INTERNATIONAL JOURNAL OF ENGINEERING RESEARCH & TECHNOLOGY
ISSN: 0974 – 3154 Volume 6, Number 2 (2013), pp. 162 – 165

# EXHAUST GAS REUTILIZATION USING THERMOACOUSTIC HEAT ENGINE

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## ABSTRACT

***The purpose of this paper is to introduce thermoacoustic phenomenon for reutilization of heat energy from exhaust gas of an engine. After a review of some relevant properties of conventional heat engines, it is explained that a parcel of fluid undergoing acoustic oscillations near a solid boundary can exhibit essential features common to all heat engines.***

***The thermoacoustic heat engine uses heat from automobile exhaust to create sound, and sound to create electricity. The thermoacoustic engine is one of the forms of renewable energy. It is a device which uses high-amplitude sound waves to pump heat from one place to another, or conversely use a heat difference to induce high-amplitude sound waves. The engines are made of commonly available materials and employ atmospheric air as the working fluid. The engines generate sound at 400-450$^o$ C temperature difference imposed between the hot and cold parts of the system. The waste heat source is the exhaust gas stream from a common internal combustion engine Since there are no moving parts, for these parts dynamic sealing or lubrication are not required. Approximate estimations for produced acoustic power of these engines are 400-500W. The thermoacoustic engine has an efficiency approaching 40% of the Carnot limit, or about 20% to 30% overall (depending on the heat engine temperatures).***

***This paper includes designing and analysis of a prototype of a thermoacoustic heat engine.***

***Keywords-thermoacoustic power conversion; heat engine; automobile exhaust***

## 1. INTRODUCTION

Acoustic waves are generated by vibrating objects that in turn causes gas particles nearby to move, compress, and expand accordingly. This traveling wave trapped in an enclosure at resonant frequency will result in a standing wave. At compression, gas particles are at a maximum pressure (antinode) with zero displacement while at a maximum displacement, they are at zero pressure (node). When a solid plate is placed parallel to the direction of vibrating particles, somewhere between the pressure node and antinode, the initially isothermal plate will experience a temperature gradient, over time. The reverse of that, particle oscillation because of an imposed temperature gradient may also happen. These are the thermoacoustic effects, the temperature gradient-induced oscillations, and oscillation induced temperature gradients, the basis for thermoacoustic heat engines. These effects occur in our everyday life but it is too small to be significant. A normal conversation would generate a temperature difference of the order of 400-500$^o$C. Confined to a closed chamber with a stack of plates, however, high-pressure acoustics can generate enough cooling or acoustic power, depending on the temperature gradient imposed on the stack.

This paper contains descriptions of the waste-heat driven thermoacoustic engine in terms of the mechanical design and instrumentation used on the apparatus, and predicted thermoacoustic performance

# 2. GENERAL CONSTRUCTION

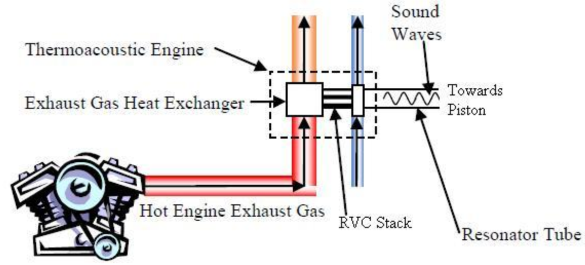


**Figure 1.** *Automobile IC Engine coupled with thermoacoustic prime mover* [Gardner, Howard, 2009].

## *2.1 Prime mover*

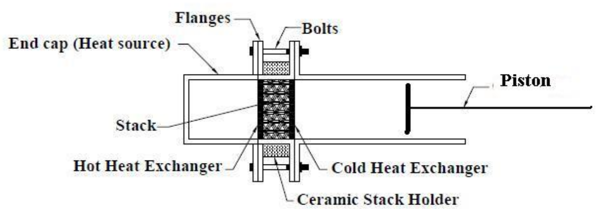


**Figure 2.** *Thermoacoustic primemover*

The thermoacoustic engine (prime mover) built in this project is a device that can capture the exhaust gas waste heat from an IC engine as shown in Fig. 1, and convert that waste heat to high amplitude standing acoustic waves within a resonator. The acoustic waves move the piston which helps in conversation of acoustic energy into mechanical power using a aluminum flywheel to which the output shaft is connected. Length of the entire engine is 200mm. The hot closed end is made of copper and filled with phosphor bronze mesh so that it acts as a heat sponge, engine exhaust gas is passed over this part. The cold open end is made of copper which acts as a resonator for travelling of sound wave and movement of piston, it is cooled by air convection .The resonator is of length 150 mm and diameter 33mm.To minimize the heat conduction leak between these sections, a ceramic stack holder was placed between the copper tube sections. Additionally, copper mesh layers were placed on the stack sides to provide more uniform temperature distribution across the tube section. The system is held together by bolts going through the flanges and thin graphite gaskets capable of sustaining high temperature were placed between the flanges to eliminate small gaps. Multilayer insulator is used to reduce heat loss.

The stack is the heat storage assembly that has loose thermal coupling to the oscillating gas. The stack needs to have properties such as low thermal conductivity, porosity and machinability. Reticulate vitreous carbon (RVC) stack of 100 pores-per-inch (ppi) is used in the system to maximize heat exchange between hot and cold end and increase its efficiency.

## *2.2 Measurement devices*

The main measured variables in our test include temperatures at the hot and cold sides of the stack and the acoustic pressure in the engine. For temperature measurements, two thin type-K thermocouples were embedded between the ceramic stack holder and the copper tube flanges into the copper mesh layers on the stack sides. The cold end tube was tapped at one place to allow the installation of pressure transducer to measure the acoustic pressure. A frequency type tachometer is used to measure the rpm of the output shaft connected to flywheel.

## 3. PROPOSED RESULTS

The engine was designed using software PTC Pro-Engineer and a computer model was put to test in software ANSYS WORKBENCH where it was simulated under exact operating conditions. The exhaust gas is passed over the closed end, and the open end tube section is air-cooled. The temperature of the exhaust gas from the IC engine is about 700$^{o}$C and approximately 145kW is rejected from the engine in the exhaust stream at higher engine power levels. The acoustic system harvests approximately 4kW from this exhaust stream. The system is supposed to be self excited when the temperature difference reaches a critical value within 400-450°C. The system continues to operate in steady state till the temperature difference across the hot and the cold end remains constant. The simulation was timed for 300seconds.

The theoretical upper limit for a heat engine's efficiency is defined as the Carnot efficiency:

$$n_{carnot} = 1 - \frac{T_c}{T_h}$$

where $T_c$ is the temperature (in Kelvin) on the cool side of the regenerator and $T_h$ that on the hot side of the regenerator.The results are plotted and tabulated below.

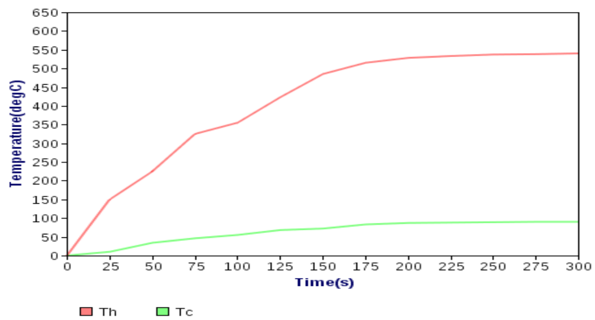


**Figure 3.** *Temperatures measured at the stack. $T_h$ and $T_c$ are the temperatures on the hot and cold sides of the stack.*

**Table 1.** *Predicted performance of thermoacoustic engine*

| Parameter | Units | Value |
|---|---|---|
| Frequency | Hz | 425 |
| Max. Temperature of Hot end | $^{o}$C | 530 |
| Max. Temperature of Cold end | $^{o}$C | 90 |
| Acoustic power | W | 450 |
| Carnot Efficiency | % | 45 |

Note that this does not include other heat loads such as radiation or convective loads.

A simplified simulation gives a satisfactory estimation for the temperature difference threshold. With possible applications of more optimal stack materials and special gas mixtures such as Helium, the thermoacoustic efficiency of the engine can be further increased. Other directions for the system improvement include a reduction of the heat leak through the stack holder and a development of a sealed device with high mean pressure inside. Further the engine can be coupled to a heat pump to produce refrigerating effect.

## 4. CONCLUSION

This paper has described the working principle and design of thermoacoustic heat engine that is powered from the waste heat from the exhaust gas of a reciprocating engine of an automobile. It is the understanding of the authors that this configuration of a simple and low cost thermoacoustic system has not been previously built and tested. This prototype will allow measuring how different parameters affect the performance of a low cost engine and optimizing its design for better efficiency. At the time of submission of this paper, the components of the system have been assembled, however laboratory testing has not commenced. Experimental data of the analysis will be presented during conference.

**Acknowledgements:** The authors would like to express a deep sense of gratitude to Prof.Dr.Kiran Chaudhari, Head of the Department, Mechanical Engineering, RGIT, Mumbai, for her cordial support and valuable guidance in field of material selection, system development and process calculation which helped in completing this paper through various stages.

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