CHAPTER 5

RESULTS AND DISCUSSION

5.1 INTRODUCTION

The results obtained from the experimental investigation for the engine operated at various loads of different inner tubes have been studied in detail and presented in this chapter. The diesel engine without heat exchanger is evaluated experimentally and found 32% of the energy is lost in the exhaust. A research attempt has been made to recover the maximum possible exhaust heat energy through a concentric tube heat exchanger with different inner tube geometries having porous materials on inner tube, way tube and helical finned tube.

5.2 PLAIN TUBE AS INNER GEOMETRY

The variation of diesel engine flue gas temperature and the cold water inlet and out temperature, heat recover in the concentric plain tube heat exchangers with respect to time for a range of engine load conditions (25%, 50%, 75% and full load condition) are shown in Figures (5.1 to 5.4 is a plain tube) In the diesel engine, exhaust gas temperature will attain steady state within duration of 5 minutes at a given load. However, it is observed the engine exhaust temperature at all loads of the flue gas at the inlet attain a steady state after 30 minutes time interval. It is as a result of the thermal inertia of the diesel engine exhaust gas pipe to insulate from manifold to the HRCPHE. The higher heat release from the engine increases engine load that
subsequently increases the exhaust gas temperature. It was observed from all loads the temperature difference of water and gas, increases in the beginning with decrease in the slope once the temperature of the water attains approximately 50°C, and with further increases in temperature to attain higher heat rate.

At 25% load, a near constant temperature around 50°C is observed for a longer duration and this duration decreases with the increase in load.

5.2.1 Temperature Distribution in a Plain Tube Heat Exchanger

The Figure 5.1 shows that the 25% of load connect to the engine, the mass flow rate of water is 0.00833 Kg/sec and Exhaust gas flow rate is 0.02611 Kg/sec. Exhaust gas temperature raises 290°C to 315°C at the period of time 30 minutes. Initially, cold water enters inside the tube at 28°C. Hot and cold fluid exchanges the heat recover energy in the concentric tube heat exchanger. Outlet of the annular side temperature gradually decreases at 130°C. The heat absorbed by the cold water temperature is 37°C.

![Figure 5.1 Temperature variations of the exhaust gas and the water at 25% Load](image)
The Figure 5.2 shows that at the 50% of load connect to the engine, the mass flow rate of water is 0.00833 Kg/sec and Exhaust gas flow rate is 0.02614 Kg/sec. Exhaust gas temperature raises 330°C to 355°C at the period of time 30 minutes.

![Temperature variations of the exhaust gas and the water at 50% Load](image)

**Figure 5.2 Temperature variations of the exhaust gas and the water at 50% Load**

Initially cold water enters inside the tube at 28°C. Hot and cold fluid exchanges the heat recover energy in the concentric tube heat exchanger. Outlet of the annular side temperature gradually decreases at 130°C. heat absorbed by the cold water temperature is 43°C. the figure 5.3 shows that 75% of load connect to the engine, the mass flow rate of water is 0.00833 Kg/sec and Exhaust gas flow rate is 0.02618 Kg/sec.

Exhaust gas temperature raises 360°C to 385°C at the period of time 30 minutes. Initially cold water enters inside the tube at 28°C. Hot and cold fluid exchanges the heat recover energy in the concentric tube heat exchanger. Outlet of the annular side temperature gradually decreases at 130°C. heat absorbed by the cold water temperature is 49°C.
Figure 5.3  Temperature variations of the exhaust gas and the water at 75% Load

The Figure 5.4 shows that the 100% of load connected to the engine, the mass flow rate of water is 0.00833 Kg/sec and Exhaust gas flow rate is 0.02629 Kg/sec. Exhaust gas temperature raises 390°C to 450°C at the period of time 30 minutes.

Figure 5.4  Temperature variations of the exhaust gas and the water at 100% Load
Initially cold water enters inside the tube at 28°C. The hot and cold fluid exchanges the heat recover energy in the concentric tube heat exchanger. Outlet of the annular side temperature gradually decreases at 130°C. Heat absorbed by the cold water temperature is 55°C. From the experimental results with different load condition on temperature difference recorded and used to calculate the effectiveness and heat extraction rate. The effectiveness of the counter flow heat exchanger can be written as

\[
\varepsilon = \frac{\text{actual heat transfer}}{\text{maximum possible heat transfer}} = \frac{T_{h,1} - T_{h,2}}{T_{h,1} - T_{c,1}}
\]  

(5.1)

It is observed from the figures, that there is a high temperature drop in the exhaust gas that declines the temperature of the water. These exist, since the heat capacity of the water \((\dot{m}_c C_{p,c})\) supersedes the heat capacity of the exhaust gas \((\dot{m}_h C_{p,h})\). The exit temperature in all four loads of the exhaust gas from heat recovery heat exchanger (HRHE) pursue the inlet temperature of the water that get equalized at the end of the test trails. These enhance the effectiveness of the Heat exchanger (plain tube) 76% at the end of the experiment trial in all the four loads.

The WHR heat exchanger is evaluated at different loads and calculated. Heat extraction rate \((kW)\) can written as in Equation 5.2,

\[
Q_{\text{est}} = \dot{m}_c C_{p,c} (T_{c,2} - T_{c,1})
\]

(5.2)

From the plain tubes geometry, shows the heat extraction rate with a different load condition, the maximum heat extraction rate for plain is 0.93 kW.
Engine Exhaust Heat ($kW$) can written as

$$Q_g = \dot{m}_h C_{p,h} (T_{h,1} - T_{h,2})$$  \hspace{1cm} (5.3)

Where $\dot{m}_h$ – mass flow rate of the exhaust gas $T_{h,1}, T_{h,2}$ – exhaust gas temperature at the inlet and outlet of HRHE. At a full load condition, the maximum heat extracted is around 0.93 kW, which is high when compared with all other engine load conditions due to intense heat release rate from the engine at maximum load. It is observed from the Figure 5.9 that heat extraction rate and times are inversely proportional in all four loads. The log mean temperature difference can be written as

$$LM\,TD = \frac{\Delta T_1 - \Delta T_2}{\ln \left( \frac{\Delta T_1}{\Delta T_2} \right)}$$  \hspace{1cm} (5.4)

The overall heat coefficient of concentric tube heat exchanger can be written as

$$U = \frac{Q_{avg}}{A \times LM\,TD}$$  \hspace{1cm} (5.5)

The Figure 5.5 shows that due to the increasing temperature of the water at the inlet of HRHE that decreases the average temperature difference between the exhaust gas and water. However, it is observed that, it is found that the 25% load, a reduction in heat extraction rate is very low which charges to chose further analysis on determining LMTD and the overall heat transfer coefficient of the heat exchanger at various load conditions. The uniform heat extraction rate with higher LMTD varies with respect to time at 25% load illustrate that the overall heat transfer coefficient is increasing with respect to time.
Figure 5.5 Heat extraction rate and LMTD at 25% load

The Figure 5.6 shows due to the increasing temperature of the water at the inlet of HRHE that decreases the average temperature difference between the exhaust gas and water.

Figure 5.6 Heat extraction rate and LMTD at 50% load
However, it is observed that, at 50% load, a reduction in heat extraction rate is very low which charges to chose further analysis on determining LMTD and the overall heat transfer coefficient of the heat exchanger at various load conditions. The uniform heat extraction rate with higher LMTD varies with respect to time at 50% load illustrate that the overall heat transfer coefficient is increasing with respect to time.

The Figure 5.7 shows the heat extraction rate with LMTD and found that due to the increasing temperature of the water at the inlet of HRHE that decreases the average temperature difference between the exhaust gas and water.

![Graph showing heat extraction rate and LMTD at 75% load](image)

**Figure 5.7 Heat extraction rate and LMTD at 75% load**

It is observed that, it is found the 75% load, a reduction in heat extraction rate is very low which charges to chose further analysis on determining LMTD and the overall heat transfer coefficient of the heat exchanger at various load conditions. The uniform heat extraction rate with
higher LMTD varies with respect to time at 75% load illustrate that the overall heat transfer coefficient is increasing with respect to time.

The Figure 5.8 shows due to the increasing temperature of the water at the inlet of HRHE that decreases the average temperature difference between the exhaust gas and water. LMTD trend is varied when compared to previous trend line at 25%, 50% and 75% load due to turbulence in the exhaust gas and cooling water. However, it is observed that, at 100% load, a reduction in heat extraction rate is very low which charges to chose further analysis on determining LMTD and the overall heat transfer coefficient of the heat exchanger at various load conditions. The uniform heat extraction rate with higher LMTD varies with respect to time at 1% load illustrate that the overall heat transfer coefficient is increasing with respect to time.

![Figure 5.8 Heat extraction rate and LMTD at 100% load](image)

**Figure 5.8 Heat extraction rate and LMTD at 100% load**

The Figure 5.9 shows the variation of heat extraction rate with time for 25%, 50%, 75%, and 100% load conditions. It obtained results for 25 % of
load heat extraction rate is minimum and gradually increased the other loads. Heat extractions rate various from 0.14 to 0.93kW.

Figure 5.9  Heat extraction rate from exhaust gas at different loads conditions

Figure 5.10  Variation of overall heat transfer coefficient of the HRHE at various loads
The Figure 5.10 shows the variation in overall heat transfer coefficient varies with respect to time at 25%, 50%, 75% and 100% condition.

Initially 25% of load variation of overall heat transfer coefficient 207 to 236 W/m^2°C, At 50% of load variation of overall heat transfer coefficient 241 to 266 W/m^2°C, At 75% of load variation of overall heat transfer coefficient 283 to 307 W/m^2°C and at 100% of load variation of overall heat transfer coefficient 315 to 355 W/m^2°C. It is found in the Figure 5.10 the overall heat loss co-efficient is maximum for 100% load due to higher mass flow rate and higher operating temperature. The lowest heat transfer co-efficient is found for minimum load compared to other three loads. The Figure 5.11 illustrates the Wilson plot chart for plain tube the varying the mass flow rate with different load condition. The correlation to compute overall heat loss co-efficient for outer surface was developed for different mass flow rates as \( y = 122.7X - 0.012 \) with \( R^2 \) value of 0.990.

![Figure 5.11 Wilson plot chart for plain tube](image)
5.2.2 Life Cycle Savings

The indicative of the percentage of fuel power is saved by introducing the storage system when the system is employed for replacing the conventional one which requires either fuel or electric power.

\[ E_s = \frac{Q_e}{m_f \times C.V} \]  \hspace{1cm} (5.6)

Exhaust gas is recovered and stored in transitory thermal energy storage system, mentioned in the figure 4.5 and the savings related to life cycle is presented in this section. The percentage energy saved varies from 1\% to 5\% as the load increases from 25\% to full load. It is found from all lower loads; the energy percentile saved is less, due to high specific fuel consumption (SFC) of 0.7135 kg/kW- hr. It is found from the full loads the percentage energy saved is more, due to the low specific fuel consumption (0.2582 kg/kW- hr). The total engine hours is (15 years * 365 days * 24 hours is equal to 1,31,400 hours) that excludes the planned maintenance hours, and other ineffective losses from the booked hours of the engine which is taken as 100000 engine hours, The whole life cycle of the engine and the experimental set-up will save 24012.6 kW-hr of electricity.

5.3 HELICAL FINNED TUBE AS INNER GEOMETRY

The variation of diesel engine flue gas temperature and the cold water inlet and out temperature, heat recover in the concentric helical finned tube heat exchangers with respect to time for a range of engine load conditions (25\%, 50\%, 75\% and full load condition) are shown in Figures (5.12to 5.15 is a helical finned tube)
In the diesel engine, exhaust gas temperature will attain steady state within duration of 5 minutes at a given load. However, it is observed the engine exhaust temperature at all loads of the flue gas at the inlet attain a steady state after 30 minutes time interval. It is as a result of the thermal inertia of the diesel engine exhaust gas pipe to insulate from manifold to the HRCPHE. The higher heat release from the engine increases engine load that subsequently increases the exhaust gas temperature. It is observed from all loads the temperature difference of water and gas, increases in the beginning with decrease in the slope once the temperature of the water attains approximately $50^\circ C$, and with further increases in temperature to attain higher heat rate.

It is found from 25% load a near constant temperature around $50^\circ C$ is observed for a longer duration and this duration decrease with increase in load.

### 5.3.1 Temperature Distribution in a Helical Finned Tube Heat Exchanger (parallel flow)

![Figure 5.12 Temperature variations of the exhaust gas and the water at 25% Load](image)
The Figure 5.12 shows the 25% of load connect to the engine, the mass flow rate of water is 0.008333kg/sec and Exhaust gas flow rate is 0.02611 Kg/sec. Exhaust gas temperature raises 323°C to 380°C at the period of time 30 minutes. Initially cold water enters inside the tube at 26°C. hot and cold fluid exchanges the heat recover energy in the concentric tube heat exchanger. Outlet of the annular side temperature gradually decreases at 120°C. The heat absorbed by the cold water temperature is 54°C. The Figure 5.13 shown the 50% of load connect to the engine, the mass flow rate of water is 0.00833 Kg/sec and Exhaust gas flow rate is 0.02614Kg/sec. Exhaust gas temperature raises 413°C to 430°C at the period of time 30 minutes.

![Figure 5.13 Temperature variations of the exhaust gas and water at 50% Load](image)

Initially cold water enters inside the tube at 26°C. Hot and cold fluid exchanges the heat recover energy in the concentric tube heat exchanger. Outlet of the annular side temperature gradually decreases at 120°C. heat absorbed by the cold water temperature is 57°C.
The Figure 5.14 shown the temperature variation of exhaust gas and water at 75% of load connect to the engine, the mass flow rate of water is 0.00833 Kg/sec and exhaust gas flow rate is 0.02618 Kg/sec. exhaust gas temperature raises 444°C to 447°C at the period of time 30 minutes.

![Figure 5.14 Temperature variations of the exhaust gas and water at 75% Load](image)

Initially cold water enters inside the tube at 26°C. Hot and cold fluid exchanges the heat recover energy in the concentric tube heat exchanger. Outlet of the annular side temperature gradually decreases at 120°C. Heat absorbed by the cold water temperature is at 59°C. The Figure 5.15 shows that 100% of load connect to the engine, the mass flow rate of water is .00833 Kg/sec and Exhaust gas flow rate is 0.02629 Kg/sec. Exhaust gas temperature raises 485°C to 490°C at the period of time 30 minutes. Initially cold water enters inside the tube at 26°C. hot and cold fluid exchanges the heat recover energy in the concentric tube heat exchanger. Outlet of the annular side temperature gradually decreases at 120°C. The heat absorbed by the cold water temperature is at 65°C.
Figure 5.15  Temperature variations of the exhaust gas and water at Full Load

From the experimental results with different load condition on temperature difference is recorded and used to calculate the effectiveness and heat extraction rate. The effectiveness of the counter flow heat exchanger computed using Equation 5.1. It is observed from the figures, that there is a high temperature drop in the exhaust gas that declines the temperature of the water. These exist, since the heat capacity of the water \((\dot{m}_t C_{p,c})\) supersedes the heat capacity of the exhaust gas \((\dot{m}_h C_{p,h})\). The exit temperature in all four loads of the exhaust gas from heat recovery heat exchanger (HRHE) pursue the inlet temperature of the water that get equalized at the end of the test trails. These enhance the effectiveness of the heat exchanger is 79% at the end of the experiment trial in all the four loads.

The WHR heat exchanger evaluated at different loads and calculated. Heat extraction rate \((kW)\) can written as in Equation 5.2. From the helical finned tubes geometry, shows the heat extraction rate with a different
load condition, the maximum heat extraction rate for parallel flow is 1.36 kW. It is found from the full load condition, the maximum heat extracted is around 1.36 kW, which is high when made compared with all other engine load conditions due to intense heat release rate from the engine at maximum load. The LMTD from Equation 5.4 and the overall heat coefficient of concentric tube heat exchanger calculated from Equation 5.5. The Figure 5.16 shows due to the increasing temperature of the water at the inlet of HRHE that decreases the average temperature difference between the exhaust gas and water.

Figure 5.16 Heat extraction rate and LMTD at 25% load

However, it is observed that, at 25% load, a reduction in heat extraction rate is very low which charges to chose further analysis on determining LMTD and the overall heat transfer coefficient of the heat exchanger at various load conditions. The uniform heat extraction rate with higher LMTD varies with respect to time at 25% load illustrate that the overall heat transfer coefficient is increasing with respect to time. The Figure 5.17 shows due to the increasing temperature of the water at the inlet
of HRHE that decreases the average temperature difference between the exhaust gas and water. However, it is observed that, it found that the 50% load, a reduction in heat extraction rate is very low which charges to chose further analysis on determining LMTD and the overall heat transfer coefficient of the heat exchanger at various load conditions. The uniform heat extraction rate with higher LMTD varies with respect to time at 50% load illustrate that the overall heat transfer coefficient is increasing with respect to time.

![Figure 5.17 Heat extraction rate and LMTD at 50% load](image)

The Figure 5.18 shows the heat extraction rate with LMTD and it is found that due to the increasing temperature of the water at the inlet of HRHE there is decrease in the average temperature difference between the exhaust gas and water. It is observed that, at 75% load, a reduction in heat extraction rate is very low which charges to chose further analysis on determining LMTD and the overall heat transfer coefficient of the heat exchanger at various load conditions.
The uniform heat extraction rate with higher LMTD varies with respect to time at 75% load illustrate that the overall heat transfer coefficient is increasing with respect to time. The Figure 5.19 shows due to the increasing temperature of the water at the inlet of HRHE there is decrease in the average temperature difference between the exhaust gas and water.

However, it is observed that, at 100% load, a reduction in heat extraction rate is very low which charges to chose further analysis on determining LMTD and the overall heat transfer coefficient of the heat exchanger at various load conditions. The uniform heat extraction rate with higher LMTD varies with respect to time at 25% load illustrates that the overall heat transfer coefficient is increases with respect to time. The LMTD least scale taken as 2°C and the figure 5.17 and 5.18 shows the LMTD least scale selected as 0.5°C and the sharp curves indicates the due to minor variation of temperature due to the vibration of mechanical loading arrangements at higher loads.
The Figure 5.20 shows the variation of heat extraction rate with time for 25%, 50%, 75%, and 100% load conditions. The results obtained for 25% of load heat extraction rate is minimum which gradually increased with the other loads. Heat extractions rate varies from 0.72 to 1.36kW.

Figure 5.20 Heat extraction rate from exhaust gas at different loads condition
The Figure 5.21 shows the variation in overall heat transfer coefficient varies with respect to time at 25%, 50%, 75% and 100% condition. Initially 25% of load variation of overall heat transfer coefficient 153 to 185 W/m²°C, it is noticed from 50% of load variation of overall heat transfer coefficient 198 to 205 W/m²°C, it is found from the 75% of load variation of overall heat transfer coefficient 210 to 213 W/m²°C and at 100% of load variation of overall heat transfer coefficient 226 to 236 W/m²°C.

![Figure 5.21 Variation of overall heat transfer coefficient of the HRHE at various loads](image)

Figure 5.21 Variation of overall heat transfer coefficient of the HRHE at various loads

It is found in the Figure 5.21 that the overall heat loss co-efficient is maximum for 100% load due to higher mass flow rate and when higher operating temperature. The lowest heat transfer co-efficient is found for minimum load compared to other three loads.
5.3.2 Life Cycle Savings

Exhaust gas is recovered and stored in thermal energy storage system and savings related to life cycle is presented in this section. The percentage of energy saved varies from 5% to 7% as the load increases from 25% to full load. It is found from all lower loads; the energy percentile saved is less, due to high specific fuel consumption (SFC) of 0.7135 kg/kW-hr. It is found from the full loads the percentage energy saved is more, due to the low specific fuel consumption (0.2582 kg/kW-hr). The total engine hours is (15 years * 365 days * 24 hours is equal to 1,31,400 hours) that excludes the planned maintenance hours, and other ineffective losses from the booked hours of the engine which is taken as 100,000 engine hours. The whole life cycle of the engine and the experimental set-up will save 35115.2 kW-hr of electricity.

5.3.3 Temperature Distribution in a Helical Finned Tube Heat Exchanger (Counter Flow)

The Figure 5.22 shows that when 25% of load is connected to the engine, the mass flow rate of water is 0.00833 Kg/sec and Exhaust gas flow rate is 0.02611 Kg/sec. Exhaust gas temperature raises 323 °C to 380 °C at the period of time 30 minutes. Initially cold water enters inside the tube at 26 °C. Hot and cold fluid exchanges the heat recover energy in the concentric tube heat exchanger. Outlet of the annular side temperature gradually decreases at 120 °C. Heat absorbed by the cold water temperature is 55 °C.
Figure 5.22 Temperature variations of the exhaust gas and water at 25% Load

The Figure 5.23 shows that 50% of load connects to the engine, the mass flow rate of water is 0.00833 Kg/sec and Exhaust gas flow rate is 0.02614 Kg/sec.

Figure 5.23 Temperature variations of the exhaust gas and water 50% Load
Exhaust gas temperature raises 413°C to 430°C at the period of time 30 minutes. Initially cold water enters inside the tube at 26°C. Hot and cold fluid exchanges the heat recover energy in the concentric tube heat exchanger. Outlet of the annular side temperature gradually decreases at 120°C. Heat absorbed by the cold water temperature is 59°C. The Figure 5.24 shown the 75% of load connect to the engine, the mass flow rate of water is 0.00833 Kg/sec and exhaust gas flow rate is 0.02618 kg/sec. Exhaust gas temperature raises 440°C to 447°C at the period of time 30 minutes. Initially cold water enters inside the tube at 26°C. Hot and cold fluid exchanges the heat recover energy in the concentric tube heat exchanger. Outlet of the annular side temperature gradually decreases at 120°C. Heat absorbed by the cold water temperature is 65°C.

Figure 5.24 Temperature variations of the exhaust gas and water at 75% Load
Figure 5.25  Temperature variations of the exhaust gas and water at Full Load

The Figure 5.25 shows that when 100% of load is connected to the engine, the mass flow rate of water is 0.00833 Kg/sec and Exhaust gas flow rate is 0.02629 Kg/sec. Exhaust gas temperature from raises 485°C to 490°C in the period of time 30 minutes. Initially cold water enters inside the tube at 28°C. Hot and cold fluid exchanges the heat recover energy in the concentric tube heat exchanger. Outlet of the annular side temperature gradually decreases at 120°C. Heat absorbed by the cold water temperature is 72°C. The figure 5.26 shows that due to the increasing temperature of the water at the inlet of HRHE there is decrease in the average temperature difference between the exhaust gas and water. However, it is observed that, at 25% load, a reduction in heat extraction rate is very low which charges to chose further analysis on determining LMTD and the overall heat transfer coefficient of the heat exchanger at various load conditions. The uniform heat extraction rate with higher LMTD varies with respect to time at 25% load illustrate that the overall heat transfer coefficient is increasing with respect to time.
Figure 5.26 Heat extraction rate and LMTD at 25% load

The Figure 5.27 shows that due to the increasing temperature of the water at the inlet of HRHE there is decrease in the average temperature difference between the exhaust gas and water.

Figure 5.27 Heat extraction rate and LMTD at 50% load
However, it is observed that, at 50% load, a reduction in heat extraction rate is very low which charges to chose further analysis on determining LMTD and the overall heat transfer coefficient of the heat exchanger at various load conditions. The uniform heat extraction rate with higher LMTD varies with respect to time at 50% load illustrate that the overall heat transfer coefficient is increasing with respect to time. The Figure 5.28 shows the heat extraction rate with LMTD and it is found that due to the increasing temperature of the water at the inlet of HRHE there is decrease in the average temperature difference between the exhaust gas and water. It is observed that, at 75% load, a reduction in heat extraction rate is very low which charges to chose further analysis on determining LMTD and the overall heat transfer coefficient of the heat exchanger at various load conditions. The uniform heat extraction rate with higher LMTD varies with
respect to time at 75% load illustrates that the overall heat transfer coefficient is increases with respect to time.

![Graph showing heat extraction rate and LMTD at Full load](image)

**Figure 5.29 Heat extraction rate and LMTD at Full load**

The Figure 5.29 shows that due to the increasing temperature of the water at the inlet of HRHE there is decrease in the average temperature difference between the exhaust gas and water. However, it is observed that, at 100% load, a reduction in heat extraction rate is very low which charges to chose further analysis on determining LMTD and the overall heat transfer coefficient of the heat exchanger at various load conditions. The uniform heat extraction rate with higher LMTD varies with respect to time at 100% load illustrates that the overall heat transfer coefficient increases with respect to time. The figure 5.26, 5.27, 5.28 and 5.29 shows the heat extraction rate trend with LMTD. The fluctuation of LMTD shows the change in the mechanical loading arrangement and the sensible heat variation of tubular materials.
The figure 5.30 shows the variation of heat extraction rate with time for 25%, 50%, 75%, and 100% load conditions. The results obtained for 25% of load heat extraction rate is minimum and gradually increases with the other loads. Heat extractions rate varies from 0.92 to 1.61kW.

![Figure 5.30 Heat extraction rate from exhaust gas at different load conditions](image)

The Figure 5.31 shows the variation in overall heat transfer coefficient varies with respect to time at 25%, 50%, 75% and 100% conditions.
Initially 25% of load variation of overall heat transfer coefficient is 151 to 171 W/m² K. At 50 % of load variation of overall heat transfer coefficient is 180 to 187 W/m² K. At 75 % of load variation of overall heat transfer coefficient is 194 to 197 W/m² K and at 100 % of load variation of overall heat transfer coefficient is 208 to 213 W/m² K. It is found in the Figure 5.31 that the overall heat loss coefficient is maximum for 100% load due to higher mass flow rate and higher operating temperature. The lowest heat transfer coefficient is found to be minimum loads when compared to other three loads. It is found in the Figure 5.31 that the overall heat loss coefficient is maximum for 100% load due to higher mass flow rate and higher operating temperature. The lowest heat transfer coefficient is found for minimum loads when compared to other three loads. The Figure 5.32 shows illustrate the Wilson plot chart for helical finned tube the varying the mass
flow rate with different load condition. The correlation to compute overall heat loss co-efficient for outer surface was developed for different mass flow rates as $y = 57.49X - 0.009$ with $R^2$ value of 0.953.

![Figure 5.32 Wilson plot chart for helical finned tube](image)

**Figure 5.32 Wilson plot chart for helical finned tube**

### 5.3.4 Life Cycle Savings

Exhaust gas is recovered and stored in thermal energy storage system and savings related to life cycle is presented in this section. The percentage of energy saved varies from 7% to 8% as the load increases from 25% to full load. It is found from all lower loads; the energy percentile saved is less, due to high specific fuel consumption (SFC) of 0.7135 kg/kW·hr.

It is found from the full loads the percentage energy saved is more, due to the lower specific fuel consumption (0.2582 kg/kW·hr). The total engine hours is 1,31,400 hours (15 years * 365 days * 24 hours) that excludes the planned maintenance hours, and other ineffective losses from the booked hours of the engine which is taken as 100000 engine hours, The whole life
cycle of the engine, the experimental set-up will save 41570 kW-hr of electricity.

5.4 POROUS MEDIUM TUBE AS INNER GEOMETRY

The results obtained from the experimental investigation for the engine operated at various load conditions are studied in detail and presented. In the present work, attempts have been made to recover the maximum possible heat energy extract from the exhaust gas through a concentric tube heat exchanger inserts with different (Cast-Iron, Mild steel) porous material and to store it in a TTES tank. The higher heat release from the engine increases engine load that subsequently increases the exhaust gas temperature. It was observed from all loads the temperature difference of water and gas, increases in the beginning with decrease in the slope once the temperature of the water attains approximately 50°C, and with further increases in temperature to attain higher heat rate. At 25% load a near constant temperature around 50°C is observed for a longer duration and this duration decreases with increase in load.

5.4.1 Temperature Distribution in a Porous Medium (cast iron) Tube Heat Exchanger

The Figure 5.33 shown the 25% of load connect to the engine, the mass flow rate of water is 0.00833 Kg/sec and Exhaust gas flow rate is 0.02611 Kg/sec. Exhaust gas temperature raises for 300°C to 330°C at the time period of time 30 minutes. Initially cold water enters inside the tube at 28°C. Hot and cold fluid exchanges the heat recover energy in the concentric tube heat exchanger. Outlet of the annular side temperature gradually decreases at 130°C. Heat absorbed by the cold water temperature is 45°C.
Figure 5.33 Temperature variations of the exhaust gas and the water at 25% Load

Figure 5.34 Temperature variations of the exhaust gas and the water at 50% Load
The Figure 5.34 shows that at 50% of load connect to the engine, the mass flow rate of water is 0.00833 Kg/sec and Exhaust gas flow rate is 0.02614 Kg/sec. Exhaust gas temperature raises 340°C to 370°C at the period of time 30 minutes. Initially cold water enters inside the tube at 28°C. Hot and cold fluid exchanges the heat recover energy in the concentric tube heat exchanger. Outlet of the annular side temperature gradually decreases at 130°C. Heat absorbed by the cold water temperature is 49°C.

![Figure 5.35](image)

**Figure 5.35  Temperature variations of the exhaust gas and the water at 75% Load**

The Figure 5.35 shows that at 75% of load connected to the engine, the mass flow rate of water is 0.00833 Kg/sec and Exhaust gas flow rate is 0.02618 Kg/sec. Exhaust gas temperature raises 380°C to 410°C at the period of time 30 minutes. Initially cold water enters inside the tube at 28°C. Hot and cold fluid exchanges the heat recover energy in the concentric tube heat exchanger. Outlet of the annular side temperature gradually decreases at 130°C. Heat absorbed by the cold water temperature is 53°C.
The Figure 5.36 shows that at 100% of load connected to the engine, the mass flow rate of water is 0.00833 Kg/sec and Exhaust gas flow rate is 0.02629 Kg/sec. Exhaust gas temperature raises 420°C to 450°C at the period of time 30 minutes. Initially cold water enters inside the tube at 28°C. Hot and cold fluid exchanges the heat recover energy in the concentric tube heat exchanger. Outlet of the annular side temperature gradually decreases at 130°C. Heat absorbed by the cold water temperature is 57°C.

![Figure 5.36](image)

**Figure 5.36  Temperature variations of the exhaust gas and the water at 100% Load**

From the experimental results with different load conditions on temperature difference is recorded and used to calculate the effectiveness and heat extraction rate. It is observed from the figures, that there is a high temperature drop in the exhaust gas that declines the temperature of the water. These exist, since the heat capacity of the water supersedes the heat capacity of the exhaust gas. The exit temperature in all four loads of the exhaust gas from heat recovery heat exchanger (HRHE) pursue the inlet temperature of
the water that get equalized at the end of the test trails. These enhance the effectiveness of the Heat exchanger (porous tube) 76% at the end of the experiment trial in all the four loads.

The WHR heat exchanger is evaluated at different loads and calculated. From the porous tubes geometry, it is noticed that the heat extraction rate with a different load condition, the maximum heat extraction rate for porous is 1.67 kW. It is found from the full load condition, the maximum heat extracted is around 1.67 kW, which is high when compared to all other engine load conditions due to intense heat release rate from the engine at maximum load.

![Figure 5.37 Heat extraction rate and LMTD at 25% load](image)

**Figure 5.37 Heat extraction rate and LMTD at 25% load**

The Figure 5.37 shows that due to the increasing temperature of the water at the inlet of HRHE there is decrease in the average temperature difference between the exhaust gas and water. However, it is observed that, at 25% load, a reduction in heat extraction rate is very low which charges to
chose further analysis on determining LMTD and the overall heat transfer coefficient of the heat exchanger at various load conditions. The uniform heat extraction rate with higher LMTD varies with respect to time at 25% load and it is noted that the overall heat transfer coefficient is increases with respect to time.

The Figure 5.38 shows due to the increasing temperature of the water at the inlet of HRHE there is decrease in the average temperature difference between the exhaust gas and water. However, it is observed that, at 50% load, a reduction in heat extraction rate is very low which charges to chose further analysis on determining LMTD and the overall heat transfer coefficient of the heat exchanger at various load conditions. The uniform heat extraction rate with higher LMTD varies with respect to time at 50% load illustrate that the overall heat transfer coefficient is increases with respect to time.

![Figure 5.38 Heat extraction rate and LMTD at 50% load](image)

**Figure 5.38 Heat extraction rate and LMTD at 50% load**
The Figure 5.39 shows that due to the increasing temperature of the water at the inlet of HRHE there is decrease in the average temperature difference between the exhaust gas and water. However, it is observed that, at 75% load, a reduction in heat extraction rate is very low which charges to chose further analysis on determining LMTD and the overall heat transfer coefficient of the heat exchanger at various load conditions.

![Figure 5.39 Heat extraction rate and LMTD at 75% load](image)

**Figure 5.39 Heat extraction rate and LMTD at 75% load**

The uniform heat extraction rate with higher LMTD varies with respect to time at 75% load illustrate that the overall heat transfer coefficient is increases with respect to time.

The Figure 5.40 shows the rise of water temperature at inlet of HRHE that decreases the average temperature difference between the exhaust gas and water. It is noticed at 25% of load, the heat extraction rate is low. The uniform heat extraction rate with higher LMTD varies with respect to time at 25% load illustrate that the overall heat transfer coefficient is increases with respect to time.
Figure 5.40 Heat extraction rate and LMTD at 100% load

Figure 5.41 Heat extraction rate from exhaust gas at different loads conditions
The Figure 5.41 shows the variation of heat extraction rate with time for 25%, 50%, 75%, and 100% load conditions. The results obtained for 25% of load heat extraction rate is minimum and gradually increases at the other loads. Heat extractions rate varies from 0.82 to 1.67 kW.

![Figure 5.42 Variation of overall heat transfer coefficient of the HRHE at various loads](image)

**Figure 5.42**  Variation of overall heat transfer coefficient of the HRHE at various loads

The Figure 5.42 shows the variation in overall heat transfer coefficient varies with respect to time at 25%, 50%, 75% and 100% condition. Initially 25% of load variation of overall heat transfer coefficient is 77 to 86 W/m²°C, At 50% of load variation of overall heat transfer coefficient is 89 to 97 W/m²°C, At 75% of load variation of overall heat transfer coefficient is 99 to 106 W/m²°C and at 100% of load variation of overall heat transfer coefficient 109 to 116 W/m²°C. It is found in the Figure 5.42 that the overall heat loss co-efficient is maximum for 100% load due to higher mass flow rate and higher operating temperature. The lowest heat transfer co-efficient is found for minimum load when compared to other three loads.
5.4.2 Life Cycle Savings

Exhaust gas is recovered and stored in thermal energy storage system and savings related to life cycle is presented in this section. The percentage of energy saved varies from 6% to 8.4% as the load increases from 25% to full load. It is found from all lower loads; the energy percentile saved is less, due to high specific fuel consumption (SFC) of 0.7135kg/kW- hr. It is found from the full loads the percentage energy saved is more, due to the low specific fuel consumption (0.2582kg/kW- hr). The total engine hours is (15 years * 365 days *24 hours is equal to 1,31,400 hours) that excludes the planned maintenance hours, and other ineffective losses from the booked hours of the engine which is taken as 100000 engine hours, The whole life cycle of the engine and the experimental set-up will save 43119.4kW-hr of electricity.

5.4.3 Temperature Distribution in a Porous Medium (Mild steel) Tube Heat Exchanger

The Figure 5.43 shown the 25% of load connect to the engine, the mass flow rate of water is 0.01388 Kg/sec and Exhaust gas flow rate is 0.02611 Kg/sec. Exhaust gas temperature raises 300°C to 330°C at the time period of 30 minutes.

Initially cold water enters inside the tube at 30°C, hot and cold fluid exchanges the heat recover energy in the concentric tube heat exchanger. Outlet of the annular side temperature gradually decreases at 125°C. heat absorbed by the cold water temperature is 52°C.
Figure 5.43  Temperature variations of the exhaust gas and the water at 25% Load

Figure 5.44  Temperature variations of the exhaust gas and the water at 50% Load
The Figure 5.44 shows that at 50% of load connected to the engine, the mass flow rate of water is 0.01388 Kg/sec and Exhaust gas flow rate is 0.02614 Kg/sec. Exhaust gas temperature raises 340°C to 370°C at the period of time 30 minutes. Initially cold water enters inside the tube at 30°C. Hot and cold fluid exchanges the heat recover energy in the concentric tube heat exchanger. Outlet of the annular side temperature gradually decreases at 125°C. Heat absorbed by the cold water temperature is 56°C.

The Figure 5.45 shows that at 75% of load connect to the engine, the mass flow rate of water is 0.01388 Kg/sec and Exhaust gas flow rate is 0.02629Kg/sec. Exhaust gas temperature raises 380°C to 410°C at the time period of 30 minutes. Initially cold water enters inside the tube at 30°C. Hot and cold fluid exchanges the heat recover energy in the concentric tube heat exchanger. Outlet of the annular side temperature gradually decreases at 125°C. Heat absorbed by the cold water temperature is 60°C.

Figure 5.45  Temperature variations of the exhaust gas and the water at 75% Load
Figure 5.46 shows that at 100% of load connected to the engine, the mass flow rate of water is 0.01388 Kg/sec and Exhaust gas flow rate is 0.02629 Kg/sec. Exhaust gas temperature raises from 420°C to 450°C at the time period of 30 minutes. Initially cold water enters inside the tube at 30°C. Hot and cold fluid exchanges the heat recover energy in the concentric tube heat exchanger. Outlet of the annular side temperature gradually decreases at 125°C. Heat absorbed by the cold water temperature is 64°C.

The Figure 5.47 shows that due to the increasing temperature of the water at the inlet of HRHE there is decrease in the average temperature difference between the exhaust gas and water. However, it is observed that, at 25% load, a reduction in heat extraction rate is very low which charges to chose further analysis on determining LMTD and the overall heat transfer coefficient of the heat exchanger at various load conditions. The uniform heat
extraction rate with higher LMTD varies with respect to time at 25% load and this illustrates that the overall heat transfer coefficient is increases with respect to time.

![Figure 5.47 Heat extraction rate and LMTD at 25% load](image)

Figure 5.47 Heat extraction rate and LMTD at 25% load

![Figure 5.48 Heat extraction rate and LMTD at 50% load](image)

Figure 5.48 Heat extraction rate and LMTD at 50% load
The Figure 5.48 shows that due to the increasing temperature of the water at the inlet of HRHE that decreases the average temperature difference between the exhaust gas and water. However, it is observed that, at 50% load, a reduction in heat extraction rate is very low which charges to chose further analysis on determining LMTD and the overall heat transfer coefficient of the heat exchanger at various load conditions. The uniform heat extraction rate with higher LMTD varies with respect to time at 50% load and this illustrates that the overall heat transfer coefficient is increases with respect to time.

Figure 5.49 Heat extraction rate and LMTD at 75% load.

Figure 5.49 shows that due to the increasing temperature of the water at the inlet of HRHE there is decrease in the average temperature difference between the exhaust gas and water. However, it is observed that, it is found from 75% load, a reduction in heat extraction rate is very low which charges to chose further analysis on determining LMTD and the overall heat transfer coefficient of the heat exchanger at various load conditions. The uniform heat extraction rate with higher LMTD varies with respect to time at
75% load and this illustrates that the overall heat transfer coefficient is increases with respect to time.

The Figure 5.50 shows that due to the increasing temperature of the water at the inlet of HRHE there is decrease in the average temperature difference between the exhaust gas and water. However, it is observed that, at 100% load, a reduction in heat extraction rate is very low which charges to chose further analysis on determining LMTD and the overall heat transfer coefficient of the heat exchanger at various load conditions. The uniform heat extraction rate with higher LMTD varies with respect to time at 100% load that illustrates that the overall heat transfer coefficient is increases with respect to time.

![Figure 5.50 Heat extraction rate and LMTD at 100% load](image)

**Figure 5.50 Heat extraction rate and LMTD at 100% load**

The Figure 5.51 shows the variation of heat extraction rate with time for 25%, 50%, 75%, and 100% load conditions. The results obtained for
25 % of load heat extraction rate is minimum and gradually increased at the other loads. Heat extractions rate varies from 1.12 to 1.96kW.

Figure 5.51  Heat extraction rate from exhaust gas at different loads conditions

Figure 5.52  Variation of overall heat transfer coefficient of the HRHE at various loads
The Figure 5.52 shows the variation in overall heat transfer coefficient varies with respect to time at 25%, 50%, 75% and 100% conditions.

Initially 25% of load variation of overall heat transfer coefficient is 72 to 79 W/m²°C. At 50% of load variation of overall heat transfer coefficient is 82 to 88 W/m²°C. At 75% of load variation of overall heat transfer coefficient is 92 to 96 W/m²°C and it is found from 100% of load variation of overall heat transfer coefficient 98 to 104 W/m²°C. It is found in the Figure 5.52 the overall heat loss co-efficient is maximum for 100% load due to higher mass flow rate and higher operating temperature. The lowest heat transfer co-efficient is found for minimum load when compared to other three loads. It is found in the Figure 5.52 the overall heat loss co-efficient is maximum for 100% load due to higher mass flow rate and higher operating temperature. The lowest heat transfer co-efficient is found for minimum load compared to other three loads.

5.4.4 Heat Extraction Rate from the Engine Exhaust Gas at Full Load Conditions

The two different porous material (cast iron, mild steel) inner tube geometry and the effective thermal conductivity can be improved the thermal performance and the heat extraction rate compare with the helical finned tube, porosity and effective thermal conductivity of the two different materials can be calculated as

\[ \varepsilon_v = \frac{V_{\text{bed}} - V_{\text{packing}}}{V_{\text{bed}}} \]  \hspace{1cm} (5.7)

\[ k_{\text{eff}} = \varepsilon_v k_{\text{fluid}} + (1 - \varepsilon_v) k_{\text{solid}} \]  \hspace{1cm} (5.8)
Where $ \varepsilon_v $, porosity of the cast iron and Mild steel, $ V_{Bed} $ - volume of the porous bed and $ V_{packing} $ - volume of porous packing material. $ k_{eff} $ - Effective thermal conductivity. Full load condition heat extraction rate shows with and without porous material. It is noted that prior to actual data collection, the test setup was checked by conducting experiments for a helical fin tube. Comparison between the porous tube and the helical finned tube heat exchanger is presented in Figure 5.53. In the figure, results of porous tube heat exchanger reasonably agree well with the available correlation within $ \pm 9\% $, $ \pm 23\% $ in comparison of helical fin tube.

![Figure 5.53](image)

**Figure 5.53** Comparison of heat extraction rate with and without porous material at all full loads

The Figure 5.54 illustrates the Wilson plot chart for porous tube the varying the mass flow rate with different load condition. The correlation to compute overall heat loss co-efficient for outer surface was developed for different mass flow rates as $ y = 263.0X - 0.028 $ with $ R^2 $ value of 0.989.
The Figure 5.55 illustrates the Wilson plot chart for porous tube the varying the mass flow rate with different load condition. The correlation to compute overall heat loss co-efficient for outer surface was developed for different mass flow rates as $y = 270.8x - 0.025$ with $R^2$ value of 0.993.
5.4.5 Life Cycle Savings

Exhaust gas is recovered and stored in thermal energy storage system and savings related to life cycle is presented in this section. The percentage of energy saved varies from 8% to 10% as the load increases from 25% to full load. It is found from all lower loads; the energy percentile saved is less, due to high specific fuel consumption (SFC) of 0.7135 kg/kW-hr. It is found from the full loads the percentage energy saved is more, due to the low specific fuel consumption (0.2582 kg/kW-hr). The total engine hours is (15 years * 365 days *24 hours is equal to 1,31,400 hours) that excludes the planned maintenance hours, and other ineffective losses from the booked hours of the engine which is taken as 100,000 engine hours, The whole life cycle of the engine and the experimental set-up will save 50607.2 kWh of electricity.

5.5 POROUS MEDIUM TUBE AS INNER GEOMETRY

The variation of diesel engine flue gas temperature and the cold water inlet and out temperature, heat recover in the concentric porous (Copper, Aluminum) tube heat exchangers with respect to time for a range of engine load conditions (25%, 50%, 75% and full load condition) are shown in Figures (5.56 to 5.59)

In the diesel engine, exhaust gas temperature will attain steady state within duration of 5 minutes at a given load. However, it is observed the engine exhaust temperature at all loads of the flue gas at the inlet attain a steady state after 30 minutes time interval. It is as a result of the thermal inertia of the diesel engine exhaust gas pipe to insulate from manifold to the HRCPHE. The higher heat release from the engine increases engine load that subsequently increases the exhaust gas temperature. It was observed from all loads the temperature difference of water and gas, increases in
the beginning with decrease in the slope once the temperature of the water attains approximately 50°C, and with further increases in temperature to attain higher heat rate.

At 25% load a near constant temperature around 50°C is observed for a longer duration and this duration decrease with increase in load.

5.5.1 Temperature Distribution in a Porous Medium (Copper) Tube Heat Exchanger

The Figure 5.56 shows that at 25% of load connected to the engine, the mass flow rate of water is 0.01388 Kg/sec and Exhaust gas flow rate is 0.02611 Kg/sec. Exhaust gas temperature raises 300°C to 325°C at the period of time 30 minutes. Initially cold water enters inside the tube at 30°C. Hot and cold fluid exchanges the heat recover energy in the concentric tube heat exchanger. Outlet of the annular side temperature gradually decreases at 120°C. Heat absorbed by the cold water temperature is 50°C.

![Temperature variations of the exhaust gas and the water at 25% Load](image)

Figure 5.56 Temperature variations of the exhaust gas and the water at 25% Load
The Figure 5.57 shows that at 50% of load connected to the engine, the mass flow rate of water is 0.01388 Kg/sec and Exhaust gas flow rate is 0.02614 Kg/sec. Exhaust gas temperature raises 330˚C to 355˚C at the time period of 30 minutes. Initially cold water enters inside the tube at 30˚C. Hot and cold fluid exchanges the heat recover energy in the concentric tube heat exchanger. Outlet of the annular side temperature gradually decreases at 120˚C. Heat absorbed by the cold water temperature is 56˚C.

![Temperature variations of the exhaust gas and the water at 50% Load](image)

**Figure 5.57  Temperature variations of the exhaust gas and the water at 50% Load**

The Figure 5.58 shows that at 75% of load connected to the engine, the mass flow rate of water is 0.01388 Kg/sec and Exhaust gas flow rate is 0.02618 Kg/sec. Exhaust gas temperature raises 360˚C to 385˚C at the time period of 30 minutes. Initially cold water enters inside the tube at 30˚C. Hot and cold fluid exchanges the heat recover energy in the concentric tube heat exchanger. Outlet of the annular side temperature gradually decreases at 120˚C. Heat absorbed by the cold water temperature is 62˚C.
Figure 5.58  Temperature variations of the exhaust gas and the water at 75% Load

Figure 5.59  Temperature variations of the exhaust gas and the water at 100% Load
The Figure 5.59 shows that at 100% of load connected to the engine, the mass flow rate of water is 0.01388 Kg/sec and Exhaust gas flow rate is 0.02629 Kg/sec. Exhaust gas temperature raises 390°C to 440°C at the time period of 30 minutes. Initially cold water enters inside the tube at 30°C. Hot and cold fluid exchanges the heat recover energy in the concentric tube heat exchanger. Outlet of the annular side temperature gradually decreases at 120°C. Heat absorbed by the cold water temperature is 68°C.

From the experimental results with different load condition on the temperature difference recorded and used to calculate the effectiveness and heat extraction rate. It is observed from the figures, that there is a high temperature drop in the exhaust gas that declines the temperature of the water. These exist, since the heat capacity of the water supersedes the heat capacity of the exhaust gas). The exit temperature in all four loads of the exhaust gas from heat recovery heat exchanger (HRHE) pursue the inlet temperature of the water that get equalized at the end of the test trails. These enhance the effectiveness of the Heat exchanger (porous tube) 78% at the end of the experiment trial in all the four loads. The WHR heat exchanger evaluated at different loads and calculated. Heat extraction rate (kW) can written as in Equation 5.2. From the porous tubes geometry, it is seen that the heat extraction rate with a different load condition, the maximum heat extraction rate for counter flow is 2.22 kW. It is found from the full load condition, that the maximum heat extracted is around 1.36 kW, which is high when compared to all other engine load conditions due to intense heat release rate from the engine at maximum load. The LMTD from Equation 5.4 and the overall heat coefficient of concentric tube heat exchanger calculated from Equation 5.5.
The Figure 5.60 shows that due to the increasing temperature of the water at the inlet of HRHE there is decrease in the average temperature difference between the exhaust gas and water. However, it is observed that, at 25% load, a reduction in heat extraction rate is very low which charges to chose further analysis on determining LMTD and the overall heat transfer coefficient of the heat exchanger at various load conditions. The uniform heat extraction rate with higher LMTD varies with respect to time at 25% load and illustrates that the overall heat transfer coefficient is increases with respect to time.

![Figure 5.60 Heat extraction rate and LMTD at 25% load](image)

The Figure 5.61 shows that due to the increasing temperature of the water at the inlet of HRHE that decreases the average temperature difference between the exhaust gas and water. However, it is observed that, at 50% load, a reduction in heat extraction rate is very low which charges to chose further analysis on determining LMTD and the overall heat transfer coefficient of the heat exchanger at various load conditions. The uniform heat extraction rate with higher LMTD varies with respect to time at 50% load and illustrates that the overall heat transfer coefficient is increases with respect to time.
Figure 5.61 Heat extraction rate and LMTD at 50% load

Figure 5.62 Heat extraction rate and LMTD at 75% load
The Figure 5.62 shows that due to the increasing temperature of the water at the inlet of HRHE there is decrease in the average temperature difference between the exhaust gas and water. However, it is observed that, at 75% load, a reduction in heat extraction rate is very low which charges to chose further analysis on determining LMTD and the overall heat transfer coefficient of the heat exchanger at various load conditions. The uniform heat extraction rate with higher LMTD varies with respect to time at 75% load and illustrates that the overall heat transfer coefficient is increases with respect to time.

![Figure 5.63 Heat extraction rate and LMTD at 100% load](image)

The Figure 5.63 shows that due to the increasing temperature of the water at the inlet of HRHE there is decrease in the average temperature difference between the exhaust gas and water. However, it is observed that, it is found from 100% load, a reduction in heat extraction rate is very low which charges to chose further analysis on determining LMTD and the overall heat transfer coefficient of the heat exchanger at various load conditions. The
uniform heat extraction rate with higher LMTD varies with respect to time at 100% load and illustrates that the overall heat transfer coefficient is increases with respect to time.

The Figure 5.64 shows the variation of heat extraction rate with time for 25%, 50%, 75%, and 100% load conditions. It shows that results obtained for 25% of load heat extraction rate is minimum and gradually increases with the other loads. Heat extractions rate varies from 0.87 to 2.22 kW.

![Graph of heat extraction rate from exhaust gas at different loads conditions](image)

**Figure 5.64 Heat extraction rate from exhaust gas at different loads conditions**

The Figure 5.65 shows the variation in overall heat transfer coefficient varies with respect to time at 25%, 50%, 75% and 100% conditions.
Initially 25% of load variation of overall heat transfer coefficient is 79 to 89 W/m²°C. At 50% of load variation of overall heat transfer coefficient is 90 to 99 W/m²°C. It is found from 75% of load variation of overall heat transfer coefficient is 101 to 108 W/m²°C and it is found from 100% of load variation of overall heat transfer coefficient 110 to 120 W/m²°C. It is found in the Figure 5.65 that the overall heat loss coefficient is maximum for 100% load due to higher mass flow rate and higher operating temperature. The lowest heat transfer coefficient is found for minimum load when compared to the other three loads.

5.5.2 Life Cycle Savings

Exhaust gas is recovered and stored in thermal energy storage system and savings related to life cycle is presented in this section. The percentage of energy saved varies from 6.3% to 11.2% as the load increases from 25% to full load. It is found from all lower loads; the energy percentile
saved is less, due to high specific fuel consumption (SFC) of 0.7135 kg/kW- hr. It is found from the full loads the percentage energy saved is more, due to the low specific fuel consumption (0.2582 kg/kW- hr). The total engine hours is (15 years * 365 days *24 hours is equal to 1, 31,400 hours) that excludes the planned maintenance hours, and other ineffective losses from the booked hours of the engine which is taken as 100000 engine hours, The whole life cycle of the engine and the experimental set-up will save 57320.4 kW-hr of electricity.

5.5.3 Temperature Distribution in a Porous Medium (aluminum) Tube heat Exchanger

The Figure 5.66 shows that at the 25% of load connected to the engine, the mass flow rate of water is 0.01388 Kg/sec and Exhaust gas flow rate is 0.02611 Kg/sec. Exhaust gas temperature raises from 300°C to 325°C at the time period of 30 minutes. Initially cold water enters inside the tube at 30°C. Hot and cold fluid exchanges the heat recover energy in the concentric tube heat exchanger. Outlet of the annular side temperature gradually decreases at 110°C. Heat absorbed by the cold water temperature is 58°C.

The Figure 5.67 shows that at 50% of load connected to the engine, the mass flow rate of water is 0.01388 Kg/sec and Exhaust gas flow rate is 0.02614 Kg/sec. Exhaust gas temperature raises from 330°C to 355°C at the time period of 30 minutes. Initially cold water enters inside the tube at 30°C. Hot and cold fluid exchanges the heat recover energy in the concentric tube heat exchanger. Outlet of the annular side temperature gradually decreases at 110°C. Heat absorbed by the cold water temperature is 64°C.
Figure 5.66  Temperature variations of the exhaust gas and the water at 25% Load

Figure 5.67  Temperature variations of the exhaust gas and the water at 50% Load
The Figure 5.68 shows that at 75% of load connected to the engine, the mass flow rate of water is 0.00833 Kg/sec and Exhaust gas flow rate is 0.02618 Kg/sec. Exhaust gas temperature raises from 360 °C to 385 °C at the time period of 30 minutes. Initially cold water enters inside the tube at 30°C. Hot and cold fluid exchanges the heat recover energy in the concentric tube heat exchanger. Outlet of the annular side temperature gradually decreases at 110°C. Heat absorbed by the cold water temperature is 70°C.

![Figure 5.68](image)

**Figure 5.68  Temperature variations of the exhaust gas and the water at 75% Load**

The Figure 5.69 shows that at 100% of load connected to the engine, the mass flow rate of water is 0.01388 Kg/sec and Exhaust gas flow rate is 0.02629 Kg/sec. Exhaust gas temperature raises from 390°C to 450°C at the time period of 30 minutes. Initially cold water enters inside the tube at 30°C. Hot and cold fluid exchanges the heat recover energy in the concentric tube heat exchanger. Outlet of the annular side temperature gradually decreases at 110°C. Heat absorbed by the cold water temperature is 77°C.
Figure 5.69 Temperature variations of the exhaust gas and the water at 100% Load

From the experimental results with different load condition on temperature the difference recorded and used to calculate the effectiveness and heat extraction rate. It is observed from the figures, that there is a high temperature drop in the exhaust gas that declines the temperature of the water. These exist, since the heat capacity of the water supersedes the heat capacity of the exhaust gas). The exit temperature in all four loads of the exhaust gas from heat recovery heat exchanger (HRHE) pursue the inlet temperature of the water that get equalized at the end of the test trails. These enhance the effectiveness of the Heat exchanger (porous tube) 81% at the end of the experiment trial in all the four loads.

The WHR heat exchanger is evaluated at different loads and calculated. From the porous tubes geometry, shows the heat extraction rate with a different load condition, the maximum heat extraction rate for porous is 2.71 kW. It is found from the full load condition, the maximum heat
extracted is around 2.71 kW, which is high when compared to all other engine load conditions due to intense heat release rate from the engine at maximum load.

The Figure 5.70 shows that due to the increases temperature of the water at the inlet of HRHE there is decrease in the average temperature difference between the exhaust gas and water. However, it is observed that, at 25% load, a reduction in heat extraction rate is very low which charges to chose further analysis on determining LMTD and the overall heat transfer coefficient of the heat exchanger at various load conditions. The uniform heat extraction rate with higher LMTD varies with respect to time at 25% load and illustrates that the overall heat transfer coefficient is increases with respect to time.

Figure 5.70 Heat extraction rate and LMTD at 25% load
The Figure 5.71 shows that due to the increasing temperature of the water at the inlet of HRHE there is decrease in the average temperature difference between the exhaust gas and water. However, it is observed that, at 50% load, a reduction in heat extraction rate is very low which charges to chose further analysis on determining LMTD and the overall heat transfer coefficient of the heat exchanger at various load conditions. The uniform heat extraction rate with higher LMTD varies with respect to time at 50% load and illustrates that the overall heat transfer coefficient is increases with respect to time.

Figure 5.71 Heat extraction rate and LMTD at 50% load

The Figure 5.72 shows that due to the increasing temperature of the water at the inlet of HRHE there is decreases in the average temperature difference between the exhaust gas and water. However, it is observed that, at 75% load, a reduction in heat extraction rate is very low which charges to chose further analysis on determining LMTD and the overall heat transfer coefficient of the heat exchanger at various load conditions. The uniform heat
extraction rate with higher LMTD varies with respect to time at 75% load illustrate that the overall heat transfer coefficient is increases with respect to time.

![Graph showing heat extraction rate and LMTD at 75% load](image)

**Figure 5.72 Heat extraction rate and LMTD at 75% load**

The Figure 5.73 shows that due to the increasing temperature of the water at the inlet of HRHE that decreases the average temperature difference between the exhaust gas and water. The trends in the LMTD variation shows the vibration of mechanical loading arrangements and utilize to compute the heat extraction rate. However, it is observed that, at 100% load, the reduction in heat extraction rate is very low which charges to chose further analysis on determining LMTD and the overall heat transfer coefficient of the heat exchanger at various load conditions. The uniform heat extraction rate with higher LMTD varies with respect to time at 100% load and illustrates that the overall heat transfer coefficient is increases with respect to time.
Figure 5.73 Heat extraction rate and LMTD at 100% load

Figure 5.74 Heat extraction rate from exhaust gas at different loads conditions
The Figure 5.74 shows the variation of heat extraction rate with time for 25%, 50%, 75%, and 100% load conditions. The results obtained for 25% of load heat extraction rate is minimum and gradually increased the other loads. Heat extractions rate various from 1.28 to 2.71kW.

The Figure 5.75 shows the variation in overall heat transfer coefficient varies with respect to time at 25%, 50%, 75% and 100% condition.

![Graph showing variation in overall heat transfer coefficient with time](image)

**Figure 5.75 Variation of overall heat transfer coefficient of the HRHE at various loads**

Initially 25% of load variation of overall heat transfer coefficient is 94 to 105 W/m²°C, At 50% of load variation of overall heat transfer coefficient is 103 to 112 W/m²°C, At 75% of load variation of overall heat transfer coefficient is 121 to 129 W/m²°C and it is found from 100% of load variation of overall heat transfer coefficient is 131 to 143 W/m²°C. It is found in the Figure 5.75 the overall heat loss co-efficient is maximum for 100% load due to higher mass flow rate and higher operating temperature. The lowest
heat transfer co-efficient is found for minimum load when compared to the other three loads.

![Figure 5.76 Comparison of heat extraction rate with and without porous material at all full Loads](image)

### 5.5.4 Heat Extraction Rate From the Engine Exhaust Gas at Full Load Conditions

The two different porous material (copper & aluminum) inner tube geometry and the effective thermal conductivity can be improved the thermal performance and the heat extraction rate compare with the helical finned tube, porosity and effective thermal conductivity of the two different materials can be calculated as

\[
e_v = \frac{V_{Bed} - V_{packing}}{V_{Bed}} \quad (5.9)
\]

\[
K_{eff} = e_v \, K_{fluid} + (1 - e_v) \, K_{solid} \quad (5.10)
\]
Where $\varepsilon_v$, porosity of the copper and aluminum, $V_{Bed}$ - volume of the porous bed and $V_{packing}$ - volume of porous packing material. $K_{eff}$ - Effective thermal conductivity. Full load condition heat extraction rate shows with and without porous material.

**Figure 5.77 Wilson plot chart for porous (copper) tube**

The Figure 5.77 shows illustrate the Wilson plot chart for porous tube the varying the mass flow rate with different load condition. The correlation to compute overall heat loss co-efficient for outer surface was developed for different mass flow rates as $y = 180.9X - 0.005$ with $R^2$ value of 0.997.
Figure 5.78 Wilson plot chart for porous (Aluminium) tube

The Figure 5.78 shows illustrate the Wilson plot chart for porous tube the varying the mass flow rate with different load condition. The correlation to compute overall heat loss co-efficient for outer surface was developed for different mass flow rates as $y = 187.5X - 0.007$ with $R^2$ value of 0.977.

5.5.4 Life Cycle Savings

Exhaust gas is recovered and stored in thermal energy storage system and savings related to life cycle is presented in this section. The percentage of energy saved varies from 9% to 13.7% as the load increases from 25% to full load. It is found from all lower loads; the energy percentile saved is less, due to high specific fuel consumption (SFC) of 0.7135 kg/kW-hr. It is found from the full loads the percentage energy saved is more, due to the low specific fuel consumption (0.2582 kg/kW·hr). The total engine hours is (15 years * 365 days * 24 hours is equal to 1,31,400 hours) that excludes the planned maintenance hours, and other ineffective losses from the booked hours of the engine which is taken as 100000 engine hours. The whole life
cycle of the engine and the experimental set-up will save 69972.2 kW-hr of electricity.

5.6 WAVY TUBE AS INNER GEOMETRY

The variation of diesel engine flue gas temperature and the cold water inlet and out temperature, heat recover in the concentric plain tube heat exchangers with respect to time for a range of engine load conditions (25%, 50%, 75% and full load condition) are shown in Figures (5.79 to 5.82 is a wavy tube)

In the diesel engine, exhaust gas temperature will attain steady state within duration of 5 minutes at a given load. However, it is observed the engine exhaust temperature at all loads of the flue gas at the inlet attain a steady state after 30 minutes time interval. It is as a result of the thermal inertia of the diesel engine exhaust gas pipe to insulate from manifold to the HRCPHE. The higher heat release from the engine increases engine load that subsequently increases the exhaust gas temperature. It was observed from all loads the temperature difference of water and gas, increases in the beginning with decrease in the slope once the temperature of the water attains approximately 50°C, and with further increases in temperature to attain higher heat rate.

It is found from 25% load a near constant temperature around 50°C is observed for a longer duration and this duration decrease with increase in load.

5.6.1 Temperature Distribution in a Wavy Tube Heat Exchanger

The Figure 5.79 shows that when 25% of load is connected to the engine, the mass flow rate of water is 0.02777 Kg/sec and Exhaust gas flow
rate is 0.02611 Kg/sec. Exhaust gas temperature raises from 290°C to 315°C at the time period of 30 minutes. Initially cold water enters inside the tube at 28°C. Hot and cold fluid exchanges the heat recover energy in the concentric tube heat exchanger. Outlet of the annular side temperature gradually decreases at 110°C. The heat absorbed by the cold water temperature is 46°C.

Figure 5.79  Temperature variations of the exhaust gas and the water at 25% Load

The Figure 5.80 shows that when 50% of load is connected to the engine, the mass flow rate of water is 0.02777 Kg/sec and Exhaust gas flow rate is 0.02614 Kg/sec. Exhaust gas temperature raises from 300°C to 355°C at the time period of 30 minutes. Initially cold water enters inside the tube at 28°C. Hot and cold fluid exchanges the heat recover energy in the concentric tube heat exchanger. Outlet of the annular side temperature gradually decreases at 110°C. Heat absorbed by the cold water temperature is 52°C.
Figure 5.80  Temperature variations of the exhaust gas and the water at 50% Load

Figure 5.81  Temperature variations of the exhaust gas and the water at 75% Load
The Figure 5.81 shows that when 75% of load is connected to the engine, the mass flow rate of water is 0.02777 Kg/sec and Exhaust gas flow rate is 0.02618 Kg/sec. Exhaust gas temperature raises from 360°C to 385°C at the time period of 30 minutes. Initially cold water enters inside the tube at 28°C. Hot and cold fluid exchanges the heat recover energy in the concentric tube heat exchanger. Outlet of the annular side temperature gradually decreases at 110°C. Heat absorbed by the cold water temperature is 58°C.

The Figure 5.82 shows that when 100% of load is connected to the engine, the mass flow rate of water is 0.02777 Kg/sec and Exhaust gas flow rate is 0.02629 Kg/sec. Exhaust gas temperature raises from 390°C to 450°C at the time period of 30 minutes. Initially cold water enters inside the tube at 28°C. Hot and cold fluid exchanges the heat recover energy in the concentric tube heat exchanger. Outlet of the annular side temperature gradually decreases at 110°C. Heat absorbed by the cold water temperature is 65°C.

![Figure 5.82 Temperature variations of the exhaust gas and the water at 100% Load](image)
From the experimental results with different load condition on temperature the difference is recorded and used to calculate the effectiveness and heat extraction rate. It is observed from the figures, that there is a high temperature drop in the exhaust gas that declines the temperature of the water. These exist, since the heat capacity of the water supersedes the heat capacity of the exhaust gas. The exit temperature in all four loads of the exhaust gas from heat recovery heat exchanger (HRHE) pursue the inlet temperature of the water that get equalized at the end of the test trails. These enhance the effectiveness of the Heat exchanger (porous tube) 81% at the end of the experiment trial in all the four loads.

The WHR heat exchanger evaluated at different loads and calculated. From the porous tubes geometry, shows the heat extraction rate with a different load condition, the maximum heat extraction rate for porous is 2.71 kW. It is found from the full load condition, the maximum heat extracted is 2.71 kW (27.93% of the exhaust gas heat), which is high when made compared with all other engine load conditions due to intense heat release rate from the engine at maximum load. The figure 5.83 shows due to the increasing temperature of the water at the inlet of HRHE that decreases the average temperature difference between the exhaust gas and water. However, it is observed that, it is found from 25% load, a reduction in heat extraction rate is very low which charges to chose further analysis on determining LMTD and the overall heat transfer coefficient of the heat exchanger at various load conditions. The uniform heat extraction rate with higher LMTD varies with respect to time at 25% load and illustrates that the overall heat transfer coefficient is increases with respect to time.
The Figure 5.84 shows that due to the increasing temperature of the water at the inlet of HRHE there is decrease in the average temperature difference between the exhaust gas and water.

Figure 5.83 Heat extraction rate and LMTD at 25% load

Figure 5.84 Heat extraction rate and LMTD at 50% load
However, it is observed that, it is found from 50% load, a reduction in heat extraction rate is very low which charges to chose further analysis on determining LMTD and the overall heat transfer coefficient of the heat exchanger at various load conditions. The uniform heat extraction rate with higher LMTD varies with respect to time at 50% load and illustrates that the overall heat transfer coefficient is increases with respect to time.

The Figure 5.85 shows that due to the increasing temperature of the water at the inlet of HRHE there is decrease in the average temperature difference between the exhaust gas and water. However, it is observed that, At 75% load, the reduction in heat extraction rate is very low which charges to chose further analysis on determining LMTD and the overall heat transfer coefficient of the heat exchanger at various load conditions. The uniform heat extraction rate with higher LMTD varies with respect to time at 75% load and illustrates that the overall heat transfer coefficient is increases with respect to time.

![Figure 5.85 Heat extraction rate and LMTD at 75% load](image)
The Figure 5.86 shows that due to the increasing temperature of the water at the inlet of HRHE there is decrease in the average temperature difference between the exhaust gas and water.

![Figure 5.86 Heat extraction rate and LMTD at 100% load](image)

**Figure 5.86 Heat extraction rate and LMTD at 100% load**

However, it is observed that, at 100% load, a reduction in heat extraction rate is very low which charges to chose further analysis on determining LMTD and the overall heat transfer coefficient of the heat exchanger at various load conditions. The uniform heat extraction rate with higher LMTD varies with respect to time at 100% load and illustrates that the overall heat transfer coefficient is increases with respect to time.

The Figure 5.87 shows the variation of heat extraction rate with time for 25%, 50%, 75%, and 100% load conditions. The results obtained for 25 % of load heat extraction rate is minimum which gradually increased with the other loads. Heat extractions rate varies from 1.52kW to 4.27kW.
Figure 5.87  Heat extraction rate from exhaust gas at different loads conditions

The Figure 5.88 shows the variation in overall heat transfer coefficient varies with respect to time at 25%, 50%, 75% and 100% condition. Initially 25% of load variation of overall heat transfer coefficient is 32 to 37 W/m²°C, It is found from 50 % of load variation of overall heat transfer coefficient is 38 to 42 W/m²°C, It is found from 75% of load variation of overall heat transfer coefficient is 43 to 47 W/m²°C and it is found from 100% of load variation of overall heat transfer coefficient is 48 to 53 W/m²°C. It is found in the Figure 5.88 the overall heat loss co-efficient is maximum for 100%load due to higher mass flow rate and higher operating temperature. The lowest heat transfer co-efficient is found for minimum load when compared to other three loads.

The Figure 5.89 shows illustrate the Wilson plot chart for wavy tube the varying the mass flow rate with different load condition. The correlation to compute overall heat loss co-efficient for outer surface was developed for different mass flow rates as $y = 326.3X - 0.010$ with $R^2$ value of 0.996.
Figure 5.88 Variation of overall heat transfer coefficient of the HRHE at various loads

Figure 5.89 Wilson plot chart for Wavy tube
5.6.2 Life Cycle Savings

Exhaust gas is recovered and stored in thermal energy storage system and savings related to life cycle is presented in this section. The percentage of energy saved varies from 11% to 22% as the load increases from 25% to full load. It is found from all lower loads; the energy percentile saved is less, due to high specific fuel consumption (SFC) of 0.7135 kg/kW-hr. It is found from the full loads the percentage energy saved is more, due to the low specific fuel consumption (0.2582 kg/kW-hr). The total engine hours is (15 years * 365 days * 24 hours is equal to 1, 31,400 hours) that excludes the planned maintenance hours, and other ineffective losses from the booked hours of the engine which is taken as 100000 engine hours. The whole life cycle of the engine and the experimental set-up will save 110251.4 kW-hr of electricity. From the table 5.1 shows the comparison between the different inner tube geometries experimental works. From these results shows the maximum percentage of energy saved in wavy tube geometry.

Table 5.1 Comparison between different inner tube geometries experimental works

<table>
<thead>
<tr>
<th>Different Tube geometry</th>
<th>Cold Water (Liter/Hr)</th>
<th>Heat Extraction Rate (KW)</th>
<th>Overall Heat Transfer Coefficient (U,W/mK)</th>
<th>Effectiveness (ε) %</th>
<th>% of exhaust gas energy saved ($E_s$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>plain tube</td>
<td>30</td>
<td>0.93</td>
<td>260</td>
<td>76</td>
<td>1-5</td>
</tr>
<tr>
<td>Helical Finned Tube</td>
<td>30</td>
<td>1.61</td>
<td>213</td>
<td>80</td>
<td>7-8</td>
</tr>
<tr>
<td>Porous tube inserts cast iron</td>
<td>50</td>
<td>1.67</td>
<td>116</td>
<td>76</td>
<td>6-8</td>
</tr>
<tr>
<td>Porous tube inserts mild steel</td>
<td>50</td>
<td>1.97</td>
<td>104</td>
<td>77</td>
<td>8-10</td>
</tr>
<tr>
<td>Porous tube inserts copper</td>
<td>50</td>
<td>2.22</td>
<td>125</td>
<td>78</td>
<td>6-11</td>
</tr>
<tr>
<td>Porous tube inserts aluminum</td>
<td>50</td>
<td>2.71</td>
<td>143</td>
<td>81</td>
<td>9-14</td>
</tr>
<tr>
<td>wavy tube</td>
<td>100</td>
<td>4.27</td>
<td>53</td>
<td>81</td>
<td>11-22</td>
</tr>
</tbody>
</table>
5.7 NUSSLELT NUMBER CORRELATION

In order to validate the experimental apparatus and testing methods, tests were performed on a plain concentric tube, with smooth inner and annular surfaces. The Figure 5.90 shows the relationship of X and Y for the validation test. The regression result of the plain tube yields $C_i = 0.0228$ which can be rounded up very close to the well-know constant 0.023 of the Dittus-Boelter correlation.

![Figure 5.90 Wilson Plot analyses for plain straight tube (Tiruselvam Ramah lingam & Vijay Raghavan 2011)](image)

The author has chosen Re exponent of 0.8 for validation purpose as such value is used extensively by previous studies, as in Shah (1990). Note that the exponent 0.8 is not necessary a constant 0.8. As addressed by shah (1990), the Re exponent it is a function of the Prantl number and Reynolds number. It varies from 0.59 at $Pr = 2.92$ to 4.24 at $Pr = 100$ for $Re = 50,000$ for circular tube. Based on the results developed Nusselt number and fanning friction correlation developed plain and wavy tube geometries.
The author has adapted an approach where the Re exponent of the Nusselt correlation is plus 1 of the Re exponent of the Fanning friction factor. The relevant data extracted from a Test is given as: Plain tube, turbulent, $Re > 2300$:

$$f = 1.07891 Re^{-0.41} \quad (5.11)$$

Wavy tube, turbulent, $Re > 8500$:

$$f = 2.2826 Re^{-0.41} \quad (5.12)$$

Based on the $Re$ exponents from the fanning friction factor correlations, the Wilson plot test was conducted and the data analyzed for the plain and wavy inner tube. The corresponding Wilson plots are shown in Figure 5.91 and 5.92.

Figure 5.91 Wilson plot analysis for plain tube, $Re^{59}$
The relationship between $1/U_o$ and $1/Re$ is statistically significant ($p < 0.05$). The relationship is positive with a correlation coefficient ($r$) of 0.99. 98.44% of the variation in $1/U_o$ can be accounted for by the regression model. The fitted equation for the linear model is:

$$Y = 0.002481 + 1.881 \times X$$

The positive correlation ($r = 0.99$) indicates that when $1/Re$ increases, $1/U_o$ also tends to increase.

Figure 5.92 Wilson plot analysis for wavy tube, Re$^{59}$

Figure 5.93 Compare the Wilson plot analysis for wavy tube using Minitab
From the experimental data compared with the Minitab statistical tool. The figure 5.93 shows that illustrates the Minitab for wavy tube the varying the mass flow rate with different load condition. The correlation to compute overall heat loss co-efficient for outer surface was developed for different mass flow rates as $y = 1.881X + 0.002481$ with $R^2$ value of 0.982. Corresponding to the turbulent flow region of the individual test section, the side Nusselt numbers for heat transfer can be written as: plain tube, turbulent $\text{Re}>2300$:

$$Nu = 0.355\text{Re}^{0.59}\text{Pr}^{1/3}$$ (5.13)

Wavy tube, turbulent, $\text{Re}>8500$:

$$Nu = 0.585\text{Re}^{0.59}\text{Pr}^{1/3}$$ (5.14)

Convective heat transfer and pressure drop characteristic for two types of enhanced concentric tubes are reported. Experiments were conducted in a concentric tube heat exchanger with hot flue gas as test fluid in annulus and water as the tube side fluid. The two annulus investigated was plain and wavy enhanced tube. The heat transfer coefficients of the inner tube side of the concentric tube test section were obtained using the standard Wilson plot technique. The Wilson plot test was conducted for turbulent flow region. An initial test was conducted for plain annulus to validate the testing method and procedure using $\text{Re}$ exponent value of 0.8. After achieving the experimental validation, the test was conducted on the plain and wavy annulus using $\text{Re}$ exponent from the fanning friction factor correlation. The Nusselt heat transfer correlation, Equation (5.13 & 5.14), obtained in this study for the tube side is used for future study.
5.8 SUMMARY

Research attempts were made to recover the maximum possible exhaust heat energy through a concentric tube heat exchanger with different inner tube geometries having plain tube, helical finned tube, porous materials on inner tube and way tube. The experimental investigation of waste heat recovery with different inner tubes for the twin cylinder diesel engine operated at various load conditions were studied in detail and was presented in this chapter. The next chapter will discuss the conclusion of this research work.