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DEVELOPMENT AND EXPERIMENTAL INVESTIGATION ON THERMOACOUSTIC STIRLING ENGINE

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Abstract: **This paper reports development of a Thermoacoustic Stirling Engine and experimental investigation carried out using Nitrogen gas as the working gas. Experimental setup mainly consists of a Regenerator Assembly which is the heart of the designed engine and is composed of a Regenerator, hot and cold heat exchangers. Regenerator is sandwiched between hot and cold heat exchangers. Brass circular punched meshes are closely packed within the hot and cold heat exchangers to improve the heat transfer rate and Regenerator tube is packed with stainless steel meshes. Experiment is carried for different working pressures of Nitrogen and for each working pressure Onset temperature, Pressure Amplitude, Frequency of oscillations are measured under no load condition.**

Keywords: **Thermoacoustic Stirling Engine, Regenerator Assembly, Regenerator, Punched Meshes, Onset temperature, Pressure Amplitude, Frequency.**

I. INTRODUCTION

Acoustics is a branch of science which deals the with study of mechanical waves in solid, liquids and gases and also includes topics like vibrations, ultrasound and infrasound. Thermoacoustic devices work on the principle of Thermoacoustic effect. If heat is supplied to a gas at its point of greatest condensation, or heat is removed from it at the point of greatest rarefaction, vibration is encouraged which results in Thermoacoustic Effect by Lord Rayleigh (1984). Devices might be used as heat engine (Engine-Power developing) or as a heat pump (Refrigerator or cooler).

In recent decades the study of Thermoacoustic has increased gradually since it is one of the simple and low cost methods of producing energy. The main source of producing power in past few decades is fossil fuels which is depleting at a fast rate. Also use fossil fuels like petrol, diesel etc.. produces harmful green house gases such as carbon di-oxide, carbon mono-oxide, etc… which affect the environment . Therefore new alternate methods of producing power must be developed and studied. Thermoacoustics is one such area whose principle can be used to develop energy at low cost and also without affecting the atmosphere. Thermoacoustic devices does not contain any moving parts, some contain few reciprocating parts like a diaphragm and hence no lubrication is necessary. Also no inertia forces are developed due to absence of moving parts. Thermoacoustic devices are silent in operation. In this investigation, development of a "Thermoacoustic Stirling Engine" and study of some of its parameters has been undertaken. This device consist of a looped tube within which energy waves propagates and are amplified with the help of buffer volume and resonator tube.

Thermoacoustic systems are used to convert thermal energy into mechanical energy (acoustic energy) and vice versa. Thermoacoustic systems works on the basis of "Thermoacoustic effect". In this phenomenon gas parcel oscillates within the solid porous material which is having a steep temperature gradient along its length. There is a certain time delay between heat transfer and motion of the wave. Ceperley [7] was the first to make the attempt to design and construct a Thermoacoustic travelling wave engine. Thermoacoustic waves were seen in the experimental setup made by Ceperley.

A. Thermoacoustic Stirling Engine:

A travelling wave Thermoacoustic prime mover is similar to a Stirling engine (Ceperley 1979) [7]. The gas parcel within the tube undergoes compression, heating, expansion and cooling just like in Stirling engine. The first travelling wave Thermoacoustic engine was attempted by Ceperley in 1979 which failed to generate acoustic power. A working travelling wave engine was first developed by Yazaki et al. [8] in 1998. The gas parcel undergoes a Stirling like cycle as it passes through the regenerator.

The gas parcel gets compressed adiabatically near the hot end of the regenerator, as the gas parcel passes through regenerator it absorbs heat from the regenerator material and this constitutes to the heating process and during process volume of gas parcel constant. When the gas parcel passes towards the cold end of the regenerator it expands adiabatically and at the cold end it give out heat and volume of the gas parcel remains constant. In a travelling wave Thermoacoustic prime mover the gas medium absorbs or rejects heat depending upon the temperature difference between the gas and the regenerator. Regenerator is made of wire mesh, ceramic material etc. When gas parcels are displaced within the thermal penetration depth of the regenerator surface, they exchange heat with it.

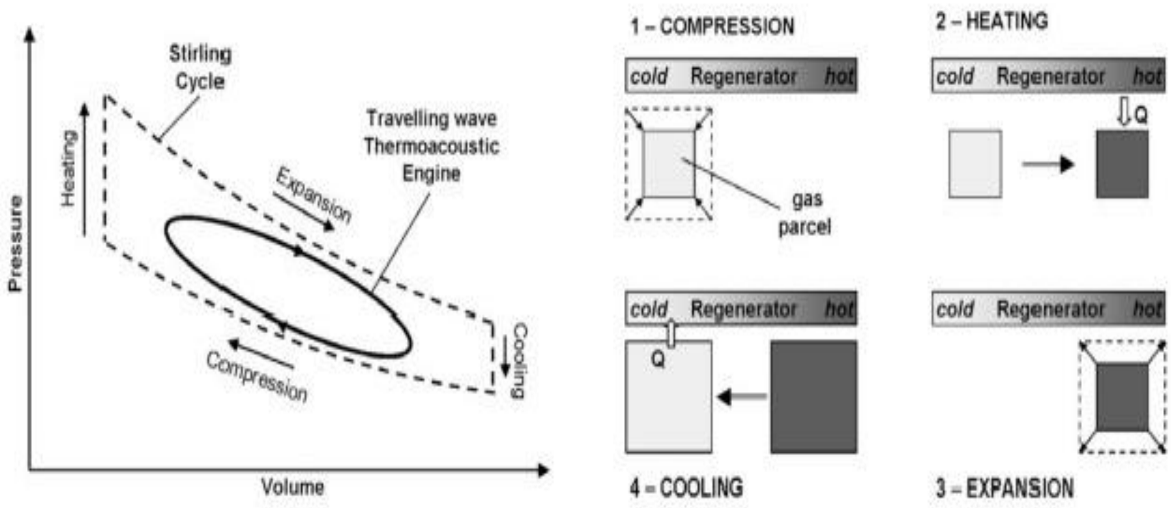


Fig.1. Principle of Thermoacoustic Stirling Engine

In travelling wave looped tube type Thermoacoustic prime mover the gas medium passes from the cold heat exchanger towards the hot heat exchanger through the regenerator material. The part of the regenerator close to the cold heat exchanger is at a low temperature. The temperature of the regenerator gradually increases as we move towards the hot end heat exchanger. As the gas medium passes from the cold heat exchanger towards the hot exchanger it absorbs heat from the regenerator material and acoustic waves are produced. As the gas medium oscillates between the hot and cold heat exchanger acoustic waves get amplified and travel through the looped tube. Therefore heat energy is converted into acoustic energy (mechanical energy) which is in the form of pressure waves. This wave energy is used to do necessary work.

II. EXPERIMENTAL SETUP

Schematic diagram of the experimental setup is as shown in the Fig. 2. In this experiment Stainless Steel **t**ubes (SS304) is used for all the parts where as for CHX and HHX Copper tubes is used. Copper tubes were used inside S.S. Test section for CHX, HHX and TBT heat exchangers to improve heat transfer. Copper tubes of CHX and HHX is packed with 10 mesh Brass (Fig. 3a) circular punchings and regenerator tube is packed with Stainless Steel 120 mesh punchings (Fig. 3b). Flanges were made of SS304 material and O-ring is used between two mating flanges to prevent leakage of working gas. Nitrogen gas is used as working gas. Apparatus fabricated has a total length of 5.8m. Diameter of the tubes is different for different parts of the apparatus. Working gas is heated using an external electrical heater rated 677W. Temperature is measured along the length of the regenerator using K-type Thermocouple. Thermo-wells are made to measure temperature of cooling water entering and leaving the heat exchanger to amount of heat rejected at CHX end of the regenerator.

Thermoacoustic oscillations generated in the apparatus is detected by the Dynamic pressure transducers which converts the pressure signals into electrical signals and sent to a storage Oscilloscope. Oscilloscope gives the Pressure amplitude and Frequency of the pressure wave.

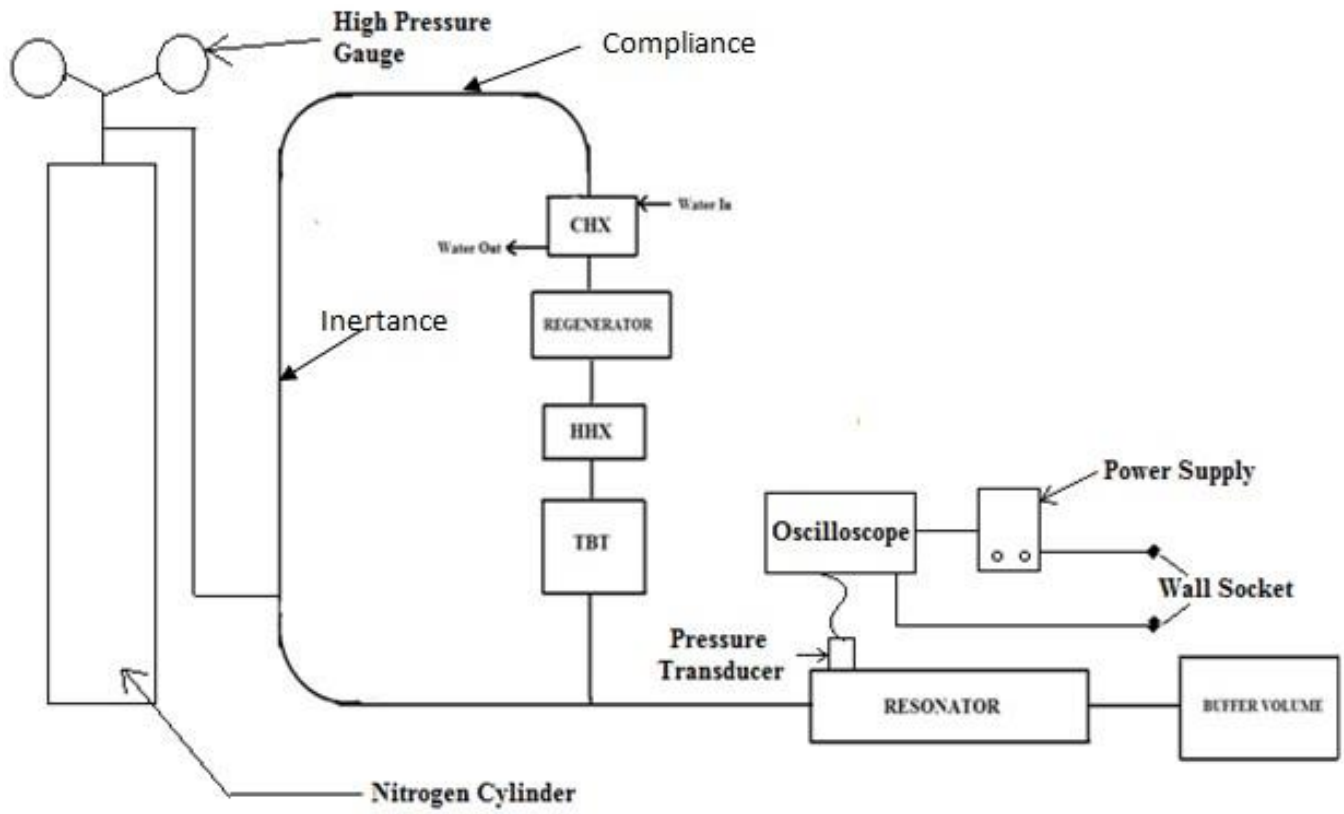
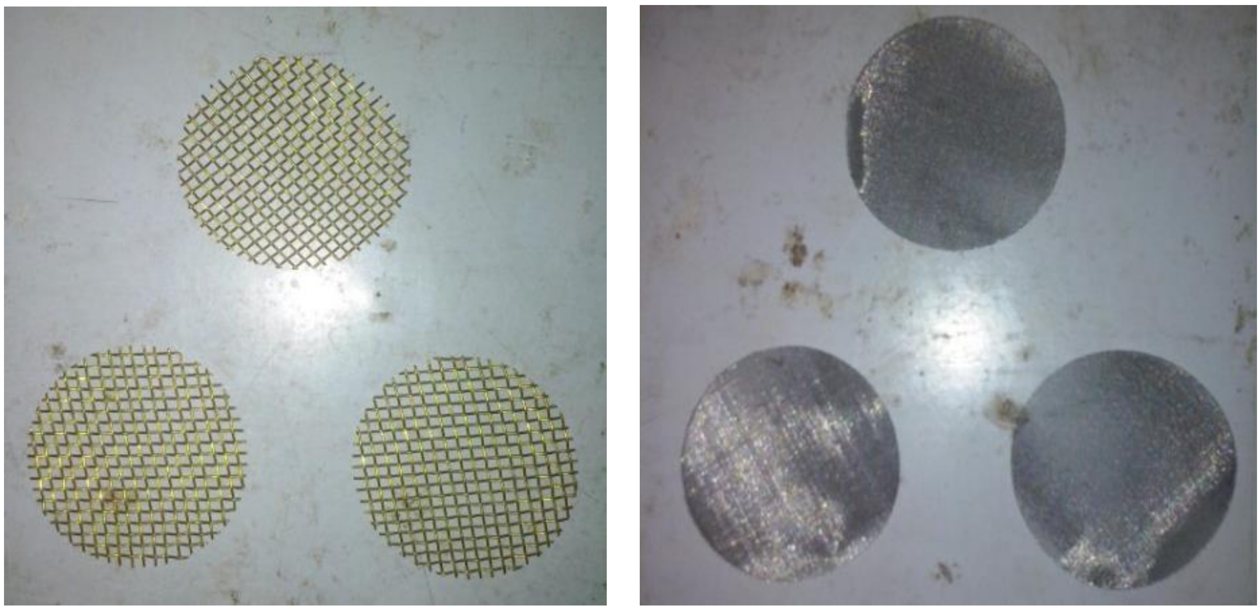


Fig.2. Schematic Diagram of the Experimental Setup

[CHX: Cold end Heat Exchanger, HHX: Hot end Heat Exchanger, TBT: Thermal Buffer Tube]



(a) **(b)**

Fig.3. Pictorial view of (a) Brass 10 Mesh Punches (b) Stainless Steel 120 Mesh Punches

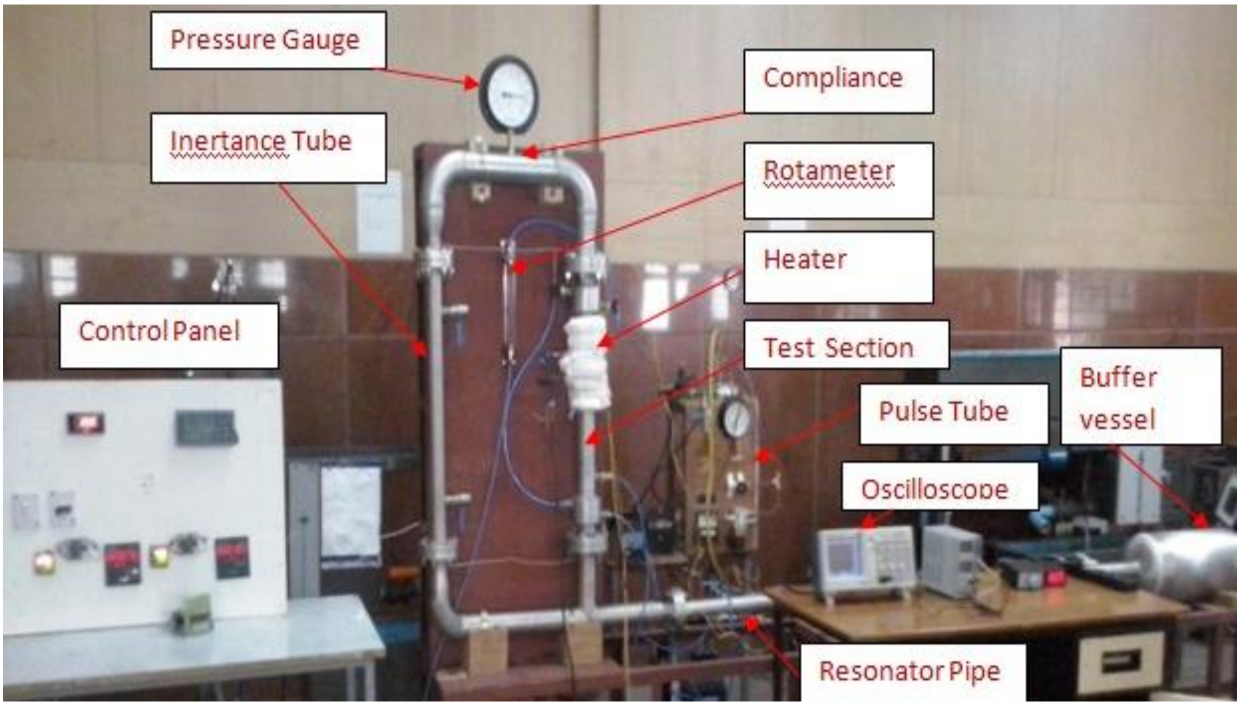


Fig.4. Photo of the fabricated apparatus

III. RESULTS

From Fig. 5, it is clear that as working pressure increases, Onset temperature gradient also increases. Initially experiment was carried out at room temperature of 26.5°C. When the same experiment to record the onset temperature at a room temperature of 29.7°C was carried out, it was observed that temperature at which Thermoacoustic oscillations started was not the same corresponding room temperature of 26.5°C. This indicates that room/surrounding temperature affects the onset temperature of the system. It was found that with the increase in the room temperature, onset temperature also increases for a given working pressure of Nitrogen.

Fig. 5 shows the variation of onset temperature of the system with change in working pressure when the experiment was carried out at a room temperature of 29.7°C. Onset temperature for a working pressure of 6 bar at a room temperature of 26.5°C is 325°C where as for the same working pressure at higher room temperature of 29.7°C onset temperature is 400°C. This is because as the room/surrounding temperature increases temperature gradient between the hot and cold end of the regenerator decreases also rate of convection heat transfer from the system to the surroundings also decreases. Further since normal water is used for cooling with elevated surrounding temperature cooling water temperature also is increased thereby decreasing the temperature gradient across the regenerator.

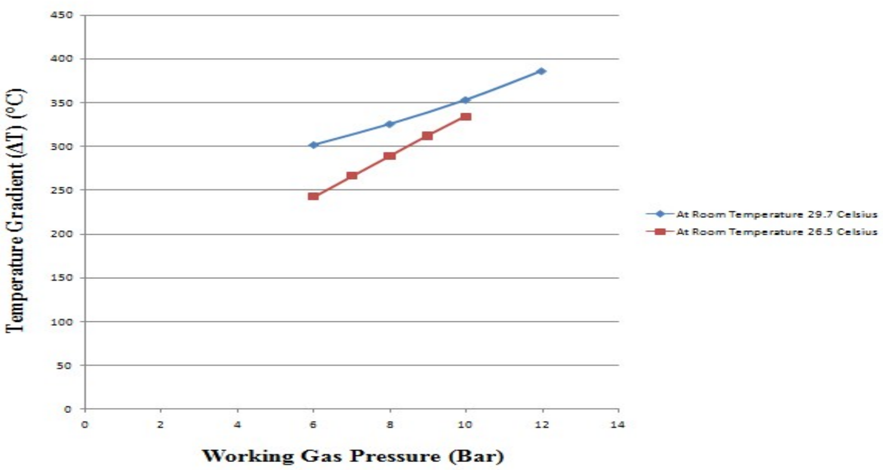
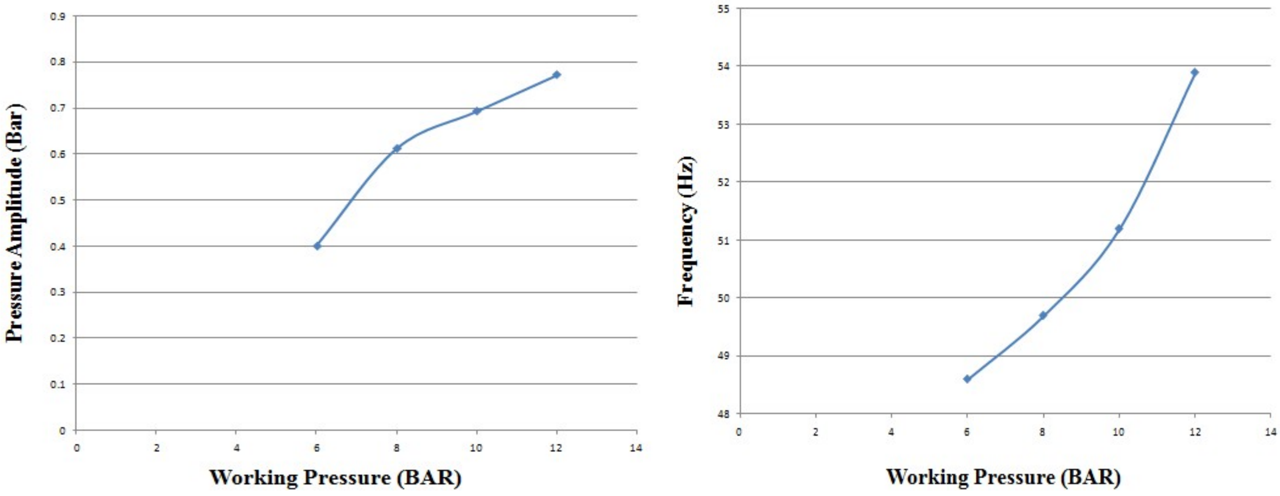


Fig.5. Variation of Onset temperature gradient with working gas pressure of Nitrogen

Pressure amplitude at different working pressures at a constant hot end temperature of the regenerator and at a room temperature of 29.7°C. Fig. 6(a) shows the variation of pressure amplitude with working pressure of nitrogen for a constant hot end temperature of the regenerator. Fig. 6(b) gives the variation of frequency with working pressure of nitrogen.

From Fig. 6(a) its clear that as the working pressure increases, amplitude of the Thermoacoustic oscillations also increases. Pressure amplitudes are measured and recorded for a constant hot end temperature of the regenerator. Readings are taken for hot end temperature of the regenerator of 500°C. Also room temperature plays an important role since onset temperature varies with room temperature.



(a) **(b)**

Fig.6. Variation of (a) Pressure Amplitude (b) Frequency with working pressure of Nitrogen

Frequency of thermoacoustic oscillations are almost same with varying working pressure. Frequency of oscillations increases slightly with working pressure which is evident from the figure 6(b).

IV. CONCLUSIONS

A Stirling engine based on Thermoacoustic principles has been successfully designed and developed. The system could be used for pressures up to 15 bar working pressure. The supply power is 650 watts. Thermal oscillations were observed at reasonably lower onset temperature of 325°C and at 'On set time' of 25 min. The Regenerator used in the system is dense wire mesh screen punching of stainless steel 120 mesh.

Preliminary performance investigations carried out on the engine with Nitrogen as the working medium has shown that Pressure amplitude close to 0.8 bar could be obtained with frequency of around 59 hz. Experimental trials have been conducted for different working pressures from 6 bar to 12 bar and pressure amplitude due to thermal oscillations were observed. The general trend observed during the investigation is, with increase in working pressure, the pressure amplitude also increased.

The system is quite sensitive to changes in ambient temperature. Investigation carried out at two different ambient temperatures revealed that considerable increase in pressure amplitude was noticed with lower ambient .temperature

Experimental results obtained were also compared with those obtained using DeltaEC and that a close agreement is observed between the two.

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