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# ANALYSIS OF SELF-SUSTAINABLE MINI GAS TURBINE ENGINE FOR DOMESTIC PURPOSE

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***Abstract- The power density of hydrocarbon fuels is 100 times as compared to other modes power producing devices at micro level. The battery system is very inefficient when it comes to provide enough power to most portable devices like humanoid robot, mobile machines and mechanism to aid humanoid motion such as future armor to soldiers (exoskeleton), these mini gas turbines can be very handy replacement power source. It can also be used as aided power in various industrial and research applications. Improved combustion efficiency may broaden our area to experiment even with bio fuels. A Tata indica vista turbocharger model k35 has been used in fabrication for gas turbine engine having impeller diameter of 25.6 mm. a reverse flow combustion chamber made to stall between the turbo compressor and turbo turbine. With help of Rota meter fuel is varied from*** $0.00018625 \frac{kg}{sec}$ ***to*** $0.000415 \frac{kg}{sec}$***. and different set of pressures and temperatures data were recorded at locations of compressor outlet, combustor outlet and turbine outlet. It has been observed that the engine was well sustained within the limits of fuel above mentioned, and we have been able to achieve improved pressure ratios on increasing the fuel supply. The results showed us that the combustion intensity of burner was settled between*** $1030 \frac{KW}{m^3-atm.}$ ***to*** $1948 \frac{KW}{m^3-atm.}$***.*** $\eta_{cycle}$ ***,energy conversion efficiency Obtained from 4.75% to 9%. Power efficiency has come out as ~90 % which is very exciting for further improvement of current set up. For further improvement we can reduce the volume of combustion chamber to increase combustion intensity and hence improving equivalence ratio and better sustainability even at very low-level supply of fuel.***

***Keyword- efficiency, combustion intensity, power efficiency, hydrocarbon, sustainability.***

## I. INTRODUCTION

Gas turbines are most compact and control form producing power. Absence of reciprocating parts means balancing and lubrication requirements are very less as compared to other modes of generating power. They have high power densities of 100 times when compared to present set of best existing batteries.

Considering all these advantages offered by gas turbines it would very exciting to work in small scale of power generation.

The main purpose of work is to develop a self-sustainable mini gas turbine engine which provides initial idea and reference data to further through our research into emerging and very exciting area of small-scale mobile power generation.

In gas turbines the chemical energy of fuel gets converted to thermal energy which in turn rotates the turbine and produces mechanical power required for driving the setup. The setup works on the operation of Brayton cycle.

The Brayton cycle comprises of standard components involving a compressor, a combustion chamber and a turbine. The current setup operates on open version of Brayton cycle which allows to measure the temperature and pressure associated with each component. The data obtained can be used to calculate the performance curves and various efficiencies of the cycle.

The engine involves the design and selection of each component and auxiliary unit's configuration at the right location. An Indica Vista model k-35 turbocharger comprising of a compressor and turbine mounted on a common shaft is being selected. A reverse flow combustion chamber is located between the outlet of turbo compressor and inlet of turbo turbine. The combustion chamber design is the most complex task and majority of the work work involves to sustain the flame inside the combustor.

To produce extra thrust a bell-shaped nozzle provided at the inlet of compressor and an additional pipe fitting also working as nozzle installed at outlet of turbine. A spark plug is installed in the middle of the flame tube for ignition purposes. As the turbocharger is exposed to environment of generating high pressure ratios, as in our it is made to run almost 12 times the normal operation of engine, therefore requires an effective technique of lubrication for bearings to accommodate such high RPM thrust. Rotameters were used to control and regulate the air and fuel flow rate and also enabling to take data at various required locations. The current set up is shown in below figure

This thesis is a progression of work initiated by Anirudh Gupta for his MTech thesis requirement. His work included selection of an automobile turbocharger and initial idea of concentric cell design to attain flame stability thereby enabling the self-sustainability of engine, since the process of self-sustainability was not achieved my primary and most important task is to bring out the desired modifications and make the engine self-sustainable. Considering the combustion parameters and bringing out slight modifications the engine was made self-sustainable. The task was well achieved by making the engine to run without the aid of external compressor. Various data were recorded for further improvement in design to generate power from the current set up.

## II. EXPRIMENTAL SET-UP

The setup must be configured and mounted in a way so that all the data required at particular locations must be obtained effectively and neatly. This can be done by installing all the measuring instruments with proper atmosphere and orientation. After installing all the instruments and taking proper safety measures. For starting the turbocharger, an external storage tank is used to supply the compressed air for starting the compressor, a 0-600 LPM rotameter is used to crank the combustion process. A pressure indicator is also attached to the delivery pipe, which gives the idea of density correction and provides the actual mass of air required to crank the combustion process, a control valve is fitted with the delivery pipe which helps to regulate the flow of air and gives the idea to determine the range of air flow rate required for cranking and sustaining the combustion with external aid. The delivery of air is made to inject through the inlet bell mouth attached to the turbocharger's compressor. The compressor when produces a nice uninterrupted sound, by acquiring enough shaft speed the delivery of air is cut off, and thereby enabling the self-sustainability of the setup. A venturi meter attached to the outlet of the compressor gives the flow rate of the air delivered from compressor by measuring the pressure difference with the manometer attached to ports of venturi meter. This air enters the combustion chamber and fuel is injected through the nozzle in the combustor, with the help of a rotameter attached to the delivery pipe of fuel, the rotameter enables to regulate the flow rate of fuel. A pressure gauge is also attached to the delivery fuel pipe which gives the density correction factor and corrected flow rate injected in the combustor. Now the gases are expanded in the turbine region and further in nozzle to achieve proper thrust to drive the setup.
The pressure sensors are attached after the compressor, combustor and turbine as shown in the figure. Thermocouples are also attached at these locations to measure the temperature at respective locations. All the pressure sensors are attached to regulated DC voltage supply and rest two supplies are connected the DAQ NI USB 6210 at AI0, AI1 and AI2 channel for measuring the samples and output pressure in the form of voltage, by using calibrated curves the voltage provides the equivalent pressure data [16]. The thermocouples are also attached to the power supply and one end connected to the digital meter providing the visual data in the digital meter.

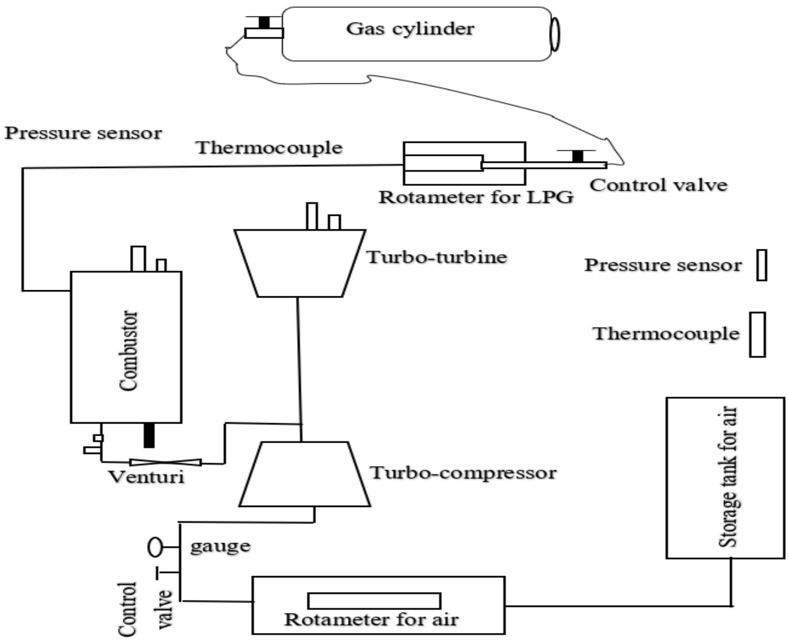


Fig 2.1 experimental setup

## III. Results and discussions

The main purpose of working on the project was to develop a self-sustainable mini gas turbine engine. For the flame stability and thereby maintaining the self-sustainability of the engine the combustion process needs to occur so that it empowers the turbo-turbine and hence empowering the turbo-compressor to supply necessary amount of air flow rate to maintain the oxidizer supply to the combustor. As explained in the experimental setup we have used pressure sensors and thermocouples to measure the data at required locations and for measuring the fuel flow rate we have employed a rotameter and for measurement of air flow rate a venturimeter connected to the water column manometer has been attached just outside the delivery pipe of turbo-compressor. We have increased the fuel flow rate in the range of 0.000186 $\mathrm{kg/sec}$ to 0.000415 $\mathrm{kg/sec}$ and data were recorded with the help of NIUSB 6210 and K type thermocouples and air flow rate was measured with the water column manometer attached to the venturimeter.

**Plotting of P-V and T-S curves for the cases considered**

When the engine made self-sustainable the data recorded and with the help of specific volume and entropy calculations P-v and T-s curves can be plotted

The calculation of the with varying equivalence ratio can be obtained

$$R_{mix} = \left[\frac{\{8314*(28.084+\emptyset)\}}{\{809.94+(52.4*\emptyset)\}}\right] \mathrm{J/(kg*k)}$$

$v = (R_{mix} * T/P)$ Where $v$ *represents* the specific volume $R_{mix}$ represents the gas constant for the mixture, $T$ , represents the temperature of given condition and $P$ stands for pressure at that condition

**Case 1**

| conditions | $pressure(\frac{N}{m^2})$ | $Temperature(K)$ | $specific\ volume(\frac{m^3}{kg})$ |
|---|---|---|---|
| Ambient | 101325 | 305 | 0.844 |
| 1 | 114902.6 | 318 | 0.7832 |
| 2 | 106391.2 | 1163 | 3.09 |
| 3 | 101730.3 | 1073 | 2.98 |

Table 3.1 pressure and specific volume case 1

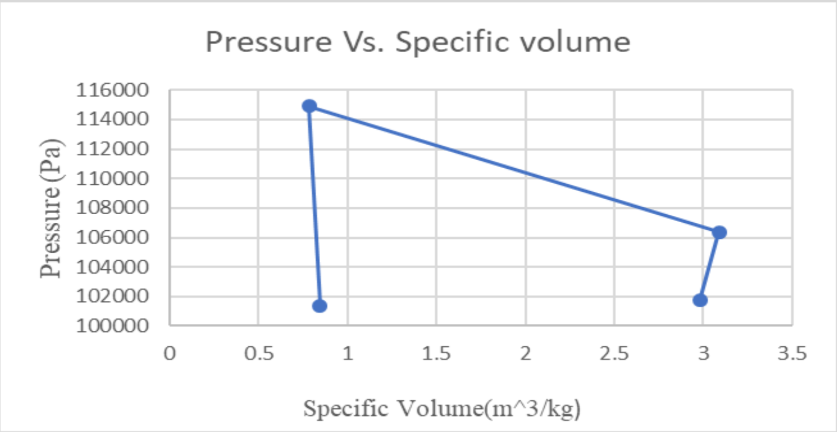


Fig 3.1 pressure and specific volume graph case 1

| Type equation here. | $compressor$ | $combustor$ | $turbine$ |
|---|---|---|---|
| $\Delta S(\frac{KJ}{kg.K})$ | 0.00636 | 1.446 | -0.0471 |

Table 3.2 entropy change across the cycle case 1

**Case 2**

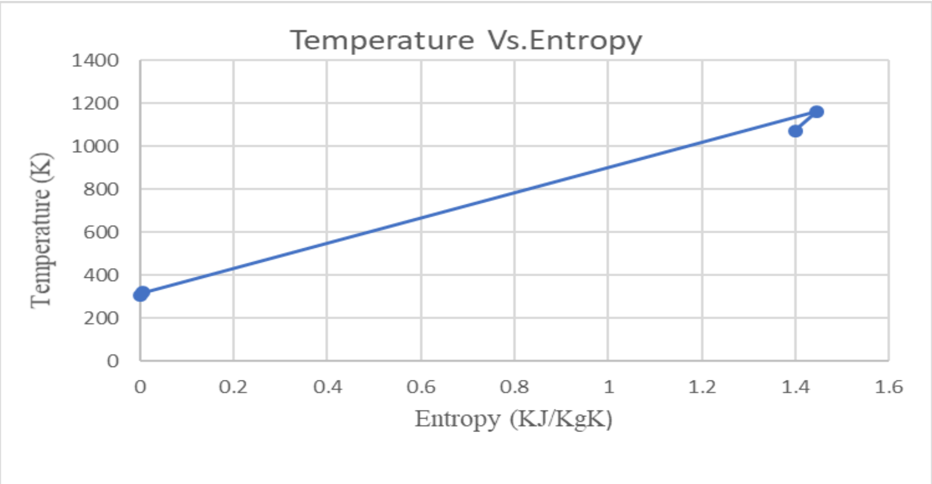


Fig 2.2 Pressure v/s specific volume (case 2)

 

| $conditions$ | $pressure(\frac{N}{m^2})$ | $Temperature(K)$ | $specific\ volume(\frac{m^3}{kg})$ |
|---|---|---|---|
| Ambient | 101325 | 305 | 0.844 |
| 1 | 124123 | 326 | 0.740 |
| 2 | 109431 | 1253 | 3.23 |
| 3 | 101933 | 1153 | 3.19 |

Table 3.3 pressure and specific volume case 2 case 2

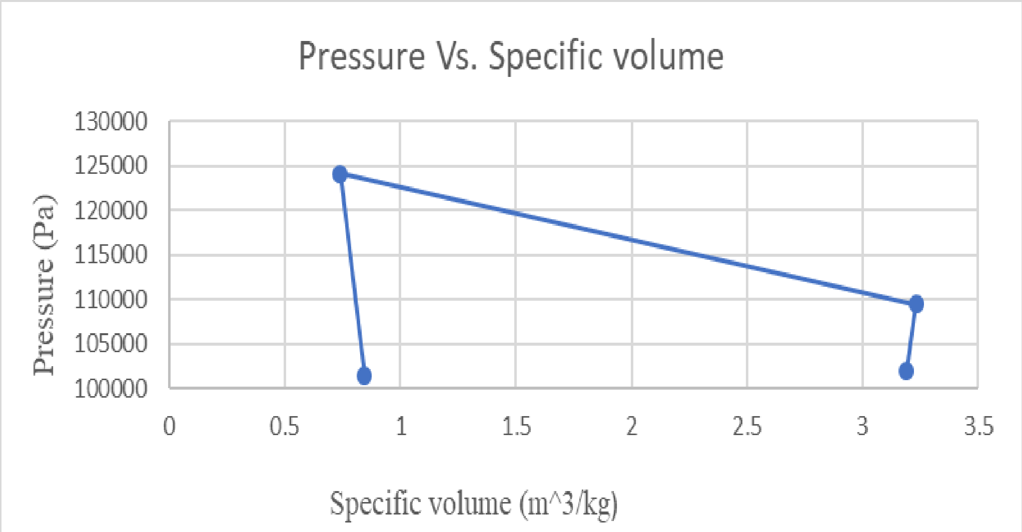


Fig 3.3 Pressure v/s specific volume (case 2)

| Type equation here. | $compressor$ | $combustor$ | $turbine$ |
|---|---|---|---|
| $\Delta S(\frac{KJ}{kg.K})$ | 0.00871 | 1.5453 | -0.0464 |

Table 3.4 entropy change across the cycle

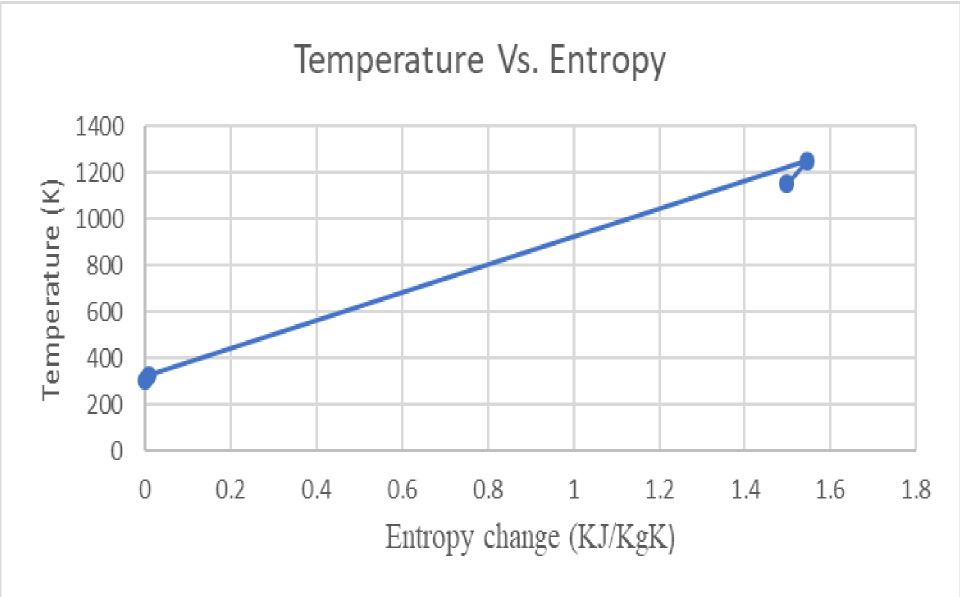


Fig 3.4 temperature and entropy variation case 2

**Compressor performance curve**

The compressor performance curve can be calculated

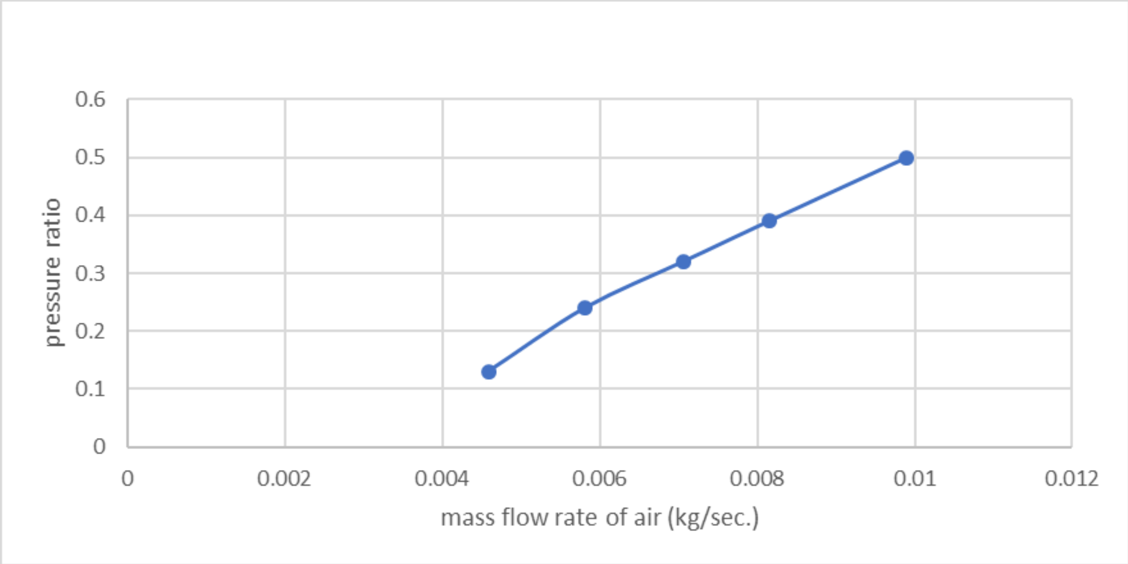


**Fig 3.3** pressure ratio Vs mass flow rate

| $\dot{m}_{air}$ | $\dot{m}_{fuel}$ | $f(FAR)$ | $P_1(Pa)$ | $P_2$(Pa) | $P_3(Pa)$ | $T_1(K)$ | $T_2(K)$ | $T_3{}'(K)$ | $T_3$(K) |
|---|---|---|---|---|---|---|---|---|---|
| 0.00458 | 0.000186 | 0.0406 | 114902.6 | 106391.2 | 101730.3 | 318 | 1163 | 1133 | 1073 |
| 0.00581 | 0.000241 | 0.0421 | 124123.1 | 109431 | 101933 | 326 | 1253 | 1218 | 1153 |
| 0.00706 | 0.000303 | 0.0432 | 132229.1 | 112977.4 | 103452.8 | 333 | 1313 | 1263 | 1213 |
| 0.00815 | 0.000359 | 0.0441 | 139929.8 | 116523.8 | 105074 | 339 | 1378 | 1330 | 1288 |
| 0.00909 | 0.000415 | 0.0456 | 150163.7 | 120576.8 | 106644.6 | 348 | 1433 | 1385 | 1338 |

Table 3.11 Table representing recorded data

From the above table following conclusions can be drawn

1) As we are increasing the mass of fuel$\left(\dot{m}_{fuel}\right)$, the the pressure ratio across the turbo-compressor improves and hence better performance is obtained in the range of increasing fuel flow rate.
2) The mass flow rate of air is increasing steadily in the range of above mentioned operation indicated by the water column manometer and further calculated with the help of energy equation across the venturimeter.
3) There is temperature loss between the combustor exit and the turbine inlet.
4) The increasing pressure ratio has been achieved but 7% to 15% pressure loss occurred in the combustion chamber.
5) The FAR has been steadily increased in the range of operation from 0.041 to 0.046.

## IV. Conclusion and future scope

The main aim of the project is to develop a self-sustainable mini gas turbine engine, sustainability of combustion could not have achieved previously, it was necessary to empower the engine with external aid and as soon as external aid is cut off the flame get extinguished, the problem of sustainability has been rectified successfully by reducing the volume of the combustor, thereby increasing the combustion intensity. Combustion chamber was designed to provide reverse flow nature of fuel and air mixture which gives the proper mixing and better combustion environment.

It is concluded that the engine was made self-sustainable in the range of 0.041 to 0.045 $FAR$(fuel to air ratio), the compressor has provided a pressure difference up to 130 mm of water column and up to 1.5 pressure ratio. The P-v and T-s curves of different conditions exhibits the same nature of the curve shown by gas turbine engine running on Brayton cycle. The combustion intensity varied in the range of $1.2\,\frac{MW}{m^3 atm.}$ to 1.9 $\frac{MW}{m^3 atm.}$ with burner efficiency varying from 0.52 to 0.65. The power efficiency comes out in the range 90% which gives enough motivation for further improvement of useful power extraction. The temperature lost from walls of combustor and turbine were found influencing the results which gives the idea for better insulation of walls, so that the temperature and pressure loses can be minimized. The energy conversion efficiency of the cycle was obtained, between 5 % to 9 %.

As the combustion intensity and burner efficiency are coming less and almost 17 % pressure drop in the combustor which means the combustion chamber design can be further modified to give the better results, the improved combustion intensity of the combustor can provide much exciting results to further look into this microscale power generation concept from hydrocarbon fuels. The electricity generation can be done by attaching a shaft or free turbine connected to generator. We can also test with other fuels like bio fuels[24] and pure vegetable oil [25] , by improving the combustor intensity of the combustor. We can further improve the efficiency of given set up by adding another turbocharger in between the combustor and turbine or by adding a recuperator (heat exchanger) to draw more energy from outlet of turbine containing hot gases and we can also try for ceramic materials for the setup design as it will improve the thermal stability limits and hence improving the cycle efficiency[26] . A catalytic combustor can also be used to enhance the cycle efficiency.

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