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An Experimental Examination into the Efficiency of a Shell-and-Tube Heat Exchanger for an EGR Cooler

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Abstract: - The increasing concerns over environmental pollution and stringent regulations on emission have led to the widespread adoption of exhaust gas recirculation (EGR) systems in interna combustion engines. EGR systems help reduce nitrogen oxide (NOx) emissions by recirculating a portion of exhaust gaes back into the combustion chamber. However, the elevated temperature of exhaust gases poses challenges related to thermal management, necessitating the use of exhaust gas recirculation cooler. The experimental setup allows for the controlled circulation of exhaust gases and cooling fluids, thereby facilitating the measurement of heat transfer rates, pressure drops and overall thermal efficiency. These parameters encompass the inlet and outlet temperatures of both the exhaust gases and the cooling fluids flow rates for both fluids resulting pressure drops. By systematically altering these factors, the intricate, interplay between the various parameters and their inputs on the heat exchangers thermal performances are comprehensively explored. Addition, the research develops into critical aspects often overshadowed in EGR cooler studies on fouling. Overtime, the accumulation of deposits in the heat exchanger surface can led to reduced heat transfer efficiency. The outcomes of this study are instrumental for the advancement of EGR cooler technologies fostering more sustainable and environmentally friendly and automotive engines.

Keywords*: Cooling fluids, Heat exchanger, Transfer efficiency, Thermal efficiency*.

1. Introduction

Enormous advancements have been made in automobile technology over the past century and in current times, the dependence on automobiles as a means of transportation makes them indispensable. The primary concerns in this connection are the emission of harmful exhaust gases resulting in environment pollution and health hazards. The function of the diffuser is to distribute the flow into the tubes and collect cooled gases from output. For better heat transfer prolong shell and tube with counter flow is preferred. The EGR cooler consist of bundles of tubes for airflow and surrounded by big tube for coolant flows.

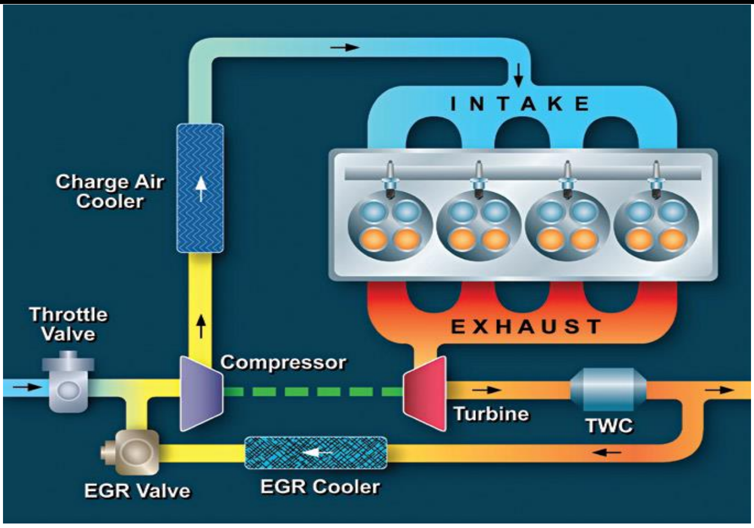

Fig 1.1 Pictorial representation showing the EGR system

Fig 1.1 EGR System is specifically engineered to minimize the generation of NOx emissions by the engine under conditions where high combustion temperatures, typically exceeding around 2500°C, are common. This system achieves NOx reduction by introducing a small portion of exhaust gases back into the intake manifold. There, these gases blend with the incoming Air/Fuel mixture. Through this blending, the concentration of the Air/Fuel mixture is reduced, subsequently lowering both peak temperature and pressure. This concerted effect leads to an overall decrease in the production of NOx emissions.

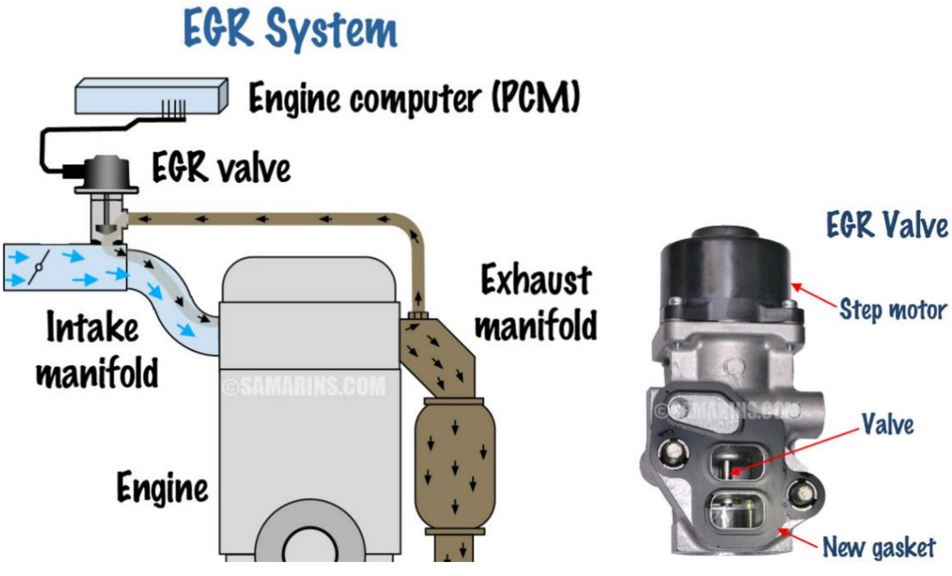

Fig 1.2 EGR valve pictorial view with its system components

The exhaust gases primarily comprise elements like carbon dioxide and nitrogen, forming a mixture with a higher specific heat compared to atmospheric air. When recirculate exhaust gas is introduced, it displaces the fresh air that enters the combustion chamber, carrying with it carbon dioxide and water vapor from the engine exhaust. This displacement leads to a decreased availability of oxygen in the incoming mixture, subsequently lowering the effective air-fuel ratio. This alteration in the air-fuel ratio has a significant impact on exhaust emissions. **Fig 1.2** gives the EGR valve's pictorial view with its system components. The EGR valve delivers a controlled reduction of oxygen content to the combustions process by introducing inert exhausted gases in to the air-fuel charge to the cylinders @ the intake manifold causing a slower explosion in the cylinders and lower combustion temperature and pressure. Since harmful NOx are mainly produced at high temperatures this allows for a reduced quantity of NO_x concentrates emitted to the environment. The quantity of the exhausted gases that are being returned into the intake manifold is only about 5 to 10% of the total, but it is enough to dilute the air-fuel mixture to have a cooling effect on engine combustion temperature. Because the engines are idling the EGR valve is closed and there is no exhaust gas return flow in to the in-take manifold, The EGR valve remains closed until the engines are warm and operating under load. A significant challenge confronts those seeking to employ a heat exchanger, as elaborated below. The core of this challenge lies in comprehensively defining the issue that needs to be addressed, a task necessitating a grasp of the thermodynamic and transport properties of fluids. This knowledge can then be integrated with straightforward calculations to precisely outline a particular heat-transfer problem and appropriately select a suitable heat exchanger. The applications of heat exchangers span a broad spectrum, encompassing space heating, refrigeration, air-conditioning, power generation, chemical and petrochemical industries, petroleum refinery, processing of natural gas and sewage treatment. The pursuit of enhancing the efficiency of internal combustion engines has persisted since the inception of this dependable workhorse within the automotive realm. Contemporary efforts are been actually concentrated on achieving this objective by curbing energy losses to the coolant during the power stroke of the cycle. Promoting the utilization of efficient diesel engines holds promise for the future, as they exhibit reduced fuel consumption and a notable decrease in potent greenhouse gases, such as carbon dioxide.

1.1 Exhausted gases re-circulations

EGR serves as an effective technique for curtailing NO_x production. The exhaust primarily comprises CO_2, N_2, and water vapor. When a portion of this exhausted gases are reintroduced to the combustion's cylinder, it functions as a diluent, subsequently lowering the O_2 concentration inside the combustion's chambers. In the diesel engine, exhaust gas recirculation is extensively employed to diminish NO_x formation. This process involves introducing exhaust gas into the engine along with fresh inlet air. The introducing of diluents in to the in-take mixtures that leads to the reducing of the peak combustion temperature and subsequently limits the generating of the NO_x. Furthermore, the heightened heat capacity of the intake mixture also impacts the internal temperature, consequently affecting the process of NO_x formations. The higher level of exhaust smoke concentration measured for inert dilution with re-circulated exhaust gas, in comparison to pure gases (Nitrogen and carbon dioxide), is due to the condition that the smoke or soot in the re-circulated exhausted gases that are fed back into the in-take manifolds, since no soot filtration is made on the re-circulated exhaust gas.

2. Literature Review

This study aims for examining the influence of the exhaust gas recirculation system on diesel engines, along with the effect of cooling the recirculate exhaust gas. Additionally, the research delves into the design aspects of a heat exchanger. As emission standards grow more stringent, manufacturers are compelled to develop cleaner diesel engines. Therefore, effectively reducing NO_x emissions in exhaust necessitates the control of peak combustion temperatures.

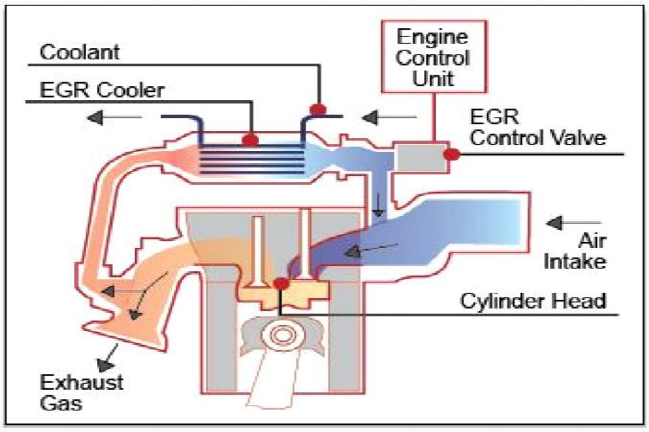

Fig 1.3 Line diagram of EGR System

Presently, automobile manufacturers face the challenge of reducing nitrogen oxide (NO_x) levels by more than 50% of the current standards for complying with the with EURO-6 and BS-4 regulations, all while maintaining the prevailing particulate matters (PM) levels. **Fig 1.3** gives the system block-diagram of the EGR system with all the details about the various sub-systems. The higher level of exhaust smoke concentration measured for inert dilution with re-circulated exhaust gas, in comparison to pure gases (Nitrogen and carbon dioxide), is due to the condition that the smoke or soot in the re-circulated exhausted gases that are fed back into the in-take manifolds, since no soot filtration is made on the re-circulated exhaust gas. The current studies are focusing on the combined effect of extended expansion cycle and internal exhausted gases re-circulations on the Turbocharged Low heat rejection engines. Therefore, for reducing the NO_x emission the peak temperature of engine cylinder must be lowered. Therefore, for reducing the NO_x emission the peak temperature of engine cylinder must be lowered. **Fig 1.4** gives the graphical representation of the reduction in pollutants and temperatures w.r.t. the exhaust emissions.

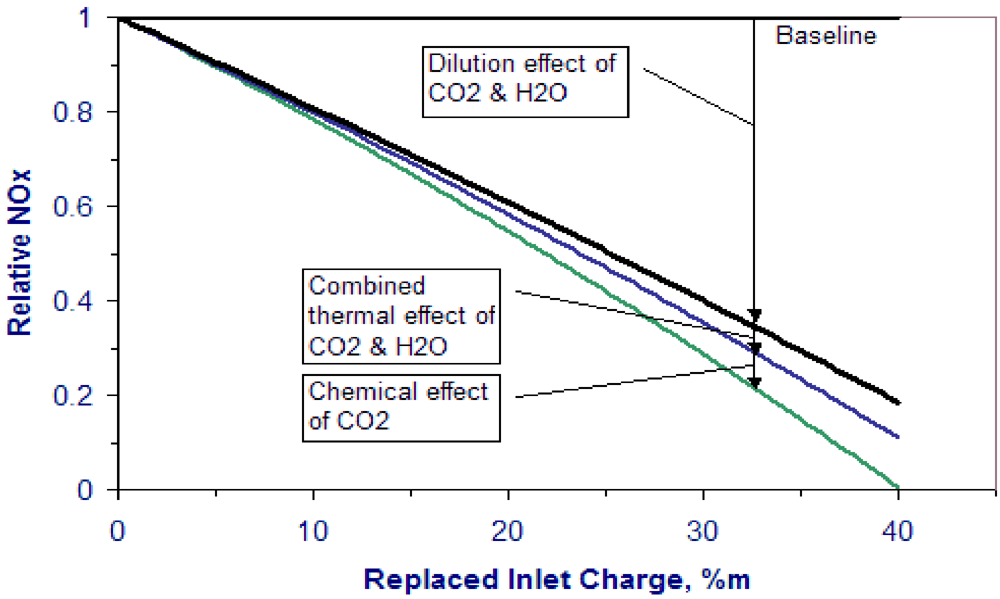

Fig 1.4 Graph of Reduction in Pollutants and temperatures w.r.t. the exhaust emission

1D simulation of a turbo-charged diesel type of engine's was conducted, comparing short and long Exhaust Gas Recirculation (EGR) route configurations. The research involved a comprehensive analyses w.r.t. the unsteady flows within the intake and exhaust systems of the current four-cylinder, turbocharged Diesel engine, employing various EGR circuits. A detailed comparison was drawn between high-pressure and low-pressure EGR systems. Computational Fluids Dynamic (CFD) technique for evaluating the effectiveness of an intake system design for homogeneous mixing of EGR with freshened air/O_2 inside the cooled chamber systems, i.e., inlet-manifold and duct. As a part of his study, five different novel concepts for EGR & the air mixing was analyzed computationally to meet the above requirement. From the five different concepts the optimized inlet manifold with larger injection area and half bluff body concept has given increase in the air and EGR mixing rate computationally. Focusing on addressing emissions from commercial vehicles by implementing well-suited designs for after-treatment devices. They employed a Diesel Oxidation Catalyst (DOC) to target reductions in hydrocarbons (HC), carbon monoxide (CO), and partial particulate matter (PM). Additionally, they utilized Cooled-Exhaust Gas Recirculation (C-EGR) systems to address nitrogen oxides (NOx) reduction for a cost-effective solution. Examining on the impact of Exhaust Gas Recirculation (EGR) on exhaust gas temperatures and opacity. They conducted a series of experiments, employing various quantities of EGR to observe their influence on exhaust gas temperatures and opacity levels. The experimental investigation aimed at comparing high and low-pressure Exhaust Gas Recirculation (HP and LP EGR) systems implemented in an automotive turbocharged diesel engine. The primary focus was to analyze their impact on fuel consumption, pollutant emissions, and the combustion process. Both experimental and numerical studies on the flow and heat transfer characteristics within a shell and tube EGR helical baffled cooler utilizing spirally corrugated tubes (HBCSCTs). An experimental setup was devised to examine how tube and baffle shapes influence heat transfer and pressure drop in both the tube side and shell side. Considering the work done by the authors, the paths and limits to reduce NO_X emissions from Diesel engines are briefly reviewed, and the inevitable uses of EGR are highlighted. This work provides a simulative comparison of different EGR systems, such as long-route EGR, short-route EGR, hybrid EGR, a system with a reed valve and a system with an EGR pump. Both the steady-state performance and transient performance are compared. Comprehensive effect of baffle configuration on the performance of STHE with helical baffles was studied. A small helix angle lead to lower pressure but less helical baffles can be arranged in the heat exchanger, which results in a high heat transfer rate. Utilization of the High-temperature Exhausted Gases Re-circulation (HOT EGR) technique to mitigate NO_x based emission in the comparative study with diesel combustion. The research encompassed the measurement and subsequent comparison of emissions. Key engine parameters, including brake's thermal efficiencies, brake-specific energies consumption powers, and combustion dynamics such as cylinder pressure, rate of heat release, pressure rise rate, and combustion duration, were meticulously assessed across various operational stages..

2.2 Identify goals based on prior research

The stringent conditions on emission in latest Euro norms lead to the introduction of a cooler in the EGR system that decreases the gases temperature previously to their recirculation. By means of the diminution of the inlet temperature, EGR-cooler strengthens the effects of the NO_x emission reduction caused by recirculation. Diesel engine exhausts containing toxic gases, mainly nitrogen-based oxide (NO_x) and soot particles. One effective method to decrease nitrogen oxide emissions from a diesel engine involves the implementation of exhaust gas recirculation. For achieving the effective EGR system, optimization of its components is must. EGR cooler being is the prime component in the system, optimizing this will lead to effective EGR System. Hence, current work is concentrated on design and optimization of EGR cooler and to carry out performance analysis of designed component for various parameters.

3. Methodology

The overall experimentation processes & their experimental results using hardware set-ups developed in the laboratory. The observation table & calculation procedures with the experimental results & discussions for Case – I/II/III with varying rate of mass flow of exhaust' gases in EGR without baffles is presented with the results, after which the final conclusions on the experimentation process and their results are drawn.

3.1 Materials and process

To start with, the material procurement, material selection process for conducting the experiments, such as the Shell & Baffle Plates, Tubes, Pipes, Flanges, Flow control valves, Fabrication process involved, Markings, Types of tools, Shearing, Cutting, Welding, Grinding, Filing, Drilling, Orifice Plates is presented. The overall block-diagram of the overall experimentation process along with the specifications for the conduction of every experiment & the experimental procedures is given next. Also, the designing of EGR Coolers & the experimental set-ups for petrol & diesel engines is presented along with their procedural aspects for different trails.

3.1.1 Shell & Baffle Plates

Stainless type of Steel was chosen for the fabrication of Shell and Baffle plate, as it has proven to become a particularly reliable and durable material for this application. For the fabrication of Shell and Baffle plate we selected Stainless Steel because, steel made of stainless was proven to be a particularly reliable and durable material here. Heat Exchangers which are fabricated using steel made of stainless types are particularly resistance to corrosion and deposits of limestone and other residues are minimized. The parameters are selected as shown in the **Table 3.1.**

Table 1.1 Parameter of EGR cooler-1

No.	Specification	Symbols	Dimensions
1	Outer diameters of tubes	d_o	6 mm
2	Inner diameters of tubes	d_i	5 mm
3	Lengths of tubes	L	220 mm
4	Number of passes	N_p	1
5	Inlet Temp of exhaust gas	T_{hi}	480 ℃
6	Outlet Temp of exhaust gas	T_{ho}	58 ℃
7	Inlet Temp of cold water	T_{ci}	31 ℃
8	Mass flow of rate exhaust gas	m_h	$7.302 \times 10^{-3}\ kg/sec$

9	Mass flowing rate of cold water	m_c	0.067 kg/sec
10	Specific heats of exhaust gas	Cp_h	1005 $J/kg-k$
11	Specific heats of cold water	Cp_c	4187 $J/kg-k$
12	Thermal conductivity of copper	k_w	380 $W/m-k$

3.1.2 Tubes

Copper has been chosen as the material for crafting the selected tubes, and this selection is based on a suite of advantageous attributes that make it exceptionally suitable for thermal efficiency & enduring heat exchanging units. Primarily, copper stands out due to its exceptional heat conductivity, enabling rapid heat transmission through the material. Beyond this, copper boasts an array of properties that render it ideal for heat exchangers. These include its resistance to corrosion and bio-fouling, as well as its capacity to withstand significant allowable stresses & inside pressure. Additionally, copper exhibits remarkable attributes like creep rupturing strengths; fatigue strengths, hardness; thermal expansions, and specific heat, all of which collectively contribute to its efficacy in heat exchanging units applications

Table 1.2 Parameters considered for designing of EGR Cooler - 2

No	Specification	Symbols	Dimensions
1	Outer diameter of tube	d_o	8 mm
2	Inner diameter of tube	d_i	7 mm
3	Length of tube	L	220 mm
4	Number of passes	N_p	1
5	Inlet Temp of exhaust gas	T_{hi}	480 ℃
6	Outlet Temp of exhaust gas	T_{ho}	58 ℃
7	Inlet Temp of cold water	T_{ci}	31 ℃
8	Mass flow of rate exhaust gas	m_h	$7.302 \times 10^{-3}\ kg/sec$
9	Mass flow rate of cold water	m_c	0.067 kg/sec
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3.2 Manufacturing procedure

The experimental processes was conducted in the M.S. Ramaiah Institute of Technology's Mechanical Engineering Laboratory & the results were observed and presented in the below mentioned sections.

3.2.1 Marking process

Marking out, also known as layout, involves the initial phase of transferring a design or pattern onto a work-piece in the manufacturing process. This process entails transferring dimensions from a blueprint to the work-piece, preparing it for the subsequent steps of machining or manufacturing. **Fig. 1.5** gives the marking and punching on the material that is done using a punching tool in the workshop of the department.

3.2.2 Shearing

Shearing, referred to as die cutting as well, is a technique that severs material without generating chips or resorting to burning or melting. Specifically, when the cutting blades are linear, the process is labeled as shearing, whereas if the blades take on a curved form, they fall under shearing-type operations. While metals and plates are the most frequent materials subjected to shearing, rods can also undergo this process. Shearing-type operations encompass activities like blanking, piercing, roll slitting, and trimming. This method finds utility in metalworking and extends its application to sectors involving paper and plastics. The material is subjected to the cutting process in the lab after marking process is over, after which it is subjected to the shearing process as shown in the **Fig. 1.6.**

3.2.2 Cutting process

Cutting is done by sawing, shearing or chiseling and via numerical control (CNC) cutters etc., which could be seen from the pictorial representation shown in the **Fig 1.7**, where the material or the pipe is cut using a hacksaw & a Jig.

3.2.3 Welding process

Welding is a process of fabrication or sculpture that unites materials, commonly metals or thermoplastics. This is obtained by applying intense heat to melt the components, which is finally left over to cool and fuse together. Welding is distinct from lower temperature metal-joining techniques such as brazing and soldering, which do not melt the base metal. The **Fig 1.7** shows the welding process of the tube using welding gun in the workshop.

3.2.3 Grinding process

Grinding is an abrasion type of the machined processes which uses a grinding wheel as the cutting tool. Metal grinding is a process which is utilized extensively in metal fabrication. Metal grinding is most often a manual operation at job shops while large custom parts fabricators will automate through the utilization of the finishing machines. Metal Grinding is utilized for finish off rough edges, deburr metal parts, smooth welds, create sharp edges and sometimes create unique finished looks like the jitterbug finish on a metal part.

Filing is a material removal process in manufacturing. Similar, depending on use, to both sawing and grinding in effect, it is functionally versatile, but used mostly for finishing operations, namely in deburring operations. Filing operations can be used on a wide range of materials as a finishing operation.

Fig 1.5 Marking and punching on the material

Fig 1.6 Cutting the material in the lab after marking process is over

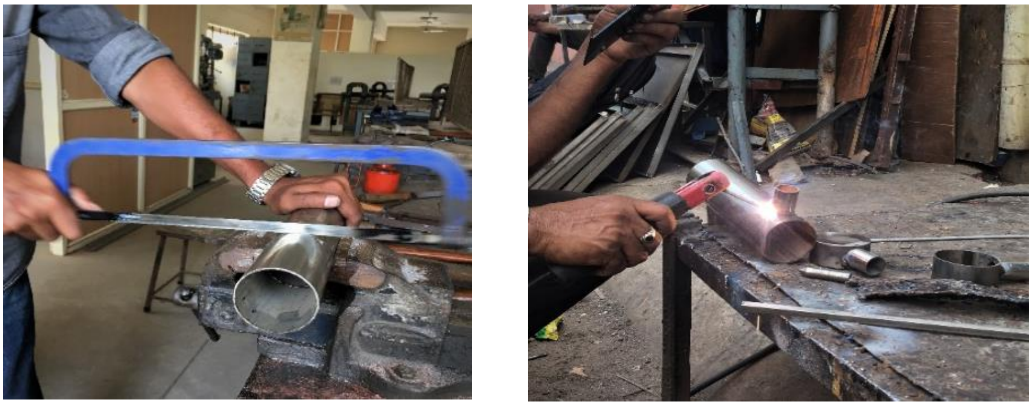


Fig 1.7 Welding process of the tube using welding gun in the workshop

Filing helps achieve work piece function by removing some excess material and deburring the surface which is shown in the **Fig 1.7** as to how the filing should be done using a file.

3.2.4 Drilling process

Drilling constitutes a cutting procedure employing a drill bit to create a hole with a circular cross-section within solid materials. The drill bit is usually a rotary cutting tool, often multi-point.

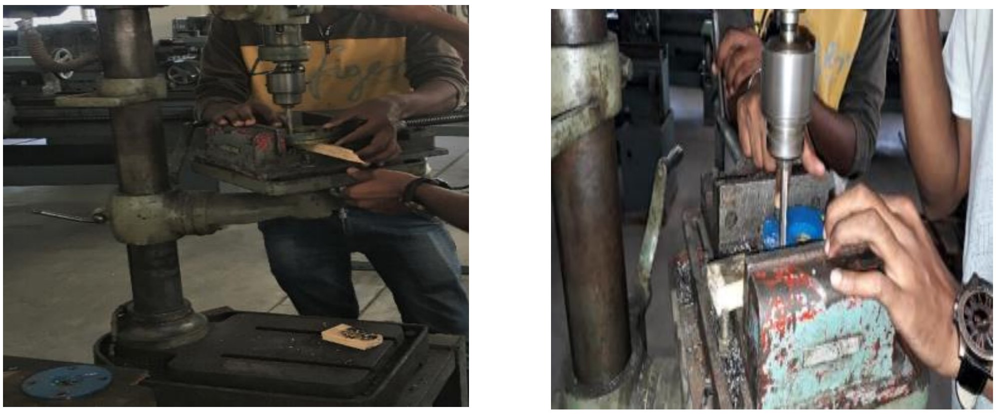


Fig 1.8 Drilling on the processed material using drill bit in the workshop, view - 1 & view - 1

3.2.5 Orifice plate process

An orifice plate serves as a device utilized to gauge flow rate, diminish pressure, or control the flow by constricting it & it is either a volumetric or mass flow rate may be determined, an orifice' plates is a thin plate with a hole in it, which is usually placed in a pipe. When a fluid passes through the orifice, its pressure builds up slightly upstream of the orifice but as the fluid is forced to converge to pass through the hole the velocity increases and fluid pressure decreases. The **Fig 1.9** shows how the orifice plate is being developed.

Fig 1.9 Development of the orifice plate

3.3 Experimentation process

The experimental setup (**Fig 1.10**) consists of galvanized iron pipe for the flowing of the hot gas fitted with a flow control valve to control the intake percentage of the hot gas to the EGR Cooler. An orifice plate to measure the discharge of Exhaust gas flow.

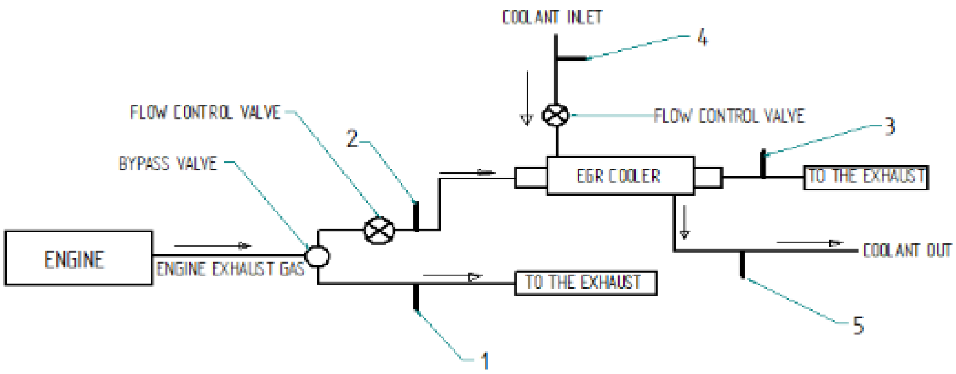


Fig 1.10 Schematic representation of experimental Setup

The **Fig 1.11** & **Fig 1.12** shows how the shell and tube arrangement in EGR Cooler developments are carried out in the laboratory. The **Fig 1.13** & **Fig 1.14** shows the EGR Plenum and baffles arrangement – Top View (Plan) & in the Elevation (side view). Combination of the plan & elevation would give the full 3D view about the fabricated material. Further, the tube sheet with tube arrangement in the top view mode could be seen in the **Fig 1.15** which gives a clear cut picture about the pipes holes.

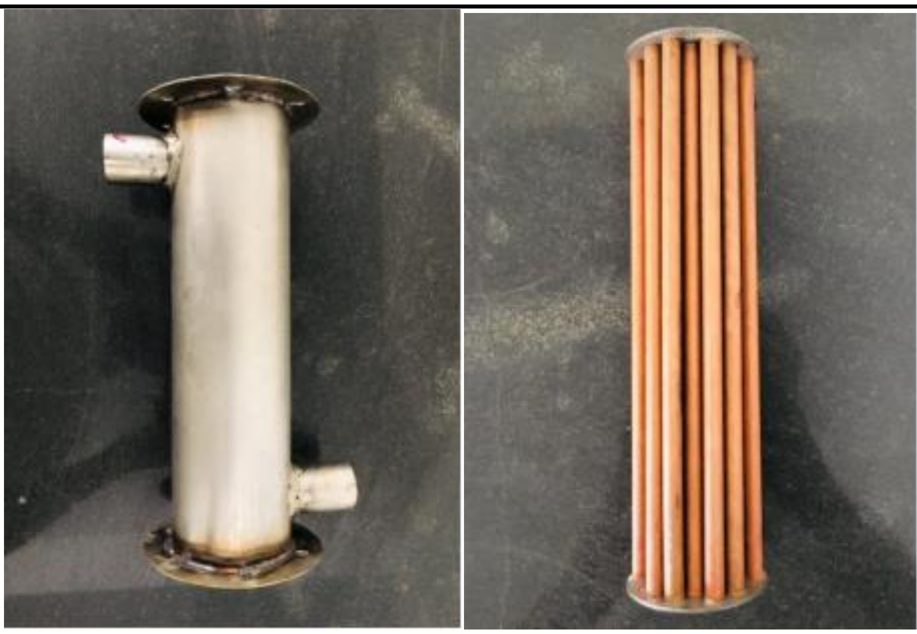


Fig 1.11 Shell and tube arrangement in EGR Cooler development-1

Fig 1.12 EGR Plenum and baffles arrangement – Top View

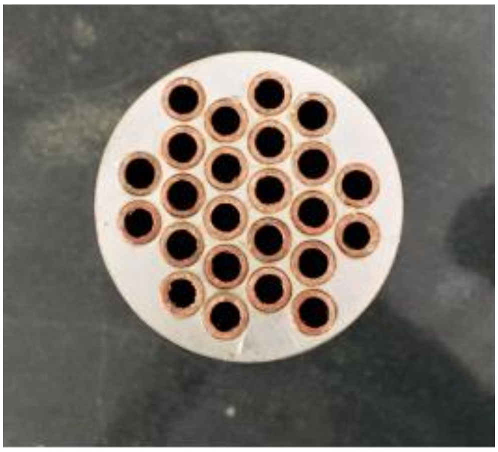


Fig 1.13 Tube sheet with tube arrangement in the top view mode

Fig 1.14 Complete Experimental setup pictorial view

Fig 1.15 EGR cooler fitted to Diesel Engine for experiment conduction

Table 1.3 Specifications for the conduction of the EGR experiment

Type	4-Stroke, Single cylinder Diesel Engine (Water Cooled), Compression Ignition
Make	Kirloskar AV-1
Rated Power	3.7 KW, 1500 rpm
Bore and Stroke	85 mm x 110 mm
Compression Ratio	16.5:1
Cylinder capacity	624.19 cc
Dynamometer	AC Alternator

Open the fuel supply and ensure no air is trapped in the fuel line connecting fuel tank and engine. Zero load is given for the engine using rope dynamometer Start the engine by cranking and ensure the rated speed at the zero load. Again, all the speed of the engines are noted. The time for 10cc of fueled consumption are noted with the manometer and a stopwatch. For measurement of air flow manometer is used. After all the readings were taken, the leftover Fuel was drained out of the tank. The exhaust muffler of the engines was removed & it is connected to a custom pipe which is utilized to calibrate the pressure, Temperature etc. The input to every EGR was taken from the exhaust port of the engines. Subsequently, the fuelled tanks are filled using high grade fuel, and the engine was operated. The EGR was allowed to run at various Mass flow rate of water and respective reading is obtained from the manometer. The engines are stopped only after it is made to run at zero loads.

3.4 Procedures for computation

Table 1.4 Data recorded and procedure computation findings

SL no	Speed rpm	Load kg	Air intake manometer reading (h_1) cm	Times used for the consuming of fuel of 10 ml in sec	Exhaust gas manometer (h_2) cm	Time taken for 1 litter of water collection from the EGR cooler sec	Temperature reading			
							Exhaust gas temp ˚C		Coolant temp ˚C	
							T_{hi}	T_{ho}	T_{ci}	T_{co}
1.	1625	-	6.5	50	5.6	75	386	59	29	37
2.	1650	-	6.5	50	7.1	75	352	69	29	40
3.	1675	-	6.5	50	7.8	75	380	79	29	45

Oxygen in-take using the rates of mass flows:

a.$(\dot{m}_a) = Q \times \rho$(kg/sec)……………………………………………………………………………………(1.1)

Discharge $(Q) = C_d \times A_o \times V = C_d \times \frac{\pi \times d_o^2}{4} \times \sqrt{2gH}$ (m³/sec) …………………………… (1.2)

b. Fuel consumption

$(\dot{m}_f) = V_f \times \rho_f$(kg/sec)……………………………………………………………………… (1.3)

c. Complete exhaust gases coming out of the engines

$(\dot{m}_e) = \dot{m}_a + \dot{m}_f$ (kg/sec)…………………………………………………………………… (1.4)

d. Exhaust flowing rates in EGR cooler

$(\dot{m}_{e1}) = Q \times \rho$ (kg/sec)………………………………………………………………………… (1.5)

Discharge $(Q) = C_d \times A_o \times V = C_d \times \frac{\pi \times d_o^2}{4} \times \sqrt{2gH}$ (m³/sec)………………………………… (1.6)

Head of exhaust gas $(H) = h_1 \times \frac{\rho_w}{\rho_a}$ m of air………………………………………………… .(1.7)

e. Mass flow rate of coolant EGR

$(\dot{m}_c) = \frac{V_f \times \rho_w}{t}$(kg/sec)…………………………………………………………………… .(1.8)

Log mean Temperature Difference

$$LMTD = \frac{(T_{hi}-T_{co})-(T_{ho}-T_{ci})}{\ln\frac{(T_{hi}-T_{co})}{(T_{ho}-T_{ci})}} \quad (1.9)$$

$C_h = \dot{m}_{e1} \times C_{s\ exht}$……………………………………………………………………………… (1.9.1)

$C_c = \dot{m}_c \times C_{s\ wt}$………………………………………………………………………………… (1.9.2)

Effectiveness of EGR cooler $(\varepsilon) = \frac{\text{actual amount of heat tranfer}}{\text{maximum amount of heat tranfer}}$

$\varepsilon = \frac{C_h(T_{hi}-T_{ho})}{C_{mim}(T_{hi}-T_{ci})} = \frac{C_c(T_{co}-T_{ci})}{C_{mim}(T_{hi}-T_{ci})}$ ………………………………………………………........ (1.10.0)

For NTU method

The Effectiveness for counter flow $(\varepsilon) = \frac{1-e^{-N(1-C)}}{1-C\, e^{-N(1-C)}}$ ………………………….................. (1.10.1)

$C = \frac{C_{mim}}{C_{max}}$ ………………………………………………………………………..………… (1.10.2)

Flow area $= A = \pi d_o\, L\, N_t$ ………………………………………………………………… (1.10.2)

$NTU = N = \frac{U\,A}{C_{mim}}$…………………………………………………………………………..…. (1.10.3)

4. Discussion and outcomes

In order to draw final conclusions about the experimentation process and its outcomes, the observation table and calculation procedures with the experimental results and discussions for Cases I, II, and III with varying rates of mass flow of exhaust gases in EGR with and without baffles.

4.1 Case - I with altering mass flow rates of exhaust gases in EGR

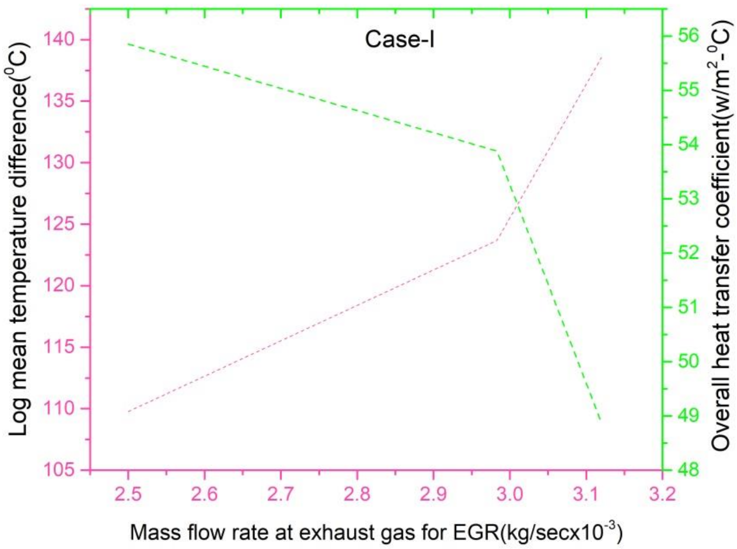


Fig 1.16 Effect of flow rate versus log mean temperature difference via overall heat transfer coefficient

For EGR cooler without baffles was fitted to the exhaust of 4 stroke diesel engine and experimental investigation was done at zero load and constant speed by varying rates of the mass flowing in the pipe of the exhaust gas. Temperature at the outlets & inlets of both shell and tube was recorded.

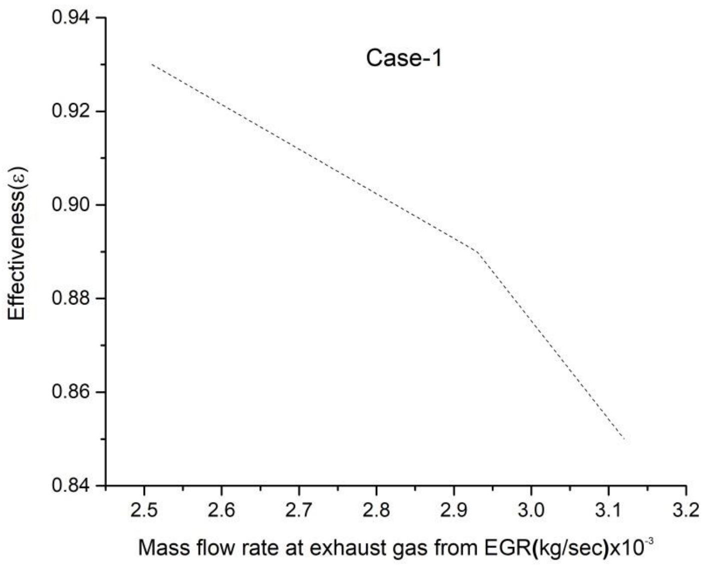


Fig.1.17 Effect of flow rate versus effectiveness of shell and tube heat exchanger

Table 1.4 It can observe for exhaust gas at a value of 2.5×10^{-3} kg/sec, 2.98×10^{-3} kg/sec, 3.12×10^{-3} kg/sec LMTD increases but effectiveness and the heat transferred quantity (overall complete) coefficient decreases gradually. Maximum effectives of 0.936 is obtained at 2.5×10^{-3} kg/sec. From this we can conclude if EGR rate of the mass flowing is = *r* less than 2.5×10^{-3} the design EGR Cooler will be more effective.

4.2 Case - II Varying load on engine for finding the performances of the EGR

For EGR cooler without baffles was fitted to the exhaust of 4 stroke Diesel engine and experimental investigation was done at varying load and speed by constant rates of the mass flowing of the exhaust gas as in the **Table 1.5**.

Table 1.5 Calculated results table for case – 2

SL no	Speed rpm	Load kg	Air intake manometer reading (h_1) cm	Time taken for fuel consumption of 10 ml in sec	Exhaust gas manometer (h_2) cm	Time in sec for cooler	Temperature reading			
							Exhaust gas temp °C		Coolant temp °C	
							T_{hi}	T_{ho}	T_{ci}	T_{co}
1.	1625	0	6.2	55	4.8	66	355	55	28	35
2.	1581	1	6.2	44	4.8	66	425	59	28	39
3.	1562	2	6.4	35	4.8	66	526	63	28	44
4.	1514	3	6.6	26	4.8	66	640	74	28	49

Temperature at the outlets & inlets of both shell and tube was recorded. From table 5.6, we can observe in the **Fig 1.17** and **Fig 1.18** for exhaust gas at 2.58×10^{-3} kg/sec and increasing the load LMTD increases but effectiveness & the heat that is being transferred with the coefficients will also increases gradually. From this we can conclude if EGR rates of the mass flowing is = or < 2.58×10^{-3} the design EGR Cooler will be the same effective for varying load.

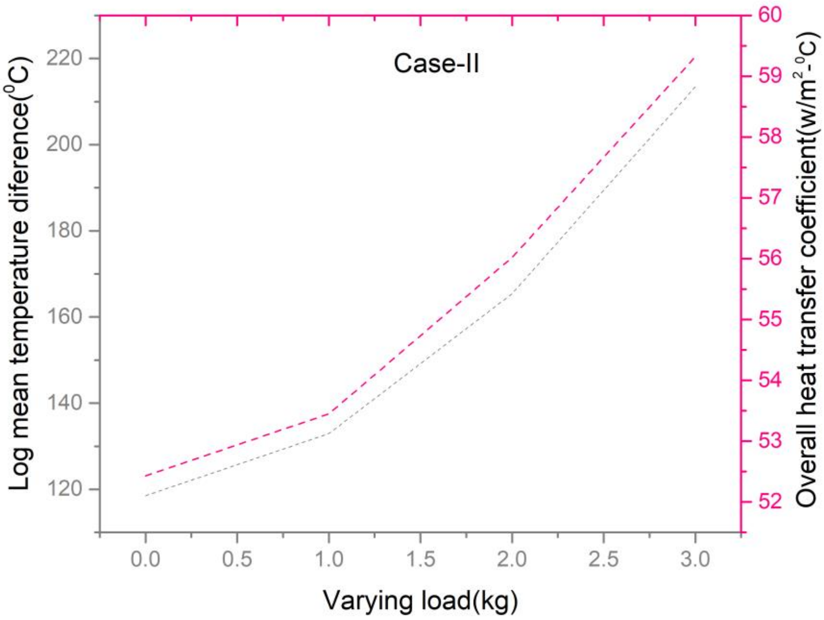


Fig 1.18 Effect of varying load versus log mean temperature difference via overall heat transfer coefficient

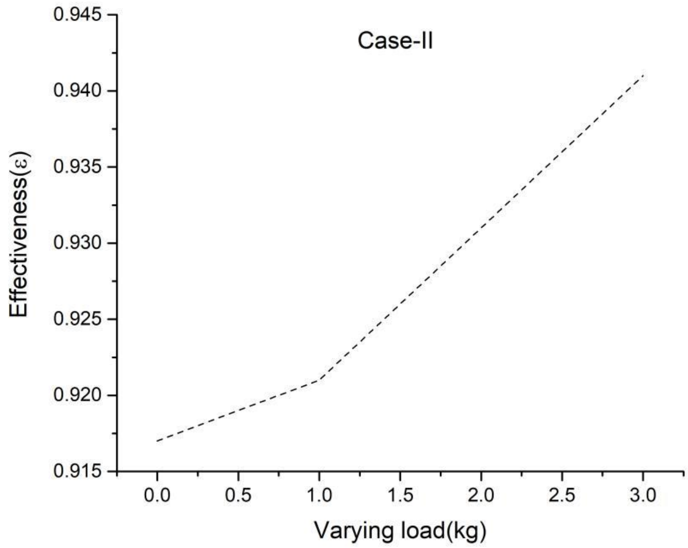


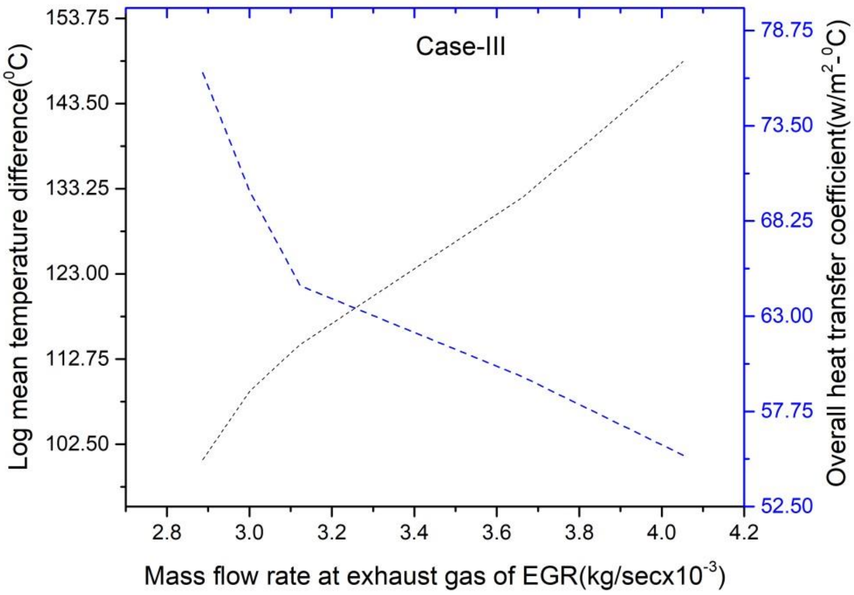
Fig 1.19 Effect of varying load versus effectiveness of shell and tube heat exchanger

4.3 Case 3:- Varying the mass flow rate of exhaust gas in EGR with baffles

For EGR cooler with baffles are then fitted in the exhaust of 4 stroke Diesel engine & experimentation with the investigations was done at zero load and constant speed by varying rates of the mass flowing of the exhaust's gases as in **Fig 1.19 and Fig 1.20**. Then the temperatures at the inlet and outlet of both shell and tube were recorded. From the **Table 1.6**, it can observe for exhaust gas at 2.887×10^{-3} kg/sec, 3.0×10^{-3} kg/sec, 3.12×10^{-3} kg/sec, 3.633×10^{-3} kg/sec, 4.05×10^{-3} kg/sec LMTD increases but effectiveness & the overall coefficients of the heat that is being transferred will decrease gradually. Maximum effectiveness of 0.959 is obtained at 2.887 × 10 $^{-3}$ kg/sec. From this we can conclude if EGR rates of the mass flowing is = to *r* less than 2.887 × 10^{-3} the design EGR Cooler will be more effective.

Table 1.6 Recorded observation table

No	Speed rpm	Load kg	Air intake manometer reading (h_1) cm	Time taken for fuel consumption of 10ml in sec	Exhaust gas manometer (h_2) cm	Time in sec for cooler	Temperature reading			
							Exhaust gas temp ˚C		Coolant temp ˚C	
							T_{hi}	T_{ho}	T_{ci}	T_{co}
1.	1627	0	6.4	52	6	80	370	42	28	37
2.	1632	0	6.4	52	6.5	80	360	48	28	37
3.	1630	0	6.4	52	7	80	351	54	28	41
4.	1631	0	6.4	52	9.5	80	343	71	28	43
5.	1632	0	6.4	52	11.8	80	345	88	28	48



Figs 1.20 Effect of log mean temperature difference and overall heat transfer coefficient by varying flow rate

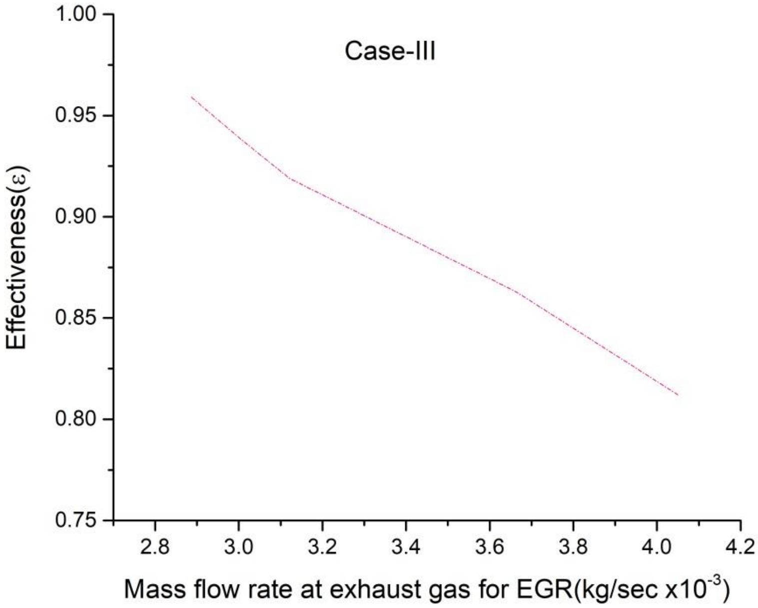


Fig 1.21 Effect of effectiveness of shell and tube heat exchanger by varying flow rate

4. Conclusions

An experimental investigation shall be conducted in fabricated models dependent on the proposed design and its result shall be compared with previous result. Then, the results indicated the following inferences.

- As the mass flow-rate increase with constant load and constant speed, there is increasing in log mean temperature difference (LMTD), i.e., that means decreasing the temperature and decreases the effectiveness and overall heat transfer confident of EGR cooler. Maximum effectiveness of 0.95 to 0.90 is obtained at 2.887 x 10^{-3} kg/sec.
- As the load and speed increase with obtained constant rates of mass flow rate (2.88 x 10^{-3} kg/sec), there is increasing in LMTD but the effectiveness & the complete heat transferred coefficients is approximately same.

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