Design and Construction of Thermo acoustic Refrigerator for its optimum Performance and Its application in Machining Process

by

Md. Sayeed Ul Hasan (131426)
Md. Saiful Islam (131459)

A Thesis Submitted to the Academic Faculty in Partial Fulfillment of the Requirements for the Degree of

BACHELOR OF SCIENCE IN MECHANICAL AND CHEMICAL ENGINEERING

Department of Mechanical and Chemical Engineering
Islamic University of Technology (IUT)
Gazipur, Bangladesh

Design and Construction of Thermo acoustic Refrigerator for its optimum Performance and Its application in Machining Process

Approved by:

Dr. Anayet U Patwari
Supervisor and Professor,
Department of Mechanical and Chemical Engineering,
Islamic University of Technology (IUT)
Boardbazar, Gazipur-1704.

Date: ……

<u>Candidates' Declaration</u>

It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

Signature of the candidate

Md. Sayeed Ul Hasan
Student no. 131426
Department: MCE
IUT,OIC
Board Bazar , Gazipur

Signature of the candidate

Md. Saiful Islam
Student no. 131459
Department: MCE
IUT,OIC
Board Bazar , Gazipur

Signature of the Supervisor

Dr. Anayet U Patwari
Professor,
Department: MCE
Islamic University of Technology (IUT),
Board Bazar, Gazipur-1704.

Dedicated

To

Our Beloved Parents

Table of Contents

Table of Figure

ACKNOWLEDGEMENT

We are grateful to Almighty Allah (Subhanahu-Tala) who made it possible for us to finish the project successfully on time and without any trouble.

Firstly, we would like to express to our heartfelt appreciation and profound gratitude to our supervisor **Dr. Md. Anayet Ullah Patwari**, Professor, Mechanical and Chemical Engineering Department, IUT, for his invaluable supervision, encouragement and guidance throughout the span of this work. It has been privilege for us, working with such ingenuity, integrity, experience and wittiness.

We would also like to thank the following instructors who provided invaluable collaborative support and made our time at IUT machine workshop exciting, fun, and productive. In particular Mohammad Mokter Hossain, Assistant Operator (A/C Lab), Md. Rajaul Karim, operator (Machine shop), Md. Abdul Motalib, Senior operator, (Fabrication and Welding Shop), Md. Shakhawat Hossain, senior operator (CAM Lab).

We would also like to convey gratitude to all other faculty members of the Department for their advice in every stage for successful completion of this project.

ABSTRACT

Different types of coolant are used in machining process to reduce heat and friction between the tool and the work piece, to improve the surface finishing and to increase tool life. But long term exposure to these kinds of working fluids can present with some health hazards. To eliminate these types of coolant in the manufacturing process, a Thermo Acoustic Refrigerator (TAR) generated air coolant is developed.

This technology uses high intensity acoustic waves in a pressurized gas tube to pump heat from one place to other to produce a refrigeration effect. In this study, an electromagnetic loudspeaker is used to generate the acoustic input inside an acoustically insulated tube filled with inert gases inside and with little or almost no moving parts which making the system highly efficient. Cooling effect produced by TAR will be applied in machining process as coolant. The result shows a promising window of application for thermo acoustic refrigerator coolant in machining process.

Chapter One: Introduction

Intense heat generated in machining processes like milling, grinding due to relatively high frictional effects impairs work piece and quality by inducing thermal damage. Therefore, cooling and lubrication play a decisive role in machining process [1-3]. Liquid coolants in flood form have been the conventional choice to deal with this problem. Long term exposure to this kind of fluid can present with many health hazards for the operators. Also relatively high surface speeds of the wheel and large contact area between the wheel and work piece cause a stiff boundary layer to form around the wheel periphery, which restricts the flow of cutting fluids into the machining zone [4]. To solve these problems, A Thermoacoustic refrigerator (TAR) is realized which produces cold air that can be used to replace the usage of liquid coolant. Thermoacoustic refrigerator is a cutting edge technology which uses sound effect to convert mechanical energy into temperature differential. They consist of a loudspeaker, attached to one end of an acoustic resonator (tube), which is closed at the other end and contains inert gas inside. Advantages of using TAR are simple and clean mechanical system which doesn’t use pistons, cranks and lubricants as the conventional refrigerator or air condition cooling systems [5-6].

1.1 Surface roughness

Surface roughness is a widely used index of product quality and in most cases a technical requirement for mechanical products. Achieving the desired surface quality is of great importance for the functional behavior of a part. On the other hand, the process dependent nature of the surface roughness formation mechanism along with the numerous uncontrollable factors that influence pertinent phenomena, make almost impossible a straightforward solution. at regions of contact.

Surface roughness is a measurement of surface texture. It is defined as a vertical deviation of a real surface from its ideally smooth form. Roughness plays an important role in various processes such as friction and adhesion and is widely measured. Our first visual or tactile contact with objects around us is through their surfaces.

1.2 Effect of Coolant in Machining Process

The coolant is used in metalworking process is used to reduce friction and wear, improve material flow and act as a parting agents. In general, coolants are made by mixing various kinds of oil, Emulsion, along with additives**.** But the presence of chemical substances like sulfur, phosphorous, chlorine or any other extreme pressure additives in the coolant introduces health hazard to the operator. It is well documented that 7–17% of machining cost of a work-piece is due to coolant-lubricant deployment [7]. The disposal of used chemical coolants involves incineration and partially contributes to global warming [8].

1.3 Thermo acoustic Phenomenon

Thermo acoustics is an emergent technology that uses the phenomenon of interaction of sound fields with solids to develop heat pumps or heat. Sound waves in air are longitudinal waves. The medium in which they move undergoes vibrations, thus experiences compression and rarefaction. This is associated with change in temperature and pressure. When the gas carrying a wave is brought in contact with a solid surface, it absorbs the heat as the gas [9]. Acoustic waves cause oscillation while propagating through a medium. This oscillation can be used as pressure waves on neighboring media. To produce the thermoacoustic effect, these oscillation in a gas should occur close to a solid surface so that heat can be transferred to and from the surface. A stack of closely spaced parallel plates is placed inside the thermoacoustic device to provide such a solid surface. The thermoacoustic phenomenon occurs by the interaction of the gas particles and the stack plates [10]

1.4 Objectives

- Aim of this study is to investigate the effect of cold air of surface roughness in machining process like turning. Cold air absorbs the heat produced due to friction between the work piece and cutting tool. Cold air is produced with the help of a Thermoacoustic refrigerator.
- For completion of the study a TAR is designed, fabricated and tested under different frequencies of sine wave for its optimum performance;
- The best obtained conditions are used for conducting the surface roughness testing.

1.5 Scopes

Thermoacoustic refrigerators have the potential to cover the whole spectrum of refrigeration down to cryogenic temperatures. It is likely that potential market for food applications will initially be in the low capacity equipment such as domestic and commercial refrigerators, freezers and cabinets. The main drivers to encourage uptake of thermoacoustic technology once they become commercially available in the food sector .Environmental considerations and legislation that significantly limits or prohibits the use of HFCs in small capacity, self-contained refrigeration equipment, limits imposed on the amount of flammable refrigerant that can be used in self-contained refrigerated cabinets, development and availability of systems that offer efficiency and cost advantages over vapor compression systems.

Chapter Two: Literature Review

Since turning is the primary operation in most of the production processes in the industry, surface finish of turned components has greater influence on the quality of the product. Surface finish in turning had been found to be influenced in varying amounts by a number of factors such as feed rate, work material characteristics, work hardness, unstable built-up edge, cutting speed, depth of cut, cutting time, tool nose radius.

Some works have recently been done on cryogenic cooling by liquid nitrogen jet in machining and grinding some steel of common use [11–17]. Cryogenic cooling provided less cutting forces, better surface finish and improved tool life compared to dry machining [11–14]. Detailed grinding studies [15–17] revealed similar benefits with improved surface integrity compared to dry grinding and grinding with soluble oil. The earlier work [18–21] of late 1960s and early 1970s reported that cryogenic cooling notably reduced cutting force and temperature and improved tool life and surface integrity in continuous as well as interrupted machining. Beneficial effects of cryogenic cooling in turning stainless steel by diamond tools were also reported [22]. The favorable role of cryogenic cooling in chip breaking and reducing cutting temperature in turning [23] and overall improvement in face milling [24] has been reported. Even in turning of reaction bonded silicon nitride by CBN inserts, cryogenic cooling provided improved tool life [25,26]

It is well known [27, 28, 29] that the frictional behavior between tool and work materials in metal cutting has significant influences on the phenomena of tool wear, BUE and surface quality. Trent [28] concluded that the factors which control the flow pattern around the cutting edge influence the plastic deformation, hardness and properties of the machined surface, its roughness, its precise configuration and its appearance. In addition, the presence or absence of seizure on those parts of the tool surface where the new work surface is generated can have a most important influence. It has been proven [30] that at low and moderate sliding velocities friction is largely due to local adhesion and shearing at regions of contact.

Thermoacoustic phenomena were originally observed from daily life more than 200 years ago. In 1777, Byron Higgins discovered that acoustic oscillations in a pipe might be excited by suitable placement of a hydrogen flame inside [31]. The oscillation was also found by glassblowers when a hot glass bulb was attached to a cool glass tube, i.e. the tube tip sometimes emitted sound [32].

The investigation on thermoacoustics began with these occasional findings.Sondhauss firstly studied the thermoacoustic effect happening in a hollow glass tube connected to a glass bulb in 1850, composing a tube with one end closed and the other open, which was then named as Sondhauss tube[33].

In 1959, Rijke observed and qualitatively analyzed the strong acoustic fluctuation, afterward called as Rijke oscillation, when he placed a heated screen in an upright tube [33]. In fact, Sondhauss and Rijke tubes are regarded as the ancestors of standing-wave and traveling-wave thermoacoustic machines, respectively.

In 1962, Carter and his colleagues effectively improved the Sondhauss tube. Stack was placed in the tube, and the thermoacoustic effect was greatly enhanced. They manufactured the first thermoacoustic engine with obvious acoustic work output, 27 W of acoustic power from 600 W of heat [32, 33]. It was the most important advance in modern experimental thermoacoustics, and marked the beginning of the investigation on the practical thermoacoustic machine.

In 1979, Ceperley from George Mason University realized that the phase relation between pressure and velocity of vibrating working fluid in the regenerator of Stirling devices was the same as that in a traveling wave field. Based on this, he proposed the concept of traveling-wave thermoacoustic machines [34]. Since pressure is in phase with velocity in traveling wave, the compression and expansion of fluid parcels separate from the heating and cooling processes. In this case, the irreversibility of poor thermal contact, which is required in a standing-wave thermoacoustic machine, is avoided, and a higher thermal efficiency may be obtained. Although the gain of acoustic power was not yet achieved in his experiment [35] due to the unsuitable acoustic impedance, Ceperley's conception pointed out a new direction to improve the efficiency of thermoacoustic machines. Theoretical thermoacoustics began in 1868, when Kirchhoff calculated acoustic attenuation in a duct due to oscillatory heat transfer between the isothermal solid duct wall and the gas in which the sound wave sustains.

In 1896, Rayleigh gave the first qualitative explanation to the thermoacoustic oscillation [36]: if the phases of working fluid's motion and heat transfer are appropriate, a vibration may be maintained. At the phase of the greatest condensation, heat is received by the oscillating fluid, and while at the phase of the greatest rarefaction, heat is given out from it, thus the acoustic fluctuation may be enhanced (heat energy is converted into acoustic energy). Contrarily, heat is taken out from the vibrating fluid in time of the greatest denseness, and is supplied to it in time of the greatest rareness, so there is a tendency of attenuation for the sound wave (acoustic energy turns into heat flow). In this case, work has to be delivered to the fluid for maintaining the acoustic oscillation. This is Rayleigh principle. So far, Rayleigh principle has been considered as a reasonable explanation for sustaining the thermoacoustic vibration in a duct. In 1969—1983, Rott from Federal Institute of Technology, Zurich, Switzerland, worked on the quantitative theory of thermoacoustic fluctuation[37-44], and established the theoretical foundation of modern linear thermoacoustics. His study provides elementary means for analyzing thermoacoustic machines quantitatively.

Chapter Three: Thermodynamic and Acoustics Consideration

3.1 Basic Refrigeration Cycle

Vapor-compression refrigeration dates back to 1834 when the Englishman Jacob Perkins received a patent for a closed-cycle ice machine using ether or other volatile fluids as refrigerants. A working model of this machine was built, but it was never produced commercially. In 1850, Alexander Twining began to design and build vapor-compression ice machines using ethyl ether, which is a commercially used refrigerant in vapor-compression systems. Initially, vapor-compression refrigeration systems were large and were mainly used for ice making, brewing, and cold storage. They lacked automatic controls and were steam-engine driven. In the 1890s, electric motor driven smaller machines equipped with automatic controls started to replace the older units, and refrigeration systems began to appear in butcher shops and households. By 1930, the continued improvements made it possible to have vapor-compression refrigeration systems that were relatively efficient, reliable, small, and inexpensive Heat flows in the direction of decreasing temperature, that is, from high-temperature regions to low-temperature ones .This heat-transfer process occurs in nature without requiring any devices. The reverse process, however, cannot occur by itself. The transfer of heat from a low-temperature region to a high-temperature one requires special devices called **refrigerators.** Refrigerators are cyclic devices, and the working fluids used in the refrigeration cycles are called **refrigerants.**

3.1.1 Vapor Compression Refrigeration Cycle

The vapor-compression refrigeration cycle is the most widely used cycle for refrigerators, air Conditioning systems, and heat pumps. It consists of four processes:

1-2	Isentropic compression in a compressor
2-3	Constant-pressure heat rejection in a condenser
3-4	Throttling in an expansion device
4-1	Constant-pressure heat absorption in an evaporator

A simple vapor compression refrigeration system consists of the following equipment:

i. Compressor
ii. Condenser
iii. Expansion valve
iv. Evaporator.

In an ideal vapor-compression refrigeration cycle, the refrigerant enters the compressor at state 1 as saturated vapor and is compressed isentropically to the condenser pressure. The temperature of the refrigerant increases during this isentropic compression process to well above the temperature of the surrounding medium. The refrigerant then enters the condenser as superheated vapor at state 2 and leaves as saturated liquid at state 3 as a result of heat rejection to the surroundings. The temperature of the refrigerant at this state is still above the temperature of the surroundings. The saturated liquid refrigerant at state 3 is throttled to the evaporator pressure by passing it through an expansion valve or capillary tube. The temperature of the refrigerant drops below the temperature of the refrigerated space during this process. The refrigerant enters the evaporator at state 4 as a low-quality saturated mixture, and it completely evaporates by absorbing heat from the refrigerated space. The refrigerant leaves the evaporator as saturated vapor and reenters the compressor, completing the cycle. In a household refrigerator, the tubes in the freezer compartment where heat is absorbed by the refrigerant serves as the evaporator. The coils behind the refrigerator, where heat is dissipated to the kitchen air, serve as the condenser.

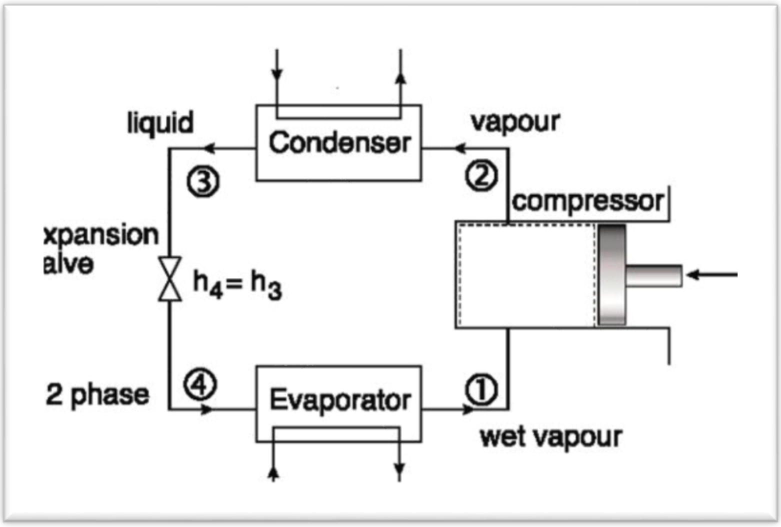

Figure 1 Schematic for the ideal vapor-compression refrigeration cycle.

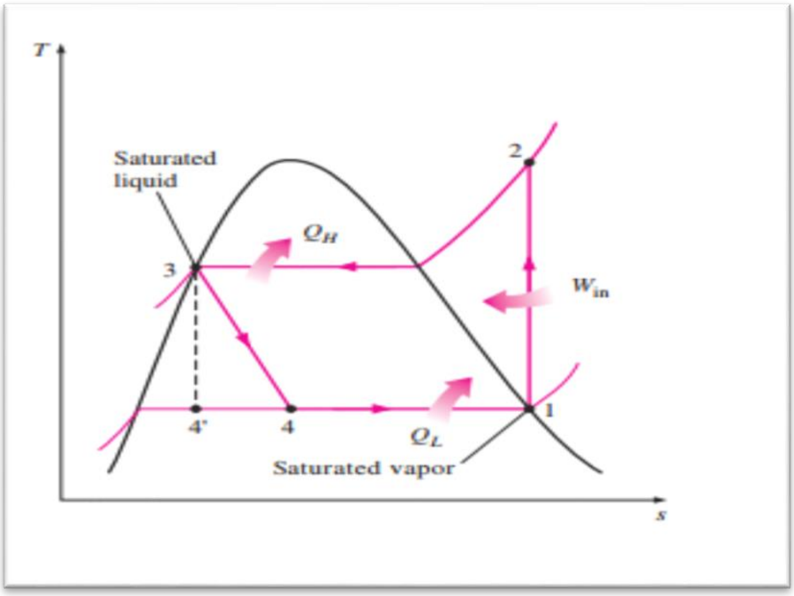

Figure 2 T-s diagram for the ideal vapor-compression refrigeration cycle.

3.1.2 C.O.P.

All four components associated with the vapor-compression refrigeration cycle are steady-flow devices, and thus all four processes that make up the cycle can be analyzed as steady-flow processes. The condenser and the evaporator do not involve any work, and the compressor can be approximated as adiabatic. Then the COPs of refrigerators and heat pumps operating on the vapor-compression refrigeration cycle can be expressed as

$$COP = \frac{Q_L}{w_{net,in}} = \frac{h_{1-h_4}}{h_{2-h_1}}$$

3.2 Acoustical Theory

Sound propagates through air as a longitudinal wave. The speed of sound is determined by the properties of the air, and not by the frequency or amplitude of the sound. Longitudinal acoustic waves are generated as a result of the compression and expansion of the gas medium. The compression of the gas corresponds to the crest of a sine wave and the expansion corresponds to the troughs of a sine wave.

In a longitudinal wave the particle displacement is parallel to the direction of wave propagation. The compression and expansion of a longitudinal wave results in the variation of pressure along its longitudinal axis of oscillation. Since a sound wave consists of a repeating pattern of high-pressure and low-pressure regions moving through a medium, it is sometimes referred to as a **pressure wave.**

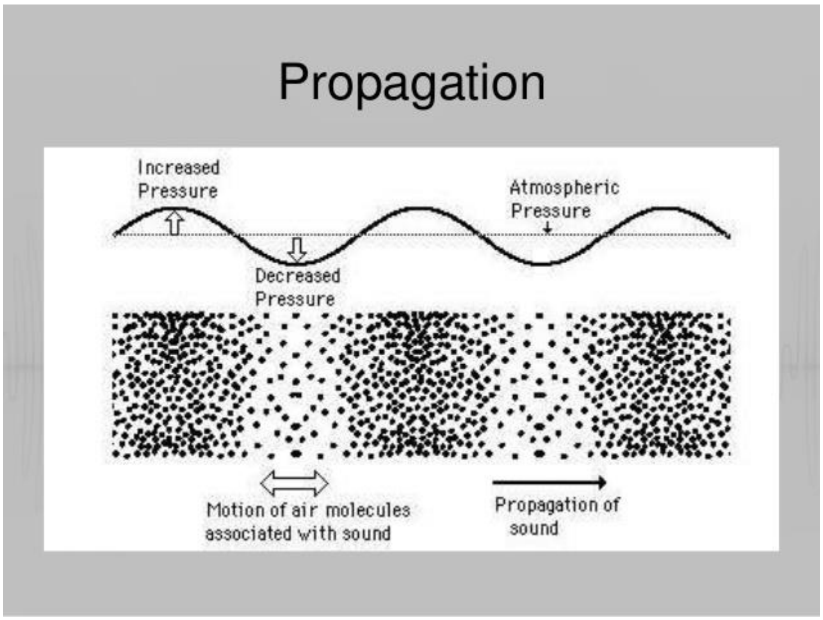

Figure 3 Propagation of Sound Wave

3.3 How does TAR works

Most of the theory behind thermoacoustic refrigeration is just simple concepts that most students learn in their introductory physics or chemistry classes. The concepts are the Ideal Gas Law and how sound waves act in an open-ended tube.

3.3.1 General theory

The theory behind thermoacoustic refrigerators rests mainly on Boyle's Law of gases:

$$PV = nRT$$

Where P is the pressure, V is the volume, n is the number of moles of molecules, R is Rydberg's constant 8.3145 J / mol K and T is temperature. Inside a closed container, V and n stay constant. Therefore if pressure oscillations are created under these conditions the temperature will also oscillate. The pressure oscillations can be created by sounds waves driven by a speaker. These changes in temperature can be exploited to pump heat from a cold area to a hot area. This creates refrigeration with the use of sound waves, commonly known as thermoacoustic refrigeration.

3.3.2 Working Principle

The main principle of thermoacoustic is the sound waves act like the pressure waves while propagating through a medium. In our device loud speaker generates the standing wave which propagates through the gas causing molecular collisions. These collisions produce a disturbance in the gas which creates constructive and destructive interference by turn. Compression of the molecules is caused by constructive interference and expansion of molecules is caused by destructive interference. As the gas molecules are compressed, pressure increases as well as temperature. On the other hand, where gas molecules are expanded, pressure decreases as well as temperature. As a result, a temperature difference is obtained at both sides of the stack inside the resonator tube.

A hot heat exchanger is used to absorb heat from the hot side of the stack and release it to the hot sink. Main component of TAR is stack. It allows the operating gas to oscillate while in contact with the solid wall. The channel like structure of the stack allows gas particles to propagate through it and increase the gas solid interface and hence enhance heat exchange. . A spherical or conical shaped buffer volume is attached to the resonator tube which creates turbulence to produce standing wave.

A cold heat exchanger is used to cool down ambient air that is to be supplied to the machining process as a replacement of coolant

3.3.3. Process Flow Chart

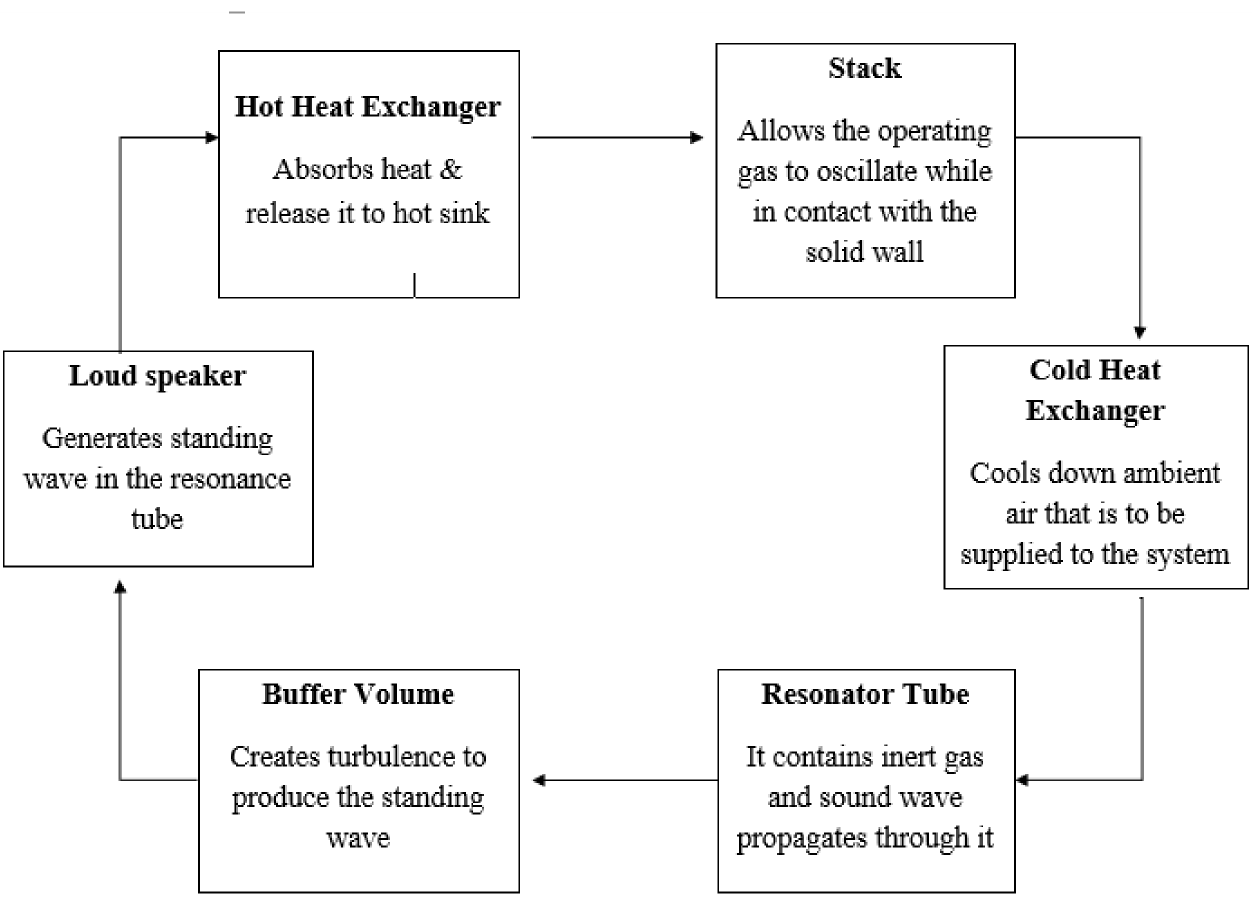

Figure 4 Process Flow Chart

Chapter Four: Design and Fabrication

The design for this project was initially based off of Tijani's Design as shown in Figure 5. Ideally this design would have been implemented entirely. Due to time and availability of parts constraints, many design aspects had to be modified.

4.1 Schematic Design

Figure 5 shows the construction of a simple thermoacoustic refrigerator. It contains a resonator tube made of PVC pipe and Copper tube and it contains the inert gas as working fluid. A loud speaker is used to produce the necessary acoustic power to drive the system. A stack, the heart of the TAR which is a porous medium is placed inside the resonator to increase the gas solid interaction and contact surface to exchange heat. Heat exchangers are used in both sides of the stack. A thermocouple is used to determine the temperature difference between hot and cold air.

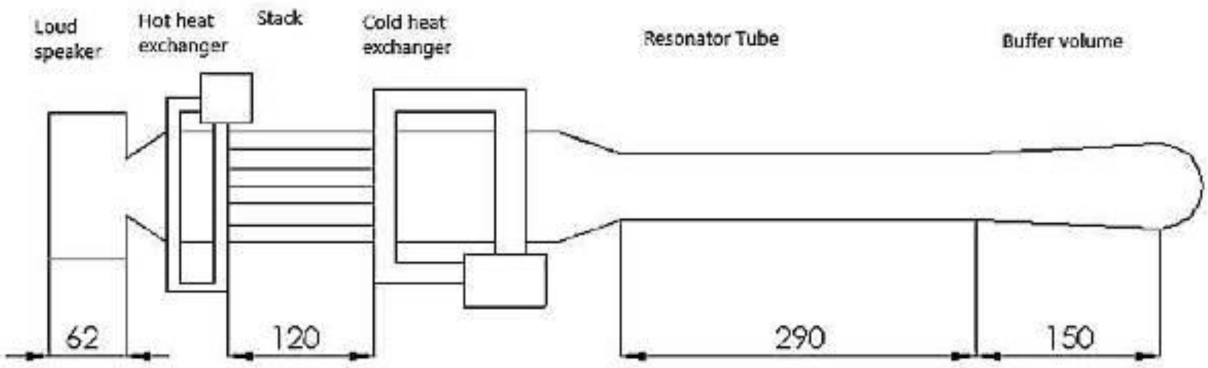

Figure 5 schematic for TAR

4.2 Components

There are several main components involved in a thermoacoustic refrigerator. The main components are the stack, heat exchangers and resonator. Each of these components has a specific purpose in thermoacoustic refrigeration which is discussed in this section.

4.2.1. Loud speaker

Loud speaker supplies the required acoustic power to drive the system. It should be compact, powerful and light weight. For these reasons an R-2430, 100 watt, 3.5 inch, 3 way speaker was used. The speaker was kept inside a PVC made speaker housing as PVC was readily available and thermally insulating.

Figure 6 Loudspeaker

4.2.2. Speaker Housing

It is made of PVC. Speaker is inserted inside it. Two holes were drilled at the back, one for electrical wiring of the speaker and another for charging the gas.

Figure 7 Speaker Housing

4.2.3. Stack

It is the heart of Thermoacoustic refrigerator. It is a porous medium that increases the heat exchange surface area. To guarantee low thermal conductivity of the stack Mylar sheet was chosen. A spiral stack of Mylar sheet is constructed wounding around a PVC dowel of 1.5inch diameter. A channel structure between the layers is realized with the help of .25 mm fishing lines. Fishing lines were attached to the Mylar sheet with the help of Glue gun and glue sticks. For the first 200 lines a distance of 1 cm was maintained and for the rest a distance of 3 cm up to the diameter of the stack became 3.5 inch. Then it was inserted inside the stack housing. Housing is made of 3.5 inch PVC pipe. PVC material is chosen for its low thermal conductivity and insulation

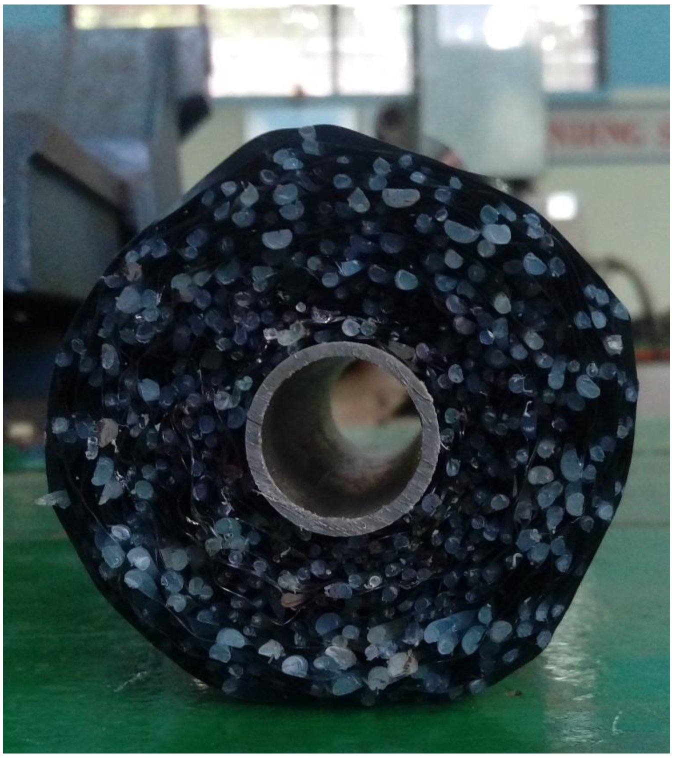

Figure 8 Stack

4.2.4. Resonator Tube

Resonator tube is the body of the thermoacoustic refrigerator in which the sound wave propagates. It consists of three major parts the resonator needs to be designed in such a way that is compact, light and strong. It must also impede the dissipation of acoustical energy as much as possible. First part consists of a large diameter PVC pipe called stack housing which contains the stack, followed by a smaller diameter Copper tube and the last part is the Buffer volume. Copper tube has relatively higher thermal conductivity and its diameter is 2 inch and 29 cm in length.

Figure 9 Resonator Tube

4.2.5. Buffer Volume

The buffer volume is to be used to simulate open-end resonator. It is a conical shaped copper tube with a taper angle of about 90 and a diameter of 2.35 inch and gradually increasing up to 2.85 inch. The total length of this buffer volume is 15 cm.

Figure 10 Buffer Volume

4.2.6. Heat Exchanger

Two heat exchangers are made of 0.25inch Copper coil. These are placed in both sides of the stack. Without the heat exchangers, heat would neither be supplied nor extracted from the ends of the stack. The heat exchanger strips and the nearby stack plates are nonparallel to each other in order to prevent the total blockage of any gaps in the stack by a heat exchanger strip. When a heat exchanger is too long, some parcels of fluid only come into contact with the ends of the heat exchanger and when it is too short parcels can jump past the heat exchanger. Poor performance of heat exchangers leads to lower efficiencies in thermoacoustic refrigerators.

Figure 11 Heat Exchanger

Chapter Five: Experimentation

5.1 Instrumentation

This section details the instruments used to collect the experimental data in the study.

5.1.1 Thermometer

A CIE 305 portable thermometer was used to measure the temperature difference between air at inlet and outlet of the cold Heat exchanger. This instrument is a portable 3.5 digit, compact-sized digital thermometer designed to use external K-type thermocouple as temperature sensor. The specifications of the thermocouple are given below:

- Display: 3.5digit liquid crystal display (LCD) with maximum reading of 1999
- Battery: Standard 9V battery (NEDA 1604. IEC 6F22)
- Dimensions: 147 mm (H) x 70 mm (W) x 39 mm (D)
- Weight: 7.4 oz. (210g)
- Ambient Operating Range: 0°C to 50°C (32°F to 122°F)
- Storage Temperature: 20°C to 60°C (-4°F to 140°F)
- Relative Humidity: 0% to 80% (O°C to 35°C) (32°F to 95°F)
  0% to 70% (35°C to 50°C) (95°F to 122°F)
- Temperature Scale: Celsius or Fahrenheit user-selectable
- Measurement Range: 50°C to 1300°C. (-58°F to 2000°F)
- Resolution: 1°C or 1°F, 0.1°C or 0.1°F
- Accuracy: Accuracy is specified for operating temperatures over the range of 18°C to 28°C (64°F to 82°F)
- Input Protection: 60V dc or 24V rms ac maximum input voltage on any combination of input pins.
- Temperature Coefficient: 0.1 times the applicable accuracy specification per °C from O°C to 18°C and 28°C to 50°C (32°F to 64°F and 82°F to 122°F)
- Input Connector: Accepts standard miniature Thermocouple connectors (flat blades spaced 7.9mm. center 10 center)

Figure 12 CIE 305 Portable Thermometer

5.1.2 Contact Surface Profilometer

A contact profilometer Mitutoyo SURFTEST SJ-210 was used to measure the surface roughness of the machined surface. The specifications of the thermocouple are given below:

- Measuring speed: Measuring: 0.01, 0.02, 0.03 in/s (0.25mm/s, 0.5mm/s, 0.75mm/s) Returning: 1mm/s
- Measuring force / Stylus tip: 0.75mN type: 0.75mN / 2µmR 60°, 4mN type: 4mN / 5µmR 90°
- Applicable standards: JIS ’82 / JIS ’94 / JIS ’01 / ISO ’97 / ANSI / VDA
- LCD dimensions: 1.45 x 1.93" (36.7×48.9 mm)
- Power supply: Two-way power supply: battery (rechargeable Ni-MH battery) and AC adapter
- Mass: About 1.1lbs (500g) (Display unit + Drive unit + Standard detector)

Figure 13 Surface Profilometer

5.1.3 Pressure Gauge

A pressure gauge was used to maintain the pressure inside the tube. We used Absolute pressure gauge in which sensors measure the pressure of a system relative to a perfect vacuum. These sensors incorporate elements which are completely evacuated and sealed which serve as the vacuum reference. Input pressure is applied through a single port. The Features of a absolute pressure gauge are given below:

- Compliance to latest EN-837 standard
- Range: 0-1kg/cm^2(a)/0-1bar(a) / 0-760mmHg(a)
- Bellow in SS316 as standard providing better mechanical properties guaranteeing repeatability and accuracy.
- Accuracy: ± 1% FSD

Figure 14 Absolute Pressure Gauge

5.1.4 Anemometer

An AM- 4201 Anemometer was used to measure the velocity of air at the outlet. The specifications are given below:

- Display: 18mm (0.7") LCD (Liquid Crystal Display), 3 1/2 digits
- Measurement: m/s (meters per second),
  Km/h (kilometers per hour),
  Ft/min (feet/per minute),
  Knots (nautical miles per hour),
  Data hold
- Operating Humidity: Less than 80 % RH.
- Power Supply: 006P DC 9V battery (heavy duty type).
- Weight: 325 g/0.72 lb (including battery).

Figure 15 Anemometer

5.1.5. Blower

A portable blower model no PB-20 was used to draw air from the inlet to the outlet of the heat exchanger. The specifications are given below:

- Power: 335 watt
- Frequency of A/C current: 50 Hz
- Voltage-Current: 220V-1.6A
- Flow rate: 2.3 m^3/min

Figure 16 Portable Blower

5.1.5 Lathe Machine

The Centre lathe used for the machining process was manufactured by Gate Inc. (model L-1/180). Lathe is a machine which removes the metal from a piece of work to the required shape and size.

Specification of the Lathe:

- Centre height in mm: 180
- Centre distance in mm: 1000-750
- Bed width in mm: 250
- Swing over front part of bed in mm: 380
- Swing over bed ways in mm: 360
- Swing over gap in mm: 510
- Gap length in front of face plate in mm: 120
- Swing over carriage in mm: 340
- Swing over cross slide in mm: 200
- Main spindle bore in mm: 42
- Main spindle nose: DIN 55022-5
- Main spindle tapper: 4
- Number of speeds: 9
- Speed range in rpm: 60-2000
- Number of longitudinal feeds: 20
- Range of longitudinal feeds in mm: 0.047-0.86
- Number of cross feeds: 20
- Range of cross feeds in mm: 0.021-0.39
- Number of metric threads: 20
- Range of metric threads in mm: 0.5-9
- Number of whit worth threads: 16
- Range of whit worth threads in t.p.i: 56-4
- Number of modular threads: 20
- Range of modular threads: 0.25-4.5

- Thread of lead screw: 6
- Cross slide travel in mm: 260
- Tool post slide travel in mm: 115
- Turn off tool post slide: 1800
- Maximum tool dimension in mm: 20×20
- Tailstock shank diameter in mm: 48
- Tailstock shank travel in mm: 145
- Tailstock taper: 3
- Main motor power in HP: 4
- Power motor power HP: 1/8HP

Figure 17 Centre Lathe

Figure 18 Tool Holder

Figure 19 Carbide Insert

5.2 Sealing

Effective sealing is an important aspect in the design of thermoacoustic devices, and is given little attention in the literature. The problem of containing up to 2bars of gas using simple materials is compounded by the small molecular size of Ar and other light gas mixtures commonly used, which are often able to penetrate rubber seals and threaded connections. Furthermore, whilst mass-produced thermoacoustic refrigerators would theoretically never need to be opened or disassembled, laboratory versions are repeatedly disassembled and reconstructed to investigate various effects. The integration of good pressure seals which can be repeatedly broken into the design will result in improved and more parameters. For the detention of leak in different joint, we performed bubble testing using soap foam and pressurized Nitrogen gas as it was readily available in the lab. Though this may be the oldest leak detention method but it is very effective in laboratory. After we find the leaks, Araldite and Super glue was used to make the joints leak proof.

Figure 20 Bubble Testing for Leak Detention

Chapter Six: Research Methodology

6.1. Temperature Testing

Temperature testing commenced with pressurized Helium gas in the TAR. A CIE 305 portable thermometer was used to measure the temperature difference between air at the inlet and outlet of the cold Heat exchanger. The speaker was driven at frequencies form 50 Hz to 1000 Hz in the form of sine wave. Data was taken after driving the speaker for 10 minute. A portable blower model no PB-20 was used to draw air from the inlet to the outlet of the heat exchanger. The velocity of air at the outlet was 0.6 m/s. ΔT was tested after He gas was inserted at 1 atm (14.7 psi) & 1.5 atm (22psi).

Figure 21 Experimental set up for Temperature Testing

6.2. Surface Roughness Testing

The Centre lathe used for the machining process was manufactured by Gate Inc. (model L-1/180). A contact profilometer Mitutoyo SURFTEST SJ-210 was used to measure the surface roughness of the machined surface. For capturing the surface image a Canon 700d DSLR camera was used. a carbide insert was used in the turning operation.

Table 1. Process Parameter

Feed rate (mm/rev)	Depth of cut (mm)	Spindle Speed (rpm)	Cutting speed (mm/min)
0.095	0.50	220	22.11

Job Piece Specification

Material	:	Mild Steel
Initial diameter	:	32 mm
Final Diameter	:	30mm

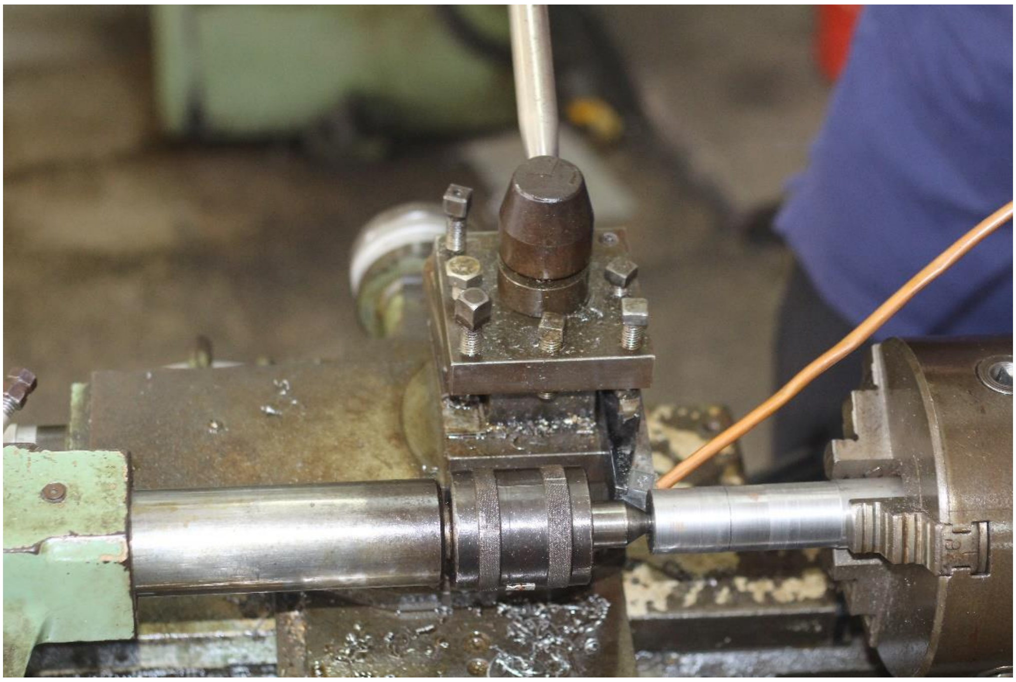

Figure 22 Experimental set up for Surface Roughness Testing

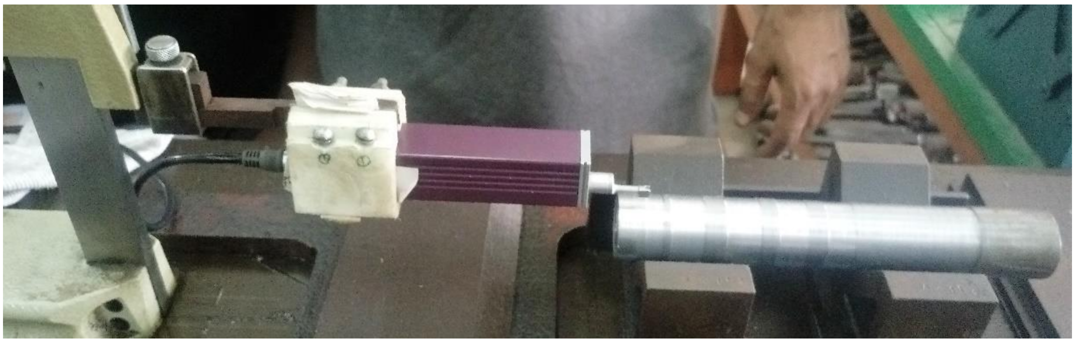

Figure 23 Surface Roughness measurement by Profilometer

Chapter Seven: Results & Conclusion

The optimal performance for a stack filled with spiral plates in a standing wave thermo acoustic refrigerator was studied. The relationship between frequency and gas pressure in TAR is investigated in the study.

7.1 Temperature Testing of TAR

7.1.1 Result

The gas pressure inside the tube affects the performance of the refrigerator. Figure 24 depicts the temperature gradient with respect to different sound frequencies at 1 atm (14.7 psi) and 1.5 atm (22 psi). A maximum temperature difference of 6^0c was observed at a frequency of 750 Hz when the gas was pressurized at 1 atm. repeating the same process for 1.5 atm pressure a maximum temperature difference of 6.3^0c was obtained at the 750 Hz.

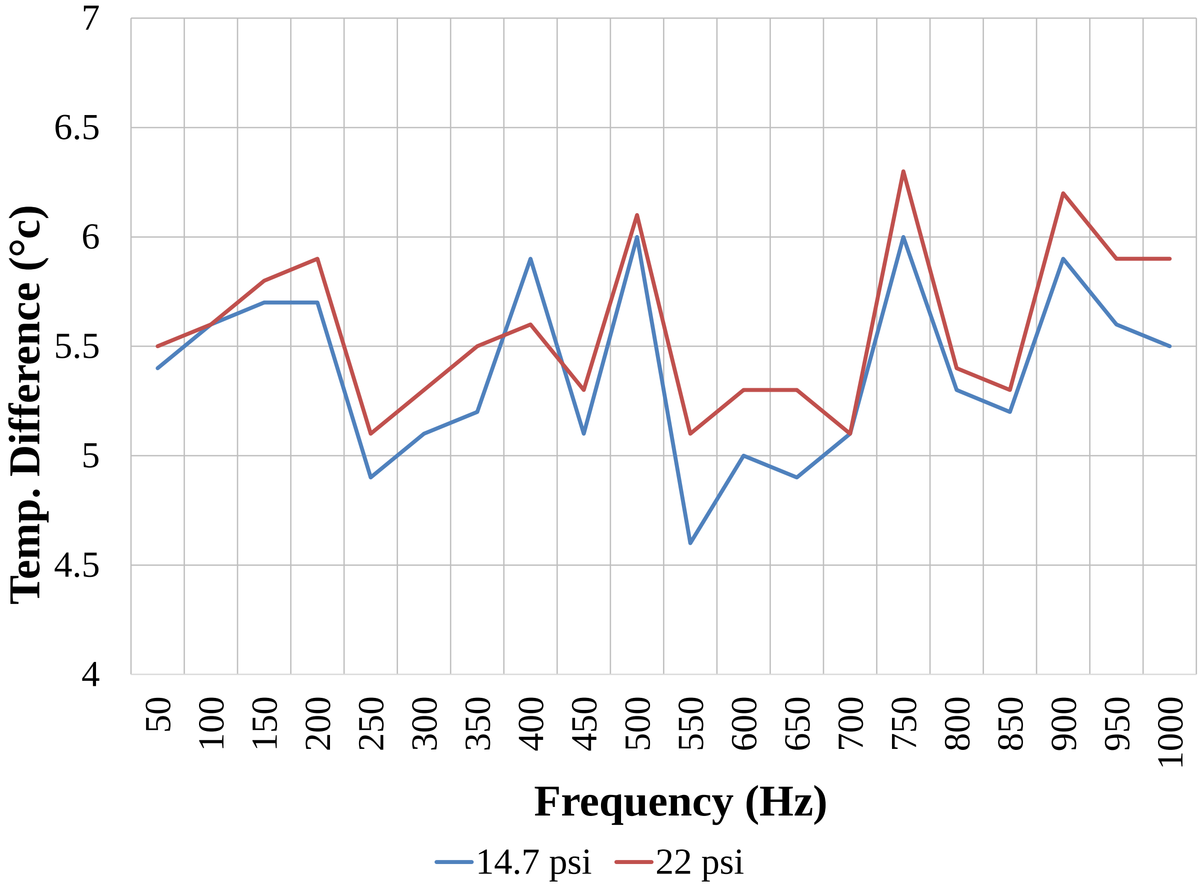

Figure 24 Effect of Frequency on temperature difference

7.1.2 Discussion

The performance of a thermoacoustic refrigerator greatly depends on the frequency used as well as the gas pressure. It has been observed that **the effect of different frequencies of sound wave is not as significant as the effect of pressure of the gas inside the tube.** This may be due to the increase of gas density inside the tube resulting more interference of the gas particles. But the increase in pressure incorporates with increased chance of leakage.

7.2. Surface Roughness Testing

7.2.1 Result

Figure 25 depicts the results obtained from the different experiments under same process parameter for the Lathe under different Frequencies of sound in TAR. The best surface finishing was obtained at 750 Hz with a profilometer reading of 2.242 µm which is then compared to Dry and Wet Matching keeping the process parameters constant.

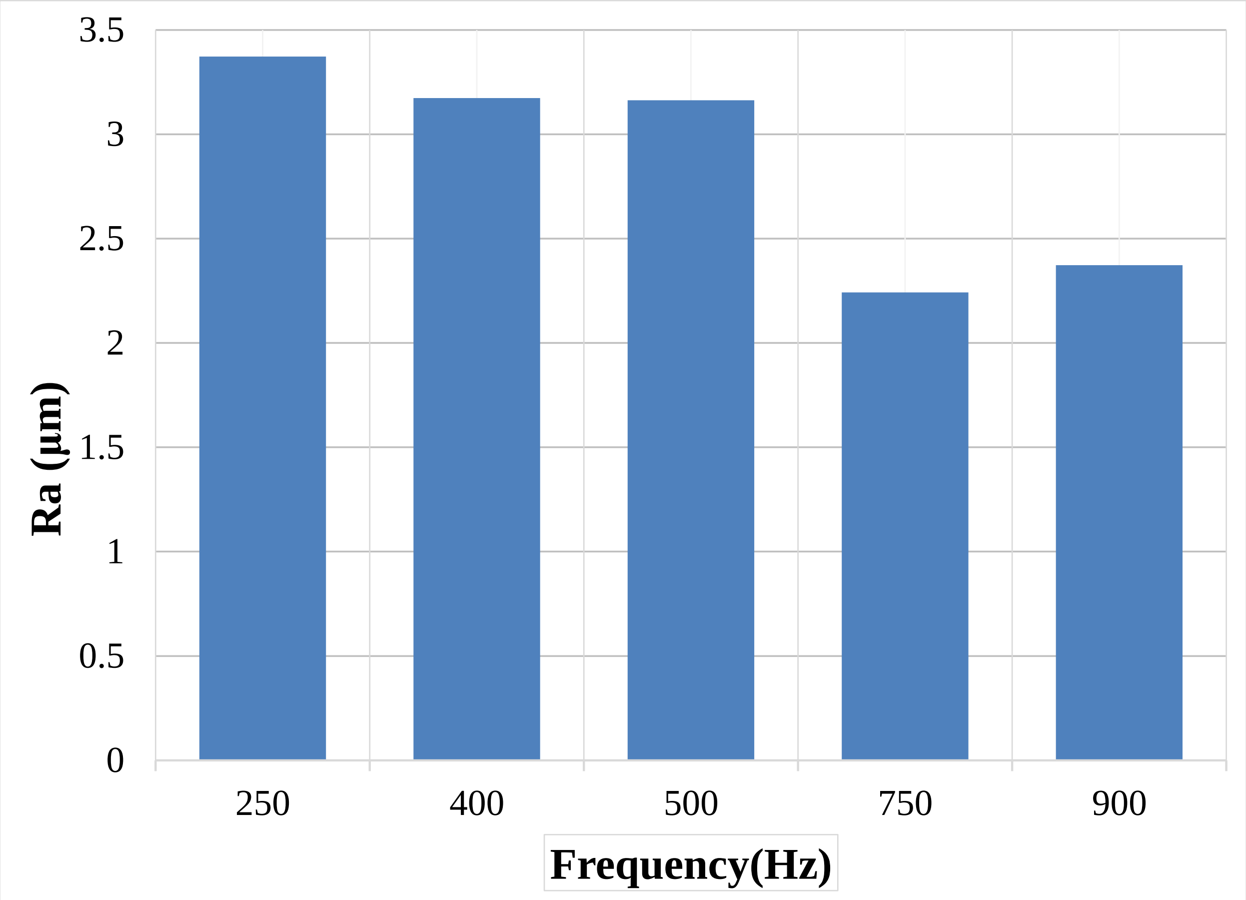

Figure 25 Effect on Surface Roughness

7.2.2 Discussion

The new experimental setup developed for the application of TAR as a means to reduce the heat generated in turning process. It has been successfully applied for finding ot the effect on cold air produced by the TAR in manufacturing process.

It has been observed that with the increase in the frequency of sound wave used in the TAR,

surface roughness progressively decreases.

7.3 Surface Roughness Comparison

7.3.1 Result

The best surface finishing was obtained at 750 Hz with a profilometer reading of 2.242 µm which is then compared to Dry and Wet Matching keeping the process parameters constant.

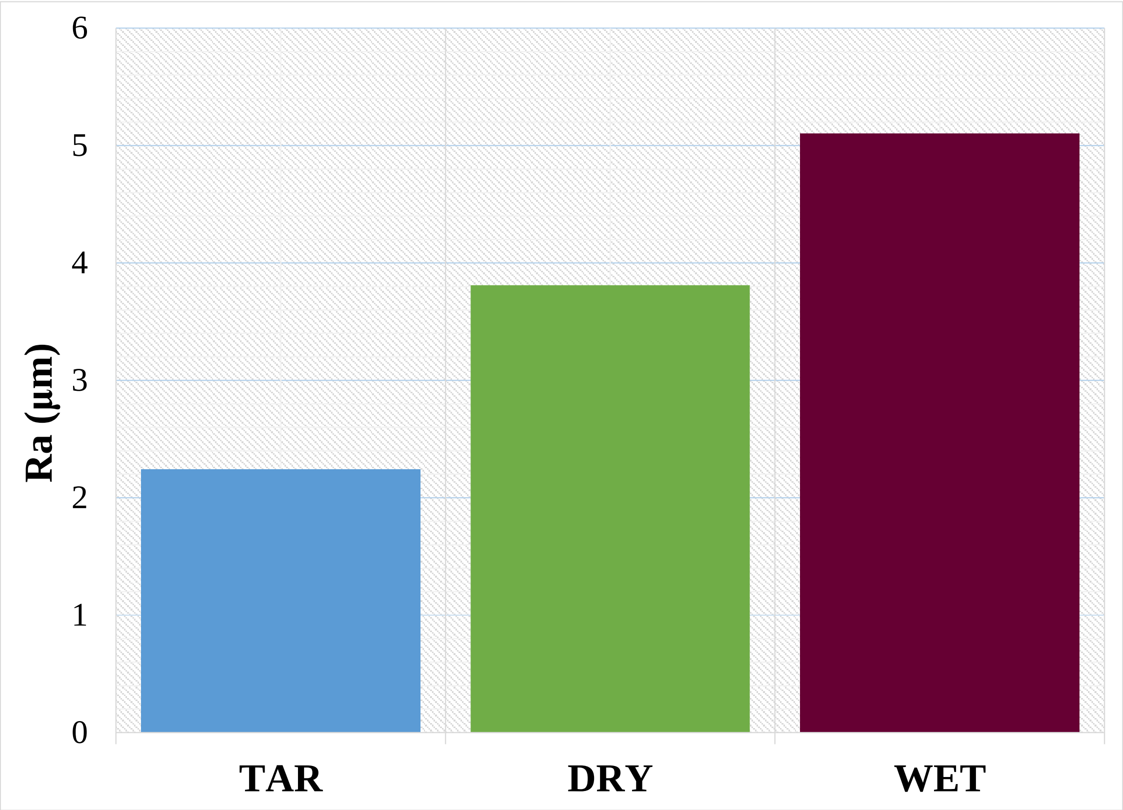

Figure 26 Comparison among Wet, Dry and TAR used Turning Process

		Surface roughness (µm)	Image of Surface	Surface Roughness data
Frequency Used in TAR	250	3.373		
	400	3.174		
	500	3.163		
	750	2.242		
	900	2.373		
Dry		4.065		
Wet (with coolant)		5.107		

Figure 27 Image of the Surfaces

7.3.2 Discussion

Different manufacturing process produce different surface characteristics. Also, different applications require different surface properties.

Based on this testing, it was determined that the quality of TAR cooled machining is better in comparison to other two methods.

Chapter Eight: Conclusion & Suggestion for Future work

Thermo acoustics, if properly explored, can serve as eco-friendly renewable energy source. A thermo acoustic refrigerator uses very little electricity to run the system. Although thermoacoustics seems to be a promising technology, significant effort is required to make an efficient one.

- To improve efficiency and reduce cost, developments are needed in the design of stacks, resonators and compact heat exchangers for oscillating flow.
- Research is also required in the development of flow-through designs (open systems) which will reduce or eliminated the use of heat exchangers and will reduce complexity and cost.
- In order to achieve maximum cooling power a more powerful speaker would be necessary. It is recommended that a more powerful speaker or acoustical driver is used

References

1. Outwater, J. O. (1952). Surface temperatures in grinding. *Trans. Asme*, 73.

2. Malkin, S. (1974). Thermal Aspects of Grinding: Part 2—Surface Temperatures and Workpiece Burn. *Journal of Engineering for Industry*, *96*(4), 1184-1191.

3. Shaji, S., & Radhakrishnan, V. (2003). Analysis of process parameters in surface grinding with graphite as lubricant based on the Taguchi method. *Journal of Materials Processing Technology*, *141*(1), 51-59.

4. Shaji, S., & Radhakrishnan, V. (2003). Analysis of process parameters in surface grinding with graphite as lubricant based on the Taguchi method. *Journal of Materials Processing Technology*, *141*(1), 51-59.

5. Mohamed Gamal Mekdad, Abdulkareem Sh. Mahdi Al-Obaidi, “Design and Analysis of A Thermo-Acoustic Refrigerator”, EURECA (2013),73-74

6. Nouh, M. A., Arafa, N. M., & Abdel-Rahman, E. (2014). Stack Parameters Effect on the Performance of Anharmonic Resonator Thermoacoustic Heat Engine. *Archive of Mechanical Engineering*, *61*(1), 115-127.

7. Tönshoff, H. K., Karpuschewski, B., & Glatzel, T. (1997). Particle emission and immission in dry grinding. *CIRP Annals-Manufacturing Technology*, *46*(2), 693-695.

8. Klocke, F., Schulz, A., Gerschwiler, K., & Rehse, M. (1998). Clean manufacturing technologies-The competitive edge of tomorrow?. *Journal for Manufacturing Science and Production*, *1*(2), 77-86..

9. Bhansali, P. S., Patunkar, P. P., Gorade, S. V., Adhav, S. S., & Botre, S. S. (2015). An overview of stack design for a thermoacoustic refrigerator. *International Journal of Research in Engineering and Technology*, *4*(6), 68-72.

10. Akhavanbazaz, M., Siddiqui, M. K., & Bhat, R. B. (2007). The impact of gas blockage on the performance of a thermoacoustic refrigerator. *Experimental thermal and fluid science*, *32*(1), 231-239.

11. Chattopadhyay, A. B., Paul, S., & Dhar, N. R. (1999). Fast production machining and grinding under clean and eco-friendly environment. In *Proceedings of the Workshop on Clean Manufacturing, IEI, India* (pp. 21-24).

12. Dhar, N. R., Paul, S., & Chattopadhyay, A. B. (2000, January). Improvement in Productivity and Quality in Machining Steels by Cryogenic Cooling. In *Proceedings of the National Conference on Precession Engineering* (pp. 247-255).

13. Dhar, N. R., Paul, S., & Chattopadhyay, A. B. (2001). The influence of cryogenic cooling on tool wear, dimensional accuracy and surface finish in turning AISI 1040 and E4340C steels. *Wear*, *249*(10), 932-942.

14. Dhar, N. R., Paul, S., & Chattopadhyay, A. B. (2002). Role of cryogenic cooling on cutting temperature in turning steel. *Journal of manufacturing science and engineering*, *124*(1), 146-154.

15. Paul, S., & Chattopadhyay, A. B. (1995). Effects of cryogenic cooling by liquid nitrogen jet on forces, temperature and surface residual stresses in grinding steels. *Cryogenics*, *35*(8), 515-523.

16. Paul, S., & Chattopadhyay, A. B. (1996). The effect of cryogenic cooling on grinding forces. *International Journal of Machine Tools and Manufacture*, *36*(1), 63-72.

17. Paul, S., & Chattopadhyay, A. B. (1996). Determination and control of grinding zone temperature under cryogenic cooling. *International Journal of Machine Tools and Manufacture*, *36*(4), 491-501.

18. Bhattacharya, A., Roy, T. K., & Chattopadhyay, A. B. (1972). Application of cryogenic in metal machining. *J. of Institution of Engs, India*, *52*, 73-81.

19. Uehara, K., & Kumagai, S. (1968). Chip formation, surface roughness and cutting force in cryogenic machining. *Ann. CIRP*, *17*(1), 409-416.

20. Kai, Y. (2012). *Sunappu: A Genre of Japanese Photography, 1930–1980*. City University of New York.

21. Fillippi, A. D., & Ippolito, R. (1970). ‘Face Milling at 180 C. *CIRP Ann*, *19*(1), 399-406.

22. Evans, C., & Bryan, J. B. (1991). Cryogenic diamond turning of stainless steel. *CIRP Annals-Manufacturing Technology*, *40*(1), 571-575.

23. Ding, Y., & Hong, S. Y. (1998). Improvement of chip breaking in machining low carbon steel by cryogenically precooling the workpiece. *TRANSACTIONS-AMERICAN SOCIETY OF MECHANICAL ENGINEERS JOURNAL OF MANUFACTURING SCIENCE AND ENGINEERING*, *120*, 76-83.

24. Economical Cryogenic Milling at http://www.columbia.edu/∼ahl21/ index2.html

25. Wang, Z. Y., & Rajurkar, K. P. (1997). Wear of CBN tool in turning of silicon nitride with cryogenic cooling. *International Journal of Machine Tools and Manufacture*, *37*(3), 319-326.

26. Wang, Z. Y., Rajurkar, K. P., & Murugappan, M. (1996). Cryogenic PCBN turning of ceramic (Si3N4). *Wear*, *195*(1-2), 1-6.

27. Boothroyd, G., & Knight, W. A. (1989). Fundamentals of Machining and Machine Tools, Marcel-Dekker. *New York*.

28. Corballis, M. C. (1998). *Evolution of the human mind* (Vol. 2, pp. 31-62). Hove,, England: Psychology Press/Lawrence Erlbaum Associates, Inc.

29. Buljan, S. T., & Wayne, S. F. (1989). Wear and design of ceramic cutting tool materials. *Wear*, *133*(2), 309-321.

30. Moore, D. F. (2013). *Principles and Applications of Tribology: Pergamon International Library of Science, Technology, Engineering and Social Studies: International Series in Materials Science and Technology* (Vol. 14). Elsevier.

31. Putnam, A. A., & Dennis, W. R. (1956). Survey of Organ‐Pipe Oscillations in Combustion Systems. *The Journal of the Acoustical Society of America*, *28*(2), 246-259.

32. Swift, G. W. (1988). Thermoacoustic engines. *The Journal of the Acoustical Society of America*, *84*(4), 1145-1180.

33. Feldman, K. T. (1968). Review of the literature on Rijke thermoacoustic phenomena. *Journal of Sound and Vibration*, *7*(1), 83-89.

34. Ceperley, Peter H. "A pistonless Stirling engine—The traveling wave heat engine." *The Journal of the Acoustical Society of America* 66.5 (1979): 1508-1513.

35. Ceperley, P. H. (1985). Gain and efficiency of a short traveling wave heat engine. *The Journal of the Acoustical Society of America*, *77*(3), 1239-1244.

36. Tominaga, A. (1995). Thermodynamic aspects of thermoacoustic theory. *Cryogenics*, *35*(7), 427-440.

37. Rott, N. (1969). Damped and thermally driven acoustic oscillations in wide and narrow tubes. *Zeitschrift für Angewandte Mathematik und Physik (ZAMP)*, *20*(2), 230-243.

38. Rott, N. (1973). Thermally driven acoustic oscillations. Part II: Stability limit for helium. *Zeitschrift für Angewandte Mathematik und Physik (ZAMP)*, *24*(1), 54-72.

39. Rott, N. (1975). Thermally driven acoustic oscillations, part III: Second-order heat flux. *Zeitschrift für angewandte Mathematik und Physik ZAMP*, *26*(1), 43-49.

40. Rott, N., & Zouzoulas, G. (1976). Thermally driven acoustic oscillations, part IV: tubes with variable cross-section. *Zeitschrift für Angewandte Mathematik und Physik (ZAMP)*, *27*(2), 197-224.

41. Zouzoulas, G., & Rott, N. (1976). Thermally driven acoustic oscillations, part V: Gas-liquid oscillations. *Zeitschrift für Angewandte Mathematik und Physik (ZAMP)*, *27*(3), 325-334.

42. Müller, U. A., & Rott, N. (1983). Thermally driven acoustic oscillations, Part VI: Excitation and power. *Zeitschrift für Angewandte Mathematik und Physik (ZAMP)*, *34*(5), 609-626.

43. Xiao, J. H. (1992). Thermoacoustic theory for cyclic flow regenerators. Part I: Fundamentals. *Cryogenics*, *32*(10), 895-901.

44. Deng, X. H., Hu, X., & Guo, F. Z. (1996). Thermoacoustic network model of regenerator. *Cryogenics*, *2*, 6-13.