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Thermal Characteristics of Different Shaped Fin Protracted Heat Exchanger in Diesel Engine Exhaust using CFD

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ABSTRACT

The current presents looks at exhaust gases' potential to recover low-grade waste-heat energy from internal combustion engines (ICEs). A Prolonged Fin Counter Flow Heat Exchange (PFCHE) double tube was planned, analyzed, and supplied with water as working fluids to achieve this objective. The structure of a double pipe, Protracted Fin Heat Exchanger (PFCHE), which performs a simulation study, is derived with exact measurements from one by Rajesh Ravi et al. (2020) research scholar, and then different shapes of the fin profiles were introduced in the designs suggested. The Fluent 17.0 is used for numerical analysis. The CFD results showing that the PFCHE with triangular fin outperforms the PFCHE with circular fin, and previous studies by Rajesh Ravi et al. (2020) showing that the PFCHE with triangular fin outperforms the PFCHE with circular fin. When compared to the PFCHE with circular fin, the PFCHE net heat transfer rate is 1.76 percent higher and 2.82 percent higher than Rajesh Ravi et al. (2020) report.

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

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I. INTRODUCTION

Systems solution plays an essential role to meet renewable energy usage goals in the energy efficiency and effective use of resources. Diesel engines are often called fuel-saving engines and are used mostly in commercial vehicles, locomotives, heavy construction machinery, ships and big pick-ups, and in electricity generation for power plants and solar plants. The diesel engines are the most preferred for generating energy in small scales because of their easy maintenance, high thermal efficiency and their decent performance.

While about 30-45 percent of the fuel in ICE (internal combustion engines) is transformed into useful operation, the EGR (exhaust gas recirculation), exhaust gas and heat loss remain unproductive. The gas wastes account for up to 40% of the thermal output, while the refrigeration device and the friction loss account for the remainder of the power. While about 30-45 percent of the fuel in ICE (internal combustion engines) is transformed into useful operation, the EGR (exhaust gas recirculation), exhaust gas and heat loss remain unproductive. The gas wastes account for up to 40% of the thermal output, while the refrigeration device and the friction loss account for the remainder of the power.

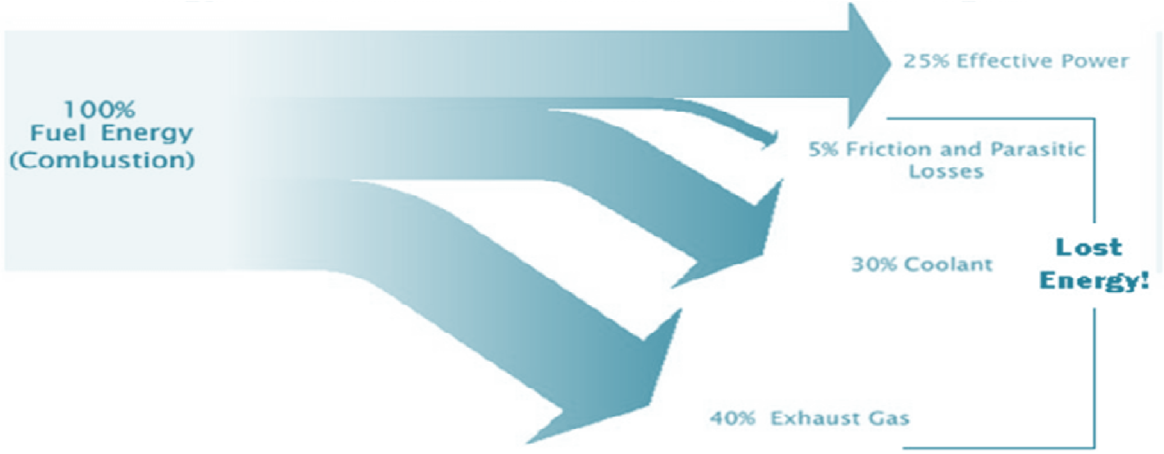


Figure 1 Loss of energy in ICEs (internal combustion engines)

ICEs are given a clear priority by the fuel prices and the re-examination of high emission requirements worldwide and the need to maximize the efficacy of the heat energy produced and the volume of dangerous pollutants emitted by engines.

The new research projects have retrieved heat from the exhaust gas engine by means of creative measures. The technologies used for the use of WHR engines include thermal electric generators, turbo blends, rankine cycles, organic rankine cycles, gas Turbine cycles, gas exhaust recycling, auto-climate, and the set-up of six strokes.

II. LITERATURE REVIEW

Every phase in research and creation of the WHR requires a well-defined review and evaluation of scientific literature. A systematic review of prior works is a first step in the analysis work. The analysis process includes specific records, comprehensive surveys and tentative evaluations. This article summarized several research articles reviewed by colleagues in order to clarify several theories.

In order to quantify the exhaust waste heat available from a 60kW car engine, the experiment was performed by **Shena Hussain Rubaiyat (2010)** and the configuration of the heat exchanger was improved by computer simulations. They used two thermal exchangers: one for saturated production and the other for superheated steam production. It has been found that at least 18 percent extra power can be accomplished with the exhaust heat available from the diesel engine[1].

In traditional, two wheels and four wheelers, **S. N Srinivasa et al. (2012)** have tried to investigate different possibilities for heat waste recovery methods. A modern hybrid engine design was also addressed in this sense. Three various methodologies recover the heat energy in the exhaust gas[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) researched various technologies for heat recovery from the exhaust gas of IC motors and concluded that waste heat can be extracted from the exhaust gas of IC engines with huge potential[3].

Mohd Noor (2013) developed waste heat recovery technologies and transforms them into usable energy like electricity. The research focused on waste heat recovery strategies based on recent advances in the automotive industry. Future energy recoveries, technical performances, and other factors that impact on deployment were analyzed[4].

MojtabaTahani (2014) analyzed the two separate Organic Rankine cycle configurations with the potential to recover simultaneous waste gas heat and 12L diesel engine coolants: Maximizing the power production and thermal cycle performance were the key goals in the optimisation process [5].

The WHR from dual cycle power generation method studied by **Miller EW et al. (2015).** To optimize WHR the machine uses the TEG and ORC technology. This is largely attributed to ORC, which results in the largest increase in the amount of electricity. Just a limited amount of energy generated by TEG can be used for parasite heat loss, i.e. for fans and power steering pumps[6].

A computational module for recovery of waste heat from exhaust gas in the engine was created by **H.Teng et al. (2015).** They concluded, whenever ORC is mounted in the engine, its output in relation to the efficiency of the original engine was improved[7].

In this analytical analysis, **Marco Cavazzuti et al. (2015)** simulated the finned concentrate pipes with the aid of a CFD heat exchanger that was also optimized with the help of a downhill optimisation algorithm from Nelder and Mead simplilex. It has been found that, by simply tuning few geometric parametern, the efficiency of the exchangers can be improved[8].

In this research, **Amir Amini et al. (2017)** documented and experimented with the heat pipe technique to increase the use of PCMs for energy storage. When superior fining techniques were used on the side of the heat pipe condenser the research findings for the heat transfer have improved[9].

The research aimed at identifying the best possible WHR solution in the FPSO "Floating production storage and deloading" platform, **Max Mauro L. Reis et al. (2018),** to ensure the demand for heat energy is met. Furthermore, the study aimed at increasing electricity generation through ORC in order to improve overall thermal efficiency and minimize CO2 emissions. The study found that if ORC is deployed in the WHR system, the fuel consumption decreased on average to 22.5 percent plus the CO2 emissions in the lifetime of the FPSO [10].

AkosRevesz et al. (2019) also suggested a new method of extracting waste heat from the Underground Railways in this study (URs). The study was completed after five separate experiments to build a framework of different geometrical parameters. The study findings showed that the operation of the UR tunnel on the adjacent vertical GHEs would have a major impact[11].

Cai et al. (2019), The study aimed to detect the effect of high bypass flow on the efficiency and architecture of the integrated PFHE plate heat exchanger. This is wished for as a directive in a variety of areas for future PFHE implementations. The findings of the analysis showed an improvement in the average heat transfer in simulation with the bypass flow, relative to the plate-fin heat exchanging unit that decreased by 19.1 percent compared to the experimental results, at 10 m/s the overall difference was 82.76 percent [12].

Rajesh Ravi et al. (2020), Examines the ability of exhaust gases to recycle energy from internal combustion engine (ICEs) to generate low-quality waste heat. To do this, a dual pipe has been planned, studied, developed and experimented with binary (water-ethanol) mixtures as work fluids by the Protracted Finned Counterflow Heat Exchanger (PFCHE). The theoretical concept was finished and computer simulation of PFCHE was carried out in the current work as a first step. A optimistic concept about the total performance of the heat recovery system has been found in laboratory research and empirical studies.

The heat transfer rate was also increased as the number of fins increased with their height, which further allowed the performance of the heat regenerating system to be improved and the brake's thermal efficiency increased from 32% to 39.6%. When the turbines operated at 1 700 rpm to 3800 rpm, the built heat recovery system could provide a capacity of 0.35 kW-0.76 kW. Overall, the analysis concludes that in comparison with conventional, fine heat exchangers the operating fluid outlet temperature, performance, heat transfer rate and overall thermal efficiency are improved by PFCHE [13].

Based on the literature analysis, the surplus heat energy in the exhaust gas is utilized by various kinds of heat exchangers and organic rankine cycles. Earlier investigations have primarily concentrated on heat exhaust energy extraction. There have been, however, no studies related to the groundbreaking heat recovery heater exchanger and parallel decreasing emissions. This involve the development of a new technical framework to boost the energy recovery and exhaust pollution reductions of diesel engines for the exhaust heat recovery interchanger.

III. GEOMETRY SETUP AND MODELLING

The present research investigates the ability of exhaust flow gasses in the internal combustion engines to recover low heat waste energy (ICEs). For this reason, a double pipe with water as working fluids has been built and analysed, Prolonged Finnish Counter flow (PFCHE).In this segment, the study establishes a CFD model for analyzing thermal transfer properties in a double tubing, Protracted Finned Heat Exchanger Counterflow (PFCHE). CFD analysis consists of three major steps: (a) pre-processing, (b) execution of solver. The first step involves the geometry of the desired model and the creation of mesh, while the results are displayed in the final step, as planned. In the solver execution (middle) level, boundary conditions are fed into the model.

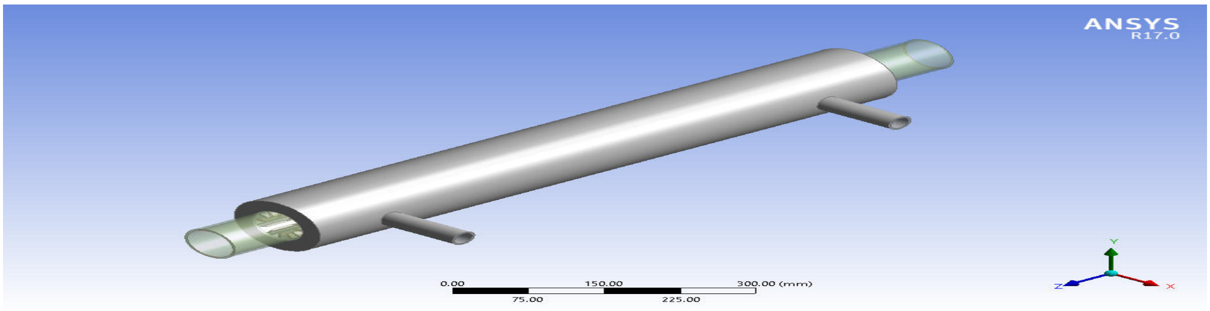


Figure 2 PFCHE model with fin (Rajesh Ravi et al., 2020)

The geometry of the double pipe, Protracted Finned Counter Flow Heat Exchanger (PFCHE) used in the simulation analysis was taken from one of the research scholar's Rajesh Ravi et al. (2020) with exact dimensions, and then separate fin profiles were used in the proposed designs. In his work, the best PFCHE configuration, consisting of 12 fins of each 30 mm protrusion height, achieved the lowest exhaust gas outlet temperature and the highest heat transfer rate. As a result, for the current analysis, 12 fins of 30mm protrusion height are considered. The model was created using the ANSYS (fluent) workbench 17.0 program.

In this study, new fin shapes in PFCHE are suggested, including circular and triangular shaped fins.

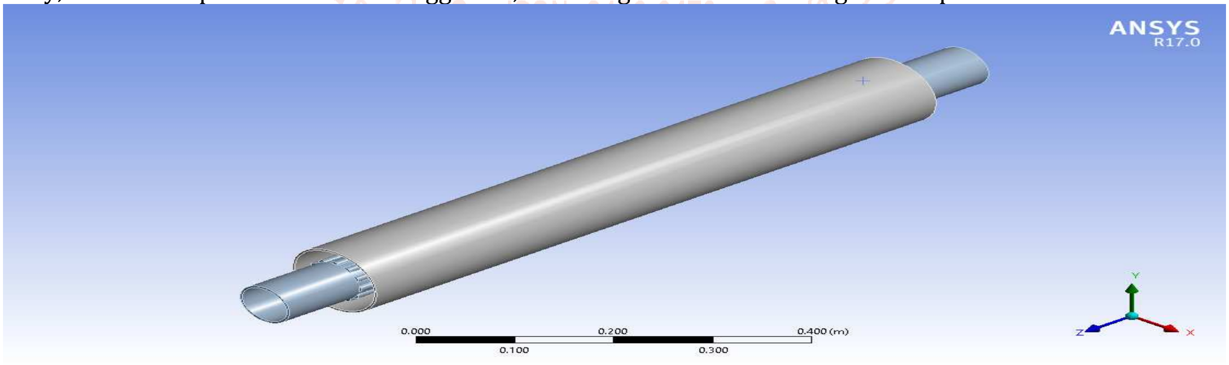


Figure 3 The PFCHE model has a circular fin shape (12fins of 30 mm fin height)

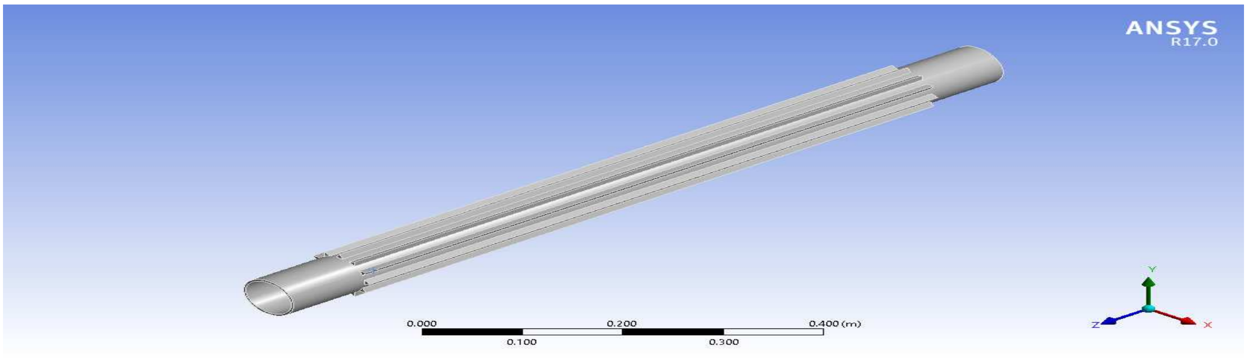


Figure 4 PFCHE model with a triangular fin (12fins of 30 mm fin height)

A three-dimensional discreet PFCHE model with fin was built in the pre-processor stage of ANSYS FLUENT R17.0. Although grid type is related to the output of simulation, the whole structure is discretized in the finite volume of the tetrahedral grids of Quad core such that PFCHE's thermal properties are reliably calculated with fine grids.

Table 1 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

To compute, the Fluent 17.0 program was used. A finite element method was used in experiments to distinguish the governing equations. The researchers used a simpler algorithm for this convective term, and the second order upwind method was used to relate pressure and velocity calculations. Turbulence was solved using a regular k-epsilon equation in conjunction with flow and energy

Table 2 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/m^2
Density	p_h	0.696	p_c	998	kg/m^3
Mass flow rate	m_h	0.00934	m_c	0.0054	kg/s

The discretized flow domain was configured with suitable boundary conditions. Inlets were assigned mass flow boundary conditions, while outlets were assigned pressure outlet boundary conditions. The surfaces of the heat exchangers were regarded as normal wall boundaries. The outer walls had insulated boundary conditions, while the inner walls had coupled-thermal wall boundary conditions. Table 5.4 outlines the boundary conditions of heat exchanger operating fluids.

Table 3 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

IV. RESULTS AND DISCUSSIONS

The aim of this section is to evaluate the thermal efficiency of various proposed fin designs in PFCHE. Variations in temperature and heat transfer are tested to study the efficiency of PFCHE with various shapes of fin subject to flow.

4.1. 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. 5.3.

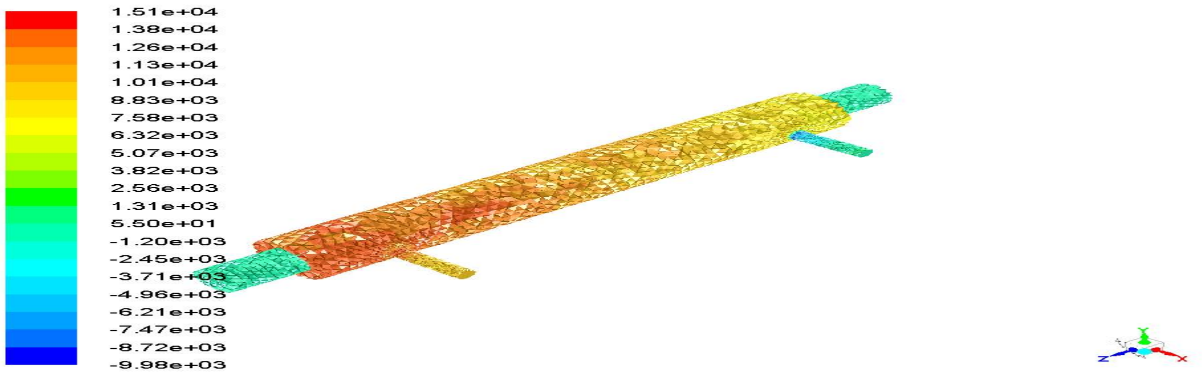


Figure 5 At a braking power of 3.53 KW, the PFCHE pressure contour

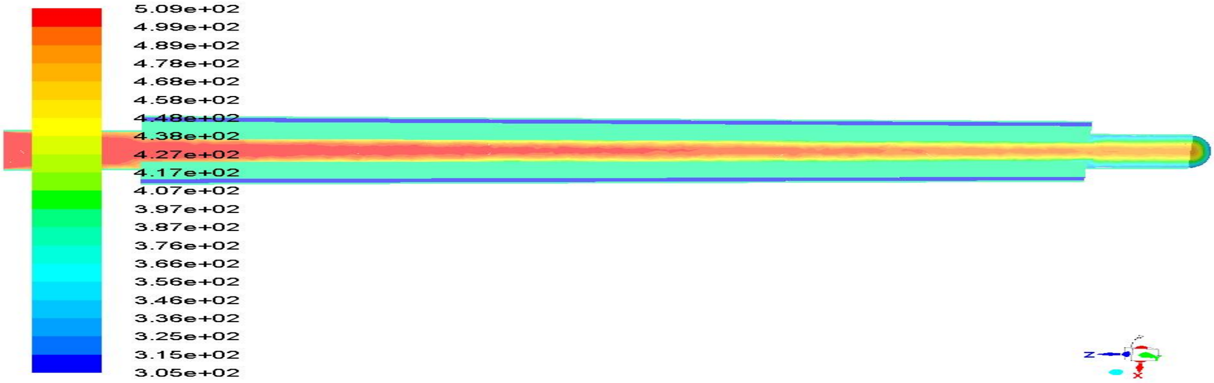


Figure 6 at a braking power of 3.53 KW, the PFCHE temperature contour

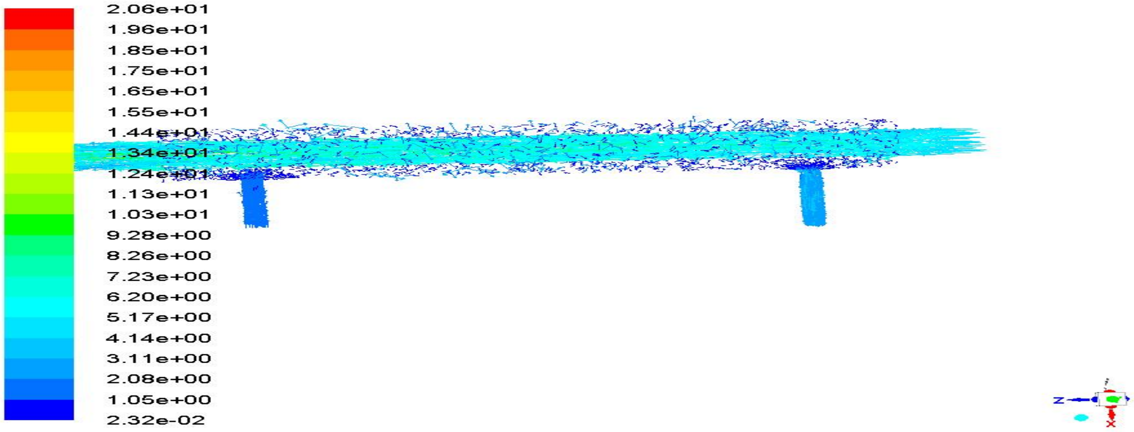
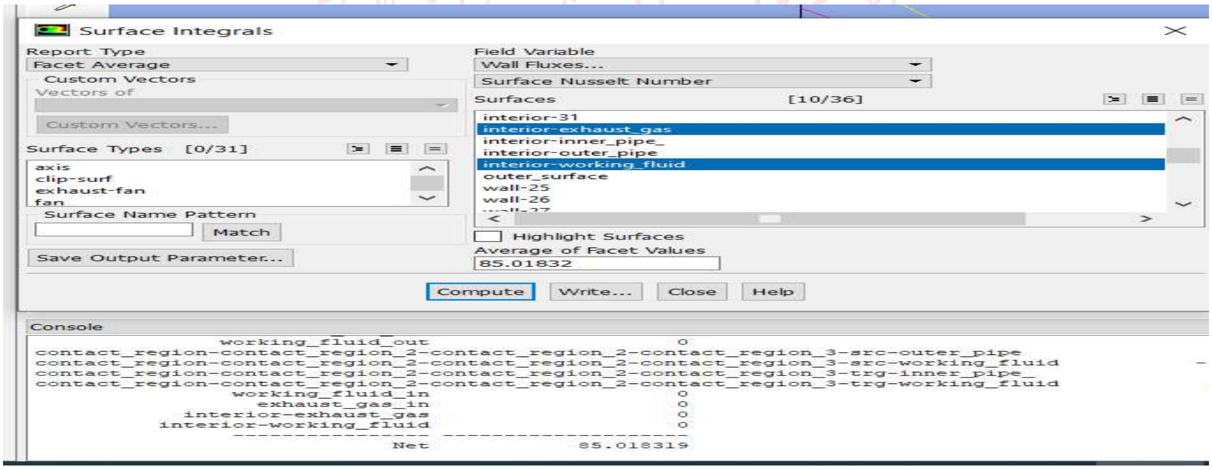


Figure 7 at a braking power of 3.53 KW, the PFCHE velocity contour



Report Type
Facet Average

Field Variable
Wall Fluxes...
Surface Nusselt Number

Surface Types [0/31]
axis
clip-surf
exhaust-fan
fan

Surfaces [10/36]
interior-31
interior-exhaust_gas
interior-inner_pipe_
interior-outer_pipe
interior-working_fluid
outer_surface
wall-25
wall-26

Average of Facet Values
85.01832

```
                  working_fluid_out                      0
contact_region-contact_region_2-contact_region_2-contact_region_3-src-outer_pipe
contact_region-contact_region_2-contact_region_2-contact_region_3-src-working_fluid
contact_region-contact_region_2-contact_region_2-contact_region_3-trg-inner_pipe_
contact_region-contact_region_2-contact_region_2-contact_region_3-trg-working_fluid
                   working_fluid_in                      0
                      exhaust_gas_in                     0
               interior-exhaust_gas                      0
             interior-working_fluid                      0
                   ---------------- --------------------
                               Net               85.018319
```

Figure 8 at a braking power of 3.53 KW, the PFCHE Nusselt number

The values derived from CFD modeling for exhaust gas outlet temperature, working fluid outlet temperature, heat transfer rate, and Nusselt number were compared to the values obtained from Rajesh Ravi et al. (2020).

Table 4 indicates the temperature of the exhaust gas outlet calculated by CFD versus the values obtained from the Rajesh Ravi et al. (2020) PFCHE analysis

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

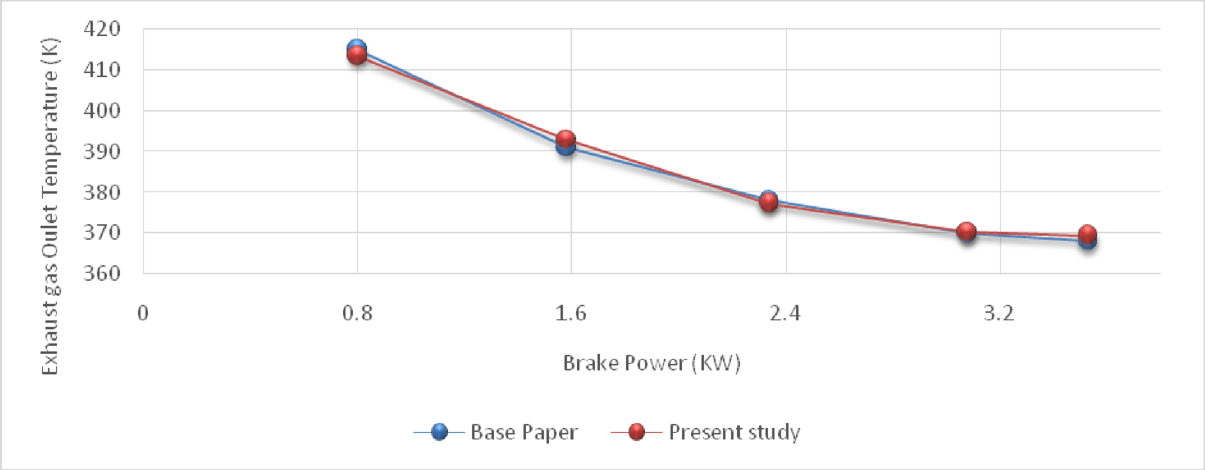


Figure 9 The temperature of the exhaust gas outlet calculated on the CFD models as against the Rajesh Ravi et al. (2020) values for PFCHE analysis

Table 5 indicates the net heat transfer performance of the CFD models against the Rajesh Ravi et al. (2020) PFCHE Sample values

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

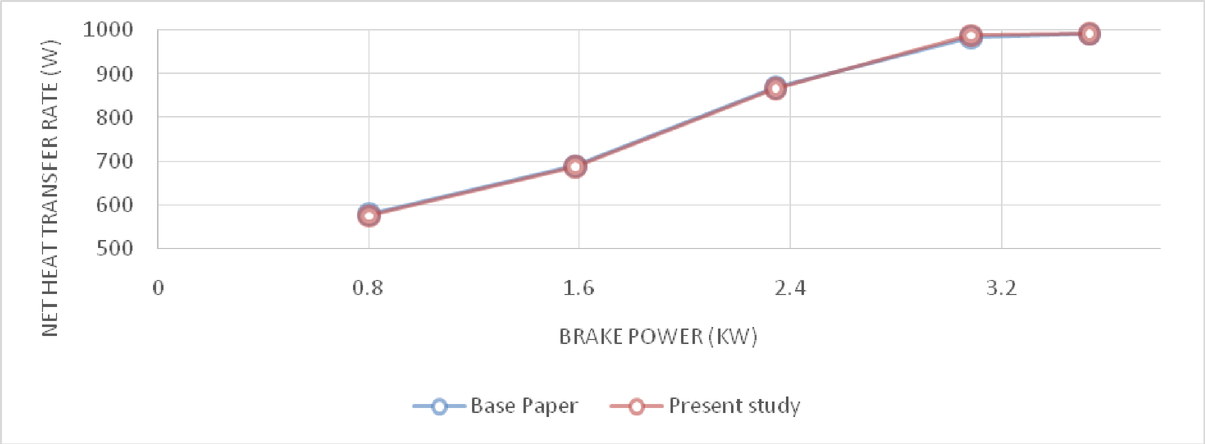


Figure 10 CFD model net thermal transfer values as opposed to Rajesh Ravi et al. (2020) values of PFCHE analysis

The latter confirmation research states that exhaust gas exhaust temperature values and CFD net heat transfer rate are identical to exhaust gas exhaust temperature values and the net heat transfer rate obtained from a basic journal. Here we can say that the PFCHE model is valid with fin CFD.

4.2. PFCHE model simulated outcomes of triangular fin results

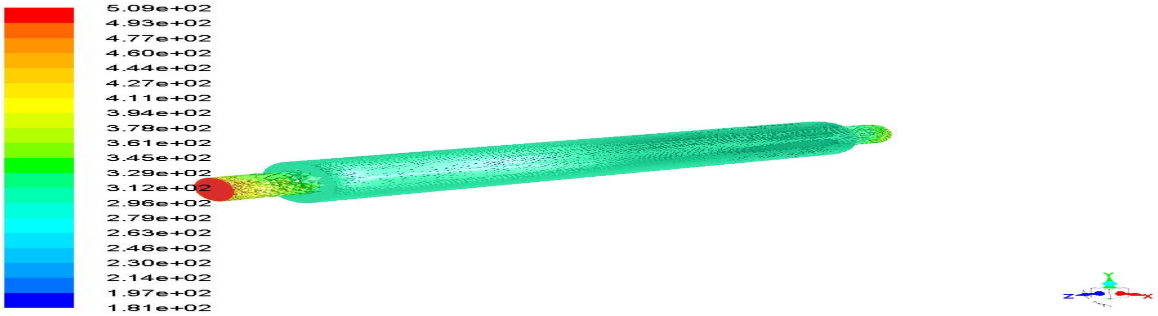


Figure 11 at a brake power of 1.58 KW, PFCHE with triangular fin temperature contour

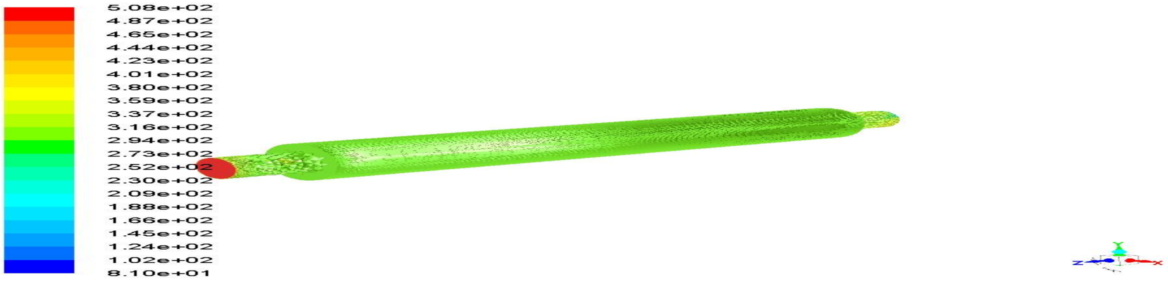


Figure 12 at a brake power of 2.34 KW, PFCHE with triangular fin temperature contour

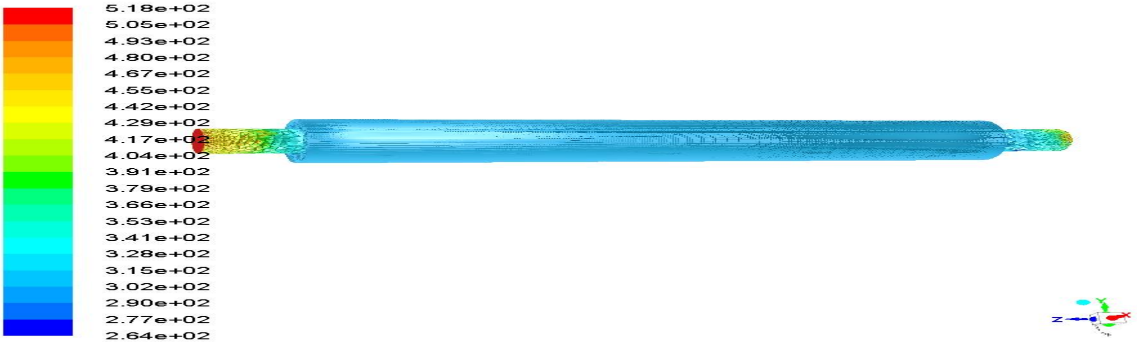


Figure 13 at a brake power of 3.08 KW, PFCHE with triangular fin temperature contour

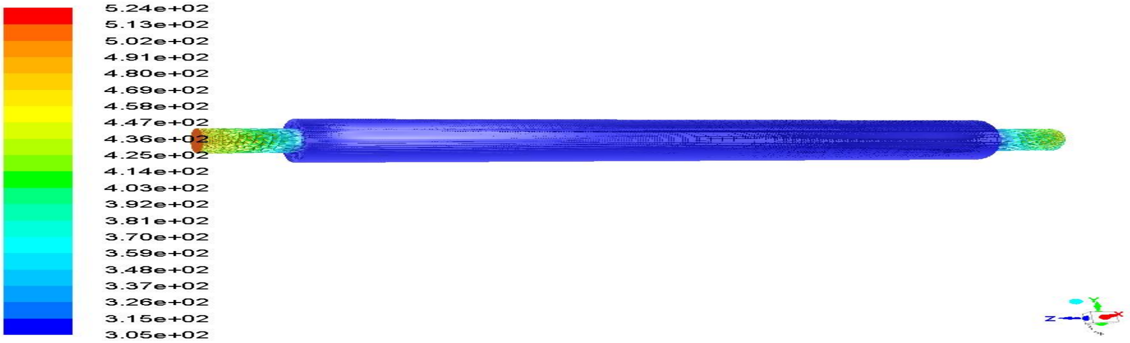


Figure 14 at a brake power of 3.53 KW, PFCHE with triangular fin temperature contour.

4.3. Comparison of PFCHE with different fin designs

Table 6 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

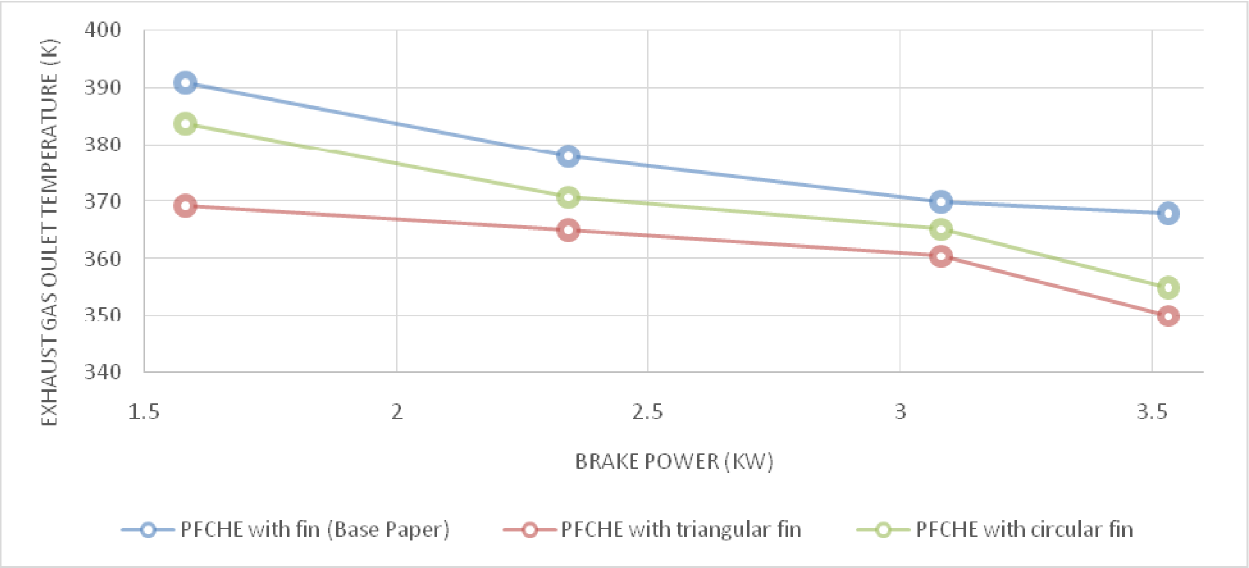


Figure 15 The temperatures of the exhaust gas outlet (K) for different fin designs are compared

Table 7 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

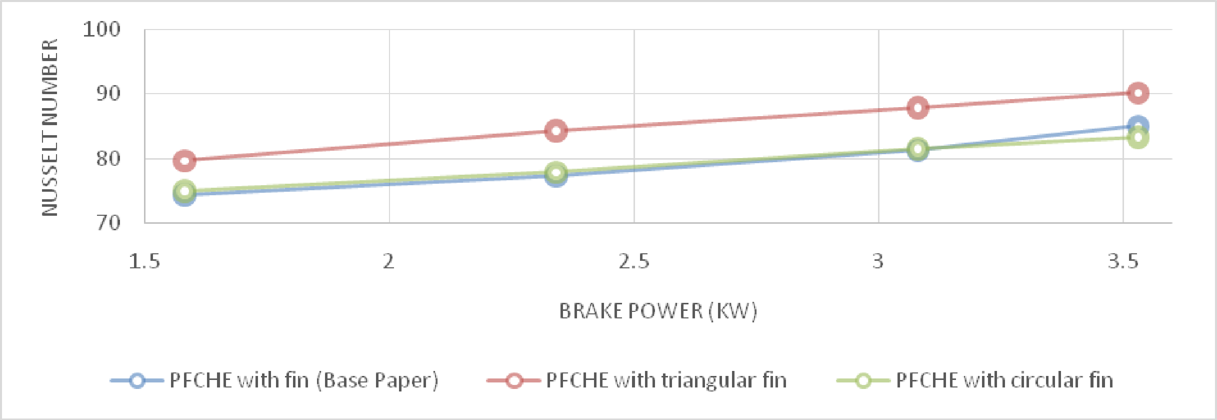


Figure 16 Comparison of the values of Nusselt number for different fin designs

Table 8 A comparisons of the values of Net heat transfer rate for various 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

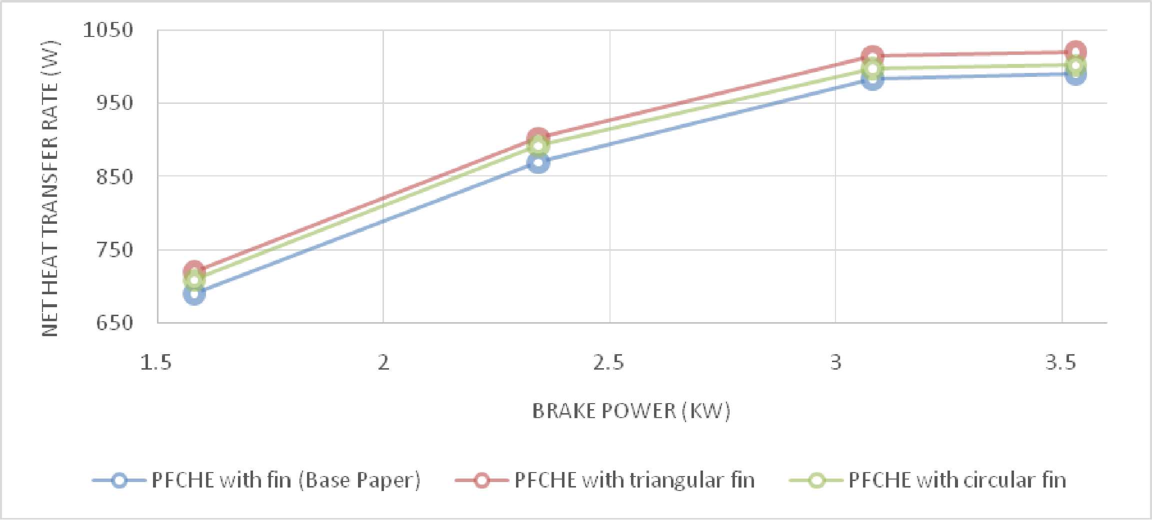


Figure 17.Net heat transfer rate values for various fin designs are compared.

V. CONCLUSIONS

The following results can be drawn from the CFD observations.

- According to the results of the study, the PFCHE with triangular fin outperforms the PFCHE with circular fin and previous work by Rajesh Ravi et al (2020).
- In contrast, the net heat transfer rate of PFCHE with triangular fin is 1.76 percent greater than that of PFCHE with circular fin and 2.82 percent greater than that of Rajesh Ravi et al (2020).
- According to the computational results, the PFCHE models with triangular fins had the highest heat transfer rates of 1020.98 W.
- In contrast, the exhaust gas temperature of the PFCHE with triangular fin at the outlet is 350.04 K at 3.53 KW brake capacity, while the circular fin has a temperature of 355.054 K and the work recorded by Rajesh Ravi et al. (2020) has a temperature of 368 K.
- In contrast, the Nusselt number of PFCHE with triangular fin is 90.26 at 3.53 KW brake capacity, while it is 83.37 with circular fin and 85.01 with work stated by Rajesh Ravi et al. (2020).

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