To Get a Power Generation Using a Waste Heat Recovery from IC Engine

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Abstract
This Research paper aims to develop and design a low-temperature organic Rankine cycle (ORC) system, focusing on enhancing the performance of the expander and selecting optimal refrigerants and heat sources. The study begins with a comprehensive analysis of available expanders and refrigerants suitable for ORC applications. The research then progresses to the development and improvement of an expander utilizing a reverse scroll compressor configuration, a novel approach aimed at enhancing efficiency and performance.

Dynamic tests are conducted to assess the performance of the scroll compressor in this new configuration, providing valuable data for further optimization. The same expander is then integrated into an ORC system to evaluate its performance within the overall setup. Various performance parameters of the scroll compressor and the ORC system are meticulously analyzed to gauge efficiency and identify areas for improvement.

Furthermore, the research paper includes a detailed process of selecting the most appropriate refrigerant and heat source from the available options. This selection is critical in optimizing the ORC system's effectiveness and sustainability. Overall, this research contributes to advancing low-temperature ORC technology by improving expander design, optimizing component performance, and selecting suitable operating parameters for enhanced energy conversion efficiency.

Keywords: Waste Heat Recovery (WHR), Internal Combustion Engine (ICE), Power Generation, Energy Efficiency, Renewable Energy, Thermal Energy Recovery, ORC System (Organic Rankine Cycle), Waste Heat Utilization, Heat Exchangers, Efficiency Improvement, Emission Reduction, Sustainable Energy, Heat Recovery Systems, Exhaust Heat Recovery, Waste Heat to Power (WHP), Cogeneration.

1. Introduction

Almost 1.5 billion individuals worldwide don't have access to electricity. Most of those electricity under privileged board geographical region and south Asia. Usually, this population lives in remote areas aloof from the centralized electricity grid with terribly low financial gain and lengthening the electricity isn't seen as economically possible for electricity firms that like better to concentrate their activities in urban areas. On the opposite hand, existing standard power plants use fossil fuels as inputs and integrated in centralized systems. Derived consequences power losses in transportation lines thanks to remoteness of the electricity infrastructure from the shoppers and environmental pollution. Pollution discharged within atmosphere are accountable of the gas depletion, warming, acid rains and contamination of land and seas. During this context, victimization renewable energies like alternative energy, wind energy, biomass and energy heat still as waste heat for electricity production becomes vital [1].

The recovery and utilization of waste heat not solely conserves fuel, typically fuel however conjointly reduces the quantity of waste heat and greenhouse gases damped to surroundings. It's imperative that serious and concrete effort ought to be launched for preserving this energy through exhaust heat recovery techniques. Such a waste heat recovery would ultimately scale back the general energy demand and conjointly the impact on heating. The inner Combustion Engine has been a primary power supply for cars and automotive over the past century. Presently, high fuel prices and considerations regarding foreign oil dependence have resulted in more and more complicated engine styles to decrease fuel consumption [1].

For instance engine makers have enforced techniques like increased fuel-air mixture, turbo-charging, and variable valve temporal order so as to extend thermal potency. However, around 60-70% of the fuel energy remains lost as waste heat through the fluid or the exhaust. Moreover, more and more rigorous emissions rules are inflicting engine makers to limit combustion temperatures and pressures lowering potential potency gains. Because the most generally used supply of primary power for machinery crucial to the transportation, construction and agricultural sectors, engine has consumed quite hour of fossil oil. On the opposite hand, legislation of exhaust emission levels has targeted on Carbon Monoxide (CO), hydrocarbons (HC), atomic number 7 oxides (NOx), and stuff (PM). Energy conservation on engine is one in all best ways in which to contend with these issues since it will improve the energy utilization potency of engine and reduces emissions.

Figure 1: 1st law and 2nd law of energy and energy distribution in an internal combustion engine [1]

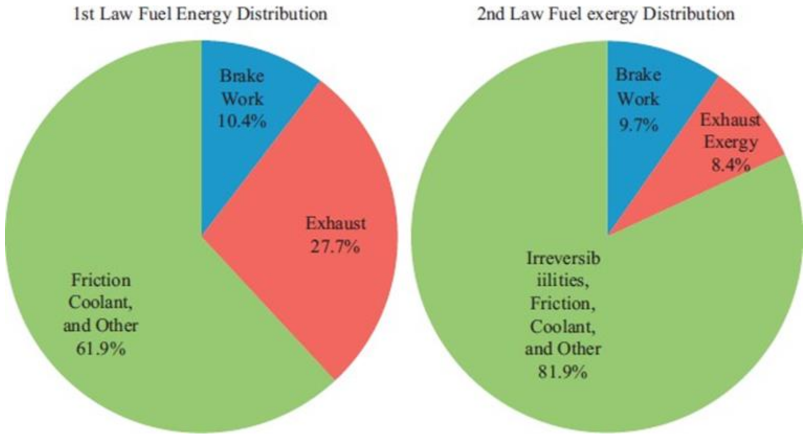
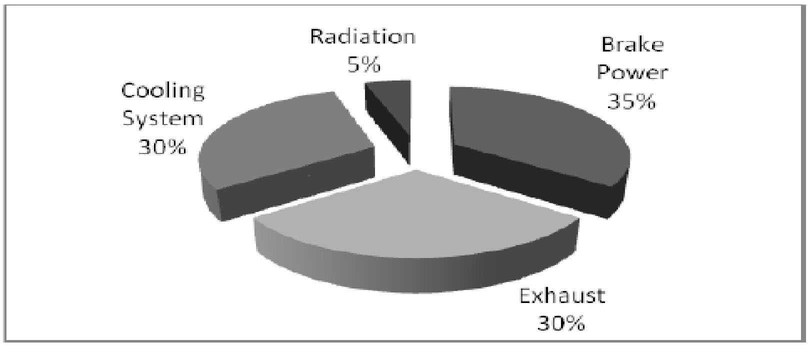


Figure 2: Total Fuel Energy Content in I. C. Engine [2].



1.1 Benefits of 'waste heat recovery' can be broadly classified in two categories

1.1.1 Direct Benefits: Recovery of waste heat encompasses a direct impact on the combustion method potency. This can be mirrored by reduction within the utility consumption and method price.

1.1.2 Indirect Benefits:

- **Reduction in pollution**: variety of deadly flammable wastes like CO (CO), hydrocarbons (HC), atomic number 7 oxides (NOx), and stuff (PM) etc., emotional to atmosphere. Sick of warmth reduces the environmental pollution levels.
- **Reduction in instrumentation sizes:** Waste heat recovery reduces the fuel consumption that results in reduction within the flue gas created. This leads to reduction in instrumentation sizes.
- **Reduction in auxiliary energy consumption:** Reduction in instrumentation sizes provides extra edges within the sort of reduction in auxiliary energy consumption.

1.2 Possibility of Waste Heat from Internal Combustion Engine

Today's modern life is greatly depends on automobile engine, i.e. Internal Combustion engines. The majority of vehicles are still powered by either spark ignition (SI) or compression ignition (CI) engines. CI engines also known as diesel engines have a wide field of applications and as energy converters they are characterized by their high efficiency. Small air-cooled diesel engines of up to 35 kW output are used for irrigation purpose, small agricultural tractors and construction machines whereas large farms employ tractors of up to 150 kW output. Water or air-cooled engines are used for a range of 35-150 kW and unless strictly air cooled engine is required, water-cooled engines are preferred for higher power ranges.

Earth moving machinery uses engines with an output of up to 520 kW or even higher, up to 740 kW. Marine and locomotive applications usually employ engines with an output range of 150 kW or more. Trucks and road engines typically use high speed diesel engines with 220 kilowatt output or a lot of Diesel engines employed in tiny electric power generating units or as standby units for medium capacity power stations.

Table 1: Various engine and their output

Sr. No	Engine type	Power output (kw)	Waste heat
1	Small air cooled diesel engine	35	30 to 40% of energy waste loss from I C Engine
2	Water cooled engine	35-150	
3	Marine application	150-220	
4	Truck and road engines	220	

The table 1, shows that various engine and there power ranges. In general, diesel engines have an efficiency of about 35% and thus the rest of the input energy is wasted. Despite recent improvements of diesel engine efficiency, a considerable amount of energy is still expelled to the ambient with the exhaust gas.

In a water-cooled engine about 35 kW and 30-40% of the input energy is wasted in the coolant and exhaust gases respectively. The amount of such loss, recoverable at least partly, greatly depends on the engine load. Mr. Johnson found that for a typical 3.0 l engine with a maximum output power of 115 kW, the total waste heat dissipated can vary from 20 kW to as much as 400 kW across the range of usual engine operation.

It is suggested that for a typical and representative driving cycle, the average heating power available from waste heat is about 23 kW, compared to 0.8–3.9 kW of cooling capacity provided by typical passenger car VCR systems. Since, the wasted energy represents about two-thirds of the input energy and for the sake of a better fuel economy, exhaust gas from Internal Combustion engines can provide an important heat source that may be used in a number of ways to provide additional power and improve overall engine efficiency.
These technical possibilities are currently under investigation by research institutes and engine manufacturers. For the heavy duty automotive diesel engines, one of the most promising technical solutions for exhaust gas waste heat utilization appears to be the use of a useful work.

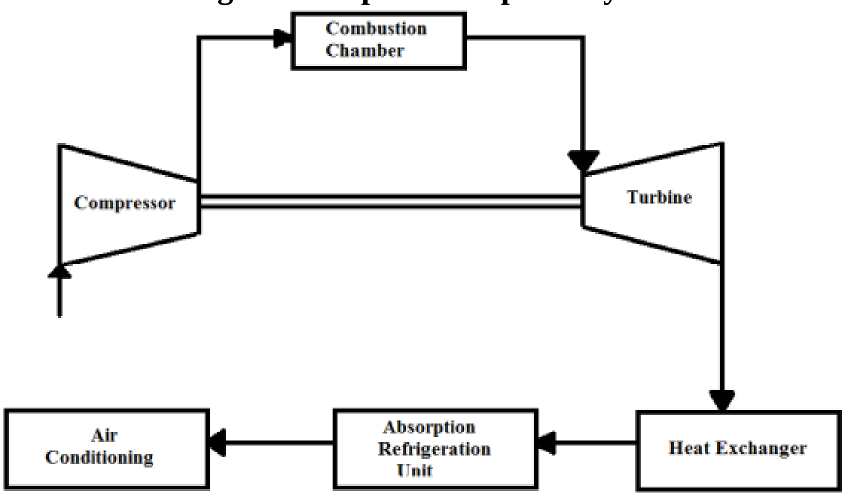
2. Literature Review

J. S. Jadhao and D. G. Thombare [1] has performed an experiment on review of Exhaust Gas Heat Recovery for I.C. Engine. The increasingly worldwide problem regarding rapid economy development and a relative shortage of energy, the internal combustion engine exhaust waste heat and environmental pollution has been more emphasized heavily recently. Out of the total heat supplied to the engine in the form of fuel, approximately, 30 to 40% is converted into useful mechanical work; the remaining heat is expelled to the environment through exhaust gases and engine cooling systems, resulting in to entropy rise and serious environmental pollution, so it is required to utilized waste heat into useful work.
The recovery and utilization of waste heat not only conserves fuel (fossil fuel) but also reduces the amount of waste heat and greenhouse gases damped to environment.
The study shows the availability and possibility of waste heat from internal combustion engine, also describe loss of exhaust gas energy of an internal combustion engine. Possible methods to recover the waste heat from internal combustion engine and performance and emissions of the internal combustion engine. Waste heat recovery system is the best way to recover waste heat and saving the fuel [1].

2.1 Possible way of using heat recovery system

- Heating Purpose
- Power Generation Purpose
- Refrigeration

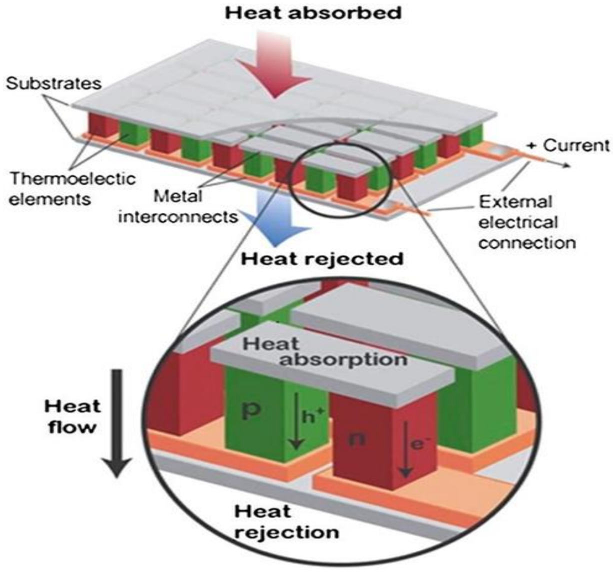
Figure 3: Vapor Absorption Cycle



R. Saidur, M.Rezaei, W.K.Muzammil, M.H.Hassan, S.Paria, M.Hasanuzzaman [2] has performed an experiment on Technologies to recover exhaust heat from internal combustion engines. The focus of this study is to review the latest developments and technologies on waste heat recovery of exhaust gas from internal combustion engines (ICE). These include thermo electric generators (TEG), organic Rankine cycle (ORC), six-stroke cycle IC engine and new developments on turbocharger technology. Furthermore, the study looked into the potential energy savings and performances of those technologies. The current worldwide trend of increasing energy demand in transportation sector are one of the many segments that is responsible for the growing share of fossil fuel usage and indirectly contribute to the release of harmful greenhouse gas (GHG) emissions. It is hoped that with the latest findings on exhaust heat recovery to increase the efficiency of ICEs, world energy demand on the depleting fossil fuel reserves would be reduced and hence the impact of global warming due to the GHG emissions would fade away[2].

2.2 Thermoelectric energy conversion technology

Figure 4: Schematic of a typical thermo electric device



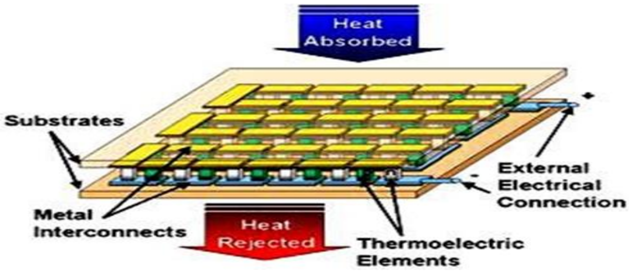
Prof. Ajit Kumar Senapati, Mr. Shakti Prasad Dash, Mr. P Rakesh [3] has performed an experiment on Thermo-Electric Generator in Turbocharged Diesel Engine. Almost every type of internal combustion engine works on the principle of Heat Engine. It's impossible to design 100% perfect Heat Engine. It converts the chemical energy into thermal energy and in the form of pressure of air carrying the heat, piston movement is done. Traditionally, only 25 to 30 percent of energy is being utilized to run the vehicles and accessories mounted on the engine and left amount of energy is wasted in various ways like in the form of exhaust and cooling of engine components.

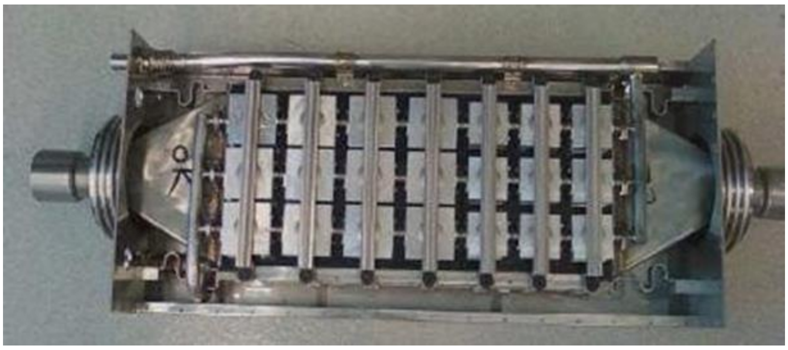
The useful energy is used to run the engine as well as generator. So the efficiency of those engines were very low. If any means energy is recovered, then the efficiency can be increased. In the current trend, based on this concept only waste energy is being recovered in different methods.

Removing the load on the engine increases the engine efficiency. Generator generally draws power from the engine through a belt drive, in turn it affects the engine efficiency. So by recovering the energy from the exhaust which contains 40% (approx.) of total amount of energy present in the fuel depending on the load on the engine. This paper describes about the thermal energy converted into electrical energy directly without any moving parts. This will help the engine to work on less load with a better fuel economy.

2.3 Construction of thermoelectric generator

Figure 5: Compact Thermoelectric Device





2.4 Problem Definition

- In the present situation, An IC engine is used in a large number of applications, and the IC engine is widely accepted worldwide.
- But, there are some limitations and disadvantages of the IC engine.
- For example, the IC engine converts only 30-40% fuel in useful work, 15-20% for coolant and the remaining 35-40% fuel is wasted in heat.
- So, our main focus to use this waste heat and convert this waste heat in useful work.

2.5 Objectives

- To generate power using waste heat.
- To generate power using refrigeration and analyze mixing of refrigerator R134 and butane.

2.6 Summary

Table 2: Summary from Literature

Author	Working on
R. Saidur	Technology to recover waste heat from I c engine
Yunfei Li	Technology to recover waste heat from I c engine
Saniya LeBlanc	Thermoelectric generators
Hua Tiana	Thermoelectric generators
Zhengchang Song	Heat transfer enhancement

By analyzing a above research paper many researcher work on the different possible way of using a waste heat of I c engine by thermo electrical charger, rankine cycle, sterling cycle And by turbocharger.

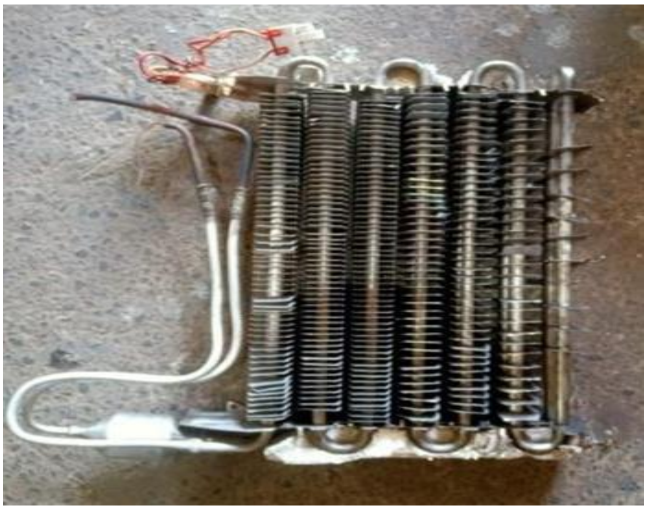
Also some researcher doing a research on material selection for thermoelectric charger. And also some has doing a great work on heat transfer and thermodynamic analysis.
From the study, it has been identified that there are large potentials of energy savings through the use of waste heat recovery technologies. The common technologies used for waste heat recovery from engine include thermo- electrical devices, organic Rankine cycle or turbocharger system.
By maximizing the potential energy of exhaust gases, engine efficiency and net power may be improved Energy efficiency is a concept which helps to obviously show the environmental impact by numbers. For waste heat recovery thermoelectric generator is use low heat, which has low efficiency. It is helpful for the same amount of increases in thermal efficiency and reduction in emission.
So, here we can do a great work on thermoelectric charger with by selecting a new electric material with good thermoelectric property. This will increase a efficiency of waste heat recovery of I c engine. Also we can do a heat recovery using a piezo electric effect and high temperature organic cycle.

3. Working principal and design

3.1 Condenser

The condenser's principle in the air-conditioning system is to remove the heat from the refrigerant vapor from the compressor. The purpose of this is to condensate the refrigerant to its liquid state. The liquid refrigerant will later achieve the refrigerating effect in the evaporator.
For a typical refrigerant condenser, the refrigerant starts by entering the condenser during a superheated state. It is then de-superheated to be condensed by rejecting heat to an external medium. Depending on the condenser's temperature and design, the refrigerant leaves the condenser as a sub-cooled or saturated liquid.

Figure 6: Condenser



Speciation:
Type: Tube Type, Multi Pass
Coil Size: 6mm
Coil Material: Copper

3.2 Scroll expander

The scroll expander is a work producing device used mostly in low-pressure heat recovery applications.

It is essentially a scroll compressor working in reverse; high enthalpy working fluid or gas enters the discharge side of the compressor and rotates the eccentric scroll before discharging from the compressor inlet.

Figure 7: Scroll Expander

Specification

Working Pressure: 343 Psi

Working Temperature Range: 75 °C to 35 °C

Mass Flow Rate: 0.1221 Kg / Sec

3.3 Compressor

In the reciprocating air compressor, the piston moves to bottom dead center (BDC) and air is sucked into a cylinder from the atmosphere and moves it to the top dead center (TDC). The compression of air starts and increasing and pressure is also increasing. After reaching the limit of the pressure the discharge valve is open and the compressed air is flowing through to the storage tank.

Figure 8: Compressor

Specification

Type: Hermotic Compressor

Pressure: 2 Psi

Capacity: 2 Tonne

3.4 Heat source

The electric heater which is immersed in water for heating the water is called Immersion Heater. In market from 250 watt to 2.0 kilo watt immersion heaters are available. The body is made of metallic substance, and the heating element is made of copper which is installed inside a capillary tube. The tube is found in „U" or Coil shape. The capillary tube is filled with magnesium oxide which works as insulator. Both the end of the tube is sealed. The supply connection is given through 3 pin socket and plug.

Figure 9: Heat source

Specification

Type: Immersion heater

3.5 Evaporator

An evaporator is a device in a process used to turn the liquid form of a chemical substance such as water into its gaseous-form/vapor. The liquid is evaporated, or vaporized, into a gas form of the targeted substance in that process.

Figure 10: Evaporator

Specification

Pass: 5 Pass

Material: Copper

Temperature Range: 70^0 to 90^0

4. Development and Experiment

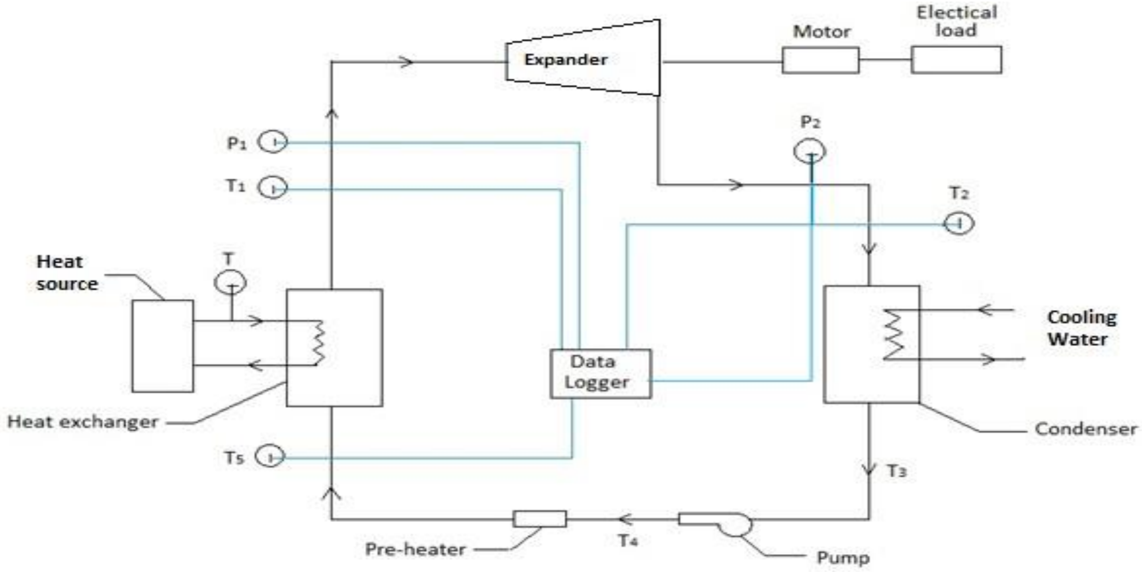
4.1 Procedure of Experiment

The main steps followed to conduct an experimental run are:

- Fully open the flow meter control valve.
- While the line flow control valve is fully closed, opened the cylinder supply valve slowly to achieve a desired regulated pressure.
- The inline flow control valve is then opened slowly to start the scroll expander and placed at full open position.
- With expander running the rotational speed in RPM is measured first with no dynamometer load and then with application of braking loads.
- Braking load is applied with varying magnitude and in each case after stabilization of shaft rotational speed data recorded.

4.2 ORC test bench

Figure 11: ORC test bench Layout

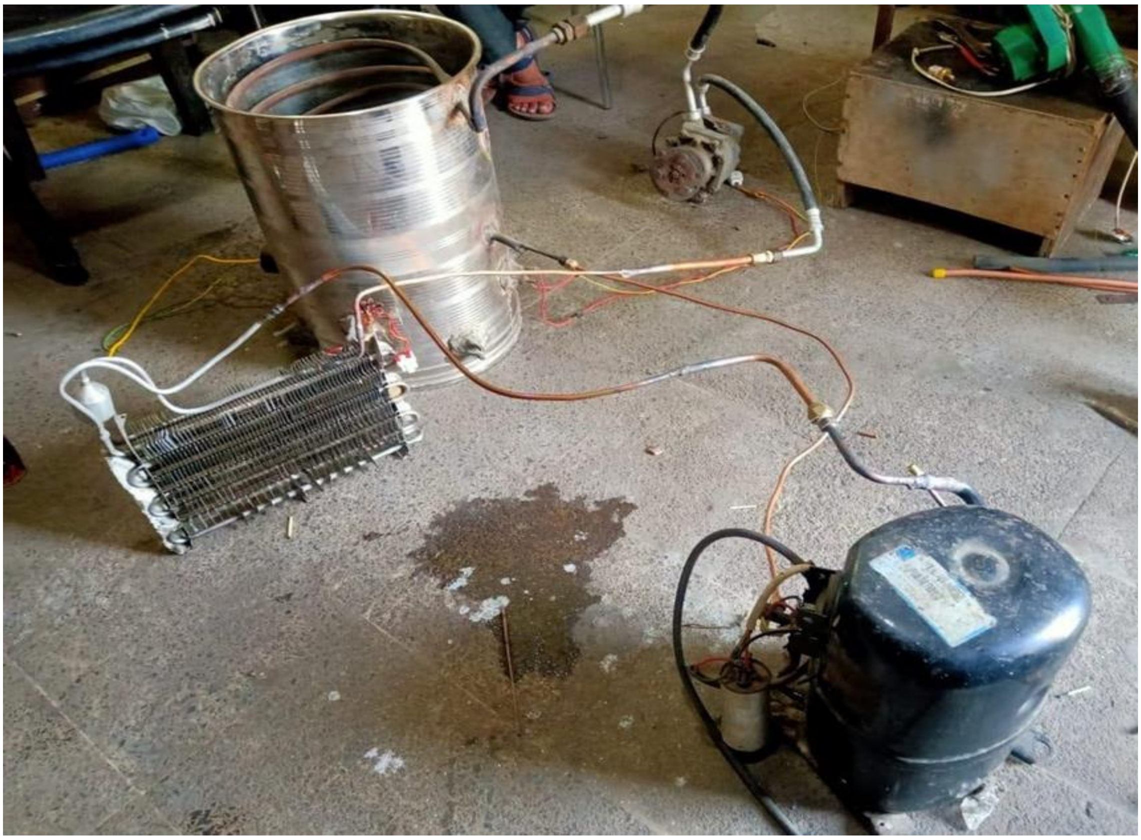


After checking of performance of expander with air same expander is used with R134a.so we can enhance the performance of expander so when same expander will use with this ORC test bench we can get appropriate power from expander.

4.3 Experiment Setup

- The most important thing while complete making of the setup is welding.
- The direction of flow is maintained as shown in the diagram, so we can perform the experiment easily.

Figure 12: Experiment Setup



4.4 Development

4.4.1 Development of Heat Source

Figure 13: Heat Source

- We have developed a heat source, so we can use a heat for our research purpose.
- We have made a heat source with 9 coil, each coil use 1200 watt power.
- We started only one coil while performing the experiment and we get the power out of it.
- **Note:** We can use other heat sources while using on a large scale, so it is affordable and the cost of the project can be easily used.

4.4.2 Development for Scroll Expander

Figure 14: Scroll Expander

During operation as a compressor, low pressure gas enters and fills the pockets to start the first orbit. With the rotation of the drive shaft the orbiting scroll closes the pair of pockets at the completion of the first orbit. As the first orbit ends, the first pair of pockets moves inward and the ends of the scroll start opening again to allow a fresh intake of gas. The second orbit moves the gas pockets inwards, decreasing its volume and consequently increasing its pressure. The third orbit further reduces the volume of the gas and finally breaks the inner tip contacts and discharges the compressed vapour through the center discharge port. This completes one cycle of operation.

The high pressure gas enters through a port in the scroll center. This high pressure gas generates forces on the scroll vanes which translates into torque and produces an orbiting movement. The orbiting scroll with the movement transfers the gas to two adjacent vanes and forms two symmetrical pockets. The trapped gas further expands, forcing the orbiting scroll to move around the center of the fixed scroll thus transmitting the rotating motion to an eccentric shaft. The pockets finally break up at the periphery of the scroll and discharge through the exhaust port. Several pairs of symmetrical pockets of increasing volumes co-exist at any time during the expander operation.

5. Result and Conclusion

5.1 Result

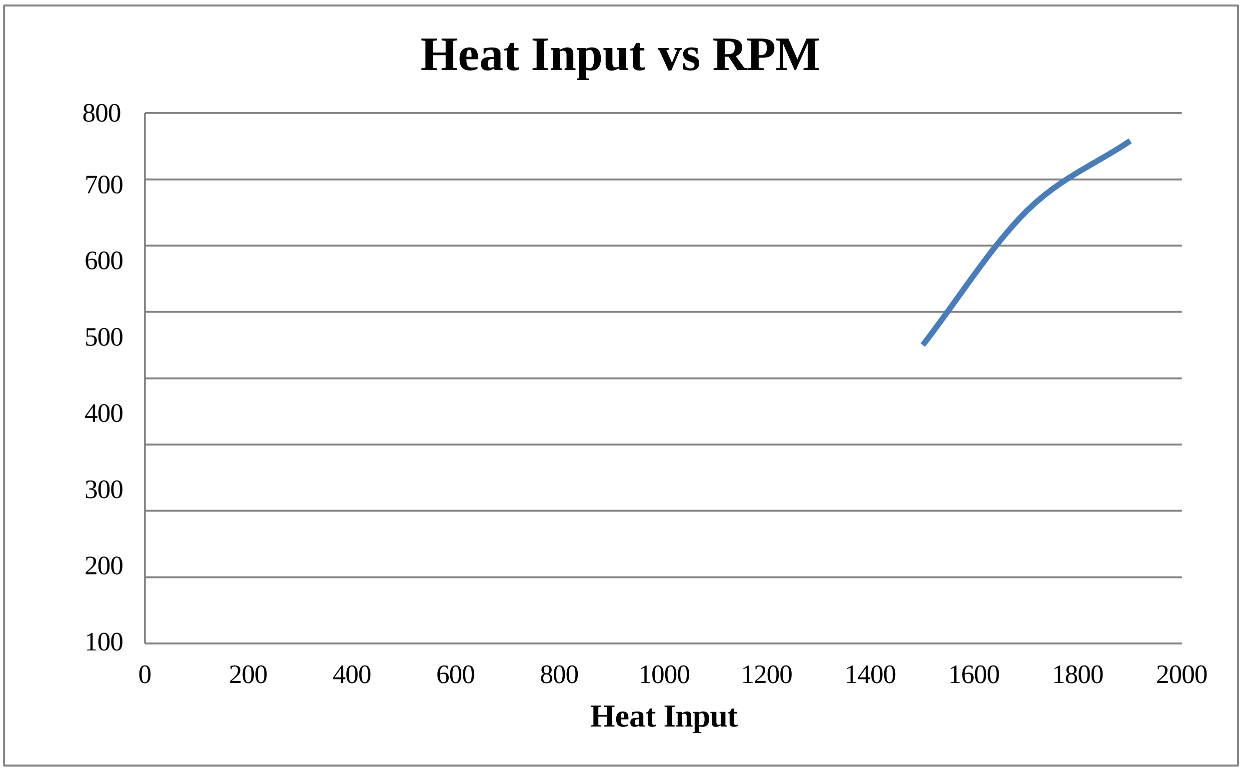
We Get Result As Below:

Table 3: Result

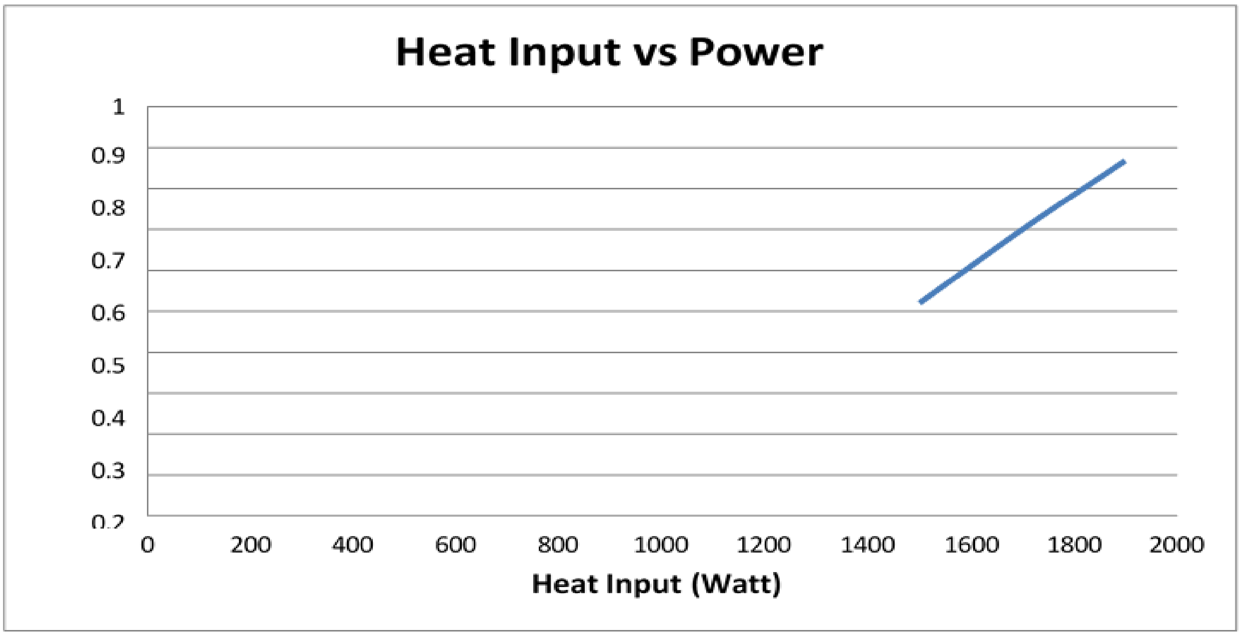
Sr. No.	Heat Input (Watt)	RPM	Power(Kw)	Efficiency
1	1500	450	0.52	34.66%
2	1700	652	0.7	41.17%
3	1900	758	0.868	45.68%

As we can see in the table, we can stated that, As Heat input increases, we get more and more efficiency.

Analysis of Heat Input vs RPM



Analysis of Heat Input vs Power



Energy Consumption Parameter Or Why Efficiency Is Lower Than Expected?

1. Scroll Compressor
2. Refrigerant
3. Pump Selection

We Can Use Vane Compressor Instead Of Scroll Compressor We Can Use R245 Refrigerant Instead Of R134a.

5.2 Conclusion

- We Perform Operations On This Project As Per Our Knowledge And Try To Increase Efficiency With Different Changing In Parameter.
- As Per Current Scenario, We Opt Out Result Is Output Power 700 Watt In Opposite Of Given Input of 200 Watt.
- This Is Not Efficient But As Heat Input Source, We Can Change Heat Input With Like Solar Plate, Hot Water Plate Etc.

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