept at 500 lpm and the volume flow rates in the condenser is varied from 500 lpm to 1200 lpm. The results showed that the Log Mean temperature difference increased with increasing volume flow rate in the condenser section

## CONCLUSION

In this paper the effectiveness NTU method is used to predict the overall thermal capacity of a heat pipe heat exchanger.

The results conclude that the even when the volume flow rate in the evaporator section is varied there is no major effect in the heat transfer rate which confirms that HPHX is suited for waste heat recovery from the automobile exhaust at actual running conditions. When the volume flow rate in the condenser is increased considerably the outlet temperature in the condenser is decreased hence reduces the heat transfer rate. Hence optimum results were obtained when the Volume flow rate in the condenser was between 600 lpm to 800 lpm.

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