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CFD Investigation on Effective Utilization of Waste Heat Recovery from Diesel Engine Exhaust using Different Shaped Fin Protracted Heat Exchanger

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ABSTRACT

In current research, the heat lost from the engine exhaust gas has been recovered through innovative steps. The numerous techniques used for WHR engines include the thermoelectric generator, turbo-compounding, Rankine cycle, organic Rankine cycle, gas turbine cycle, exhaust gas recirculation, car air conditioning, and six-stroke engine design. The current investigation investigates the ability of exhaust gases to extract low-grade waste-heat energy from internal combustion engines (ICEs). To accomplish this goal, a Protracted Fin Counter Flow Heat Exchange (PFCHE) double tube was designed, analyzed and provided with water as working fluids. The geometry of a double pipe, Protracted Fin Heat Exchanger (PFCHE), which conducts a simulation analysis, is extracted from the one by Rajesh Ravi et al. (2020) research scholar with exact measurements and afterwards, different shapes of the profiles of the fin were added in the designs suggested. For numerical processing the Fluent 17.0.The findings of the CFD can be taken from the following assumptions, study showing, in comparison to PFCHE in a circular fin and previous research of Rajesh Ravi et al. (2020) the PFCHE with triangular fin shows superior thermal performance. By comparison, the PFCHE net heat transfer rate is 1.76% more than the PFCHE with circular fin, and 2.82% higher than Rajesh Ravi et al.'s (2020) report.

KEYWORDS: *Waste heat recovery, Heat exchanger, protracted fin, CFD, Heat Transfer and Nusselt number*

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I. INTRODUCTION

Systems approach has a vital role to play in energy conservation and efficient management of resources to achieve cleaner energy production objectives. Diesel engines are usually referred to as fuel efficient engines and are mainly used in commercial trucks, locomotives, heavy building equipment, ships and large pick-ups, as well as in power generation for power stations and power factories. Thanks to its simple maintenance, strong thermal efficiency and its good output, the diesel motor is the most favored for producing electricity in small scales.

Around 30-45 percent of fuel is effectively converted into useful work in ICEs (internal combustion engines), but the EGR (exhaust gas recirculation), exhaust gas and heat loss are still unproductive. The waste of exhaust gas makes up to 40% of the heat output, while the cooling system and the loss of friction make up the rest of the output. Around 30-45 percent of fuel is effectively converted into useful work in ICEs (internal combustion engines), but the EGR (exhaust gas recirculation), exhaust gas and heat loss are still unproductive. The waste of exhaust gas makes up to 40% of the heat output, while the cooling system and the loss of friction make up the rest of the output.

Figure 1 Energy loss in ICEs (internal combustion engines)

The rise in fuel cost and the revision of high emissions standards across the globe have given ICEs a strong priority and a growing need to optimize the efficiency of the heat energy available and the amount of hazardous contaminants released by engines.

In the current research work, the heat wasted from the exhaust gas engine has been recovered through innovative steps. The various technology used for using WHR engine include thermo electrical generators, turbo blends, rank cycles, organic Rankine cycles, gas turbine cycles, recirculation of gas exhaust, auto air conditioning and six stroke engine configuration.

II. LITERATURE REVIEW

There is a well-defined need for study and analysis of scientific literature in any step of WHR's research and development. The first step in the research work is a thorough review of the works previously performed. Specific data, detailed surveys and preliminary assessments are part of a review process. This paper analyzed multiple scientific papers reviewed by colleagues to explain various fields of hypotheses.

Shekh Nisar Hossain Rubaiyat (2010) conducted experiments to measure the exhaust waste heat available from a 60 kW automobile engine and a computer simulation was carried out to improve the design of the heat exchanger. Two heat exchangers were used: one to generate saturated and the other to generate super-heated vapor. It is found that with the exhaust heat available from the diesel engine at least 18% additional power can be achieved [1].

S N Srinivasa et al. (2012) have attempted to explore the various possibilities of waste heat energy recovery methods in conventional commercial two wheeler and four wheelers. In this context, a new concept of hybrid engine has also been discussed. The heat energy contained in the exhaust gases are recovered in three different methodologies [2].

- Firstly, the waste heat energy is utilized to burn an additional amount of fuel.
- The second stage, a thermoelectric generator producing electrical energy by utilizing the heat of exhaust gases.
- The third stage energy recovery is done by coupling a compressor and an alternator.

Saidur et al. (2012) have studied the different technologies to recover the heat wasted from the exhaust gas of IC engines and concluded that there is a huge potential for extracting the waste heat from the exhaust gas of IC engines [3].

Mohd Noor (2013) developed technologies to recover waste exhaust heat and turn it into useful energy such as electricity. Their extensive work focused on the waste heat recovery technology based on current developments in the automotive sector; the study looked into potential energy recoveries, performances of each technology and other factors affecting the implementation [4].

Mojtaba Tahani (2014) studied two different configurations of Organic Rankine cycle with the capability of simultaneous waste heat recovery from exhaust gas and coolant of a 12L diesel engine: main objective in optimization process was maximization of the power generation and cycle thermal efficiency [5].

Miller EW, et al. (2015) studied on WHR from dual cycle system for power generation. The system uses TEG and ORC technique to maximize WHR. Shows an overall improvement mainly due to ORC that produces most of the energy improvement. Only small fraction of energy generated through TEG but may be useful for parasitic heat loss i.e., fans and power steering pumps [6].

H. Teng et al. (2015) the authors developed a numerical module to regain the waste heat from exhaust gas of the engine. They inferred that irrespective of the working conditions be, when ORC is installed in the engine, its performance got enhanced when compared to the performance of original engine [7].

Marco Cavazzuti et al. (2015) in this empirical study, the authors simulated the finned concentric pipes heat exchanger with the help of CFD after which was also optimized with the help of Nelder and Mead simplex downhill optimization algorithm. From the results, it was inferred that the performance of the exchangers can be enhanced by simple fine tuning of few geometrical parameters [8].

Amir Amini et al. (2017), in this study, the heat pipe technique was reported and experimented in order to improve the usage of PCMs in storing the energy. The study results for the heat transfer saw an increase when utilizing superior finning strategy at the heat pipe's condenser side [9].

Max Mauro L. Reis et al. (2018), the study had the objective of finding the best alternative for WHR in FPSO "Floating Production Storage and Offloading" platform in order to give assurance for the heat energy demand is met. Further, the study aimed to increase the generation of electricity via ORC so that the overall thermal efficiency can be enhanced and the carbon-di-oxide emission can be reduced. The study results inferred that when ORC is implemented in WHR system, the fuel consumption got reduced to 22.5% on an average plus the carbon-di-oxide emissions were reduced in the FPSO lifetime [10].

Akos Revesz et al. (2019), in this study, the authors proposed a new way to harvest the waste heat from Underground Railways (URs). The research was conducted after reviewing five different studies in order to develop a system with alternative geometrical parameter variations. The study results showed that a notable influence would be present on the operation of UR tunnel upon the neighboring vertical GHEs [11].

Huikun Cai et al. (2019), The study had an objective to expose the impact of top by-pass flow upon the performance of plate fin heat exchanger as well as the design principle of the optimized PFHE. This is hoped as an instruction for the future PFHE applications in a number of fields. The study results observed an increase in the average heat transfer coefficient in simulation with the bypass flow whereas the maximum difference reached 82.76% at 10 m/s velocity in comparison to plate-fin heat exchanger excluding that, which got diminished upto 19.1% in contrast with the experimental results [12].

Rajesh Ravi et al. (2020), investigates the energy recovery capability of exhaust gases in Internal Combustion Engines (ICEs) in order to reap low grade waste heat energy. In order to achieve this aim, a double pipe, Protracted Finned Counter flow Heat Exchanger (PFCHE) was designed, analyzed, fabricated and experimented with binary (water-ethanol) mixtures as working fluids. In the current work, as a first step, the theoretical design was completed and the computational simulation of PFCHE was executed. From the experimental investigation and analytical results, a positive notion was observed about the overall efficiency of the heat recovery system. It was proved that when the number of fins increased along with its height, then the heat transfer rate also got increased which further resulted in the improved performance of heat recovery system and increased Brake Thermal Efficiency from 32% to 39.6%. The developed heat recovery system was able to produce 0.35 kW-0.76 kW of power when the turbines were made to run at 1700 rpm to 4800 rpm respectively. Overall, the study concludes that the PFCHE increased the working fluid outlet temperature, effectiveness, heat transfer rate as well as the overall Brake Thermal Efficiency when compared with traditional heat exchangers that lack fins [13].

Based on the literature review, different types of heat exchangers and Organic Rankine Cycles are used to use the excess heat energy contained in the exhaust gas. Previous research works focused mainly on extracting exhaust heat energy. Studies related to the heat exchanger with innovative heat recovery and simultaneous emission reduction were not conducted, however. This includes the development of a new technological system on the exhaust heat recovery heat exchanger to improve energy recovery and exhaust emission reductions for diesel engines.

The main objectives of the present study are:
- To develop CFD model to analyze the heat transfer in a double pipe, Protracted Finned Counter flow Heat Exchanger (PFCHE) on ANSYS 17.0.
- To investigate the heat transfer characteristics of a Protracted Finned Counter flow Heat Exchanger (PFCHE) with different fins shape.
- Validation will be carried on CFD model with previous model.
- Comparing the heat transfer rate and overall heat transfer coefficient of proposed model with respect to conventional model.

III. COMPUTATIONAL MODEL

The geometry of double pipe, Protracted Finned Counter flow Heat Exchanger (PFCHE) performing the simulation study is taken from the one of the research scholar's **Rajesh Ravi et al. (2020)** with exact dimensions and after than in the proposed designs different fin profile were used . In his work, the best PFCHE design i.e., 12 fins of each 30 mm protrusion height achieved the least exhaust gas outlet temperature and maximum heat transfer rate. So, for present study 12 fins of each 30mm protrusion height is considered. The part of the model designed in ANSYS (fluent) workbench 17.0 software.

Table 1 Geometry of heat exchanger

Parameter	Symbols	Inside	Outside	Units
Inside diameters of pipe	d_i, D_i	0.064	0.114	m
Outside diameters of pipe	d_0, D_o	0.07	0.12	m
Total area of finned tube heat exchanger	A_t	0.7127	0.7315	m^2
Number of fins	N_f	12	12	-

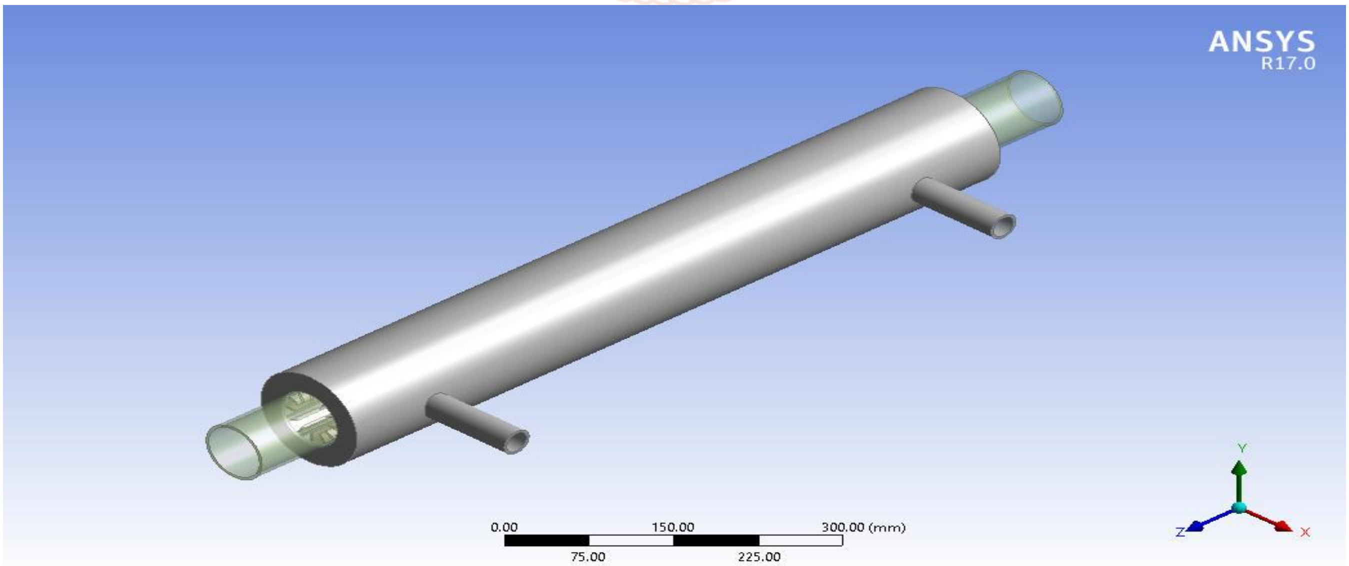

Figure 2 Model of PFCHE with fin (**Rajesh Ravi et al. (2020)**).

In this present work, new fin shapes in PFCHE are proposed i.e. circular and triangular shaped fins.

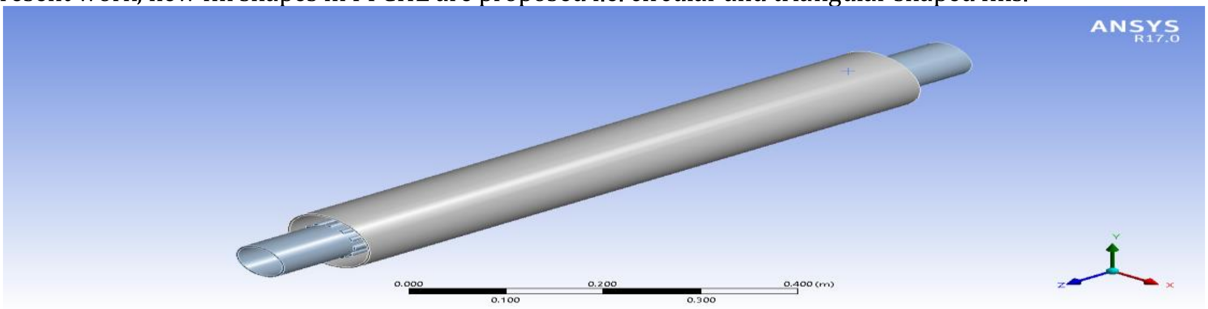

Figure 3 Model of PFCHE with circular fin shaped (12fins of 30 mm fin height)

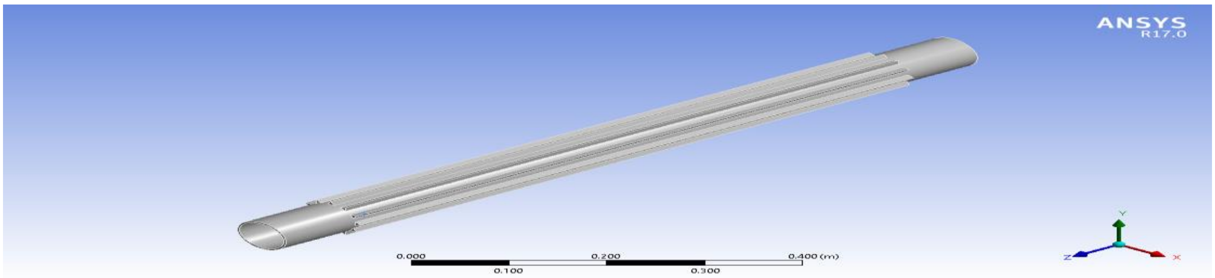

Figure 4 Model of PFCHE with triangular fin shaped (12fins of 30 mm fin height)

In the pre-processor step of ANSYS FLUENT R17.0, a three-dimensional discretized model of PFCHE with fin was developed. Although the styles of grids are connected to simulation performance, the entire structure is discretized in the finite volume of Quadcore tetrahedral grids in order to reliably calculate the thermal properties of PFCHE with fin using correct grids.

Table 2 Mesh details

The applied design	Number of nodes and elements
PFCHE with fin (**Rajesh Ravi et al. (2020)**)	933784 and 876683
PFCHE with circular fin	1306383 and 1092769
PFCHE with triangular fin	700159 and 667908

IV. NUMERICAL PROCEDURE

The Fluent 17.0 was used to calculate computationally. In research, the approach used to differentiate the governing equations was a finite element. For this convective term, the researchers used a simpler algorithm, and for connecting calculations of the pressure and velocity the second order upwind method was implemented.

A standard k-epsilon equation was used with flow and energy equations to solve turbulence.

4.1. Governing equations

The numerical simulation was with a 3-Dimensional steady state turbulent flow system. In order to solve the problem, governing equations for the flow and conjugate transfer of heat were customized according to the conditions of the simulation setup. The governing equations for mass, momentum, energy, turbulent kinetic energy and turbulent energy dissipation are expressed as follow,

Mass:

$$\frac{\partial(\rho u_i)}{\partial x_i} = 0$$

Momentum:

$$\frac{\partial(\rho u_i u_k)}{\partial x_i} = \frac{\partial\left(\mu \frac{\partial u_k}{\partial x_i}\right)}{\partial x_i} - \frac{\partial p}{\partial x_k}$$

Energy Equation:

$$\frac{\partial(\rho u_i t)}{\partial x_i} = \frac{\partial\left(\frac{K}{C_p}\frac{\partial t}{\partial x_i}\right)}{\partial x_i}$$

In this work, renormalization-group (RNG) k-ε model was used because it can give improved predictions of near wall flows and flows with high streamline curvature, Also the thermal effect parameter was selected in improved wall treatment panel transport equations for RNG k-ε model in common form.

4.2. Thermodynamic Properties of working fluid
For any kind of analysis material property are the main things which must be defined before moving further analysis. There are thousands of materials available in the ANSYS environment and if required library is not available in ANSYS directory the new material directory can be created as per requirement.

Table 3 Thermodynamic Properties of working fluids

Input Parameters	Symbols	Hot fluid(Exhaust gas)	Symbols	Cold fluid(Water)	Units
Inlet Temperature	T_{hi}	235	T_{ci}	32	°C
Thermal conductivity	K_h	0.0404	K_c	0.6	W/m-K
Specific heat capacity	c_{ph}	1030	c_{pc}	4182	J/kg-K
Viscosity(Absolute)	μ_h	0.000027	μ_c	0.0006	N-s/m²
Density	ρ_h	0.696	ρ_c	998	kg/m³
Mass flow rate	m_h	0.00934	m_c	0.0054	kg/s

4.3. Boundary Conditions
The discretized flow domain was set up with appropriate boundary conditions. The mass flow boundary conditions were assigned to inlets whereas it was pressure outlet boundary conditions, in case of the outlets. The heat exchanger surfaces were treated as standard wall boundaries. The outer walls were provided with insulated boundary conditions whereas the inner walls were provided with coupled-thermal wall boundary conditions. The boundary conditions of heat exchanger working fluids are consolidated in Table 4.

Table 4 Details of boundary conditions

Detail	Boundary Type	Value	Remarks
Inlet-Exhaust gas	Mass flow inlet	0.00934 kg/s	Hydraulic diameter=0.06m and Turbulent intensity=3%
Inlet-Working fluid	Mass flow inlet	0.0054 kg/s	Hydraulic diameter=0.025m and Turbulent intensity=3%
Outlet	Pressure outlet	0 Pa (gauge)	3% Turbulent intensity with Hydraulic diameter
Inner surfaces, fin surfaces, etc.	Standard wall	Coupled	Coupled between solid and fluid
Outer surfaces	Standard wall	Heat flux=0	Insulated

V. RESULTS AND DISCUSSIONS
This segment aims to evaluate the thermal performance of different proposed fin designs in PFCHE. To study the performance of PFCHE with different shape of fin subject to flow, the variations in the temperature and Heat transfer are measured.

5.1. Validation of numerical computations
To validate the accuracy of developed numerical approach, comparison was made with the work reported in **Rajesh Ravi et al. (2020)**. The PFCHE geometry that used for validation of numerical computations was considered to be as same as the geometry shown in Fig. 3.

The values of exhaust gas outlet temperature, working fluid outlet temperature, heat transfer rate, and Nusselt number calculated from the CFD modeling were compared with the values obtained from the analysis performed by **Rajesh Ravi et al. (2020)**.

Table 5 Indicates the exhaust gas outlet temperature values determined from CFD models opposed to the values derived from Rajesh Ravi et al. (2020) study for PFCHE

S. No.	Brake Power (KW)	Exhaust gas outlet Temperature (in K) (Base Paper)	Exhaust gas outlet Temperature (in K) (Present Study)
1.	0.8	415	413.45
2.	1.58	391	392.89
3.	2.34	378	377.21
4.	3.08	370	370.23
5.	3.53	368	369.39

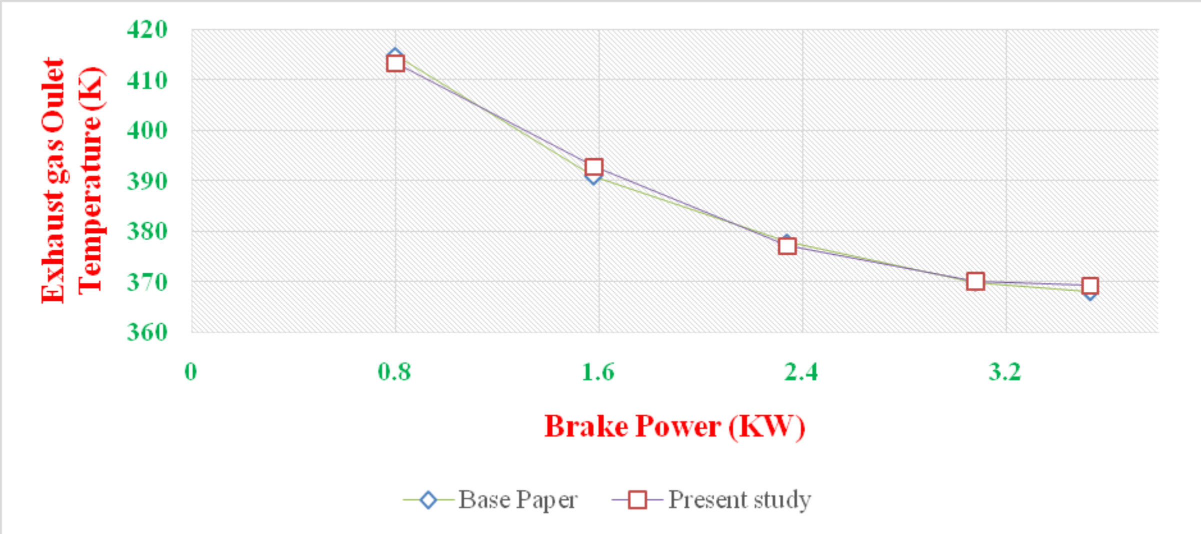

Figure 5 Exhaust gas outlet temperature values determined from CFD models opposed to the values derived from Rajesh Ravi et al. (2020) study for PFCHE

Table 6 indicates the net heat transfer rate values determined from CFD models opposed to the values derived from Rajesh Ravi et al. (2020) study for PFCHE

S. No.	Brake Power (KW) (W)	Net heat transfer rate (in W) (Base Paper)	Net heat transfer rate (in W) (Present Study)
1.	0.8	580	575.67
2.	1.58	690	688.24
3.	2.34	870	866.81
4.	3.08	985	988.43
5.	3.53	992	993.24

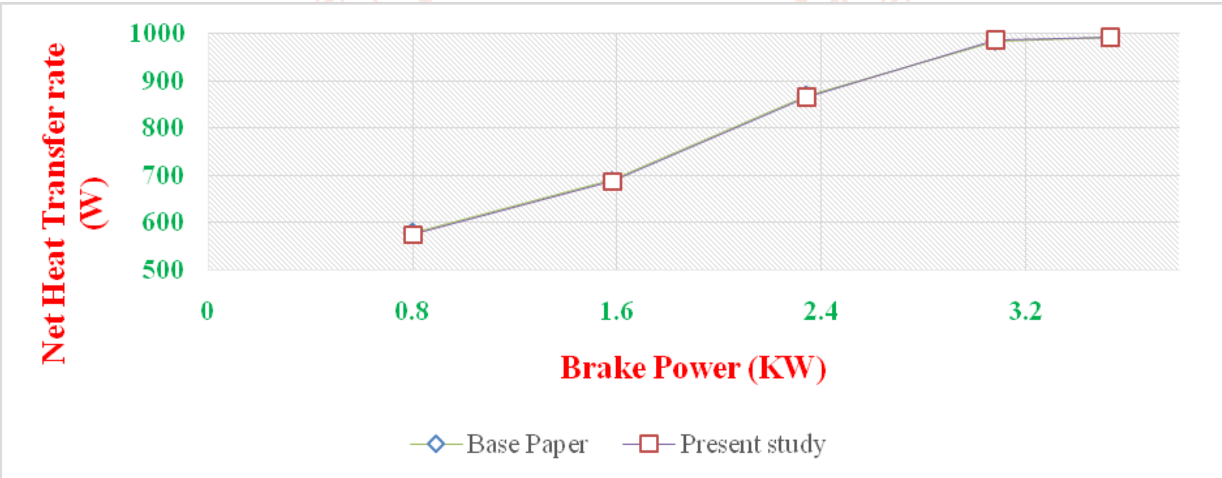

Figure 6 Net heat transfer rate values determined from CFD models opposed to the values derived from Rajesh Ravi et al. (2020) study for PFCHE

From the aforementioned validation study it is observed that the values of the exhaust gas outlet temperature, and Net heat transfer rate measured from CFD study are similar to the values of the exhaust gas outlet temperature, and Net heat transfer rate obtained from the base journal. So here we can claim the PFCHE model with fin CFD is right.

5.2. Comparison of PFCHE with different fin designs

Table 7 Comparison of the values of Exhaust gas outlet temperature (K) for different fin designs

S. No.	Brake Power (KW)	Exhaust gas outlet temperature (K)		
		PFCHE with fin (Base Paper)	PFCHE with triangular fin	PFCHE with circular fin
1.	1.58	391	369.38	383.84
2.	2.34	378	365.1	370.84
3.	3.08	370	360.53	365.2
4.	3.53	368	350.04	355.054

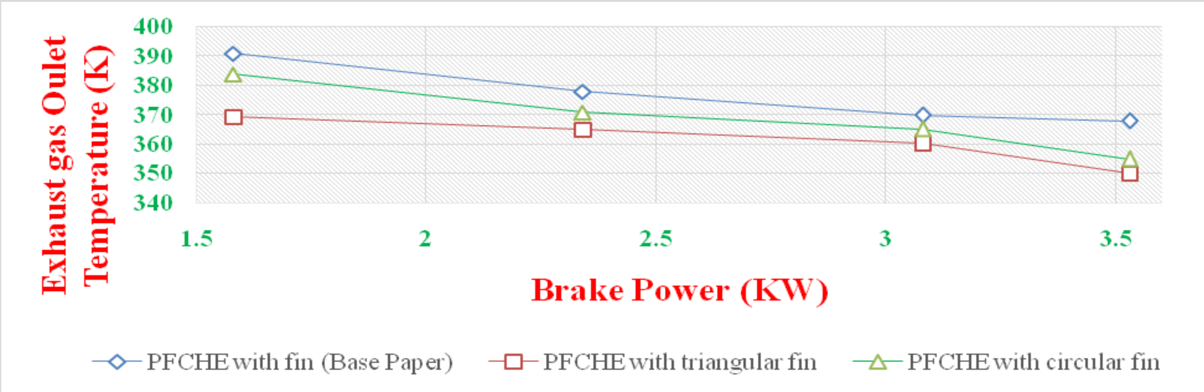

Figure 7 Comparison of the values of Exhaust gas outlet temperature (K) for different fin designs

Table 8 Comparison of the values of Nusselt number for different fin designs

S. No.	Brake Power (KW)	Nusselt Number		
		PFCHE with fin (Base Paper)	PFCHE with triangular fin	PFCHE with circular fin
1.	1.58	74.32	79.682	74.93
2.	2.34	77.26	84.382	77.84
3.	3.08	81.24	87.982	81.5
4.	3.53	85.01	90.26	83.37

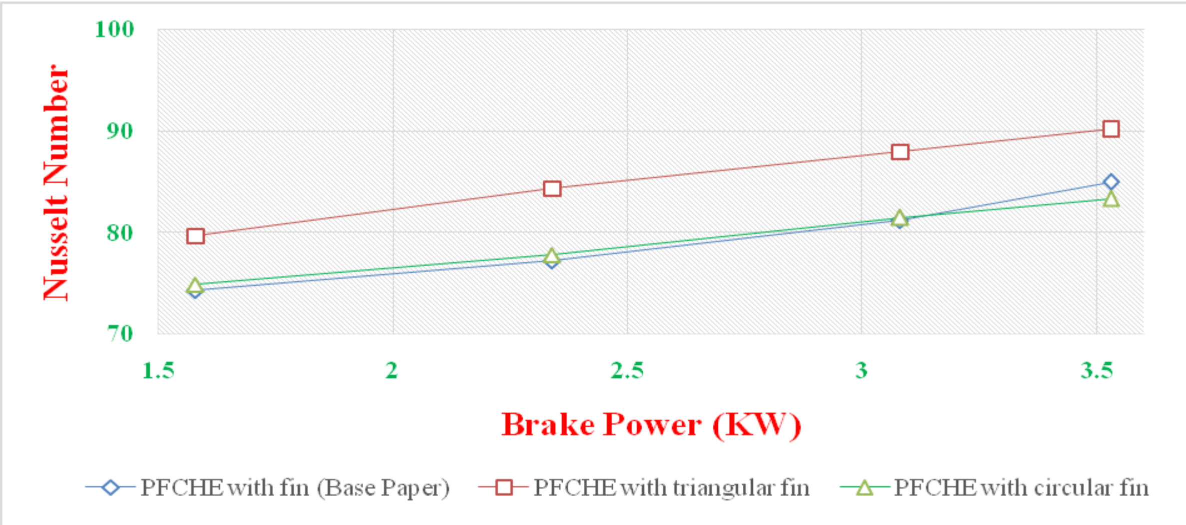

Figure 8 Comparison of the values of Nusselt number for different fin designs

Table 9 Comparison of the values of Net heat transfer rate for different fin designs

S. No.	Brake Power (KW)	Net Heat Transfer rate (W)		
		PFCHE with fin (Base Paper)	PFCHE with triangular fin	PFCHE with circular fin
1.	1.58	690	720.34	708.76
2.	2.34	870	902.65	892.81
3.	3.08	985	1015.54	998.41
4.	3.53	992	1020.98	1002.54

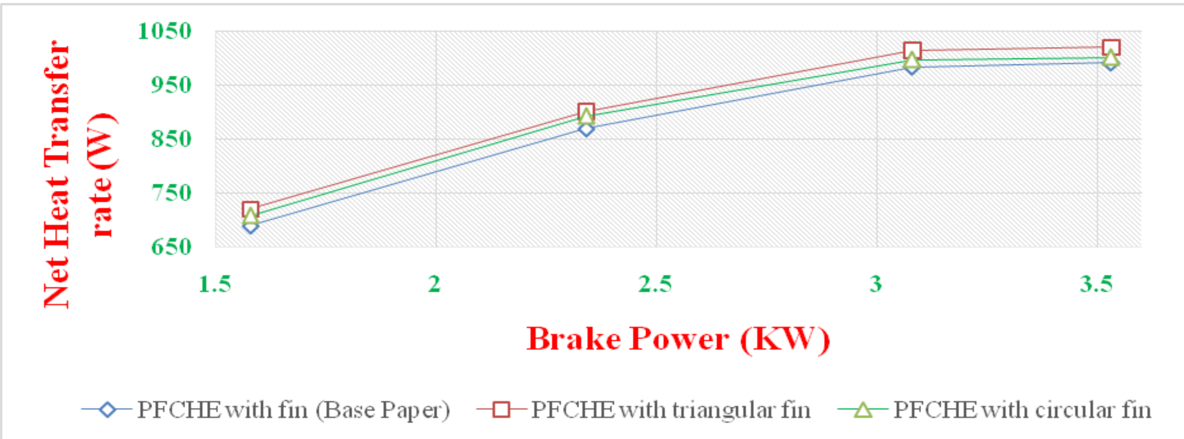

Figure 9 Comparison of the values of Net heat transfer rate for different fin designs

VI. CONCLUSIONS

Around 70 percent of the heat energy produced by pistons is lost in internal combustion engines (ICEs) because of the exhaust and cooling process. The research involved the designing and extracting of heat out of exhaust gas from the engine of an advanced double tube, both internally – externally PFCHE of different fin shape. The findings of the CFD may be taken from the following conclusions.

- The analysis has shown that the PFCHE with triangular fin demonstrate superior thermal performance as compared to PFCHE with circular fin and previous work done by Rajesh Ravi et al. (2020).
- By comparison, the net heat transfer rate of PFCHE with triangular fin is 1.76 % higher than PFCHE with circular fin and 2.82 % higher than work reported by Rajesh Ravi et al. (2020).
- From the computational outcomes, the PFCHE models with triangular fin unveiled the best heat transfer rates of 1020.98 W.
- By comparison, the exhaust gas temperature of PFCHE with triangular fin at the outlet of 350.04 K at 3.53 KW brake power while in case of circular fin it is of 355.054 K and in case of work reported by Rajesh Ravi et al. (2020) it is of 368 K.
- By comparison, the Nusselt number of PFCHE with triangular fin is of 90.26 at 3.53 KW brake power while in case of circular fin it is of 83.37 and in case of work reported by Rajesh Ravi et al. (2020) it is of 85.01.

REFERENCES

[1] Shekh Nisar Hossain Rubaiyat*, Saiful Bari "Waste heat recovery using shell and tube heat exchanger from the exhaust of an automotive engine" Proceedings of the 13th Asian Congress of Fluid Mechanics 17-21 December 2010, Dhaka, Bangladesh.

[2] S.N.Srinivasa Dhaya Prasad N.Parameshwari "A Feasibility Study On Waste Heat Recovery In An Ic Engine Using Electro Turbo Generation" Proceedings of the National Conference on Trends and Advances in Mechanical Engineering, YMCA University of Science & Technology, Faridabad, Haryana, Oct 19-20, 2012.

[3] R. Saidur, "Technologies to recover exhaust heat from internal combustion engines", Renewable and Sustainable Energy Reviews 16, 2012, 5649–5659.

[4] Mohd. Noor, Yamagami T, Oda N, Hattori M, Sorazawa M, Haraguchi T., "Modeling a Thermoelectric Generator Applied to Diesel Automotive Heat Recovery", Journal of Electronic Materials, vol. 39, pp. 1446-1455,2013.

[5] Mojtaba TAHANI, Saeed JAVAN, Mojtaba BIGLARI "A comprehensive study on waste heat recovery from internal combustion engines using organic Rankine cycle". Thermal Science 2013 Volume 17, Issue 2, Pages: 611-624.

[6] Miller EW, Hendricks TJ, Peterson RB. "Modeling energy recovery using thermoelectric conversion integrated with an organic Rankine bottoming cycle". Journal of Electronic Materials 2015; 38.

[7] H. Teng, G. Regner, C. Cowland, "Waste Heat Recovery of Heavy-Duty Diesel Engines by Organic Rankine Cycle Part I: Hybrid Energy System of Diesel and Rankine Engines," SAE Int. Publication 2007-01- 0537 (2015).

[8] Cavazzuti Marco, Agnani Elia, Mauro A. Corticelli. Optimization of a finned concentric pipes heat exchanger for industrial recuperative burners. Appl Therm Eng 2015; 84:110-7.

[9] Amini Amir, Miller Jeremy, Jouhara Hussam. An investigation into the use of the heat pipe technology in thermal energy storage heat exchangers. Energy 2017; 136:163-72.

[10] Reis Max Mauro L, Gallo Waldyr LR. Study of waste heat recovery potential and optimization of the power production by an organic Rankine cycle in an FPSO unit. Energy Convers Manag 2018; 157:409-22.

[11] Revesz Akos, Chaer Issa, Thompson Jolyon, Mavroulidou Maria, Gunn Mike, Amendment Graeme. Modelling of heat energy recovery potential from underground railways with nearby vertical ground heat exchangers in an urban environment. Appl Therm Eng 2019; 147:1059-69.

[12] Cai Huikun, Su Lijun, Liao Yidai, Weng Zeju. Numerical and experimental study on the influence of top bypass flow on the performance of plate fin heat exchanger. Appl Therm Eng 2019; 146:356-63.

[13] Rajesh Ravi, Senthil Kumar Pachamuthu, Padmanathan Kasinathan. Computational and experimental investigation on effective utilization of waste heat from diesel engine exhaust using a fin protracted heat exchanger, Energy 200 (2020) 117489.

[14] Fernandez Ya, Armas O, Capetillo A, Martínez-Martínez S. Thermal ~ analysis of a thermoelectric generator for light-duty diesel engines. Appl Energy 2018; 226:690-702.

[15] Baidya Durjoy, Marco Antonio Rodrigues de Brito, Sasmito Agus P, Scoble Malcolm, Ghoreishi-Madiseh Seyed Ali. Recovering waste heat from diesel generator exhaust; an opportunity for combined heat and power generation in remote Canadian mines. J Clean Prod 2019; 225:785-805.

[16] Hatami M, D Ganji D, Gorji-Bandpy M. Experimental and thermodynamically analyses of the diesel exhaust vortex generator heat exchanger for optimizing its operating condition. Appl Therm Eng 2015; 75:580-91.

[17] Hatami M, D Ganji D, Gorji-Bandpy M. Experimental and numerical analysis of the optimized finned-tube heat exchanger for OM314 diesel exhaust exergy recovery. Energy Convers Manag 2015; 97:26-41.

[18] Mastrullo R, Mauro AW, Revellin R, Viscito L. Modeling and optimization of a shell and louvered fin mini-tubes heat exchanger in an ORC powered by an internal combustion engine. Energy Convers Manag 2015; 10:697-712.