**Rotor Engine- A Waste Energy Recovery Device from I. C. Engine Exhaust**

*In partial fulfillment of the requirements for the award of the degree*

*of Bachelor of Engineering in*

MECHANICAL ENGINEERING

***Submitted by***

Nakul Sharma Parag Gajbhiye

Prasanna Raut Dattatray Kale

Shiwaji Thakre

Under the Guidance of

**Guide:-PROF-R. N. CHAKRABORTY**

**Assistant professor, Mechanical Engineering**

**Co-Guide:-PROF-M. S. DESHMUKH**

**Assistant professor, Mechanical Engineering**

Academic Year 2011 - 12

Department of Mechanical Engineering



ST. VINCENT PALLOTTI COLLEGE OF ENGINEERING AND TECHNOLOGY,

Wardha Road, Gavsi Manapur, Nagpur

**CERTIFICATE**

Certified that this project report “Rotor Engine- A Waste Energy Recovery Device from I. C. Engine Exhaust” is the bonafide work of “Nakul Sharma, Shiwaji Thakre, Prasanna Raut, Dattatray Kale, Parag Gajbhiye” who carried out the project work under my supervision in partial fulfillment of the requirements for the award of the degree of Bachelor of Engineering in Mechanical Engineering of RASHTRASANT TUKADOJI MAHARAJ NAGPUR UNIVERSITY, NAGPUR.

PROF. A. D. PACHCHHAO PROF. R. N. CHAKRABORTY

**HEAD OF THE DEPARTMENT GUIDE**

Mechanical Engineering **ASSISTANT PROFESSOR**

Mechanical Engineering

PROF. M. S. DESHMUKH

**CO-GUIDE**

**ASSISTANT PROFESSOR**

Mechanical Engineering

**PRINCIPAL**

ST. VINCENT PALLOTTI COLLEGE OF ENGINEERING AND TECHNOLOGY **Acknowledgement**

*\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_*

It is with great satisfaction and euphoria that I am submitting the Technical seminar report “Rotor Engine- A Waste Energy Recovery Device from I. C. Engine Exhaust**”**. I have completed it as a part of the curriculum of our university.

I would like to thanks Head of the Department Prof. A. D. PACHCHHAO for his support and guidance in assistance provided at every stage.

I would extremely thank our Project Guide Prof. R. N. CHAKRABORTY and Co-Guide Prof. M. S. DESHMUKHwho has always been a great source of inspiration & has encouraged me through.

**NAKUL. R. SHARMA,**

**SHIWAJI. P. THAKRE,**

**PRASANNA. P. RAUT,**

**DATTATRAY. P. KALE,**

**PARAG. N. GAJBHIYE**

**ABSTRACT**

*\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_*

Due to the current globalization in the present world there is a need to utilize the energy and heat which is being exposed to atmosphere from the exhaust of automobiles, industries, power plants etc. The energy which is being wasted can be recovered by energy recovery systems. This may vary according to applications. Recovery systems largely depend upon exhaust gas temperatures. InRotor Engine Kinetic Energy should be recovered so that it can be efficiently used, for other purposes. There is an element which can store the sensible heat and energy, and then recovered energy can be used for specific applications.

The basic purpose of the project is to make use of energy of exhaust gases that are produce from the combustion of fuel in the engine. In an internal combustion engine fuel in the presence of air burns from which various gases produce. These gases are thrown out in the atmosphere from the engine through an exhaust pipe with a certain velocity. With the help of a proper arrangement at the exhaust pipe we can make use of these exhaust gases which can be used in many ways. We have used the trial and error method along with theoretical approach. The nozzles are tilted 600 to the horizontal for the maximum thrust. The gases finally are passed through the nozzles with potential energy which exist a thrust thus giving motion in the opposite direction, thus rotating the whole assembly. This rotational work can be coupled to any other system for usage of the work produced according to the standard conditions.

We have successfully fabricated Rotor Engine as a waste heat recovery device. An efficient transient system was developed so as to measure the power recovered from the exhaust gases of, I.C Engine. And it was useful in successfully generating power from the intake air of I.C engine. And following results were observed.

Selecting an appropriate energy recovery technology, properly designing the system, meeting the applicable codes, and commissioning the system are all important. When an energy recovery system is been design, installed and operated correctly it will provide significant energy and environmental benefits.

**CONTENTS**

*\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_*

|  |  |  |
| --- | --- | --- |
| **CHAPTER NO.** | **TITLE** | **PAGE NO.** |
|  | **ABSTRACT** |  |
|  | **LIST OF TABLE** |  |
|  | **LIST OF FIGURES** |  |
|  | **LIST OF SYMBOLS, ABBREVIATIONS AND NOMENCLATURE** |  |
| **CHAPTER 1.0** | **INTRODUCTION** |  |
| 1.1 | Introduction to Waste Energy Recovery Device System |  |
|  | 1.1.1 Classification and Application |  |
|  | 1.1.2 Benefits of Waste Heat Recovery |  |
| 1.2 | Development of a Waste Heat Recovery System |  |
| 1.3 | EGR Technology |  |
| **CHAPTER 2.0** | **REVIEW OF LITERATURE** |  |
| 2.1 | Various Energy Recovery Devices Used For I-C Engine Exhaust |  |
|  | 2.1.1 Turbocharger |  |
|  | 2.1.2 Superchargers |  |
|  | 2.1.3 Heat Wheels |  |
|  | 2.1.4 Heat Pipe |  |
|  | 2.1.5 Regenerator |  |
|  | 2.1.6 Recuperators |  |
|  | 2.1.7 Radiation/Convective Hybrid Recuperator |  |
|  | 2.1.8 Ceramic Recuperator |  |
|  | 2.1.9 Economiser |  |
|  | 2.1.10 Plate heat exchanger |  |
| 2.2 | Nozzle |  |
| **CHAPTER 3.0** | **WORK DONE** |  |
| 3.1 | Equation of the Nozzle |  |
| 3.2 | Mach Number |  |
| 3.3 | Back Pressure |  |
| **CHAPTER 4.0** | **CALCULATIONS** |  |
| 4.1 | Nozzle |  |
| 4.2 | Compressor |  |
| 4.3 | Problem Identification |  |
| 4.4 | Solution to the problem |  |
| **CHAPTER 5.0** | **RESULTS AND DISCUSSIONS** |  |
| **CHAPTER 6.0** | **CONCLUSION** |  |
| 6.1 | Scope Of Future Work |  |
|  | **COST ESTIMATE** |  |
|  | **REFERENCES** |  |
|  | **RESUME** |  |
|  | **SETUP PICTURE** |  |
|  | **PROJECT TEAM MEMBERS INFORMATION** |  |

**LIST OF TABLES**

*\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_*

|  |  |  |
| --- | --- | --- |
| **TABLE NO.** | **TABLE** | **PAGE NO.** |
| Table 1.1 | Waste Source And Quality |  |
| TABLE 1.2 | Typical Waste Heat Temperature at High Temperature Range from Various Sources |  |
| TABLE 1.3 | Typical Waste Heat Temperature At Medium Temperature Range From Various Source |  |
| TABLE 1.4 | Typical Waste Heat Temperature At low Temperature Range From Various Sources |  |
| TABLE 1.5 | Energy Recovery Devices |  |
| TABLE 1.6 | Waste Source And Quality |  |
| TABLE 3.1 | Gas Properties |  |
| TABLE 3.2 | Observation Table |  |
| TABLE 4.1 | Engine specifications |  |
| TABLE 4.2 | Observation Table |  |
| TABLE 4.3 | Observation Table |  |

**LIST OF THE FIGURES**

*\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_*

|  |  |  |
| --- | --- | --- |
| **FIGURE NUMBER** | **NAME OF THE FIGURE** | **PAGE NUMBER** |
| Fig 1.1 | Exhaust Gas Recirculation (EGR) Process |  |
| Fig 2.1 | Turbocharger is plumbed in a car |  |
| Fig 2.2 | Centrifugal supercharger |  |
| Fig 2.3 | Heat Wheels |  |
| Fig 2.4 | Heat Pipe |  |
| Fig 2.5 | Regenerator |  |
| Fig 2.6 | Waste Heat Recovery using Recuperator |  |
| Fig 2.7 | Metallic Radiation Recuperator |  |
| Fig 2.8 | Convective Recuperator |  |
| Fig 2.9 | Convective Radiative Recuperator |  |
| Fig 2.10 | Economizer |  |
| Fig 2.11 | Plate Heat Exchanger |  |
| Fig 2.12 | Enthalpy and Entropy Relations for Nozzle Efficiency |  |
| Fig 2.13 | Nozzle Schematic Layout |  |
| Fig 3.1 | Nozzle Schematic Layout |  |
| Fig 3.2 | Nozzle Temperature Vs Entropy Diagram |  |
| Fig 3.3 | Nozzle Performance |  |
| Fig 4.1 | The system designed by the team |  |
| Fig 4.2 | Wire View of Rotor Engine |  |

**NOMENCLATURE**

*\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_*

m1 = mass flow rate of exhaust gas at inlet; Kg/sec.

m2 = mass flow rate of exhaust gas at outlet; Kg/sec.

m3 = mass flow rate of air at inlet; Kg/sec.

m4 = mass flow rate of air at outlet; Kg/sec.

Z1= head at inlet; m

Z2 = head at outlet; m

h1 = enthalpy at exhaust inlet; kj/kg

h2 = enthalpy at exhaust outlet; kj/kg

h3 = enthalpy at air inlet; kj/kg

h4 = enthalpy at air outlet; kj/kg

Q = heat transfer rate; kj/sec

W = work done per sec; kj/sec

g = acceleration due to gravity; m/s2

v1=velocity at exhaust inlet; m/s

v2=velocity at exhaust outlet; m/s

v3=velocity at air inlet; m/s

v4=velocity at air outlet; m/s

CHAPTER I

**INTRODUCTION**

CHAPTER I

**INTRODUCTION**

*\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_*

The basic purpose of the project is to make use of energy of exhaust gases that are produce from the combustion of fuel in the engine. In an internal combustion engine fuel in the presence of air burns from which various gases produce. These gases are thrown out in the atmosphere from the engine through an exhaust pipe with a certain velocity. With the help of a proper arrangement at the exhaust pipe we can make use of these exhaust gases which can be used in many ways.

The basic principle of the engine is identical to any and all engines that extract energy from chemical fuel.

The basic 4 steps for any internal combustion engine are:

1. Intake of air (and possibly fuel).

2. Compression of the air (and possibly fuel).

3. Combustion, where fuel is injected (if it was not drawn in with the intake air) and burned to convert the stored energy.

4. Expansion and exhaust, where the converted energy is put to use.

**1.1 Introduction to the waste heat recovery system**

Waste heat is heat, which is generated in a process by way of fuel combustion or chemical reaction, and then “dumped” into the environment even though it could still be reused for some useful and economic purpose. The essential quality of heat is not the amount but rather its “value”. The strategy of how to recover this heat depends in part on the temperature of the waste heat gases and the economics involved.

Large quantity of hot flue gases is generated from Boilers, Kilns, Ovens and Furnaces.

If some of this waste heat could be recovered, a considerable amount of primary fuel could be saved. The energy lost in waste gases cannot be fully recovered. However, much of the heat could be recovered and loss minimized by adopting following measures as outlined in this chapter.

**1.1.1 Classification and Application**

In considering the potential for heat recovery, it is useful to note all the possibilities, and grade the waste heat in terms of potential value as shown in the following Table 1.1:

**TABLE 1.1 WASTE SOURCE AND QUALITY**

|  |  |  |
| --- | --- | --- |
| **S.No** | **Source** | **Quality** |
| 1 | Heat in flue gases. | The higher the temperature, the greater the potential value for heat recovery |
| 2 | Heat in vapour streams | As above but when condensed latent heat also recoverable. |
| 3 | Convective and radiant heat lost from exterior of equipment | Low grade – if collected may be used for space heating or air preheats. |
| 4 | Heat losses in cooling water. | Low grade – useful gains if heat is exchanged with incoming fresh water |
| 5 | Heat losses in providing chilled water or in the disposal of chilled water | a) High grade if it can be utilized to reduce demand for refrigeration  b) Low grade if refrigeration unit used as a form of heat pump. |

**High Temperature Heat Recovery**

The following Table 1.2 gives temperatures of waste gases from industrial process equipment in the high temperature range. All of these results from direct fuel fired processes.

**Medium Temperature Heat Recovery**

The following Table 1.3 gives the temperatures of waste gases from process equipment in the medium temperature range. Most of the waste heat in this temperature range comes from the exhaust of directly fired process units.

**TABLE 1.2 TYPICAL WASTE HEAT TEMPERATURES AT HIGH**

**TEMPERATURE RANGE FROM VARIOUS SOURCES**

|  |  |
| --- | --- |
| **Types of Device** | **Temperature, °C** |
| Nickel refining furnace | 1370 –1650 |
| Aluminium refining furnace | 650–760 |
| Zinc refining furnace | 760–1100 |
| Steel heating furnaces | 925–1050 |
| Copper reverberatory furnace | 900–1100 |
| Open hearth furnace | 650–700 |
| Cement kiln (Dry process) | 620– 730 |
| Glass melting furnace | 1000–1550 |
| Hydrogen plants | 650–1000 |

**Low Temperature Heat Recovery**

The following Table 1.4 lists some heat sources in the low temperature range. In this range it is usually not practical to extract work from the source, though air production may not be completely excluded if there is a need for low-pressure air. Low temperature waste heat may be useful in a supplementary way for preheating purposes.

**TABLE 1.3 TYPICAL WASTE HEAT TEMPERATURES AT MEDIUM**

**TEMPERATURE RANGE FROM VARIOUS SOURCES**

|  |  |
| --- | --- |
| **Type of Device** | **Temperature, °C** |
| Air boiler exhausts | 230–480 |
| Gas turbine exhausts | 370–540 |
| Reciprocating engine exhausts | 315–600 |
| Reciprocating engine exhausts (turbo charged) | 230–370 |
| Heat treating furnaces | 425–650 |
| Drying and baking ovens | 230–600 |
| Catalytic crackers | 425–650 |
| Annealing furnace cooling systems | 425–650 |

**TABLE 1.4 TYPICAL WASTE HEAT TEMPERATURES AT LOW**

**TEMPERATURE RANGE FROM VARIOUS SOURCES**

|  |  |
| --- | --- |
| **Source** | **Temperature, °C** |
| Process air condensate | 55–88 |
| **Cooling water from :**Furnace doors | 32–55 |
| Bearings | 32–88 |
| Welding machines | 32–88 |
| Injection molding machine | 32–88 |
| Annealing furnaces | 66–230 |
| Forming dies | 27–88 |
| Air compressors | 27–50 |
| Pumps | 27–88 |
| Internal combustion engines | 66–120 |
| Air conditioning and refrigeration condensers | 32–43 |
| Liquid still condensers | 32–88 |
| Drying, baking and curing ovens | 93–230 |

**1.1.2 Benefits of Waste Heat Recovery**

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

**Direct Benefits:**

Recovery of waste heat has a direct effect on the efficiency of the process. This is reflected by reduction in the utility consumption & costs, and process cost.

**Indirect Benefits:**

a) **Reduction in pollution:**

A number of toxic combustible wastes such as carbon monoxide gas, sour gas, carbon black off gases, oil sludge, Acrylonitrile and other plastic chemicals etc, releasing to atmosphere if/when burnt in the incinerators serves dual purpose i.e. recovers heat and reduces the environmental pollution levels.

b) **Reduction in equipment sizes:**

Waste heat recovery reduces the fuel consumption, which leads to reduction in the flue gas produced. This results in reduction in equipment sizes of all flue gas handling equipments such as fans, stacks, ducts, burners, etc.

c) **Reduction in auxiliary energy consumption:**

Reduction in equipment sizes gives additional benefits in the form of reduction in auxiliary energy consumption like electricity for fans, pumps etc.

**1.2 Development of a Waste Heat Recovery System**

**Understanding the process**

Understanding the process is essential for development of Waste Heat Recovery system. This can be accomplished by reviewing the process flow sheets, layout diagrams, piping isometrics, electrical and instrumentation cable ducting etc. Detail review of these documents will help in identifying:

a) Sources and uses of waste heat

b) Upset conditions occurring in the plant due to heat recovery

c) Availability of space

d) Any other constraint, such as dew point occurring in an equipments etc.

After identifying source of waste heat and the possible use of it, the next step is to select suitable heat recovery system and equipments to recover and utilise the same.

**Economic Evaluation of Waste Heat Recovery System**

It is necessary to evaluate the selected waste heat recovery system on the basis of financial analysis such as investment, depreciation, payback period, rate of return etc. In addition the advice of experienced consultants and suppliers must be obtained for rational decision. Next section gives a brief description of common heat recovery devices available commercially and its typical industrial applications.

**Waste heat recovery unit:-**

A **waste heat recovery unit** (WHRU) is an energy recovery heat exchanger that recovers heat from hot streams with potential high energy content, such as hot flue gases from a diesel generator or air from cooling towers or even waste water from different cooling processes such as in steel cooling.

**Principle Heat recovery units**

Waste heat found in the exhaust gas of various processes or even from the exhaust stream of a conditioning unit can be used to preheat the incoming gas. This is one of the basic methods for recovery of waste heat. Many steel making plants use this process as an economic method to increase the production of the plant with lower fuel demand. There are many different commercial recovery units for the transferring of energy from hot medium space to lower one:

**1. Recuperators:** This name is given to different types of heat exchanger that the exhaust gases are passed through, consisting of metal tubes that carry the inlet gas and thus preheating the gas before entering the process. The heat wheel is an example which operates on the same principle as a solar air conditioning unit.

**2. Regenerators:** This is an industrial unit that reuses the same stream after processing. In this type of heat recovery, the heat is regenerated and reused in the process.

**3. Heat pipe exchanger:** Heat pipes are one of the best thermal conductors. They have the ability to transfer heat hundred times more than copper. Heat pipes are mainly known in renewable energy technology as being used in evacuated tube collectors. The heat pipe is mainly used in space, process or air heating, in waste heat from a process is being transferred to the surrounding due to its transfer mechanism.

**4. Thermal Wheel or rotary heat exchanger:** consists of a circular honeycomb matrix of heat absorbing material, which is slowly rotated within the supply and exhaust air streams of an air handling system.

**5. Economizer:** In case of process boilers, waste heat in the exhaust gas is passed along a recuperator that carries the inlet fluid for the boiler and thus decreases thermal energy intake of the inlet fluid.

**6. Heat pumps:** Using an organic fluid that boils at a low temperature means that energy could be regenerated from waste fluids.

**7. Run around coil:** comprises two or more multi-row finned tube coils connected to each other by a pumped pipework circuit.

**Heat to power units**

According to a report done by Energitics, Inc. [2] for the DOE in November 2004 titled *Technology Roadmap*[3] and several others done by the European commission, the majority of energy production from conventional and renewable resources are lost to the atmosphere due to onsite (equipment inefficiency and losses due to waste heat) and offsite (cable and transformers losses) losses, that sums to be around 66% loss in electricity value.[4] Waste heat of different degrees could be found in final products of a certain process or as a by-product in industry such as the Slag in steelmaking plants. Units or devices that could recover the waste heat and transform it into electricity are called WHRUs or heat to power units. Such units, for example, uses an Organic Rankine cycle with an organic fluid as the working fluid. The fluid has a lower boiling point than water to allow it to boil at low temperature, to for a superheated gas that could drive the blade of a turbine and thus a generator. Another unit like the Thermoelectric could be named a WHRU since they transform the change of heat between two plates directly into a small DC Power (Seebeck, Peltier, Thosmson effects) which could be amplified to produce a usable electric power.

A WHRU is different from a Heat Recovery Air Generator (HRSG) in the sense that the heated medium does not change phase.

**Advantages and disadvantages of waste heat recovery**

The waste heat recovery process has no visible disadvantage on Ecology or Economy. In the contrary, these systems have many benefits which could be direct or indirect.

• **Direct Benefits: -** The recovery process will add to the efficiency of the process and thus decrease the costs of fuel and energy consumption needed for that process.

• **Indirect benefits:-**

**1. Reduction in Pollution:** Thermal and air pollution will dramatically decrease since less flue gases of high temperature are emitted from the plant since most of the energy is recycled.

**2. Reduction in the equipment sizes:** As Fuel consumption reduces so the control and security equipment for handling the fuel decreases. Also, filtering equipment for the gas is no longer needed in large sizes.

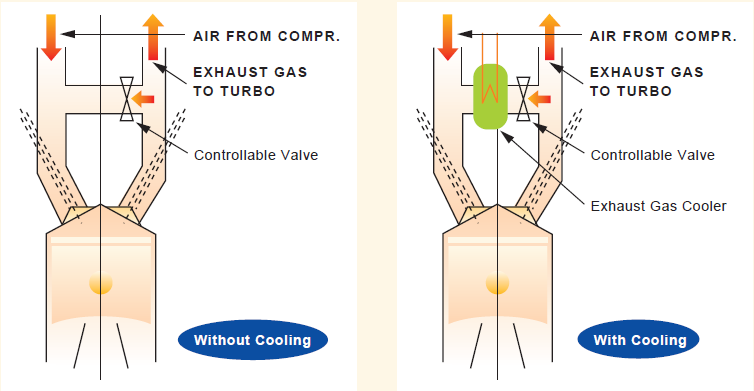
**3. Reduction in auxiliary energy consumption:** Reduction in equipment sizes means another reduction in the energy fed to those systems like pumps, filters, fans, etc.

**Example**

During the past years, companies have developed many products for the recovery of the waste heat. A new concept is being introduced by Cyclone Power Technologies that uses an external combustion engine design for the waste heat recovery application

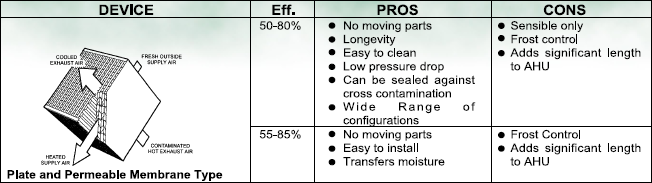
**1.3 EGR TECHNOLOGY**

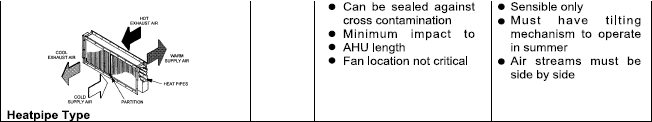
Apart from oxygen which is essential for fuel combustion, ambient air contains nitrogen. The high temperatures found with engines cause nitrogen to react with oxygen to form nitrogen oxide. One of the most effective means of tackling nitrogen oxide is through the Exhaust Gas Recirculation (EGR) technology. EGR directs some of the exhaust gases back into the intake of the engine (Fig 3). By mixing the exhaust gases with fresh air, the amount of oxygen entering the engine is reduced. Since there is less oxygen, temperatures are reduced and less nitrogen oxide is formed. This can greatly reduce the amount of nitrogen oxide that a vehicle releases into the atmosphere.

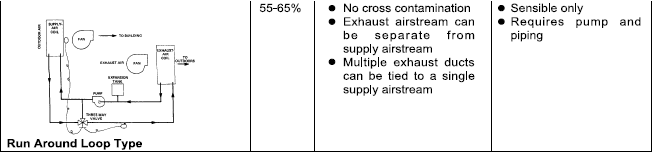


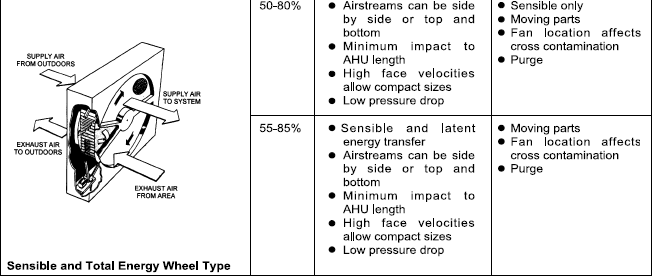
**Figure 1.1: Exhaust Gas Recirculation (EGR) Process**

**TABLE 1.5 ENERGY RECOVERY DEVICES**

****

****

****

****

|  |  |  |
| --- | --- | --- |
| **TABLE 1.6. WASTE SOURCE AND QUALITY** | | |
| **Sr. No.** | **Source** | **Quality** |
| 1. | Heat in flue gases. | The higher the temperature, the greater the potential value for heat recovery |
| 2. | Heat in vapour streams. | As above but when condensed latent heat also recoverable. |
| 3 | Convective and radiant heat lost from exterior of equipment | Low grade – if collected may be used for space heating or air preheats. |
| 4. | Heat losses in cooling water. | Low grade – useful gains if heat is exchanged with incoming fresh water. |
| 5. | Heat losses in providing chilled water or in the disposal of chilled water. | a) High grade if it can be utilized to reduce demand for refrigeration.  b) Low grade if refrigeration unit used as a form of heat pump. |
| 6. | Heat stored in products leaving the process | Quality depends upon temperature. |
| 7. | Heat in gaseous and liquid effluents leaving process. | Poor if heavily contaminated and thus requiring alloy heat exchanger. |

CHAPTER II

**REVIEW OF LITERATURE**

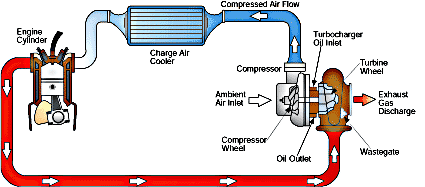
CHAPTER II

**REVIEW OF LITERATURE**

*\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_*

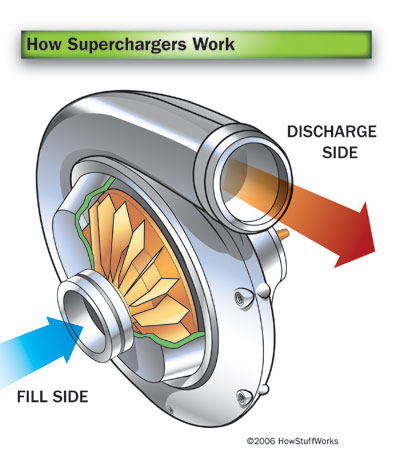
**2.1 Various Energy Recovery Devices Used For I-C Engine Exhaust:-**

**2.1.1 Turbocharger**

  
Image courtesy Garrett   
**Figure 2.1: Turbocharger is plumbed in a car**

The turbocharger is bolted to the exhaust manifold of the engine. The exhaust from the cylinders spins the turbine, which works like a [gas turbine engine](http://science.howstuffworks.com/turbine.htm). The turbine is connected by a shaft to the compressor, which is located between the air filter and the intake manifold. The compressor pressurizes the air going into the pistons.

**2.1.2 Superchargers**



**Figure 2.2: Centrifugal supercharger**

Since the invention of the internal com­bustion engine, automotive engineers, speed junkies and race car designers have been searching for ways to boost its power. ­One way to add power is to build a bigger engine. But bigger engines, which weigh more and cost more to build and maintain, are not always better.

Another way to add power is to make a normal-sized engine more efficient. You can accomplish this by forcing more air into the combustion chamber. More air means more fuel can be added, and more fuel means a bigger explosion and greater horsepower. Adding a **supercharger** is a great way to achieve forced air induction. In this article, we'll explain what superchargers are, how they work and how they compare to turbochargers.

A supercharger is any device that pressurizes the air intake to above atmospheric pressure. Both superchargers and turbochargers do this. In fact, the term "turbocharger" is a shortened version of "turbo-supercharger," its official name.

The difference between the two d­evices is their source of energy. Turbochargers are powered by the mass-flow of exhaust gases driving a turbine. Superchargers are powered mechanically by belt- or chain-drive from the engine's crankshaft.

**2.1.3 Heat Wheels**



**Figure 2.3: Heat Wheels**

It is a sizable porous disk, fabricated with material having a fairly high heat capacity, which rotates between two side-by-side ducts: one is a cold gas duct, the other a hot gas duct. The axis of the disk is located parallel and on the partition between the two ducts. As the disk slowly rotates, sensible heat (moisture that contains latent heat) is transferred to the disk by the hot air and, as the disk rotates, from the disk to the cold air. The overall efficiency of sensible heat transfer for this kind of regenerator can be as high as 85 per cent. Heat wheels have been built as large as 21 meters in diameter with air capacities up to 1130 m3 / min.

**2.1.4 Heat Pipe**



**Figure 2.4: Heat Pipe**

A heat pipe can transfer up to 100 times more thermal energy than copper, the best-known conductor. In other words, heat pipe is a thermal energy absorbing and transferring system having no moving parts and hence requires minimal maintenance.

The heat pipe comprises of three elements – a sealed container, a capillary wick structure and a working fluid. The capillary wick structure is integrally fabricated into the interior surface of the container tube and sealed under vacuum. Thermal energy applied to the external surface of the heat pipe is in equilibrium with its own vapour as the container tube is sealed under vacuum. Thermal energy applied to the external surface of the heat pipe causes the working fluid near the surface to evaporate instantaneously. Vapour thus formed absorbs the latent heat of vaporization and this part of the heat pipe becomes an evaporator region. The vapour then travels to the other end the pipe where the thermal energy is removed causing the vapour to ondense into liquid again, thereby giving up the latent heat of the condensation. This part of the heat pipe works as the condenser region. The condensed liquid then flows back to the evaporated region.

**2.1.5 Regenerator**

The Regeneration which is preferable for large capacities has been very widely used in glass and steel melting furnaces. Important relations exist between the size of the regenerator, time between reversals, thickness of brick, conductivity of brick and heat storage ratio of the brick. In a regenerator, the time between the reversals is an important aspect. Long periods would mean higher thermal storage and hence higher cost. Also long periods of reversal result in lower average temperature of preheat and consequently reduce fuel economy. (Refer Figure 1.5). Accumulation of dust and slagging on the surfaces reduce efficiency of the heat transfer as the furnace becomes old. Heat losses from the walls of the regenerator and air in leaks during the gas period and outleaks during air period also reduces the heat transfer.

****

**Figure 2.5: Regenerator**

**2.1.6 Recuperators**

In a recuperator, heat exchange takes place between the flue gases and the air through metallic or ceramic walls. Duct or tubes carry the air for combustion to be pre-heated, the other side contains the waste heat stream. A recuperator for recovering waste heat from flue gases is shown in Figure 2.6



**Figure 2.6: Waste Heat Recovery using Recuperator**

The simplest configuration for a Recuperator is the metallic radiation Recuperator, which consists of two concentric lengths of metal tubing as shown in Figure 1.2. The inner tube carries the hot exhaust gases while the external annulus carries the combustion air from the atmosphere to the air inlets of the furnace burners. The hot gases are cooled by the incoming combustion air which now carries additional energy into the combustion chamber. This is energy which does not have to be supplied by the fuel; consequently, less fuel is burned for a given furnace loading. The saving in fuel also means a decrease in combustion air and therefore stack losses are decreased not only by lowering the stack gas temperatures but also by discharging smaller quantities of exhaust gas. The radiation recuperator gets its name from the fact that a substantial portion of the heat transfer from the hot gases to the surface of the inner tube takes place by radiative heat transfer. The cold air in the annuals, however, is almost transparent to infrared radiation so that only convection heat transfer takes place to the incoming air. As shown in the diagram, the two gas flows are usually parallel, although the configuration would be simpler and the heat transfer more efficient if the flows were opposed in direction (or counterflow). The reason for the use of parallel flow is that recuperators frequently serve the additional function of cooling the duct carrying away the exhaust gases and consequently extending its service life.



**Figure 2.7: Metallic Radiation Recuperator**

A second common configuration for recuperators is called the tube type or convective recuperator. As seen in the figure 1.3, the hot gases are carried through a number of parallel small diameter tubes, while the incoming air to be heated enters a shell surrounding the tubes and passes over the hot tubes one or more times in a direction normal to their axes. If the tubes are baffled to allow the gas to pass over them twice, the heat exchanger is termed a two-pass recuperator; if two baffles are used, a three-pass recuperator, etc. Although baffling increases both the cost of the exchanger and the pressure drop in the combustion air path, it increases the effectiveness of heat exchange. Shell and tube type recuperators are generally more compact and have a higher effectiveness than radiation recuperators, because of the larger heat transfer area made possible through the use of multiple tubes and multiple passes of the gases.



**Figure 2.8: Convective Recuperator**

**2.1.7 Radiation/Convective Hybrid Recuperator:**

For maximum effectiveness of heat transfer, combinations of radiation and convective designs are used, with the high-temperature radiation recuperator being first followed by convection type. These are more expensive than simple metallic radiation recuperators, but are less bulky. A Convective/radiative Hybrid recuperator is shown in Figure 1.4



**Figure 2.9: Convective Radiative Recuperator**

**2.1.8 Ceramic Recuperator**

The principal limitation on the heat recovery of metal recuperators is the reduced life of the liner at inlet temperatures exceeding 1100°C. In order to overcome the temperature limitations of metal recuperators, ceramic tube recuperators have been developed whose materials allow operation on the gas side to 1550°C and on the preheated air side to 815°C on a more or less practical basis. Early ceramic recuperators were built of tile and joined with furnace cement, and thermal cycling caused cracking of joints and rapid deterioration of the tubes. Later developments introduced various kinds of short silicon carbide tubes which can be joined by flexible seals located in the air headers. Earlier designs had experienced leakage rates from 8 to 60 percent. The new designs are reported to last two years with air preheat temperatures as high as 700°C, with much lower leakage rates.

**2.1.9 Economiser**

In case of boiler system, economizer can be provided to utilize the flue gas heat for preheating the boiler feed water. On the other hand, in an air pre-heater, the waste heat is used to heat combustion air. In both the cases, there is a corresponding reduction in the fuel requirements of the boiler. An economizer is shown in Figure 1.8.For every 22°C reduction in flue gas temperature by passing through an economiser or a pre-heater, there is 1% saving of fuel in the boiler. In other words, for every 6°C rise in feed water temperature through an economiser, or

20°C rise in combustion air temperature through an air pre-heater.



**Figure 2.10: Economizer**

**2.1.10 Plate heat exchanger**

The cost of heat exchange surfaces is a major cost factor when the temperature differences are not large. One way of meeting this problem is the plate type heat exchanger, which consists of a series of separate parallel plates forming thin flow pass. Each plate is separated from the next by gaskets and the hot stream passes in parallel through alternative plates whilst the liquid to be heated passes in parallel between the hot plates. To improve heat transfer the plates are corrugated. Hot liquid passing through a bottom port in the head is permitted to pass upwards between every second plate while cold liquid at the top of the head is permitted to pass downwards between the odd plates. When the directions of hot & cold fluids are opposite, the arrangement is described as counter current. A plate heat exchanger is shown in Figure 1.9.



**Figure 2.11: Plate Heat Exchanger**

Typical industrial applications are:

– Pasteurisation section in milk packaging plant.

* Evaporation plants in food indust

**2.2 Nozzle:-**

Nozzle is a passage of varying cross-section, which converts heat energy of air into kinetic energy. During the first part of the nozzle, the air increases its velocity. But in its later part, the air gains more in volume than in velocity. Since the mass of air, passing through any section of the nozzle remains constant, the variation of air pressure in the nozzle depends upon the nozzle, specific volume and the dryness fraction of the air. Well design of the nozzle converts the exhaust energy of the air into kinetic energy with a minimum loss.

**Types of Nozzle:-**

Following three types of the nozzles are the important from the subject point of view:

1. **Convergent nozzle**:-

When the cross-section of the nozzle decreases continuously from entrance to exit, it is called a convergent nozzle.

1. **Divergent nozzle**:-

When the cross-section of the nozzle increases continuously from entrance to exit, it is called a divergent nozzle.

1. **Convergent- Divergent nozzle**:-

When the cross-section of a nozzle first decreases from its entrance to throat, and then increases from its throat to exit, it is called a convergent-divergent nozzle as shown in fig.

This type of nozzle is widely used these days.

**Flow of air through convergent-divergent nozzle:-**

The air enters in the nozzle with a high pressure, but with a negligible velocity. In the convergent portion (i.e. from the inlet to the throat) there is a drop in the air pressure with a rise in its velocity. There is a drop on the enthalpy or total heat of the air. This drop of the heat is not utilised in doing some external work**;** but is converted into kinetic energy. In the divergent portion (i.e. from the throat to outlet), there is further drop of air pressure with a further rise in its velocity. Again there is a drop in the enthalpy or total heat of air, which is converted into kinetic energy.

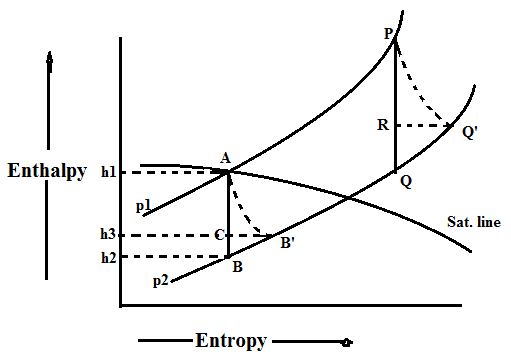
It will be interesting to know that the air enter the nozzle with a high pressure and negligible velocity. But leaves the nozzle with high velocity and small pressure. The pressure, at which the air leaves the nozzle, is known as back pressure. Moreover, no energy is supplied or rejected by the air during flow through a nozzle. Therefore, it is considered as isentropic flow, and corresponding expansion is known as isentropic expansion.

**Friction in the Nozzle or nozzle efficiency:-**

As a matter of fact, when the air flows through a nozzle, some loss in its enthalpy or total heat takes place due to friction between the nozzles surface and flowing air. This can be best understood with the help of h-s diagram or moiller chart as shown in fig. Which can be completed as discussed below.

1. First of all locate the point A for the initial condition of the air. It is the point where the saturation point meets the initial pressure (p1) line.
2. Now draw vertical line through A to meet final pressure P2 line. This is done as the flow through the nozzle is isentropic which is expressed by vertical line AB. The heat drop (h1-h2) is known as isentropic heat drop.
3. Due to friction in nozzle the actual heat drop in the air will be less than (h1-h2) let this heat drop be shown as AC instead of AB.
4. Expansion of the air ends at pressure p2, therefore final condition of the air is obtained by drawing horizontal line through C to meet final pressure P2 line at B’
5. Now the actual expansion of the air in the nozzle is expressed by the curve AB’ (adiabatic expansion) instead of AB (isentropic expansion). The actual heat drop (h1-h3) is known as useful heat drop.

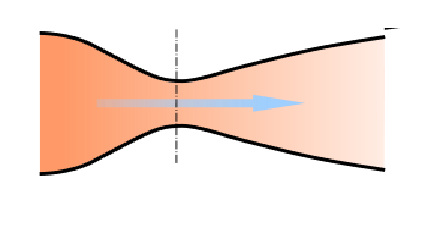
Now the co-efficient of nozzle efficiency (usually denoted by K) is defined as the ratio of useful heat drop to the isentropic heat drop.



**Figure 2.12:- Enthalpy and Entropy Relations for Nozzle Efficiency**

Mathematically,

K = = =



**Inlet of Nozzle 🡪 Outlet of Nozzle 🡪**

**Figure 2.13 - Nozzle Schematic Layout**

CHAPTER III

**WORK DONE**

CHAPTER III

**WORK DONE**

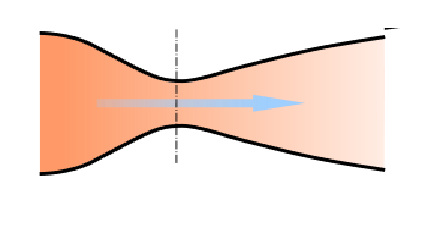
*\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_*

In the presented nozzle analysis, only air is considered as the working fluid behaving as a perfect gas -- specific heat has a constant value.  Ideal gas state equation is valid -- Pν = RT.   
Air enters a nozzle at point 1 and it exits the nozzle at point 2.  Isentropic expansion is considered with no entropy change.

**3.1Equation of the Nozzle:-**

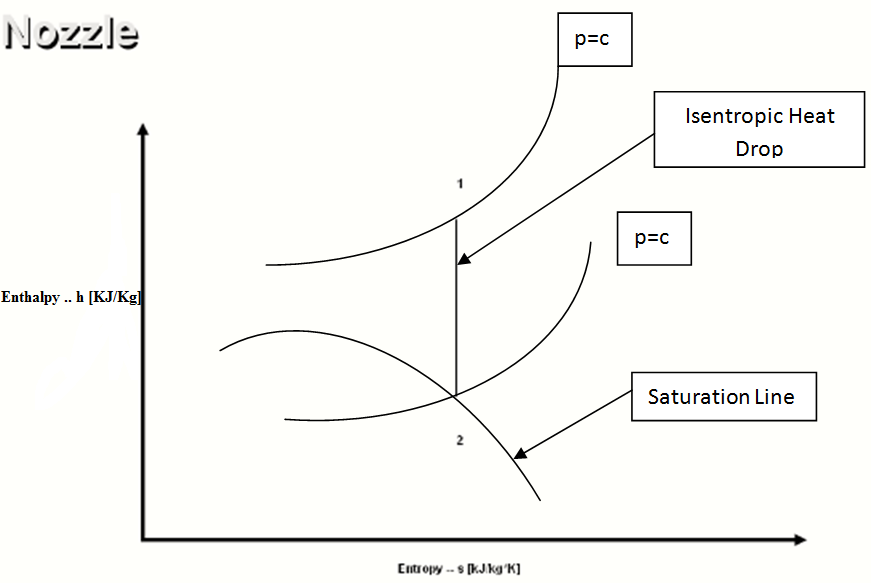
Control volume analysis of nozzle

* P2= P1+(U12 - U22) - first law applied to nozzle
* U1 = Inlet Velocity of exhaust
* U2 = Outlet Velocity of exhaust
* P1 = Inlet pressure
* P2 = Outlet pressure
* ρ= Density of exhaust gas

****

**Inlet of Nozzle 🡪 Outlet of Nozzle 🡪**

**Figure 3.1 - Nozzle Schematic Layout**

****

**Figure 3.2 - Enthalpy Vs Entropy Diagram**

Figure 3 presents nozzle performance -- stagnation over static temperature and pressure values -- as a function of the Mach Number.  Only subsonic nozzle operation is considered.  It should be noted that air enters the nozzle at the stagnation conditions of 1,500 [K] and 10 [atm] of absolute pressure.

**3.2 Mach Number**:-

**Mach number** is the speed of an object moving through air, or any other fluid substance, divided by the speed of sound as it is in that substance for its particular physical conditions, including those of temperature and pressure. It is commonly used to represent the speed of an object when it is travelling close to or above the speed of sound.

\ M = \frac {{V}}{{a}}

Where,

\ M  is the Mach number

\ V is the relative velocity of the source to the medium and

\ a is the speed of sound in the medium

Regime Subsonic Transonic Sonic Supersonic Hypersonic High-hypersonic Mach<1.00.8–1.21.01.2–5.05.0–10.0>10.0

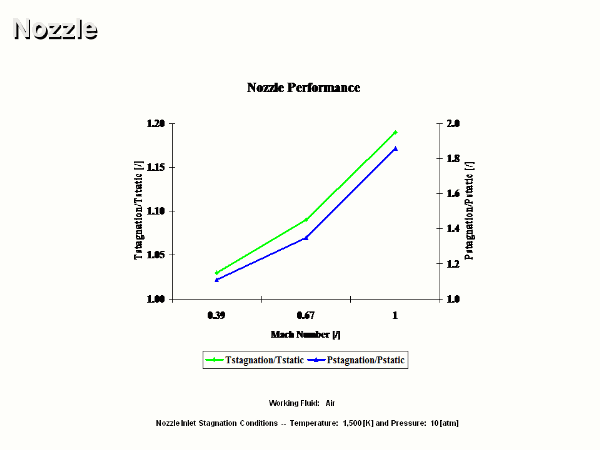
**3.3 Back Pressure:-**

Back Pressure is a pressure due to a force that is operating in a direction opposite to that being considered, such as that of a fluid flow.

The value of back pressure for 90° is approximately 3.2 times more than the standard value.

Back pressure value increases 0.08 KPa with increase in manifold angle by 1°. This nature of back pressure is applicable up to 60°.

After 60°, the increase in back pressure turns out to be 0.44 KPa with 1° rise in manifold angle.

****

**Figure 3.3 - Nozzle Performance**

**One can notice that nozzle stagnation over static temperature and pressure ratio values increase with an increase of the Mach Number**

**Table 3.1: GAS PROPERTIES**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Speed of sound in a Gas**  **(Pressure Wave Velocity)**    The main parameter involved in expansion chamber design is the speed of sound, since this governs the speed of the pressure pulses that we use in the chamber.     |  |  | | --- | --- | |  | Where:-    Tkis Exhaust gas temp, Kelvin    R is 287     is 1.4 a0 is in m/s | | **Tuned Length of Exhaust**  Blair's formulae assume that the tuned length of the exhaust is to a point on the plugging cone, and is given by the formula below.     |  |  | | --- | --- | |  | Where:-    Lt is tuned length, mm    A0 is in m/s    ep is exhaust duration, degrees | |
| **Brake Mean Effective Pressure -**  **Engine State of Tune**  If we want to guess the exhaust gas temperature based on engine state of tune, then we need to determination an index of state of tune. This is usually a function of the engine’s state of tune or BMEP. This value BMEP for an engine is used in several of the expansion chamber design parameters, and is calculated as shown.     |  |  | | --- | --- | |  | Where:-    kW is engine power, kW (1bhp=746W)    SVCC is swept volume, cc    Rpm is engine speed, rpm    BMEP is in Bar | | **Average Exhaust Temperature**    Once the engine BMEP is determined, the exhaust average temperature can be calculated from the formula shown. This is an empirical measure based on readings taken during dyno run tests.  From the table by John Robinson.     |  |  |  | | --- | --- | --- | | **Bike** | **BMEP, Bar** | **Mean Ex Gas Temp, C** | | Grand Prix Racer | 11+ | 650 | | Enduro | 8 | 500 | | Roadster | 5 | 350 | |

**Experimental Setup**:-

**Table 3.2: Engine specifications**

**Maruti Suzuki Alto LXI, I.C Engine Test Rig**.

|  |  |
| --- | --- |
| Items | Values |
| Engine Displacement | 796cc |
| Make | Maruti Suzuki make |
| Bore diameter | 68.5 mm |
| Stroke length | 72.0 mm |
| Exhaust temperature idling | 380 0C |
| Power | 47 PS ( 6,200 rpm ) |

**Setup Dimensions:-**

= 2.4 cm

= 12.3 cm

Motor RPM = × Flywheel RPM

Motor RPM = × Flywheel RPM

Motor RPM = 5.125 × Flywheel RPM

CHAPTER IV

**CALCULATIONS**

CHAPTER IV

**CALCULATIONS**

The exhaust gases coming out form the vehicle are passed through the nozzles with potential energy which exist a thrust thus giving motion in the opposite direction, thus rotating the whole assembly

**4.1 Nozzle**: -

Nozzle Design Calculation:-

We have successfully fabricated Rotor Engine as a waste heat recovery device. An efficient transient system was developed so as to measure the power recovered from the exhaust gases of three cylinders, **Maruti Suzuki Alto LXI, I.C Engine Test Rig**. And it was useful in successfully generating power from the intake air of I.C engine.

**Problem:-** For known inlet dimensions of three nozzle structure arranged at 1200 with each other, the outlet dimensions of a nozzle is to be calculated?

Given: - (from manual)

Inlet Pressure (P1) = 2 bar

Inlet Diameter of Nozzle (D1) =30mm

Inlet Temperature of Exhaust Gas in Rotor Nozzle (T1) = 3800C

Outlet Temperature (T2) = Inlet Temperature (T1) = 3800C

Inlet Velocity (V1) = 40 m/s

Density of Flue Gas () = 0.538 kg/m3

Specific Volume of flue gas (ν) = 1.8593 m3/kg

**Solution: -** First of all we need to find out the mass flow rate of flue gases which is constant throughout the nozzle,

Therefore, Mass Flow Rate (m),

A= area of the nozzle

D= Diameter of nozzle

M =mass of the gas

V = velocity

v= specific volume of the gas

h1= enthalpy of the inlet

h2=enthalpy of the outlet

A1 =

× D12 =

× (30×10-3)2 =

**Mass Flow Rate (m) = 0.015 kg/s**

From Air Property Diagram,

For, Inlet Pressure (P1) = 2 bar,

Inlet Enthalpy (h1) =2710 KJ/Kg

Inlet Entropy (s1) = 7.1 KJ/Kg K

For, Outlet Pressure (P2) = 1.2 bar,

Outlet Enthalpy (h2) =2680 KJ/Kg

Outlet Entropy (s2) = 7.4 KJ/Kg K

Enthalpy Drop (hd) = h1 – h2

= 2710-2680

= 30 KJ/Kg

Exit Velocity (V2) = 44.72

= 44.72

**Exit Velocity (V2) = 245 m/s**

* **Formula for Area of outlet**

A2 =

× D22 =

× (D2)2 =

* **Outlet Diameter of Nozzle (D2) = 12 mm**

Thrust produced by rotor,

Thrust = Inlet Velocity (V1) × Mass Flow Rate (m) + (Pressure –Inlet Pressure)×Area

= 40 × 0.015 + (4 - 2) × × 122

= 0.6 N

**Thrust = 0.6 N**

Work Done = Thrust × Radius of rotor × No of Nozzles

= 0.6 × (8×10-3) × 3

= 0.144 Watts.

**Table 4.2 OBSERVATION TABLE:-**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Sr. no | Pressure [Bar] | Exhaust inlet temp. (°C) | Exhaust outlet temp. (°C) | Flywheel RPM | Motor RPM |
| 1 | 4 | 380 | 380 | 268 | 1271 |
| 2 | 5 | 380 | 380 | 511 | 2619 |
| 3 | 6 | 380 | 380 | 833 | 4270 |
| 4 | 7 | 380 | 380 | 1194 | 6120 |
| 5 | 8 | 380 | 380 | 1306 | 6694 |
| 6 | 9 | 380 | 380 | 1365 | 6996 |
| 7 | 10 | 380 | 380 | 1440 | 7380 |

**4.2 Compressor-**

* **TO CHECK THE PERFORMANCE OF THE EXPERIMENTAL SETUP, AIR COMPRESSOR IS USED AND FOLLOWING READINGS ARE OBTAINED TO CHECK EFFICIENCY OF THE SETUP-**

**COMPRESSOR SPECIFICATIONS:-**

Reciprocating air compressors are designed to be a compress air for specific utility. They are built for efficiency and lower operating costs, producing more compressed air at a lower horsepower. Local made Type: Standard, Volts: 230, Motor Phase(s): Single, HP: 5, Amps: 21 Max. PSI: 175, CFM at 175 PSI: 15.2, CFM at 100 PSI: 15.4, Tank Type: Vertical, Air Outlet Size (in.): 1/2, Stage: Two, Drive: Belt, Air Tank Size (gal.): 60, After-Cooler Included: No, Drain System: Manual ball valve, Portable or Stationary: Stationary, Pump: Cast iron, Duty Cycle: 100%, Pump Life (hrs.): 50,000+, Dimensions L x W x H (in.): 29 x 21 x 64.

**CALCULATION:-**

We have performed calculations on the compressor

Given:-

The mass flow rate of the given compressor is 162.57 m/s

Which is calculated by the discharge formula Q= ρ/m

Where (ρ) = Density of Air

(m) = Mass Flow Rate of Air in m/s

There for discharge to the inlet of the nozzle is given by

Q = Q= ρ/m

Q= (1.164 kg/m3)/ (7.16 x)

Q= 162.57m/s

Finding the velocity at the inlet of the nozzle

Discharge = Area X Velocity

= 0.01716 x3 x velocity

Discharge (Q) = 162.57 and area at the inlet = 0.01716 (given values)

Therefore inlet velocity (v1) = 766.66 m/s

For calculating the velocity v2 we apply the formula as

Given values, Outlet Velocity (V2) = 766.6 m/s

n = 1.4

p1 = 2 bar

v1 = 0.64

V1 is calculated by using the law PV= mRT

Thus v,

V2 = 24.5m/s

Similarly calculating the velocity v2 for the pressure p2 p3 p4 p5

Now finding the kinetic energy at the inlet of nozzle

K.E =

M= mass or air = 28.97

V= velocity at inlet = 766.6m/s

K.E =

K.E=

The kinetic energy at the outlet of the nozzle is given by,

K.E =

K.E =

K.E = 24.5

Thus calculating K.E for velocities v2 similarly,

Now calculating the Waste Heat Recovered,

Waste Heat Recovered = K.E2 – K.E1

**Table 4.3 OBSERVATION TABLE:-**

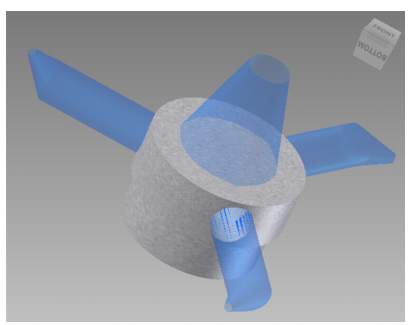
|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Inlet Pressure [bar] | Outlet Pressure [bar] | Inlet Velocity [m/s] | Outlet Velocity [m/s] | Kinetic Energy Inlet | Kinetic Energy Outlet | KE2-KE1 |
| 2 | 1.056 | 766 | 1.31 | 8.51 | 24.5 | 16 |
| 3 | 1.585 | 766 | 1.6 | 8.51 | 37.08 | 28.57 |
| 4 | 2.113 | 766 | 1.85 | 8.51 | 50 | 41.5 |
| 5 | 2.641 | 766 | 2.066 | 8.51 | 61.46 | 52.95 |
| 6 | 3.17 | 766 | 2.263 | 8.51 | 74.6 | 66.1 |
| 7 | 3.7 | 766 | 2.44 | 8.51 | 86.25 | 77.74 |

**4.3 Problem Identification:-**

The work area is the automobile engine which throws the waste/ flue gases in to the atmosphere. Observation was given to these gases and we found that the gases coming out of the engine from the exhaust pipe contain energy, and heat also. The gases posses K.E as they are thrown with certain velocity, it is calculated that the pressure exerted by the flue gases is about 2bar. For the bikes or motor cycles with standard specification, so the final identification is that the energy is just released by the combustion engine is wasted into the atmosphere without any use of it.

**4.4 Solution to the problem:-**

Thus by the law of conservation of energy, energy can be converted from one form to the other; we made attempt to convert the waste Kinetic energy of the gases in to the useful work by designing a nozzle system assembly.

The energy coming out of the combustion chamber contains the kinetic energy and heat energy thus we are converting the kinetic energy of the gases in to the potential energy. The system designed is shown in figure below.

Main inlet for exhaust gases containing K.E

**Figure 4.1: The figure shown shows the system designed by the team.**

Nozzles throwing the gases with thrust.

We have used the trial and error method along with theoretical approach.

The gases possessing the kinetic energy and velocity enter the main nozzle as shown in the figure; We have taken convergent nozzle in the system by use of these nozzles total kinetic energy of the exiting gases from the exhaust pipe are converted in to the potential energy thus these gases with potential energy are distributed equally to the three tubes which are inclined to each other in circular manner in one plane as in the figure above.

The nozzles are tilted 600 to the horizontal for the maximum thrust.

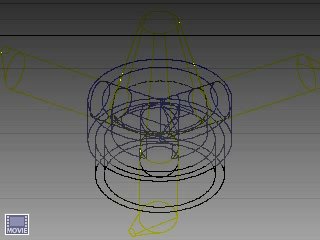
The gases finally are passed through the nozzles with potential energy which exist a thrust thus giving motion in the opposite direction, thus rotating the whole assembly.

This rotational work can be coupled to any other system for usage of the work produced according to the standard conditions.

Thus the system is named rotor engine, because it is converting the existing energy into work.

For the maximum conversion of the energy along with other parameters such as heat energy possessed by the gases.

The model is designed in AUTODEST INVENTOR; the wire frame of the system is given below as in figure the system is hollow form inside.



**Figure 4.2: Wire View of Rotor Engine**

The inlet parameters are given such as diameter of inlet of the nozzle and thermal coefficients and fluid properties are taken according to air.

We are working on the finest possible solutions;

The dimensions of the system are calculated are as shown

The length of the tube which connects the main nozzle to the three nozzles which are fitted at tubes arranged at 1200 is depended upon the law that velocity is directly proportional to the pressure. The more the distance travelled by the gases in the pipe more the loss in energy will b there. Hence deciding the particular length and then decreasing and increasing the length for maximum output.

CHAPTER V

**RESULTS AND DISCUSSIONS**

CHAPTER V

**RESULTS AND DISCUSSIONS**

*\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_*

The exhaust gases coming out form the vehicle are passed through the nozzles with potential energy which exist a thrust thus giving motion in the opposite direction, thus rotating the whole assembly

**5.1:** - **Maruti Suzuki Alto LXI, I.C Engine Test Rig Graphs.**

We have successfully fabricated Rotor Engine as a waste heat recovery device. An efficient transient system was developed so as to measure the power recovered from the exhaust gases of three cylinders, **Maruti Suzuki Alto LXI, I.C Engine Test Rig**. And it was useful in successfully generating power from the intake air of I.C engine. And the graph for their readings is plotted as below.

**Graph 1: Flywheel RPM Vs Pressure**

Graph is drawn inlet pressure verses flywheel shows there is an increase in RPM with increase inlet pressure, it means that the there is a moderate amount of energy recovery by the setup.

**5.2:** - **Air Compressor Test Rig Graphs.**

To Check the Performance of the Experimental Setup, Air Compressor Is Used and Following Readings Are Obtained To Check Efficiency of the Setup.

**Inlet Pressure**

**Outlet Pressure**

**Graph 2: Inlet Pressure Vs Outlet Pressure**

Graph is drawn inlet pressure verses Outlet Pressure shows there is an increase in Pressure with increase Outlet pressure, it means that the there is a moderate amount of energy recovery by the setup.

**Inlet Velocity**

**Inlet Pressure**

**Graph 3: Inlet Pressure Vs Inlet Velocity**

Graph is drawn Inlet Pressure Vs Inlet Velocity, shows a straight line.

**Outlet Velocity**

**Inlet Pressure**

**Graph 4: Inlet Pressure Vs Outlet Velocity**

Graph is drawn Inlet pressure verses Outlet Velocity shows there is an increase in Pressure with increase Outlet pressure with slight deviation, it means that the there is a moderate amount of energy recovery by the setup.

**Inlet Kinetic Energy**

**Inlet Pressure**

**Graph 5: Inlet Pressure Vs Inlet Kinetic Energy**

Graph is drawn Inlet Pressure Vs Inlet Kinetic Energy, shows a straight line.

**Outlet Kinetic Energy**

**Inlet Pressure**

**Graph 6: Inlet Pressure Vs Outlet Kinetic Energy**

Graph is drawn Inlet pressure verses Outlet Kinetic Energy shows there is an increase in Pressure with increase Outlet pressure with slight deviation, it means that the there is a moderate amount of energy recovery by the setup.

Waste Heat Recovered

**Inlet Pressure**

**Graph 7: Inlet Pressure Vs Waste Heat Recovered**

Graph is drawn Inlet pressure verses Waste Heat Recovered shows there is an increase in Pressure with increase Outlet pressure with slight deviation, it means that the there is a moderate amount of energy recovery by the setup.

**Inlet Velocity**

**Outlet Pressure**

**Graph 8: Outlet Pressure Vs Inlet Velocity**

Graph is drawn Outlet Pressure Vs Inlet Velocity, shows a straight line.

**Outlet Velocity**

**Outlet Pressure**

**Graph 9: Outlet Pressure Vs Outlet Velocity**

Graph is drawn Outlet pressure verses Outlet Velocity shows there is an increase in Pressure with increase Outlet pressure with slight deviation, it means that the there is a moderate amount of energy recovery by the setup.

**Inlet Kinetic Energy**

**Outlet Pressure**

**Graph 10: Outlet Pressure Vs Inlet Kinetic Energy**

Graph is drawn Outlet Pressure Vs Inlet Kinetic Energy, shows a straight line.

**Outlet Kinetic Energy**

**Outlet Pressure**

**Graph 11: Outlet Pressure Vs Outlet Kinetic Energy**

Graph is drawn Outlet Pressure verses Outlet Kinetic Energy shows there is an increase in Pressure with increase Outlet pressure with slight deviation, it means that the there is a moderate amount of energy recovery by the setup.

Waste Heat Recovered

**Outlet Pressure**

**Graph 12: Outlet Pressure Vs Waste Heat Recovered**

Graph is drawn Outlet Pressure verses Waste Heat Recovered shows there is an increase in Pressure with increase Outlet pressure with slight deviation, it means that the there is a moderate amount of energy recovery by the setup.

CHAPTER VI

**CONCLUSION**

CHAPTER VI

**CONCLUSION**

*\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_*

Selecting an appropriate energy recovery technology, properly designing the system, meeting the applicable codes, and commissioning the system are all important. When an energy recovery system is been design, installed and operated correctly it will provide significant energy and environmental benefits.

**6.1 SCOPE OF FUTUREWORK:-**

The energy recovery system is basically a device which utilizes the waste energy or it utilizes the temperature of the gases. The energy recovery system has got wide range of the application in the future .it can be a transient test methodology to measure the humidity and temperature. The Rotor Engineis the transient system which enables to use the waste energy from the engines which enters the atmosphere at the high temperatures.

The energy recovery system is the device which can directly connected to the outlet of the exhaust gas .energy recovery systems are the system which can be used in the devices like boilers , super heater, gas duct systems ( from turbines/engines) . The energy recovery system is the device which consumes minimal energy thus it help to the recover energy at the minimal price .Thus it can help in the conservation of the energy .these devices are one time investment .these system are capable of recovering 75% of the energy.

The Rotor Enginehas got wide range of the application, like it can be used in automobiles. It can also be used in generators. The energy recovery system can be also used in the thermal power stations where the high temperature of the heat is exhausted, which can be used for secondary power generation.

**CHAPTER VII**

**COST ESTIMATE**

CHAPTER VII

**COST ESTIMATE**

**Components Quantity Cost In Rupees**

1 Stainless Steel for Nozzles 4 40/-

2 Rod Bar (Metal) 1 210/-

3 Ball Bearings 2 650/-

4 Screws 10 60/-

5 Tripod Stand 1 170/-

6 Galvanized Plate 1 200/-

7 Connectors 2 100/-

8 Led Light 10 30/-

9 Cover Body 1 800/-

10 Clamp 3 10/-

11 Battery 6v 1 300/-

12 Clutch 1 10/-

13 Switch 1 15/-

14 Generator 1 320/-

15 Fabrication Work 1850/-

16 Sealing Material 350/-

TOTAL COST Rs. 5115/-

**REFERENCES**

**REFERENCES**

*\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_*

**BOOKS**

1. **R .K Rajput** “Thermal Conductivity of Material” *Heat Transfer* Volume 1.
2. Heat Recovery Systems by ***D.A.Reay*, E & F.N.Span**, London, 1979.
3. **R. S. Khurmi** “Design of Shaft and Pulley Design” *Machine Design* Volume1.
4. **Besant, R.W.** and **Simonson,** C.J., 2000. Air –to-Air Energy Recovery, *ASHRAE Journal*, **42**(5):31-42.
5. **Besant, R.W. and Simonson C.J.,** 2003. Air-to-Air Exchangers, *ASHRAE Journal*, **45**:42- 52.
6. **Brion, K.Carr**, 1986. *Moisture Sensors in Process Control*, Elsevier Applied Science
7. Publishers, London and New York.
8. **Ciepliski, D.L**., 1997. *Testing an Air-to-Air Rotary Energy Recovery Device Using*
9. *Performance Test Standard*, M.Sc. thesis in mechanical engineering, University of
10. Saskatchewan, Canada.
11. **Ciepliski, D.L., Besant, R.W. and Simonson, C.J**., 1998. Some Recommendations for
    1. Improvements to ASHRAE Standard 84-1991, *ASHRAE Transactions*, **104**(1B), 1651-
    2. 1665.
12. **Delpha, C., Siadat, M.** and **Lumbreras, M**., 2000. Discrimination of A Refrigerant Gas in A Humidity Controlled Atmosphere by Using Modelling Parameters, *Sensors and*
13. *Actuators B*, **62**, 226-232.
14. **Ingleby, P., Gardner, J.W**. and **Bartlett, P.N.,** 1999. Effect of Micro-electrode Geometry on Response of Thin-film Poly(pyrrole) and Poly(aniline) Chemoresistive Sensors, *Sensors and Actuators B*, **57**, 17*-27*.
15. **Kuse, Takashi** and **Takahashi**, Sachio, 2000. Transitional Behavior of Tin Oxide
16. Semiconductor under a Step-like Humidity Change. *Sensors and Actuators B*, **67**, 34-42.
17. **Lafarie, J.P.,** 1985. Relative Humidity Measurement: A Review of Two State-of –The-Art Sensors. *Moisture and Humidity: Measurement and Control in Science and Industry*, **1**, 875-883.
18. Literature of ENERGY RECOVERY FOR VENTILATION AIR LABORATORIES.
19. The design of an energy management system M . Tech thesis submitted by **Jason Allan** on august 24, 2007 Helsinki University of technology.
20. Incropera, **F.P. and Dewitt**, D.P., 1996. *Fundamentals of Heat and Mass Transfer*, John Wiley & Sons, New York.

**WEBSITES**

1. http://www.engineeringtoolbox.com/molecular-mass-air-d\_679.html
2. http://www.engineering-4e.com/calc5.htm
3. http://www.answers.com/topic/back-pressure
4. www.cast-safety.org/pdf/3\_engine\_fundamentals.pdf
5. www.bardyne.com/Publications/index.htm
6. http://www.globalccsinstitute.com/publications/good-plant-design-and-operation-onshore-carbon-capture-installations-and-onshore-pipe-5

**RESUME**

**RESUME**

*\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_*

.

The basic purpose of the project is to make use of energy of exhaust gases that are produce from the combustion of fuel in the engine. In an internal combustion engine fuel in the presence of air burns from which various gases produce. These gases are thrown out in the atmosphere from the engine through an exhaust pipe with a certain velocity. With the help of a proper arrangement at the exhaust pipe we can make use of these exhaust gases which can be used in many ways. We have used the trial and error method along with theoretical approach. The nozzles are tilted 600 to the horizontal for the maximum thrust. The gases finally are passed through the nozzles with potential energy which exist a thrust thus giving motion in the opposite direction, thus rotating the whole assembly. This rotational work can be coupled to any other system for usage of the work produced according to the standard conditions.

We have successfully fabricated Rotor Engine as a waste heat recovery device. An efficient transient system was developed so as to measure the power recovered from the exhaust gases of, I.C Engine. And it was useful in successfully generating power from the intake air of I.C engine. And following results were observed.

Waste heat is heat, which is generated in a process by way of fuel combustion or chemical reaction, and then “dumped” into the environment even though it could still be reused for some useful and economic purpose. The essential quality of heat is not the amount but rather its “value”. The strategy of how to recover this heat depends in part on the temperature of the waste heat gases and the economics involved.

Large quantity of hot flue gases is generated from Boilers, Kilns, Ovens and Furnaces.

If some of this waste heat could be recovered, a considerable amount of primary fuel could be saved. The energy lost in waste gases cannot be fully recovered. However, much of the heat could be recovered and loss minimized by adopting following measures as outlined in this chapter.

**SETUP PICTURE**

**SETUP PICTURE**

*\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_*

Exhaust of I. C Engine



Generator [Dynamo]

Glowing Light Due To Current Generation

**ACTUAL PICTURE**

****

**PROJECT TEAM MEMBERS INFORMATION**

**PROJECT TEAM MEMBERS INFORMATION**

*\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_*



Name of the Guide: - R.N.Chakraborty

Contact No. : - + 91-9822693894

E-mail ID:- ramanoj\_chak@yahoo.com



Name of Co-Guide:- M.S.Deshmukh

Contact No. : - +91- 9922946761

E-mail ID: - [msdngp@gmail.com](mailto:msdngp@gmail.com)



Name: - Nakul. R. Sharma

Contact No. : - +91 -9665759837

E-mail ID: - [nakul.r.sharma7@gmail.com](mailto:nakul.r.sharma7@gmail.com)



Name: - Prasanna.P.Raut

Contact No. : - +91- 9595337050

E-mail ID: - [rautprasanna7@gmail.com](mailto:rautprasanna7@gmail.com)



Name: - Parag. N. Gajbhiye

Contact No. : - +91 -9665989693

E-mail ID: - [parag\_ng@hotmail.com](mailto:parag_ng@hotmail.com)



Name: - Dattatray.P.Kale

Contact No: - +91-9096348195

E-mail ID: - [dkale@rediffmail.com](mailto:dkale@rediffmail.com)

Name: - Siwaji.P.Thakre

Contact No. : - 9579119464

E-mail ID: - [shiwajithakre@gmail.com](mailto:shiwajithakre@gmail.com)