Experimental investigation of performance of shell and coil heat exchanger in waste heat recovery systems in CI engine

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Abstract: This study analyses heat transfer coefficients in a shell and tube heat exchanger and the effectiveness of reduced temperature of exhaust gases in shell and helically coiled tube heat exchanger. This facilitates low installation cost, high performance and improved safety. The experimental setup consists of a shell with a coaxial outer tubular, end plates attached to the inner walls and a spiral coil through which water flows. These end plates encompass a shell cavity in tubular shape. This facilitates the inlet and outlet intended for exhaust gas. The coil is wounded in such a way that the axis of shell fit the inner and outer walls with limited radial clearance. Due to axial spacing of coils from one another, a spiral path is generated in the interior shell cavity which provide amenities for water flow. This path creates, helps in reducing the temperature of exhaust gas.

Keywords: Heat exchanger, Shell heat exchanger, Helical coil sides, Heat transfer coefficient, Heat exchanger efficiency

1. Introduction

In order to assist the movement of heat from one to alternative fluid, devices such as heat exchangers are employed. Condensers, evaporators, coolers, heaters, boilers, and other types of heat exchangers are common. The core principle of its functioning is created on thermodynamics second law. Indifferences in temperature leads to transference of heat from higher to lesser temperature.[1]

Heat transfer is widely used in power plants, air conditioning, refrigeration, food preservation, and the medical field, among other places. The applications of heat exchangers are several. Frequent applications of heat exchangers are in industrial and manufacturing industries.[2] The preferred type of heat exchanger is tube and shell heat exchangers. Intramural boiling water heat exchangers, seal coolers, vacuum condensers, and vent condensers are myriad examples of applications.

Shell and coil heat exchanger are equipped with densely packed coils. These circular shaped coils are packed in helical layers of tube. These components are enclosed within a compressed shell. The flow of different fluids in opposite directions are separated using walls with proper welding trims in its entry and exit surfaces.[3] One advantage of manufacturing this type of heat exchanger is its ease as it does not have components. In this experimental work, the heat exchanger is used to analyze the waste recovery system in internal combustion engines. The coolant is used to reduce the temperature of the heating engine. This circulating fluid flows through the radiator coils to cool down the temperature of engine.[4]
Heat exchanger is paired with the exhaust of the four stroke diesel engine. Since the exhaust gas streams through the side of shell and the cooling water streams inside coil, heat from the exhaust gas is passed to the coil fluid (water). [5] Tardily, the temperature of the exhaust gas in the atmosphere is lowered. Heat is passed into two different temperature mediums. Heat exchangers are usually designed and arranged in accordance with the rhythm of design and flow of arrangement. [6] The figure 1 depicts a typical shell and tube heat exchanger.

![Figure 1. Schematic of Heat Exchanger](image)

### 2. Experimental Setup

The apparatus consists of a concentric tube heat exchanger. One of the fluids run inside the tube and other through the shell. An electric geyser is used as source for hot water. Inner ends of the tubes are occupied by this hot water whereas the annular spaces which is the shell have cold water streaming through it. Table 1 depicts the specifications and parameters of the shell through which the cold water flows.

| PARAMETER      | DIMENSION |
|---------------|-----------|
| Shell Length  | 395 mm    |
| Shell Width   | 210 mm    |
| Inner & Outer | 35 mm     |

![Table 1. Specifications of the Shell](image)

Need for this kind of heat exchanger are wide-ranging for industrial claims especially in air conditioning, cooling and heating arrangements. [7] One of the main precaution is to turn ON the heater only after the water begins to flow. Figure 2 depicts the shell specifications such as the inner diameter, outer diameter, shell width, shell length and the distance between the turns of the two coils.
In the chosen application, that is heat transfer in internal combustion engines, the purpose of the exchanger is to transfer heat. On the basis of the principles of second law, fluid at higher temperature transmits heat to fluid at lower temperature. This is done with the assistance of radiator tube.[8] Table 2 illustrates the parameters and values of coil specifications.

### Table 2: Coil Specifications

| PARAMETERS          | DIMENSIONS  |
|---------------------|-------------|
| Inner Diameter (Di) | 10 mm       |
| Outer Diameter (Do) | 12.7 mm     |
| Coil Length (L)     | 300 mm      |
| Coil Width (W)      | 130 mm      |
| Pitch (P)           | 2           |
| Number of turns (n) | 13          |
| Inlet & Outlet      | 20 mm       |

Engine selected for this experiment is a single cylinder TV1 Kirloskar engine. It has a bore of 87.5mm and stroke length of 110mm. It is a 4 stroke diesel engine type with the total capacity of 661cc and speed of 1500 rpm. Table 3 depicts the specifications of the engine selected for this experiment.

### Table 3: Engine specifications

| PARAMETER       | SPECIFICATIONS                     |
|-----------------|-------------------------------------|
| Model           | TV1                                 |
| Cylinder type   | Single cylinder                     |
| Engine type     | 4 stroke Diesel                     |
| Speed           | 1500 rpm                            |
| Power           | 5.2 kW (7 BHP)                      |
| Stroke          | 110 mm                              |
| Bore            | 87.5                                |
| compression ratio| 17.5:1                             |
| Capacity        | 661 cc                              |
| Engine Make     | Kirloskar                           |
| Product         | Engine test setup 1 cylinder, 4 stroke, Diesel |

Figure 3 shows the image of the heat exchanger used in this experiment. This type was chosen due to the densely packed coils. This will provide efficient cooling of the internal combustion engine. The baffles arrangements present in this heat exchanger allows for efficient heat transfer coefficient. This supports uniform spacing and increases the efficiency of heat transfer.
There are numerous parameters deciding the capability and efficiency if transfer of heat. It depends on the design, the material of coil, maintenance cost, performance and transfer rates. The helical design of the coil has an advantage of high temperature differentials without high stress level. Moreover, this design is flexible, inexpensive and compact for the current application. It also has small pressure drop, improved energy efficiency and improved safety.[9]

The illustrated type of heating coils was initially used for applications of heating, cooling and ground water systems for domestic dwelling.[10] In terms of industrial applications, shell and tube heat exchanges are used in waste-water treatment, Refrigeration systems, petroleum refining and in nuclear power plants. The variation of load tested in this experiment ranges from 4 kilograms to 16 kilograms. The exhaust gas temperature at the inlet and exhaust gas temperature at the outlet were calculated and the following observations were tabulated in Table 4.

3. Results & Discussion

From the calculations, if the load of the engine intensifies mass flow rate of exhaust gas rises, hence efficiency of heat exchanger is less from the observation table. If the load increases, the temperature of
the exhaust gas temperature and at the same time the cold fluid outlet temperature also increases. If the mass flow rate increases efficiency decreases.

Table 5 shows the values of torque, total fuel consumption, brake power which is the power obtained at the engine flywheel and is measured with the help of dynamometer and brake thermal efficiency were calculated while performing the experiment.

| Load (kg) | Torque (Nm) | TFC Total Fuel Consumption (kg/hr) | Brake Power (watts) | Time Taken (sec) | Brake Thermal Efficiency (%) |
|----------|-------------|-----------------------------------|--------------------|-----------------|-----------------------------|
| 4        | 7.25        | 0.00020                           | 1.13               | 40.25           | 12.83                       |
| 8        | 14.51       | 0.00026                           | 2.27               | 32              | 20.41                       |
| 12       | 21.77       | 0.00031                           | 3.41               | 27.03           | 25.86                       |
| 16       | 29.03       | 0.00038                           | 4.55               | 21.75           | 25.74                       |

Table 6 shows the values of Air/fuel ratio and volumetric efficiency during the intake stroke to the mass density of air in intake manifold was observed and calculated while performing the experiment.

| Load (kg) | \( Q_{\text{actual}} \) | \( Q_{\text{theoretical}} \) | A/F Ratio | \( h_a \) (mm) | Volumetric Efficiency (%) |
|----------|-------------------------|-------------------------------|----------|-----------------|---------------------------|
| 4        | 0.0077                  | 0.008264                      | 46.29    | 86              | 93.64                     |
| 8        | 0.0069                  | 0.008264                      | 32.89    | 69              | 83.68                     |
| 12       | 0.0067                  | 0.008264                      | 27.07    | 65              | 81.56                     |
| 16       | 0.0066                  | 0.008264                      | 21.50    | 64              | 80.48                     |

Figure 5 illustrates the schematic representation of load and brake power. It is observed that when load is 4 kg the brake power is 1.13 Watts, when the load is 8 kg the brake power is 2.27 Watts, when the load is 12 kg the brake power is 3.41 kg and finally when the load is 16 kg the brake power is 4.55 Watts. This concludes that the increase in load give rise to higher brake power.

From the observation table, with the help of density, calorific value and mass flow rate values of brake thermal efficiency and volumetric efficiency were calculated. These calculated values were illustrated in form of graphical representation in Figure 6.
Figure 6. Schematic Graph of Brake Power vs Volumetric Efficiency

Figure 7 shows the variations in the exhaust gas inlet temperature and exhaust gas outlet temperature alongside brake power. It is noticed that as load increases the temperature rises. This concludes that efficient cooling of engine can be obtained.

4. Conclusion

The chosen shell and tube exchanger is observed to have good potential to be used in internal combustion engines due to its dense helical coils. It was noted that the exhaust gas temperature at the inlet increase from the lower load to heavier loads from 188˚C to 375˚C. The exhaust gas temperature outlet increased from 74˚C to 106˚C. also it was noted that the trend in growth of brake thermal efficiency rises from 12.83% to 25.74% as the load increases from 4kg to 16kg. This increase is due to the lessening in heat loss and intensification in power with heavier load. Overall, the brake power increases with the increase in heavier load from 1.13 watts to 4.55 Watts.

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