Thermoacoustic Effect: the Power of Conversion of Sound Energy & Heat Energy: Review

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Abstract—*Thermo acoustic effect is the conversion of heat energy to sound energy or vice versa. Sound waves in "thermoacoustic" engines and refrigerators can replace the pistons and cranks that are typically built into such machinery. Thermoacoustic devices take advantage of sound waves reverberating within them to convert a temperature differential into mechanical energy or mechanical energy into a temperature differential. Such machines can thus be used, for example, to generate electricity or to provide refrigeration and air conditioning. Because thermoacoustic devices perform best with inert gases as the working fluid, they do not produce the harmful environmental effects such as global warming or stratospheric ozone depletion.*

Keywords—Thermoacoustic Engine, Heat Engine, Refrigerators effect, Sound waves, Sound Energy.

I. INTRODUCTION

Thermoacoustics combine thermodynamics, fluid dynamics and acoustics to describe the interactions that exist between heat and sound. Under the right conditions, these interactions can be harnessed to design useful devices that convert heat into large amplitude sound waves and vice-versa. A thermoacoustic engine turns part of the heat flowing through a temperature gradient inside a porous solid into sound waves. The work in these sound waves can then be harnessed with a piston to drive a flywheel or a linear alternator, or it can be used to transport heat from a lower to a higher temperature reservoir in what is known as a thermoacoustic heat pump or refrigerator.

Thermoacoustic devices have two major advantages over conventional technologies: their inherent mechanical simplicity, and the use of environmentally friendly working gases. Despite these qualities, most thermoacoustic engines, heat pumps and refrigerators built to this day were for research purposes, and are seldom encountered in the industry.

Thermoacoustic engines are formally defined as heat engines "that exploit gas inertia, compliance, and resistance to create passive acoustical-phasing mechanisms."

Thermoacoustic engine is based upon the same principles as a thermodynamic engine. When heat is put into a thermoacoustic engine, the engine produces work in the form of sound with an amount of waste heat rejected into the cooler environment. However, unlike a traditional heat engine, a thermoacoustic engine contains no moving parts, thus making it a desirable alternative to tradition engines due to its high reliability and low cost.

II. THERMOACOUSTIC EFFECT

Thermo acoustic effect is the conversion of heat energy to sound energy or vice versa. Utilizing the Thermo acoustic effect, engines & refrigerators can be developed that use heat as an energy source and have no moving parts!

To explain the thermo acoustic effect, consider a sound wave generated through a loud speaker in a tube. If we have a stack of plates in the tube and force one end to be hot and the other cold and put that in a tube, we can create a very loud sound. Thus by using waste heat (say from a fire) we could create sound in a tube and use that sound to cool off another part of the tube (say where a beer can is sitting). We have now created a refrigerator that can cool a beer at one end by putting the other end in the campfire! A device that creates sound from heat is called a thermo acoustic heat engine.

Even more spectacular is the fact that it can work in reverse. To explain the thermo acoustic effect, consider a high amplitude sound wave in a tube. As the sound wave travels back and forth in the tube, the gas compresses and expands (that's what a sound wave is). When the gas compresses it heats up and when it expands it cools off. The gas also moves back and forth, stopping to reverse direction at the time when the gas is maximally compressed (hot) or expanded (cool). Now, put a plate of material in the tube at the same temperature as the gas before the sound wave is started. The sound wave compresses and heats the gas. As the gas slows to turn around and expand, the gas close to the plate gives up heat to the plate. The gas cools slightly and the plate below the hot gas warms slightly. The gas then moves, expands, and cools off, becoming colder than the plate. As the gas slows to turn around and expand, the cool gas takes heat from the plate, heating slightly and leaving the plate below the gas cooler than it was.

So, what has happened is one part of the plate gets cooler, and one part gets hotter. If we stack up many plates atop each other (making sure to leave space for the sound to go through), place the plates of an optimal length in the optimal area of the tube and attach heat exchangers to get heat in and out of the ends of the plates, we have created a useful refrigerator.

III. TRANSFORMATION OF HEAT ENERGY INTO INTENSE

As shown in Fig. 1.1, Thermo acoustic device consists, in essence, of a gas-filled tube containing a "stack" *(top)*, a porous solid with many open channels through which the gas can pass. Resonating sound waves (created, for example, by a loudspeaker) force gas to move back and forth through openings in the stack. If the temperature gradient along the stack is modest *(middle)*, gas shifted to one side *(a)* will be compressed and warmed so that a parcel of gas with dimensions that are roughly equal to the thermal penetration depth (d_k) releases heat to the stack. When this same gas then shifts in the other direction *(b)*, it expands and cools enough to absorb heat. Although an individual parcel carries heat just a small distance, the many parcels making up the gas form a "bucket brigade," which transfers heat from a cold region to a warm one and thus provides refrigeration. The same device can be turned into a thermo acoustic engine *(bottom)* if the temperature difference along the stack is made sufficiently large. In that case, sound can also compress and warm a parcel of gas *(c)*, but it remains cooler than the stack and thus absorbs heat. When this gas shifts to the other side and expands *(d)*, it cools but stays hotter than the stack and thus releases heat. Hence, the parcel thermally expands at high pressure and contracts at low pressure, which amplifies the pressure oscillations of the reverberating sound waves, transforming heat energy into acoustic energy.

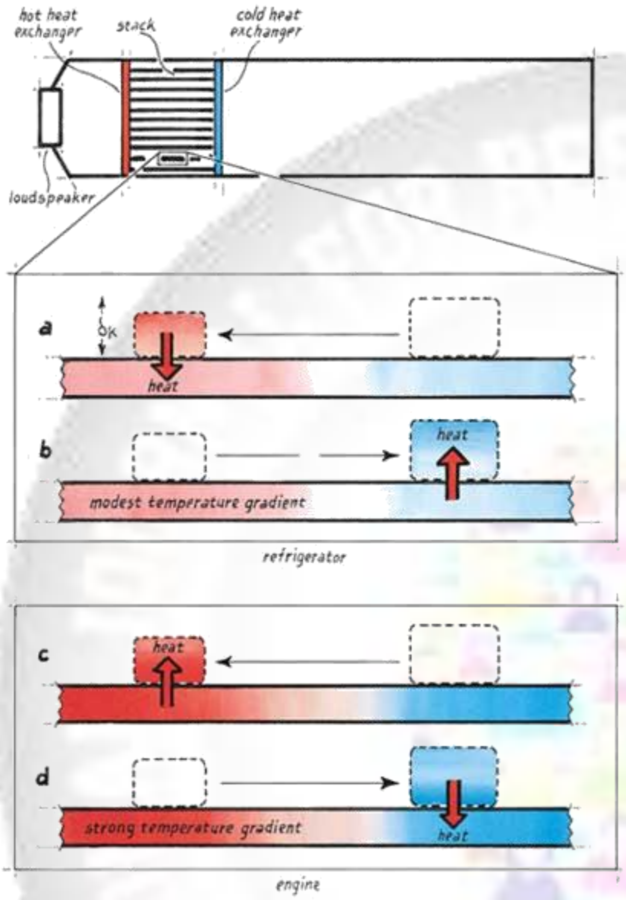

Fig. 1 Transformation of Heat Energy into intense Acoustic Energy

IV. Literature Review

In Sophie Collard, the performance of thermoacoustic engine prototype has done on pressure Variation. Thermoacoustic devices have two major advantages over conventional technologies: their inherent mechanical simplicity, and the use of environmentally friendly working gases. Despite these qualities, most thermoacoustic engines, heat pumps and refrigerators built to this day were for research purposes, and are seldom encountered in the industry. This thesis documents the design and assembly of a low cost traveling wave thermoacoustic engine prototype intended for low temperature waste heat recovery. The prototype will later be tested at four different internal mean pressures (ranging from atmospheric to 3 bars gauge pressure) and with one, two, three and four regenerator units in order to measure how these parameters affect the performance of a low cost engine.

Increasing a thermoacoustic engine's internal mean pressure is a well-known way to improve its performance. However, the rate at which acoustic power in the engine increases with increasing internal mean pressure tends to decrease with increasing internal mean pressure and to eventually reach a maximum. Increasing an engine's internal mean pressure also means that the engine's capital cost will be higher, as stronger materials have to be used to ensure a good seal. In the European Union, the manufacturing of pressurized devices is regulated by the Pressure Equipment Directive 97/23/EC, which requires that the equipment be subject to conformity assessment procedures that may in turn drive the capital costs up.

The toroidal geometry of traveling wave thermoacoustic engines makes it possible, in principle, to insert an arbitrary number of regenerators inside the engine's feedback loop, in an effort to increase acoustic gain and improve performances at lower temperatures. The regenerators in today's most efficient thermoacoustic devices are usually built from metal mesh screens stacked together. Metal mesh is a very costly material, and the process of cutting and assembling the screens together is a labor intensive one. In the absence of mass manufacturing techniques that would allow reducing both materials and labor costs of manufacturing regenerators, they will clearly be the most expensive component in a low cost engine. The number of regenerators used is thus of primary importance when optimizing the design of a low cost thermoacoustic device to reach the best possible capital cost per power output ratio.[1]

In Andrew C. Trapp Florian Zink Oleg A. Prokopyev Laura Schaefer, the work on the thermoacoustic engine has done as a heat engine or as a refrigerator. Thermoacoustic heat engines (TAEs) are potentially advantageous drivers for thermoacoustic refrigerators (TARs). Connecting TAEs to TARs means that waste heat can effectively be utilized to provide cooling, and increase overall efficiency. However, this is currently a niche technology. Improvements can be made through a better understanding of the interactions of relevant design parameters. This work develops a novel mathematical programming model to optimize the performance of a simple TAE.The model consists of system parameters and constraints that capture the underlying thermoacoustic dynamics. We measure the performance of the engine with respect to several acoustic and thermal objectives (including work output, viscous losses and heat losses). Analytical solutions are presented for cases of single objective optimization that identify globally optimal parameter levels. We also consider optimizing multiple objective components simultaneously and generate the efficient frontier of Pareto optimal solutions corresponding to selected weights.
The goal of this work is to demonstrate how optimization techniques can improve the design of thermoacoustic devices. Thermoacoustic devices utilize sound waves instead of mechanical pistons to drive a thermodynamic process. One of their advantages is the inherent mechanical simplicity. While this concept is not new, the technology has not been advanced to a high degree, as compared to, for example, the internal combustion engine. After reviewing some fundamental physical properties underlying thermoacoustic devices, we will then proceed to discuss our approach to optimize their design.[2]

In Holly Ann Smith, Impedance Measurement of a Thermoacoustic Engine has done, which is constructed from a Helmholtz Resonator. A thermoacoustic engine was constructed from a 5-Liter Helmholtz flask by inserting a ceramic stack into the lower portion of the flask's neck. A cold heat exchanger and hot heat exchanger located on opposing faces of the stack provided very large temperature differences across the stack, and if the temperature difference was great enough then the system would produce sound. A previous experiment investigated how the resistance in the system changed as the temperature difference increased by observing changes in the quality factor; however, due to the nature of the measurements, it was not possible to observe how the imaginary part of the resistance changed as the temperature difference increased. This thesis focuses on how impedance measurements at the opening of the flask's neck might be analyzed in order to determine the frequency and temperature difference at which this system would reach onset and to see if this calculation for the onset temperature difference corresponds to the experimentally observed onset for the engine at 207±C from the prior experiment. This thesis will also focus on the behavior of the incident sound wave as the temperature difference across the engine's stack increases.

When a person blows air into a bottle, the air blown into the bottle causes the air inside the bottle to oscillate. If the person blows too hard or too softly, the air inside the bottle oscillates, but the amplitude of the oscillation is small. However, when a person blows into a bottle just right," the amplitude becomes increasingly large, and the bottle will produce sound. A bottle is a special kind of resonator known as a Helmholtz resonator. A thermoacoustic engine made by inserting a porous ceramic stack into a Helmholtz flask. Adding a porous ceramic material into a Helmholtz flask increases the system's resistance due to the friction between the oscillating air and the walls of the pores. However, the resistance of this system can be decreasedby applying a temperature difference across the stack. If the system's resistance is eliminated, then the system produces work in the form of sound.[3]

In Master Thesis Chris van Dijk TUDelft, the Comparison of multistage thermoacoustic engines in serial versus parallel configurations has done. In industrial processes about 80% of the energy demand is in the form of heat. One of the problems of the industrial waste heat is the low temperature of this heat. The department of energy efficiency and infrastructure, 'E&I' of the Energy research Center of the Netherlands 'ECN' runs projects in order to use industrial waste heat with a thermoacoustic heat pump. Thermoacoustic engines can deliver the power to drive a thermoacoustic heat pump and can be driven by waste heat. The desired hot temperatures exceed the temperatures of the waste heat. It is believed that more than one thermoacoustic engine is necessary in order to gain sufficient temperature lift. In this study a parallel configuration of thermoacoustic engines is compared to a serial configuration of thermoacoustic engines. Additionally the losses in a coaxial thermoacoustic engine are analyzed. In two sets of experiments two regenerator units were placed in parallel and serial configuration inside a symmetric resonator. The regenerators were heated with an electrical heater and cooled with cooling water. Power was subtracted with a load. The power that can be subtracted by the load is the same as the power that could be used in a heat pump. The main objective is to gain maximum load power with a hot regenerator temperature as low as possible.

The experiments show that the serial configuration produced more acoustic power in the load than the parallel configuration. In contrast the efficiency of the power produced in the resonator is found to be about the same for both configurations. This is because of the assumption that the power dissipated in the resonator is equal to twice the power dissipated in an empty half of the resonator, while in reality the power dissipated in the resonator depends also on the internal geometries in the resonator, and the internal velocity.[4]

In SUDEEP SASTRY, the work is focused on the design and development of a thermoacoustic cooling system for the Venus and other space exploration missions where it is necessary to cool down electronic component from high temperatures (145°C) to reasonable temperatures (50°C) so that the electronic components can function efficiently. The objectives include, addressing key areas of design of a thermoacoustic cooling system. This comprises of investigating and optimizing the effect that various parameters such as geometry, gas mixture ratios, pressure, frequency, etc. have on the functioning of the thermoacoustic system. The work involves development of an efficient and coupled thermoacoustic engine (pressure pulse engine) thermoacoustic refrigerator system to suit the Venus exploration requirements and a design of a prototype device. A further objective of the study is to design a system which will be able to cool electronic components on the surface of Venus down to operable temperature levels, i.e., from 450°C to 50°C.

Unique cooling systems have to be designed to cool the electronic components of space exploration rover, especially in places like Venus, which has harsh surface conditions. The atmospheric pressure and temperature on the surface of Venus are 92 bars and 450°C respectively, which make operation of electronic devices and sensors very difficult. An exploration rover sent to operate at an altitude of 40 km above Venus' surface will also need active refrigeration of its electronic components as the temperature can be around 145°C.Conventional cooling methods are currently deemed unfeasible due to the short life span of moving parts of the refrigerator systems at high temperatures. Furthermore, alternate energysources such as solar power are not an option on Venus, since the cloud layer consisting of concentrated sulfuric acid droplets is thick and the cloud layer reduces the solar intensity at the surface to about 2% of the intensity above the atmosphere. Therefore, developing alternate method of power and cooling systems are essential for Venus surface operation of any robotic rover. The advantages of using thermoacoustic systems are that there are no moving parts, and they have efficiencies comparable to conventional systems. This work discusses the development and optimization of a standing wave thermoacoustic engine refrigerator system to be used as a cooling device for the electronic components. The effects of various parameters such as gas mixture ratio, pressure, stack material, etc. is discussed. The system designed provides 150 W of cooling power while operating between 170°C and 50°C. The surface cooling temperature drop of 400°C is too large to be achieved by a single unit. Hence, multiple units are staged in series to obtain the required cooling temperature on the surface.[5]

In Abdulrahman Sayed Ahmed Abduljalil, investigation of thermoacoustic processes in a travelling-wave looped-tube thermoacoustic engine has done. In thermoacoustic devices, thermal energy is directly converted to an acoustic wave (mechanical energy) or an acoustic input is converted into thermal energy. This is a result of heat interaction between a solid material and adjacent gas, within the so-called ‘‘thermal penetration depth” of the compressible oscillatory flow. Thermoacoustic technology is receiving growing interest in research for its many advantages, such as having no moving parts, being environmentally friendly and the possibility of using renewable energy for its operation (Adeff and Hofler, 2000). However, this technology is still at the development stage and needs more research to produce feasible and practical devices that are ready for domestic and industrial applications.

A looped-tube travelling-wave thermoacoustic engine was designed using DELTAEC (Design Environment for Low-amplitude ThermoAcoustic Energy Conversion). The device was equipped with a ceramic regenerator, which is commonly used in catalytic converters for automotive applications, with square channels. The results of preliminary testing of the device were compared with theoretical values estimated from the numerical model. Very close agreement was observed at the qualitative level and reasonable agreement was observed at the quantitative level.After the validation stage, the device was equipped with three selected low-cost porous materials for performance testing and studies. In addition to the ceramic regenerator that was tested before, regenerators made from stainless steel scourers, stainless steel wool and wire mesh screens were tested. This last type is widely available and commonly used in this application. To facilitate meaningful comparison, the regenerators were made in two sets: one having a common hydraulic radius of 200 μm and the other of 120 μm. In total, six regenerators were successfully tested. Before the performance experiments, all of the regenerators were tested in a steady air flow rig that was built for this purpose, to estimate their relative pressure drop due to viscous dissipation. The relative performance of the regenerators was then investigated. The testing focused on the onset temperature difference, the maximum pressure amplitude generated and the acoustic power output as a function of mean pressure as it varied from 0 to 10 bar gauge pressure. This comparative testing revealed a poor relative performance for the regenerators made of scourers and steel wool, while the cellular ceramic regenerator seems to offer an alternative for traditional regenerator materials, which may reduce the overall system cost.[6]

In Kees de Blok, the working is done with Novel 4-stage traveling wave thermoacousticPower generator. Utilizing low temperature differences from solar vacuum tube collectors or waste heat in the range 70-200 °C seems to be the most promising and commercial interesting field of applications for thermoacoustic systems. Recently a novel 4-stage “self matching” traveling wave engine is developed and tested. Beside the low acoustic loss and compactness, due to traveling wave feedback, all components per stage are identical which is beneficial from (mass) production point of view. Based on this concept a 100 kWT thermoacoustic power (TAP) generator is under construction. This project is carried out in the framework of phase two of the Dutch SBIR program. The 100 kWT TAP will be installed at a paper manufacturing plant in the Netherlands for converting part of the flue gas at 150°C from the paper drying process into electricity. Emphasis in this project is on production and cost aspects lowering the investment per kWe to a level competitive to ORC’s. After successful completion of this pilot, commercialization and delivery of 100kW to 1 MW thermoacoustic power generators for industrial waste heat recovery and as add-on for CHP systems is planned to begin in 2012. The same concept of the 4-stage traveling wave engine is also implemented in an atmospheric pressure operated thermoacoustic cooking device for developing countries which generate beside hot water up to 50 W electricity. Details, ongoing work and experimental results of these projects will be presented.

In a standing wave type resonator the local pressure and velocity amplitude is the result of two interfering traveling waves. Due to this interference local amplitude could be nearly twice the amplitude of the initial wave resulting in high local acoustic losses1. Actually, in a standing wave resonator the net transferred power to the load is the difference in power between forward and reverse wave.[7]

The purpose of study in A Study on the Synchronization Characteristics ofThermoacoustic Laser was to acoustically couple the two thermoacoustic lasers and study the interaction between the acoustic waves generated by the coupling. In some of the experiments, focused the sound waves of two thermoacoustic lasers, in order to understand the effects of coupling and determine the acoustic amplitude of the coupled sound wave. [11]

The following figures show the effect of sound waves in Thermoacoustic Engine.

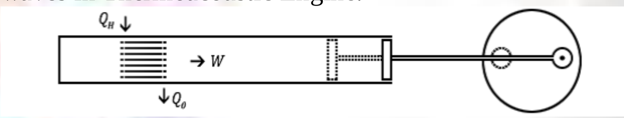

Fig. 2: Standing wave thermoacoustic engine

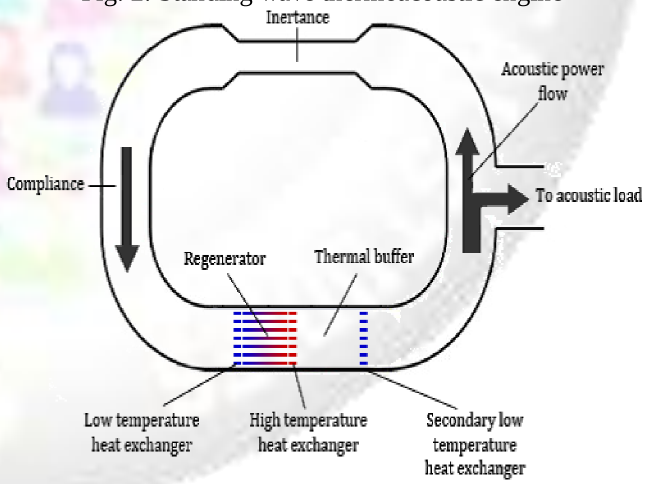

Fig. 3:Traveling wave thermoacoustic engine. The inertance and compliance are required to maintain the traveling wave phasing in a single-stage engine. The thermal buffer helps thermally isolating the hot heat exchanger from ambient-temperature components below, thus limiting heat losses.

V. RESULTS

The overall results from all the review is summarized in the table I, given below,

Paper No.	Year Of Paper	Authors &Title	Set up	Variables	Results
1	2008	Holly Ann Smith, Impedance Measurement of a Thermoacoustic Engine Constructed from a Helmholtz Resonator	In this experiment a thermoacoustic engine was constructed from a 5-Liter Helmholtz resonator, by inserting a ceramic stack into the bottom portion of the flask's neck	1]By allowing water to flow through the cold heat exchanger, the density and speed of sound of the air decreased from their values at ¢T=0°c, causing the pressure recorded by microphone to shift upwards. 2] The overall range for the acoustic pressure amplitudes is decreasing as the temperature difference across the stack increases from ¢T=5°cto 176°c	1]The overall range for the acoustic pressure amplitudes is decreasing as the temperature difference across the stack increases 2]Resonance Frequency (Hertz) are, 97.5 ± 0.00297 For 0°c To 109.0 ± 0.00375 For 203°c
2	2010	Chris van Dijk TUDelft, Comparison of multistage thermoacoustic engines in serial versus parallel configurations	This paper describes the experimental setup that was used to determine the performance of parallel and serial configurations of regenerators	1] The pressure and velocity profile are not the same for serial and parallel configurations. 2]The acoustic power measured in the load is used to compute the external efficiency. The internal efficiency is calculated from the resonator losses and the power measured in the load. The resonator losses were originally determ ined from two microphone measurements of an empty resonator half, without the consideration of internal geometries. 3]Hence internal efficiencies of two configurations cannot be compared, whereas the external efficiencies can be compared to draw conclusions.	1] In the parallel configuration at a pressure of 19.9 bar, a drive ratio of 3.03 and a heat input of 324W, 5.96 W of acoustic power can be subtracted while the hot regenerator temperature rises till 274°C. 2] In the serial configuration at a pressure of 19.5 bar, a drive ratio of 2.95 and a heat input of 367 W, 11.63 W of acoustic power can be subtracted while the hot regenerator temperature rises till 290 °C. 3] This means the 2nd law external efficiency of the serial configuration is 47% better than for the parallel configuration.
3	2010	Bruno Schuermans, Felix Guethe Douglas Pennell, Daniel Guyot, Thermoacoustic Modeling of a Gas Turbine Using Transfer Functions Measured Under Full Engine Pressure	The process of Alstom burner development and improvement includes combustion tests under high-pressure conditions. The test rig consists of a plenum chamber upstream of the burner, two tubular pressure vessels and the rectangular chamber liner.	1] The optical detection is accomplished by a non-imaging system of quartz lenses focusing the light on one thick fiber of 15 m length. From this thick fiber, the light is transmitted into seven different fibers by an optical splitter. 2] The excitation frequency is controlled by defining the siren disk speed and can be varied between 0 Hz and 400 Hz.	1] To perform transfer function measurements in a given frequency range, the test-rig was generally consecutively excited at discrete frequencies 2] In most cases, frequency steps of 5–10 Hz were chosen. 3] The generated acoustic forcing amplitude was sufficiently high to limit the recording time per frequency step of10–20 s
4	2010	Kees de Blok, Novel 4-Stage Travelling Wave Thermoacoustic Power Generator.	In this paper, details, ongoing work & expt. results on this novel concept are presented. All configurations are based on the same symmetric 4-stage configuration.	1] At maximum load (18W) and temperature difference (132 K) total heat rejected from the four cold hex's is measured to be 656 W. 2] Due to the short regenerator total static heat flow is	1] For helium at 2.1 Mpa the regenerator's are found quite dense (wt < 0.08) leading to a higher onset temperature of about 42 K. At 90 K water temperature difference acoustic loop power however is already raised up to 250 W at 2.5% drive

				4*0.85*132 = 449 W leaving 207 W rejected by the thermoacoustic process. Without static heat loss thermal efficiency of the 4-stage engine is 18 / (207+18) = 8 % corresponding with 27 % of the Carnot factor which is conform the simulation for such a simple atmospheric air operated device running at low temperature. 3] While due to the high static heat loss, this test rig has no Practical use, at least it demonstrate the feasibility of the 4-stage concept.	ratio. 2] The more steep Pac loop / DT curve for helium indicate less Acoustic losses due to lower effective Reynolds number in the feedback loops and a better heat transfer in the hex.
5	2011	Andrew C. Trapp, Florian Zink, Oleg A. Prokopyev, Laura Schaefer,Thermoacoustic Heat Engine Modeling and Design Optimization	Variables: The fundamental properties of the stack using following five structural variables: L: Stack length, H: Stack height, Z: Stack placement, dc: Channel diameter, N: Number of channels. Each variable has positive lower and upper bounds	1] The maximum length of the Resonator tube to be a quarter-wavelength, i.e., Zmax = $\lambda/4$, implying that Z can effectively range from Zmin to Zmax-L to properly account for the stack length. 2] Because the geometry of the porous stack is based on the monolith structure used in experimentation Zink et al. 3]The model it using square channels, representing the channel size with continuous variable dc, so that the channel perimeter Πc = 4dc and area Ac = dc^2	1] This paper demonstrate how optimization techniques can improve the design of thermoacoustic devices. 2]Previous studies have largely relied upon parametric studies. In contrast to these, where only one parameter is varied while all others are kept constant
6	2011	Sudeep Sastry, A Thermoacoustic Engine Refrigerator System For Space Exploration Mission	Variables are, Cooling power required (W), Cooling temperature to be achieved (K),Maximum heat addition temperature (K),Ambient atmospheric heat rejection temperature (K), Ambient surface heat rejection temperature (K), Radioisotope Heat addition increments (W)	1] To produce a cooling power of 300 W, 114 units are required, 800W of Heat is supplied to Unit 1 at 1223K, which generates thermoacoustic wave and generates a cooling of 150W at 323K. The unit rejects overall about 1000W of heat at 443K. 2] Now this cannot be directly rejected into the ambient Venus atmosphere as the ambient temperature is about 723K and the rejection temperature needs to be higher.	1] One Unit 1 system rejects a total amount of 1000 W of energy at 443K. As this is too big to be handled by a single unit, it is proposed that the rejected heat be split up into 7 equal chunks of approximately 150W each. 2] These are then rejected at 580K using Unit 2 systems. The number of Unit 2 systems required is 7. Similarly, heat rejected by each of these systems is further divided into chunks of 150W and then rejected at 743 K using 7 systems of Unit 3 for each Unit 2 system.

7	2011	WU ZhangHua, MAN Man, LUO ErCang, DAI Wei & ZHOU Yuan, Experimental investigation of a 500 W traveling-wave Thermoacoustic electricity generator	In this paper, an expt. investigation of a traveling-wave thermoacoustic electricity generator, which consists of a traveling-wave thermoacoustic heat engine and a linear alternator driven by that engine, is presented. Using the results of previous theoretical & expt. research, we designed and fabricated a traveling-wave thermoacoustic heat engine and a linear alternator.	1] An electrical power of 450.9 W was achieved with a maximum thermal-to-electrical efficiency of 15.03%, and a maximum electrical power of 481.0 W was obtained with 12.65% thermal-to-electrical efficiency. 2] The working fluid was 3.54 MPa pressurized helium and the working frequency was 74 Hz.	1] In the experiments, 450.9 W of electrical power was obtained with a maximum thermal-to-electrical efficiency of 15.03%, and a maximum electrical power of 481.0 W was achieved with 12.65% thermal-to-electrical efficiency.
8	2012	Sophie Collard, Design and Assembly of a Thermoacoustic Engine Prototype	The travelling wave thermo- acoustic engine prototype consisted of four pressure vessels, each housing a regenerator clamped between two heat exchangers, a feedback loop connecting the vessels to one another, & loudspeaker that would serve as a linear alternator. The engine had to be easy to assemble and disassemble, so that various configurations could be tested. It also had to withstand internal gauge pressures up to 3bars.	1] The thermoacoustic engine prototype built for this thesis project will later be tested at four different internal mean pressures (ranging from atm to 3 bars gauge pres-sure) and with one, two, three and four regenerator units in order to measure how these parameters affect the performance of a low cost engine.	1] This prototype was designed to withstand a maximum gauge pressure of 3 bars, This configuration was tested with a laboratory DC power supply & seemed to be working properly, only the power supplied was insufficient and the temperature of the hot heat exchangers would not exceed 45°C. 2] This configuration will later be tested using 230 Volts AC current from grid, which will hopefully be sufficient to bring the temperature of the hot heat exchangers up to at least 100°C.
9	2012	Kees de Blok, Multi-Stage Travelling Wave Thermoacoustic In Practice	The TAP was designed for converting 100 kW of thermal power of flue gas at 150-160ºC into 10 kW electricity with an exegetic efficiency of > 40%. Basically it is also a 4-stage traveling wave feedback system using He at a mean pressure of 750 kPa as working gas.	1] In this configuration the three engine stages are converting 20 kW waste heat into 1.64 kW acoustic output power dissipated by the fourth stage. 2] At an input temperature of 99°C and heat rejection at 20°C this corresponds with 38% efficiency relative to the Carnot factor.	1] The measured values for a 3-stage engine at these low power levels(relative to the design values) are found to agree well with the simulations7. 1.64 kW output power is reached with He at a mean pressure of 750kPa & at only 1.7% drive ratio. 2]Simulation for this engine running at a drive ratio of 5% shows that for an input temperature of 140 °C the acoustic output power available for alternators will be about 11kW.

10	2012	Abdulrahman Sayed Ahmed Abduljalil, Investigation of thermoacoustic processes in a travelling-wave looped-tube thermoacoustic engine	In each set of experiments one condition is varied, while the others are fixed. For example, for a fixed mean pressure value (e.g. *P*m = 8 bar), the engine is tested with different input heat power from the minimum to the rated power input of the heater.	1] The pressure amplitude at the trough is around 0.4kPa, while that at the peak is up to 16.4 kPa. 2] The time of each individual burst *Δt* was around 38 s at the beginning , and reduced to around 30 s at the end of the recording time, by expanding the time scale even further it can be found that the temperature peaks lead the pressure amplitude peaks by about 1-2 s	1] The mean pressure varied from the atmospheric pressure to 11 bar, while the input heat power was constant at 488 W, For the given *Q*, there is a critical mean pressure of 5.7 bar, below which the quasi-periodic bursts have never been observed regardless of the level of the input heat power.
11	2013	Sung Seek Park, Seung Jin Oh, Won Gee Chun, Kuan Chen, and Nam Jin Kim, A Study on the Synchronization Characteristics of Thermoacoustic Laser	The experimental apparatus consists of a Pyrex tube as a resonator, a Celcor ceramic catalytic converter as a stack material, copper magnet wire with enamel insulation, nichrome (NiCr) resistance heater wire and DC power supply for making necessary electricity.	1]The variations in sound pressure levels for the three different orientations and input power rates. The sound pressure level at the open end of the laser tube was about 120 dB for an electric power input of 25W. 2]The sound pressure level decreased by 20 dB for each increment of 2 cm, from r = 2 cm to r = 20 cm. This confirms that the sound pressure level of the sound waves generated outside the laser tube decreases with distance according to 1/r	1] In all three orientations, at any distance greater than 10 cm from the open end of the laser tube, the sound intensities were almost the same. 2]At r = 0.4 m, there was a slight increase in pressure level. This could be due to either the reflected sound waves or phase differences between harmonics.

VI. Conclusion

Thermoacoustics is a relatively new field of physics that combines acoustics, thermo-dynamics and fluid dynamics to describe the interplay between heat and sound. Since the late sixties, research in this area has yielded devices capable of converting part of the heat flowing through a temperature gradient into large amplitude sound waves and vice-versa with efficiencies now close to those of established technologies. In recent years, thermoacoustic engines, heat pumps and refrigerators have been gaining a lot of attention due to their inherent mechanical simplicity and to their use of environmentally friendly working gases. One of the most promising areas of application for these devices seems to be the use of low temperature industrial waste heat. This thesis focused on the design and assembly of a low cost traveling wave thermoacoustic engine prototype intended to be used for low temperature waste heat recovery. This prototype will allow measuring how different parameters affect the performance of a low cost engine, in search for an optimal configuration.

At temperature differences below the onset temperature, the incident sound wave is partially reflected upon encountering the ceramic stack, while being partially transmitted. Pressure measurements from microphone B show that as the temperature difference across the stack increases, the pressure is decreasing. Because this recorded pressure is a superposition of the incident and reflected wave, the reflected pressure must be decreasing as the temperature difference increases. Therefore, as the temperature difference increases, the reflection coefficient is decreasing, and one can assume that the resistance in the system is decreasing.

The work in Synchronization Characteristics of Thermoacoustic Laser was to study the interaction between the sound waves, generated from the two thermoacoustic lasers which were coupled acoustically.Sound pressure levels were measured in three different orientations from the open end of the tube, inorder to study the nature of the spherical sound waves exiting the laser tube. For all the orientations, there was a slight variance in pressure levels in the close vicinity of the openend of the laser tube, whereas at distances greater than 10 cm away from the open end, the pressure levels were approximately equal.

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