e-ISSN: 2249-8303, p-ISSN: 2319-2208 © VSRD International Journals: www.vsrdjournals.com

RESEARCH PAPER

DEVELOPMENT OF TEST RIG TO EVALUATE 4 STROKE DIESEL ENGINE BY WAST HEAT RECOVERY USING HEAT PIPE

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ABSTRACT

Development of Test-Rig to evaluate comparative engine performance is analysed. Performance parameter such as brake thermal efficiency, sound pressure level without heat pipe (without inlet-air-preheating) and with heat pipe (with inlet air preheating) is observed. Exhaust gases energy is used to preheat the inlet air supplied to diesel engine with the help of heat pipe. A heat pipe without bend is used in which working fluid is water with 10 mm diameter and 300mm length. As a result there is an increase in brake thermal efficiency 1.75 to 11% and reduction in sound pressure level 0.7 to 1.2 db.

Keywords: Test Rig, Heat Pipe and Diesel Engine.

1. INTRODUCTION

Total energy is supplied to the engine in the form of heat energy from the fuel. A large amount of energy is expelled to environment through engine cooling system and exhaust gases. Increasing energy problem, economic development and energy crises over the world have caused the automotive world researcher's attention on saving of IC engine exhaust gases energy. The effort is focused on improving overall vehicle energy efficiency. For waste energy can be converted in to useful work by various means. One way to use this energy is to supply the exhaust gas energy into inlet air by means of Heat pipe.

This research work will make use of preheating of inlet air using heat pipe as shown in fig 5. In the heat pipe one end is connected to exhaust gas (Higher temperature) i.e. evaporator heats up and vaporizes the heat pipe fluid, and then rises to the condenser where it is condensed and working fluid return to evaporator, condenser is attached to inlet air (Low temperature) take the heat and condense heat pipe fluid i.e. water.

Heat Pipe Operation: A heat pipe is essentially a passive heat transfer device with an extremely high effective thermal conductivity. The two-phase heat transfer mechanism results in heat transfer capabilities from one hundred to several thousand times that of an equivalent piece of copper.

As shown in Figure 1, the heat pipe in its simplest configuration is a closed, evacuated cylindrical vessel with the internal walls lined with a capillary structure or wick that is saturated with a working fluid. Since the heat pipe is evacuated and then charged with the working fluid prior to being sealed, the internal pressure is set by the vapor pressure of the fluid.

As heat is input at the evaporator, fluid is vaporized, creating a pressure gradient in the pipe. This pressure gradient forces the vapor to flow along the pipe to a cooler section where it condenses giving up its latent heat of vaporization. The working fluid is then returned to the evaporator by the capillary forces developed in the wick structure.

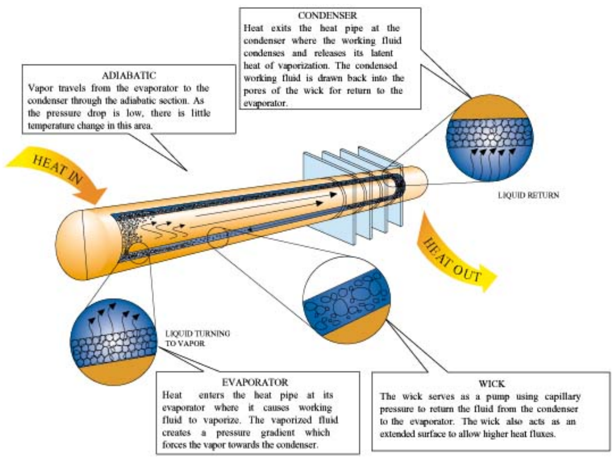


Fig. 1: Heat Pipe Operation Source [1]

Heat pipes can be designed to operate over a very broad range of temperatures from cryogenic (< -243°C) applications utilizing titanium alloy/nitrogen heat pipes, to high temperature applications (>2000°C)using tungsten/silver heat pipes. In electronic cooling applications where it is desirable to maintain junction temperatures below 125-150°C, copper/water heat pipes are typically used. Copper/methanol heat pipes are used if the application requires heat pipe operation below

0°C.[1]

Heat Pipe Design: There are many factors to consider when designing a heat pipe: Compatibility of materials, operating temperature range, diameter, power limitations, thermal resistances, and operating orientation. However, the design issue are reduced to two major consideration by limiting the selection to copper/water heat pipe for cooling electronics. This consideration are the amount of power the heat pipe is capable of carrying and its effective thermal resistance.[1]

Effective Heat Pipe Thermal Resistance: The other primary heat pipe design consideration is the effective heat pipe thermal resistance or overall heat pipe T at a given design power. As the heat pipe is a two-phase heat transfer device, a constant effective thermal resistance value cannot be assigned. The effective thermal resistance is not constant but a function of a large number of variables, such as heat pipe geometry, evaporator length, condenser length, wick structure, and working fluid [1].

Fig. 2 : Effective heat Pipe Thermal Resistance[1]

The total thermal resistance of a heat pipe is the sum of the resistances due to conduction through the wall, conduction through the wick, evaporation or boiling, axial vapor flow, condensation, and conduction losses back through the condenser section wick and wall.

The detailed thermal analysis of heat pipes is rather complex. There are, however, a few rules of thumb that can be used for first pass design considerations. A rough guide for a copper/water heat pipe with a powder metal wick structure is to use 0.2°C/W/cm2 for thermal resistance at the evaporator and condenser, and 0.02°C/W/cm2 for axial resistance.

The evaporator and condenser resistances are based on the outer surface area of the heat pipe. The axial resistance is based on the cross-sectional area of the vapor space. This design guide is only useful for powers at or below the design power for the given heat pipe.

For example, to calculate the effective thermal resistance for a 1 cm diameter copper/water heat pipe 30 cm long with a .8 cm diameter vapor space, the following assumptions are made. Assume the heat pipe is dissipating 75 watts with a 5 cm evaporator and a 5 cm condenser length. The evaporator heat flux (q) equals the power divided by the heat input area ($q = Q/A_{evap}$; $q = 4.77\ W/cm^2$). The axial heat flux equals the power divided by the cross sectional area of the vapor space ($q=Q/A_{vapor}$; $q = 149.28\ W/cm^2$).

The temperature gradient equals the heat flux times the thermal resistance.

$$\Delta T = q_{evap} * R_{evap} + q_{axial} * R_{axial} + q_{cond} * R_{cond}$$

$$\Delta T = 4.77 W/cm^2 * 0.2°C/W/cm^2 + 117.44 W/cm^2 * 0.02°C/W/cm^2 + 4.77 W/cm^2 * 0.2°C/W/cm^2$$

$$\Delta T = 4.888\ °C$$

It is important to note that the equations given above for thermal performance are only rule of thumb guidelines. These guidelines should only be used to help determine if heat pipes will meet your cooling requirements, not as final design criteria. More detailed information on power limitations and predicted heat pipe thermal resistances are given in the heat pipe design books listed in the reference section.

2. SELECTION OF HEAT PIPES

Types of Wick Structures: It's impossible to tell what type of wick a heat pipe uses in your favorite heat sink just by looking at it from the outside. The heat pipe would need to be cut open to find out the answer to that question, and doing so obviously destroy the thermal solution in the process. Instead we offer a rare look at behind the scenes technology which greatly influences thermal performance of modern CPU heat sinks - the heat pipe wick structure

As you probably know, heat pipes are hollow metal tubes that efficiently conduct heat from one location to another. They operate by means of a small amount of working fluid contained in a sealed tube, held under a slight vacuum. The vacuum lowers the boiling point of the working fluid, so relatively small increases in temperature vaporize the liquid which is then naturally drawn towards the colder end of the heat pipe where it condenses back to liquid. An internal wick structure then acts to return the condensed working fluid back to the hot end of the heat pipe, by a force called capillary action. When you put the edge of a paper towel in a small puddle of water, this is the force that soaks up the liquid into the paper. The crux of the situation is that some wick structures are more efficient than others, and some have limitations with respect to orientation and gravity.

The three main types used in commercial heat sinks are Sintered metal powder wick, Grooved wick and Metal Mesh wick.

Sintered Metal Powder Wick:

Fig. 3 : Sintered Metal Powder Wick [2]

Fig. 4 : Sintered Metal Powder Wick[2]

The working fluid in the heat pipe is drawn along the length by the capillary action of the porous sintered copper metal lining the inside of the tube. The sintered copper powder is formed in a bonding process so the material is actually hard (not loose). Manufacturing cost for this type of heat pipe is highly easy and at low cost.

3. EXPERIMENT SETUP AND PROCEDURE

The experiment was conducted in a four stroke diesel engine. The specification of tested engine has been shown in table.

Items	Specification
Type	1-Cylender, 4 Stroke
Bore stroke	80X110 mm
Compression ratio	16.5:1
Type of cooling	Water cooled
Company	Kirloskar

The rpm was measured proximity sensor is attached with dynamometer.

The outlet temperature of cooling water and exhaust gas temperature was measured directly by using thermocouple attached to these lines.

Engine noise was measured at a constant distance from the engine by a digital sound level meter (Model SL-4010)

- Fill up sufficient diesel in diesel tank
- Check the level of lubricant oil in the sump by oil dip stick. It should be up to top edge of the flat
- Portion provided over the dip stick
- Fill up water in manometer up to half of manometer height
- Start the water supply and see water is flowing through engine jacket, brake drum and exhaust
- Gas calorimeter
- Release the loading screws, so that there is no tension in the rope.
- Start the engine with the help of auto ignition key
- Load the engine with loading screw and set the balance difference to say 2 Kgs
- Open the burette filling cock, take sufficient diesel in burette and close the cock
- Now turn the selector cock to engine and note down the time required for 20 ml fuel consumption
- Note down the brake drum speed with tachometer
- Note down difference in two limbs of manometer
- Note the following temperatures from digital thermometer
- Note down jacket cooling water and calorimeter water flow rates
- Take 2 sets of reading for different load

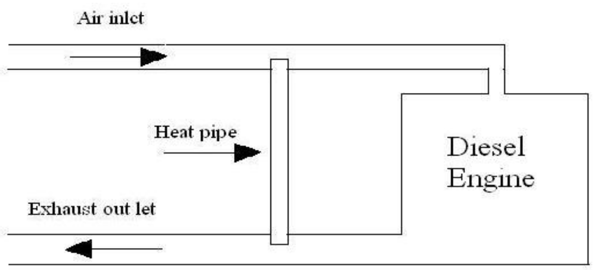
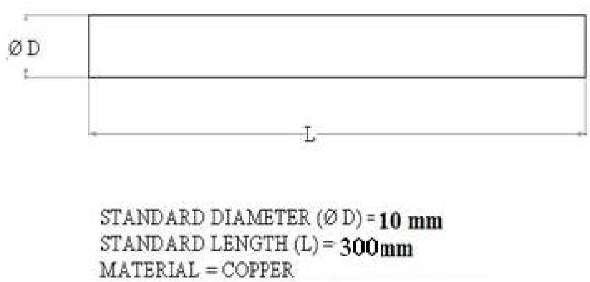


Fig. 5: Experiment Setup

4. HEAT PIPE GEOMETRY-SIZE SELECTION

TYPE A



Two layer of mesh with mesh no 180 and material

phosphorous bronze
Thickness of wall 0.5 mm
Vacuum in side heat pipe 0.017 bar

Maximum Watts at Different Temperature

DIAMETER	80°C	120°C
10 mm	151	169

The power handling figures are for heat pipe working in horizontal position.
Length 180 mm long
Evaporator length 50 mm
Condenser length 50 mm
Sintered copper powder

5. RESULT

Brake thermal efficiency (η_{BT})

$$\eta_{BT} = \frac{\text{Heat equivalent to BP x 100\%}}{\text{heat supplied by fuel}}$$

Brake power (BP)

$$BP = \frac{2\pi NT}{1000x60} \text{ KW}$$

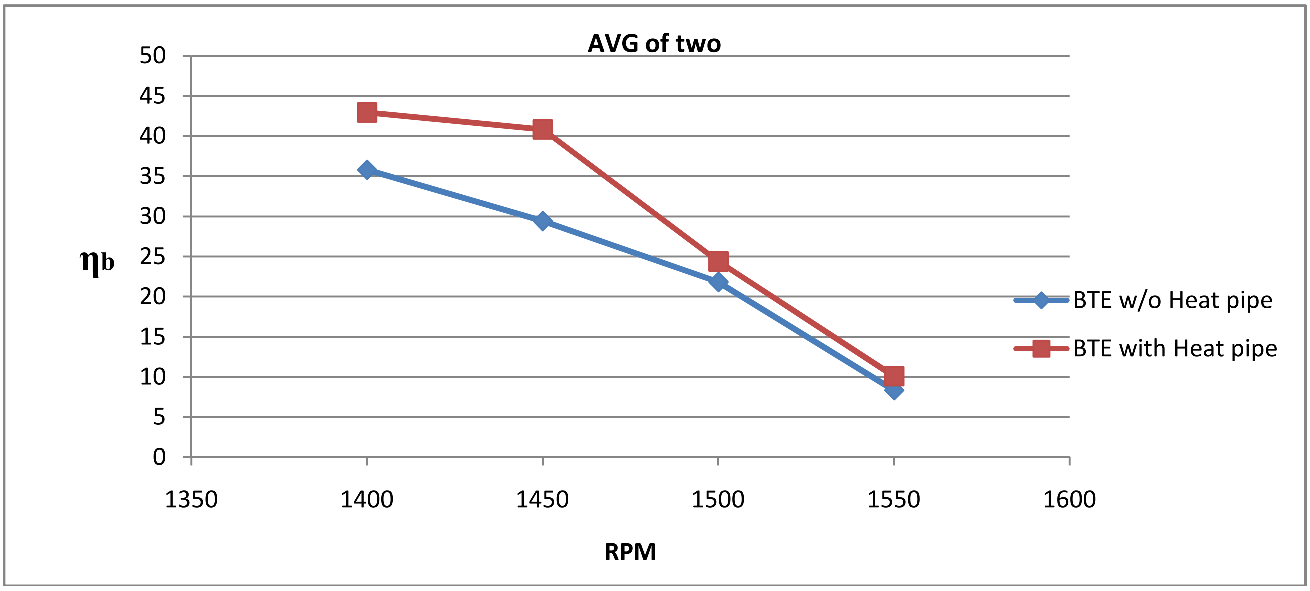
Where
T = Torque = Force x distance
= (W1-W2)x radius of brake drum
= (W1-W2) x9.8x0.15 Nm
(when W1 & W2 are in Kg)
[Where N= Engine RPM]

Heat supplied by fuel (HF)
HF = Fuel consumption x calorific value of fuel
= fuel consumption in kg x 44631.96 kJ/Kg

Average of two Brake thermal efficiency readings

rpm	BTE w/o Heat pipe	BTE with Heat pipe
1400	35.78084	42.91705
1450	29.40036	40.81047
1500	21.81691	24.38471
1550	8.340058	10.10349

BTE (Brake Thermal Efficiency)

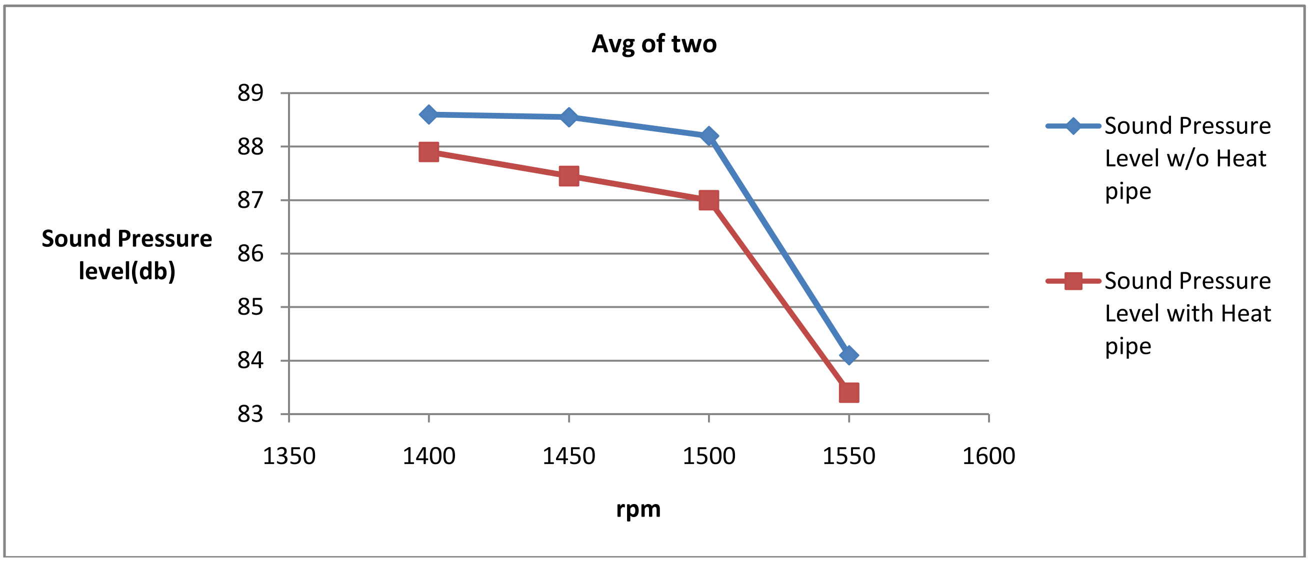


Graph 5.1 Shows Increment in Brake Thermal Efficiency with heat pipes

Fig 5.1 shows the increase in efficiency with heat pipes. In the beginning when heat pipes are not used in the experiment, the calculated efficiency is less as compare to the heat pipe is use.

Average of two Sound pressure level readings

rpm	Sound Pressure Level (db) w/o Heat pipe	Sound Pressure Level (db) with Heat pipe
1400	88.6	87.9
1450	88.55	87.45
1500	88.2	87
1550	84.1	83.4



Graph 5.2 Shows Decrease in sound level with heat pipes

Fig 5.2 shows the decrease in sound level with heat pipes. In the beginning when heat pipes are not used in the experiment, the calculated sound level is less then without heat pipe.

6. CONCLUSION

In this work an air preheating system has been designed and fabricated and its effect has been tested on diesel combustion and exhaust emissions. The results of this work may be summarized as follows:

Heat energy is recovered from the exhaust gases, which causes lower heat addition, thus improving engine thermal efficiency

Sound pressure level is also decrease with inlet air heating with heat pipe.

7. FUTURE SCOPE

Test conducted for comparison between brake thermal efficiency of engine w/o heat pipe and heat pipe used for air preheating, heat pipe reduce maintenance and operating cost.

This test rig is important for automobile purpose.

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