DESIGN AND OPTIMIZATION OF LEMON GRASS OIL EXTRACTOR

BY

BRAIMAH SOALE RASHID BSc. (Hons)

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DECLARATION

I hereby declare that, except for specific references which have been duly acknowledged, this project is the result of my own research and it has not been submitted either in part or whole for any other degree elsewhere.

BRAIMAH SOALE RASHID ……………………… ………………………

Student-PG1177713 Signature Date

Certified by:

DR. P. Y. ANDOH ……………………… ………………………

(Supervisor) Signature Date

Certified by:

PROFESSOR F. K. FORSON ……………………… ………………………

(Head of Department) Signature Date

ABSTRACT

Lemon grass is broadly used in medicine, perfumery industry, vitamin A manufacturing and pharmaceuticals. The need for lemon grass oil, especially in human health and its problem of extracting the oil have directed this thesis to design and optimize a mechanical system that will be used to extract and separate lemon grass oil using direct steam method. The direct steam distillation method eliminates contaminants in the oil and it is environmentally friendly. The steam distillation is carried out under controlled temperature and pressure. In all, three concepts were developed based on the orientation of the condensers, source of power, and method of oil production. The three (3) concepts, Direct Steam Distillation, Hydro Diffusion and Diffuser Diffusion Concepts were evaluated and the best concept, (Direct Steam Distillation), was selected as the final design. Design analyses were performed on each part to determine their specification, the material to be used and manufacturing processes for the fabrication. Lemon oil was extracted from fresh lemon grass that was harvested from a demonstration farm. Two extraction tests were performed, to determine the efficiency and the effect of the operation conditions. Two chemical tests were conducted to determine the quality of the oil and a stress analysis was performed using ANSYS to determine the stresses and deformations on the machine.

From the results, it can be established that the prototype machine developed can be used to extract lemon grass oil from the leaves. The efficiencies were computed and the values obtained ranges from 5.87 to 6.33 ml/kg. The results obtained for the quality tests responded positive, a citrus value of 43.56 % was obtained when the pressure was 1.4 bar and the flow rate of 18.5 g/s. The effects of the process parameters on the extraction suggest that, increasing the mass from 20 to 27 Kg results in an increase in the quantity

of oil of 39.85 cm^3, a decrease of time of 3 minutes, an increase of LPG of 0.41 kg, and a decrease of the quality of the oil of 1.68%. The significant effects and the interactions were used to establish the models of the responses and the process parameters. The predicted model were calculated at each experimental condition and then compared with their measured results. From the results, the predicted (model) results differ from the measured results but it is within the experimental error except one of them which is above the experimental error.

DEDICATION

This research work is dedicated to the Lord Almighty who granted me the grace to complete this work successfully.

I also dedicate this piece of work to my lovely wife Madam Yakubu Namawu for her support and understanding, my daughters Drimoka, Amabage, Shunkpa Masaluwe and the unborn baby who have been a real source of support and inspiration, to my mother Kayansewurache Memuna Harunah, to my late Father Chief Kabachewura Soale Braimah, my late brother Braimah Soale Ibrahim and the entire Braimah family of Kpembe, Allah bless you all.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

A	Heat transfer area (m^2)
ANSYS	Software used for finite element analysis
℃	Degree Celsius
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CO_2	Carbon dioxide
Dia.	Diameter
DSDM	Direct Steam Distillation Method
EO	Essential oils
f	gas flow rate
FD	Factorial Design
GC-MS	Gas Chromatography-Mass spectrometry
GDP	Gross Domestic Product
GH¢	Ghana Cedi
GSB	Ghana Standards Board
ICS –UNIDO	International Centre for Science and High Technology-United Nations Industrial Development Organization
K	Thermal conductivity of the material (W/(m. k))

kg Kilogram l Liters

LMTD Log mean temperature

difference LPG Liquefied

petroleum gas m Mass of grass in

kg mm Millimeters

NSF National Science Foundation

P Pressure in bars C Quality of oil collected Q

Amount of LPG used

q Quantity of oil collected

SCO_2 Supercritical Carbon dioxide

SDM Steam Distillations Method

SE Solvent Extraction

SS Stainless steel T

Surface temperature in K t_b

Temperature of boiler t_c

Temperature of chamber

TD Turbo Distillation

V Volume

WD Water Distillation x

Material thickness (m)

α_v volumetric coefficient of thermal expansion

ΔT Temperature difference across the material

E Emissivity constant

$\dot{q}$ Gas flow rate

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CHAPTER ONE

INTRODUCTION

This chapter introduces the need for the extraction of oil from lemon grass, the problem statement, general and specific objectives of the study, the significance, and the organization of the study.

1.1 Background of the Study

Lemon grass (*Cymbopogon citratus)*, is an odorous tropical grass which yields oil that smells of lemon, used in cooking, perfumery and medicine (Concise Oxford Dictionary Tenth Edition). The genus *Cymbopogon* belongs to the grass family, *Poaceae (syn. Gramineae)*. The *Poaceae* family has about 700 genera and 11,000 species (Bertea and Maffei, 2010) widely distributed in all regions of the world. *Cymbopogon* is a genus comprising about 180 species, subspecies, varieties, and subvarieties (Bertea and Maffei, 2010). It is largely grown as a decorative plant, in spite of that lemon grass has so many other uses, for example (i) as food crop, e.g., it is used in herbal tea because of its sharp lemon flavour, (ii) as perfume in soaps, and (iii) as medicine to treat various health diseases, such as acne, athlete's foot, turgidity, muscle aches and scabies (Athens, 2002).

There are two main types of Lemon grass, East Indian lemon grass *Cymbopogon flexuosus* which is considered to have its origins in southern India, and West Indian lemon grass *Cymbopogon citratus* which is thought to have its origin in Malaysia and is largely grown in Central and South America and parts of Africa, South East Asia and the Indian Ocean Islands. Both species yield essential oil rich in citral (Bertea and

Maffei, 2010). *Cymbopogon* plants are tall up to and above 1 m perennial plants, with narrow and long leaves that are mostly characterized by the presence of silica thorns aligned on the leaf edges (Bertea and Maffei, 2010).

SEPTEMBER, 2016

Figure1.1: Lemon grass from a domestic backyard garden Tamale

The name *Cymbopogon* is derived from the Greek words *'kymbe'* (boat) and *'pogon'* (beard), referring to the flower spike arrangement (Shah, et al., 2011). *Cymbopogon citratus* has been used by the Brazilian *Quilombolas* tribe to decrease blood pressure and to calm individual's anxiolytic (Rodriques and Carlini, 2004). *Cymbopogon citratus* has been traditionally used to treat gastrointestinal discomforts (Devi et al. 2011).

In Guatemala, a tea from the leaves is used for flatulence, fever, and gripe by the Carib population (Jayasinha, 1999). Lemon grass is widely used in Asian cuisine for its citrus flavor. The tea from its leaves has been widely used as an antiseptic, febrifuge, antidyspeptic, carminative, tranquilizer and stomachic (Selvi et al. 2011). Lemon grass oil is widely used in perfumery, cosmetics, soaps, detergents and confectionary and in the production of vitamin A (Ganjewala, 2008). The essential oils of the grasses of species of *Cymbopogon* have an industrial profile; they are used in beverages, foodstuffs, fragrances, household products, personal care products such as deodorants, herbal tea, skin care products, insect repellents, pharmaceuticals, in tobacco etc. (Akhila, 2010). People use lemon grass oil to subdue toothache. A drop of lemon grass oil is put on a cotton bud and put on the exact place where the toothache occurs (Dorji Wangdi and Galey Tenzin, 2006). It is said that lemon grass oil can help to accelerate the healing of scratches and cuts. However, when pure lemon grass oil comes into direct contact with the skin, it causes a burning sensation

(Karma Yangzom, 2006). It is often used as a tea in African countries such as Ghana, Togo and the Democratic Republic of the Congo.

Lemon grass oil is a sherry colored with a pungent taste and lemon like odour with citral as the principal constituent. The contents of this oil vary with the age of the grass. Fresh lemon grass contains 0.67% of essential oil, which has substantial amount of citral (Maiti et. al., 2006). Dry lemon grass yields 0.4 percent essential oil containing 72.3 percent citral (Bleasel et. al., 2002). According to Inan et. al., 2011, time of harvest is one of the key factors influencing the chemical composition, quality and quantity of the lemon grass oil. The increase in the citral content of lemon grass might also be influenced by fertilizer application. Miyazaki, 1965, reported that nitrogen deficiency affect the increase in the citral content of lemon grass.

Today, most people across the world are looking towards natural base products since there are no side effects when taken accordingly. Currently, there is also an interest in the production of functional, high value, natural products without chemical modification and residues of solvents or additives. This trend in consumer preference has increased the demand tremendously with variety of products ranging from essential oils from other plants such as Ginger (*Zingiber officinale Roscoe)*, Citronella

Grass *(Cymbopogon nardus)*, Lavender flowers (*Lavandula angustifolia Mill*, Lamiaceae), Gaharu (*Agarwood*), Thyme (*Thymus vulgaris L.)*, and Misai Kucing (Orthosiphon *Stamineus)* (Nurul, 2005; C. Z. Kelly et al., 2002).

Currently in Ghana, essential oil such as lemon grass oil is gaining popularity as herbal medication as it gave a lot of benefits to overcome certain diseases. Lemon grass oil has a lot of medicinal properties that are used in the treatment of fever, malaria, and other health related ailments in Ghana. In soap making, the oil comes in handy as fragrance and insecticide, while acting as an agent to remove stains from plastic and metal surfaces. Since the lemon grass oil insecticide is edible, it can be used to treat intestinal bacterial infection (Samuel Donkoh, 2013).

The global market for essential oils has been in the increase and estimated at US$2.6 billion, with an annual growth rate of 7.5 percent (Noor Azian, 2001). Over the years, a lot of extraction methods have been developed and used globally for the extraction of essential oils. For the purpose of this research, the direct steam distillation method (DSDM) was adopted because it enables a compound or mixture of compounds to be distilled and subsequently recovered at a temperature substantially below that of the boiling points of the individual constituents (Denny, E. F. K. 2001).

1.2 Problem Statement

Lemon grass oil has variety of uses such as in food, as perfume in soaps, as medicine to treat various health diseases, such as acne, athlete’s foot, turbidity, muscle aches and scabies. The need for lemon grass essential oil and its applications cannot be over emphasized. A lot of extraction techniques have been developed and used for the extraction of the oil over the years. These techniques used hydrocarbon solvents for the extraction which have effects on human consumption and the environment.

Hence, the reasons to design and optimize a mechanical system that will be used to extract and separate lemon grass oil using the direct steam method.

1.3 Research Objectives

The main objective of the study is to design and optimized lemon grass oil extractor. The specific objectives were:

- **(i)** to design a mechanical system that will be used to extract hydrosol from lemon grass and to separate the oil from the hydrosol.
- **(ii)** to determine the quality and chemical composition of the lemon grass oil.
- **(iii)** to optimize the oil extractor using factorial design technique.
- **(iv)** to model the extractor and determine the stresses and the deflections on the extractor using finite element approach (ANSYS).

1.4 Significance of the Study

Ghana is blessed with a variety of flora, such as orange, lemon, and tangerine; the peels of them are generally disposed. The lemon grass usually taken as a weed, most of which has remained unexploited. Extraction of lemon grass oil in Ghana can help in addressing societal needs, increase the gross domestic product (GDP) of the country, reduce the unemployment situation in the country, development of human capital and infrastructure, facilitate capacity building, technology transfer, knowledge creation and sharing in all fields of science and technology and to improve the quality of life of our people. These benefits are in line with the vision and objectives of the

National Science Foundation. Hence the objectives of the research work.

1.5 Organization of Study

The thesis is organized into five chapters. Chapter one, is the introduction; it describes the background of the study, highlights the problem statement for the research, states the objective and specific objectives of the study, comments on the significance of the study and lastly, discusses the organization of the thesis.

Chapter two presents the overview of relevant literature concerning extraction of essential oils, and highlights on Medicinal plant extract, the distinctiveness of essential oil, uses of essential oils, importance of essential oil is pharmaceuticals and lastly describe extraction methods used in the extraction of essential oils.

Chapter three gives a description of the review of the existing design, redesign of the existing design, performance analysis on the redesign prototype, performance of the factorial design experiment, optimization of the oil extractor using finite element approach (ANSYS), material and method used and finally development of the conceptual designs.

Chapter four consists of discussion of results, efficiency of the modified results, effects of processing parameters, standard error of the extraction, the factorial experimental results, development of the predicted model, verification of the model and discussion of the ANSYS results.

Chapter five contains summary of key findings, conclusion and recommendations of the thesis.

CHAPTER TWO

LITERATURE REVIEW

This chapter reviews essential oil from lemon grass and also focuses on previous attempts at solving the extraction problem of lemon grass oil for small scale purposes.

2.1 Description of Essential oils

Essential oils (EO) contain unpredictable substances that are extracted by physical techniques from plants of a specific plant species. The oils ordinarily bear the name of the plant species from which they are extracted. Essential oils are so termed as they are accepted to speak to the very substance of smell and flavor. Essential oil plants and culinary herbs incorporate a wide scope of plant species that are utilized for their sweet-smelling quality as flavorings in drinks and as aromas in pharmaceutical and consumer care products (K. Satish Kumar, 2010).

Essential oils are utilized as a part of the protecting procedures, in prescription and in purification ceremonies. There are likewise more than 200 references to aromatics, incense and balms in the Old and New Testaments. Research has affirmed of the pragmatic utilization of Essential Oils hundreds of years ago; most of these are available in herbal shops. There are around three hundred known fundamental oils on the planet and these key oils are well utilize today by professionals to treat viral diseases caused by, bacterial, parasitic and contagious damages which attack our bodies (K. Satish Kumar, 2010).

Plants have been used for treatment or prevention of various human diseases throughout history. From the most recent century, enthusiasm for experimental phytotherapy has expanded in a few therapeutic fields, for example, immunology, oncology, hematology and the utilization of plants in medicine has influenced the distinguishing proof of phytomoleules (Liyana B.T. Yahya 2011).

Home grown cures have turned out to be more prevalent in the treatment of minor illnesses these days, because of increasing hospital bills and success stories of the home grown cures. Individuals have utilized a few plants constituents for quite a long time, e.g., to get ready noxious points for fighting and chasing. Plant inferred substances have generally assumed vital parts in the treatment of human ailments. Today, around 80% of the world populace who lives in underdeveloped nations still depends completely on plant items for their essential human services (Dennis et al., 2000).

2.2 Medicinal Plants Extract

Extraction is the process of selectively removing a compound of interest from a mixture. The extracts so gotten from plants are moderately polluted fluids, semisolids or powders expected just for oral or outer use. These incorporate classes of arrangements known as decoctions, restoratively dynamic parts of plant or creature tissues from the latent or idle segments mixtures, liquid concentrates, arrangements, pilular (semisolid) removes and powdered concentrates. Such arrangements famously have been called galenicals, named after Galen, the second century Greek doctor (International Center for Science and High Technology, Trients, 2008).

The reasons of institutionalized extraction systems for unrefined medications are to separate the restoratively wanted segment and to dispose of the inactive material by treatment with a specific dissolvable known as menstruum. The concentrate consequently obtained might be prepared for use as a medicinal agent in the form of solution and fluid extracts. It might further be consolidated into various shapes, for example, tablets or capsules, or it might be fractionated to segregate singular synthetic elements, for example, ajmalicine, hyoscine and vincristine, which are modern drugs. Consequently, institutionalization of extraction techniques contributes fundamentally to the last nature of the home grown medication (International Centre for Science and High Technology, Trients, 2008).

2.3 The Distinctiveness of Essential Oils

Essential oils are active substances extracted from various parts of plants, containing many substances, but typically with the prevalence of one, two or three of them that really characterize fragrance (Mendes, 2007).

In early work, the term "fundamental oils" was characterized as the unpredictable oils acquired by the steam refining of plants. This definition was obviously expected to have many kind of effect between "greasy" and essential oils which are easily volatile. With the development of science came enhancements in the techniques for extracting the oils, and parallel with this advancement, a superior knowledge of the constituents of the oils was acquired. It was found that, the oils contain numerous classes of natural substances with different volatilities. In spite of the fact that, a rundown of all the known oil categories, which incorporate an assortment of

artificially irrelevant mixtures will entail a long list, it is conceivable to characterize these into four principal gatherings of crucial oils (Guenther, 1960). These are Terpenes, identified with isoprene; straight-chain mixtures, not containing any side branches; Benzene subsidiaries; and Miscellaneous (Liyana B.T.yahya, 20011).

2.4 Uses of Essential Oils

Essential oils have been utilized for a large number of years in different societies for restorative and wellbeing purposes. Essential oil utilization ranges from fragrance based treatment, family unit cleaning items, individual excellence consideration and regular drug medicines. The particles in essential oils originate from refining or separating the diverse parts of plants, including the blooms, leaves, bark, roots, sap and peels. In old times, Jews and Egyptians made essential oils by absorbing the plants oil and afterward separating the oil through a material sack (Dr. Hatchet, 2016).

2.4.1 Importance of Essential Oil in Pharmaceuticals

Essential Oils have flexible applications in pharmaceutics. A percentage of the applications are recorded. The germicide properties of Essential Oil make them dynamic against extensive variety of microorganisms as anti-microbial safe strains. Notwithstanding this they are used likewise against parasites and yeasts. The most well-known wellsprings of essential oils utilized as cleaning agents seem to be: Cinnamon, thyme, clover, eucalyptus, culinsavory, and lavender. citral, geraniol, linalool and thymol are considerably stronger than phenol.

At the point when utilized remotely, essential oils (L'essence de terebenthine) expand microcirculation and give a slight neighborhood sedative activity. Till now, essential oils are utilized as part of various treatments. They are known not exceptionally to be viable in diminishing sprains and other articular agonies. Oral administration of essential oils like eucalyptus or pin oils, arouse ciliated epithelial cells to emit bodily fluid. On the renal system, these are known to increase vasodilation and in consequence bring about diuretic effect (K. Satish Kumar, 2010).

Fundamental oils from the Umbellifereae family, Mentha species and verbena are alleged to diminish or dispense with gastrointestinal fits. These essential oils expand discharge of gastric juices. In different cases, they are known to be powerful against sleep deprivation (K. Satish Kumar, 2010).

2.5 Extraction of Lemon Grass Oil

Essential oils have high liquor segments. Thus, it has a higher instability and a quick vanishing rate. Keeping in mind the end goal to get the best quality and amount of essential oils, extraction methodology appears to hold the key controlling step. Elements worth considering in the extraction of essential oils are sorts of plant, compound constituents of oils, area of oils inside of the plant i.e. root, bark, wood, branch, leaf, blossom, foods grown from the ground and picking the right extraction strategy (Norulshahida Binti Che Din 2006).

Some plants like rose and jasmine contain minute essential oil. Their significant sweet-smelling properties are separated utilizing a compound dissolvable. The deciding item, known as a flat out, contains essential oil alongside other plant constituents. (Norulshahida Binti Che Din 2006).

The estimation of the fresher handling strategies depends significantly on the experience of the distiller, and also the expected utilization of the last item. Every strategy is vital, and has its place really taking shape of aromatherapy grade of essential oils (Extraction of key oil and its application by Virendra P.S. Rao and Diwaker Pandy 2007). The accompanying are the techniques for extraction of

essential Oil and their disadvantages.

2.5.1 Solvent Extraction

A hydrocarbon dissolvable is added to the plant material to disintegrate the fundamental oil. At the point when the mixture is sieved and thought by refining, a substance contains gum (resinoid), or a blend of wax and key oil known as solid remains. From the concentrate, immaculate liquor is utilized to remove the oil. At the point when the liquor vanishes, the oil is deserted. This is not viewed as the best strategy for extraction as the solvents can leave a little measure of buildup behind which could cause allergies and affect the immune system (Virendra P.S. Rao and Diwaker Pandy 2007).

2.5.2 Maceration Method

Maceration really makes a greater amount of imbued oil instead of an essential Oil. This straightforward broadly utilized method includes leaving the pounded plant to absorb a suitable dissolvable in a shut compartment. Basic maceration is performed at room temperature by blending the ground plant with the dissolvable and leaving the blend for a few days with periodic shaking or mixing. The procedure is rehashed for more than one occasion with new dissolvable. Ultimately the last deposit of concentrate is squeezed out of the plant particles utilizing a mechanical press or an axis. The technique is suitable for both introductory and mass extraction. The fundamental hindrance of maceration is that the procedure can be very tedious, taking from a couple of hours up to a few weeks and some of the time the likelihood of changing the structure of the oil (K. Satish Kumar, 2010).

2.5.3 Cold Pressing

This strategy is utilized to remove the Essential Oils from citrus peels, for example, orange, lemon, grapefruit and bergamot. This strategy includes the straightforward squeezing of the peels at around 49 ℃ to extricate the oil. The peels are isolated from the organic product, ground or hacked and after that squeezed. The outcome is a watery blend of crucial oil. The outcome will separate given time by virtue of differences in densities. Little adjustment from the oil's unique state happens and these citrus oils hold their brilliant, crisp, inspiring fragrances like that of noticing a magnificently ready natural product. The downside of this technique is that, the oils removed have a moderately short self-life (K. Satish Kumar, 2010).

2.5.4 Effleurage Method

This is one of the conventional methods for separating oil from blooms. The procedure includes layering fat over the blossom petals. After the fat has assimilated the key oils, liquor is utilized to discrete and removes the oils from the fat. The liquor is then vanished and the Essential Oil is gathered (K. Satish Kumar, 2010).

2.5.5 Super Critical CO_2 Extraction

Supercritical CO_2 extraction includes carbon dioxide warmed to 30.6 ℃ and pumped through the plant material at around 551.58 bars, under these conditions the carbon dioxide is contrasted with a "thick haze" or vapor. With the arrival of the weight in either prepare, the carbon dioxide escapes in its vaporous structure, deserting the Essential Oil. The typical strategy for extraction is through steam refining. After extraction, the properties of decent quality crucial oil ought to be as close as could be allowed to the pith of the first plant. The way to decent fundamental oil is through low weight and low temperature handling. High temperatures, quick handling and the utilization of solvents change the sub-atomic structure, will annihilate the helpful esteem and modify the scent (K. Satish Kumar, 2010).

2. 5. 6 Water Distillation

In this strategy, the material is totally submerged in water, which is boiled by applying heat by direct fire, steam coat, shut steam coat, shut steam loop or open steam curl as shown in figure 2.1 below.

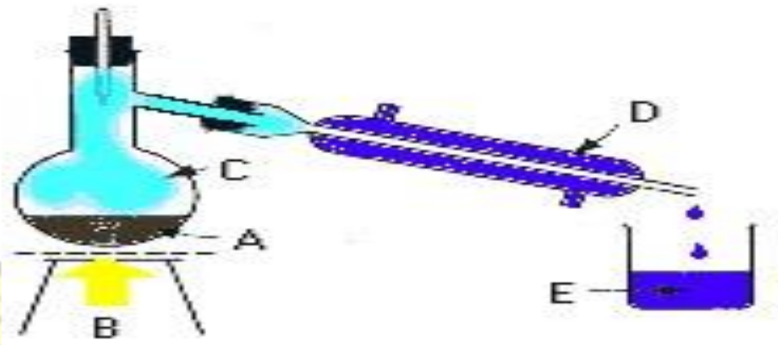


Figure 2.1 flow process of water distillation method.

Source: www.i4at.org/surv/distill.htm

The procedure is that, there is immediate contact between boiling water and plant material. When the still is warmed by direct fire, sufficient safety measures are important to keep the charge from overheating. When a steam coat or shut steam loop is utilized, there is less peril of overheating. In any case, with open steam, care must be taken to counteract gathering of dense water inside of the still. In this way, the still ought to be all around protected. The plant material in the still should be upset as the water boils, generally collections of thick material will settle on the base and turn out to be thermally debased. Certain plant materials like cinnamon bark, which are rich in adhesive, must be powdered so that the charge can promptly scatter in the water; as the temperature of the water increases, the separation occurs and the rest settles at the bottom of the still. This enormously builds the consistency of the water charge blend, permitting it to boil. Before any field refining is done, small- scale water refining in a dish is performed to find out whether any advances happen amid the refining process. From this trial, the yield of oil from a known weight of the plant material can be resolved.

Amid water refining, all parts of the plant charge must be kept in movement by boiling water; this is feasible when the refining material is charged freely and stays free in the boiling water. Thus, just water refining has one particular point of interest,

i.e. it permits processing of finely powdered material or plant parts that, by contact with live steam, would otherwise form lumps through which the steam cannot penetrate (UNIDO, ICS, 2008).

2.5.7 Turbo Distillation Extraction

Turbo refining is suitable for difficult to separate or coarse plant material, for example, bark, roots, and seeds of plants. In this procedure, the plants absorb water and steam is coursed through this plant and water blend. All through the whole process, the same water is consistently reused through the plant material. This technique permits quicker extraction of fundamental oils from difficult to concentrate plant materials. (UNIDO, ICS, 2008).

2. 5. 8 Steam Distillations Method

As the name implies, direct steam refining is the procedure of refining plant material with steam produced outside the still in a satellite steam generator by and large alluded to as a kettle. With the direct steam refining technique, the plant material is bolstered on a punctured framework over the steam gulf. A genuine reason for preference of satellite steam generator is that the quantity of steam can be promptly controlled. Since steam is produced in a satellite heater, the plant material is warmed to around 100°C and, thus, it ought not to experience warm corruption. The steam which then contains the fundamental oil is passed through a cooling system to condense the steam, which form a fluid from which the essential oil and water is then separated. Direct steam refining (DSD) is the most broadly acknowledged procedure for the generation of crucial oils on substantial scale. In the flavor and fragrance supply business, the direct steam distillation method is a standard practice since this method does not change the composition of the oil. (UNIDO, ICS, 2008).

A conspicuous disadvantage to steam distillation method is the much higher capital cost expected to construct such a facility. The cost of essential oils such as Rosemary, Chinese cedarwood, lemongrass, litsea cubeba, Spike Lavender, Eucalyptus, citronella, cornmint, across the world are sufficiently high to legitimize their generation by steam distillation method without amortizing the capital use required to fabricate the facility over a period of 10 years or more (UNIDO, ICS, 2008). Figure 2.2 shows the flow process of steam distillation method of extracting lemon

grass oil.

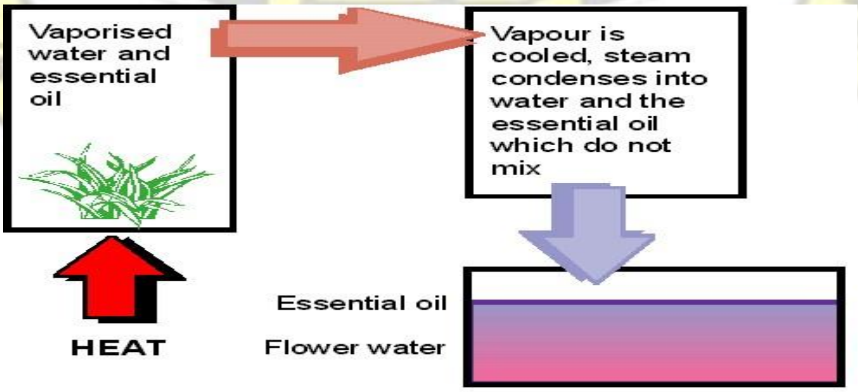


Figure 2.2 Flow process of steam distillation method

Source: Virendra P. S. Rao and Diwaker Pandy 2007.

2.5.9 Factorial Design

Experimentation has been utilized as a part of assorted regions of learning. Montgomery (John Wiley and Sons, 2009) characterizes a trial as a test or a progression of tests in which deliberate changes are made to the information variable elements of a procedure or framework with the goal that we might look at and distinguish the purposes behind changes that might be seen in the yield reaction. Measurable configuration of tests alludes to arranging the trial in a way that legitimate information will be gathered and dissected by factual strategies, bringing about substantial and target conclusions ((John Wiley and Sons, 2009).

Exploratory outline has three standards these are; randomization, replication, and blocking. The request of the keeps running in the test outline is arbitrarily decided. Randomization helps in staying away from infringement of autonomy brought on by unessential components, and the supposition of freedom ought to dependably be tried. Replication is an autonomous rehash of every blend of components. It permits the experimenter to acquire an appraisal of the trial mistake. Blocking is utilized to represent the variability brought about by controllable irritation variables, to lessen and dispense with the impact of this component on the estimation of the impacts of hobby. Blocking does not kill the variability; it just confines its belongings. A disturbance variable is a component that might impact the exploratory reaction however in which we are not intrigued ((John Wiley and Sons, 2009).

The test arrangement for factorial design follows the following steps:

- defining of objectives of the experiment,
- choosing measures of performance, factors to explore, and factors to be held constant
- designing and executing the experiment.
- analyzing the data and drawing conclusions and

- reporting the experiment's results (Barr et al., 1995).

A 2 k factorial outline includes k considers, each at two levels. These levels can be quantitative or subjective. The level of a quantitative element can be connected with focuses on a numerical scale, as the span of populace or the quantity of islands. For subjective elements, their levels cannot be masterminded altogether of greatness, for example, topologies, or methodologies of determination. The two levels are alluded as "low" and 'high', and indicated by '- 'and '+', individually. It doesn't make a difference which of the component qualities is connected with the "+" and which with the '- sign, the length of the naming is consistent. At the start of a 2 k factorial design, factors and levels are indicated. When we combine them all one of them, a design matrix is obtained (Monica S. Pais et al., 2014).

2.6 Finite Element Analysis

Finite element (ANSYS) is a useful programming tool, used to recreate connections of all controls of material science, basic, vibration, liquid elements, heat exchange and electromagnetic for Engineers. Finite element empowers Engineers to reproduce plans, before assembling models of items. (Figes A.S., 2016). ANSYS programming with its secluded structure gives an open door for taking just required elements (Figes A.S., 2016).

2.6.1 Gas Chromatography Mass Spectrometry

Gas Chromatography (GC) is a kind of chromatography in which the versatile stage is a transporter gas, for example, nitrogen, and the stationary stage is an infinitesimal layer of fluid or polymer on an idle strong backing, inside glass or metal tubing, called a segment. The fine section contains a stationary stage, a fine strong backing covered with a nonvolatile fluid. The strong can itself be the stationary stage. The gas is cleared through the section by a flood of helium gas. The segments are isolated from each other due to the fact that some take more time to go through the section than others (Skoog et al., 2007). As the sample leaves the end of the GC section it is divided by ionization and the pieces are sorted by mass to frame a discontinuity design. It is specific to the point that; it is regularly alluded to as the atomic unique finger impression. Gas chromatography-mass spectrometry (GC-MS) is a systematic technique that joins the components of gas-fluid chromatography and mass spectrometry to distinguish distinctive substances inside the sample. GC can isolate unpredictable and semi unstable mixes with extraordinary accuracy, yet it can't distinguish the compounds (Skoog et al., 2007). MS can give point by point auxiliary data on most mixes such that they can be precisely distinguished, yet it can't promptly

isolate them. The GC-MS joins two diverse investigative strategies, Gas Chromatography (GC) and Mass Spectrometry (MS), used to dissect complex natural and biochemical blends (Skoog et al., 2007). The GC-MS instrument comprises of two primary parts. The gas chromatography parcel that isolates distinctive mixes in the example into beats of immaculate chemicals in light of their instability (Oregon State University, 2012) by streaming an idle gas which conveys the specimen, through a stationary stage settled in the section (Skoog et al., 2007). Spectra of mixes are gathered as they leave a chromatographic segment by the mass spectrometer, which distinguishes and evaluates the chemicals according to their mass to charge proportion

(m/z). These spectra can then be put away on the PC and examined (Oregon State University, 2012).

CHAPTER THREE

METHODOLOGY

This chapter presents the methodology of the study, describes the building of the prototype, the principle of the direct steam method, the composition and quality of the oil by GC-MS test, optimize the oil extracted using factorial design technique.

Finally, optimize the oil extractor using finite element approach (ANSYS).

3.1 Building of the Prototype

The schematic drawings of the hydro diffusion, water/hydro distillation and direct steam distillation concepts were developed and presented in figure 3.1, 3.2 and 3.3 respectfully.

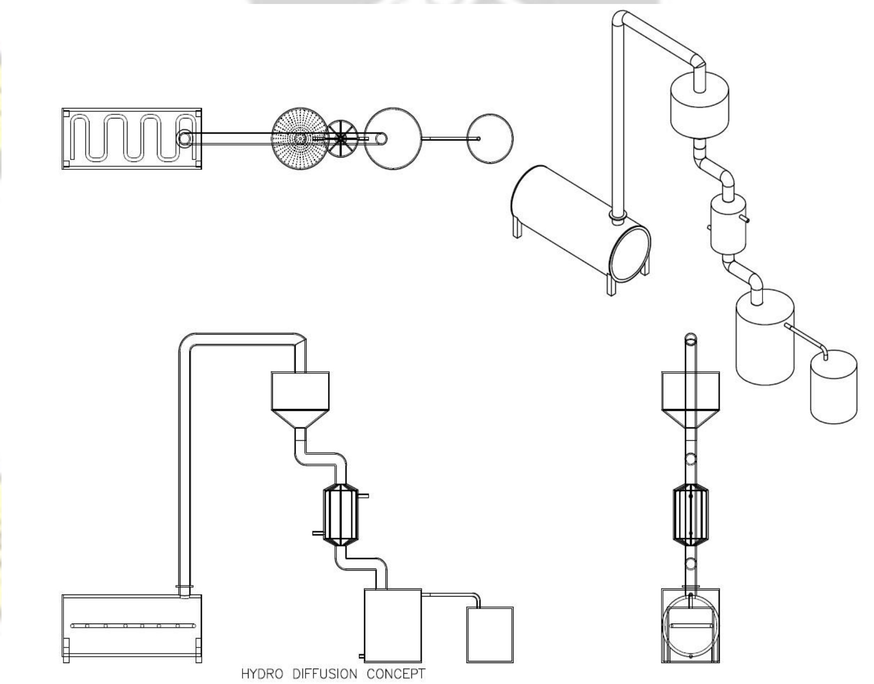


Figure 3.1 Orthographic and cross sectional drawing of the Hydro Diffusion concept

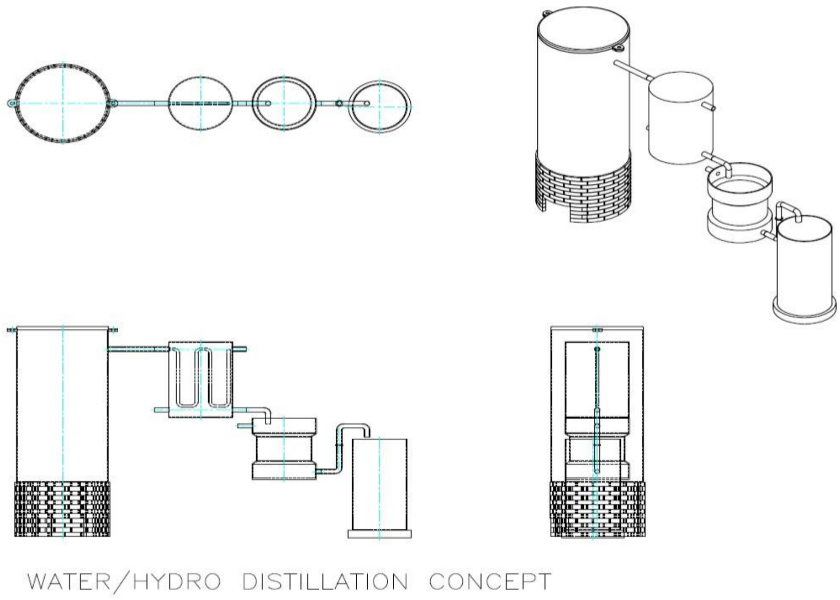


Figure 3.2 Orthographic and cross sectional drawing of the Water/Hydro Distillation concept

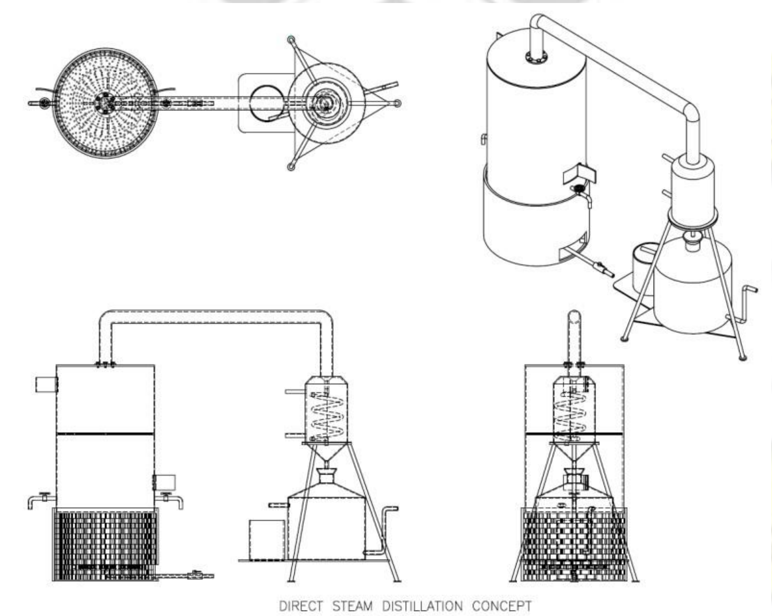


Figure 3.3 Orthographic and cross sectional drawing of the direct steam concept.

Three concepts were developed and evaluated based on the orientation of the condensers, source of power, method of producing the oil, components parts, weight, manufacturability, cost, portability, ease of assembling and maintenance. After the consideration and selection of the final design, the selected concept is presented in Figure 3.4

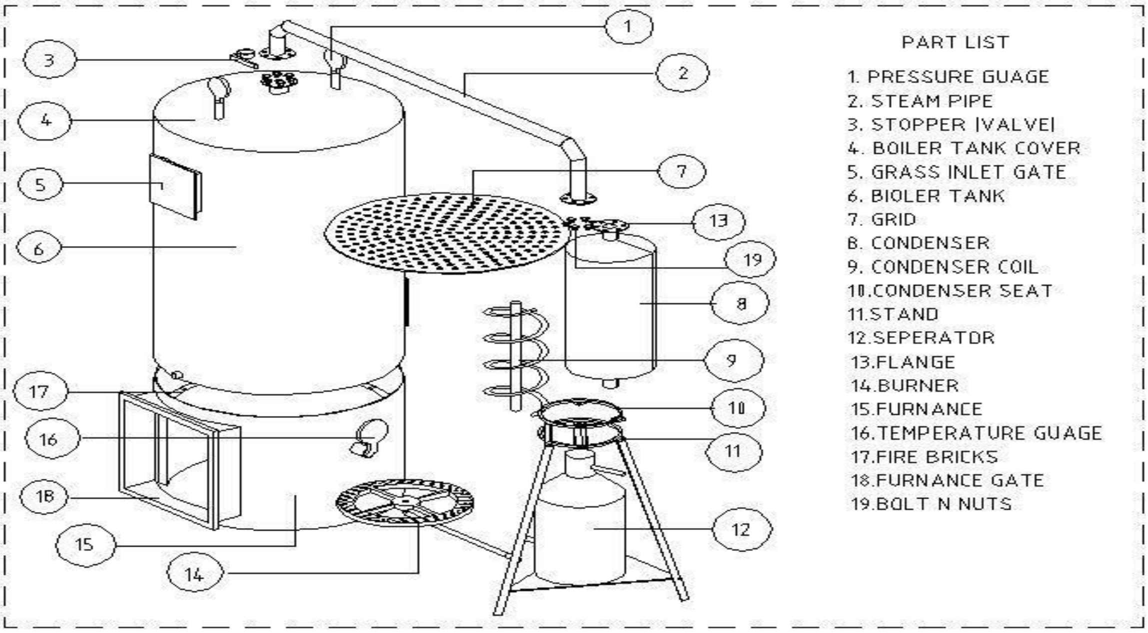


Figure 3.4 exploded view of the selected Extractor with balloon reference

The design specifications of individual parts and subassemblies of various units were based on various design equations. The unit consists of nineteen (19) parts as listed in Figure 3.4. Table 3.1 shows the dimensions, the material and the manufacturing processes selected for the individual parts.

Table 3.1: Design Specification

Part #	Part name	Dimension (mm)	Material used	Manufacturing process
01	Furnace	Dia. 825.5 x 609.6	Mild steel (3mm)	Measuring, cutting, folding, welding and grinding.
	Furnace gate	457.2 x 457.2	Mild steel	Measuring, cutting, folding, and grinding

02	Fire bricks	68.58 x 114.3 x 238.76	Clay	Purchased
03	Valve			Purchased
04	Boiling Tank	Dia. 825.5 x 1245 thickness	Stainless steel	Measuring, cutting, folding, welding and grinding.
05	Inlet Gate		Stainless steel	Measuring, cutting, drilling and grinding.
06	Outlet Gate		Stainless steel	Measuring, cutting, drilling and grinding.
07	Grid	Dia. 812.8 x 3	Stainless steel	Measuring, cutting, drilling and grinding.
08	Boiling Tank cover (conical)	Dia. 825.5 x 101.6	Stainless steel	Measuring, cutting, folding, welding and grinding.
09	Flange	Dia. 50.8 x 5 thick	Stainless steel	Measuring, cutting, drilling and grinding.
10	Steam pipe	Dia. 50.8 x 1178.4 x 371	Stainless steel	Measuring, cutting, drilling welding and grinding.
11	Condenser	Dia. 203.2 x 914.4	Stainless steel	Measuring, cutting, folding welding and grinding.
	Conical side	Dia. 101.6 x 202.8		Measuring, cutting, folding welding and grinding.
	Throat side	Dia. 50.8 x 202.8		Measuring, cutting, welding and grinding.
12	Condenser coil	Dia. 15.875 x 18 turns	Copper pipe	Measuring, burning and cutting
13	Condenser bottom cover			
	Conical side	Dia. 101.6 x 202.8	Stainless steel	Measuring, cutting, folding welding and grinding.

	Throat side	Dia. 50.8 x 202.8	Stainless steel	Measuring, cutting, welding and grinding.
14	Stand	3 mm square pipe	Mild steel	Measuring, cutting, welding and grinding.
15	Separator	Dia. 368.3 x 531.5	Stainless steel	Measuring, cutting, folding welding and grinding.
16	Collector		Any stainless steel container/plastic	Purchased
17	Burner	-	Mild steel	Purchased

The Boiler is a container used for the steam generation. The retort of the boiler consists of a cylindrical container or tank with a diameter equal to or slight less than its height. The height of the still for direct steam distillation should be greater than the diameter so that the rising steam passes as much plant material as possible. It is equipped with a removable cover, which can be clamped upon the cylindrical section. A pipe is attached to the top of the cylindrical section that leads the vapor to the condenser. In the direct steam distillation, the grid is supported at about 5 inches to the bottom. Here direct steam is introduced through steam line from the steam generator below the still. The cylindrical section is slightly tapered to facilitate flange arrangement. A 6 to 8 feet length of pipe flanged at both ends is connected to the condenser.

The gooseneck leads from the center of a convex or spherical top cover to the condenser. It is not too high, as it might act as a sort of reflux condenser. This pipe should be at least 4 inch in diameter and it may even be wider if the rate of distillation is to be very rapid. A still wire mesh at the bottom is also attached, to act as support for the plant material. The height and width of the still depends on the porosity of the plant material.

A greater height is chosen for voluminous material and shorter for more compact material. The bottom of the still is provided with a drain valve so that water condensing within the charge can be drained off in the course of the extraction process. It also serves as an outlet for the wash water when the still is cleaned. The top of the still should be short and well insulated. If convex, it curves gradually and tapers so that it fits into the gooseneck. The gooseneck is slightly curved and gradually descending from the retort into the condenser. It should not be ascending, as this would increase the vapor condensation, the resultant liquid refluxing into the top of the boiling tank have pressure gauge, temperature gauge and on the steam pipe a stopcock to provide safety for operators. A thermocouple is also mounted on the furnace to provide reading of the furnace.

The boiler, steam pipe, condenser, separator and the collector are all made of a 3mm ASMT A240 TP316L Stainless Steel which has ultimate tensile strength of 480 MPa, Yield stress of 170 MPa, Poisson ratio of 0.29, density of 7850-8000 kg/m^3, thermal conductivity of 14.6 W/mk and elongation of 40%.

Apart from the furnace the rest of the extractor is made of stainless steel. The furnace is made of A1018 mild/low carbon steel (3mm) which has Ultimate tensile steel of 440 MPa, yield tensile strength of 370 MPa, Young's modulus 205 GPa and Poisson ratio of 0.29 and thermal conductivity of 51.9 W/mk. Figure 3.5 shows the picture of the extractor showing all instruments mounted on the lemon grass oil extractor.

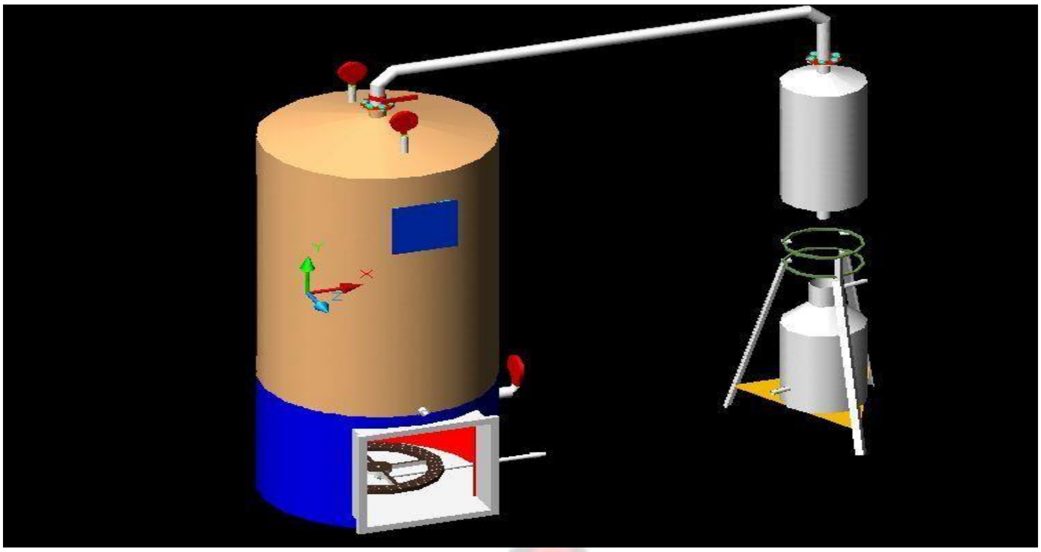


Figure 3.5 Picture of the direct steam extractor

3.2 Extraction of the Oil

Lemon grass *(Cymbopogon citratus)*, water and LPG gas were the main materials used for the production of the oil. Fresh lemon grasses were harvested from a demonstration farm, washed, weighed and introduced into the boiling tank. The boiler was then closed tightly with bolts and nuts, to prevent steam leakage from the system and ready for the extraction process. The equipment was set up for the extraction, after which the furnace was lit with a liquefied petroleum gas (LPG) as the source of energy. Extraction was done as the steam was generated from the boiling tank and made to pass through the plant material in the boiler forcing the pockets of the lemon grass opened to extract the oil. The stopcock was closed so that the predetermined pressures and temperatures could be attained. After the required pressures and temperatures were reached, the stopcock was then opened and both the oil and water in the form of steam passes through the steam pipe and water runs through the condenser pipe serving as heat exchanger to condense the steam into liquid which drops into the separator. By virtue of density differences the oil is separated from the hydrosol and measured. The setup for the extraction process of the oil is shown in Figure 3.6

Figure 3.6 Experimental Set-up

Temperature and pressure transducers were used to record the temperature and the pressure at the boiling chamber. Also the burner's temperature was recorded by a thermocouple. The time duration for the whole process was recorded and the mass flow rate for the LPG used was set to flow between 0.8-1.00 kg per hour depending on the set parameters of the experiment The amount of oil collected was measured, recorded and presented in Table 3.2 and the sample of oil produced shown in Figure 3.7.

Table 3.2: Test Results

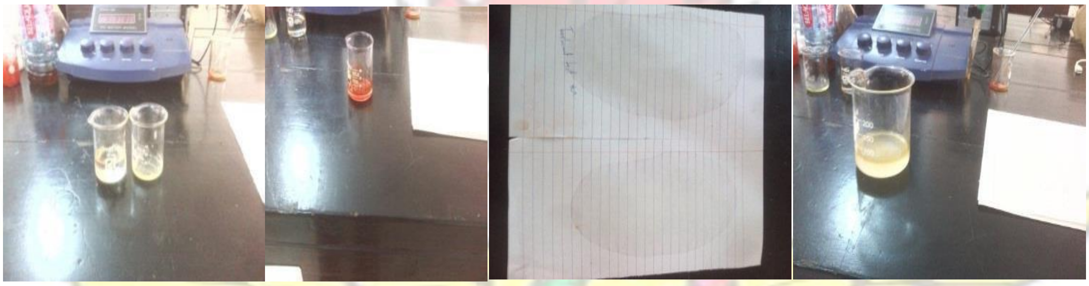
EXPT	Quantity of Grass (kg)	Burner Temp. ^oC	Boiler Temp. ^oC	Boiler pressure (bar)	Time consumed (hours)	Volume of oil collected (ml)
1	27.00	270.00	110.00	1.60	3.03	100.00
2	27.00	250.00	108.00	1.40	3.30	80.80
3	27.00	230.00	106.50	1.40	3.45	80.10
4	27.00	180.00	105.00	0.20	3.55	75.00

5	22.00	290.00	110.00	1.40	3.48	80.70
6	34.00	270.00	65.00	1.40	3.33	80.50
7	28.80	270.00	100.00	1.40	3.30	98.00
8	22.00	265.00	95.00	1.45	3.37	87.00

Figure 3.7 Sample Oil Obtained

Four chemical tests were performed on the sample oil obtained to determine its pureness. These include solubility test, Sudan IV test, grease spot test and emulsification test. In the solubility test, the Lemon grass oil was poured in test container and a small quantity of water was added to the lemon grass in the test container. The mixture was stirred vigorously and allowed to settle for a few minutes. After sometime it was realized that the lemon oil remains as a separate phase from the water showing an indication that it is pure lemon grass oil. Sudan IV ($C_{24}H_{20}N_4O$) is a lysochrome (fat-soluble dye) diazo dye used for the staining of lipids, triglycerides and lipoproteins on frozen paraffin sections. It has the appearance of reddish brown crystals. Sudan IV was added to a mixture of lemon grass oil and water and stirred vigorously and the solution was allowed to settle for some time. The Sudan IV only moved into the lemon grass layer coloring it red. The red colour obtained with only the lemon grass oil is an indication that the lemon grass oil is pure.

The grease spot test was performed by smearing some oil and water onto two pieces of paper. After some time, the water smear dried up on the paper but the smear of oil on paper kept translucent marks for a long period of time. Emulsification test was carried out by mixing soup solution with lemon grass in water. The lemon grass oil was broken down into smaller fragments, which remain suspended for long periods of time in water. This implies that the substance is oil. Figure 3.8 shows the test results of the four chemical tests.



A B C D

Figure 3.8 Test results for the four (4) chemical tests

The results obtained is tabulated and presented in Table 3.3.

Table 3.3 Chemical Tests

PARAMETER	RESULT
Solubility in water	Not Soluble (Positive)
Sudan IV test	Positive
Grease spot test	Positive
Emulsification test	Positive

3.3 Factorial Design Experiment

The importance of factorial designs are: 1) per factor of study, few runs are required; 2) They indicate major trends that can determine likely directions for additional experimentation. Three quantitative variables, namely, the mass of the lemon grass (M-kg), the boiler pressure (P-bars) and the LPG flow rates (F-m^3/s) were used to study the response of the extraction. Table 3.4 shows the experimental matrix and the magnitude of the variables.

Table 3.4: The Experimental Matrix

Variables	**Lower Level (-)**	**Upper Level (+)**
Mass of grass M (kg)	20	27
Boiler Pressure P (bars)	1.4	2.6
LPG Flow rate f (g/s)	18.5	23.0

Note: (-) represents the lower level of the variables

(+) represents the upper level of the variables

Table 3.4 shows the experimental matrix, each extracting experiment run uses a combination of factors. These factors could be a combination of a lower factor, upper factor or both upper and lower factors combined. Figure 3.9 shows the samples of the experimental results of the oil extracted from lemon grass.

Figure 3.9 Sample Oils Obtained

The sample oils (Figure 3.9) still contain some amount of water in it. The samples were then put in a water bath machine for the water to be evaporated. After removing each sample of oil from the water bath, sodium sulphate was dropped in each. This (sodium sulphate addition) is done to further remove possible remaining water in the oil samples. The resulting mixtures were filtered, separated and poured into test tubes ready for GC-MS analysis to be carried out as in Figure 3.10 and 3.11.

Figure 3.10 filtration of sample oils Figure 3.11 final sample ready for (GC-MS) test

Gas Chromatography -Mass Spectrometry (GC - MS) is a method that combines the features of gas - liquid chromatography and mass spectrometry to identify different substances within a test sample. Applications of GC - MS include drug detection, fire investigation, environmental analysis, explosives investigation, and identification of unknown samples. Additionally, it identifies trace elements in the sample that were previously thought to have disintegrated beyond identification. GC results are passed to the MS machine which then breaks the profile of the GC into individual profiles. The MS contains a library which was used to search for the various compounds and percentages. For the purposes of factorial design technique, sixteen extraction experiments were carried out and the results are tabulated and presented in Table 3.5.

Table 3.5: Experimental results

Std.	Run	M (kg)	P(bar)	F (g/s)	t_b (^0C)	t_C (^0C)	Time in minute (T)	q (cm^3)	C %	Q (kg)
1	5	20	1.4	18.5	108	290	216	118	43.569	4.0
2	16	27	1.4	18.5	107	205	222	161	23.36	4.1
3	10	20	2.6	18.5	123.5	180	216	122	39.315	4.0
4	7	27	2.6	18.5	125	285	227	165.05	37.122	4.2
5	1	20	1.4	23.0	104	150	157	120	39.219	3.6
6	14	27	1.4	23.0	105	200	178	158.5	41.943	4.1
7	2	20	2.6	23.0	123.5	150	148	126.5	41.645	3.4
8	6	27	2.6	23.0	124.5	200	174	159.5	28.437	4.0
9	8	20	1.4	18.5	107.5	185	222	120	34.674	4.1
10	12	27	1.4	18.5	109	205	222	162	41.97	4.1
11	9	20	2.6	18.5	123.5	180	222	123	40.888	4.1
12	3	27	2.6	18.5	125.5	195	232	165.5	40.255	4.3
13	11	20	1.4	23.0	108	215	148	118	23.713	3.4
14	15	27	1.4	23.0	105	200	178	158.71	33.898	4.1
15	13	20	2.6	23.0	125	200	135	124	35.873	3.1

16	4	27	2.6	23.0	124	195	178	160	38.506	4.1

Where, M = mass of grass in kg, P = pressure in bars, q = quantity of oil, C = quality of oil, Q = amount of LPG used, t_c = temperature of chamber, t_b = temperature of boiler, f = flow rate in g/s

3.4 Calculation of the Effects and the Standard Errors

From Table 3.5, the averages of the runs were computed for each set of condition. Tables 3.6 to 3.9 shows the measured and the average values of LPG (Q-kg) used, time consumed (T-minutes), quantity of oil collected (q-m^3/s) and the quality of the oil obtained C%.

Table 3.6: The Measured and Average Values for the LPG used

pts	Code			Amount of LPG Q used (kg)		
	m	**p**	**f**	**Run 1**	**Run 2**	**Mean**
1	-	-	-	4.0	4.1	$Q_1 = 4.05$
2	+	-	-	4.1	4.1	$Q_2 = 4.10$
3	-	+	-	4.0	4.1	$Q_3 = 4.05$
4	+	+	-	4.2	4.3	$Q_4 = 4.25$
5	-	-	+	3.6	3.4	$Q_5 = 3.50$
6	+	-	+	4.1	4.1	$Q_6 = 4.10$
7	-	+	+	3.4	3.1	$Q_7 = 3.25$
8	+	+	+	4.0	4.1	$Q_8 = 4.05$

Note: (-) represents the lower level of the variables

(+) represents the upper level of the variables

Table 3.7: The Measured and Average Values for Time used

pts	Code			Time (T) in minutes		
	m	**p**	**f**	**Run 1**	**Run 2**	**Mean**
1	-	-	-	218	238	$T_1 = 228$

2	+	-	-	210	210	T_2 =210
3	-	+	-	210	210	T_3 =210
4	+	+	-	212	212	T_4 =212
5	-	-	+	210	210	T_5 =210
6	+	-	+	210	210	T_6 =210
7	-	+	+	212	210	T_7 =211
8	+	+	+	218	212	T_8 =215

Note: (-) represents the lower level of the variables

(+) represents the upper level of the variables

Table 3.8: The Measured and Average Values for quantity of oil obtained

pts	Code			Quantity of oil q (cm^3)		
	m	p	f	Run 1	Run 2	Mean
1	-	-	-	118.0	120.0	q_1 =119.000
2	+	-	-	161.0	162.0	q_1 =161.500
3	-	+	-	122.0	123.0	q_1 =122.500
4	+	+	-	165.05	165.5	q_1 =165.275
5	-	-	+	120.0	118.0	q_1 =119.000
6	+	-	+	158.5	158.71	q_1 =158.605
7	-	+	+	126.5	124.0	q_1 =125.250
8	+	+	+	159.5	160.0	q_1 =159.750

Note: (-) represents the lower level of the variables

(+) represents the upper level of the variables

Table 3.9: The Measured and Average Values for quality of oil obtained

Pts	Code	Quality of oil C %

	m	p	f	Run 1	Run 2	Mean
1	-	-	-	43.569	34.674	C_1 = 39.1215
2	+	-	-	23.36	41.97	C_2 = 32.665
3	-	+	-	39.315	40.888	C_3 = 40.1015
4	+	+	-	37.122	40.255	C_4 = 38.6885
5	-	-	+	39.219	23.713	C_5 = 31.466
6	+	-	+	41.943	33.898	C_6 = 37.9205
7	-	+	+	41.645	35.873	C_7 = 38.759
8	+	+	+	28.437	38.506	C_8 = 33.4715

Note: (-) represents the lower level of the variables
(+) represents the upper level of the variables

The main effect of each of the process variables reflects the changes of the respective responses as the process variables change from a low to a high level as shown in Table 3.10.

Table 3.10 Factor Interactions

Std	m	p	f	mp	mf	pf	mpf
1	-	-	-	+	+	+	-
2	+	-	-	-	-	+	+
3	-	+	-	-	+	-	+
4	+	+	-	+	-	-	-
5	-	-	+	+	-	-	+
6	+	-	+	-	+	-	-
7	-	+	+	-	-	+	-
8	+	+	+	+	+	+	+

Note: (-) represents the lower level of the variables
(+) represents the upper level of the variables

The average of the four measures is the main effect of the factor (variable) and is given as:

The main effect of the mass is:

$$E_m = \frac{1}{4}\left[(A_2 + A_4 + A_6 + A_8) - (A_1 + A_3 + A_5 + A_7)\right] \qquad (1)$$

The main effect of the pressure is:

$$E_p = \frac{1}{4}\left[(A_3 + A_4 + A_7 + A_8) - (A_1 + A_2 + A_5 + A_6)\right] \qquad (2)$$

The main effect of the LPG flow rate is:

$$E_f = \frac{1}{4}\left[(A_5 + A_6 + A_7 + A_8) - (A_1 + A_2 + A_3 + A_4)\right] \qquad (3)$$

Two or more of the variables may jointly influence the responses. These joint influences are referred to as interactions. These interactions are given as:

The interaction between the mass and the pressure is defined as:

$$I_{mp} = \frac{1}{4}\left[(A_1 + A_4 + A_5 + A_8) - (A_2 + A_3 + A_6 + A_7)\right] \qquad (4)$$

The interaction between the mass and LPG flow rate is defined as:

$$I_{mf} = \frac{1}{4}\left[(A_1 + A_3 + A_6 + A_8) - (A_2 + A_4 + A_5 + A_7)\right] \qquad (5)$$

The interaction between pressure and LPG flow rate is defined as:

$$I_{pf} = \frac{1}{4}\left[(A_1 + A_2 + A_7 + A_8) - (A_3 + A_4 + A_5 + A_6)\right] \qquad (6)$$

The three-factor interaction is expressed as:

1

$$I_{mpf} = \frac{1}{4}\left[(A_2 + A_3 + A_5 + A_8) - (A_1 + A_4 + A_6 + A_7)\right] \quad (7)$$

The mean of the runs is defined as:

$$E_M = \left(\sum_{i=1}^{8} A_i\right) / 8 \quad (8)$$

Where A_i represents the extracting parameters, the estimates for the four parameters i.e. (amount of LPG Q, time T, quantity of oil q, and quality of oil C) are under consideration.

When genuine run replicates are created under a given set of experimental conditions, the variation among their associated observations are used to estimate the standard deviation of a single observation and, hence, the standard deviation of the results. In general, if g sets of experimental conditions are genuinely replicated and the n_i replicate runs made at the i^{th} set yield an estimate s_i^2 having $v_i = n_i - 1$ degree(s) of freedom, the estimate of run variance is (Hunter, 1978).

$$s^2 = \frac{v_1 s_1^2 + v_2 s_2^2 + v_3 s_3^2 + \ldots + v_g s_g^2}{v_1 + v_2 + v_3 + \ldots + v_g} \quad (9)$$

With only $n_i = 2$ replicates at each of the g sets of conditions, the formula for the i^{th}

Variance reduces to $s_i^2 = d_i^2 / 2$ (10)

with $v_i = 1$, where d_i is the difference between the duplicate observations for the i^{th} set of conditions.

Thus, Equation 9 will yield:

$$s^2 = \sum \left(d_i^2 / 2\right) / g \quad (11)$$

In general, if a total of N runs are made conducting a replicated factorial design, then the variance of an effect is given as:

$$V(effect) = \frac{4}{N} s^2 \qquad (12)$$

and the standard error of the effect is given as:

$$s_e = \sqrt{V(effect)} \qquad (13)$$

A full model may consist of three main effects, three two-factor interaction and a three-factor interaction. This is defined as:

$$AT = \alpha_0 + \alpha_1 m + \alpha_2 p + \alpha_3 f + \alpha_4 mp + \alpha_5 mf + \alpha_6 pf + \alpha_7 mpf \qquad (14)$$

where $\alpha_0, \alpha_1, \ldots, \alpha_7$ are the constants and m, p, and f are the mass of lemon grass, operating pressure and amount of LPG, respectively. It can be shown that a

$$\alpha_0 = Ea, \quad \alpha_1 = \frac{E_m}{2}, \quad \alpha_2 = \frac{E_p}{2}, \quad \alpha_3 = \frac{E_f}{2}, \quad \alpha_4 = \frac{I_{mp}}{2}, \quad \alpha_5 = \frac{I_{mf}}{2},$$

$$\alpha_6 = \frac{I_{pf}}{2} \quad \text{and} \quad \alpha_7 = \frac{I_{mpf}}{2}$$

3.5 Finite Element Analysis

Two materials were selected for the construction of the boiler and the furnace. Mild steel was used to construct the furnace whilst stainless steel was used to build the boiler. The properties of the materials used are presented in 3.11.

Table 3.11: Material Specification of the Extractor

Properties Name	Stainless Steel (3 mm) ASMT A240 TP316L	Mild Steel (3 mm) AISI 1018
Ultimate Tensile Strength	480 MPa	440 MPa
Yield tensile strength	485 MPa	370 MPa
Poisson ratio	0.27-0.30	0.29
Young's modulus	200 GPa	205 GPa
Yield Strength	205 MPa	200 MPa
Percentage elongation	40.00%	50%
Linear Coefficient of thermal Expansion	16.6×10^{-6} cm//°c	-
Thermal conductivity	16.3 W/m.K	51.9 W/m.K
Density	7900 (kg/m^3)	7870 (Kg/ m^3)

The ANSYS software was used to model the extractor. Figure 3.12 shows the flow chart for the modeling of the boiler.

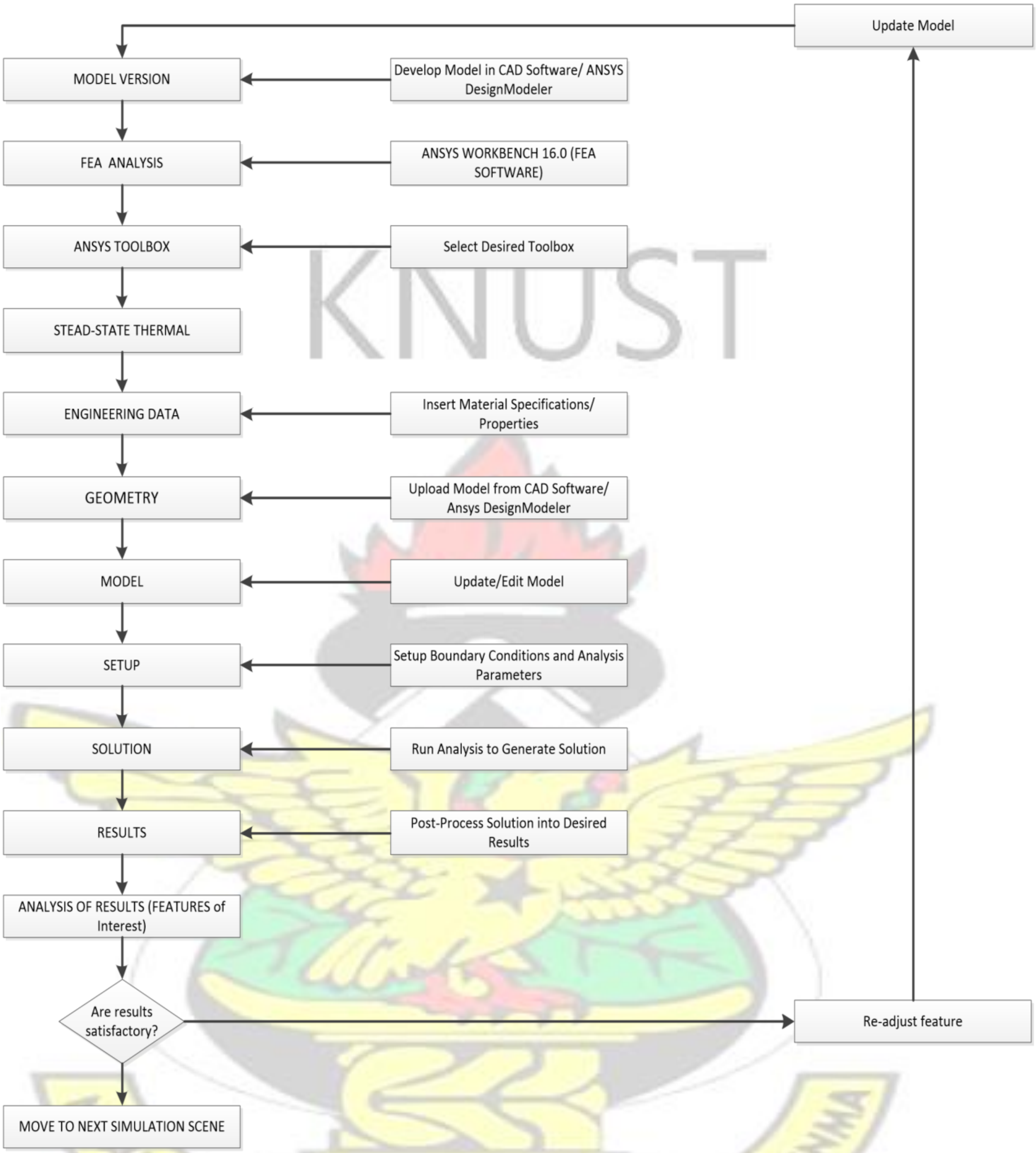


Figure 3.12: modeling flow chart

The activities in the ANSYS modeling was categorized into three processes, namely, the preprocessor, the solution and the post processing. Generation of the model was conducted in this preprocessor, which involves material definition, creation of a solid model, and the meshing. In the solution stage, analysis type was defined and the boundary conditions were specified and the solution was done. The results were generated from the post processor stage. The 3D model of the steam boiler assembly was developed using NX-8.0 software. Steam boiler assembly converted to surface model for analysis. Modal analysis is used to determine a structure's vibration characteristics, natural frequencies and mode shapes. It is the most fundamental of all dynamic analysis types and is generally the starting point for other, more detailed dynamic analyses. The modal analysis of the steam boiler assumes a fixed support at the base of the boiler. The vibrations are set to ten modes.

CHAPTER FOUR

DISCUSSIONS OF RESULTS

This chapter presents the analysis, interpretation and discussion of the results obtained from the design and optimization of the extractor, the chemical and the GC-MS tests, the factorial design experiment and the finite element modeling of the boiler.

4.1 Quality of the Oil

From Table 3.3, the results for the solubility in water test performed indicate that there were no indication of solubility, meaning positive results is attained; hence, the sample is pure oil. Sudan IV test, grease spot test, and emulsification test also responded positive giving an indication of the pureness of the oil.

The quality of lemon grass oil is also determined by the citral percent in the oil. The constituent of the oil was also determined. Other compounds of lemon grass oil are geranyl acetate, myrcene, nerol, citronellal, terpineol, methyl heptenone, dipentene, geraniol, neral, farnesol, and limonene. Figure 4.1 presents the GC results of the sample of lemon grass perform. The peaks in the graph represent the constituent in the samples of oil.

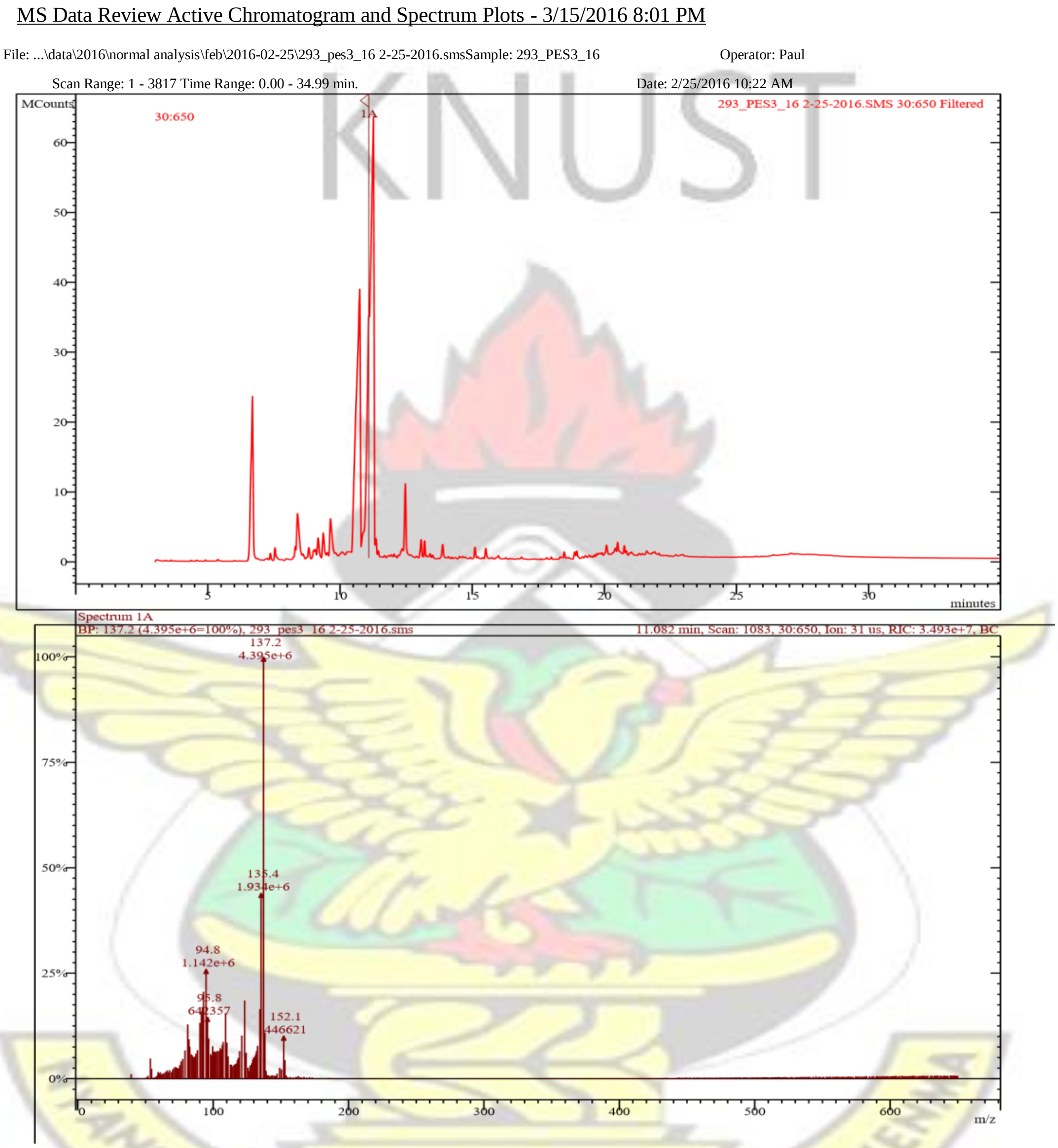
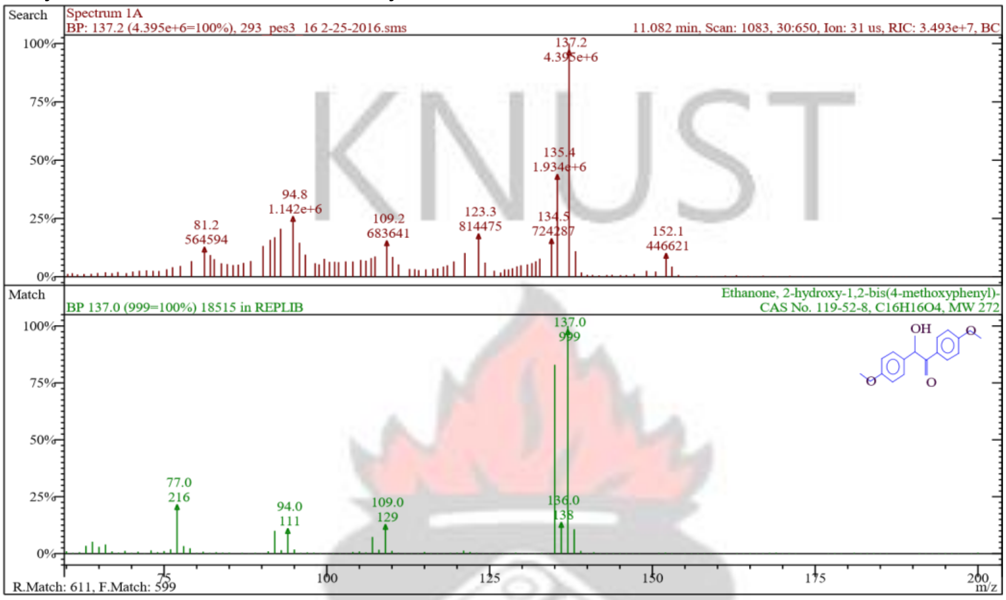


Figure 4.1: Graph of GC Results of oil constituent as performed at GSB

The mass spectrometry test is performed after the Gas Chromatography to break the various peaks in the GC profile into individual profiles as shown in figure 4.2. The mass spectrometry has a library in it, which can search for the percentage of compounds in each sample peaks.

Scan 1083 from ...\normal analysis\feb\2016-02-25\293_pes3_16 2-25-2016.sms

Entry 18515 from REPLIB NIST Library



1st Spectrum from ...alysis\feb\2016-02-25\293_pes3_16 2-25-2016.sms
Scan No: 1083, Time: 11.082 minutes No averaging. Background corrected.
Comment: 11.082 min. Scan: 1083 30:650 Ion: 31 us RIC: 3.532e+7
Pair Count: 622 MW: 0 Formula: None
CAS No: None Acquired Range: 29.5 - 650.5 m/z

MDT: Centroid, Time: 0.00 - 35.00
Seg 1, Filament off , Time: 0.00- 3.00, Filament Off
Chan 1, 40-650 m/z
Seg 2, isolation , Time: 3.00-35.00, EI-Auto-Full
Chan 1, 30-650 m/z
Product Mass Range: 29.5 - 650.5 m/z

Ion	Int	Norm	Ion	Int	Norm	Ion	Int	Norm
...	...		109.2	683641	155	159.1	13307	3
60.2	54403	12	110.1	375766	85	159.7	9494	2
60.9	67671	15	111.0	232547	53	161.2	20285	5
61.7	44936	10	112.7	147800	34	162.0	13601	3
62.7	51976	12	113.5	145047	33	162.9	27855	6
63.8	55743	13	114.1	125704	29	164.0	10933	2
64.8	70911	16	115.2	140856	32	164.7	15785	4
66.0	86040	20	116.3	150483	34	165.3	8526	2
67.0	67564	15	117.0	158150	36	166.2	9564	2
67.9	89697	20	117.9	193074	44	167.0	19219	4
69.2	68459	16	118.5	217259	49	168.1	9030	2
70.2	97689	22	119.5	289120	66	169.2	11732	3
71.2	115000	26	121.2	449519	102	169.9	4296	1
72.3	122348	28	123.3	814475	185	171.1	16412	4
73.3	112221	26	124.3	268487	61	172.0	6300	1
74.2	109713	25	125.7	114222	26	173.1	14264	3
75.4	141107	32	126.7	79989	18	174.2	3805	1

Figure 4.2 MS Results of the Lemon Grass Oil as performed at GSB

Print Date: 26 Feb 2016 10:03:02

Plot 1. 293_pes2_16 2-25-2016001.sms - 2/25/2016 9:11 PM

Parameters:	From Data File
Peak Width (sec):	4.0
Slope Sensitivity (SN):	20
Tangent %:	10
Peak Size Reject (counts):	2000
Smoothing:	None
Spike Threshold Factor:	None
Noise:	RMS

	Retention Time	Area	% of Total	Signal/Noise	Scan Description
5.	6.612	7.615e+7	9.462	5366	30:650 (2)
8.	7.519	3.848e+6	0.478	168	30:650 (2)
10.	8.292	2.277e+6	0.283	36	30:650 (2)
11.	8.381	2.189e+7	2.720	219	30:650 (2)
12.	8.589	2.244e+6	0.279	24	30:650 (2)
14.	8.806	3.074e+6	0.382	32	30:650 (2)
15.	8.989	2.209e+6	0.274	17	30:650 (2)
16.	9.053	3.508e+6	0.436	26	30:650 (2)
17.	9.158	6.067e+6	0.754	36	30:650 (2)
18.	9.347	8.284e+6	1.029	96	30:650 (2)
19.	9.501	2.213e+6	0.275	18	30:650 (2)
20.	9.623	1.797e+7	2.233	155	30:650 (2)
21.	9.825	2.512e+6	0.312	19	30:650 (2)
22.	9.965	2.069e+6	0.257	19	30:650 (2)
23.	10.030	2.697e+6	0.335	15	30:650 (2)
24.	10.236	5.635e+6	0.700	20	30:650 (2)
25.	10.623	1.822e+8	22.637	658	30:650 (2)
26.	10.865	4.654e+7	5.783	233	30:650 (2)
27.	11.100	3.164e+8	39.315	1037	30:650 (2)
35.	12.431	3.452e+7	4.290	504	30:650 (2)
37.	13.036	3.585e+6	0.445	108	30:650 (2)
38.	13.175	3.491e+6	0.434	114	30:650 (2)
42.	13.896	3.513e+6	0.436	188	30:650 (2)

Figure 4.3 Library search results of various compounds of Lemon oil as **performed at GSB**

Figure 4.3 presents the various compounds in the sample oil of lemon grass. The sample results presented is for sample 293 (J). The rest of the results are presented in the appendix C.

4.2 Efficiency of the Prototype

Analysis was performed on the results obtained to determine the efficiency of the machine and how to improve upon it. Also, the quality of the oil produced and economic viability were determined. Table 3.2 shows the results obtained during the extraction of the oil using the developed prototype machine. From the results, it can be established that the prototype machine developed can be used to extract lemon grass oil from the leaves. The efficiencies were then computed and the results obtained are tabulated and presented in Table 4.1.

Table 4.1: Efficiency of the Machine

EXPT	Quantity of Grass (kg)	Volume of oil collected (ml)	Efficiency (ml/kg)
1	27.0	100.0	3.70
2	27.0	80.8	2.99
3	27.0	80.1	2.97
4	27.0	75.0	2.78
5	22.0	80.7	3.67
6	34.0	80.5	2.37
7	28.8	98.0	3.40
8	22.0	87.0	3.95

From Table 4.1, it can be established that, the efficiency of the machine ranges from 2.37 to 3.95 ml/kg. The result also shows that, the mass of the lemon grass has an effect on the amount of oil produced, and the boiler's temperature. The investigation reveals that using an optimized quantity of lemon grass may improve the efficiency of the machine.

The cost analysis for the extraction of the oil was also estimated. Table 4.2 shows the prices of the items used to produce the oil. From Table 3.2 with a 27 kg of lemon grass at burner's temperature of 270 ^{o}C having boiler's temperature and pressure of 110 ^{o}C and 1.6 bar produces 100 ml of lemon grass oil for a time duration of 3.03 hours at a LPG flow rate of 1 kg per hour, then the cost of production can then be estimated.

Table 4.2: Cost of Material Used

Material	Price (GH¢)
Cost of building the machine	2349.00
18 kg of LPG	42.00
Cost of 27 kg of lemon grass	30.00
Cost of 35 liters of water (GWCL)	7.27
Cost of 5ml of lemon grass oil	9.54

A 35 litres of water was used for this purpose and the total time duration including the set-up was estimated to be six (6) hours with a labor cost of GH¢ 7.00. The machine was to be run once a day for two hundred and fifty (250) days having a life expectancy to be between ten (10) to twelve (12 years) , the machine cost per day is GH¢ 1.00, then the production is GH¢ 0.66/ml of oil produced. It is also estimated from Table 4.2 that the cost of the lemon grass oil is GH¢ 1.90/ml, yielding an amount of GH¢ 1.24. This procedure was repeated for the remaining seven experiments. The computed results are tabulated and presented in Table 4.3. It can be established that the machine seems to be economically viable, effective and efficient.

Table 4.3: Cost Analysis

EXPT	Quantity of Grass (kg)	Volume of oil collected (ml)	Time consumed (hours)	Cost of Grass (GH¢)	Cost of LPG Used (GH¢)	Cost of Water Used (GH¢)	Production Cost (GH¢/ml)	Gain (GH¢/ml)
1	27	100	3.03	30.00	7.07	7.26	0.66	1.24
2	27	80.8	3.3	30.00	7.70	7.26	0.83	1.08
3	27	80.1	3.45	30.00	8.05	7.26	0.84	1.07
4	27	75	3.55	30.00	8.28	7.26	0.90	1.01
5	22	80.7	3.48	24.44	8.12	7.26	0.77	1.14
6	34	80.5	3.33	37.78	7.77	7.26	0.93	0.98
7	28.8	98	3.3	32.00	7.70	7.26	0.70	1.20
8	22	87	3.37	24.44	7.86	7.26	0.71	1.20

Note: Cost of Lemon grass oil: GH¢1.90/ml; Labour cost for 3 laborers: GH¢21.00; Machine Cost: GH¢1.00/day

Referring to Table 3.2, it was observed that, when a mass of 27 kg of the lemon grass was used the amount of oil produced differs for the four experiments performed. This means that the amount of oil produced do not depend on the quantity of lemon grass used. However, when the mass of the lemon grass was varied for the same burner temperature, the amount of the oil produced changes as shown in Figure 4.4a.

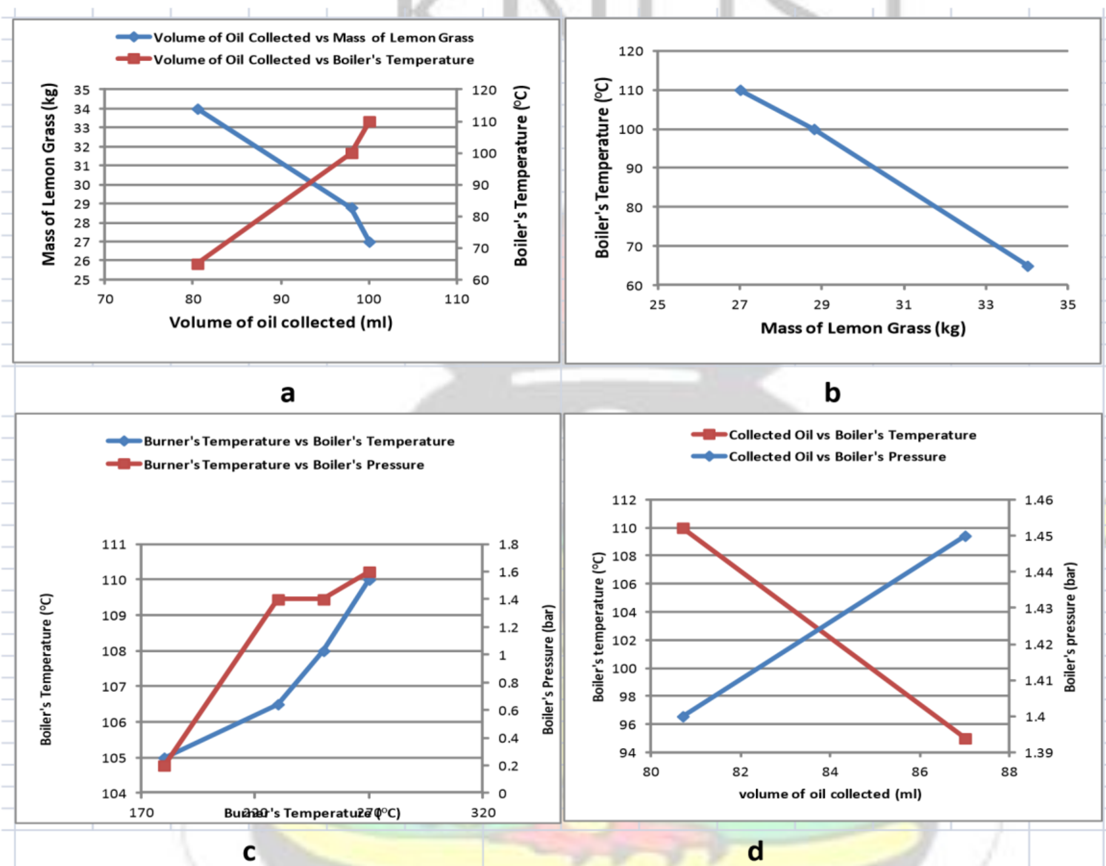


Figure 4.4 a, b, c and d: graphs of various extracting parameters

Further observation shows that as the quantity of lemon grass changes, with the same burner temperature, the boiler's temperature changes as illustrated in the Figure 4.4 b. This implies that the boiler temp increases with decreasing in the quantity of the lemon grass at constant burner temperature. Also increasing boiler's temperature increases the amount of oil produced as indicated in Figure 4.4 a.

Given the burner's temperature in Figure 4.4 a, a graph of volume of oil collected vs. boiler's temperature and mass of lemon grass; for b given the burner's temperature, a graph of mass of lemon grass vs. boiler's temperature; at c given mass of lemon grass, a graph of burner's temperature vs. boiler's temperature and pressure; and d given mass of lemon grass, a graph of volume of oil collected vs. boiler's temperature and pressure. From Figure 4.4 c, the boiler's temperature and pressure increases with increasing burner's temperature. From Figure 4.4 a, it was observed that, the volume of oil collected increases with increasing boiler's temperature, however, in Figure 4.4 d, or Table 3.2, using the 22 kg mass of lemon grass, increasing the boiler temperature decreases the amount of oil produced. Hence there is the possibility of an interaction that may exist between the boiler's temperature and pressure. Therefore, a further investigation can be performed to optimize the amount of oil produced.

From the results in Table 3.2, it can be seen that the quantity of oil does not largely depend on the amount of lemon grass used. It can also be predicted that the amount of lemon grass oil may depend on other factors other than the amount of grass. Hence the need for further investigation on other parameters to determine the best combination of factors that can be used in the extraction process in order to obtain the best yield of the lemon grass oil, hence the need to carry out a factorial design experiment.

4.3 The Effects of the Processing Parameters

The estimates for the four responses are shown in Table 4.4.

Table 4.4: Effects of Process Parameters on the Extraction

Effects and Interactions	LPG (Q) (kg)	Time (T) (minutes)	Quantity (q) (cm^3)	Quality (C) (%)
E_a	3.92	213.25	141.36	36.52

E_m	0.41	-3.00	39.85	-1.68
E_p	-0.04	-2.50	3.67	2.46
E_f	-0.39	-3.50	-1.42	-2.24
I_{mp}	0.09	6.00	-1.21	-1.67
I_{mf}	0.29	5.00	-2.79	2.26
I_{pf}	-0.11	5.50	0.03	-1.04
I_{mpf}	0.01	-4.00	-1.35	-4.20

The results from Table 4.4, suggest that increasing the mass from 20 to 27 kg results in an increase in the quantity of oil of 39.85 cm^3; a decrease of time of 3 minutes; an increase of LPG of 0.41 kg; and a decrease of the quality of oil of1.68%. Increasing the pressure from 1.4 to 2.6 bar results in an increase of quality of oil of 2.46%; a decrease of time of 2.50 minutes; a decrease of LPG of 0.04 kg; and an increase of the quantity of oil of 3.67 cm^3. Increasing the flow of LPG from 0.8 to 1.0 m^3/s results in a decrease of LPG 0f 0.39, a decrease of quality of oil of 2.24; a decrease of time of 3.50 minutes; and a decrease of the quantity of oil of -1.42. These results may be confirmed by the application of the experimental error as discussed below.

Using the results obtained for the factor responses during the extraction process and presented in Tables 3.5 to 3.8, the d_i and the $d_i^2/2$ are computed for each i^{th} condition. These values are used to compute the corresponding standard errors for each factor response. The results are presented in Table 4.5.

Table 4.5: Standard Errors for the Extraction Process

Parameters	LPG	Time	Quantity	Quality
Variance,	0.09	220.00	8.40	438.80

Variance of an effect	0.04	110.00	4.20	219.40
Standard Error,	0.21	10.49	2.05	14.81

The combination of the results and the values in Tables 4.4 and 4.5 produce the final results for the factorial analysis. This is illustrated in Table 4.6. These results are used to establish the models of the responses and the processing parameters.

Table 4.6: The Factorial Experimental results

Effects and Interactions	LPG (Q)	Time (T)	Quantity (q)	Quality (C)
E_a	3.92	213.25	141.25	36.52
E_m	0.41±0.21	-3.00±10.49	39.85±2.05	-1.68±14.81
E_p	-0.04±0.21	-2.50±10.49	3.67±2.05	2.46±14.81
E_f	-0.39±0.21	-3.50±10.49	-1.42±2.05	-2.24±14.81
I_{mp}	0.09±0.21	6.00±10.49	-1.21±2.05	-1.67±14.81
I_{mf}	0.29±0.21	5.00±10.49	-2.79±2.05	2.26±14.81
I_{pf}	-0.11±0.21	5.50±10.49	0.03±2.05	-1.04±14.81
I_{mpf}	0.01±0.21	-4.00±10.49	-1.35±2.05	-4.20±14.81

From Table 4.6, it is not clear which of the estimates are important (factors) and which are unimportant (chance). By examining the confidence intervals of each result, it can be determined if each effect or interaction is significant (a factor). However, it is established that, if the range of an effect include zero then, it is by a chance, otherwise it is a factor. Table 4.7 shows the results obtained, the effects and interactions that are significant (factor).

Table 4.7: Factorial Experimental for Factor/Chance results

	Effects and Interactions			
	LPG (Q)	**Time (T)**	**Quantity (q)**	**Quality (C)**
E_a	3.92	213.25	141.25	36.52
E_m	factor	chance	factor	chance
E_p	chance	chance	factor	factor
E_f	factor	chance	chance	chance
I_{mp}	chance	chance	chance	chance
I_{mf}	factor	chance	factor	factor
I_{pf}	chance	chance	chance	chance
I_{mpf}	chance	chance	chance	chance

The significant effects and interactions are used to develop the empirical model for each response with the use of Equation 14.

4.4 Development of the Predicted Model

From Table 4.8, the mass of the lemon grass, the flow of the LPG and the interaction of the mass of grass and flow of have a significantly effect on the amount of LPG used. Hence, the empirical model for the LPG (Q) is

$$Q = 3.92 + \left(\frac{0.41}{2}\right)m + \left(\frac{0.39}{2}\right)f + \left(\frac{0.29}{2}\right)mf \quad (15)$$

Similarly, the model for the quantity of oil (q) and the quality of oil (C) are:

$$q = 141.25 + \left(\frac{39.85}{2}\right)m + \left(\frac{3.67}{2}\right)p + \left(\frac{2.79}{2}\right)mf \quad (16)$$

$$C = 36.52 \quad \frac{2.46}{2} \; p \quad \frac{2.26}{2} \; mf \qquad (17)$$

Where Q, q, and C are the maximum values for the LPG, quantity of oil, and Quality of the oil responses respectively. Since the process parameters (m, p, and f) are coded, their values are -1 to +1 in these models.

4.5 Verification of the Model

The value of LPG Q is calculated at each experimental condition and then compared with the mean value in Table 3.5.

For example, at the lower values of m, p and f,

$$Q = 3.92 \quad 0.241 \; m \quad 0.239 \; f \quad 0.229 \; mf$$

$$Q_1 = 3.92 \quad 0.241 (1) \quad 0.239 (1) \quad 0.229 (1)(1) = 4.055$$

This process is then repeated for the remaining process parameters and the results obtained are presented in Table 4.7. The procedure is repeated for the quantity and quality of oil produced, and the results are presented in Table 4.8.

Table 4.8: Comparison of the Measured Mean and the Model Mean

LP Gas			Quantity of Oil			Quality of Oil		
4.05	4.06	-0.12	119.00	118.10	0.76	39.12	36.42	6.91
4.1	4.18	-1.83	161.50	160.74	0.47	32.67	34.16	-4.58
4.05	4.06	-0.12	122.50	121.77	0.60	40.10	38.88	3.05
4.25	4.18	1.76	165.28	164.41	0.53	38.69	36.62	5.35

3.5	3.38	3.57	119.00	120.89	-1.58	31.47	34.16	-8.56
4.1	4.08	0.61	158.61	157.95	0.42	37.92	36.42	3.96
3.25	3.38	-3.85	125.25	124.56	0.55	38.76	36.62	5.52
4.05	4.08	-0.62	159.75	161.62	-1.17	33.47	38.88	**-16.16**

Table 4.8 shows that the error percentage for the LPG Gas is within a range of 0.12% to 3.85%. This finding means that the two sets of mean LPG are in close agreement. Similarly, the results obtained for the quantity of the oil produced are also within the experimental error except however, one of the results obtained for the quality of oil produced does not agree with the experimental data. Hence that value needs to be investigated if this model may be used for further work.

4.6 The Stresses and Deformation of the Boiler

Figure 4.5 present the 3D model of the steam boiler.

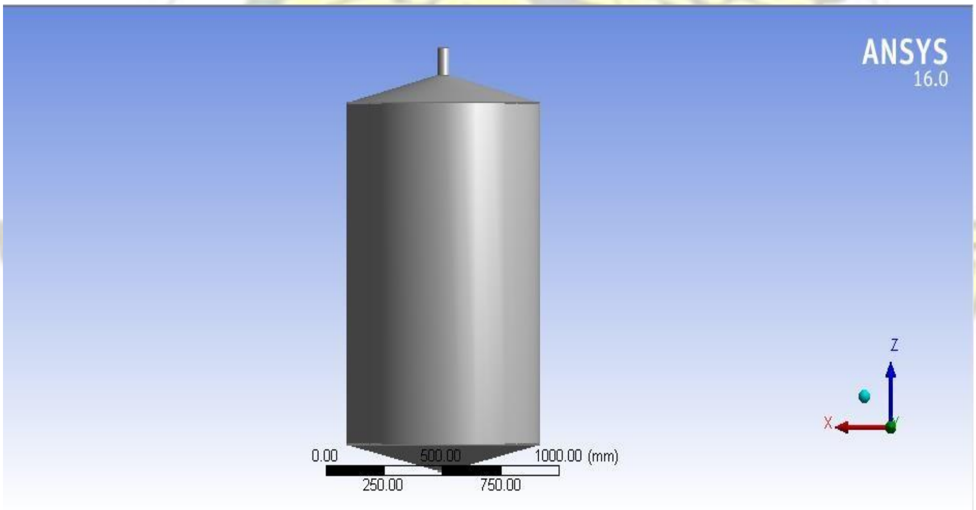


Figure 4.5: 3D model of the steam boiler assembly (surface model)

The result of the static structural total deformation of the Boiler occurred at a maximum of 1.93 mm as shown in Figure 4.6.

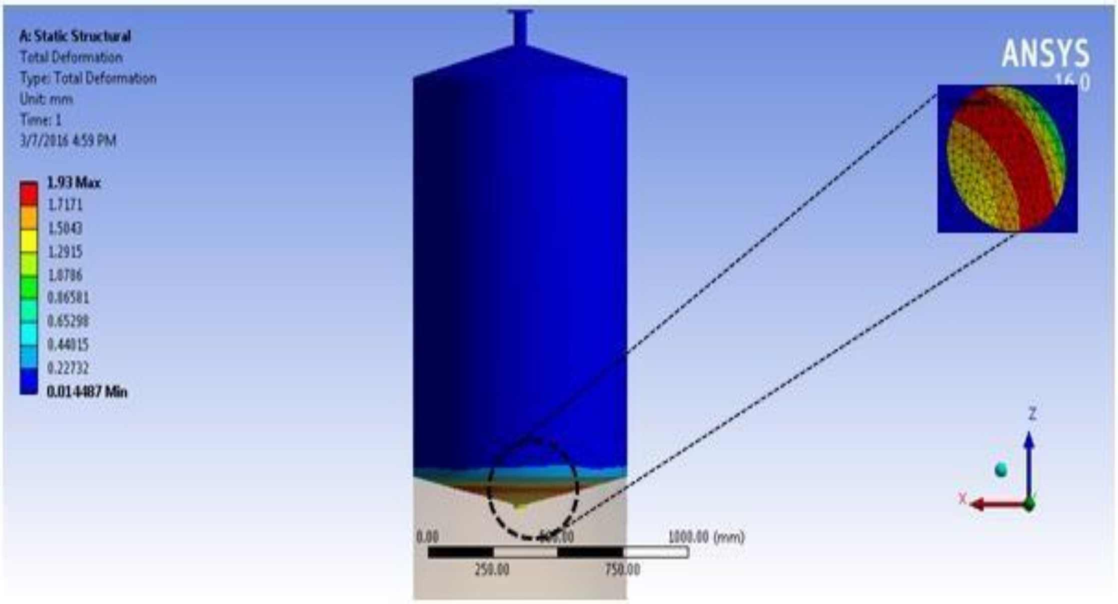


Figure 4.6: Deformation on the boiler

According to the Maximum yield stress theory, for a boiler to be safe for operation, the maximum Von Misses stress on the component should be lower than the yield strength of the material. Figure 4.7 present the results for the maximum Von misses stresses on the operating boiler.

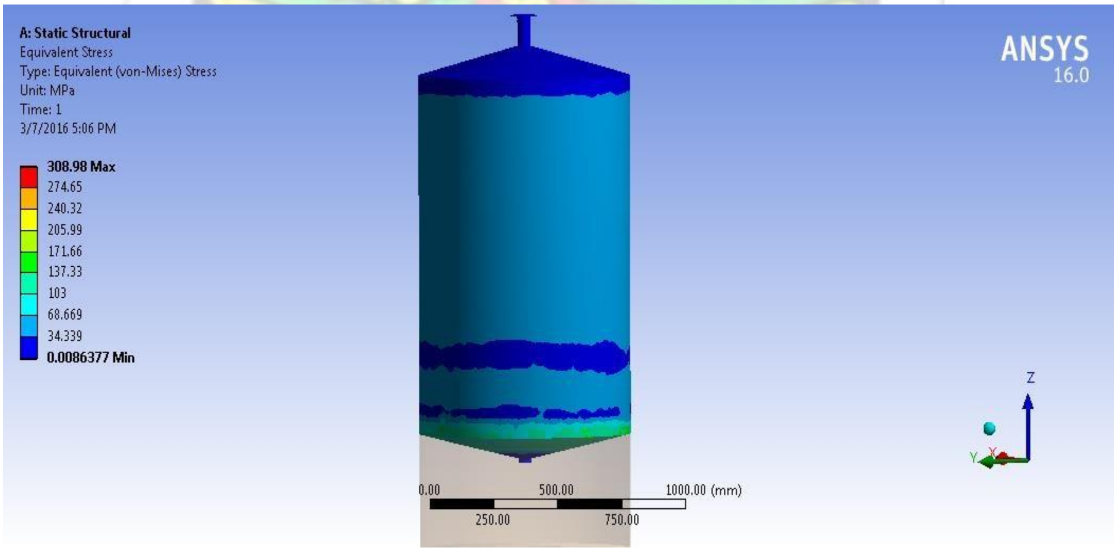


Figure 4.7 Maximum Von misses stresses on the operating boiler.

The result for the normal static structural is also shown in Figure 4.8.

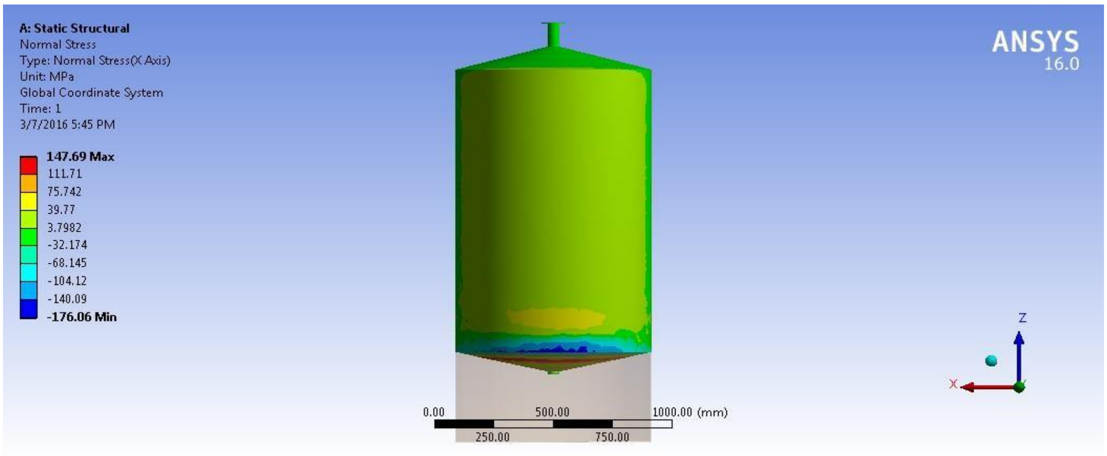


Figure 4.8: Normal Stress on boiler

The maximum tensile stress and deformation are 308.9 MPa and 1.93 mm respectively. From the results, the tensile stress obtained is below the yield strength of the material used. The stresses on the Boiler's top section were at their bearest minimum whilst, the stresses on the whole body of the Boiler was also at minimal values.

Hence according to the Maximum Yield Stress Theory, the Von Misses stress is lower than the yield strength of the material. This is indication that the design of the steam boiler is safe for the above operating condition.

Figure 4.9 present the temperature distribution solution of the steady-state condition of the operating boiler where temperature load of 290 ^{o}C was applied to the furnace.

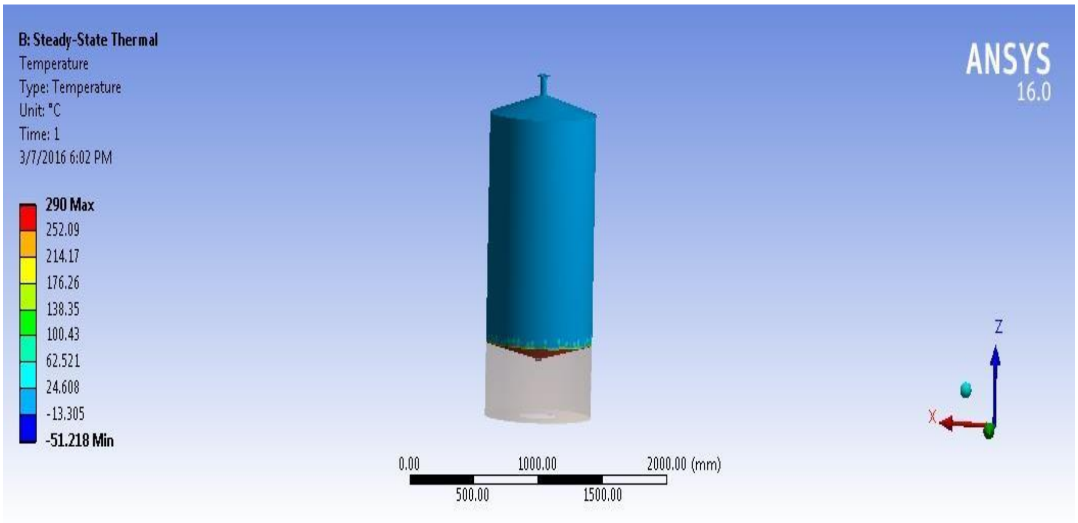


Figure 4.9 Temperature Distribution

Figure 4.10 shows the modal deformation which indicates the total deformation at a frequency of 181.74 Hz and its Equivalent (von-Misses) Stress is shown in Figure 4.11 and the remaining deformation shapes are shown in appendix B.

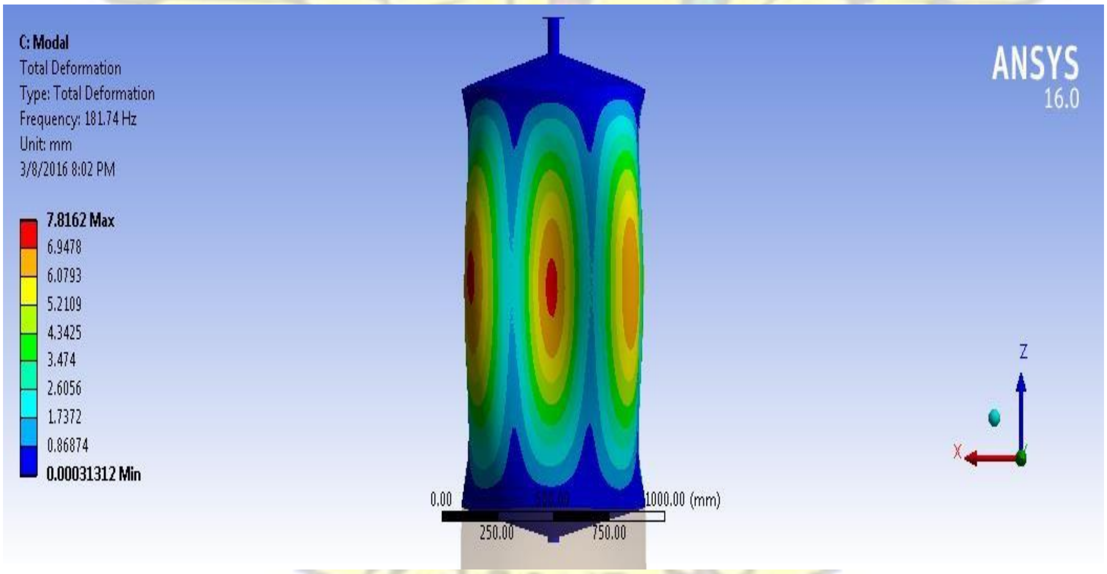


Figure 4.10: Total Deformation

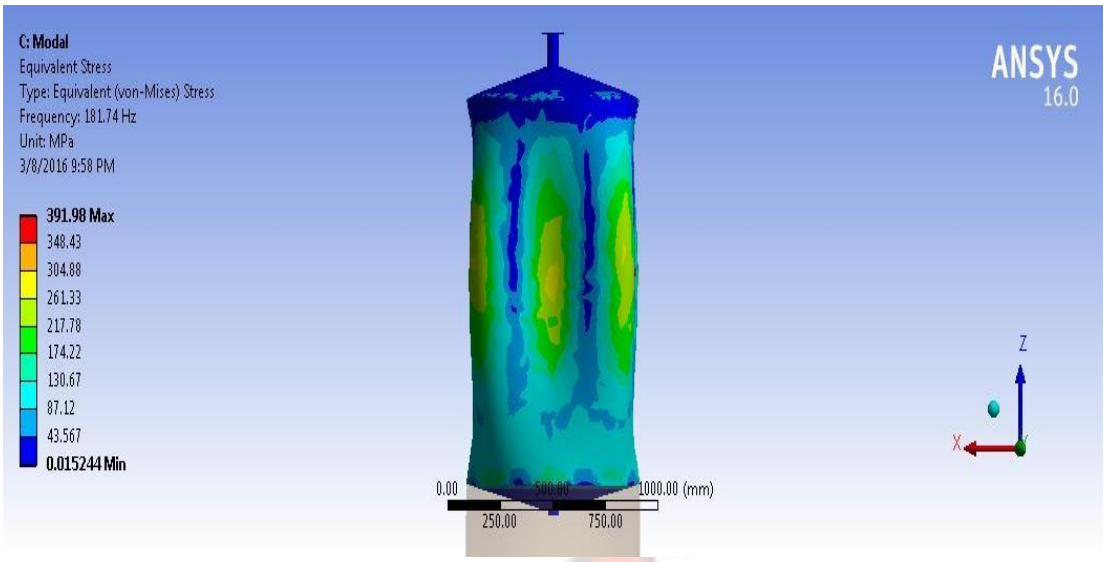


Figure 4.11: Equivalent (Von-Misses) Stress

Table 4.9: Vibration Modes at varying Frequency

Mode	Frequency (Hz)	Deformation (mm) for Maximum values	Von Misses Stresses (MPa) for Maximum values
1	181.74	7.8162	391.98
2	183.69	8.0777	378.78
3	185.33	5.9935	207.43
4	185.35	5.9763	209.77
5	218.32	8.9472	674.39
6	220.60	8.2115	608.75
7	228.22	7.2397	348.33
8	228.73	7.9382	364.77
9	318.03	8.8852	991.03
10	321.61	8.7827	1821.4

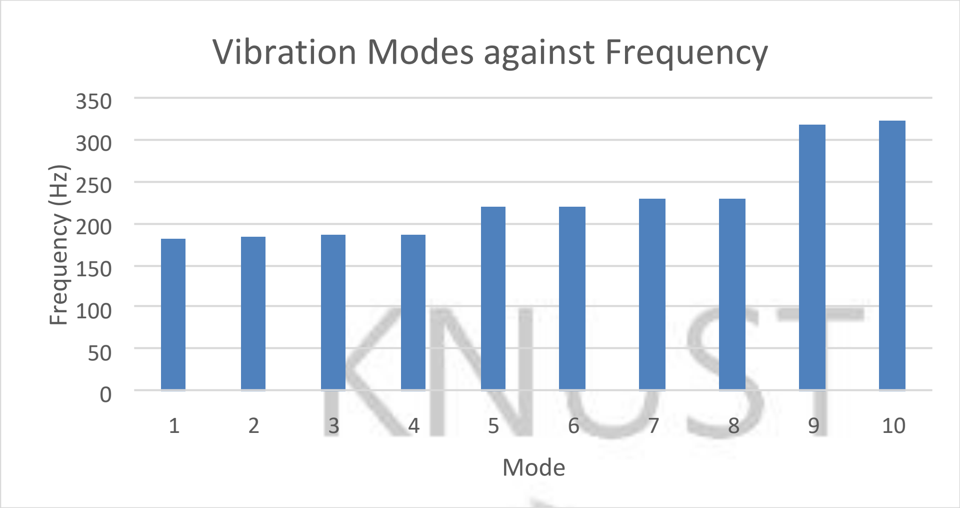


Figure 4.12: Graph of Vibration Modes against Frequency

Figure 4.12 shows a graph of vibration modes against frequencies, which shows clearly that the higher the vibration mode the higher its frequency and the closer its possibility of collapsing.

The maximum tensile stress and deformation for the modal occurs at the side walls of the boiler are 391.90 MPa and 7.8162 mm respectively which occurred at a frequency of 181.74 Hz which is below maximum tensile stress of chosen material.

The stresses on the Boiler's top section were at their bearest minimum whilst, the stresses on the whole body of the Boiler was also at minimal values. Permissible frequency range for the operation of steam boilers from literature is between 50-60 Hz. From the results, the minimum ANSYS frequency is 181.74 Hz which is greater than the permissible frequency range of the boiler. Hence the design of the steam boiler assembly is safe for the operating condition.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

The objective of this study was to design and optimized lemon grass oil extractor. The specific objectives were: (i) to design a mechanical system that will be used to extract hydrosol from lemon grass and to separate the oil from the hydrosol. (ii) to determine the quality and chemical composition of the lemon grass oil using chemical and Gas Chromatography Mass spectrometry tests. (iii) to optimize the oil extractor using factorial design technique to predict effects of process parameters on extraction and finally (iv) to optimize the oil extractor using finite element approach (ANSYS) to determine the stresses and deformation on the boiler. From the results, the following were some findings of the study.

5.1 Findings

(i) It can be concluded that the optimized machine can be used to extract lemon grass oil from the leaves and its efficiency ranges from 2.37 to 3.95 ml/kg.

(ii) The oil produced is pure and the machine seems to be economically viable, effective and efficient.

(iii) The mass of the lemon grass, the flow of the LPG and the interaction of the mass of grass and flow of have significant effect on the amount of LPG used. Hence, the empirical model for the LPG (Q).

(iv) The mass of lemon grass, the operating pressure and the interaction of the mass of grass and flow of LPG have significant effect on the quantity of the oil obtained. Hence, the empirical model for the quantity oil (q).

(v) The operating pressure and the interaction of the mass of grass and flow of LPG have significant effect on the quality of the oil obtained. Hence, the empirical model for the quantity of oil (C).

(vi) The quality of oil obtained from the GC-MS experiment conducted shows a great variation of the quality of the oils.

(vii) The steam boiler has stresses and deflections within the design limits of the material used. Hence, the designed steam boiler is safe under the given operating conditions.

(viii) One of the results obtained for the quality of oil produced does not agree with the experimental data. Hence that value needs to be investigated if this model may be used for further work.

5.2 Conclusions

It can be concluded that;

The design and optimization of lemon grass oil extractor using the direct steam distillation technique was carried out. It can be concluded that;

(i) The prototype machine developed can be used to extract lemon grass oil from the leaves of lemon grass and its efficiency ranges from 2.37 to 3.95 ml/kg. The oil produced is pure and the machine seems to be economically viable, effective and efficient.

(ii) The significant effects were used to developed models that relate the operating condition of the responds variables. These models can be used to monitor, forecast and control the operation parameters or process of the extraction.

(iii) Finite element software (ANSYS) was used to model the lemon oil extractor. The result obtained shows a maximum tensile stress and deformation of the boiler as 308.90 MPa and 1.93 mm respectively. From the results, the tensile stress obtained is below the yield strength of the material used which is safe for operation under those conditions according to Maximum yield stress theory.

(iv) The quality tests performed show that, there were no indication of solubility in water, meaning positive results is attained; hence, the sample is pure oil. Sudan IV test, grease spot test, and emulsification test also responded positive given an indication of the pureness of the oil. The Gas Chromatography Mass Spectrometry test results show a higher citral value of the oil of 43.56 %. It can be concluded that, the objective of designing and optimizing lemon grass oil extractor was achieved and the model can be used to predict effects of process parameters on extraction of lemon grass oil.

5.3 Recommendations

From the results and analysis, it is recommended that the boiler be

- Lag to avoid heat losses by convection. ➢ Extraction should carry out during raining season.
- It is recommended that, further extraction be done taking into consideration the age of the grass
- Further extraction work be done taking into consideration the amount of rainfall the lemon grass receives.

- Further work should be carried out taking into consideration the soil in which the lemon grass is coming from.
- It is recommended that, further work be done on the results obtained for the value of the quality of oil produced which does not agree with the experimental data to ascertain its cause.

For commercial application, the direct steam technique is recommended because it eliminates contaminant in the oil and also environmentally friendly. Ghana government through its poverty eradication strategy should inculcate or encourage private individuals to set up small scale industries for the extraction of lemon grass oil. This would not only reduce the problem of unemployment in the country but also meet the high demand of this God given commodity and increase the Gross domestic product (GDP) of the country.

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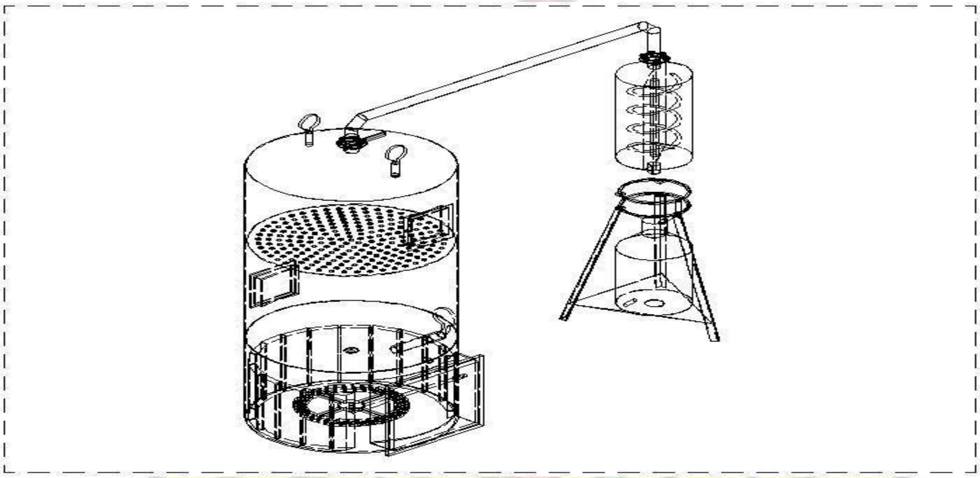
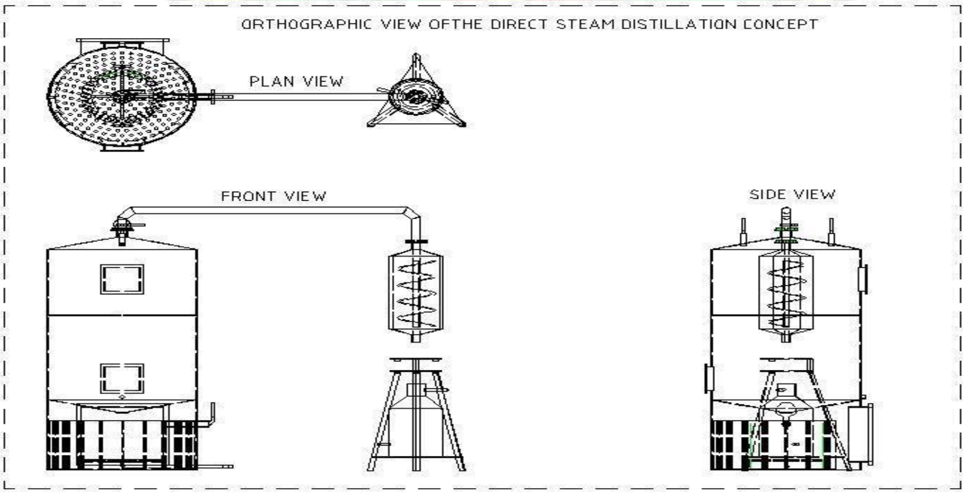
APPENDICES

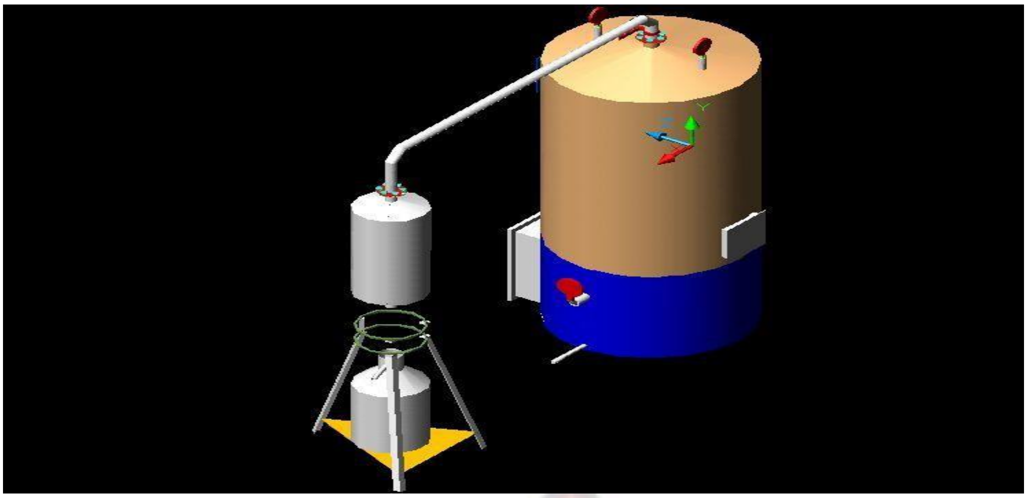
APPENDIX A: Cross Sectional Views of the Direct Steam Lemon Grass Oil Extractor



APPENDIX A1: Skeletal view of the direct steam concept



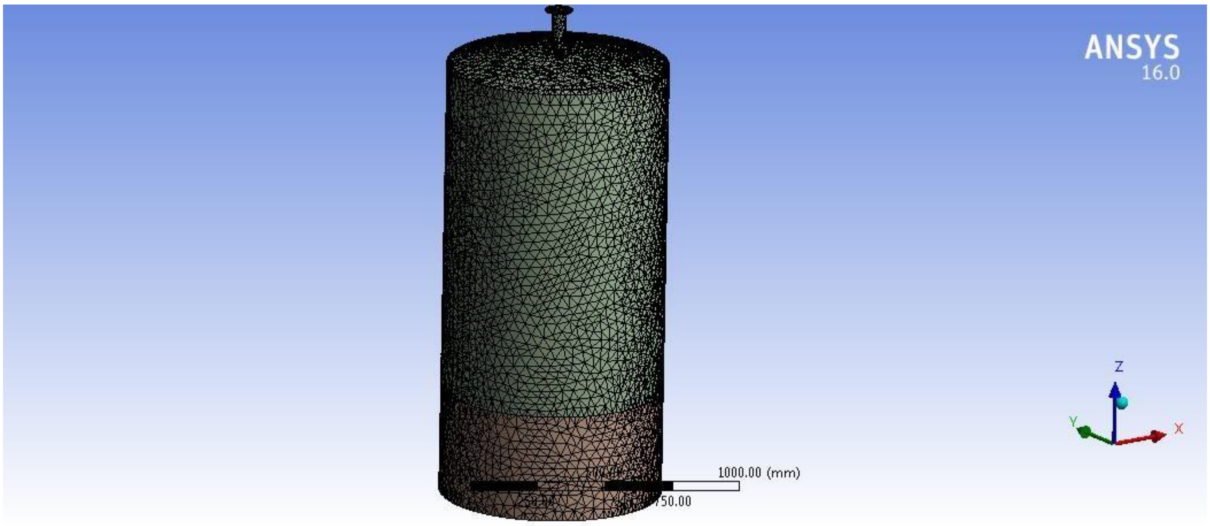
APPENDIX A2: Orthographic Drawings of the Direct Steam Concept



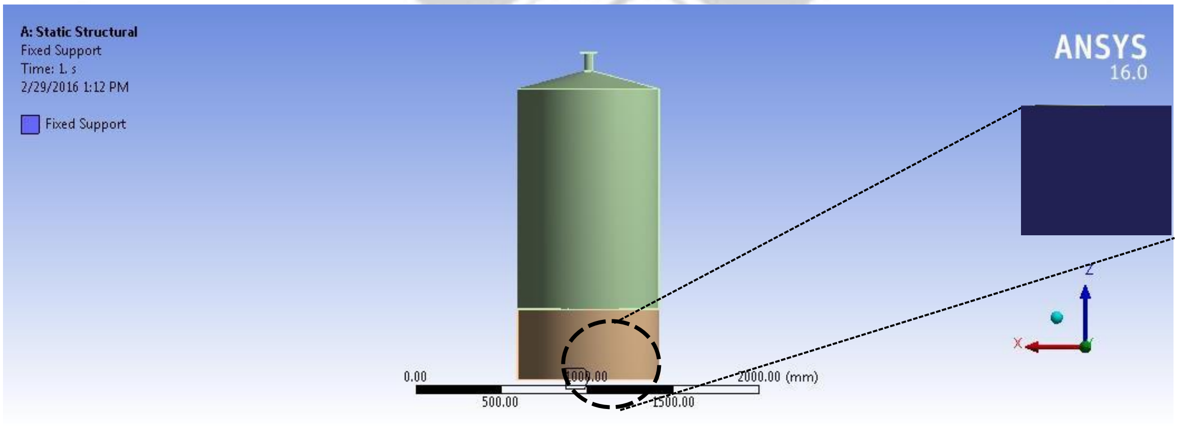
APPENDIX A3: Pictorial View of the Direct Steam Concept

APPENDIX A4: A Picture of a Cylinder on a scale With Flow Meter

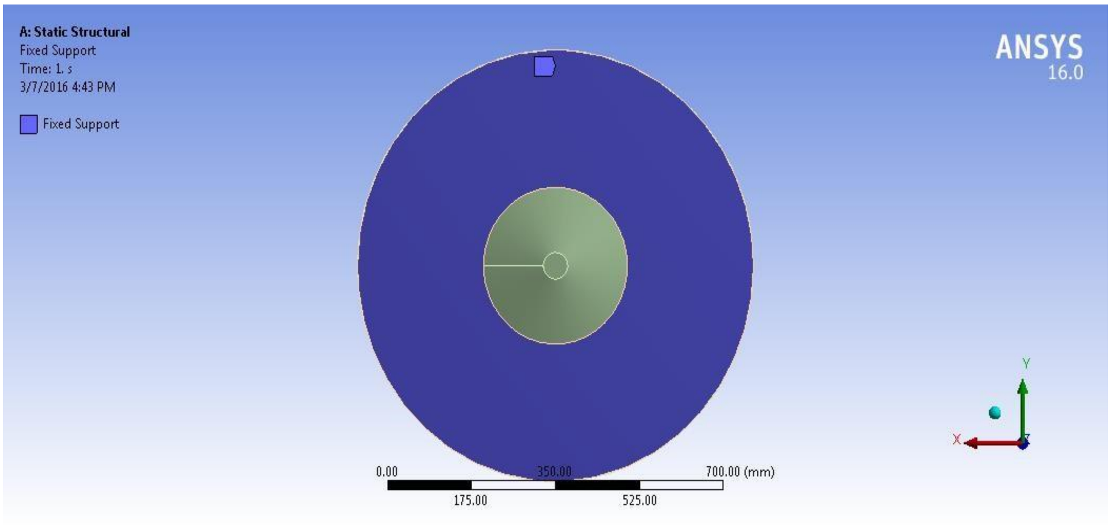
APPENDIX B: DESIGN SIMULATION AND ANALYSIS FOR ANSYS



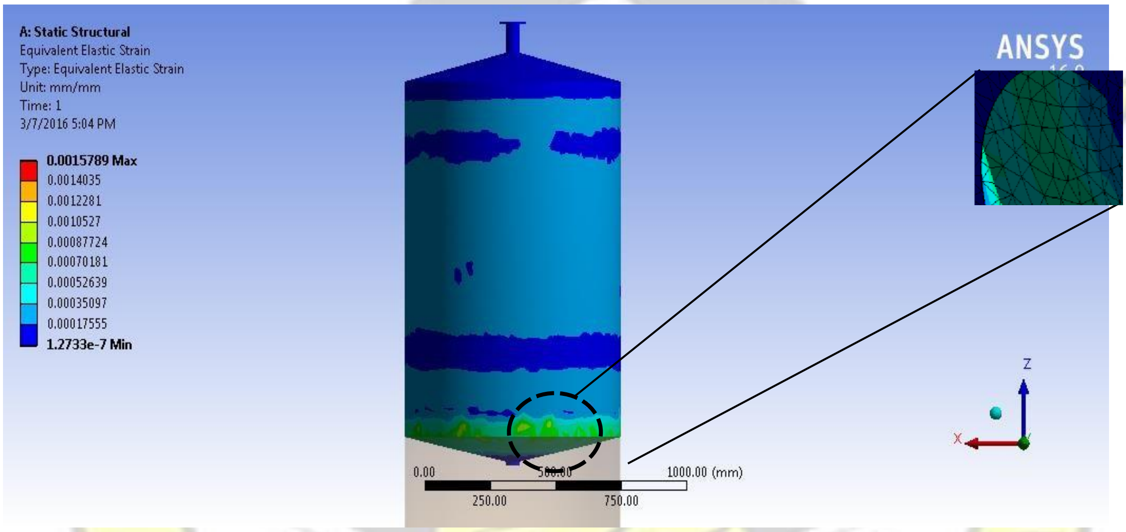
APPENDIX B1: Meshed Boiler Mounted on a Furnace



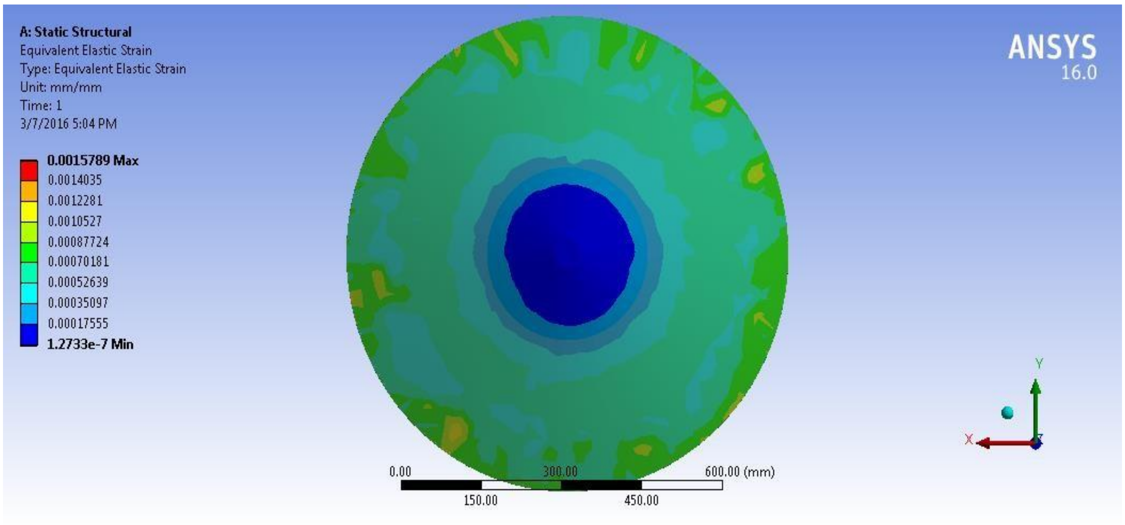
APPENDIX B2: Fixed support assigned to furnace.



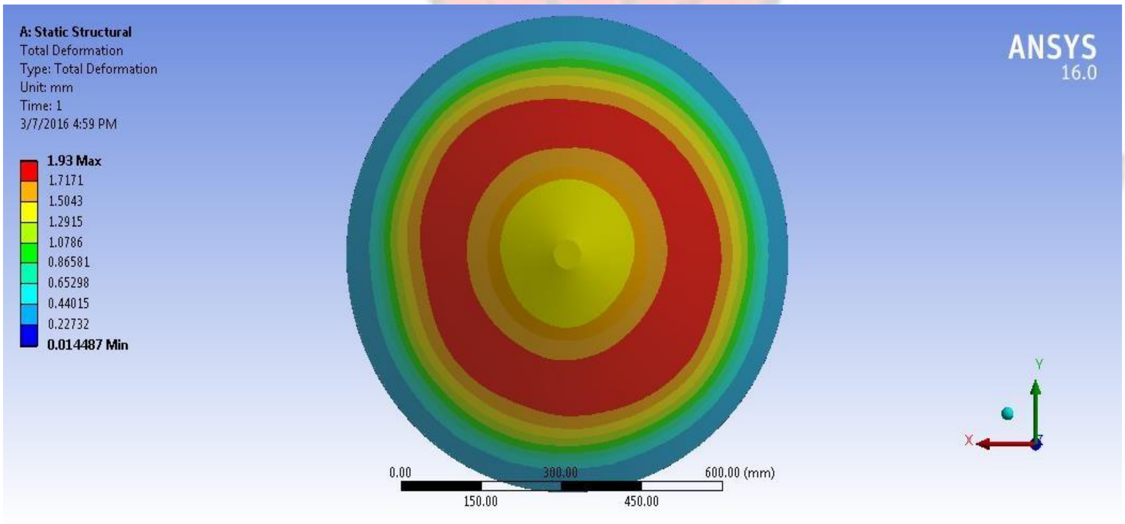
APPENDIX B3: Fixed Support assigned to the base of the Furnace of Boiler



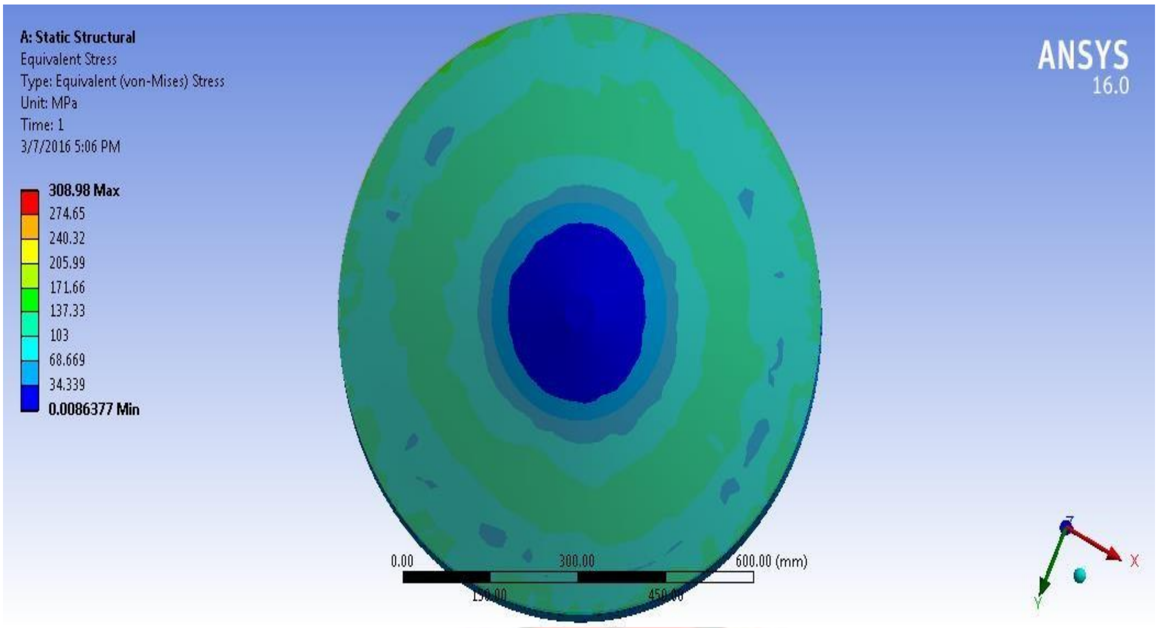
APPENDIX B4: Equivalent Elastic strain on boiler



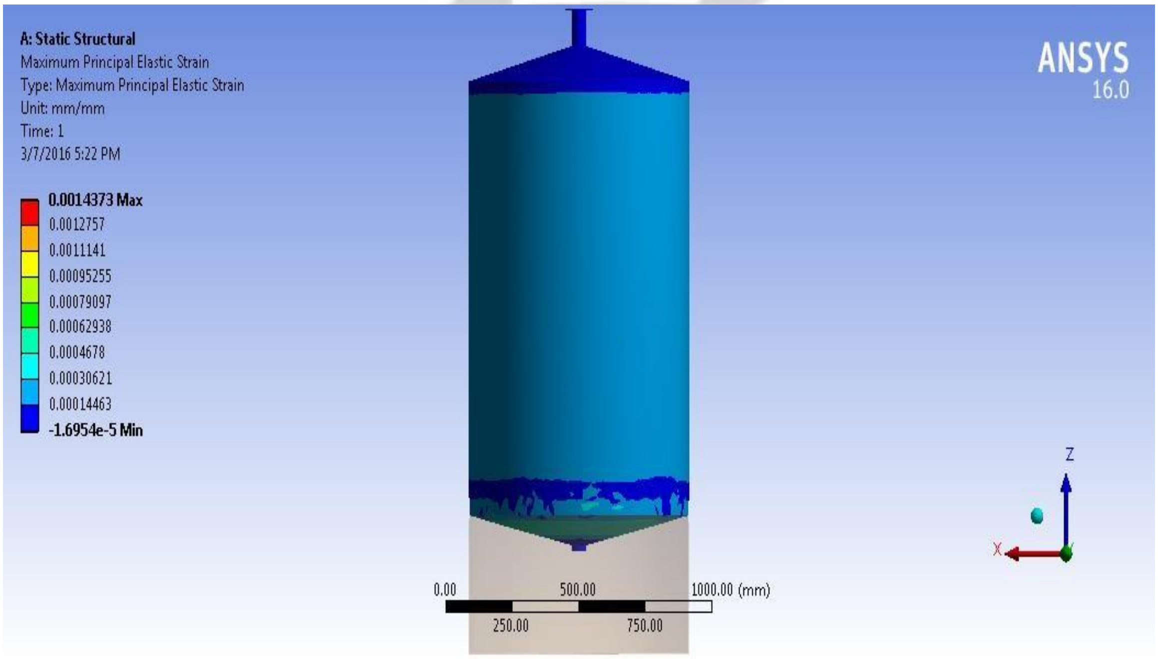
APPENDIX B5: Equivalent Elastic strain on boiler base



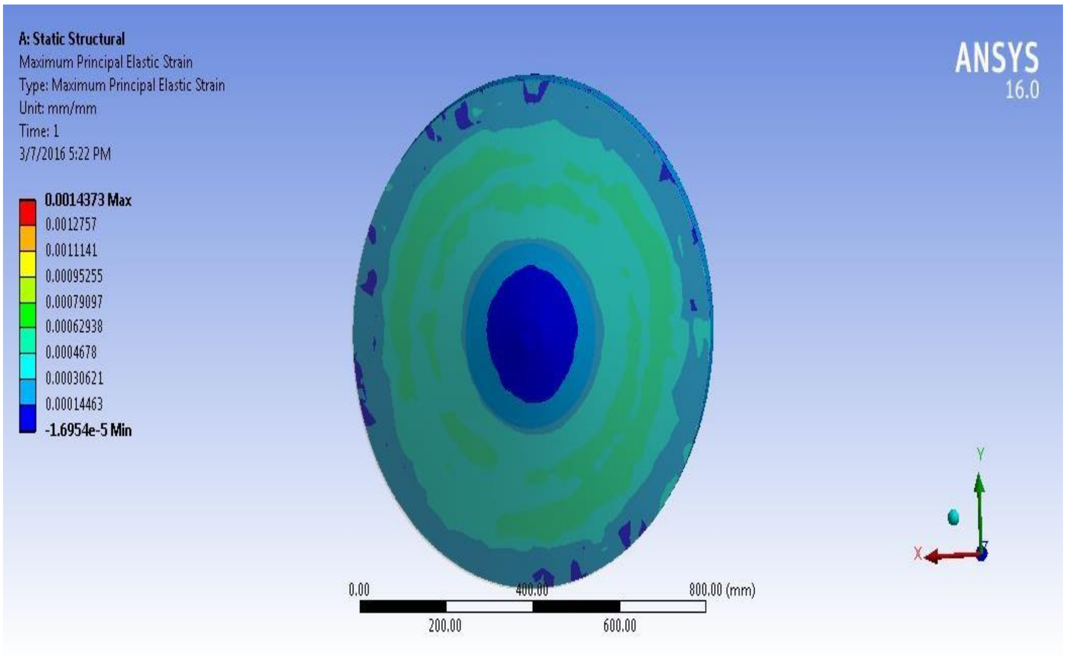
APPENDIX B6: Deformation on boiler base



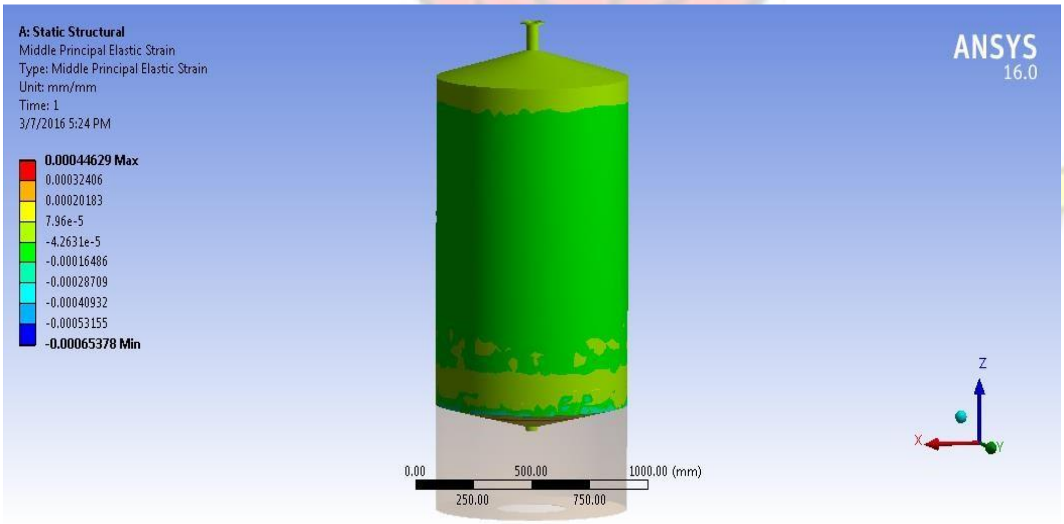
APPENDIX B7: Equivalent (von-Misses) Stress on boiler base



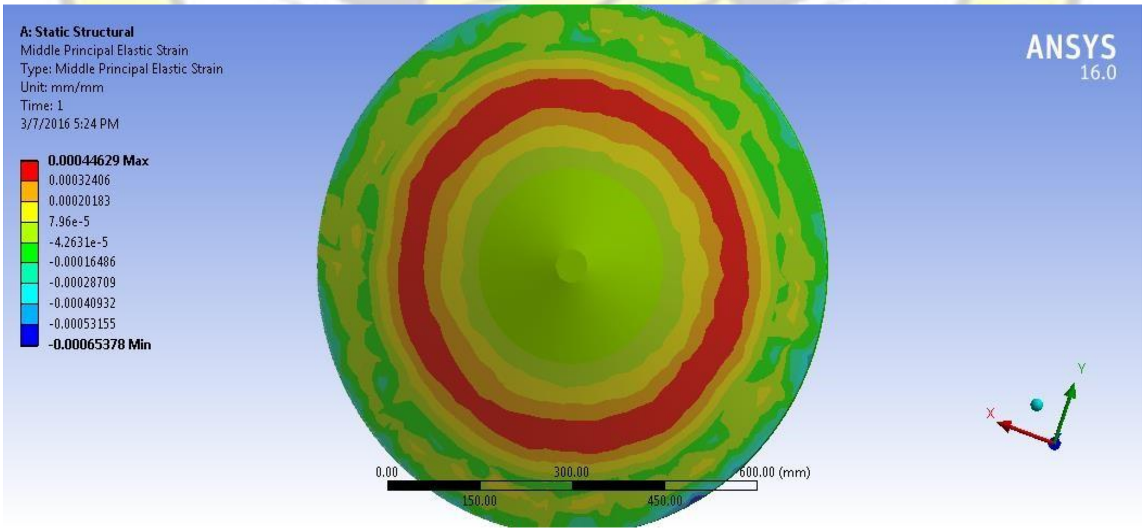
APPENDIX B8: Maximum Principal Elastic Strain on boiler



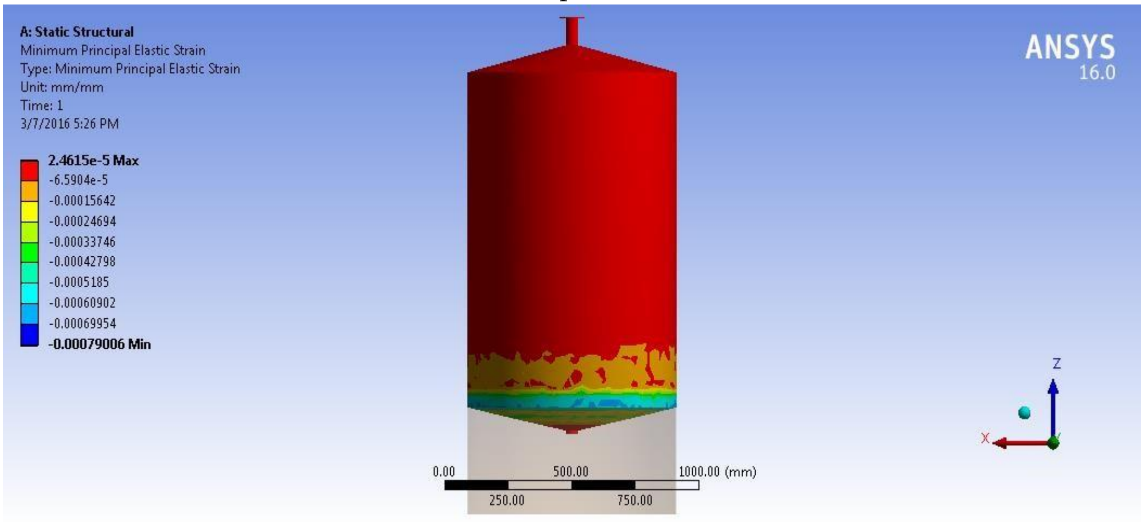
APPENDIX B9: Maximum Principal Elastic Strain on boiler base



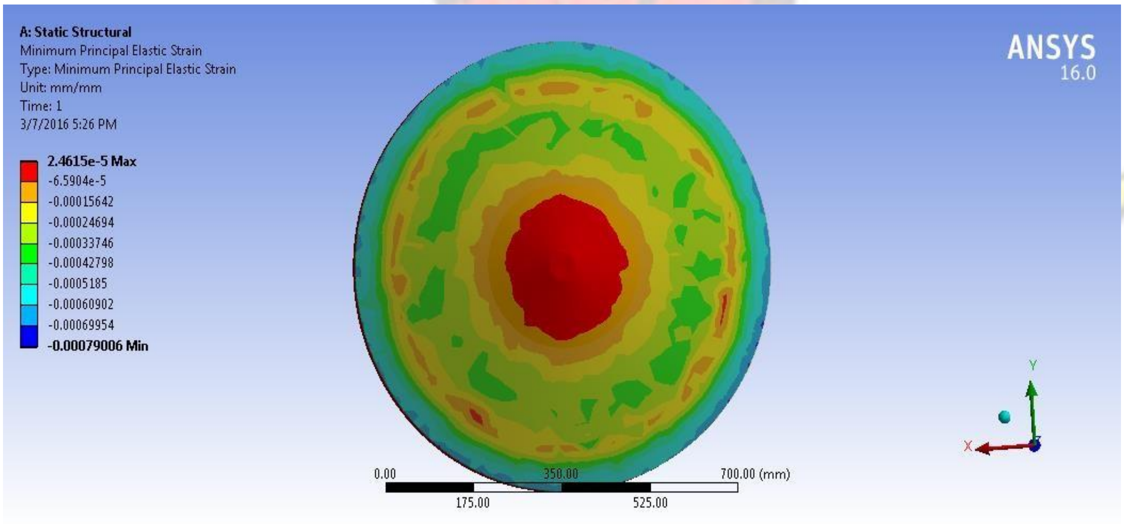
APPENDIX B10: Middle Principal Elastic Strain on boiler



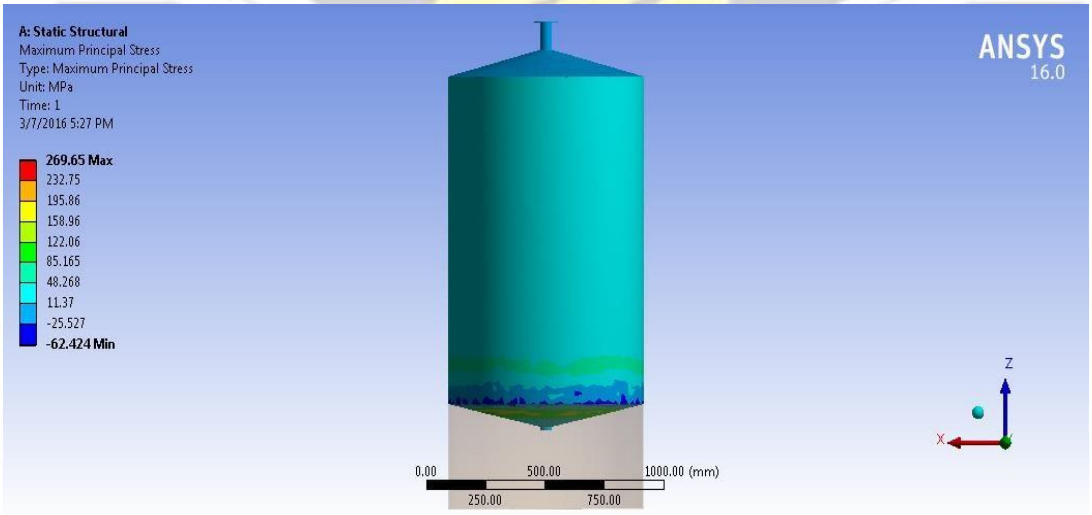
APPENDIX B11: Middle Principal Elastic Strain on boiler base



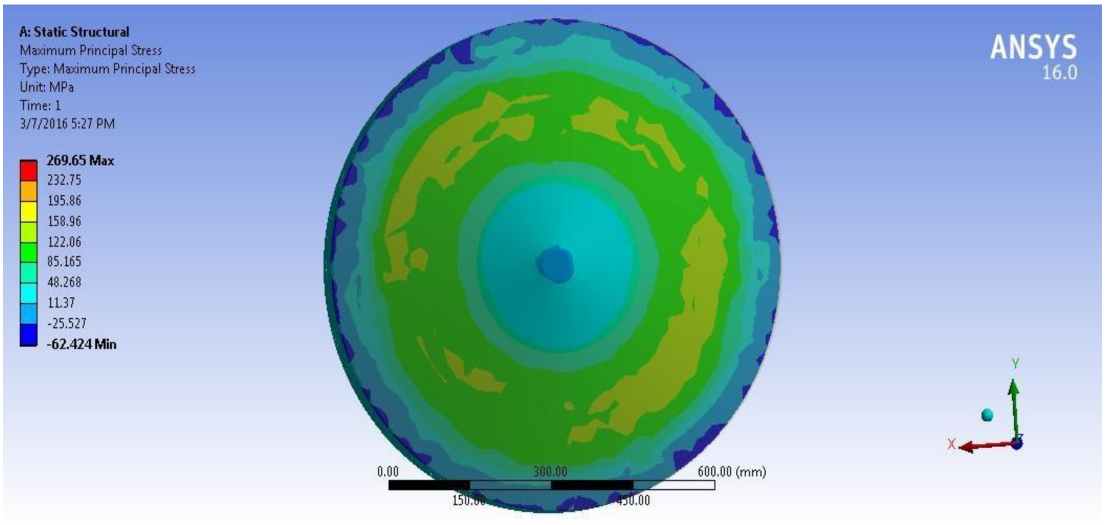
APPENDIX B12: Minimum Principal Elastic Strain on boiler



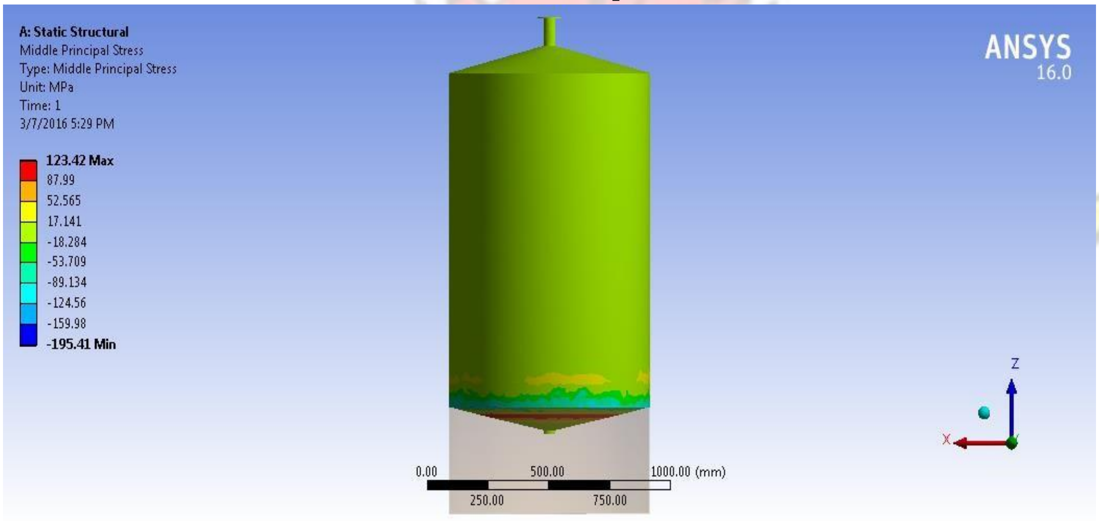
APPENDIX B13: Minimum Principal Elastic Strain on boiler base



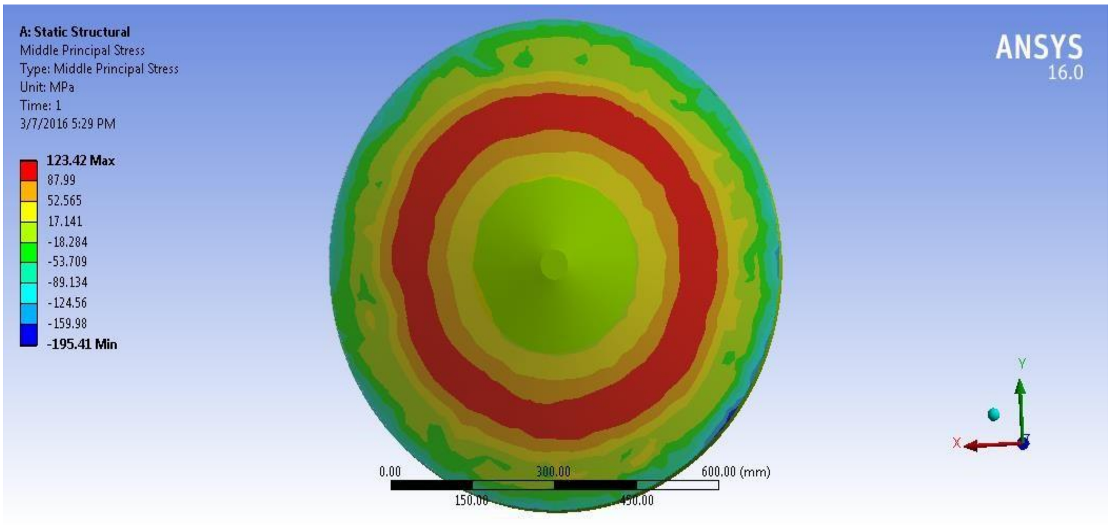
APPENDIX B14: Maximum Principal Stress on boiler



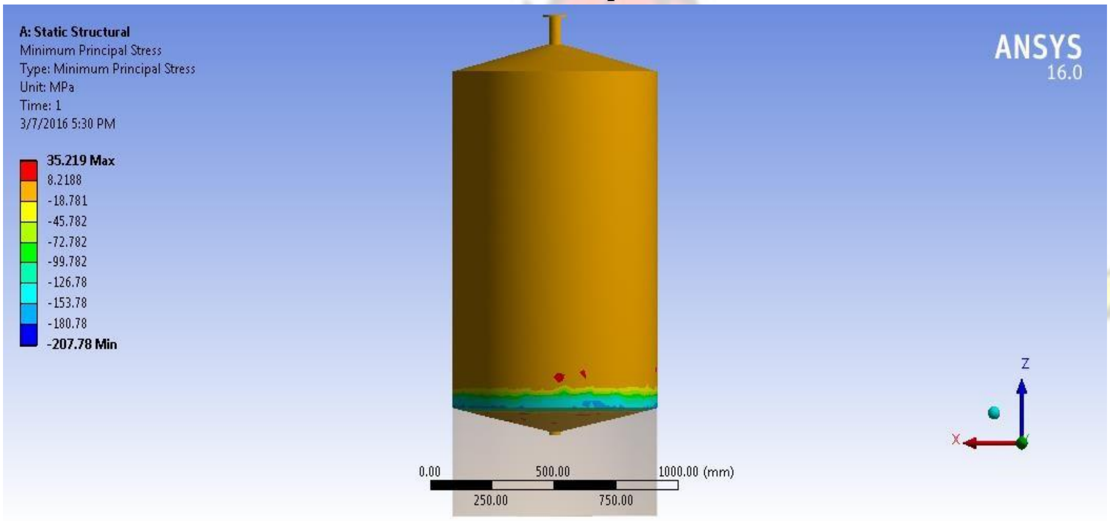
APPENDIX B15**:** Maximum Principal Stress on boiler base



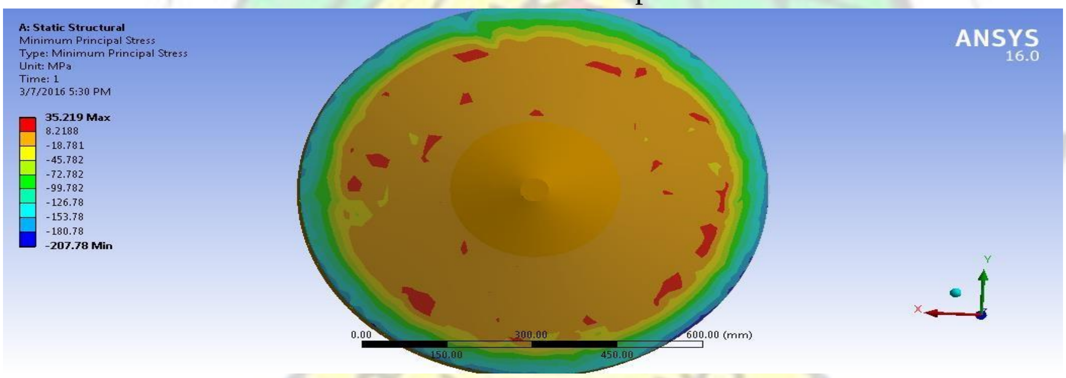
APPENDIX B16: Middle Principal Stress on boiler



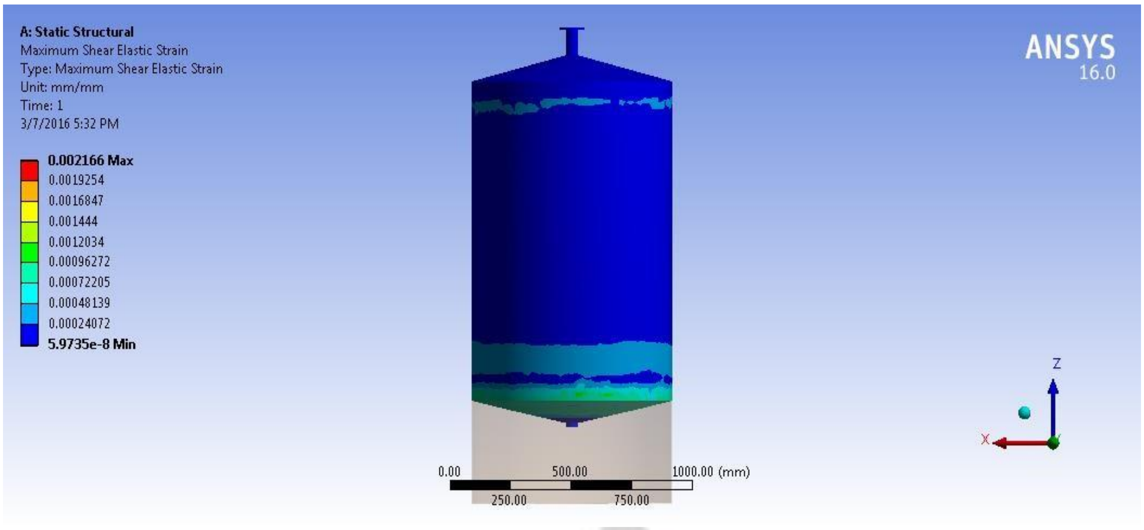
APPENDIX B17: Middle Principal Stress on boiler base



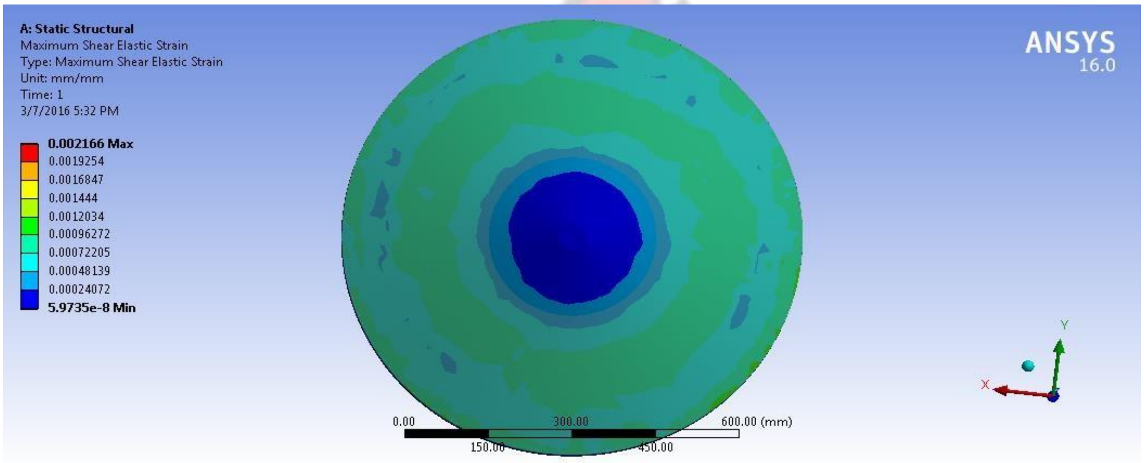
APPENDIX B18: Minimum Principal Stress on boiler



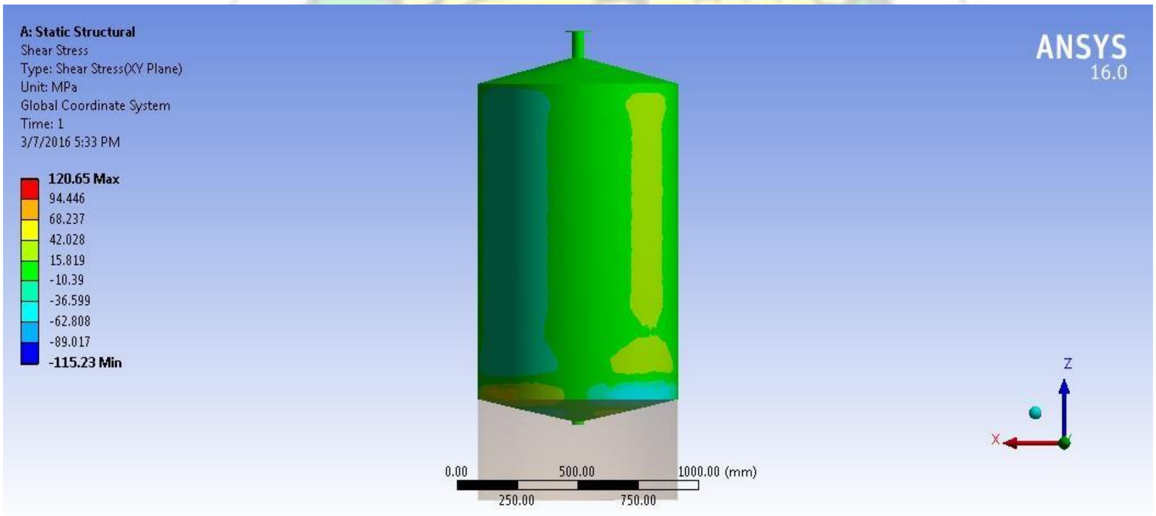
APPENDIX B19: Minimum Principal Stress on boiler base



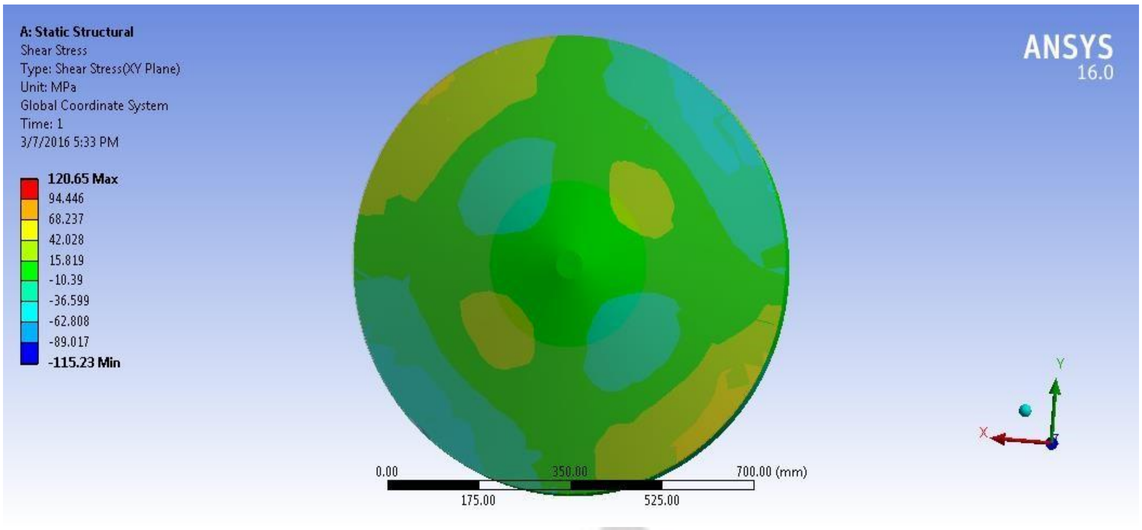
APPENDIX B20: Maximum Shear Elastic strain on boiler



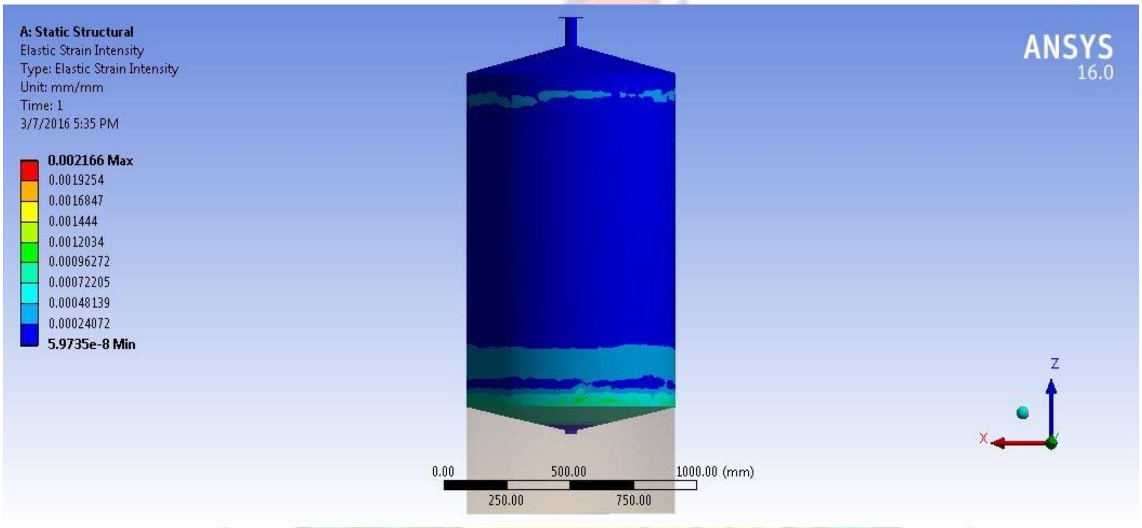
APPENDIX B21: Maximum Shear Elastic strain on boiler base



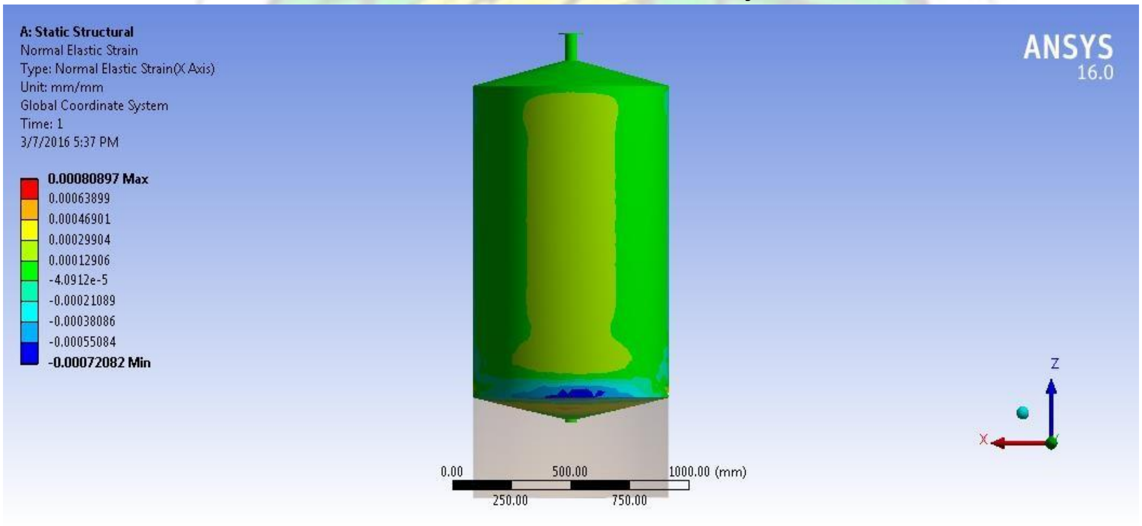
APPENDIX B22: Shear Stress on boiler



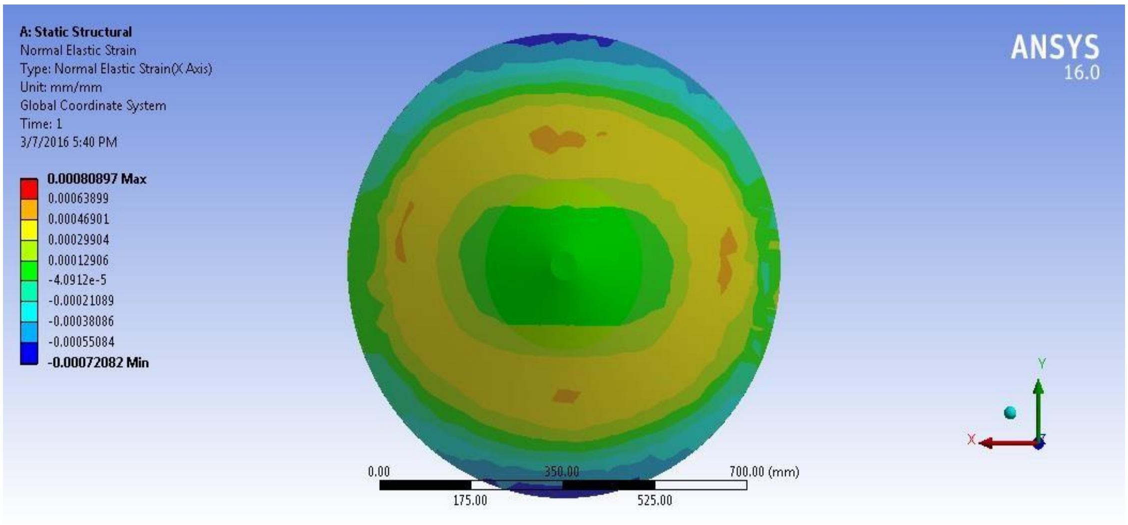
APPENDIX B23: Shear Stress on boiler base



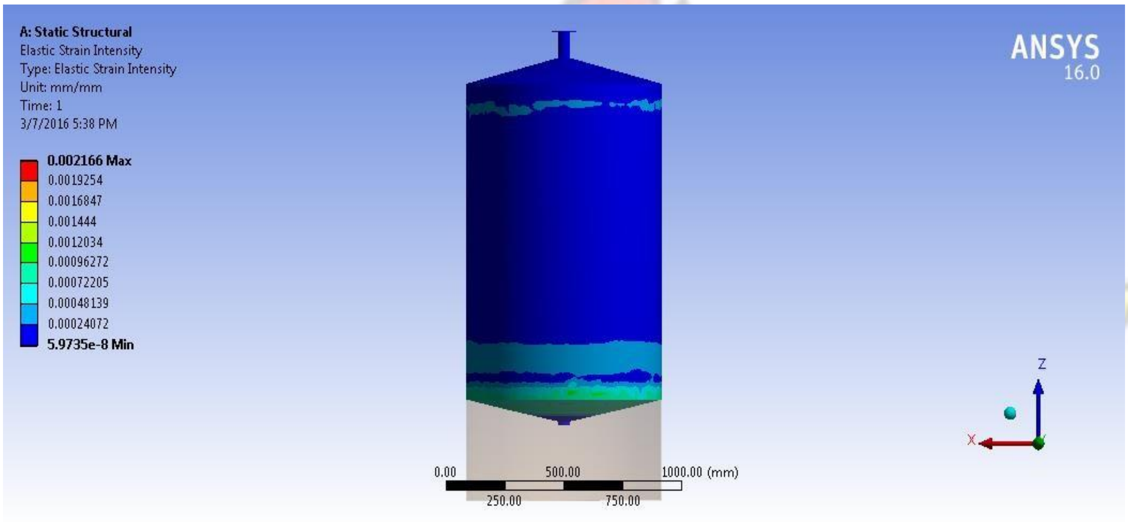
APPENDIX B24: Elastic Strain Intensity on boiler



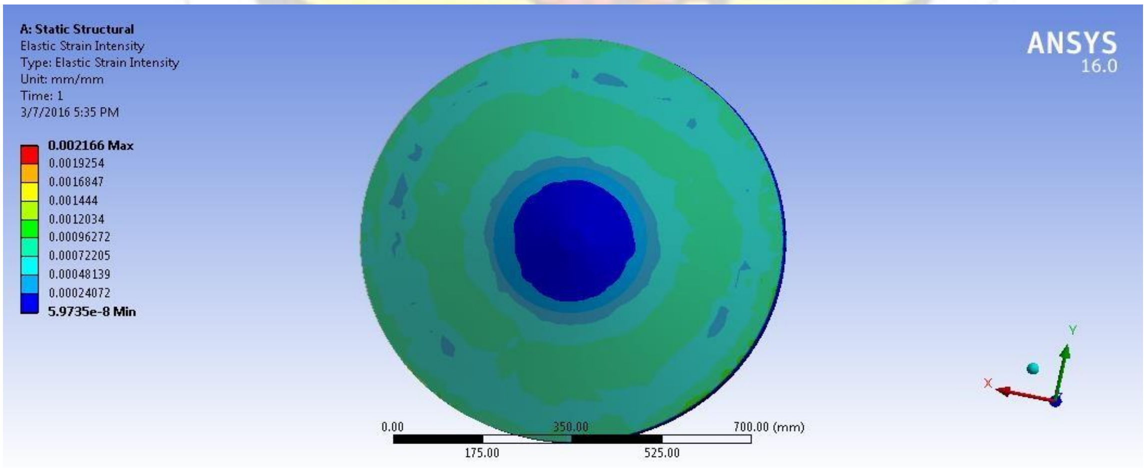
APPENDIX B25: Normal Elastic Strain on boiler



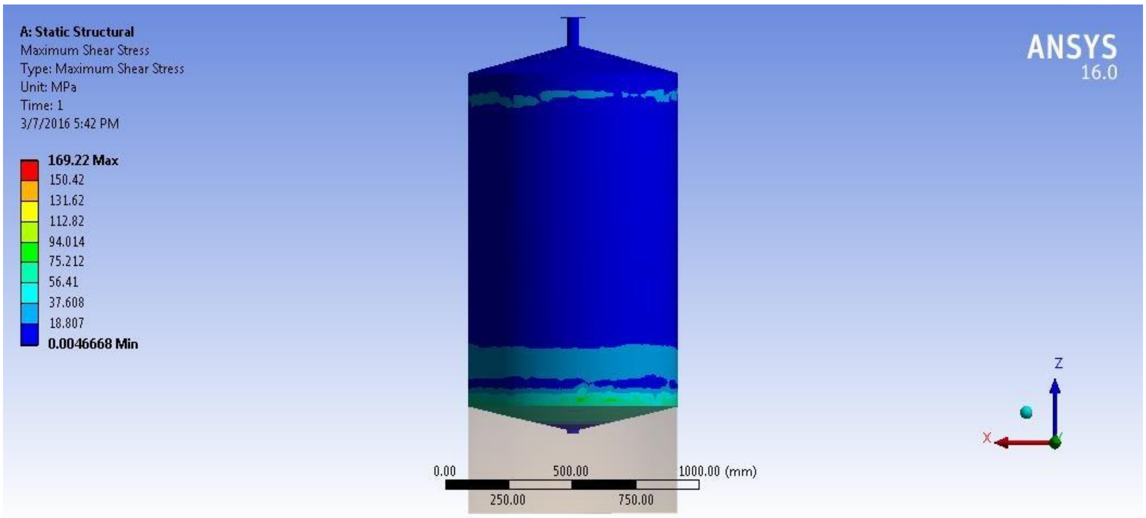
APPENDIX B26: Normal Elastic Strain on boiler base



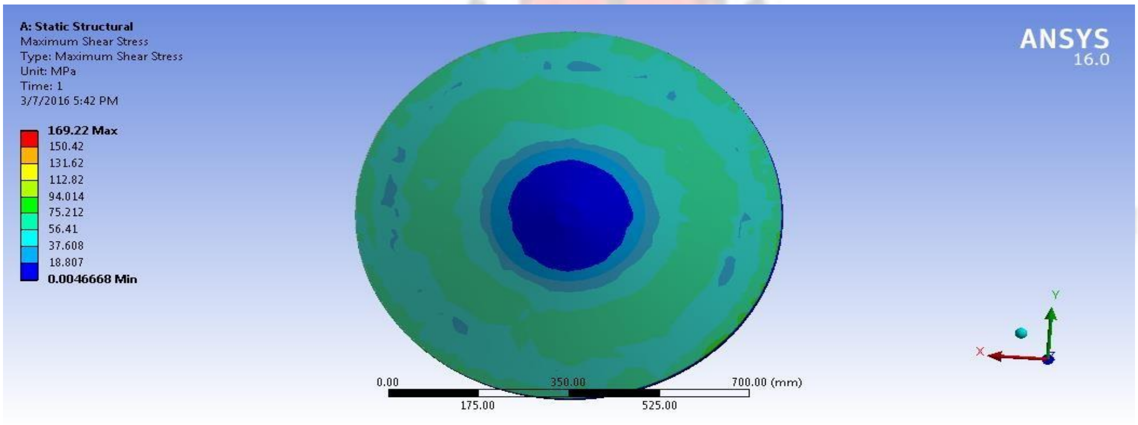
APPENDIX B27: Strain Intensity on boiler



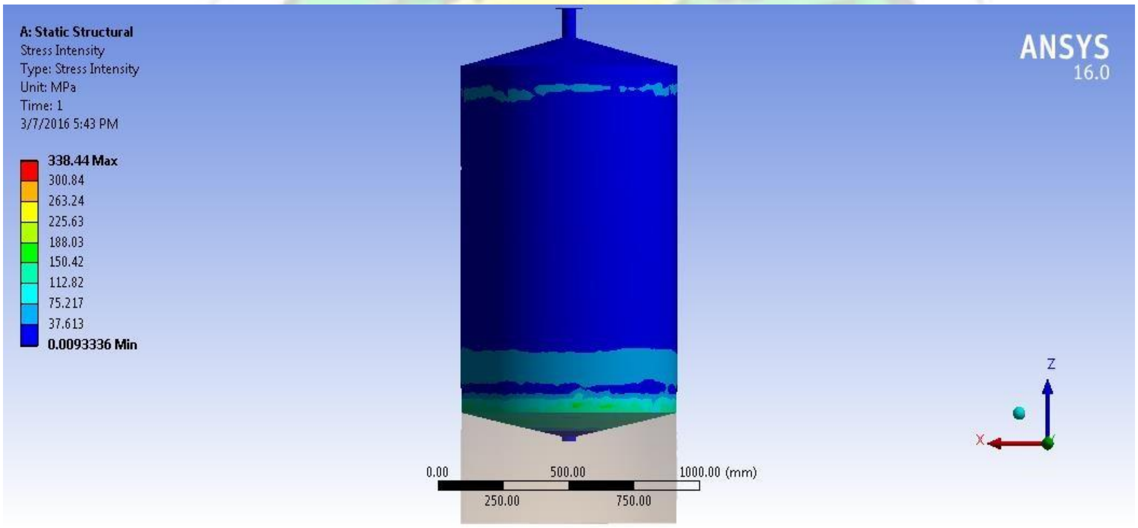
APPENDIX B8: Strain Intensity on boiler base



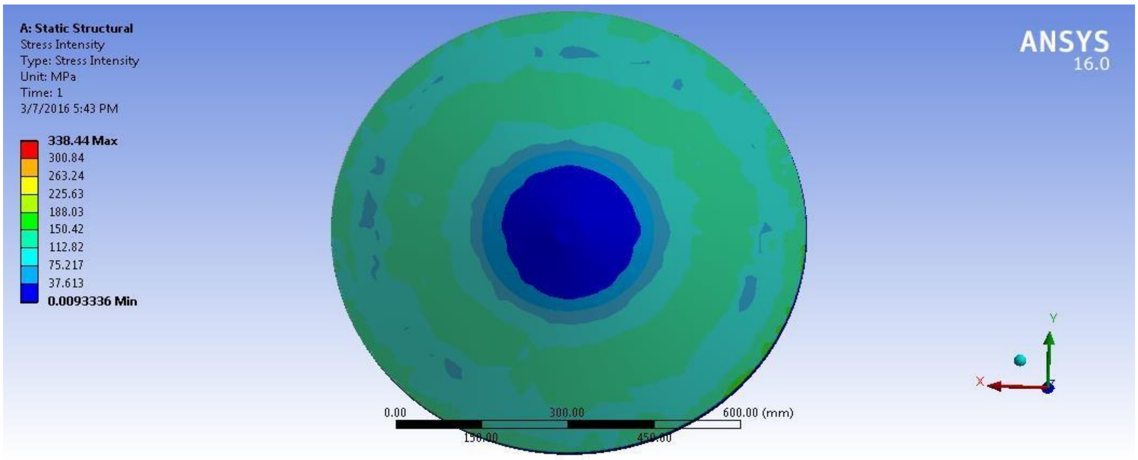
APPENDIX B29: Maximum Shear Stress on boiler



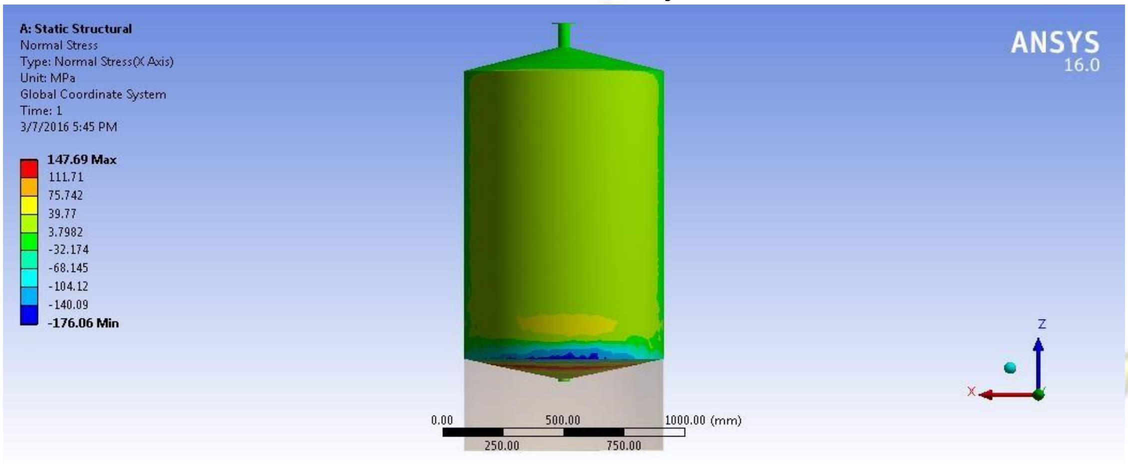
APPENDIX B30**:** Maximum Shear Stress on boiler base



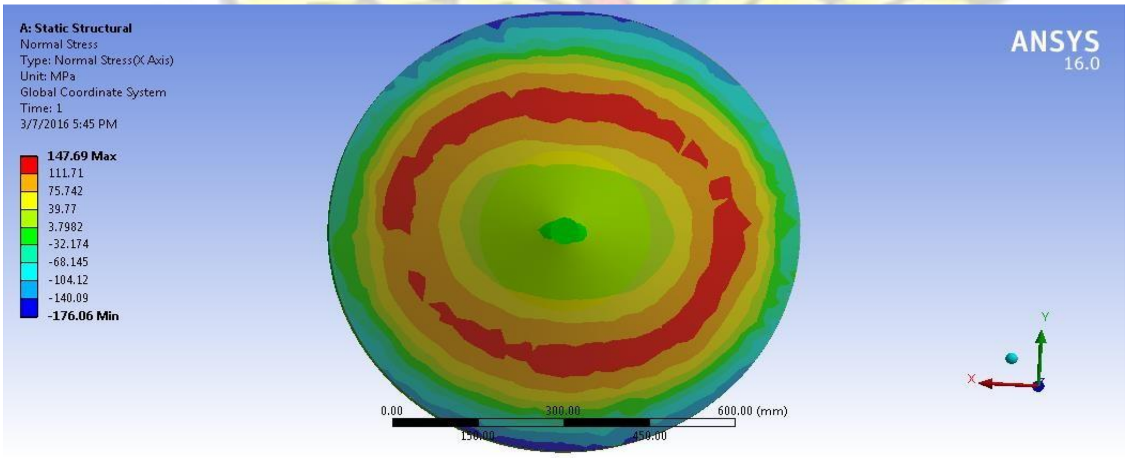
APPENDIX B31: Stress Intensity on boiler



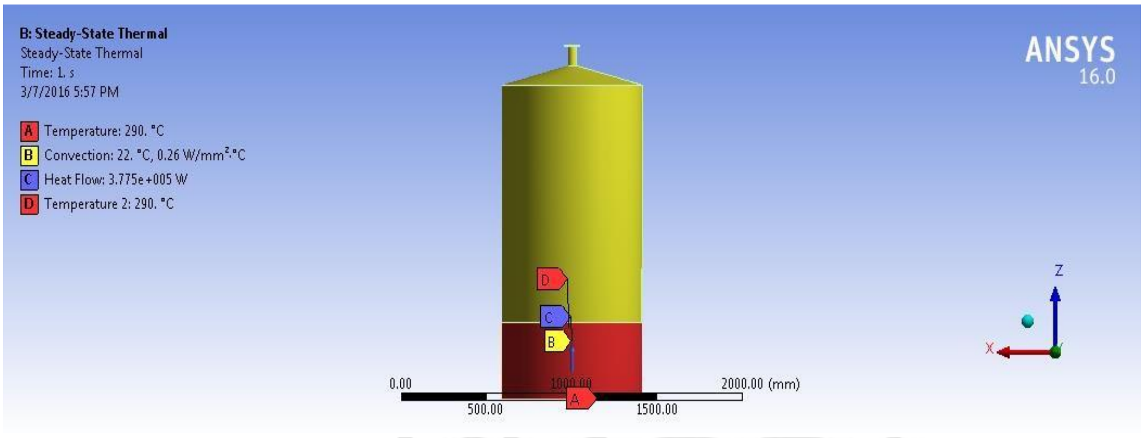
APPENDIX B32: Stress Intensity on boiler base



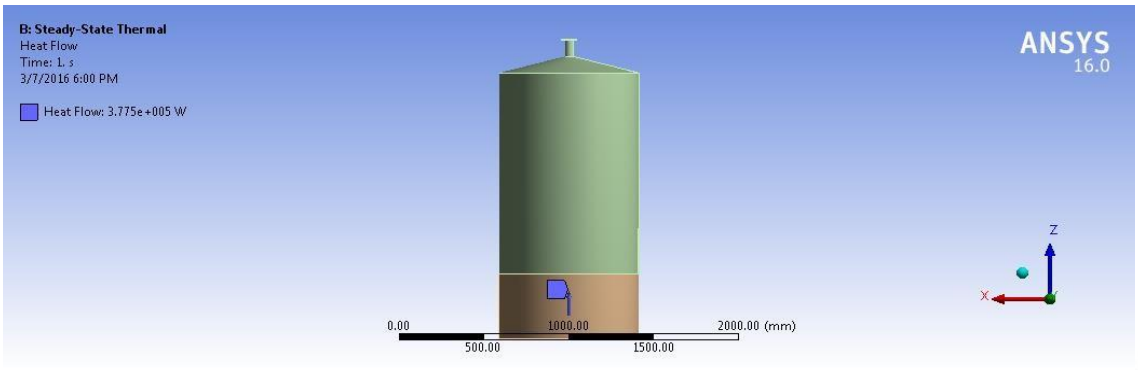
APPENDIX B33: Normal Stress on boiler



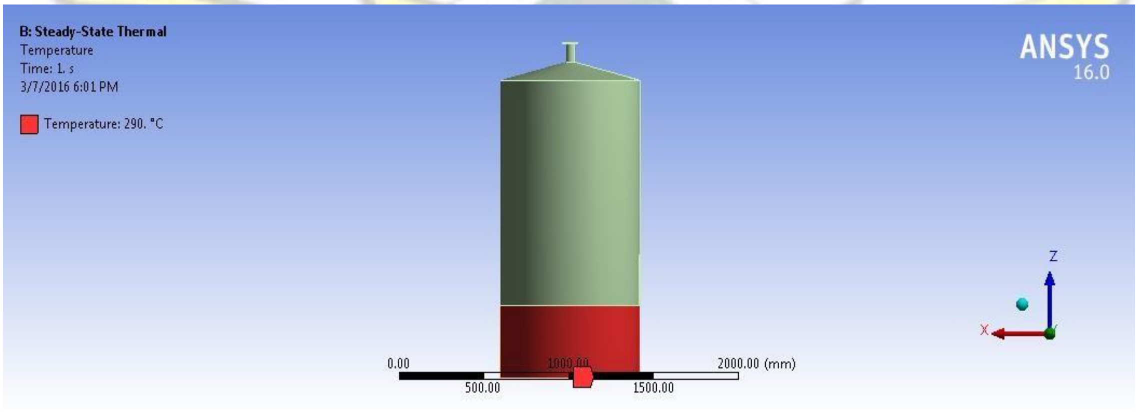
APPENDIX B34: Normal Stress on boiler base



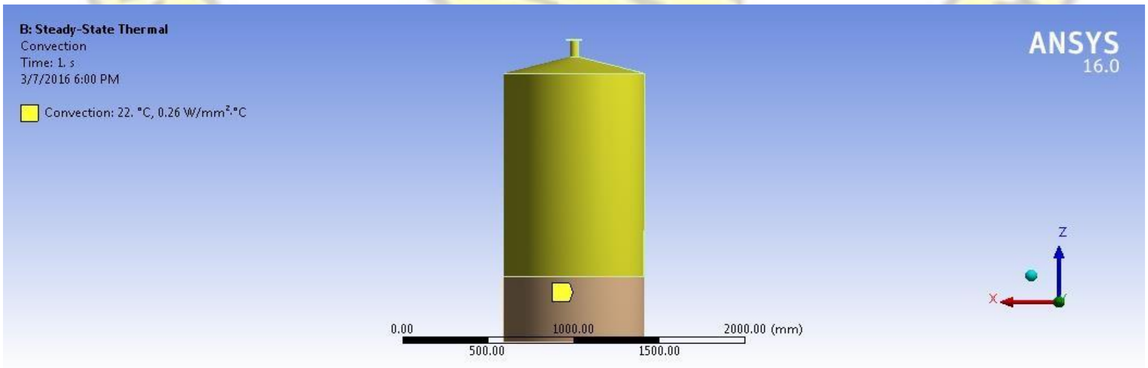
APPENDIX B35: Steady State Thermal input parameter assignment.



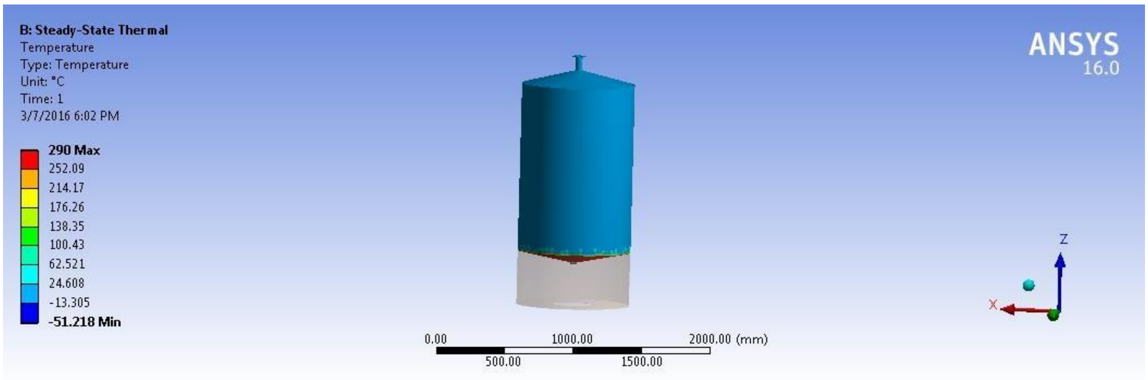
APPENDIX B36: Steady State Thermal Heat Flow assignment.



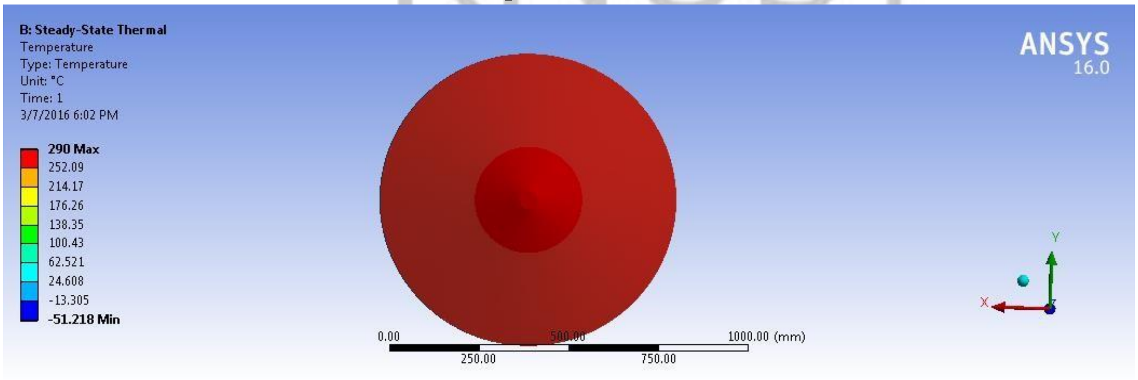
APPENDIX B37: Steady State Thermal Temperature assignment.



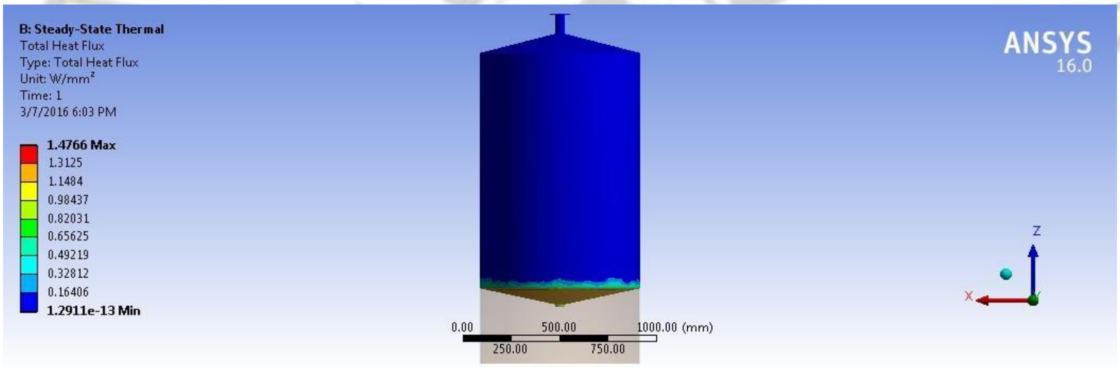
APPENDIX B38: Steady State Thermal Convection assignment.



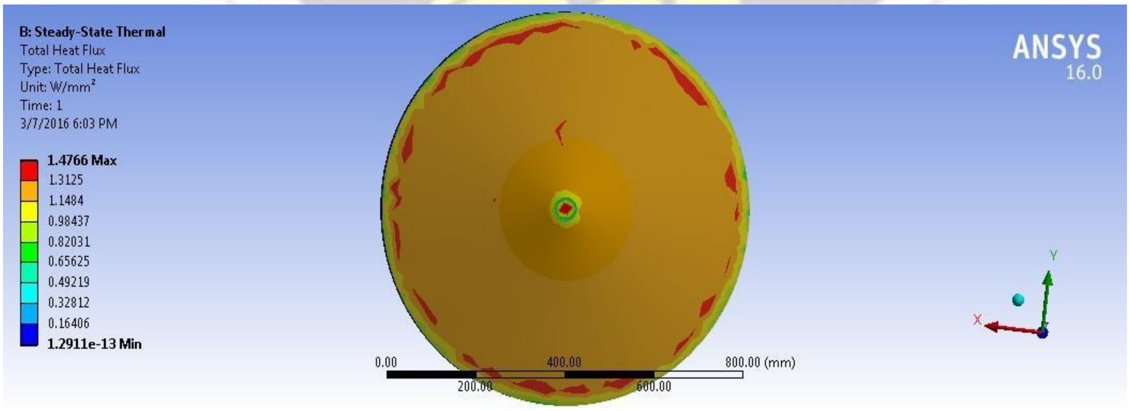
APPENDIX B39: Temperature Distribution on boiler.



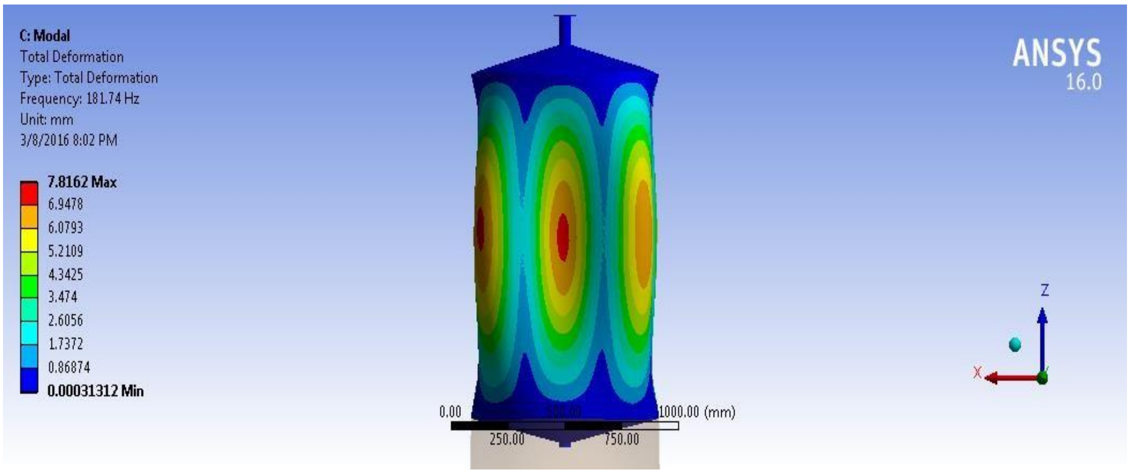
APPENDIX B40: Temperature Distribution on boiler base.



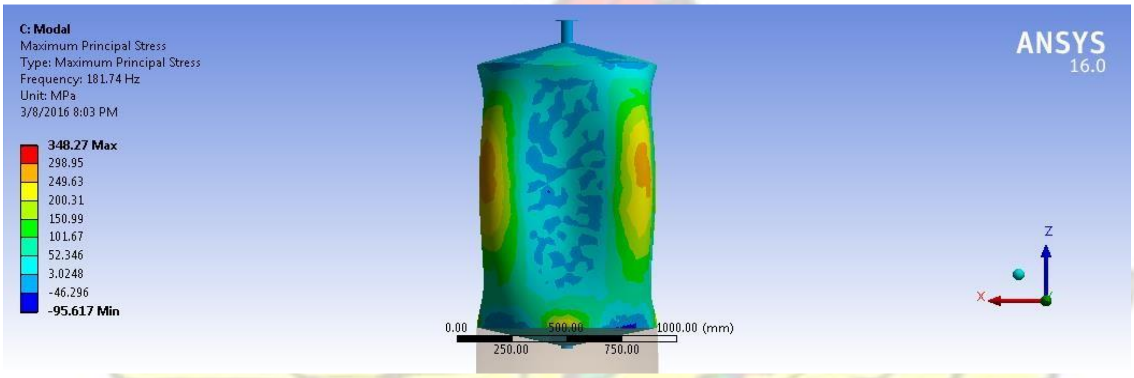
APPENDIX B41: Total Heat Flux Distribution on boiler



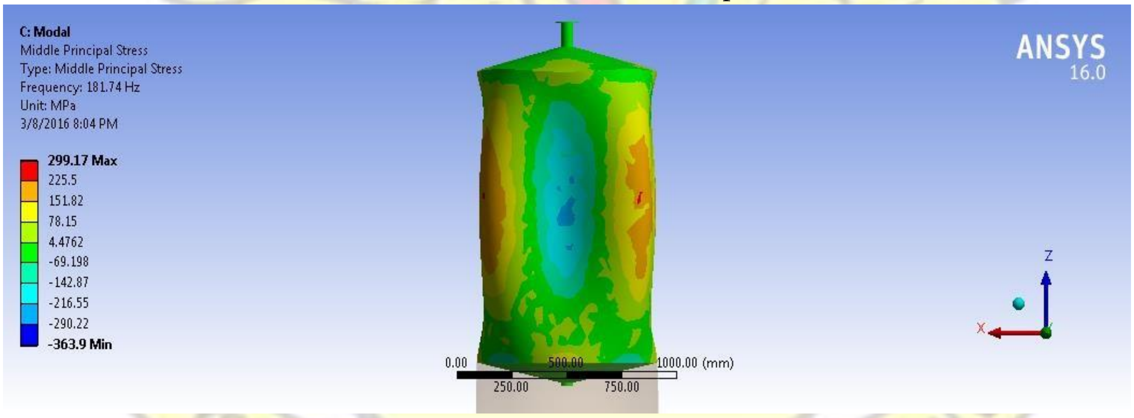
APPENDIX B42: Total Heat Flux Distribution on boiler base



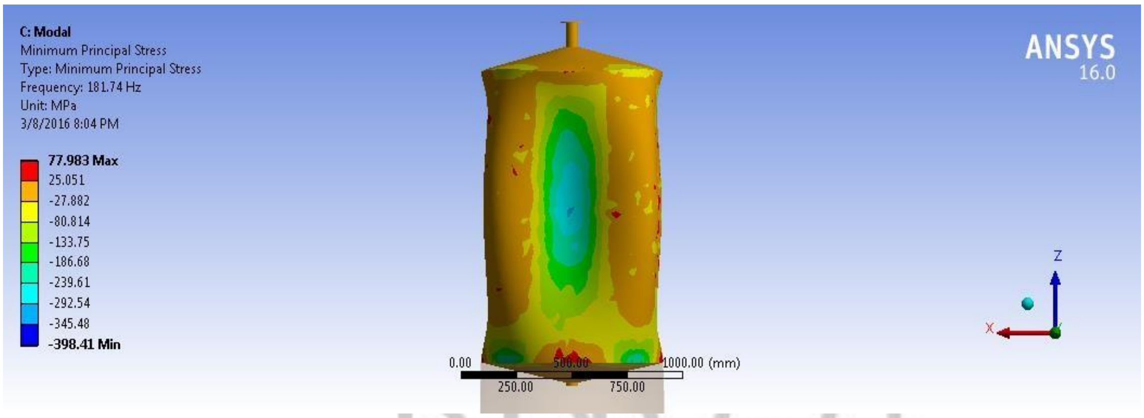
APPENDIX B43: Total Deformation



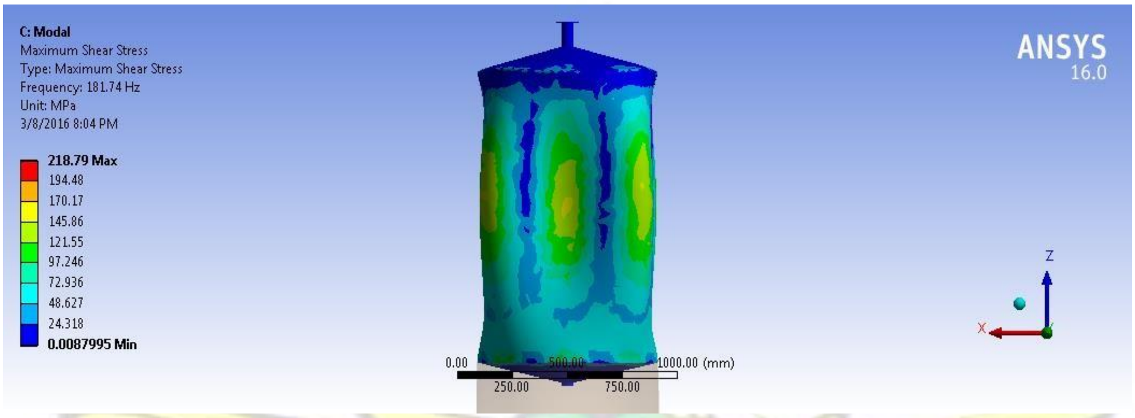
APPENDIX B44: Maximum Principal Stress



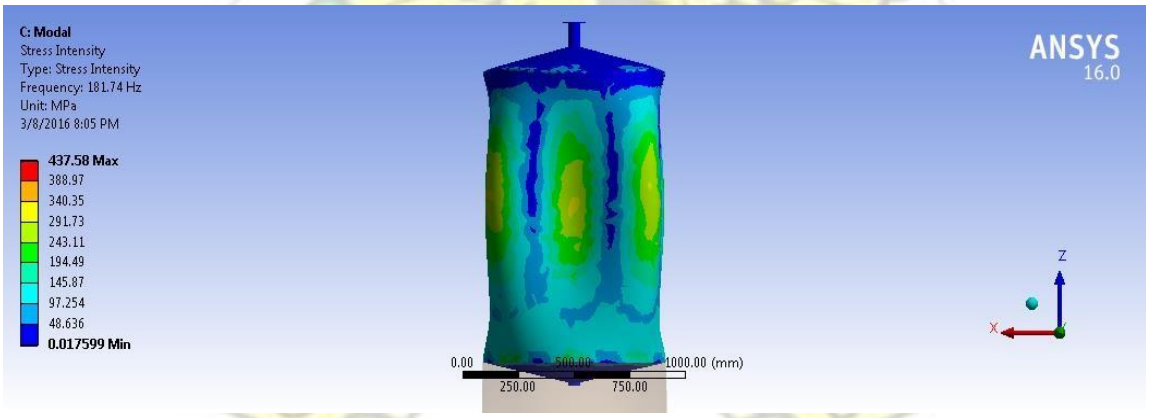
APPENDIX B45: middle principal Stress



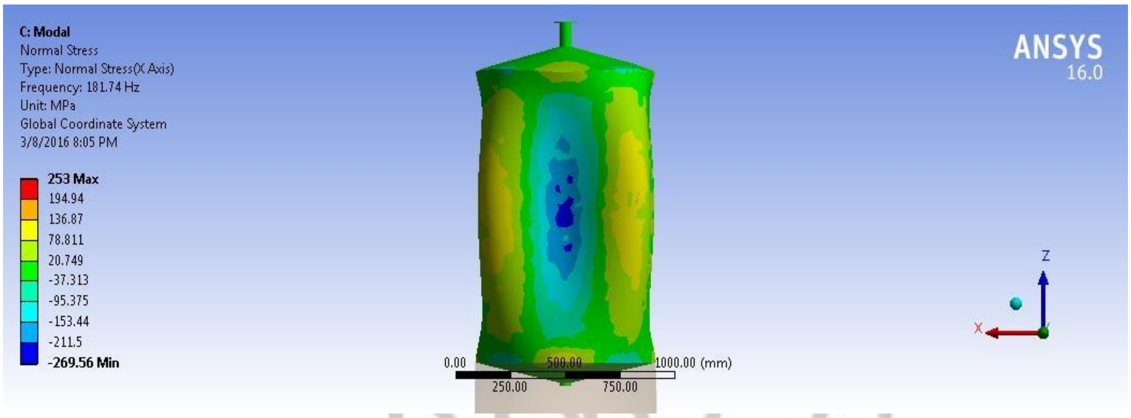
APPENDIX B46: Minimum Principal Stress



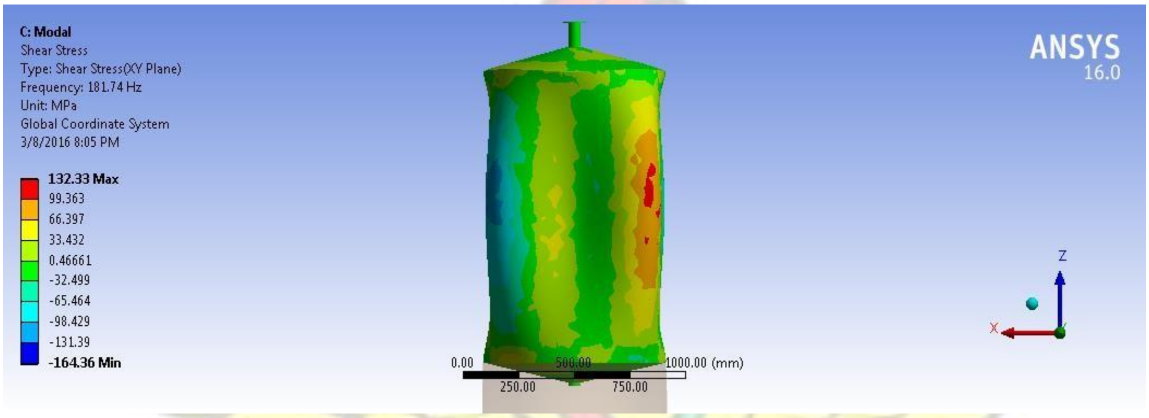
APPENDIX B47: Maximum Shear Stress



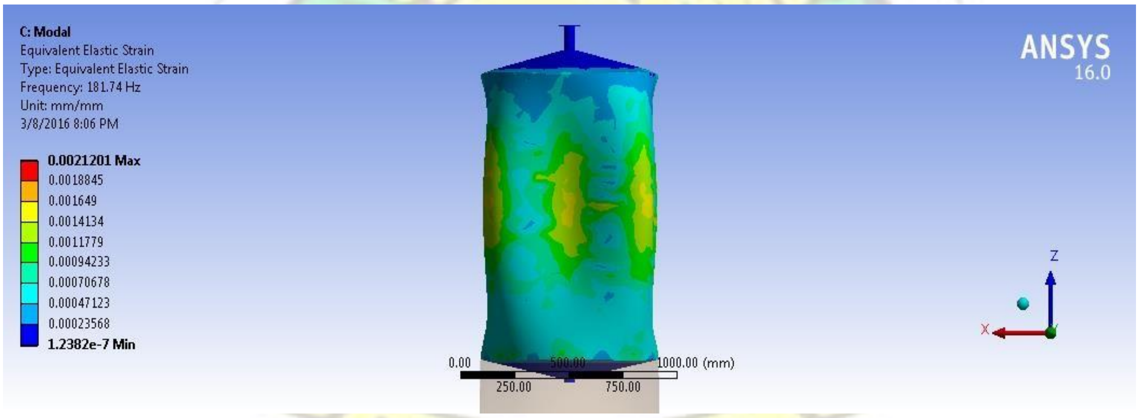
APPENDIX B48: Stress Intensity



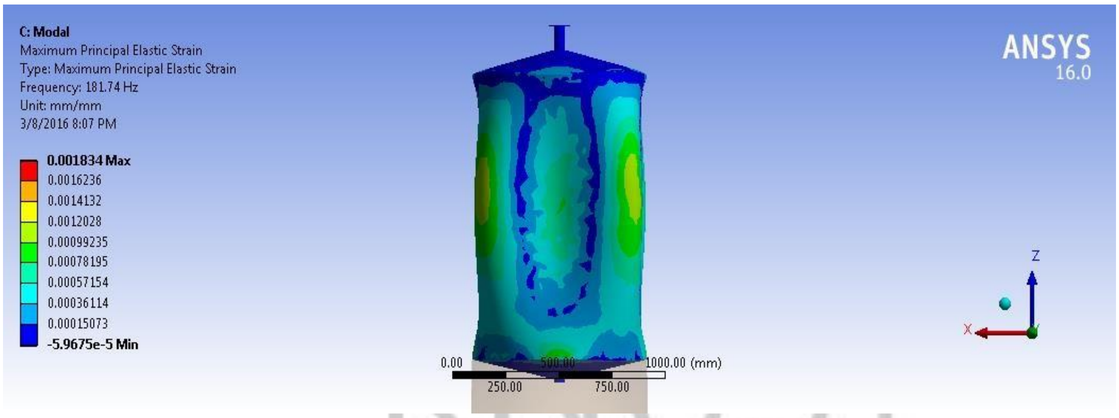
APPENDIX B49: Normal Stress



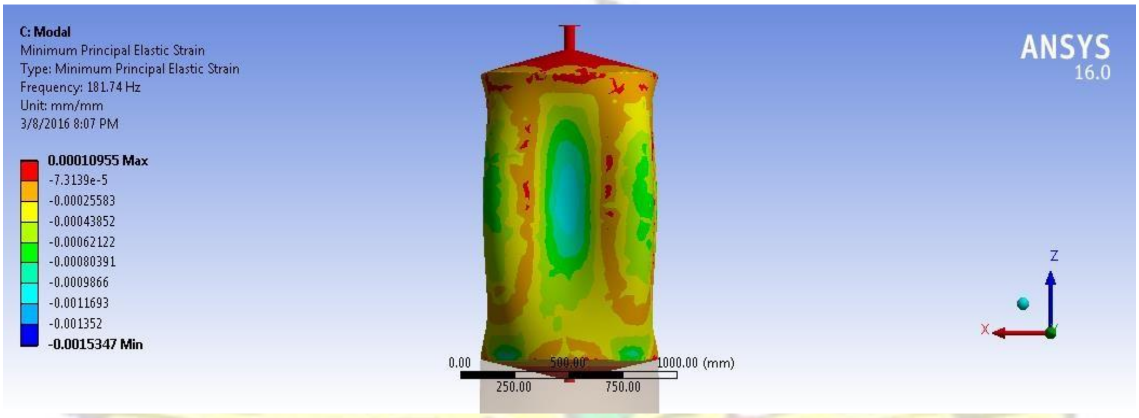
APPENDIX B50: Shear Stress



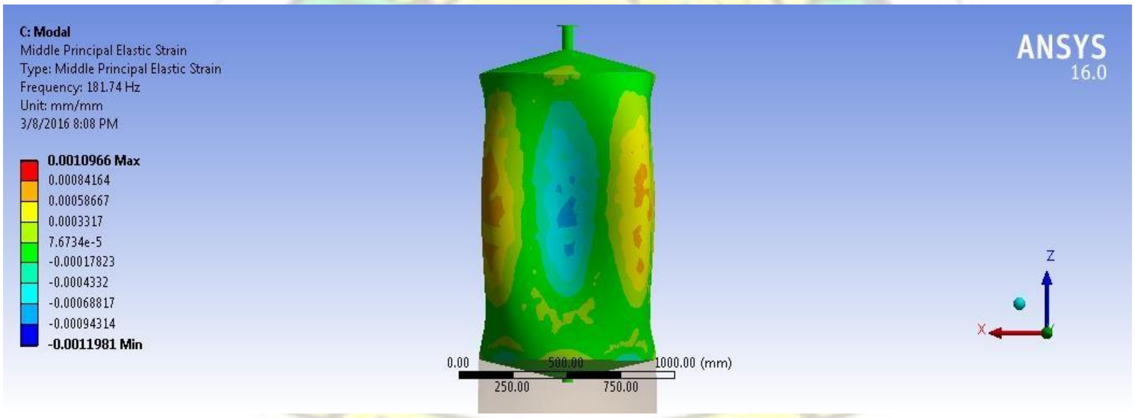
APPENDIX B51: Equivalent Elastic Strain



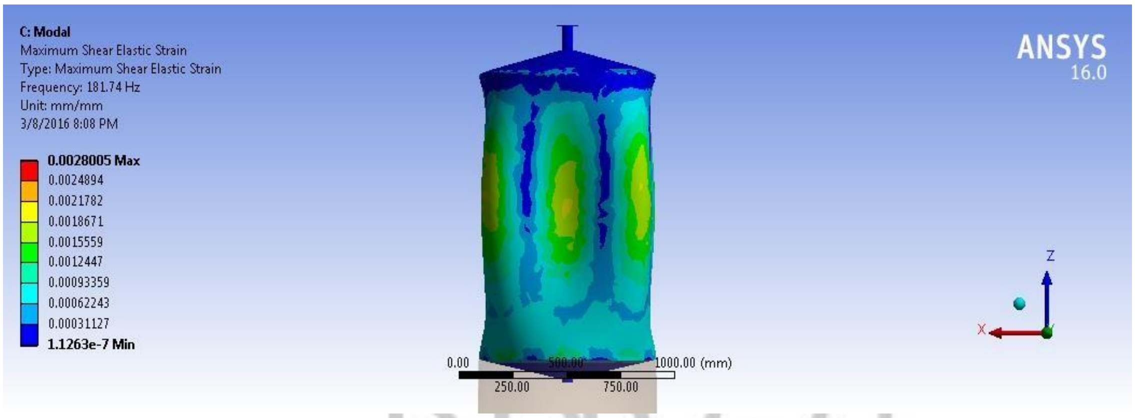
APPENDIX B52: Maximum Principal Elastic Strain



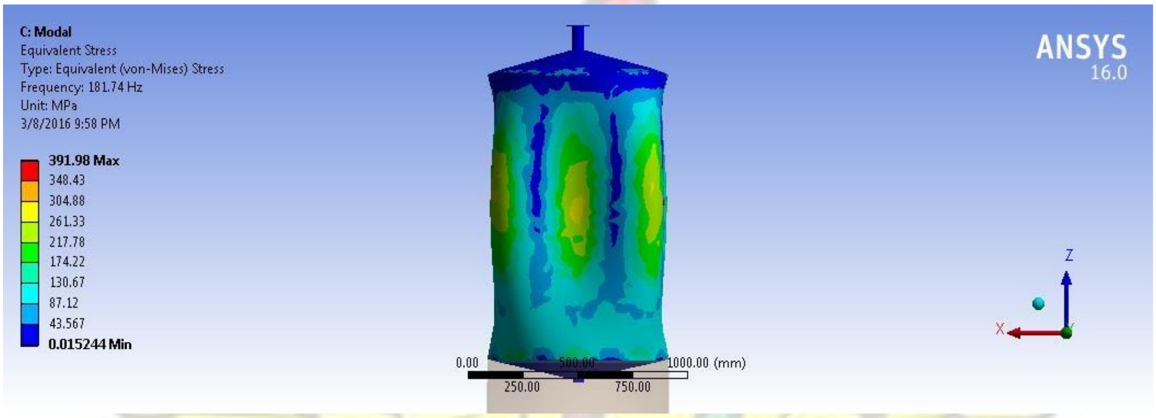
APPENDIX B53: Minimum Principal Elastic Strain



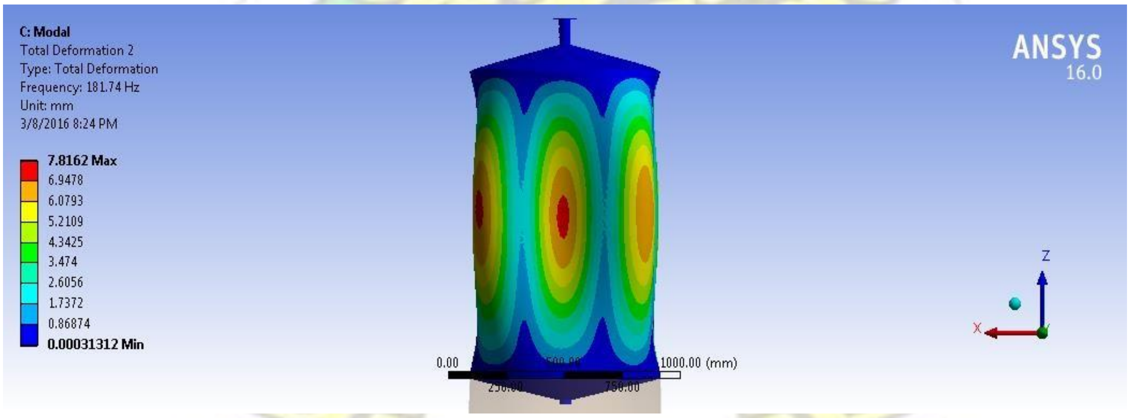
APPENDIX B54: Middle Principal Elastic Strain



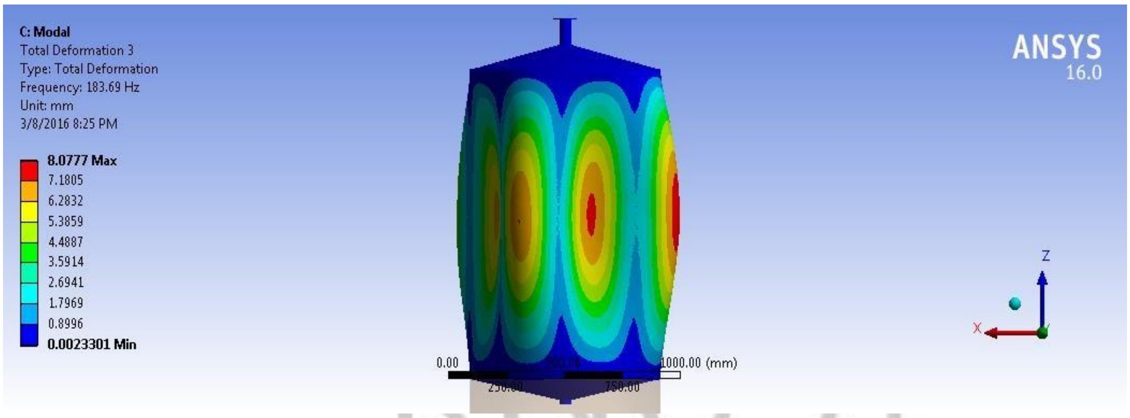
APPENDIX B55: Maximum Shear Elastic Strain



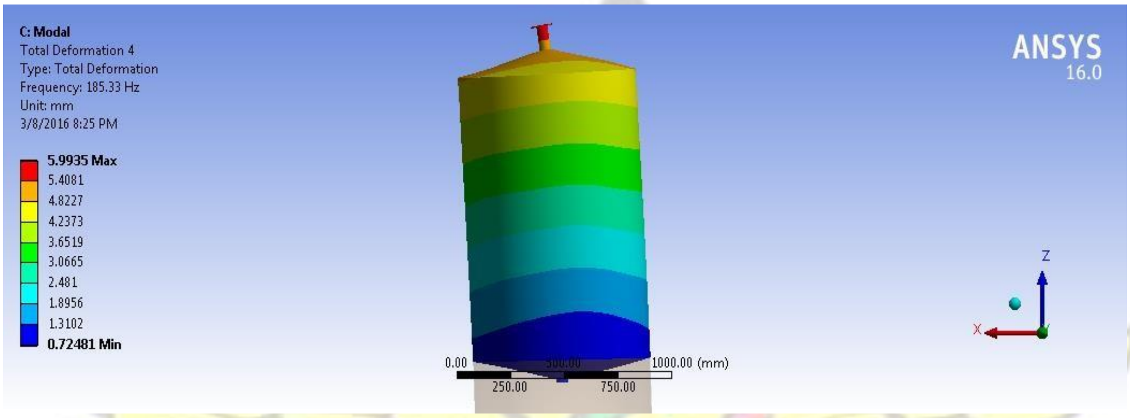
APPENDIX B56: Equivalent (von-Misses) Stress



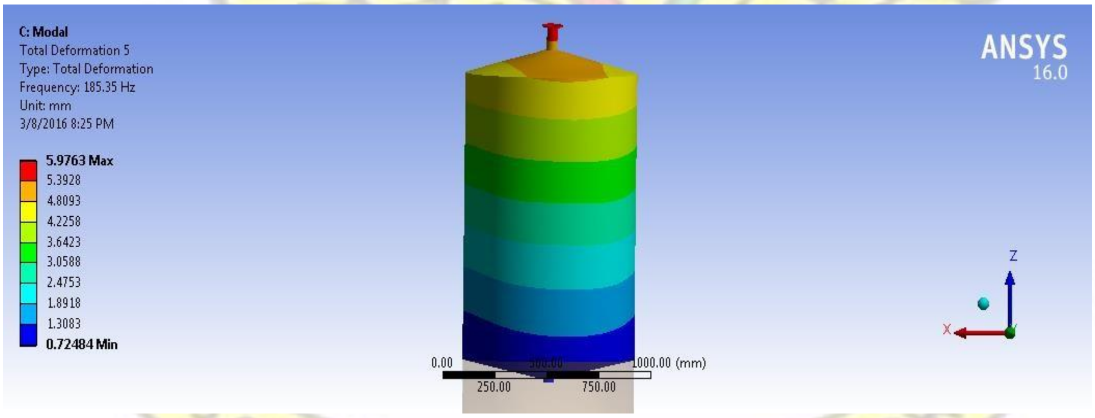
APPENDIX B57: Total Deformation at Vibration Mode 1



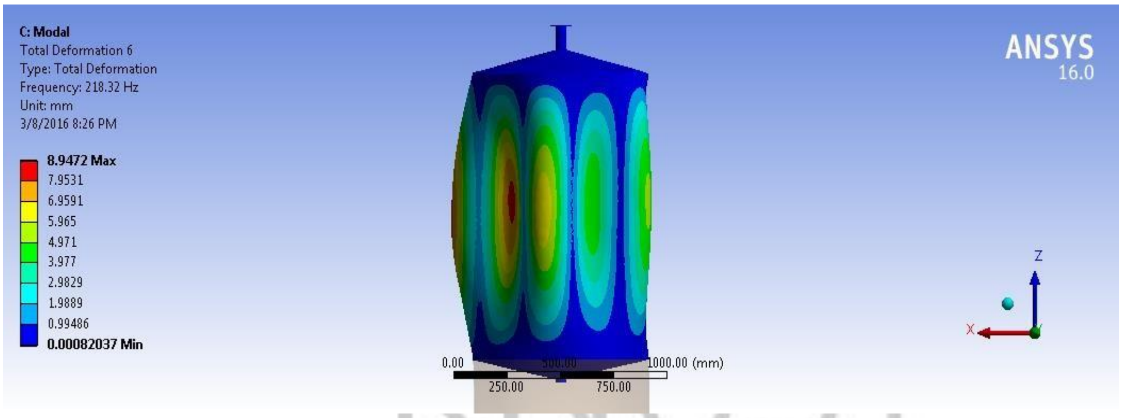
APPENDIX B58: Total Deformation at Vibration Mode 2



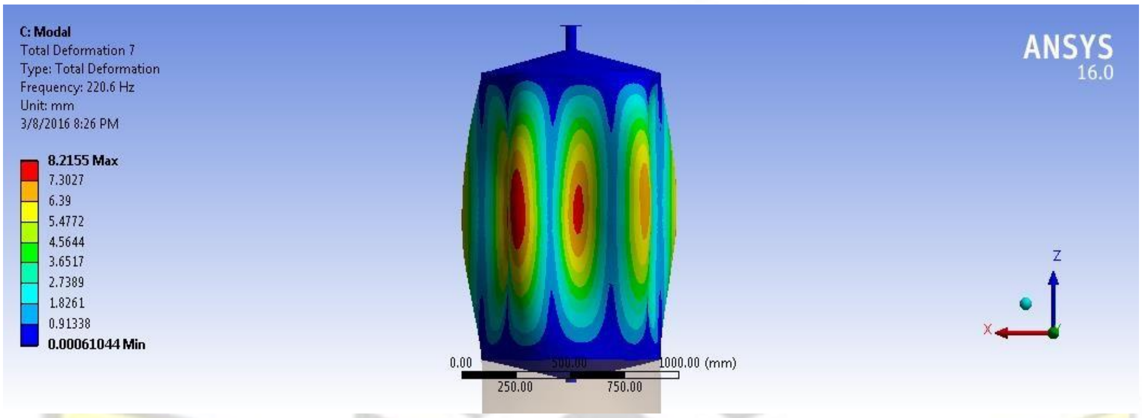
APPENDIX B59: Total Deformation at Vibration Mode 3



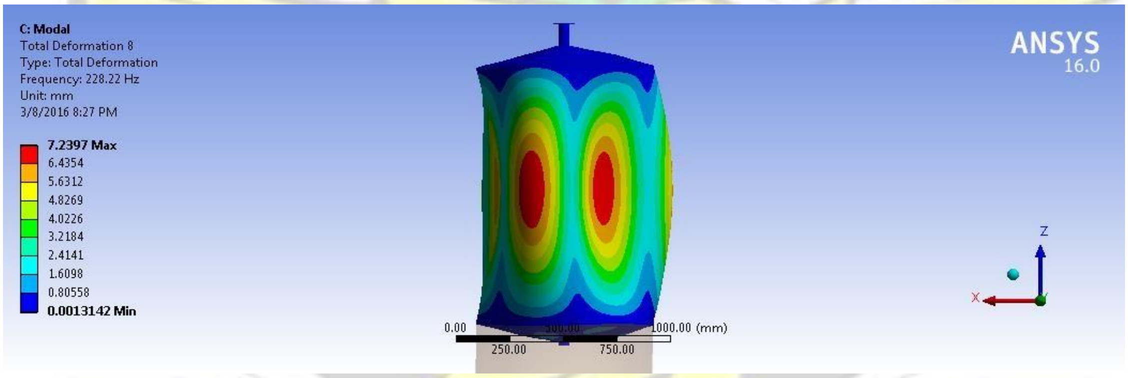
APPENDIX B60: Total Deformation at Vibration Mode 4



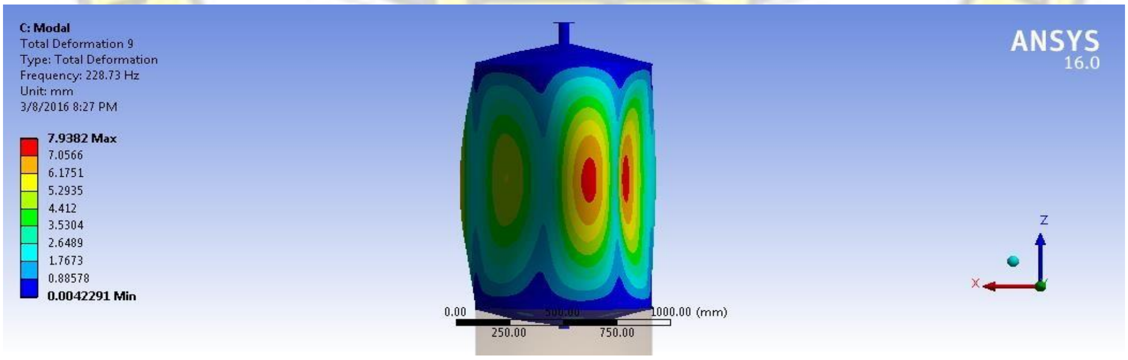
APPENDIX B61: Total Deformation at Vibration Mode 5



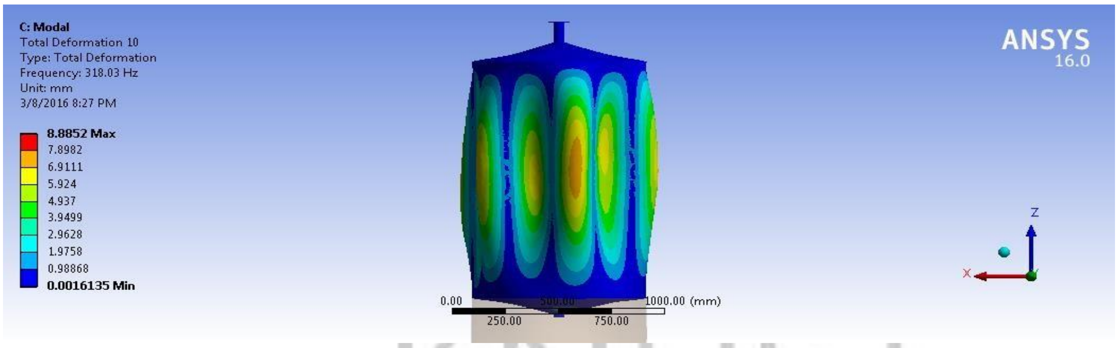
APPENDIX B62: Total Deformation at Vibration Mode 6



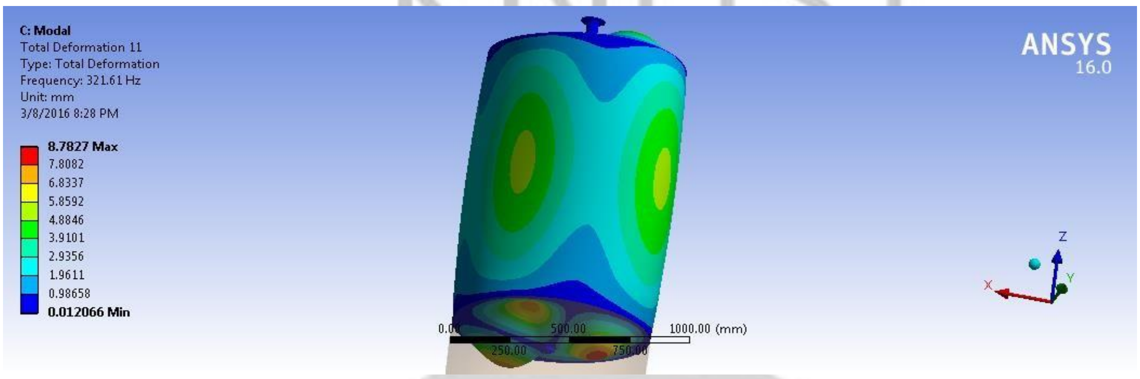
APPENDIX B63: Total Deformation at Vibration Mode 7



APPENDIX B64: Total Deformation at Vibration Mode 8



APPENDIX B65: Total Deformation at Vibration Mode 9



APPENDIX B66: Total Deformation at Vibration Mode 10

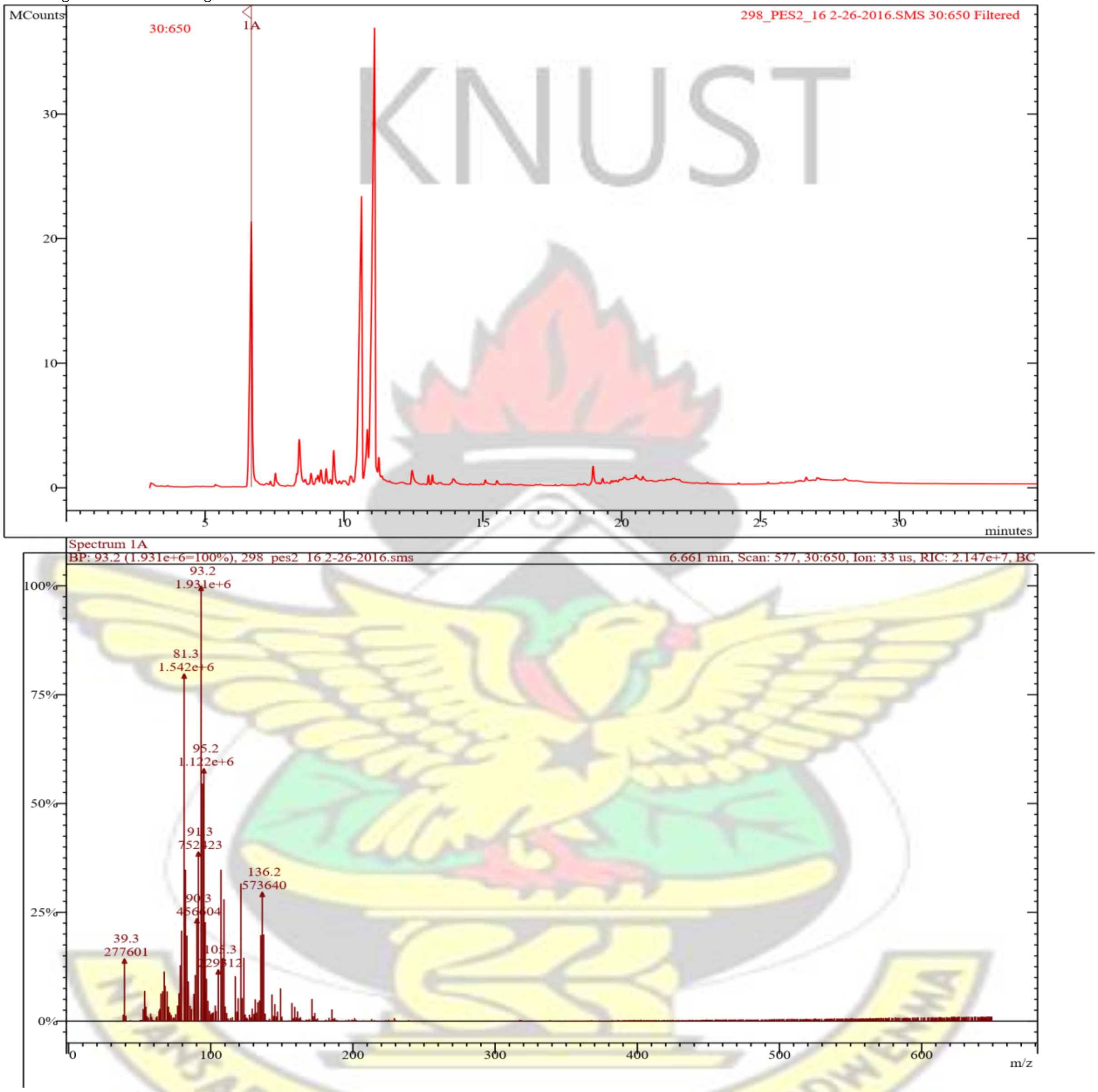
APPENDIX C: Gas Chromatography Mass Spectrometry Graphs

MS Data Review Active Chromatogram and Spectrum Plots - 3/15/2016 7:26 PM

File: ...\data\2016\normal analysis\feb\2016-02-25\298_pes2_16 2-26-2016.sms

Sample: 298_PES2_16 Operator: Paul

Scan Range: 1 - 3804 Time Range: 0.00 - 34.98 min. Date: 2/26/2016 12:36 AM

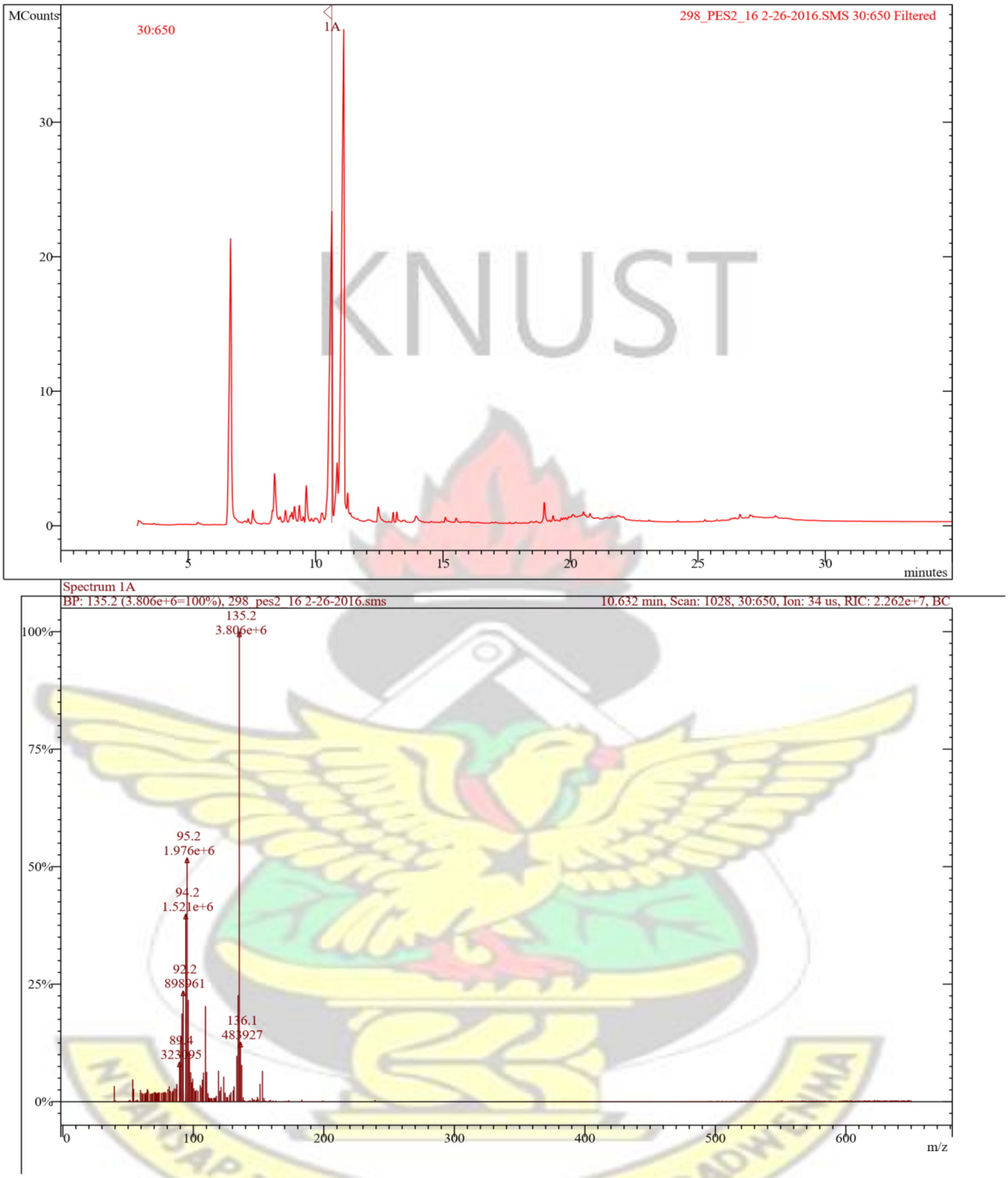


MS Data Review All Plots - 3/15/2016 7:27 PM

File: ...\data\2016\normal analysis\feb\2016-02-25\298_pes2_16 2-26-2016.sms

Sample: 298_PES2_16 Operator: Paul

Scan Range: 1 - 3804 Time Range: 0.00 - 34.98 min. Date: 2/26/2016 12:36 AM

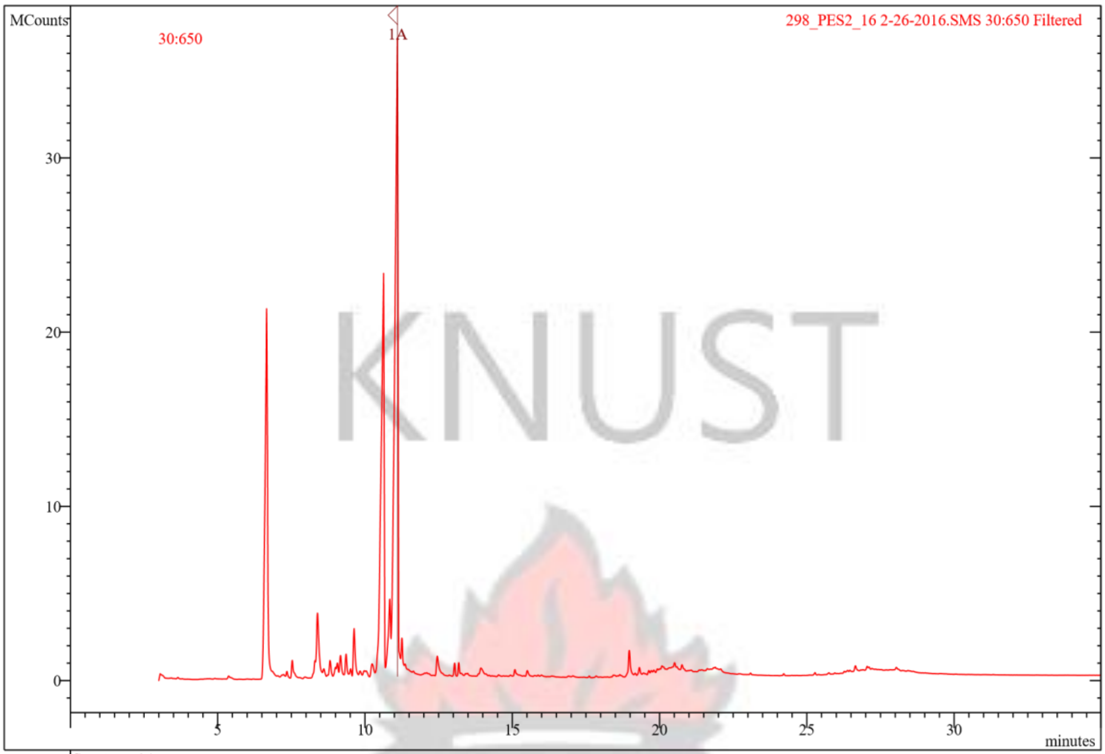


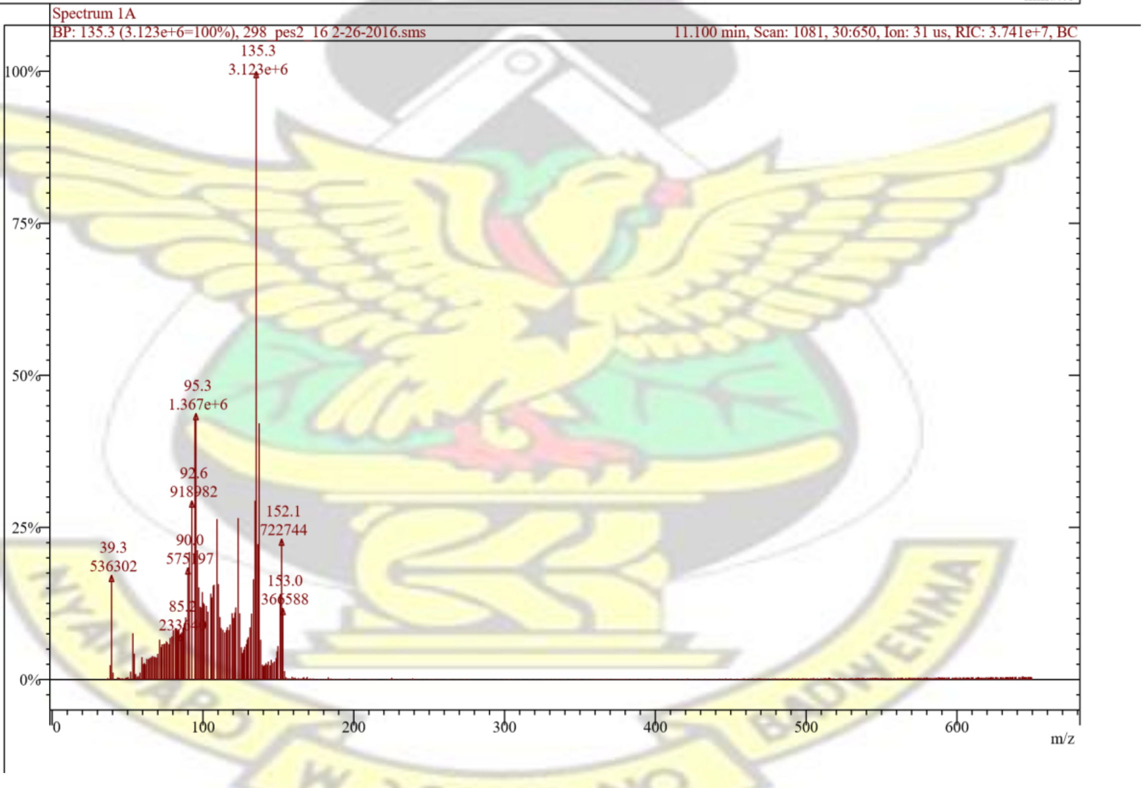
<u>MS Data Review Active Chromatogram and Spectrum Plots - 3/15/2016 7:30 PM</u>

File: ...\data\2016\normal analysis\feb\2016-02-25\298_pes2_16 2-26-2016.sms

Sample: 298_PES2_16 Operator: Paul

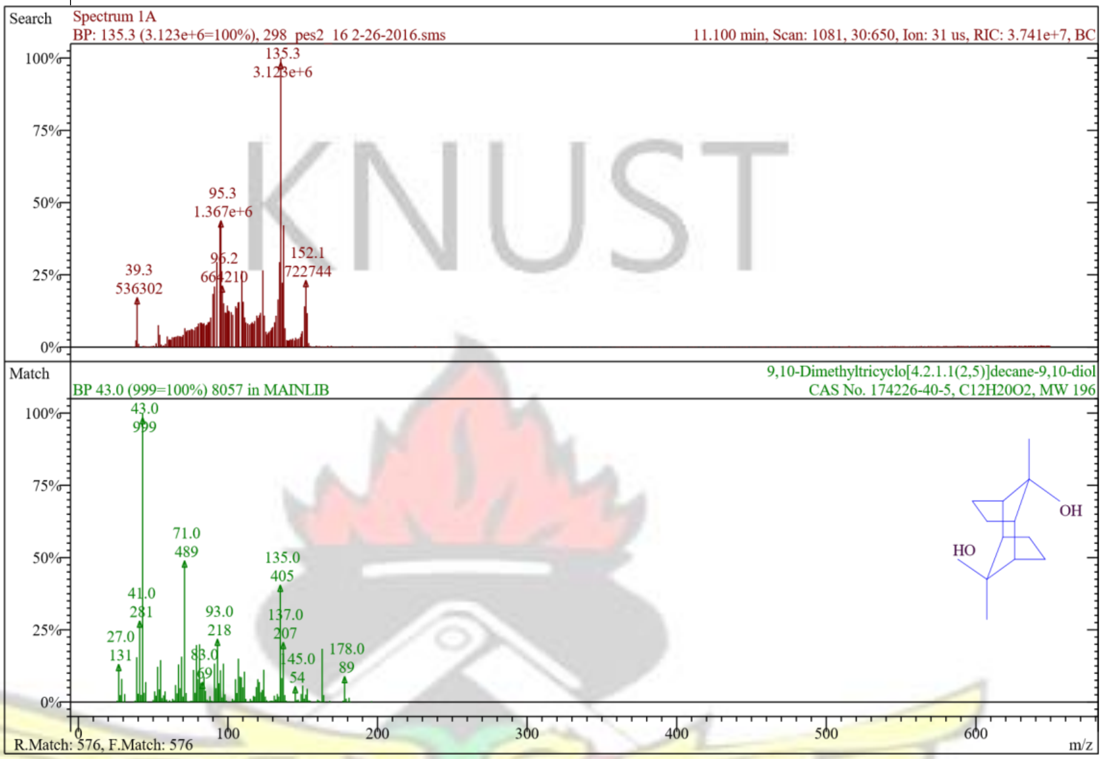
Scan Range: 1 - 3804 Time Range: 0.00 - 34.98 min. Date: 2/26/2016 12:36 AM


MCounts
30:650
1A
298_PES2_16 2-26-2016.SMS 30:650 Filtered
minutes


Spectrum 1A
BP: 135.3 (3.123e+6=100%), 298_pes2_16 2-26-2016.sms
11.100 min, Scan: 1081, 30:650, Ion: 31 us, RIC: 3.741e+7, BC
135.3
3.123e+6
95.3
1.367e+6
152.1
722744
39.3
536302
153.0
m/z

Scan 1081 from ...\normal analysis\feb\2016-02-25\298_pes2_16 2-26-2016.sms

Entry 8057 from MAINLIB NIST Library



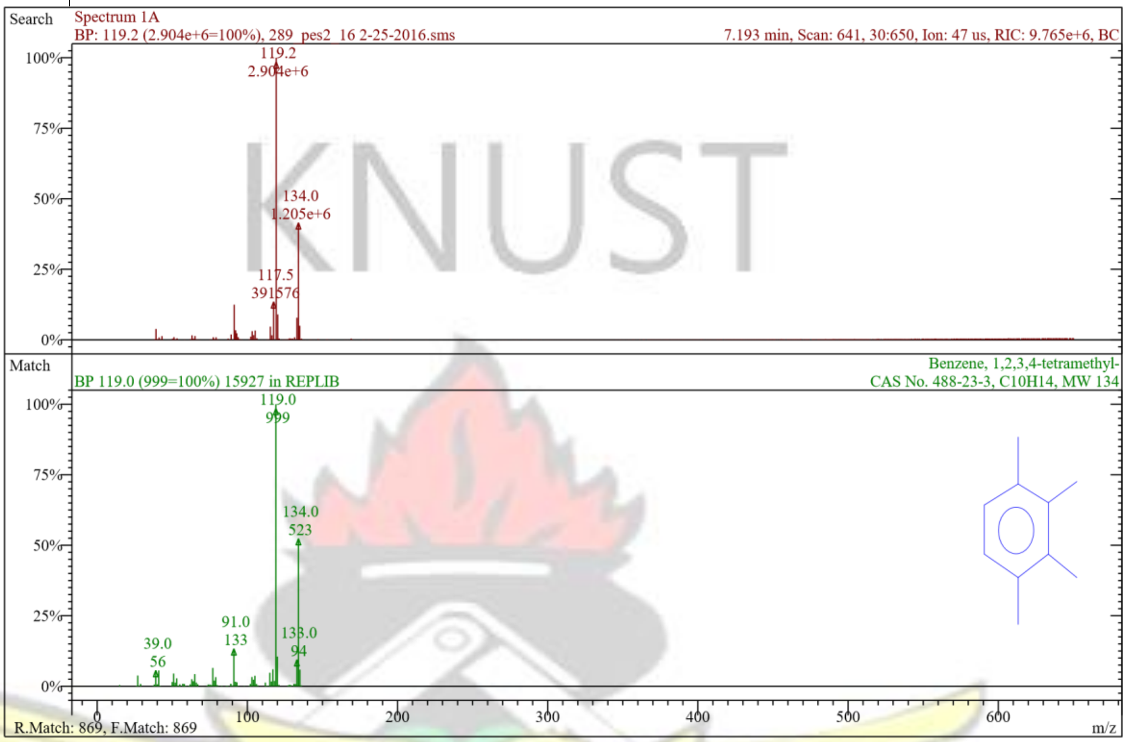
1st Spectrum from ...alysis\feb\2016-02-25\298_pes2_16 2-26-2016.sms Scan No: 1081, Time: 11.100 minutes No averaging. Background corrected.
Comment: 11.100 min. Scan: 1081 30:650 Ion: 31 us RIC: 3.760e+7
Pair Count: 550 MW: 0 Formula: None
CAS No: None Acquired Range: 29.5 - 650.5 m/z

MDT: Centroid, Time: 0.00 - 35.00
Seg 1, Filament off , Time: 0.00- 3.00, Filament Off
Chan 1, 40-650 m/z
Seg 2, isolation , Time: 3.00-35.00, EI-Auto-Full
Chan 1, 30-650 m/z
Product Mass Range: 29.5 - 650.5 m/z

Ion	Int	Norm	Ion	Int	Norm	Ion	Int	Norm
30.4	135	0	224.1	872	0	483.2	4743	2
35.8	2412	1	225.2	9223	3	484.2	4785	2
36.8	7053	2	226.3	2480	1	485.2	5689	2
38.5	73969	24	227.3	1176	0	486.9	6291	2
39.3	536302	172	229.2	2135	1	487.5	4709	2
40.3	35658	11	230.4	2485	1	488.5	5693	2
43.3	10600	3	232.8	936	0	490.7	6297	2
44.0	9121	3	234.0	1199	0	491.2	4683	1
44.8	8332	3	234.6	794	0	492.2	4758	2
46.1	5629	2	235.5	867	0	492.8	5784	2
46.6	6827	2	236.8	2140	1	494.8	6264	2
47.8	3922	1	238.4	1655	1	495.5	4740	2
48.7	8790	3	239.1	5772	2	496.5	4740	2
49.3	8918	3	240.0	2283	1	497.5	5696	2
50.3	13126	4	241.8	927	0	498.2	6290	2
52.0	40838	13	243.0	932	0	498.8	4712	2
53.5	237365	76	244.0	930	0	499.7	5784	2

Scan 641 from ...\normal analysis\feb\2016-02-25\289_pes2_16 2-25-2016.sms

Entry 15927 from REPLIB NIST Library



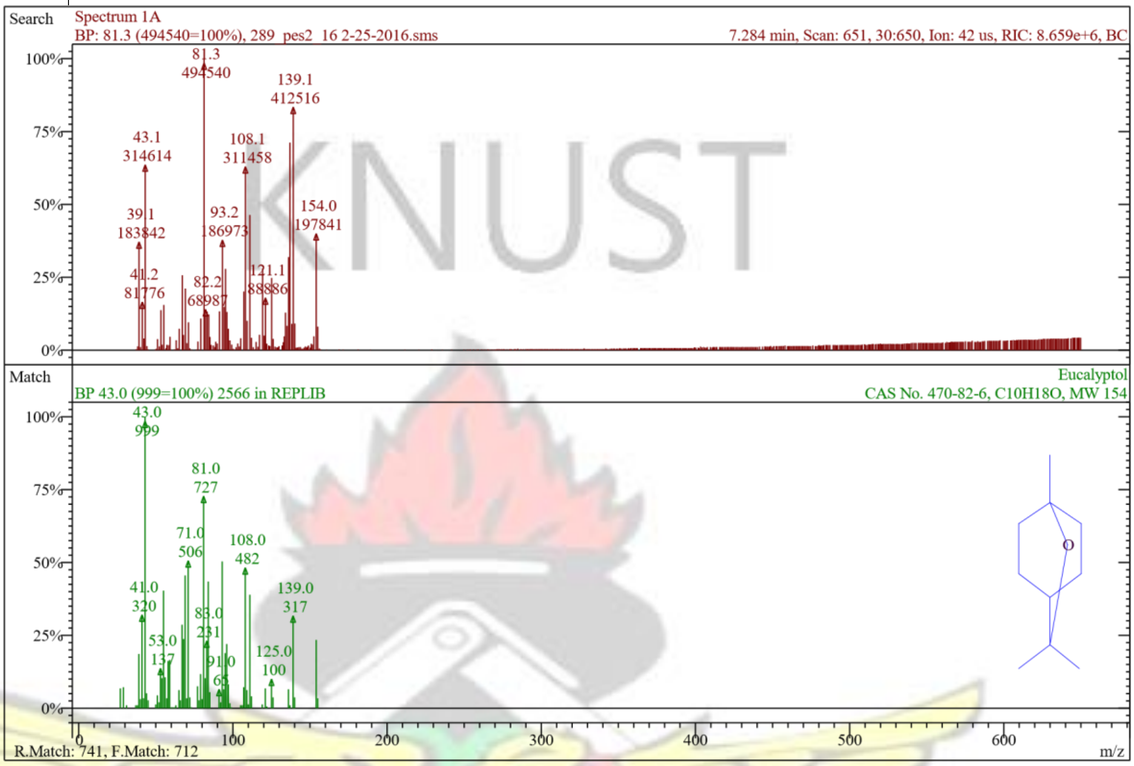
1st Spectrum from ...alysis\feb\2016-02-25\289_pes2_16 2-25-2016.sms
Scan No: 641, Time: 7.193 minutes
No averaging. Background corrected.
Comment: 7.193 min. Scan: 641 30:650 Ion: 47 us RIC: 9.920e+6
Pair Count: 552 MW: 0 Formula: None
CAS No: None Acquired Range: 29.5 - 650.5 m/z

MDT: Centroid, Time: 0.00 - 35.00
Seg 1, Filament off , Time: 0.00- 3.00, Filament Off
Chan 1, 40-650 m/z
Seg 2, isolation , Time: 3.00-35.00, EI-Auto-Full
Chan 1, 30-650 m/z
Product Mass Range: 29.5 - 650.5 m/z

Ion	Int	Norm	Ion	Int	Norm	Ion	Int	Norm
34.4	83	0	297.7	1596	1	476.1	6319	2
36.4	212	0	298.7	1560	1	477.0	6209	2
37.2	2362	1	299.6	1596	1	478.0	6832	2
38.4	6123	2	300.5	1551	1	479.5	6187	2
39.2	111879	38	301.5	1439	0	480.4	6259	2
40.2	7752	3	302.2	1431	0	481.3	6313	2
41.2	23999	8	303.1	1567	1	482.3	6318	2
42.2	1912	1	304.0	1581	1	483.2	6258	2
43.2	38627	13	305.0	1580	1	484.2	6889	2
44.1	399	0	306.0	1596	1	485.0	7284	3
45.8	36	0	306.9	1543	1	485.7	6218	2
47.3	824	0	307.8	1596	1	486.6	6384	2
48.0	296	0	308.8	1561	1	487.4	7040	2
49.2	2484	1	309.8	1549	1	488.2	7110	2
50.2	12209	4	310.7	1549	1	489.0	6976	2
51.2	27583	9	311.7	1553	1	489.8	7354	3
52.2	6634	2	312.6	1552	1	490.5	7840	3

Scan 651 from ...\normal analysis\feb\2016-02-25\289_pes2_16 2-25-2016.sms

Entry 2566 from REPLIB NIST Library



1st Spectrum from ...alysis\feb\2016-02-25\289_pes2_16 2-25-2016.sms
Scan No: 651, Time: 7.284 minutes
No averaging. Background corrected.
Comment: 7.284 min. Scan: 651 30:650 Ion: 42 us RIC: 8.811e+6
Pair Count: 539 MW: 0 Formula: None
CAS No: None Acquired Range: 29.5 - 650.5 m/z

MDT: Centroid, Time: 0.00 - 35.00
Seg 1, Filament off , Time: 0.00- 3.00, Filament Off
Chan 1, 40-650 m/z
Seg 2, isolation , Time: 3.00-35.00, EI-Auto-Full
Chan 1, 30-650 m/z
Product Mass Range: 29.5 - 650.5 m/z

Ion Int Norm Ion Int Norm Ion Int Norm
| 37.2 1497 3 | 304.8 1770 4 | 479.8 8164 16 |
| 38.2 6445 13 | 305.8 1785 4 | 480.4 8231 17 |
| 39.1 183842 371 | 306.8 1737 4 | 481.0 6969
14 | | 40.0 5129 10 | 307.7 1785 4 | 481.7
7961 16 |
41.2 81776 165	308.7 1754 4	482.6 7767 16
42.3 19687 40	309.6 1740 4	483.2 8556 17
43.1 314614 636	310.5 1743 4	484.5 8812 18
44.2 6848 14	311.5 1747 4	485.2 8665 18
45.0 1057 2	312.5 1745 4	486.2 8658
17		48.3 93 0	313.4 1743 4	487.2
8696 18
49.5 547 1	314.3 1756 4	489.3 8629 17
50.2 2035 4	315.3 1758 4	490.0 8644 17
51.1 18802 38	316.3 1741 4	490.9 8616
17		52.3 6321 13	317.2 1741 4	491.5
7861 16
53.3 67910 137	318.2 1737 4	492.2 8589 17

54.1	9191	19	319.2	1754	4	493.6	8753	18
55.2	76631	155	320.1	1760	4	494.5	8650	17