Influence of stack material and buffer volume on pressure amplitude on a standing wave thermoacoustic prime mover

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1. ABSTRACT

An experimental investigation on standing wave thermoacoustic prime mover (SWTAPM) was carried out using brass screen mesh punching as a stack and heat exchanger matrix due to its small pore size. Investigation is to study the pressure amplitude for basic model with varying buffer volume for different operating pressure and compare with DeltaEc results. Maximum pressure amplitude was recorded for buffer space length 250mm at 12 bar as 1.985bar, using nitrogen as a working gas.

Key words: thermoacoustic prime mover, stack, heat exchangers, frequency, pressure amplitude.

2. INTRODUCTION

Thermoacoustic engines convert heat energy into high amplitude sound waves, which can be used to drive thermoacoustic refrigerators by replacing the mechanical pistons such as compressors. The increasing interest in thermoacoustic technology is due to its potentiality of environmental protection. Refrigerators with Freon gas as working fluid is prohibited due to its destruction of stratospheric ozone. Thermoacoustic device are categorized as either standing-wave devices, which are described with the Brayton cycle; or travelling-wave devices, which are described with the Stirling thermodynamic cycle [5]. The thermo-acoustic refrigerator does not use any harmful working substances but uses working medium such as nitrogen, argon, helium and mixture of it in proper composition. Sound waves in gas are usually expressed in terms of oscillation of displacement and pressure. Actually, temperature oscillations exist together with pressure oscillations. In order to produce thermoacoustic effect, these oscillations should occur close to a solid surface, so that heat can be transferred to or from the surface. When a sound wave travels through the gaseous medium in small channels, it creates pressure and temperature oscillations by transferring heat from the gas to wall. The reverse of that, the temperature and pressure oscillations induce sound waves. An experimental setup has been built based on the linear thermoacoustic model and some simple design parameters with no moving parts.

The engines produce acoustic energy at the temperature difference of 350-500K imposed along the stack of the system. This work illustrates the influence of stack parameters such as brass wire mesh screen punches with resonator length on the performance of thermoacoustic engine, which are measured in terms of onset temperature difference, resonance frequency and pressure amplitude using nitrogen as a working fluid. The results obtained from the experiments are in good agreement with the theoretical results obtained from DeltaEc.

3. EXPERIMENTAL SETUP

Fig 1 shows the line diagram of thermoacoustic prime mover assembly. The brass wire mesh punches are used as a stack and heat exchanger matrix. A resonator accompanied with two same thermoacoustic engines at its both sides. Each thermoacoustic generator mainly consists of stack, hot heat exchanger, cold heat exchanger and hot buffer. The thermoacoustic engine core housing is made of stainless steel tube of 51mm inner diameter houses stack and heat exchangers. The stack composed of brass matrix of 6 mesh and 10 mesh alternatively with the ratio of 1:2, while the matrix in the hot and cold heat exchanger is with the ratio of 2:1. The buffer volume is increased from 0.28liters to 0.82liters to improve the performance of engine. The zones of hot heat exchangers are heated by external resistance wire heating element of 1kw. The heaters are insulated with several layers of ceramic wool to minimize the loss of heat to the surroundings. Temperature control unit and variable output voltage transformer are used to control the input power to the heater. The ambient heat exchanger is provided with water jacket and cooling water is supplied to remove the heat so as to maintain it at ambient temperature. The existing resonance tube was fabricated using stainless steel tube of 4m length and 36mm inner diameter along with stainless steel end flanges and tap holes at either ends to pick up pressure amplitude.

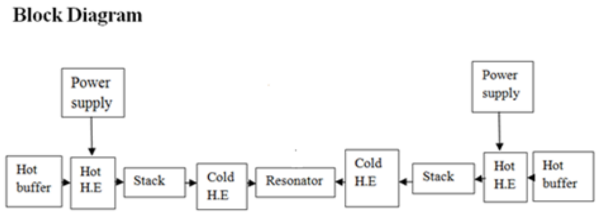


Fig 1; Block diagram of standing wave Thermo-acoustic Prime mover

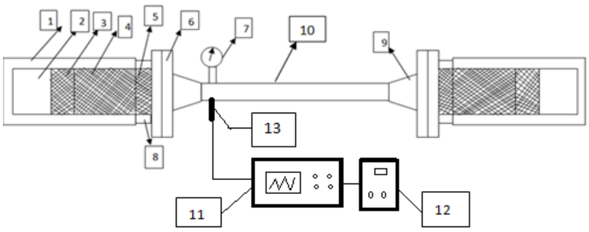
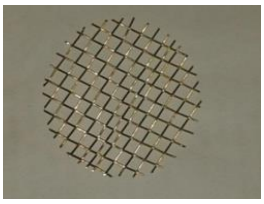


Fig.2 Outline of the standing wave thermoacoustic prime mover

1-ceramic insulation; 2-buffer volume; 3-hot HE; 4-stack; 5-ambient HE, 6-flange; 7-pressure gauge; 8-water jacket; 9-raducer; 10-resonator; 11-Oscilloscope; 12-Power supply; 13-Pressure Transducer

Table 1; Thermoacoustic prime mover parameters

Parameters	Buffer volume	Hot end heat exchang	Stack	Cold end heat exchang	Resona r
Diameter (mm	51	51	51	51	36
Length (mm)	400	100	200	60	4000



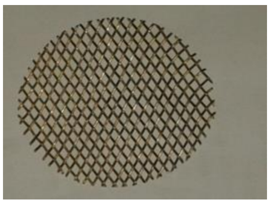


Fig 3: 6 size brass wire mesh Fig 4: 10 size brass wire mesh

The stack must be able to efficiently convert the acoustic pressure oscillations into a temperature gradient. It is desirable for the stack material to have a low thermal conductivity and greater heat capacity than the working gas. Furthermore, the geometry of the pores must be designed by balancing the thermal efficiency and viscous losses within the stack via the thermal and viscous penetration depths.

The shape of the channels, or pores, can affect the efficiency of the stack in converting acoustic work into cooling power. The best stack geometry is actually a pin array; however, such stacks are more difficult to manufacture than stacks with other geometries. Therefore, a pin array stack was not considered a viable option for this project as hard and thin pins corresponding to the required size were not readily available.

Next to a pin array, the best geometry is a stack of parallel plates. Manufacturing this kind of stack is much more manageable. For example, parallel plates can be achieved using chemical etching techniques or parallel plates can be approximated by a spiral wound stack. Furthermore, all other things being equal, parallel plate stacks can allow approximately 10% more heat and work flows than stacks with closed cross-section pores. In the end to compare the pressure amplitude and frequency for different geometry stack the parallel plate geometry and brass screen mesh is used.

4. RESULTS AND DISCUSSIONS

Series of experiments have been carried out on the engine with the nitrogen as a working fluid for different pressures, i.e. 0.6MPa, 0.8MPa, 1.0MPa and 1.2Mpa. With an input power of 1Kw, and constant cold-end temperature of 27^0C was maintained using a spray of return water and appropriate mixing of cooling water. The temperatures mentioned below refer to the hot-end heating temperatures.

4.1 ONSET TEMPERATURE

It is necessary to impose a temperature gradient on the stack to make the thermoacoustic prime mover oscillate. The temperature at the hot end of the stack (T_H) is assumed to be equal to the heater temperature and at the cold end of the stack (T_C) is assumed to be equal to the temperature of cold heat exchanger, which was maintained at about 300K with water cooler

Length of Buffer volume: 500 mm

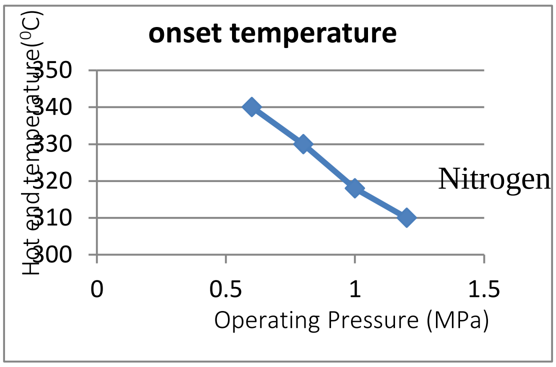


Fig 4; Variation of hot end temperature with respect to operating pressure

From the above graph we can conclude that the time taken for reaching onset temperature and to sustain thermal oscillations decreases with increasing operating pressure.

4.2 RESONANCE FREQUENCY

The equation for the frequency of sound is f=a/λ where "a" is the sound speed of gas, and λ the wavelength. Sound speed "a" is the function of the kind of gas and its temperature. When the thermoacoustic prime mover oscillates at half wavelength mode, the total length L of the system equals λ/2, so f=a/2L. If the diameters of the stack and resonator tube do not differ too much, then the equivalent length of the system, which is defined as the total volume of the system divided by the cross-sectional area of the resonator tube, could be used to calculate the resonance frequency of the system. For a thermoacoustic prime mover with its structure fixed, its resonance frequency should be proportional to the sound speed.

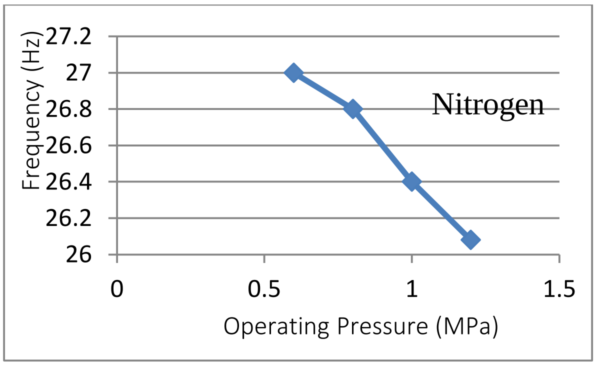


Fig 5: variation of frequency for different operating pressure

Form the above graph we can observe that there is no much frequency difference for different operating pressure of Nitrogen.

4.3 PRESSURE RATIO

Pressure ratio is defined as the ratio of mean working pressure and operating working pressure. Mean pressure is nothing but, the pressure at which oscillations starts. The pressure increases as the temperature increases, when its reach onset temperature and mean pressure, the system starts oscillating.

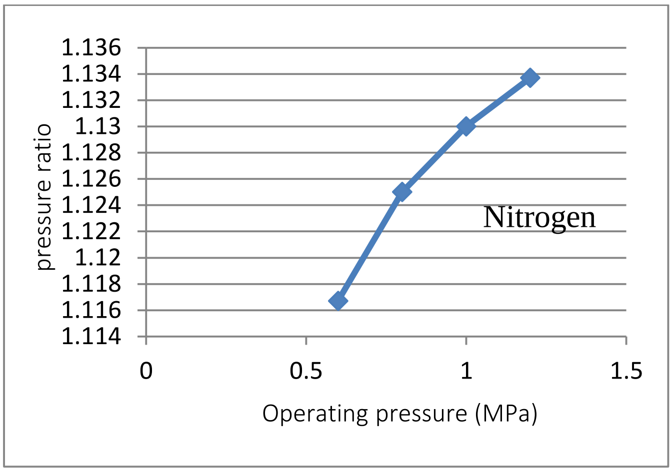


Fig 6; variation of pressure ratio for different operating pressure

4.4 PRESSURE AMPLITUDE

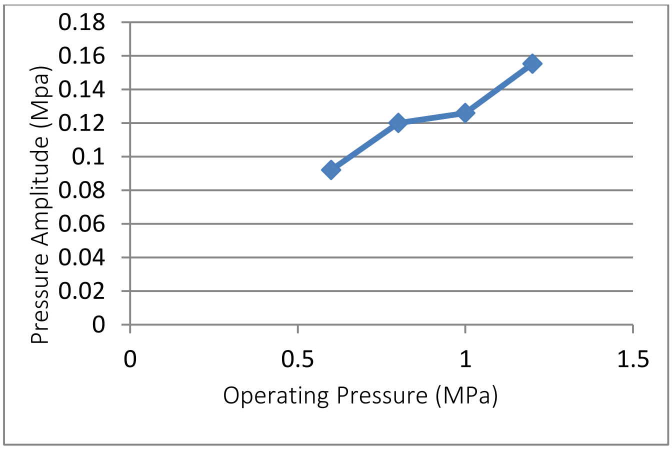
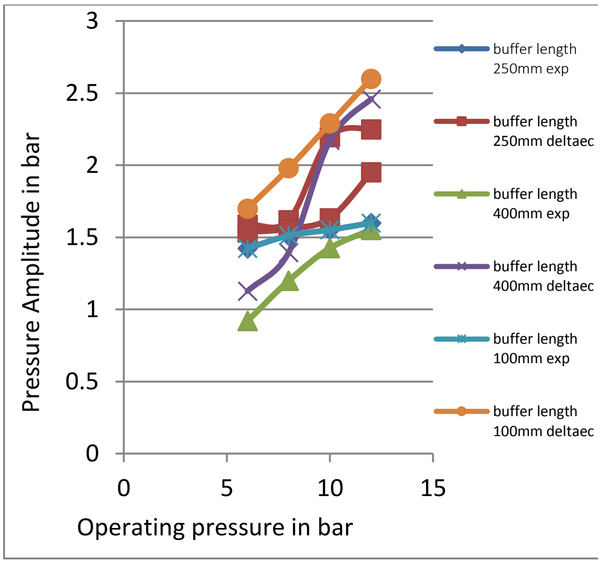


Fig 7: Variation of pressure amplitude for different operating pressure

It is also noticed that the values of pressure amplitude obtained with parallel plate stack are much lower compared to those obtained with brass wire mesh screen punching as the stack material for any given operating pressure. The main reason for this poor performance of parallel plate stack is attributed to the imperfect thermal contact between the edges of the parallel plate and the stack holder (stainless steel pipe). It was also encouraging to notice the performance the engine is much better with the brass wire mesh screen punching. With this stack material closer thermal penetration depths could be obtained compared to parallel plate stack. This also accounts for better heat transfer between the matrix and shuttling gas which over weighs the effects of viscous drop.



An increase in Buffer space length results in increase in pressure amplitude until the nodes and antinodes of the pressure and velocity waves matches and ensures better energy transfer from acoustic to pressure energy. A buffer volume length is less than this, value results in poorer performance, i.e. lower pressure amplitude. At the same time with further increase in the buffer volume length again results in mismatch and incomplete energy conversion and hence lower pressure amplitude. With buffer volume length of 250mm corresponding to the 51mm inside diameter of the engine, the experimental values of pressure amplitude are closer to the values obtained from DeltaEc.

5. CONCLUSIONS

Experimental investigation has been carried out on a twin type Standing Wave Thermoacoustic Engine. Results obtained initially using parallel plate arrangement for stack as well as the heat exchanger was not encouraging. Further modifications were carried out using brass wire mesh screen punching of 10 mesh and 6 mesh in the ratio of 1:2 in the stack and 2:1 in the heat exchangers, for the same dimensions of the stack and heat exchangers. Operating pressure as high as 12 bar and hot end temperature of 500^0C have been investigated. Pressure amplitudes obtained as a result of acoustic oscillations were measured using dynamic pressure transducer along with storage oscilloscope. Significant increase in pressure amplitude was parallel plate arrangement. The results were also compared with those obtained from using software DeltaEc for the given configurations.

Investigation was also carried out on the influence of buffer volume on the performance of engine. In this connection, the test rig was modified to investigate for various buffer volume lengths from 100mm to 400mm. From the results it is established that there lies an optimum buffer volume corresponding to a length of 250 mm. It is noticed that there is a significant improvement in the pressure amplitudes obtained for this particular buffer space length.

Acknowledgement: The authors wish to thank the Visveswaraya Technological University for providing the financial support for carrying out the above research work.

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