A Sustainable Solution for Electricity Generation using Thermo-acoustic Technology
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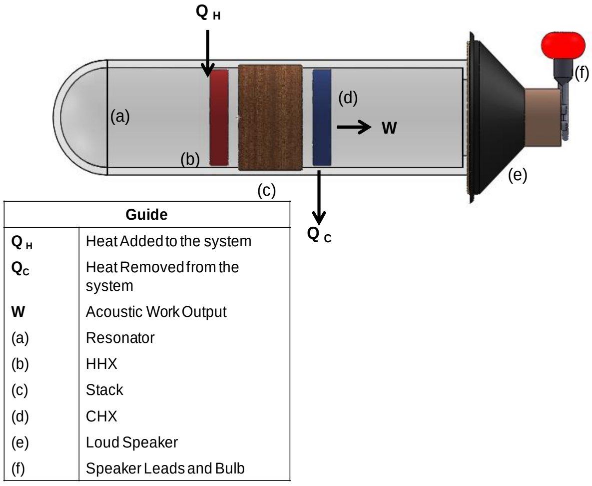
Abstract - This work explores the use of thermo-acoustic system as alternative technology for electricity generation. This technology is proposed as a potential replacement for low-cost electrical power generation because of its simplicity and lack of moving parts. Thermo-acoustic generators providing clean electrical energy to power small appliances. The energy conversion from heat into sound wave is done within thermo-acoustic engine. The latter is coupled to a linear alternator for electricity generation. The study investigates the influence of the geometrical configuration of the device on to the whole functionality of the generator. The paper studies the technology through experimental trails performed using a simple arrangement to simulate the generator. The experiment is conducted in phases; the first phase identifies the best geometrical configuration of the thermo-acoustic engine by measuring the sound pressure level and the temperatures. The second phase consist of measuring the electricity generated using a Loudspeaker. The results obtained show the potential for this sustainable solution for electricity generation.

Index Terms—Thermo-acoustic, sound, electricity, generator

1. INTRODUCTION

In this work, Thermo-acoustic technology is proposed as an alternative solution intended to lower pollution, to provide clean energy and to eradicate key issues related to the lack of electricity in some areas in developing countries. Thermo-acoustic, first qualitatively documented by Rayleigh in 1896 [1], is a phenomenon that is described as a combination of thermodynamics, fluid dynamics~~,~~ and acoustic [2]. The phenomenon has since been used taking advantage of these interactions in order to design useful devices that convert heat into sound waves, making use of the sound wave to remove heat or generate electricity.

Thermo-acoustic generator is a combination of a thermo-acoustic engine and a linear alternator. The Thermo-acoustic Engine (TAE) converts heat energy into acoustic energy while the linear alternator is used to convert the acoustic energy into electrical energy. The simplest form of a thermo-acoustic generator can be configured as shown in Fig. 1. The configuration consists of a resonator, Hot Heat Exchanger (HHX), Cold Heat Exchanger (CHX), a stack and a linear alternator.



Guide	
Q_H	Heat Added to the system
Q_C	Heat Removed from the system
W	Acoustic Work Output
(a)	Resonator
(b)	HHX
(c)	Stack
(d)	CHX
(e)	Loud Speaker
(f)	Speaker Leads and Bulb

Fig. 1. Schematic representation of a Thermo-acoustic Generator

The thermal to acoustic conversion occurs when heat is added through the HHX; the heat is transferred to the gas on one end of the stack. The gas will be heated even further because of the pressure increase in the stacks pores. The high pressure, high temperature gas parcel is driven away from the hot side of the stack by its own thermal expansion. The gas parcel will then move towards the opposite end of the stack (low pressure and low temperature area) cooled by the CHX. Heat will be conducted out of the parcel into the walls of the stack. The cooled gas parcel is then forced back to the hot end of the stack due to the low pressure where this cycle will start over again [2]. Provided that the resonator length is adequate and the temperature difference between the stack is sufficient, the gas will fall into a steady rhythm known as a standing wave which will produce a sound. For the TAE to convert acoustic energy into electrical energy, a linear alternator is coupled to the engine. Fig. 2 shows the thermo-acoustic cycle inside the stack.

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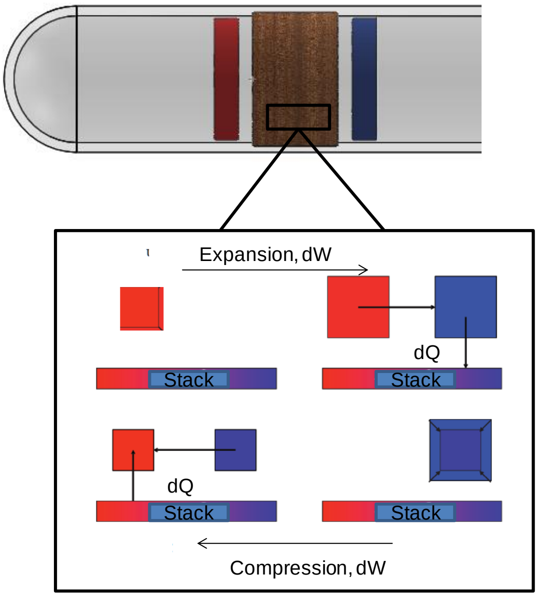

Fig. 2. Schematic representation of a Thermo-acoustic Cycle in the stack

2. LITERATURE REVIEW

The concept of Thermo-acoustic generators has been the interest of researcher over the past decade. Researcher have designed different configurations of Thermo-acoustic generators to investigated and eliminate challenges associated with the generators. Research on thermo-acoustic system is largely based on the work of Rott [3] and Swift [4]. Jaworski and Mao [5] designed and tested a large scale standing-wave thermo-acoustic engine. The engine used pressurized helium as the working gas. The engine converted heat into acoustic power at a thermal efficiency of 9% and was able to produce 630W of acoustic power to the external acoustic load. In 2007, the Stove for Cooking, Refrigeration and Electricity (SCORE) project [6] proposed a design for a standing wave thermo-acoustic generator. One of the model developed is a propane-fuelled device which managed to generate 400mW of electricity. DeBlok [7] designed a different model which consists of a propane-powered traveling wave half-wavelength dual regenerator unit. This model was able to produce 16W of electricity. Chen *et al.* [8] developed and assessed two thermo-acoustic generators powered by waste heat energy from a cooking stove. One stove was powered by waste heat from a propane-driven stove and the other was powered by waste heat from wood-burning stove. The propane powered thermo-acoustic generator produced approximately 15watts of electricity while the wood-powered thermo-acoustic generator managed to produce a maximum of 22.7 watts of electricity.

3. MOTIVATION

This work is mainly focusing on demonstrating the potential of thermo-acoustic technology as a suitable electricity generator for small appliances. The research will investigate experimentally the feasibility of the coupling of an engine with a loudspeaker used as an electrical generator. Focus will also be put on the geometrical configuration of the engine and how the stack impacts the overall performance of the generator. This work provides some clarity on the challenges related to the conversion of heat into electricity.

4. EXPERIMENTAL PROCEDURE

The objectives of the experimental investigation are detailed below:

- To measure the temperature difference across the stacks at different position in the resonator;
- to identify the engine configurations that produced the highest sound and
- to get an insight into the relation between the heat source and the electricity generation.

The experiment is divided into two phases; the first phase describes the TAE experimental procedure. The second phase reports the experimental procedure related to the electricity generation.

4.1 Phase 1: Thermo-acoustic Engine Experimental Procedure

The components used for Phase 1 are:

- A 200mm resonator marked at 5 different positions;
- Nickel-chromium wire (NiCr) and
- Honeycomb ceramic stacks of 300 Cells per Square Inch (CPSI) and 230 CPSI ranging from 8mm to 25mm in length

Heat is initially supplied to the Nickel-chromium (NiCr) wire using a variable voltage power supply. The voltage supplied is kept constant at 5.3Volts. A NiCr wire is used to provide the necessary heat required for the thermo-acoustic engine. Two K-type thermocouple from National Instruments have been used to measure the temperature each side of the stack. The thermocouples are made of chromel and alumael and have a temperature range of 0 – 482 ˚C. The accuracy of the thermocouples is ±2.2˚C. The signal processing, analysis and visualization were performed through the use of a NI DAQ (9211A) data acquisition and Labview. The sound generated was measured using a sound level meter by Lutron Electronic. The accuracy of the sound level meter is ±1.5dB. The sound level meter was positioned in front of the resonator in order to measure the sound produced by the engine as indicated in Fig. 3. Each experiment lasted 5 minutes in order to ensure the sustainability of the sound generated. This procedure was repeated for all the different stacks described in Table 1. Fig. 3 below shows the experimental set-up in phase 1 and Fig. 4 is an example Cordierite Ceramic Honeycomb stacks used.

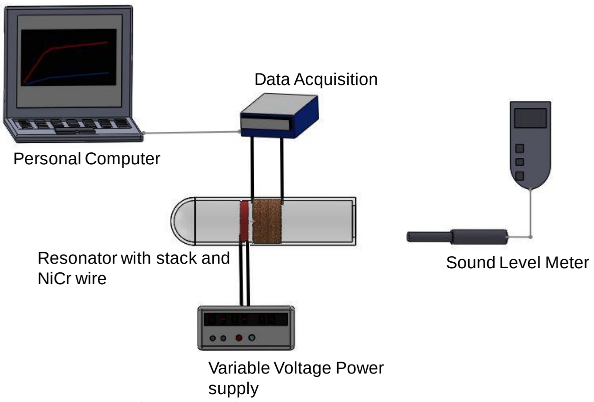

Fig. 3. An image of Phase 1 of the experimental apparatus

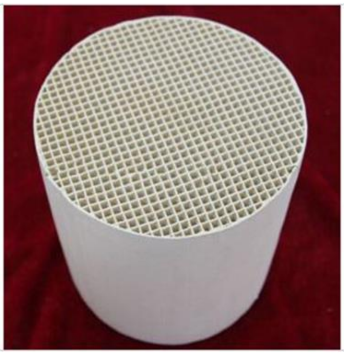

Fig. 4. Example of Cordierite Ceramic Honeycomb stacks used

Table 1: Stack Properties and Geometry

Stack Material	**Cordierite Ceramic Honeycomb**	
Stack Pore	230 CPSI	300CPSI
Plate Thickness(mm)	0.160	0.140
Plate Spacing (mm)	1.675	1.467
Porosity(BR)	≈0.9	≈0.9
Density (kg/m³)	2500	2500
Thermal Conductivity (W/m K)	0.42	0.42
Specific Heat (J/kg K)	1047	1047
Melting point (˚C)	1450	1450
Stack Length (mm)	8 14 17 23 25	
Stack Position (mm) from Closed End	Position1 = 40mm Position2 = 60mm Position3 = 80mm Position4 = 100mm Position5 = 120mm	

4.2 Phase 2: Thermo-acoustic Generator Experimental Procedure

The components used during Phase 2 are:

- The thermo-acoustic engine (TAE) and
- a Loudspeaker.

The best geometrical configuration of the stack with respect the sound generated was identified from the previous experiment. In this set of experiment, a loudspeaker will be coupled to the previous thermo-engine. The loudspeaker used is a Kenwood speaker with a resistance of 4Ω and 210W peak power output. The influence of the heat input to the TAE on the electricity generated will be investigated. The generated voltage will be measured with a digital multi-meter. A pictorial representation of the experimental setup is shown in Fig. 5.

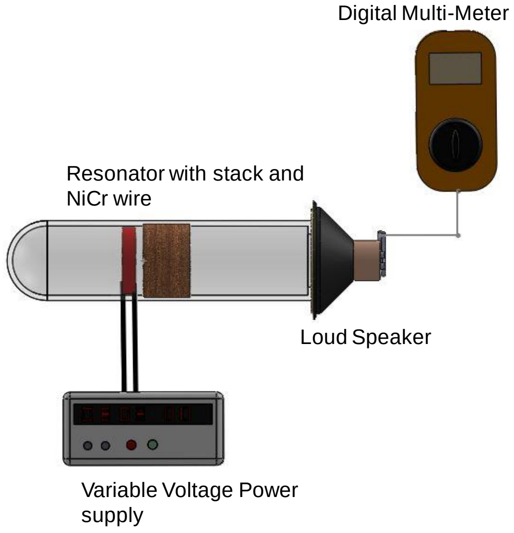

Fig. 5. An image of Phase 2 of the experimental apparatus

5. RESULTS AND DISCUSSION

In this section, results from the experimental investigation are consolidated and analyzed. The section below details the effect of the stack length on the temperature difference, the impact of the stack position in the resonator on the temperature difference and the details related to the electrical voltage generated.

5.1 Temperature difference as a function of stack length

Fig. 6 and Fig. 7 show the results obtained from the experiments performed. The impact of the stack length on the temperature difference (across the stack) is reported graphically. The stacks described in Table 1 are used in the experiment. From the results reported in Fig. 6 and Fig. 7, the relationship between the stack length and the expected temperature difference is not linear. These results suggest that the position of the stack and its porosity has to be taken into account. These parameters (stack length, stack position and porosity) appear to be interdependent. However, these results clearly show the highest and lowest temperature differences for all geometrical configurations.

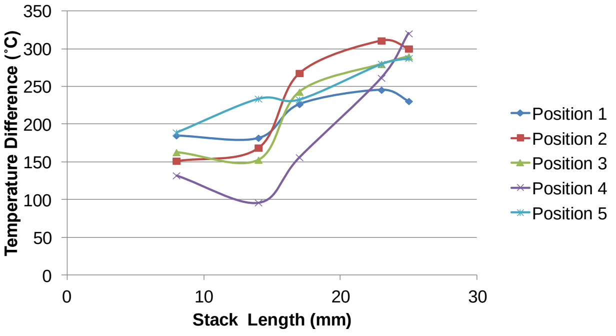

Fig. 6. Temperature difference behavior as a function of stack length/230 CPSI (lines are used for visual guidance)

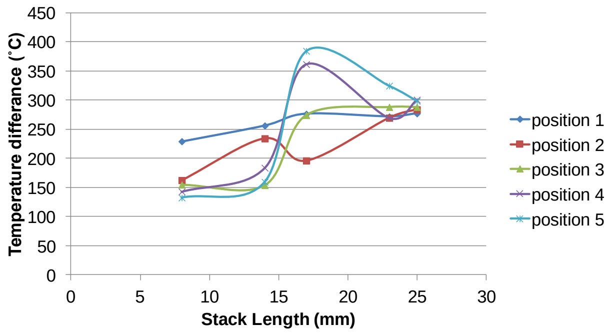

Fig. 7. Temperature difference behavior as a function of stack length/300 CPSI (lines are used for visual guidance)

5.2 Temperature difference as a function of stack position

In this section, the impact of the stack position in the resonator on the temperature difference is reported in Fig. 8 and Fig. 9. From Fig. 8, the results seem to suggest that a larger stack result in a higher temperature difference for some positions. However, looking at the results reported in Fig. 9, there is clearly interdependence between the parameters describing the stack namely the stack length, the stack position and the porosity. The maximum (or minimum) temperature differences are related to a specific stack length corresponding to a specific stack position and specific porosity. From Fig. 8, the lowest temperature difference is expected with a 14 mm stack positioned 100 mm (position 4) from the closed end. Interestingly, the highest temperature difference (Fig. 9) is expected with a 17 mm stack positioned 120 mm from the closed end.

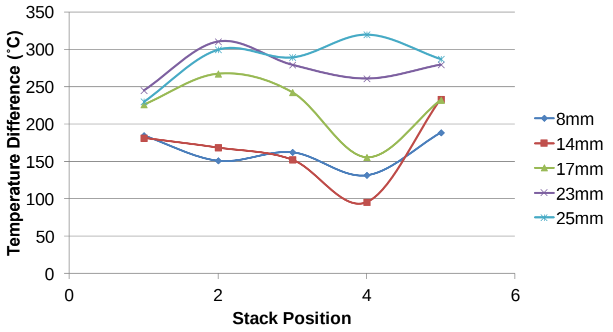

Fig. 8. Temperature difference as a function of stack position/230 CPSI (lines are used for visual guidance)

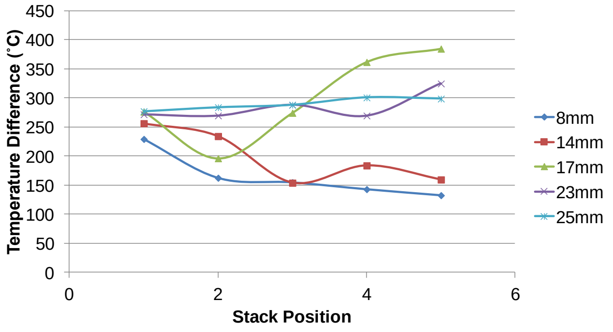

Fig. 9. Temperature difference as a function of stack position/300 CPSI (lines are used for visual guidance)

5.3 Sound Produced as a function of stack position

In this section the sound produced by the engine is analyzed as a function of the stack position. Fig. 10 reports the results obtained with a 230 CPSI stack. The highest magnitude of the sound level measured was 81.6 dB. This magnitude was obtained with a 14 mm long stack. The 300CPSI set produced a maximum sound of 88.5dB at position 3 as shown in Fig. 11. Based on these results, the 25mm long, 300CPSI stack was identified as the stack that generates the highest sound level and was subsequently used in the next phase of the experiment

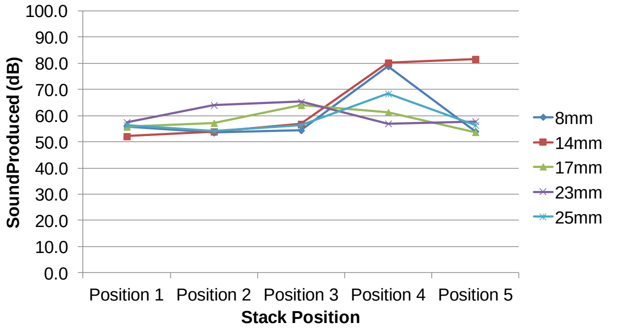

Fig. 10. Sound Produced as a function of stack position/230 CPSI (lines are used for visual guidance)

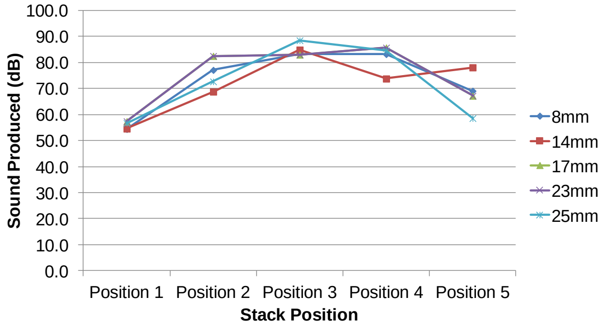

Fig. 11. Sound Produced as a function of stack position/300 CPSI (lines are used for visual guidance)

5.4 Electrical Voltage Produced

This section discusses results obtained from Phase 2 of the experimental procedure. The 25mm long, 300CPSI stack at position 3 is the configuration chosen for this section. The adjustable power supply was used to investigate the effect of the heat input to the TAE on the output voltage of the Loudspeaker shown in Fig. 5. The results in Fig. 12 show that the temperature difference is directly proportional to the output voltage. As the temperature difference increases, the output voltage of the loudspeaker also increases. The efficiency of the thermal to electrical power conversion was low because of the mechanical losses within commercial loudspeaker, the low magnitude of the sound generated (88.5dB) and the simplicity of the prototype (no CHX).

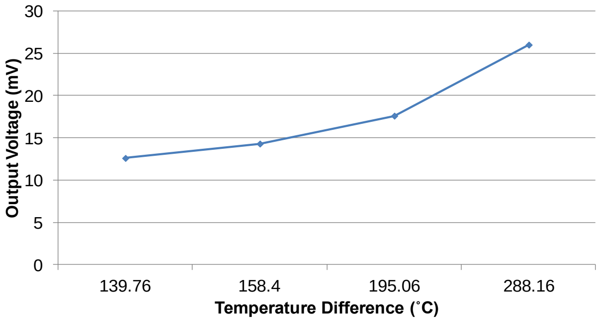

Fig. 12. Output Voltage as a function of Temperature Difference/ 25mm; 300CPSI stack

6. CONCLUSION

The paper discussed the performance of a Thermo-acoustic Generator which was investigated experimentally. Stack pore size, stack length and resonator position were the factors being tested to identify a configuration which would yield optimum results with respect to electricity generation. 10 different samples of cordierite honeycomb ceramic stack are used in the experiment. The temperature difference across the stack and the sound level meter were used as indicator of the performance of the TAE. The results obtained suggest that the relationship between parameters describing the stack (namely the stack length, the stack position and the porosity) is interdependent for maximum performance of the TAE. The best geometrical configuration of the TAE was identified. This optimal system was connected to a Loudspeaker in order to get an insight into the relation between the heat input and the electricity generated. A maximum voltage of 0.0026V was measured. Although the efficiency of the thermal to electrical power conversion was low because of the mechanical losses within commercial loudspeaker, this work demonstrates the potential of thermo-acoustic technology for electricity generation. This work will undoubtedly open ways for the development of suitable electricity generator locally. For future work, a high efficient sound-to-electricity convertor and heat exchangers will be incorporated in the developed prototype in order to generate relatively higher power.

7. REFERENCES

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AUTHORS BIO

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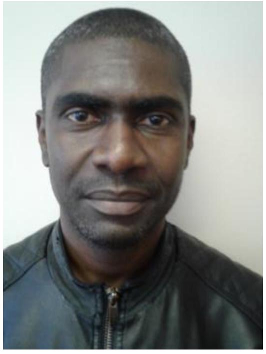

C. D.V. Kallon Dr. Daramy is a Sierra Leonean holder of a PhD degree obtained from the University of Cape Town (UCT) in 2013. He holds a year-long experience as a Postdoctoral researcher at UCT. At the start of 2014 Dr Kallon was formally employed by the Centre for Minerals Research (CMR) at UCT as a Scientific Officer working with a team coordinating research in the field of Computational Mechanics and was also involved with post graduate student supervision. In May 2014 Dr Kallon transferred to the University of Johannesburg as a full-time Lecturer in the Department of Mechanical and Industrial Engineering Technology (MIET), which is a part of the School of Mechanical and Industrial Engineering (SOMIE). He has been teaching at the BTech level of this department since. At the start of October 2015 Dr Kallon was promoted to a Senior Lecturer position. Dr. Kallon's primary research areas are Acoustics Technologies, Mathematical Analysis and Optimization, Vibration analysis, Pollution Control and Water Research.

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