Addis Ababa University
School of Graduate Studies
Addis Ababa Institute of Technology
School of Mechanical and Industrial Engineering
Thermal Engineering

Design, Manufacture and Experimental Investigation of Biogas Injera Baking Pan

By

Dessie Gashay Ergette

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Thermal engineering

Advisor: Abdulkadir Aman (PhD)

December, 2019

ADDIS ABABA, ETHIOPIA

Addis Ababa University
Addis Ababa institute of Technology
School of Mechanical and Industrial Engineering

Approval of MSc. Thesis Proposal

Submitted by:

Dessie Gashay	________________	________________
Student's Name	Signature	Date

Recommended by:

Abdulkadir Aman (PhD)	________________	________________
Advisor	Signature	Date

Approved By:

Abdulkadir Aman (PhD)	________________	________________
Chair of Thermal Stream	Signature	Date

Endorsed by:

Yilma Tadesse (PhD)	________________	________________
Dean School of Mechanical and Industrial Engineering	Signature	Date
Ermias Tesfaye (PhD)	________________	________________
	Signature	Date

Declaration

I, hereby, declare that the work which is presented in this thesis, entitled "biogas injera baking pan design, manufacturing and experimental investigation" in partial fulfillment of the requirements for the award of the degree of Master of Science in Thermal Engineering, is an authentic record of my own work carried out from November 2009 to march 2012 under the supervision of Dr. Abdulkadir Aman, School of Mechanical and Industrial Engineering, Addis Ababa Institute of Technology, Addis Ababa, Ethiopia. The matter embodied in this thesis has not been submitted by me or any other person for the award of any degree or diploma. All relevant resources of information used have been duly acknowledged.

Name

Dessie Gashay ______________ ________________

Signature Date

This is to certify that the statement made by the candidate is correct to the best of my knowledge. This thesis has been submitted for examination with my approval:

Abdulkadir Aman (PhD) ______________ _____________

Signature Date

Abstract

Energy is a primary and basic question for living things of peoples to lead their life. Energy is a key factor for the development of one country. Energy demand increases with respect to the population size. Energy is utilized from different sources for conducting day to day activities of human beings. Even though there exist so many sources of energy developing and under developing countries relays on biomass energy sources for cooking purposes. Biogas is a fuel which can be obtained from different sources like animal manure, animal slaughter, plants, sewage, ruminant, etc. biogas encompasses different gases depending on the sources such as, methane, carbon dioxide major constituent while hydrogen sulfide, hydrogen, nitrogen may include.

By doing so we human being faces a number of problems such as shortage of cooking fuel, health problem due to emission of firewood, air pollution, acid rain formation depending on the content of emissions and ozone layer depletion those are the typical challenging problems which encounters our surrounding. The main aim or goal of this research paper minimizing or overcoming previously mentioned problems that come due open fire stoves most commonly. In order to implement this paper we were used the following methodology data collection of biogas thermal property and baking clay pan thermal property; input fuel content; knowing biogas properties its composition as well as flow rate; chemical kinetics of biogas, determined dimension of ,3D burner assembly using CATIA, design of flame port geometry,3D flame port assembly by CATIA, design of insulation layer were have been done finally we manufacture the optimized burner geometry and carried out the experimental investigation hence we obtain the result of 22.1% thermal efficiency the prototype somewhat portable and can be movable able to bake by transporting somewhere we desired, the burner ables to drive biofuel uniformly to the beanth of clay mitad because of flame port geometry orientation and distribution over the circular flame port surface. Here we can deduce that this stove ables to distribute heat to mitad uniformly as can be observed from the experimental investigation

Biogas used for power generation, thermal heating upon with modification of utilizing equipment’s. Biogas generates heat energy up on combustion reaction with in the combustion chamber.

Keywords biogas, flame port, cooking, fuel, experimental investigation, manufacturing, and waste.

Acknowledgements

First of all, I would like to owe many thanks to almighty GOD for giving an encourage, patience as well as strength.

I would like to provide my great thanks to my advisor Dr. Abdulkadir Aman for his pleasant patient and invaluable comment that supports me for the successful accomplishment of this research paper.

My specials thanks extend to Ato Meweled Seifu, for his help in the manufacturing of the prototype or laboratory model. I would also like to extend my thanks to Nathnael Bekele who helps me in carrying out the experimental investigation of models and Balcha Tola who are informing me for any kind of information that are posted by the

Hear I would also thank my family as well as friends. Furthermore, the meeting with the staff of was very interesting, especially the stories they told us about their work to alleviate poverty. I would like to thank for their help and assistance during writing this paper, which took much more time than anticipated.

Finally, I would also like to thank my family especially my lovely mother Tiru Biazen, father Gashay Ergette aunt Tanchiwodia Ergette and her husband Demissew Geta as well as for my uncle Amanu Biazen finally my brother, sister and girlfriend Getahun Gashay, birhane gashay and finally Silenat Yibelital those who are resides to me that supports in every aspect to relive from serious sickness of nerve TB, for their encouragement, patience, support and also to be back towards my previous work of status in academic situation

Abbreviation

E_{st} amount of energy demanded to bake *injera*

Ƞ efficiency

P power

Q volume flow rate of biogas

CH_4 methane gas

O_2 oxygen gas

N nitrogen gas

CO_2 carbon dioxide gas

H2O water

do orifice diameter

s specific gravity of biogas fuel

p power

p pressure before orifice

d diameter of mixing tube

L_{max} length of mixing tube

L length of mixing pipe

D diameter of mixing chamber

$V_{o\,\mathrm{velocity}}$ of gases in the region of nozzle

A_o area of nozzle

V_t velocity of gases in the vicinity of throat

P_t pressure before throat

P_o pressure of the orifice

r primary air entrainment ratio

d_t throat diameter

Re Reynolds number

Δp pressure drop

μ viscosity of mixture

ρ density of mixture

Q_m flow rate of gas mixture

A_p area of burner port

g acceleration due to gravity

V_i velocity of gases in the vicinity of throat

r_o outer diameter of skirt

ri inner diameter of skirt

T_o ambient temperature

T_i inner temperature of skirt

t thickness of skirt

K thermal conductivity of skirt mitad

L length of skirt

R thermal resistance

hcb convective heat transfer from the bottom of mitad

hrb equivalent convective transfer of radiative coefficient of heat transfer of bottom of mitad

hc1 convective heat transfer coefficient of lid cover

hr1 equivalent convective transfer of radiative coefficient of heat transfer of lid cover

Ta ambient temperature

Tb bottom plate temperature

Rtot total thermal resistance

Qx generated heat from biogas fuel

Δpind change in pressure induced in chimney

g gravity

hchim height of chimney

Pamp ambient pressure

Phot hot gas pressure

Tamp ambient temperature

Thot hot gas temperature

m mass flow rate of flue gas

Lc loss coefficient

fl flame lift

$_{NU}$ non dimensional nussult number

Gr grashoff number

hi interfacial convective heat transfer

$_{KA}$ thermal conductivity

$_{KB}$ therma$_{l}$ conductivity

ho $_{c}$onvective heat transfer coefficient

F force acting on standing

Q_r radiative heat loss

Qc convective heat loss

Ap area of pan

Tp pan surface temperature

T_{lc} lid cover temperature

hlc lid cover convectional heat transfer coefficient

hrc radiation heat transfer coefficient

Ra Reynolds number

Gr grashoff number

h_{lc} lid cover convective heat transfer coefficient

h_{bc} bottom convective heat transfer coefficient

h_{rlc} the equivalent radiative heat transfer coefficient of lid cover

h_{rbc} the equivalent radiative heat transfer coefficient of lid cover

^{o}c degree Celsius

^{o}c degree Celsius

^{o}k degree kelvin

Stefan Boltzmann constant

h_{1r} the equivalent radiative heat transfer coefficient

z h_{1c} the equivalent convective heat transfer coefficient

εeff Effective emissivity of the baking pans

$_{Ut}$ top overall heat transfer coefficient

$_{Ul}$ bottom overall heat transfer coefficient

H_C is chimney height

V_o is volume of air at 32^{o}F

W is weight of fuel burned or combusted

n is ratio of combustor area to that of chimney area

§ is weight of cubic meter of gases in the chimney

A_c is section of chimney in square meter

b is width or diameter of chimney is 110mm

T_o absolute temperature of ice melting 461^{o}F

T_1 absolute temperature of chimney gas

T_2 is absolute temperature of external air 32°F

List of figures

List of Tables

Table of Contents

1.1.1 **Chapter One: Introduction**

1.1 Background

The utilization of new renewable energy sources such as biogas to decrease our dependence on fossil fuels has been an important goal worldwide during the past years. The composition of biogas strongly deviates from that of standard natural gas, which results in a low caloric value of biogas. Therefore, it is not obvious that the conventional existing combustion equipment can be used for the combustion of biogas.

As the demand for the world's fuel increases, their prices rise. Thus interest is now rightly focused on the development of renewable energy sources. Renewable sources of energy often offer the most potential energy conservation and development options for the future. The use of these energy sources can meet considerable energy demands for our institutions and villages across the country. Amongst the renewable sources of energy, biomass is the most promising. Biomass refers to the different forms of organic matter including crop residues, agro-industrial by products, urban and municipal wastes, and animal dung.

This may be transformed by physical, chemical and biological processes to bio-fuels. In chemical form biomass is stored solar energy and can be converted into solid, liquid and gaseous energy. A detailed study of energy demands in Kenya indicates that firewood, charcoal and crop residues accounts for more than 75% of the total energy consumed. This implies that the forest cover is being depleted at a faster rate than are efforts at growing trees. Electrical power cannot also be relied on not only because of the cost implication, but also because of the very unpredictable weather patterns largely attributed to global warming. Depends on firewood for cooking Electricity is used for lighting and for running machines in the mechanical workshop. Firewood is not a good option as the forest cover is reducing at an alarming rate. In view of the above, an alternative source of power is urgently required. MUC has a number of cows plus a lot of food waste from the kitchen. This would be a good source of raw material for a biogas generator. The unit would supply the much needed energy for cooking, lighting and any other use that could require heating.

Energy demand of the world increases proportional to the population growth for conducting and fulfilling day to day activities. Each and every sector run by use of energy input so that there is no alternative for energy. Sectors become blind without energy. Manufacturing sector, industrial sector, mining sector, institutional sector, agricultural sector, house hold activities all are dependent on energy input.

Energy can be obtained from different sources. Some sources of energy are solar, nuclear, petroleum, natural gas, hydroelectric, geothermal, tidal, biomass, biogas etc. based on their occurrence and pollutant emission to the atmosphere energy sources can be categorized into two such as renewable and non-renewable energy sources. Renewable energy source is a source that would use again and again whereas non renewable energy sources are sources that cannot be obtained once depleted/run out (Lohan, Dixit, Modasir, & Ishaq, 2012).

Nonrenewable energy sources are sources that emit particulate matters, pollutants into the atmosphere upon combustion. The particulate matters are fly ash, sludge, whereas the pollutants are sulfuric acid, nitric acid, chlorofluorocarbons. Those particulate matters and pollutants cause for poisoning the soil, water, atmosphere/air intern affects living things on the plant, earth. Renewable energy sources are sources most commonly obtained from solar, geothermal, biomass, hydroelectric, biogas. Its emission to the environment could be promising (Kadam & Panwar, 2017).

Our country Ethiopia obtains energy from different sources, mostly from biomass source. Ethiopia has underutilized resources for the generation of energy. The most common unutilized resources are waste. Waste is substances that are disposed of due to its uselessness for a specific sector.

Waste incorporates so many different inorganics as well as organic molecules, compounds. Waste may include sugar, protein, fats, polymers, cellulose, and hemicellulose so that those constituent compounds are disposed of to landfill.

Waste considered as harmful, poison for the environment, atmosphere if it is not disposed properly. Though, it is environmental unfriendly it has its own advantages for the generation of

Electrical energy as well as thermal energy by allowing passing through a serious of steps. Wastes are processed to produce a green energy source called biogas. To prepare biogas first collect Wastes from the surrounding environment by then pouring water and other ingredient stir up for a certain day. Later allow it to pass through hydrolysis for breaking down a large molecule into smaller once. Next to that, allow to under goes acid genesis/fermentation by depleting oxygen to obtain acetic acid. Following this, methanogens is conducted in order to obtain methane and carbon dioxide. The technology utilized for the production of biogas is said to be digester (Chen, & Song, ethal 2012).

As mentioned above biogas can be prepared from waste. Waste incorporates so many things like cow manure, dung, slaughter, sewage, ruminant, shrubs, trees etc. so that biogas easily prepared from those waste that are easily accessible. The existence of biogas technology provides numerous advantages against the environment i.e. biogas obtained from animal dung, manure, sewages that are disposed carelessly in a field contains methane. Methane is one of the contributing factors for greenhouse gas effect in the atmosphere intern which causes for the increment of atmospheric temperature so that it causes for ozone layer depletion (Chen et al., 2012). biogas technology overcomes the health problem that faces women in the rural area because of the traditional means of cooking (three stone fire) causes high temperature feeling, exposure of smoke, indoor air pollution(Chen et al., 2012). So that using biogas technology eradicates the above problems as well acts as a source of fertilizer.

Biogas used for power generation, thermal heating upon with some modification of utilizing equipment's (Chen et al., 2012). Biogas generates heat energy up on combustion reaction with in the combustion chamber Therefore, the heat that generates/liberates up on combustion used for cooking purpose. This research paper underlines the utilization of heat for making injera using baking pan. So that up on heating baking pan we make injera by transferring heat from the combustion chamber via pan to grain poured solvent on the pan. However, mostly cooking, baking, boiling in urban and rural areas can be carried out using biomass due to the absence of electrical energy accesses hence Ethiopians all most all predominantly uses open three stone fire due to underutilization of renewable energy and electrical energy delivery deficient(Haile Selassie, Bayray, & Jørgen, 2014b).

1.1.1 **Biogas**

The matured biogas production technology has led to the development of a number of biogas appliances for lighting, power generation, and cooking. The most promising among them is the biogas stove to meet the energy requirement for cooking application at domestic level. In this paper attempt has been made to design and develop a domestic biogas stove for meeting domestic cooking energy need

Biogas is a versatile gas used for cooking and lighting. Biogas is a relatively clean gaseous fuel produced mainly from cattle dung and other animal waste in anaerobic digesters. It typically consists of about 60% methane, 30% CO2 and 2% H2 with traces of ammonia, nitrogen, and hydrogen sulfide. Widespread dissemination of biogas plants began in 1981 through the National Project on Biogas development. Since several animals are needed to supply for each biogas plant, biogas stoves are mainly found in rural areas where, overall, somewhat more than 1% have such devices. Biogas does not contribute to increase in atmospheric carbon dioxide concentration because it comes from an organic source with a short carbon cycle and is the green solution in the development of sustainable fuel. Household stoves, although individually small, are numerous and thus have the potential to contribute significantly to inventories of greenhouse gases (GHG), particularly in those many developing countries where household use is a significant fraction of total fuel use. In addition, the simple stoves in common use in such countries do not obtain high combustion efficiency, thereby emitting a substantial amount of fuel carbon as products of incomplete combustion (PIC) - such as carbon monoxide (CO), methane (CH4), and total non-methane organic compounds (TNMOC) - as well as carbon dioxide (CO2). This is true for fossil fuels, such as coal and kerosene, but is particularly important for unprocessed biomass fuels (animal dung, crop residues, and wood), which make up the bulk of household fuel use in developing countries

It is an alternative fuel which is both sustainable as well as renewable obtained from fermentation of organic materials by depleting oxygen. Biogas provides a number of advantages do not contribute to the enhancement of atmospheric carbon dioxide concentration this is due to the fact that it obtains from an organic source with short carbon cycle. Biogas contains 50%-70% methane, 30%-50%carbon dioxide, in addition small amount of other gases. It has a calorific value of 21-24MJ/m3. Methane is a flammable gas whereas carbon dioxide is inhibitor. Biogas is used for cooking /heating

1.1 Combustion Characteristics of Biogas

If combustion is perfect, the flame is dark blue as well as almost invisible in daylight. If too little air is available, the gas does not combust fully and part of the gas escapes unused. On the other hand if too much air is supplied the flame cools off hence elongating the working time and enhancing the gas demand. Up on combustion it liberates heat and produces water as well as carbon dioxide

1.2 Problem statement

Energy input is the primary concerning issue at the present scenario for each and every sector worldwide for socio economic development and growth. In developing countries about 2.6 billion peoples relay on biomass to obtain energy for fulfilling and carrying out their day to day activities, while 400 million obtain from coal for cooking purpose, above 700milion people with no access to LPG. The majority of this population is involved in smallholder agriculture hence has opportunity of access to agricultural waste that can be easily converted to biogas (Tumwesige, Fulford, & Davidson, 2014). Ethiopia is one of the developing countries so that she is the sipper of the above energy source share. All those sources have its own disadvantages by emission of pollutants and particulate maters into the atmosphere. Ethiopian government was launched the national biogas program of Ethiopia with the support of SNV from Netherland in 2008 to upscale use of domestic biogas so that NBPE started its implementation phase by the end of 2013. Ethiopia now a day promotes the utilization of waste energy production as a substituent of biomass for cooking purposes somehow for electrical energy production because of the absence of sustainable resources. The main problems encountering in injera baking is distribution of heat to mitad particularly in biogas baking technology delivery of fuel to the combustion chamber due to pressure drop and the existing other technology causes for high significant problems for injera bakeries like indoor air pollution, high energy waste, high energy cost etc. The program is coordinate by national biogas program of Ethiopia in some parts of the country (Manon & Bermúdez, 2016). Biogas can be obtained from waste by passing through different processes in biogas digester. In order to obtain biogas, fist we have to collect waste materials that are used as an input for biogas production. Once we collect this waste it stirs up and allows to pass through hydrolysis process for converting the larger molecules like sugar, protein, fats into simple one such as amino acids, monosaccharide molecules (galactose, fructose) then it passes to the next stage of fermentation i.e. converting those simplest molecules in to acetic acid with depletion of oxygen. Finally allows passing through methanogens to obtain methane and carbon dioxide (Bond & Templeton, 2011).

Even though there exist other renewable sources of energy utilization, biogas can be easily accessible with optimum economy from waste in addition to this provides so many advantages regarding to the environment. The contribution of existence of biogas technology provides numerous advantages for the environment i.e. biogas obtained from animal dung, manure, sewages are disposed of carelessly in a field that contains methane. Methane is one of the contributing factors for greenhouse gas effect in the atmosphere intern which causes for the increment of atmospheric temperature so that it causes for ozone layer depletion, global warming (Bansal et al., 2017). Since 80% of the population lives in rural areas so that energy demand for cooking relays on biomass. Biomass based cooking has numerous problems such as exposure of smoke, low efficiency, high fuel consumption, indoor air pollution (Bansal et al., 2017), (Vaccari et al., 2017). Thus promoting biogas technology mitigates the impact that arises from deforestation like drought, soil erosion so that using biogas technology eradicates the above problems as well acts as a source of fertilizer (Grima-olmedo, Ramírez-gómez, & Alcalde-cartagena, 2014).

In Ethiopia *injera* is the most common traditional foods all over the country. To make injera a limited number of technologies are available for baking purpose. Biogas baking pan but most of the population uses sun dried biomass baking pan due to shortage of electrical power distribution, existence of freely gathered fire wood. The country predominantly uses open three stone fire injera baking pan. So that there exist a number of problems in *injera* baking technology i.e. shortage of electric power supply, inefficient use of energy, environmental pollution, low conversion efficiency to heat, indoor air pollution, loss of fertilizer as well as health problem on the woman i.e. respiratory disease. Biogas is a combustible gas yet now it has no any proper combustor that forms uniform heat distribution on the pan. Thus, to overcome those problems this research paper device an efficient biogas *injera* baking pans technology.

1.3 Objective of the study

1.3.1 **Main objective**

Main objective of this research paper is to design, model, and manufacture, conduct the experimental investigation of biogas *injera* baking pan designing burner that provides heat or fuel via the pan.

1.3.2 **Specific objective**

, the specific activities that have been done as shown below:

- Design each components of baking pan such as biogas pipe line, fuel air mixing tube, burner holder, combustor skirt, nozzle, flue gas exhaust manifold, air inlets line (primary, secondary).
- Designing insulation layers and Identifying the amount of energy exhaust via flue gas from pan
- manufacturing prototypes of biogas baking pan using low cost material and analyzing baking pan heat transfer characteristics
- experimental investigation of the performance characteristics of the baking pan
- Evaluating amount of heat loss considering the mode of heat transfer characteristics
- calculating the performance or efficiency of pan

1.4 Significance and application of the study

. Since 80% of the Ethiopian population lives in rural area all most all population of the country adopt biomass/open three fire stone baking pan due to free gathering of wood, electrical power shortage (Kelebe & Olorunnisola, 2017). Hence, currently sun-dried biomass/three stone fire *injera* baking pan is the widely available technology throughout the country with high energy losses due to combined heat flow, high pollution rate and health problems, less fuel conversion efficiency, indoor air pollution, loss of fertilize/bio-slurry. Therefore, the main expected outcome of this research paper could be alleviating the above problems by providing biogas *injera* baking pan. So that the outcome of this paper will be designing, manufacturing an efficient and effective biogas *injera* baking pan. As a result, biogas *injera* baking pan reduces dependency of the country from biomass fuel consumption by a certain amount.sothat the signifacancey of doing thisproject

. avoi

Generally, the advantage of this reach can be viewed from two points such that from internal point of view and external point of view.

When viewed from internal point of view at the nation level, it alleviates indoor air pollution so that gives a guarantee for human health so that abated death due to indoor air pollution. It also ing indoor air pollution

Means of alternative energy source

Acts as a means of waste removal

Used as a means of cost reduction lessen the expense for charcoal and electricity

production of biogas. implementing biogas provides fertilizer/slurry hence enhance agricultural productivity.in addition implementing biogas oven abated looking for biomass fuel so that people leans from biomass to biogas as a result mitigates deforestation.

When viewed from external point of view at world level it ensures environmental clean lines this is due to the fact that it ceases the emission of pollutants and particulate maters to the atmosphere.it minimizes the effect of global warming, ozone layer depletion, effect of drought, soil erosion

1.5 Scope and limitation

This research paper covers all the relevant steps and procedures to arrive at the desired product. The scope of this paper includes design, analysis of combustion, manufacturing, testing of the prototype. Nevertheless, due to the absence of molding/casting some part of baking pan may have obligated to be manufactured using the available work shop milling and turning machine. Moreover, design of biogas *injera* baking pan is underutilization so that it is difficult to assess and obtain information about previously studied baking pan. Manufacturing of clay pan in this research is not the scope so that we have to use conventionally available baking pan by purchasing from market.

Chapter Two: Literature review

2.1 Energy Situation

Sources of energy in Ethiopia can be categorized as traditional and modern energy sources. Traditional energy sources encompass wood fuel, agricultural residue, animal dung which we call as biomass fuel. The biomass fuel accounts about 95% of the nation energy usage. Modern energy consists of electricity and petroleum products which incur cost or it is commercialized as well as needs a certain processing to used.it accounts 4.2% of the country energy usages. Petroleum energy shares around 86% of the modern energy sources of the nation. Whereas the remaining energy coverage from electricity [2].From the total energy usage of the nation around 88% of energy is consumed in the house hold activities. Service3%, industrial 5% and agricultural 1% [1].In biogas injera baking pan the distribution of heat on the surface of mitad is not uniform yet now i.e. the pan causes for well baking on one side but over baking in other surfaces. But today or yet now under research hence to overcome this problem this research paper tries to impart a solution by providing uniform distribution of biogas fuel by adjusting the port hole to distribute fuel equally throughout the circular surface at the respective time.the solution imparts by equal angular spacing or radial arrangement of burner port holewe able to distributfuel uniformly hence the sprayed batter gets uniform heat from mitad surface hence we able to get well baked injera.

In Ethiopia, biomass energy usage is a key issue in the national economy and energy sector. Cooking and baking consumes too much energy. Unwise exploitation of biomass resources exposed for adverse economic and environmental effects [2].

2.1.1 **Injera**

Injera is the most commonly consumable foods in east Africa particularly in Ethiopia, Eritrea, and Somalia. Injera is a processed food prepared from different grains such as teff, sorghum, wheat; barely etc. injera can be made by passing a number of steps starting from powder preparation of grain up to well baked powder solvent. Injera can be baked by using a circular geometry plates having a diameter of 500mm-600mm is called Mitad. Baking injera takes too much duration as well as high energy consumption. In spite of the fact that injera baking pan is high in energy demand yet now under research (Haile Selassie, Bayray, & Jørgen, 2014a), (Kebede & Kiflu, 2014). Injera baking process requires very high surface temperature usually 180^{o}C to 220^{o}C.

2.1.2 Injera baking pan

Injera baking pan on the other hand called *mitad*, used for making *injera* by radiation and convection heat transfer from a certain source to *mitad* and then by conduction and convection to solvent grain powder. Depending on the heat source *injera* baking pan can be electrical powered, solar powered, biomass/three stone fired, biogas powered etc.

2.1 Electric powered cooking stove (ecook)

Cook **ecook** is a technology utilized for cooking where electrical energy is the primary source of heat. However, the distribution of electrical energy in developing country is limited. So that it is difficult to adopt electrical cooking stoves (Brown, Leary, Davies, Bachelor, & Scott, 2017).

Figure 2.1 Electric powered cooking stove (ecook) (Brown, Leary, Davies, Bachelor, & Scott, 2017).

2.1.1.1 Solar powered cooking stove

Solar powered *injera* cooking pan is also another technology employed for cooking where solar radiation is the primary source of energy. *Injera* to be baked very well it needs to have too much energy as well as time so that it requires a temperature of 180 – 220 degree centigrade. However, except a very few parts of the country it is impossible to collect such amount of temperature (Haile Selassie et al., 2014a).

Figure 2.2 Solar powered cooking stove(Haile Selassie et al., 2014a).

2.1.1.1 Biomass powered/three stone fire cooking stove

Open three stone fires is the most commonly available technology in developing and under developing country. Hence, biomass is the primary source of energy/heat for cooking in an individual house. Nevertheless, adopting three stone fire stoves responsible for contributing factors for environmental disorder. In addition to this it cause for high energy loss, less fuel conversion efficiency, indoor air pollution, loss of fertilizer, respiratory disease etc.(De, Nathaniel, & Olawole, 2014)and (Vaccari, Vitali, & Tudor, 2017).

Figure 2.3: Biomass injera baking mitad. (De, Nathaniel, & Olawole, 2014) and (Vaccari, Vitali, & Tudor, 2017).

2.1.1.1 Liquefied Petroleum Gas Stove (LPG)

LPG is also a kind of stove technology used for cooking purpose. Indeed, liquefied petroleum is a primary source of energy. Petroleum is obtained from purification of fossil fuel that exist naturally. However, petroleum fuel is nonrenewable source of energy which cannot be replaced once run out/used up. In addition to this petroleum fuel is one of the responsible contributing factors for environmental dis order. Hence causes for formation of acid rain, global warming, loss of soil fertility, loss of living things, etc. (Ogedengbe & Ajibade, 2017).

2.1.1.2 Biogas Powered Cooking Stove

This is also another cooking technology where biogas is the primary source of energy/heat (Bansal, Saini, & Khatod, 2017) Biogas contains a number of gases majority of it methane and carbon dioxide, depending on the constituent of waste minor hydrogen sulfide, hydrogen and nitrogen may include (Bond & Templeton, 2011). Even though biogas baking pans the most and acceptable technology for cooking, it needs a certain modification to be efficient and effective than the existing baking pan. As combustion of biogas takes place within the combustion chamber it gives of carbon dioxide, nitrogen as well as water if the combustion is perfect. So that this flue gas must have a passage or manifold for expelling from combustion chamber else if either it forms soot at the bottom of *mitad* and part of combustors hence affect heat transfer and combustion.

Figure 2.4 Biogas Powered Cooking Stove ((Bansal, Saini, & Khatod, 2017)

2.1.2 **Burner**

Burners are thermal equipment’s used to deliver gas air mixtures to the combustion chamber zone. The gas burner is used to create flame of fire that heats the desired object. Energy demand of the population increases to fulfill their day to day activities for instance in order to accomplish house hold activities like cooking relays on energy input from different source may be biomass, LPG, there is an ever-increasing demand of fossil fuel by the time fuels are depleting at rapid rate. Efforts are made to sustain it. Efforts are concentrated on burner to conserve the depletion of fuels so that different burners were designed regarding to the type of fuel i.e. liquid or gaseous fuel. Such as swirl, porous burner (axial, radial). For domestic cooking purpose conventional Bunsen type burner is widely available. Bunsen burner is partially aerated; primary air is draws in as a result of momentum transfer due to the high jet gas flow, high velocity and ambient air. Design of domestic conventional burner relay upon open combustion flame such that energy loss through dispersion of the flue gas to surrounding is very large resulting low thermal efficiency by prolonging the dispersion of flue gas then thermal efficiency can be improved by swirl flow since it lengthens residence time, enhances mixing by means of rotating flow between fuel and oxidants, flame stabilization but conventional burners are non-swirl flow. This implies that flow type affects burner performance. In any combustion system, burner plays a vital role to overcome this problem that it is necessary to use the correct design and material, improvement of thermal efficiency of any stove in another way to save fuel to do this the previous study combine effects of porous media and insulation of the combustion chamber of stoves. Porous media improves heat transfer rate and improves thermal efficiency while insulation provides reduction of radiation losses. Efforts contribute two different methods to improve the performance of burner’s use of porous media and insulation of combustion chamber of stove.

2.1.2.1 Swirl Burner

Swirl burner is a burner which has vanes at different vane angle and 3mm diameter jet and 25mm inner diameter and 75mm outer diameter of vane. Biogas combustion using a swirl can enhance flame stability. In low swirl condition the flame attaches to the rim of burner and an increase in flow velocity causes flame blow off. On the other hand, at higher swirl condition enhancing (45and 60 swirl), enhancing fuel velocity causes flame lifts off as well stabilizes at the

Downstream of burner.Swirl burner in addition to this used for air dilution. Swirl improves flame stability (Science, 2017).

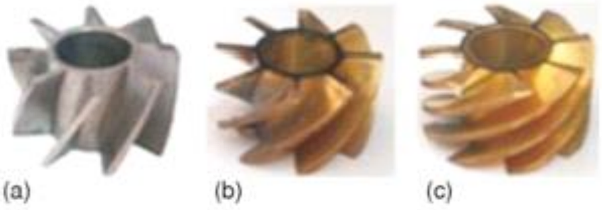


Figure 2.5 Swirl Burner (Science, 2017).

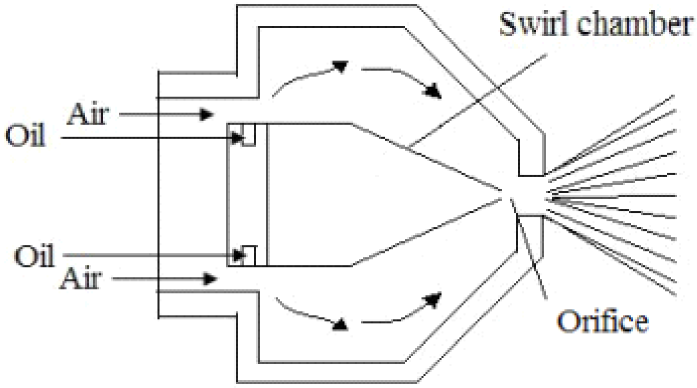


Figure 2.6 Swirl Burner (Science, 2017).

2.2 Conventional burner

Air needed for combustion delivered in the furnace in Bunsen burner small portion of air is supplied as primary air and the rest amount can be supplied as secondary air as shown in the figure below hence the combustion is open combustion so that the heat liberated upon combustion dispersed via flue gas intern results in dissipation of energy finally results in the system is inefficient.as shown in the figure the mass of air is 10 times that of the fuel. A small amount of this air is mixed with fuel as primary air, whereas secondary air is added in the combustion point so that mixing and combustion takes place simultaneously. A jet of fuel is produced in the downstream side of burner at the time of discharge of fuel. The velocity of the gas in the orifice is proportional to the square root of the differential pressure across the orifffice.as shown in the figure venture tube is provided for mixing. As the mixture of air and fuel passes through the nozzle they mixed in the divergent section of the venture. Secondary air added to the flame to complete combustion.

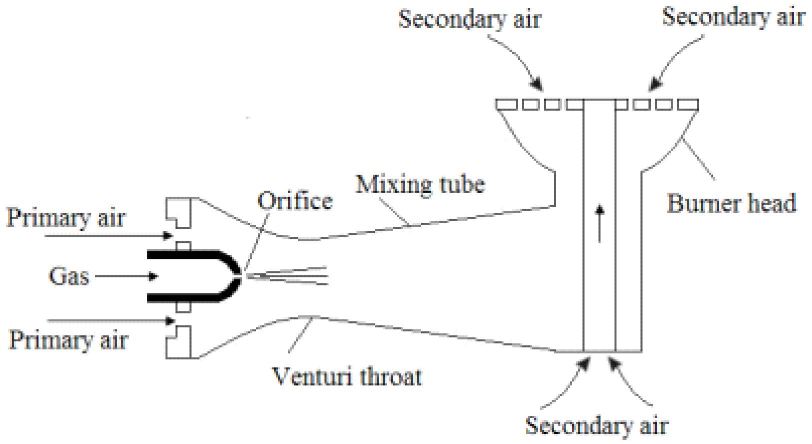


Figure 2.7 Conventional burner

2.1.2.1 Porous burner

Porous media combustion facilitates heat transfer rate.it gives rise to high radiant output, low emission, in porous medium there exist more efficient heat transfer from burned gases to unburned mixture in conventional combustion system convection is the dominating mode of heat transfer since conduction in gases has low thermal conductivity from burned to unburned.in porous combustion conduction and convection heat transfer is effective. Convection heat transfer is high due to increment of surface area in the porous matrix. Uniformity of temperature across the porous matrix and a presence of a significant amount of radiation help to preheat the incoming air fuel mixture upstream, causes for improving the combustion effficiencey.in order to control flame stabilization porous medium constructed from two different materials forming two separate zones i.e. preheating zone made of low porosity and low conducting materials the other is the combustion zone made of highly radiating and conducting materials.

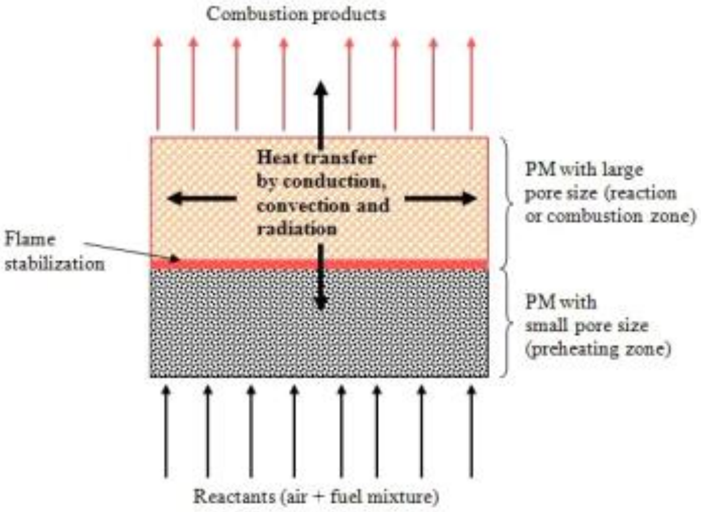


Figure:2.8 Porous Burner (Malico & Mujeebu, 2015), (Article, n.d.).

With the use of swirling internal flame burner the heat transfer coefficient between hot flue gas And vessel increases thermal efficiencies. When compare porous burner to conventional burner it has several advantages combustion occurs inside of the solid matrix of open cavities enough to sustain combustion. Porous burners work with steady, premixed. The thermal energy liberated during combustion process heat by convection the solid matrix and then radiates and conducts heat upstream in turn the incoming fuel and oxidants are preheated. This internal recirculation of heat from combustion and products zones to the reactants region results in high power densities, low pollutant emissions (Malico & Mujeebu, 2015), (Article, n.d.).

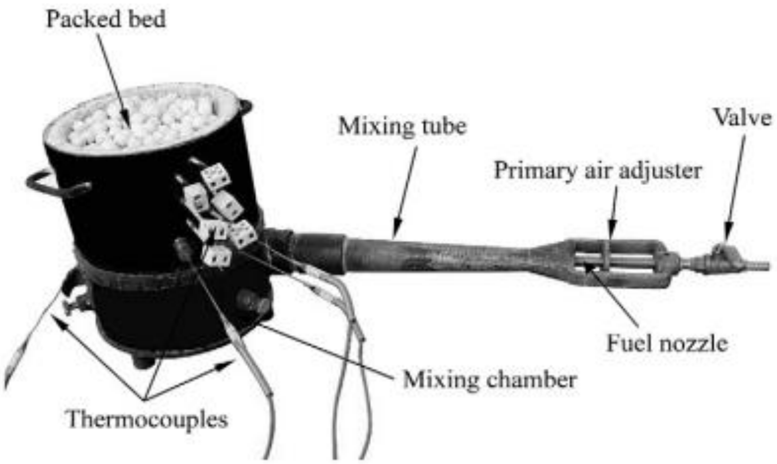


Figure 2.9 packed bed with thermocouple burner(Malico & Mujeebu, 2015), (Article, n.d.).

2.2 Biomass fuel and its impact on the environment

2.2.1 Deforestation

In rural area biomass fuels are freely gathered which results in destruction of forest/jungle. In developing countries, biomass is the only means of cooking. Actually, 90% of the fire wood is produced and utilized in developing country. In developing countries spatially in rural area three stone firestone is the widely available means of cooking. Open stone fire is inefficient, has high energy loss, less fuel conversion. Generally, the utilization of three stone fire integrated with high population growth rate of the developing country leads thigh deforestation rate throughout the world [[2]].

2.2.2 Indoor air pollution

Pollution of air takes places due to emission of pollutants and particulate maters into the atmosphere in the developed country primarily from industry’s emission from fossil fuel where as in the developing country from biomass i.e. cooking most commonly in the rural house hold.

The constituent of emissions depends on several factors such as constituent of fuel, nature of combustion, ambient temperature type of burner.

Emission of organic compounds arises from incomplete combustion. Inorganic particle and water in combination forms smoke. This emitted pollutants and particulate maters have health and environmental problems. [2]

2.3 Cooking stove

Conventional stoves waste a lot of energy and pose many pollution hazards. Most traditional stoves can utilize only 2–10% of the energy generated by the fuel. Because of growing gap between availability and demand for firewood, scarcity of fossil fuels, poor thermal performance and pollution caused by traditional stoves, the technologists focused their attention on improving the thermal efficiencies of these stoves and also to develop

More efficient smokeless stoves conceptually, conventional stoves can be improved in three ways: (i) increasing thermal efficiency, (ii) reducing specific emissions and (iii) increasing ventilation. Researchers have designed various models by incorporating various components, like tunnels, baffles, dampers, and grate

And chimney in earlier cook stove models; the efforts were made to improvement of Heat transfer efficiency via an enclosed combustion chamber and enhanced contact between hot gases and the cooking vessel. The two features which were the most complained of or Rejected by the users were the tunnel baffle and the door damper. The cook stoves are generally made up of mud, mud brick, ceramics or metal and/or combination of these. The Research work carried out on cook stoves can be looked into via three categories that are, the financial analysis, the environmental analysis and the performance analysis.

2.4 Stove in Ethiopia History of cooking

In industrial countries, the switch to more efficient stoves took place

Smoothly as fuel wood prices increased and stove makers increased efforts to build more efficient models. This was followed by a transition to cleaner fuels for cooking, such as coal and petroleum-based fuels.

As the availability of and access to petroleum-based fuels began to increase at the beginning of the 20 the century, many urban households in developing countries switched to stoves using oil-based products such as kerosene or LPG as fuels, just like their developed nation counterparts. On the other hand, rural households continued their dependence on the burning of biomass fuels for cooking and heating purposes. This was mainly due to weak delivery channels for petroleum-based products and rural people’s inability to afford these fuels especially compared to biomass resources, which were more freely available

2.5 Improved cooking stove

The most common method of cooking used in developing countries is an open fire. The fire is usually shielded or surrounded by “three stones, bricks, mounds of mud, or lumps of other incombustible material

2.6 Mode of heat transfer

Heat transfer is the transition of thermal energy, or simply heat, from a hotter object to a cooler object. There are three main modes of heat transfer[3]

Data’s that are available for heat transfer analysis obtained from different literatures regarding the conventionally used *mitad* and *injera* batter about heat transfer coefficient and thermal property[4,5]

Table2. 1: Summary of Parameters and Values

Name of parameter	**Standard pan**	**Unit**
Average side temperature	66.66	^{o}C
Average *injera* upper surface temperature	68.48	^{o}C
Average lid cover temperature	61.15	^{o}C
Average bottom plate temperature	120.18	^{O}C
Clay pan surface temperature	180	^{O}C
Clay pan temperature when batter poured	90	^{o}C
Emissivity of lid cover and pan	0.11	-
Bottom heat transfer coefficient	20	W/m^{2}K
Edge/lateral heat transfer coefficient	7.15	W/m^{2}K
Top heat transfer coefficient	$h_{1ct=9.624}$	W/m^{2}K
	$h_{1rt=1.555}$	W/m^{2}K
`	$h_{1cb=107.712}$	W/m^{2}K
	$h_{1rb=11.8}$	W/m^{2}K
	h2c=14.8	W/m^{2}K
	h2r=	W/m^{2}K

2.6.1 **Conduction**

Conduction is the most significant means of heat transfer in a solid. On a microscopic scale, conduction occurs as hot, rapidly moving or vibrating atoms and molecules interact with neighboring atoms and molecules, transferring some of their thermal energy (heat) to these neighboring atoms. The free movement of Electrons also plays a vital role to conductive heat transfer. To quantify the ease with which a particular medium conduct, the thermal conductivity, also known as the conduction coefficient, λ, has been employed. The thermal conductivity λ is defined as the quantity of heat, Q, transmitted in time (t) through a thickness (x), in a direction normal to a surface of area (A), due to a temperature gradient (ΔT).

A mathematical explanation defines the rate of heat flow, the temperature difference and the nature of the conducting material is contributed to Fourier Law of heat flow= -k*A*ΔT/X

Conduction heat transfer is defined as the transfer of energy from one point of a medium to another under the influence of temperature variation. A distinguishing characteristic of conduction is that it takes place within the boundary of a medium, or across the boundary of a medium into another medium in contact with the first, without an appreciable displacement of the matter. Heat conduction is important in stove top cooking, where heat is conducted from the heat source, gas flame or electric coils directly to the bottom side of the pan. Conduction continues as heat passes through the pan to the food from the baking pan. Even after the pan is removed from the heat source, conduction continues until the pan and the food reach the isothermal state. The equation of heat transfer mode by conduction can be explained mathematically as follows:

$$kA_b\frac{T_{bp}-T_{pt}}{x} = q = \cdots \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.2.1$$

Where: q = Heat transfer due to conduction, Ab= Area of the pan surface, Tbp– the temperature of bottom plate, Tpt = Temperature top pan surface and x – is the average thickness of the pan and if there is no heat generation in the slab.[3]

2.6.2 **Convective Heat Transfer**

Convection aids heat transfer through fluid medium, which otherwise conduct heat slowly. It involves the constant movement of cold currents of air or liquid toward warmer currents. Because warmer liquids and gases are less dense and rise up while colder liquids and gases are denser and they sink. Heat and mass transfer in fluids takes place, almost always, simultaneously with bulk movement of the medium. This system is called convection heat transfer. In the Ethiopian flat bread /„injera‟/ convection heat transfer is considered as heat loss/gain of the system even if in such cases it uses for heat balance of the product.

$$q_F = h_F A\left(T_{lc} - T_p\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.2$$

Where; q F = Heat transferred by convection, kJ; h_F = Convective heat transfer coefficient, W/m2 K; A p = Surface area of the product, m^2 Tlc = Temperature of the lid cover; and T_p = Temperature of the pan surface in ^oC.

The movement is caused by heat or mass transfer itself, usually by virtue of density differences is known as natural (free) convention heat transfer. Air in contact with the stove surface is heated, expands, becomes less dense, moves upwards and is replaced by colder, heavier air. Empirical correlations for convection heat and mass transfer for natural (free) convection, which is essentially based on differences in density, hence on thermal expansion of the fluid, the correlations contain the Grashof number (Gr). This dimensionless group contains the term $\Delta\rho$, the difference in the density of the fluid, which in turn is related to the differences in temperature (ΔT) and the coefficient of thermal expansion, β. The following correlation is often recommended for the calculation of natural convection heat transfer from vertical surfaces:

$Nu= 0.59\ Pr^{0.25}\ Gr^{0.25}$ For a sphere immersed in fluid the following equation is proposed:

$Nu=2+\ 0.6\ Pr^{0.33}Gr^{0.25}$ for horizontal plate and uniform surface temperature, the recommended correlation for the heated upper surface: and, $Nu = 0.54(Ra)^{0.25}$ for $10^5<Ra<2*10^7$

, $Nu= 0.14(Ra)^{1/3}$ for $2x10^7<Ra<3x10^{10}$ Where; Ra=Rayleigh number, and Pr = Prandl number Convection is usually the dominant form of heat transfer in liquids and gases. Convection comprises the combined effects of conduction and fluid flow. In convection, enthalpy transfer occurs by the movement of hot or cold portions of the fluid/gas together with heat transfer by conduction [3].

2.7 *Injera* Baking Pan

Injera baking pan on the other hand called *mitad*, used for making *injera* by radiation and convection heat transfer from a combustor to *mitad* and then by conduction and convection to dough. Depending on the heat source *injera* baking pan can be electrical powered, solar powered, biomass/three stone fired, biogas powered etc.

Figure 2.10: Front and back Surface texture of injera (a review of injera baking technology in Ethiopia by (Kamil Dino(phd)and demiss alemu(phd) 2017))

2.7.1 Biogas Powered Cooking Stove

This is a cooking technology where biogas is the primary source of energy/heat (Bansal et al., 2017). Biogas contains a number of gases majority of it methane and carbon dioxide, depending on the constituent of waste minor hydrogen sulfide, hydrogen and nitrogen may include (Bond & Templeton, 2011). Even though biogas baking pans the most and acceptable technology for cooking, it needs a certain modification to be efficient and effective than the existing baking pan. As combustion of biogas takes place within the combustion chamber it gives of carbon dioxide, nitrogen as well as water if the combustion is perfect. So that this flue gas must have a passage or manifold for expelling from combustion chamber else if either it forms a soot at the bottom of mitad and part of combustors hence affect heat transfer and combustion. Efforts were made different biogas cooking stove so that lets a look at the previously studied biogas cooking stove or biogas burner.

On researching a best performance of gas burner, it is crucial to look a good design of burners leading a result of combustion efficiency enhanced. In addition, now a day's emission of pollutants and particulate maters are a primarily concerning issue of combustion so that the gas burner expected to have as much as possible less emissions. Some of the emissions are NO_Z and CO. Some of the techniques to reduce emissions and enhance efficiency of burner a number of researches has been done. Swirl burner (Surjosatyo & Ani, 2011), partially premixing burner [(Media et al., 2015),], porous burner [(Malico & Mujeebu, 2015)], heat recirculation burner (Mechanics, 2013), rotating matrix swirl burner [(Hou & Chou, 2013)], recirculating and re-burning emitted gasses are all used to satisfy the above stated statements.

One of the methods of enhancing the performance and efficiency of gas burner could be using porous medium. Porous medium is a medium which has too much porous matrix enables for good combustion ,high heat transfer rate by radiation conduction ,enhances convective heat transfer rate due to increasing surface area of porous matrix, since combustion takes place in side of the porous it sustain combustion, the temperature distribution throughout the pores uniform so that heat distribution becomes uniform, as well as heat transfer from burned gas to downstream is good so that combustion conducted effectively(Malico & Mujeebu, 2015).

An eco-friendly, compact premixed liquefied petroleum gas burner on matrix stabilized combustion in porous medium has been attempted to develop. The premixing is the integration of guide vane and wire mesh packing. As compared with conventional burner premixed swirl burner produces a sustainable flame at any rate of fuel input. The flame produced by swirl premixed burner at 0.4lpmis much higher than the flame produced by conventional burner operated at 1lpm. As well as the emission is much lower than CB. Specifically swirl premixed burner reduces emission as well as reduces consumption of fuel by 60% as compared to CB (Surjosatyo & Ani, 2011).

Various works have been concentrated on the amendment of the efficiency and emission features of the LPG (liquefied petroleum) cooking oven. In order to improve the efficiency of a stove, the concern ought to be on the improvement of the specification, design and material in this research air preheating taken as a factor for better efficient burner. In addition, the shape of the burner plays a vital role for the improvement of the performance of the oven (Dahiya, Lather, & Bhatia, 2016).

LPG is a clean fuel for domestic use.it is a source of energy aiming with the improvement of thermal efficiency and emission behavior of the existing LPG cooking oven. The experimental investigation of on the performance of LPG cooking stove shows that using different burner heads affect efficiency. So that based on this investigation the combustion efficiency recorded by flue gas analyzer86.9% and Selection of right burner material also contribute for better efficiency. In this research it was illustrated that porous media gives rise to 10% efficiency improvement, and use of insulation alone rises by 6% efficiency improvement. Integration of porous media and insulation layer enhances efficiency of burner by about 18% (Dahiya et al., 2016,), (Walecha & Revaskar, n.d.), (Article, n.d.)

Flameless combustion is combustion in which there exist flue gas recirculation inside of the furnace dilutes the oxidizer and minimizes air concentration, hence temperature dissemination is uniform along the combustion chamber eliminating hot spot and mitigating heat loss due to NO_Z and radiation flux net increases by about 30%.By preheating the combustion air to the temperature of flue gases when it passes via the honeycomb before the entrance of the combustion chamber. The honeycombs play a vital role on the combustion and recover around 72% of energy recovered from the combustion carried flue gas (Mechanics, 2013).

Biogas production led to the development of a number of biogas appliances lighting, power generation and cooking. Biogas stove is the most promising one, to meet the energy requirement for cooking .design and development of community biogas stove for baking bread on a hotplate for canteen or community purposes. The gas feeding rate of the stove was 1m3 and cooking efficiency of the stove was 43.96%.The efficiency of using biogas is 55% in ovens, 24% in engines and 3% in lamps (Kurchania, Panwar, & Pagar, 2017).

Biogas stove used to achieve energy requirement for cooking purposes at domestic as well as at the community level. Biogas stove for baking injera was designed by masking the flame under an insulating material. The gas burner has been designed based on energy demand during baking and the amount of gas supplied from plant.Heat transfer analysis between burner and mitad via radiation, convection as well as between flame and also analyzed (Kebede & Kiflu, 2014).

An efficient burner has been designed based on the characteristics of simplicity, cost effectiveness, efficiency as well as safety. Selecting the heating rate of burner, flame related aspects of the burner have been established. Here the two most important factors are primary air entrainment and burning velocity. Factor that affect Burning velocity have been also identified as thermal diffusivity, average reaction rate, fuel concentration, flame temperature, ignition temperature and initial temperature of the reactants.so that taking into account of this the burning velocity have been approximated as 0.22m/s. other texts suggests that between 0.25and 0.34m/s (Obada, Obi, Dauda, & Anafi, 2014).

Porous radiant burner (PRB) used in LPG cooking stove performance investigation have been carried out. Thermal efficiency of this burner has been found using water boiling in IS: 4246:2002. PRB showed a maximum thermal efficiency of around 71% which is 6% more thank. In this study influence of ambient temperature on thermal efficiency of the pre identified. The emissions of PRB I.e. CO and NO_Z much less than that of CB (Muthukumar, Anand, & Sachdeva, 2011). The maximum thermal efficiency of PRB 71%AT 1.24kw and equivalent ratio of 0.68 at an atmospheric temperature of 31degree Celsius. This is 6% more than the maximum thermal efficiency of LPG CB, that is in arrange of 60%-65%it has been also identified that thermal efficiency of PRB found to be decrease with equivalent ratio of fuel –air mixture. AT 1.24Kw the maximum thermal efficiency was found to be 66.8% at equivalent ratio of 0.6 and lowest was 63.1% at equivalent ratio of 0.68 thermal efficiency of PRB was also found to increases with ambient temperature. The maximum thermal efficiency at 1.24kw and equivalent ratio of 0.68was found to be 71%at 31degree Celsius and 61.1% at 18.5 degree Celsius (Muthukumar et al., 2011).

Fossil fuel demand increases time to time by the time this fuel is going to deplete at a faster rate.so to minimize this effect experimental investigation was conducted to see effects on different burner design heads on the performance of LPG stove. In addition, different materials also used to see effects of material on performance of the stove.it was experimentally found that thermal efficiency of stove using flat and flower face brass burners were higher as compared with cast iron burner. Four percent (4%) improvement was obtained when brass burner was used instead of cast iron burner. Maximum thermal efficiency of 58% was seek when flat face brass burner used and 50%thermal efficiency achieved when used flower face burner was used (Khan & Saxena, 2016).

2.8 Methodology

In this section of the paper some of the techniques that I was followed stipulated and described below to achieve objectives mentioned on the objective section. Methodology that is used for the successful achievement of this research paper could be: for the very beginning decide about the problem is it realistic or not by collecting information via may be interview, observation, previously audited data etc. Then make sure that whether there exist available input materials or not for construction of *injera* baking pan and then make sure that weather the access of biogas fuel easily handled in all parts of the country or not. After while doing so, start to allocate relevant information about cooking technology that would exist in the market. Then let's identify the constituting elements of biogas with regard to the homogeneity or heterogeneity of the waste material used for the production of biogas. Therefore, based on the constituent of the biogas, analyses the combustion reaction that would be takes place in the combustion chamber and identify the flue gases that emits from the combustor as well as quantifying the temperature of the flue gas and energy generated. Based on this information proceed to select the available materials for the main components of *injera* baking pan by considering of other criteria for selection.. Before we have carried out design of each components we were collected data about the thermal property of biogas and mitad from previous journal i.e. entirely worked papers after then we had made designing of components of biogas *injera* baking pan had been started. When we comes to the end designing, make part drawing for manufacturing as well as modeling of the product. The next stage has been manufacturing of the prototype; after then the components of *injera* baking pan assembled and went to laboratory for testing purpose. So that relaying on the data collected from experimental investigation, make calculation of *injera* baking pan efficiency following this draw deduction about the performance, efficiency of biogas *injera* baking pan. Finally based on the calculated efficiency and performance, this research paper forwards about the recommendation of the project as well as limitation of the project.

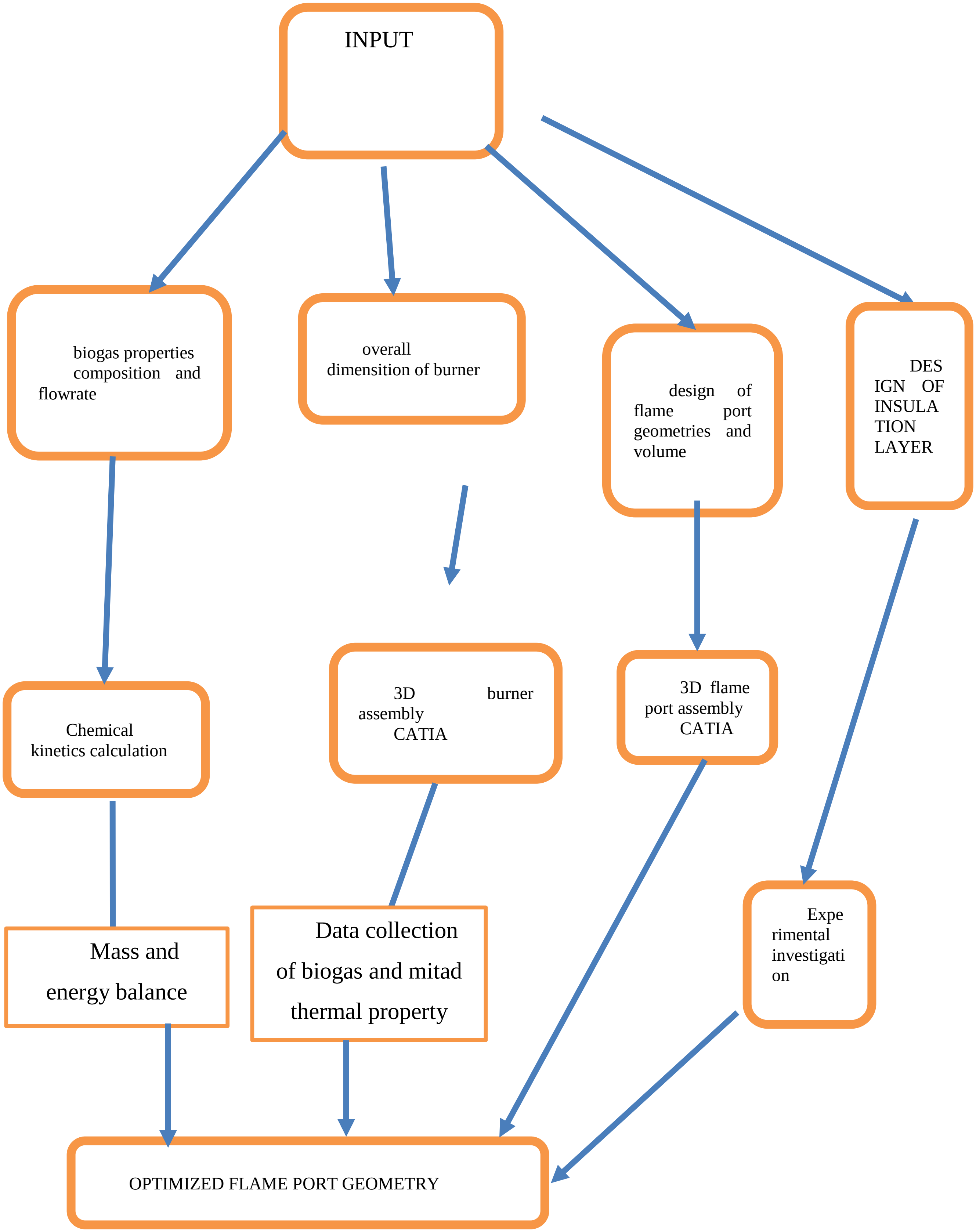


Figure 3:1 flow chart of methodology

Chapter Three: Design of biogas injera baking stoves

3.1 Energy demanded for baking injera

The average energy required for *Injera* baking implies the energy that is necessary to raise the temperature of batter from room temperature to boiling point and evaporate the required amount of water during the baking process. This useful baking energy estimated in the form of sensible heat for heating-up of the batter from room temperature to water boiling temperature and Latent heat responsible for evaporating some of the water content of the batter. The net useful energy in *Injera* baking has modeled mathematically as follows.

3.2 Available data

Data that expresses the content of dough obtained from GIZ illustrated as shown below .the constituent of dough most of the time *teff* and water with a percentage of 40 and 60 respectively (Kebede & Kiflu, 2014).

Table 3.1 data of injera *batter (Kebede & Kiflu, 2014)*

Measurement	Weight of dough[gm]	Water (60)	Teff (40)
1	580	348	232
2	581	348.6	232.4
3	582	349.2	232.8
4	581	348.6	232.4
5	580	348	232
Average	580.8	348.48	232.32

Table 3.2: Property of biogas essential for designing stove and lamp

Property	60% and 40%
Methane and carbon dioxide content60%	22mj/m3
Specific gravity	0.940
Flame speed factor	11.1
Air requirement for combustion	5.7m3/s
Combustion speed	40cm/s
Inflammability in air	6.25%

Table 3.3: composition of biogas essential for designing stoves

Methane content	60
Carbon dioxide content	40
Specific gravity	21-24MJ/m3

Data collected from different materials (Haile Selassie et al., 2014a) (Kebede & Kiflu, 2014) (Mulugeta & Demissie, 2017)

Table3. 2: dimension of conventionally used mitad *and property of constituting element*

No	Parameters	Dimension
1	*Mitad* diameter	60cm
2	Loss of temperature from *mitad*	150-180
3	Thickness of *mitad*	20mm
4	Maximum efficiency of biogas stove@8mpa	51%
5	Efficiency of baking stove @7.48mpa	45.1%
6	Specific gravity of *teff*	1.046
7	Combustion temperature of biogas at26ambient temperature	126
8	Specific heat capacity of clay	1381J/kg ^{o}C
9	Density of clay	1.746g/cm3

The amount of energy demand to cook a single meal can be obtained from (Bansal, Saini, & Khatod, 2013)

$$ES=\frac{\sum_{k=1}^{n} mkck(Tb-Ta)+\sum_{m=1}^{n} mmem+mwl}{t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.1$$

Where k-n represents different food item

Mk mass of food item

Ck specific heat capacity of food item

Tb boiling point temperature

Ta ambient temperature

Mm mass of vessel

Em energy demanded to bring chemical change

Mw mass of water

L latent heat of vaporization

Mmem is equivalent to the amount of energy required for heating baking pan in order to bring the chemical change of dough to injera. Therefore, ed can be given by:

$em = cm(Tc - Ta)$ ….3.2

$mm = \varrho mVm$ … ..3.3

Where Tc combustion temperature

Ta ambient temperature

ϱm Density of mitad equivalent to clay

Vm volume of mitad.

Rearranging the above equations will give:

Since the food items that has been going to be baked is identical only injera therefore the equation will be come to:

$ES = (n(mkck(Tb - Ta) + mwl) + \varrho mVmcm(Tc - Ta\ ))$/t

Where n total number of *injera* that has been going to be baked 25.Therefore, once determined the amount of energy required to bake 25 *injera* then Tc-Ta determine the amount of power required for baking this much *injera* must be calculated. The time taken to bake a single *injera* has been assumed to be 2 minutes or 120 second. Having 2minute for a single injera so that for 25injera it takes about 50 minute or 3000second.

Then the output power can be calculated as shown:

$\boldsymbol{P = \frac{Es}{\eta}}$ ….3.4

$ES = \frac{n(mkck(Tb-Ta)+mwl)+\varrho mVmcm(Tc-Ta\ )}{t}$ … … … … … … … … … … … … … … … … … ..3.5

$Es = (25(0.23232 * 1.046(100 - 26) + 0.34848 * 4.2 * (126 - 26)) + 1746 * 0.02 * \pi * 0.09 * 1.38 * (126 - 26)))/3000$

=45.59kw=45590W

$$P = \frac{45.592}{0.451}$$

P = 363.9MJ/h

The volume flow rate of biogas from the digester can be given by:

$$Q = \frac{P}{Cg} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots .. 3.6$$

$$Q = \frac{363.9}{22}$$

$$Q = 16.542\mathrm{m}^3/h$$

3.3 Heat Losses of the Baking Process

The heat transfer mechanism of the *mitad* is modeled in Figure 8. Considering an overall energy balance on the *Mitad* system, the heat losses has been calculated as shown below

$Q_{losses} = Q_{rad, top} + Q_{conv, top} + Q_{rad, bottom} + Q_{conv, bottom} + Q_{rad, side} + Q_{conv,sid}$…………………..3.7

3.4 Heat transfer characteristics of the baking pans

Heat can be lost in three directions of the baking pans /“*mitad”*/. Those are bottom, lateral and top directions of the baking pans which energy dissipates to the environment (or surrounding). Ovens use all three fundamental heat transfer modes; convention, conduction, radiation, and in various combinations. The bottom surface of *injera* is heated mainly through conduction and only a little part of the heat is transferred to its upper surface by means of convection and radiation mechanism.

Figure3-1: Heat loss from injera mitad

3.5 Heat Loss Coefficient determination of the Baking Pan

Heat lost coefficients are the wastes that occurs due to conduction, convection and radiation as shown below in the thermal resistance circuit, The heat source of the baking pan */”mitad“/* is the flame of combusted gases from combustion chamber for biogas *mitad* and the current flow through Ni–Cr coil (or wire) that inserted in the bottom side of the baking pan for electric *mitad.*

Different parameters are required in order to carry out the analysis of baking pan parameters such as thermo-physical properties of *injera* batter as well as heat transfer coefficient of batter those parameters are illustrated/tabulated below the table[4,5].

Table3.3: Thermo-physical property of injera batter

Parameter	**Value**
Thermo-physical property of injera batter	
Thermal conductivity	K=0.654w/m^{o}k
Specific heat capacity	C_p=4.375KJ/Kgk
Heat of evaporation of water	h_{fg}=24.31*10^{5}J/kg
Density of injera batter	ρ=1160.29kg/m^{3}
Heat transfer coefficient values of batter	
Convective heat transfer coefficient	h_c=7.1w/m^{2}k
Boiling heat transfer coefficient	$h_{b=2000w/m}{}^{2}$k
Radiative heat transfer coefficient	h_r=8.5w/m^{2}k

3.6 Top Heat Transfer Coefficient

3.6.1 Convective Heat Transfer Coefficient

Heat transfer occurs across the baking pan lid cover by free convection to the environment. In many food preparation processes, involving cooling, transient convective heat transfer happens between a fluid medium and the solid food item. Heat transfer coefficient from the pan surface to the lid cover can be quantified mathematically using

$h_{1c} = kNu/L$……………………………………………………..3.8

Where, Nu– is the Nusselt number, geometric Pr, (Ra, f=Nu k – Thermal conductivity of evaporated water fluid L – pan to lid cover distance In order to determine the convective heat transfer coefficient between the pan and lid cover, the air properties will be considered at mean temperature between them (Appendix A):

$Tf = (Tlc + Tp)\ /2$ ………………………………………………………...3.9

$Tf = (60 + 180)\ / 2 = 120^oC$

Where, T_{lc} temperature of lid cover (^0C)

Tp temperature of baking pan surface (^0C)

Nusselt number (Nu) is determined from the Rayleigh number (Ra) as follows:

$Ra= GrPr=g\Delta\beta\ PrL^3/v^2$……………………………………………………………………………3.10

$Ra=GrPr= (9.81*120*0.000858*1.4611)/ (2.5*10^{-7)2}$

$Ra= 2.17*10^8$

The Nusselt number (Nu) for horizontal plate (β=0) and uniform surface temperature, the recommended correlation for the heated upper surface is given as follows:

$Nu =0.14 *(2.17*10^8)^{1/3}, 2*10^7< Ra<3*10^{10}$

$Nu =0.14 *(2.17*10^8)^{1/3}, 2*10^7< Ra<3*10^{10}$

$Nu = 0.14 * 166.39,\ 2*10^{7} < Ra < 3*10^{10}$

$Nu = 0.14 * 166.39,\ 2*10^{7} < Ra < 3*10^{10}$

$Nu = 84.08$

$h_{11c} = k\ Nu / L$

$h_{11c} = 0.68*84.07/0.1 = 571.74\ w/m^{2}k$

II. Heat transfer coefficient from the lid cover to the ambient. Here the heat transfer accompanied due to movement of air convection because of air as a result we consider property of air hence we use appendix(c)

Therefore $\Delta T = T_{lc} - T_{a}$

$\Delta T = 61.18 - 21 = 40^{o}c$

$\Delta T = 40^{o}c$ properties of air at this temperature obtained from appendix (c)

$Ra = GrPr = g\ \Delta T\ \beta\ PrL^{3}/v^{2}$

Thermal expansions of common gases are the reciprocal of temperature. The volumetric (cubical) thermal expansion coefficient of any permanent gas (at constant pressure) is given by;

$\beta = 1/T_{k}$ ………………………………………………………………………………3.11

$T_{K=273+40=313}{}^{O}{}_{K}$

$\beta = 0.0032$

$Ra = GrPr = 9.81*40*0.6^{3} *0.7255*0.0032/(1.701*10^{-5})^{2}$

$6.801*10^{8}$

The Nusselt number (Nu) for horizontal plate (β=0) and uniform surface temperature, the recommended correlation for the heated upper surface is given as follows:

$Nu = 0.14 *(6.701*10^{8})^{1/3},\ 2*10^{7} < Ra < 3*10^{10}$

$Nu = 0.14 *(6.701*10^{8})^{1/3},\ 2*10^{7} < Ra < 3*10^{10}$

$Nu = 0.14 * 878.4,\ 2*10^{7} < Ra < 3*10^{10}$

$Nu = 0.14 * 878.4,\quad 2*10^{7} < Ra < 3*10^{10}$

$Nu = 122.116$

$h_{21c} = k\ Nu / L$

$h_{21c} = 0.02662 * 122.116 / 0.1$

$h_{21c} = 32.7 w/m^{2}k$

3.6.2 Radiative heat transfer coefficient

For the baking pans, it was considered that, it has the same radiating, pan surface area, and also has a unit value of geometric factor. Therefore, the overall coefficients for radiation heat transfer (F_{pr}) are equal to the summation of series emissivity (ε_{eff}) of pan and lid cover. Radiative heat transfer coefficient from the baking pan surface to the lid cover,

$$h_{lcp} = \zeta\varepsilon eff\left(\frac{(Tp+273)^{4}}{Tp-Tlc} - \frac{(Tlc+273)^{4}}{Tp-Tlc}\right) \quad \ldots 3.12$$

Where; ζ – Stefan Boltzmann constant [5.67x10-8 $W/m^{2}.K$], Tp – surface baking pan temperature T l c – temperature of lid cover of the baking pans from the appendix (B); and

The effective emissivity of the baking pans is given by: $\varepsilon_{eff} = [1/\ \varepsilon p + 1/\ \varepsilon_{lc} - 1]^{-1} = 0.11$for conventional baking pan;

The radiative heat transfer coefficient of convection is determined as:

$$h1r = \zeta\varepsilon eff\left(\frac{(Tp+273)^{4}}{Tp-Tlc} - \frac{(Tlc+273)^{4}}{Tp-Tlc}\right) \quad \ldots 3.13$$

$$h1r = \zeta\varepsilon eff\left(\frac{(Tp+273)^{4}}{Tp-Tlc} - \frac{(Tlc+273)^{4}}{Tp-Tlc}\right)$$

$$h1r = \zeta\varepsilon eff\left(\frac{(Tp+273)^{4}}{Tp-Tlc} - \frac{(Tlc+273)^{4}}{Tp-Tlc}\right)$$

$$\mathrm{h1r} = 5.67 * 10\hat{} - 8 * 0.11(\frac{(180 + 273)^4}{180 - 61.15} - \frac{(61.15 + 273)^4}{180 - 61.15})$$

$$\mathrm{h1r} = 6.237 * 10\hat{} - 8(\frac{(453)^4}{118.85} - \frac{(334.15)^4}{118.85})$$

$$\mathrm{h1r} = 6.237 * 10(\frac{4.211 * 10}{118.85} - \frac{1.247 * 10}{118.85})$$

$$\mathrm{h1r} = 6.237 * 10(\frac{(4.211 * 10)^{10}}{118.85} - \frac{(1.247 * 10)^{10}}{118.85})$$

$$\frac{6.237 * 10^{-11}(4.211)10^{10}}{118.85} + \frac{6.237 * 10^{-11}(1.247)10^{10}}{118.85} \ldots$$

$$\mathrm{h1r} = \frac{6.237 * 10^{-9}(4.211 - 1.247)10^{10}}{118.85}$$

$\mathrm{htr} = 1.555$ W/m2k

3.6.3 From lid cover to ambient or surrounding

The sky temperature or (temperature of the surrounding) (Tsky) given by: T_{sky}=Ta − 6 =20

The radiative heat transfer coefficient is expressed as:

$$\mathrm{h2r} = \zeta\varepsilon\mathrm{eff}(\frac{(\mathrm{Tlc} + 273)^4}{\mathrm{Tlc} - \mathrm{Ta}} - \frac{(\mathrm{Tsky} + 273)^4}{\mathrm{Tlc} - \mathrm{Ta}})$$

$$\mathrm{h2r} = 5.67 * 0.11(\frac{(61.15 + 273)^4}{61.15 - 26} - \frac{(26 + 273)^4}{61.15 - 26})$$

$$\mathrm{h2r} = \frac{6.237 * 10^{-9}(1.247 - 0.737)10^{10}}{35.15}$$

$\mathrm{h2r} = 0.9049\mathrm{wm}^2\mathrm{k}$

The total effective top heat transfer coefficient from pan surface to the ambient is U_t which is evaluated by using the following formula.

$Ut= [(1/h_1) + (1/h_2)]^{-1}$ ……………………………………………………………………….....................3.14

Where, h1 and h2the transfer of heat due to convection as well as the equivalent radiation heat transfer from pan surface which can be given by

h1 = h1lc + h1r =571.74+1.56

h1 =573.3wm2k

h2 = h2lc + h2r = 32.7+ 0.905

h2 =33.6wm2k

Therefore, $Ut= [(1/h_1) + (1/h_2)]^{-1}$

$Ut= [(1/573.3) + (1/33.6)]^{-1}$

$Ut= 31.74wm^2k$

The rate of heat transfer from baking pan surface to the ambient per unit area can be given by Qt

$Q_{t=}U_{t\,(}T_{p\text{-}}T_{li)}$..3.15

$Q_{t=}31.74_{(}180_{\text{-}60)}$

$Q_{t=}3808.8w/m^2$

From this the amount of energy loss can be

$Q_T=Q_t*A$, $A=3.14*d^2/4$

$Q_T=Q_t*A$……………………………………………………………………..3.16

$Q_T=3808.8$

$Q_T=3808.8\ w/m^2$

The rate of heat waste transfer from baking pan surface to the ambient can be energy absorbed by the output and or energy deliver for evaporating the water content of poured batter on mitad to the ambient. This much amount of energy waste takes place by the time of heating up of mitad/clay as well as subsequent injera baking cycles.

$Q_{t=}U_{t\ (}T_{p}\text{-}T_{li)\ =}31.74(180\text{-}60)$

$Q_{t=}U_{t\ (}T_{p}\text{-}T_{li)\ =}31.74(120)$

$Q_{t=}3808.8*Aw$

$Q_{t=}3808.8*3.14*0.6^{2}/4$

$Q_{t=1076.4w}$

And the rate of heat loss from the top per unit area can be given as :) T (for a given diameter of the baking pans has similar value as shown below: q q Improved of Side Top Loss, al Convention of Side Top Loss this heat transfer rate might not be considered as energy loss from the baking pan completely because it includes an energy absorbed by the product (or latent energy evaporation from the product to the ambient). Hence, the heat loss occurs during the heating up and between consecutive baking cycles.

3.6.4 Bottom Heat Transfer Coefficient

Heat is lost from the plate to the ambient, by conduction through the insulation to the plate casing and subsequently by convection and radiation from the bottom casing surface to the ambient: -1binin b h 1 + K t =U and convection and radiation heat transfer coefficient from the bottom casing surface to the ambient is given as follows:

Conduction from pan to plate then Convection from plate to the environment

$\Delta T= 120\text{-}21=100^{O}C$

$\Delta T= 100^{o}c$ properties of air at this temperature obtained from appendix (C)

$Ra= GrPr=g\ \Delta T\ \beta\ PrL^{3}/v^{2}$

Thermal expansion of common gases is the reciprocal of temperature. The volumetric (cubical) thermal expansion coefficient of any permanent gas (at constant pressure) is given by

$\beta =1/T_{k}\ _{,}\ T_{K=}273+120=393^{O}K$

$\beta=2.5*10^{-3}$

Ra= GrPr=$9.81*40*0.6^3 *0.7255*0.0032/ (1.701*10^{-5})^2$

$6.801*10^8$

The Nusselt number (Nu) for horizontal plate ($\beta=0$) and uniform surface temperature, the recommended correlation for the heated upper surface is given as follows:

Nu $=0.14 *(7.2*10^8)^{1/3}$, $2*10^7< Ra<3*10^{10}$

Nu $=0.14 *(7.2*10^8)^{1/3}$, $2*10^7< Ra<3*10^{10}$

Nu $=0.14 *193$, $2*10^7< Ra<3*10^{10}$

Nu $=0.14 *193$, $2*10^7< Ra<3*10^{10}$

Nu =27.048

h_{bc} =k Nu /L

h_{bc} =0.03095* 27.048 /0.1

h_{bc} =8.37wm^{2}k

$$\text{hbr} = \zeta\varepsilon\text{eff}(\frac{(\text{Tpl}+273)^4}{\text{Tpl}-\text{Tamb}}-\frac{(\text{Tsky}+273)^4}{\text{Tp}-\text{Tam}})$$

$$\text{hbr} = \zeta\varepsilon\text{eff}(\frac{(\text{Tpl}+273)^4}{\text{Tp}-\text{Tam}}-\frac{(\text{Tlc}+273)^4}{\text{Tp}-\text{Tam}})$$

$$\text{hbr} = 5.67*10-8*(\frac{(120.18+273)^4}{120.18-26}-\frac{(20+273)^4}{120.18-26})$$

$$\text{hbr} = 6.237*10-8(\frac{(393)^4}{94.18}-\frac{(293)^4}{94.18})$$

$$\text{hbr} = 6.237*10-8((4.211*10)/94.18-(1.247*10)/94.18)$$

$$\text{hbr} = 6.237*10(\frac{(2.39*10)^{10}}{94.18}-\frac{(1.247*10)^{10}}{94.18})$$

$$\frac{6.237 * 10^{-11}(2.39)10^{10}}{94.18} - \frac{6.237 * 10^{-11}(0.74)10^{10}}{94.18} \dots$$

$$\text{hbr} = \frac{6.237 * 10^{-9}(2.93 - 0.74)10^{10}}{94.18}$$

hbr =1.451wm^{2}k

The bottom heat loss coefficient can be given as shown below

$Ub_{L=}\ [t_{cl}/k_{cl+}t_{in}/k_{in+}t_{p}/k_{pl\ +1}/h_{b}]^{-1}$

Where

h_b is the sum of convection heat transfer coefficient as well as the equivalent radiative heat transfer coefficient.

$h_{b\ =}\ h_{bc} + h_{br}$………………………………………………………………………………………………..3.17

$h_{b\ =}$8.37+ 1.45

$h_{b\ =}$9.82wm^{2}k

$Ub_{L=}\ [t_{cl}/k_{cl+}t_{in}/k_{in+}t_{p}/k_{pl\ +1}/h_{b}]^{-1}$

UbL= [0.02/0.3+1/9.82+0.004/0.13+0.004/40]-1

UbL= [0.1996]-1

UbL= 5.01w/m2k

The energy loss via the bottom of baking pan casing can be quantified mathematically as shown below

Qb=Ubl *A*(Tpl-Tsky)

Qb=5.01*3.14*0.62*(120.18-20)/4

Qb=141.84w

From those energy losses the total energy loss can be the total sum of each energy waste (Q_t)

$(Q_{total}) = Qb + Q_t + Q_{l/e}$ ………………………………………………………………………………………….3.18

$Q_{total}) = 141.84+1076.4 + Q_{l/e}$

$Q_{total}) = 1218+ Q_{l/e}$

$Q_{total}=1473w$

$Q_{l=} U_L*A*(T_{le}-T_o)$

$A=3.14*0.6*0.11=0.21m^2$

$^T{}_{le,}$ is lateral edg temperature 190^Oc

T_o is ambient temperature 20^Oc

$Q_{l=} U_L*A*(T_{le}-T_o)$

$Q_{l=}$ 7.14*0.21*170

$Q_{l=}$ 254.898w

3.6.5 Edge/Lateral heat Transfer coefficient

Energy lost from the lateral side of the baking pan casing may be taken to have similar value with the bottom side of the baking pan if the thickness and area of the edge insulation has the same to that of back (or bottom) insulation. But they have different thickness and area.

$U_{L=} [t_{cl}/k_{cl+}t_{in/}k_{in+}t_p/k_{pl}]^{-1}$ ………………………………………………………………………………3.19

$U_{L=} [0.02/0.5+0.03/0.3+0.006/200]^{-1}$

U_L= (0.140030-1

$U_{L=}$ 7.14w/m^{2}k

3.7 Overall heat energy loss coefficient

The total heat energy waste is the individual sum of energy loss via top, bottom and edge/lateral side heat energy waste.

3.8 Radiation

Radiation is the only form of heat transfer that can occur in the absence of any form of medium (i.e., in a vacuum). Thermal radiation is based on the emission of electromagnetic radiation, which carries energy away from the surface. At the same time, the surface is constantly bombarded by radiation from the surroundings, resulting in the transfer of energy to the surface. The term radiation covers a vast array of phenomena that involve energy transport in the form of waves. Above the absolute temperature of zero °K, all substances emit electromagnetic radiation. In contrast with conduction and convection, heat transfer by radiation does not require the presence of a material medium. Hot pans radiate heat; to assure this, stretch a hand over not on the surface of the baking pan and feel the heat radiating from its surface. Dark surfaces typically radiate more heat than lighter ones because dark surfaces absorb more heat energy to begin with. Radiation is the transfer of heat energy from surface of the pan to the ambient or to the product.

$Q_r=F_{pr}A_p\,\sigma(T^4{}_h-T^4{}_{pt})$ Where: Q_r = Heat transferred by radiation, kJ; A_p= Surface area of the pan σ =Stefan-Boltzmann constant,$5.67*10^{-8}$ W/m^2 K4.[3]

3.9 Thermal Insulation of stove

The main objective of insulation is to reduce the amount of heat escaping from the oven to atmosphere. In order to work effectively, the insulation material must have a low thermal conductivity. Insulations are used to decrease heat flow and surface temperatures. Usually, the engineering approach to insulation is the addition of a low-conducting material to the surface .The values of conductivity of gypsum plasterboard at very high temperatures and specific heat have been modified to some extent in the calibration of the heat transfer model. Conductivity was increased substantially at higher temperatures to allow for ablation. The 1947 Guide lists a thermal conductivity of 0.20 W/ (m-k) for gypsum board at a density of 1005 kg/m3, based on tests at the Armour Institute of Technology (a precursor to the Illinois Institute of Technology). Valore (Valore, 1988) provides a correlation for the conductivity of gypsum as a function of density (ρ), $k=0.025*\exp(0.08\,\rho^{0.5})$

Where; ρ = Density of the insulation in kg/m^3 and

k= Thermal conductivity of the insulation in W/ (m-K) generally, a substance which has lower thermal conductivity than the other can be used as insulation of the system. For instance, fired clay, primitive dried clay and clay brick can be used as good insulation for high thermal conductivity of metals for 50-250kW/m2K.

Thermal insulation materials are typically designed to reduce the heat flow or loss by constraining heat transfer via conduction, convection, radiation or all three while performing one or more of the following purposes out of the target area that has been provided.

1. Conserving energy by mitigating heat loss or gain
2. Monitoring surface temperatures for personnel protection and comfort
3. Activating vapor flow and water condensation of a process
4. Enhancing operating efficiency of heating / ventilating / cooling, plumbing, steam, process and power systems found in commercial and industrial installations
5. Assisting mechanical systems in meeting standard criteria in food and cosmetic plants

There are three material types in-which thermal insulation can be classified as. ()

3.9.1 Cellular Insulations

Cellular insulations contain small individual cells separated from each other.

The cellular material may be glass or foamed plastic such as polystyrene (closed cell), polyurethane, polyolefin, or elastomer.

3.9.2 Fibrous Insulations

Fibrous insulations are composed of small diameter fibers which finely divide the air space. The fibers may be perpendicular or parallel to the surface being insulated, and they may or may not be bonded together. Silica, glass, rock wool, slag wool and

Alumina silica fibers are used. The most commonly used insulations of this type are glass fiber and mineral wool.

3.9.3 Granular Insulations

Granular insulations have small nodules which contain voids or hollows. These are not considered true cellular materials since gas can be transferred between the individual spaces. This type may be produced as a loose or pourable material, or combined with a binder and fibers to make a rigid insulation. Materials used for this type are for instance calcium silicate, expanded vermiculite, perlite, cellulose, diatomaceous earth and expanded polystyrene.

3.10 Insulation design of the stove

Perfected insulating technology ensures a considerable, lasting reduction in heat losses. This saves costs in the long term and protects resources, climate and the environment. With shorter heat-up times and the resulting increased productivity as well as the minimization of downtimes due to improved operational reliability, insulating measures pay for themselves in an extremely short time.

This results in:

- Longer system durability
- Energy savings
- Fewer switching cycles

The radial conduction heat flow for a hollow cylinder is expressed by the Fourier's law as:

The heat loss across the cylindrical wall of the heating chamber is expressed by Fourier's law:

$$Q\, r = -KA\, R\, \frac{dT}{dr} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.2$$

where: K is the thermal conductivity of the cylinder material; A is the area of the walls of the cylinder heating chamber across which heat transfer occurs; and dT/dr is the radial temperature gradient across the walls.

For a steady state heat flow in which Q r is

Independent of r and $T_i > T_o$, the equation can be integrated and rearranged to become

Where the subscripts 'i' & 'o' define inside and Outside surfaces of the cylinder respectively.

For a composite cylinder with Known inside and outside surface temperatures

K is the thermal conductivity of the cylindrical walls; A is the area and

Is the radial temperature gradient across the wall? At steady state, heat flow is independent of r and T I > Integrating the above Equation results in:

$$Q\,r = -KA\,R\;dT/dr$$

The governing equation for the Convection heat transfer and the radiation heat transfer mechanism can be represented by basic heat transfer equations

Table3. 4: Convective hear transfer coefficients

Type of fluid and flow	**Convective heat transfer coefficient $h_{c,}$ (W/m^2 K)**
Air, free convection	6 – 30
Water, free convection	20 – 100
Air or superheated steam, forced convection	30 – 300
Oil, forced convection	60 – 1800
Water, forced convection	300 – 18000
Synthetic refrigerants, boiling	500 - 3000
Water, boiling	3000 – 60000
Synthetic refrigerants, condensing	1500 - 5000
Steam, condensing	6000 – 120000

The thermal conductivity coefficient of insulation material is usually lower than 0.2 W m−1 K−1. This is an important index for evaluation of the thermal performance of a material. The thermal conductivity coefficients of gypsum plaster with the addition of rosin and K12 is selected for insulation purpose in this paper. As expected, the thermal conductivity coefficient decreases with increased foaming agent. When the mass fraction of K12 was 0.1 %, the thermal conductivity coefficient was 0.18 W m−1 K−1.the convective coefficient of air taken from the above table could be 30 W m−2 K−1 for free convection over the surface of manifold considered to be flow over cylinder. hence the critical thickness can be calculated as shown.

t=k/h……………………………………………………………………3.2.1

t=0.18/30

t=6mm

3.10.1 Critical Thickness of Insulation

The critical radius effect is an essential feature of heat transfer in insulated objects/materials. Insulating a cylinder or sphere greater than the critical radius has the assumed or considered effect of retarding heat loss. If the radius of cylinder or sphere is smaller than the critical radius, adding insulation will basically enhance dissipation of heat .The additional insulation increases the conduction resistance of the insulation layer but mitigates the convection resistance of the surface because of the larger in the outer surface area for convection. Therefore the net heat transfer from the pipe may increase or decrease, depending on which effect dominates. Critical radius is independent of radius of circular pipe/tube. It depends on conductivity of insulation 'k' and the convective heat transfer coefficient 'h', between exposed surface of insulation and its surroundings. The value of the critical radius 'Rc' will be the largest when conductivity of insulation 'k'is large and convection heat transfer 'h' is small.

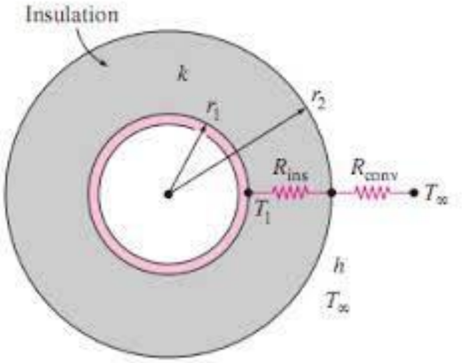


Figure 4-2: Schematics of thermal resistance

3.11 Chemical Kinetics of Biogas

3.11.1 Combustion of Biogas

Combustion is burning of biogas fuel in order to liberate the chemical energy possessed by biogas fuel. Since biogas fuel contains methane the combustion of biogas fuel is similar to that of hydrocarbon compounds of alkane [power plant]. Therefore, the balanced combustion equation can be given by:

3.11.1 Air Requirement for Combustion

To liberate the chemical energy contained in a fuel, it is a must to burn it with a sufficient amount of air. Insufficient air causes the combustion to be incomplete inherently results in loss of potential energy of fuel on the other hand supply of excess air causes unduly loss of large amount of heat

Energy. It is necessary to know the air requirement for complete combustion i.e. the stoichiometric air requirement.

The combustion reaction is as follows:

$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O + \text{Energy}$

From the laws of Avogadro, which states that equal volume of gases under identical conditions of temperature and pressure contains the same number of molecules, it implies that

One molecule of CH_4+two molecules of O_2 one molecule of CO_2 + two molecule of H_2O + energy.

Then, provided that ideal gas behavior,

1 volume CH_4+ 2 volume O_2 1volume CO_2 +2volume H_2O + energy

Due to the fact that air contains 20.9% in volume basis, the air requirement is given by oxygen requirement times 100 divided by amount of oxygen in air, each volume of oxygen is accompanied by 3.78 volume of nitrogen to make up 4.78 volume of air. So that,

$CH_4 + 2O_2 + 7.56N_2 \longrightarrow CO_2 + 2H_2O + 7.56N_2 + \text{Energy}$

Or

$CH_4 + 9.56\ \text{air} \longrightarrow CO_2 + 2H_2O + 7.56N_2 + \text{Energy}$

$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$ + Energy, implies theoretical O 2 per unit volume of gas is 2 as well as stoichiometric air per unit volume of gases is 9.56.

Since there exist 60% of methane in biogas and 21% of oxygen in air then;

Volume of biogas requires volume of air

1 volume of biogas requires volume of air in other terms 1/ (1+5.72)

= 14.88%biogas in air

If the stoichiometric air requirement is 5.72, then the entrainment ratio r should be but 2.86.

3.11.3 Design analysis of the stove

Design analysis of the stove involves design analysis of a biogas stove involves the determination of the following main components equivalent to diameter of mitad.

The steps of design of biogas burners by IN Itodo, G E Aygo P Ysuf et al were employed in the design of the stove.

1. Diameter of the jet (do)

Injector orifice/jet (do)

The amount of gas consumed by a burner is monitored by the size of the gas jet/nozzle.

This is usually a brass thimble with a hole drilled in the end, assembled onto the end of the gas line fitting. Nozzle monitors the gas flow rate; the injector has another important role of segregating the burner from the gas supply. **[**("Biogas Stove Design," 1996)**]**

The injector orifice is made up of aluminum. The gas inlet is drilled with 3mm diameter and the outer diameter is maintained to be 11mm with a length of 24mm. From the injector nozzle tip as well as side, a 2.9mm≈3mm hole. The connection between the nozzle and the other inlet hole has a draft angle of 33^0. The external chamfer is 45^0

The dimension of an orifice can be given by the following formula:

$$do = \frac{\sqrt{Q}}{\sqrt{(0.0367Cd)}} *(S/P)^{\wedge}0.25 \ldots\ldots 3.2.2$$

Where Q gas flow rate

S specific gravity of biogas fuel

P pressure before orifice

Cd coefficient of discharge of the orifice

do diameter of orifice

The coefficient of discharge for the orifice considers the vena contractor and friction losses through the orifice. It usually has a value between 0.85 and 0.95

Therefore:

$do= \frac{\sqrt{Q}}{\sqrt{(0.0367Cd)}}$ *(S/P)^0.25

do= $\frac{\sqrt{Q}}{\sqrt{(0.0367Cd)}}$ *(S/P) ^0.25

do =$\frac{\sqrt{16.542}}{\sqrt{(0.0367Cd)}}$ *($0.94/7.47$) ^0.25

do =2.87mm≈3mm

Length of nozzle can be determined according to the following correlation

$l=0.8d_o$ ……………………………………………………………………………………………3.2.3

l=8*2.87

l=8*3mm

l=24mm

the outer diameter of the orifice or nozzle can be determine according/ to the diameter of throat or in reference to the diameter of throat hence somewhat lower than throat internal diameter that gives an insertion or clearance to it so that the paper takes about 11mm.

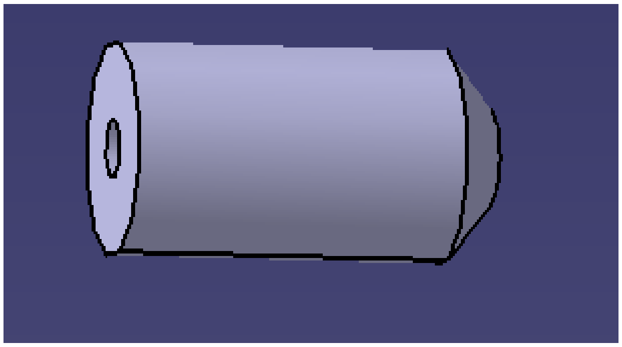


Figure 3-3:Orifice of biogas baking pan

Following important dimensions:

1. Diameter of the jet (do)

   Diameter of the jet can determined already on the above as of 2.87mm. The remaining dimensions can be calculated as shown below.
2. Length of the air intake holes measured from the end of the jet (Lmax)
3. The diameter of mixing tube(d)

   Diameter of mixing tube also given by the following formula so that diameter of mixing tube will be: $d=6d_o=6*2.87=17.22mm$

   The length of air intake also determine using the following equations

   $L_{max}=7d$……………………………………………………………3.2.4

   7*17.22

   120.54mm

   $L_{min}=1.35d$…………………………………………………………3.2.5

   1.35*17.22

   23.247mm

4. Length of the mixing pipe (L)

The length of mixing pipe is equivalent to the length of mixing chamber and hence given by the following mathematical relations

L=1.5d

=1.5*17.22

=25.83mm≅26mm

4. Diameter of mixing chamber (D)
5. The diameter of mixing pipe is equivalent to the length of mixing chamber and hence given by the following mathematical relations

D=1.3d……………………………………………………………………3.2.6

=1.3*17.22

=22.39mm

The steps of design of biogas burners by IN ITODO, was employed in the design of the stove.

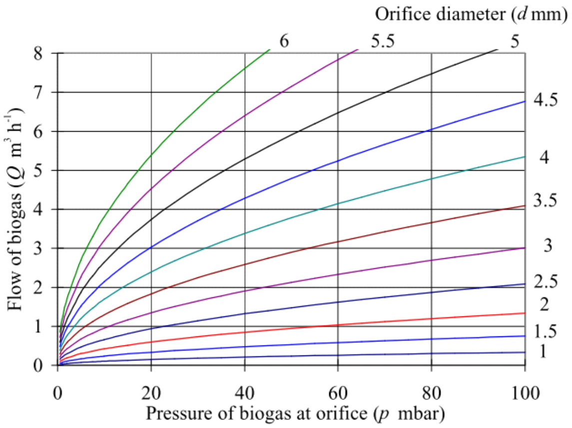


Figure 3-4: Orifice diameter, flow rate of biogas and pressure chart

Throat

The gas comes via the injector enters the end of the mixing tube in a region called the "throat". The throat has greater diameter than the injector, so the velocity of the stream is reduced.

The flow rate of the mixture in the throat (Qm) is then given by

Qm flow rate of gas mixture

Q flow rate

r primary air entrainment ratio

The velocity of gas in the region of nozzle can be given by

$vo = \frac{Q}{0.036*Ao}$ …..3.2.7

$$vo = 16.542/(0.036 * 12.9$$

=35.51m/s

$AO = \pi * \frac{d}{2}$ ….3.2.7

$$AO = \frac{\pi * 2.87\text{^}2}{2}$$

$$AO = 12.9385mm2$$

vo =35.51m/s

While the velocity of gases in the vicinity of throat:

$vt = \frac{voAo}{At}$ …..3.2.8

$$vt = vodo^2/dt^2$$

$$vt = vodo^2/dt^2$$

$$vt = vodo^2/dt^2$$

=8.24*35.51/2311.6864

vt =$0.12652mm/s$

Using Bernoulli equation, the following correlation has been obtained:

$pt = po - \frac{\varrho vo^2\left(1-\frac{do^4}{dt^4}\right)}{2g}$ …………………………………………………………3.2.9

The primary air entrainment relays on the entrainment ratio(r), which can be determined by using prig's formula as shown below

$$r = \sqrt{s}(\frac{\sqrt{At}}{\sqrt{AO}} - 1) \text{ ………………………………………….3.3}$$

$r = \sqrt{s}(\frac{dt}{do} - 1)$

$dt = do(\frac{r}{\sqrt{s}} + 1)$

$dt = 2.87(\frac{2.86}{\sqrt{0.95}} + 1)$

$dt = 11.29mm$

$$pt = po - \varrho vo^2(1 - do^4/dt^4)/2g$$

$$pt = 10^5 - 940 * \frac{35.628961\left(1 - \frac{2.87^4}{11.29^4}\right)}{2 * 9.81}$$

Mixing tube

For a cylindrical throat, the mixing tube must be long enough to allow good mixing of the gas and air. A length of 7d is usually accepted.

Lm=7d

Lm=7*17.22

Lm=120.54mm

Primary air entrainment hole design

The amount of mixture flow rate as can be calculated 0.017m3/s from this we can obtain the flow rate of air via primary air passage as shown below

Volume of mixture can be:

Q m=Q m*time…………………………………………………..3.3.1

Q m = Q m*time

Q m = 0.017*120

Q m =2.04m3

From this 14.88% of mixture is air hence volume of air can be

Q air = Q m*14.88**%...3.3.2**

Q air =2.04*14.88%

Q air =0.303552 m3/s

Hence Q air is also given by

Q air =nπ (d) 2l/4; l taken as unity and n is no of hole taken as of 2

Q air =nπ (d) 2l/4; rearranging

4Qair/lnπ =d2…………………………………………………….3.3.3

(4Qair/lnπ) 0.5 =d

(4*0.303552/1*2π) 0.5 =d

(4*0.303552/1*2π) 0.5 =d

(0.193345) 0.5 =d

0.0139048m =d

13.9mm=d=14mm

Here to assure that the delivery of air around the circular surface it is better to have four holes around having 4mm diameter each but the amount of air delivery to the system is the same as that of two holes having a diameter of 14mm each.

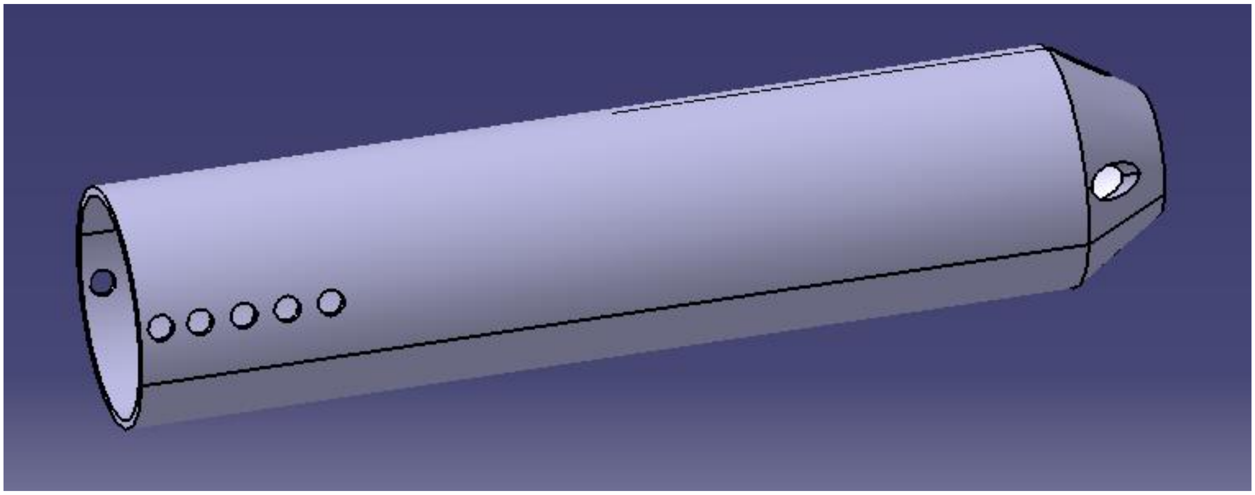


Figure 3-.5: mixing tube of baking pan

Burner or flame port

Small flame ports are normally employed as they minimize the tendency to light back. On the other hand, large numbers of small drilled ports are expensive to produce and may be prone to blockage. A suitable compromise size of 2.5–3.1 mm was quoted for the optimum performance (Prigg). As a result, the calculated diameter of burner port can be 2.87mm hence approximating this value to3mm because it lies on the range of biogas burner port hole diameters for the optimum performance of biogas burner appliances. Hence this paper takes for burner port diameter to be 3mm.Easy cross-lighting from port to port is necessary to prevent delayed ignition, and it has been shown that the cross-lighting distance is approximately proportional to the flame-port diameter.

The flame-port diameter/burner

The main importance of a gas burner is that the heat can be pointed towards where it is needed, by designing the burner carefully able to distribute heat generated uniformly to the breadth of clay. However, the design must allow for particular problems that can occur when burning gas, especially biogas.

The QM mixture flow rate can be obtained by:

$$QM = \frac{Q(1+r)}{3600} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \ldots .3.3.4$$

$$QM = 16.542(1 + 2.87)/3600$$

$$QM \ = 0.017m3/s$$

The pressure drop due to the flow of the mixture down the mixing tube should be checked, by first calculating the Reynolds number:

dtvt4Qmρ)/ (940μπ4*0.017)/ (11.29*1.71*$10^{-5}\pi$)

Re=10547

Where ρ and μ are the density and viscosity for the mixture (use ρ = 1.15 kg m-3 and μ = 1.71 × 10-5 Pa s at 30°C). The pressure drop (Δp) is then given by:

Δp=0.5*f*v2Lm /dt2………………………………………………………3.3.5

Where f =64 /Re, when Re < 2000 and f =0. 316 1 4/ Re when Re > 2000

Since Reynolds number is greater than 2000 the flow is turbulent as a result f will be 0. 316 1 4/ Re=0. 316 1 4/105470.25=0.31636 then the pressure drop is given by:

Δp= 0.5*f*v2Lm /dt2……………………………………………………3.3.6

Δp=0.5*0.31636*0.0172*120.54/ $(3.14*11.29)^2$

Δp=1.554*10-5pa

Iodol and full ford uses 2.25mm and 1.25mm radius of burner port holes respectively. Use of 0.5mm radius port hole brought challenge of flame lift. Availing 2mm diameter holes to mitigate the challenge of flame lift. The total number of port whole $_{Np}$ required will be:

N_p=4*A_P/**π**d_p^2………………………………………………………………………………3.3.7

N_p=4*A_P/**π**d_p^2

A_P>>$_{QM/}$Vp>>0.068

A_P>.>$_{QM/}$Vp

A_P>>$_{QM/}$Vp

AP >>$\frac{0.017m3}{s}$/0.25

$0.068\ m^2$

Therefore we choose the area of the burner port area as of $0.07m^2$

$N_p=4*A_P/N\pi d_p^2$

$N_p=4*0.07/\pi d_p^2$

$N_p=4*0.07/\pi 0.002^2$

N_p=0.28/1.2566*10^-5

N_p=22281.69=22282

Now using flame stabilization theory to reduce the number of burner ports by up to 1/20, holes were arrived at with appropriate finishing. Where $1.5 \leq A_P \leq 2.2$Burner manifold **(**(Obada et al., 2014)**)**

Therefore, the number of burner port can be reduced 22282/20=1114

The flow of the mixture through each burner ports must be uniform, so each burner port should be of equal in size. The pressure drops in the supply pipes leading to the burner ports must be of the same value. The common method to assure this is to use a manifold that is symmetrical and with a cross-sectional area that is greater than that of total flame port area: here to assure that the uniform distribution of burner port over the circular surface at an angle of 36 degree interval which has 10 array accounts about 60 holes per that arrays are diverging mean that no more holes are presented the remaining holes having 544 holes. Those holes are distributed accounts about 60 holes per array the remaining holes are asserted on the area where the successive array on the pan gets less heat or biogas so that the holes are arrayed with radial path of at a uniform angular distance of 4 degree around the peripheral of mitad. Three of circular array handle's 103 burner port holes per circular array. While the inner two circular arrays carries 66 hole per circle array the holes are distributed with a distance of 5mm from center to center distance. The peripheral part of mitad may be getting less fast heat due to divergence of burner port hole so that taken into account of the divergence the gap between successive burner port holes becomes 4mm.the geometry of burner port holes as shown below.

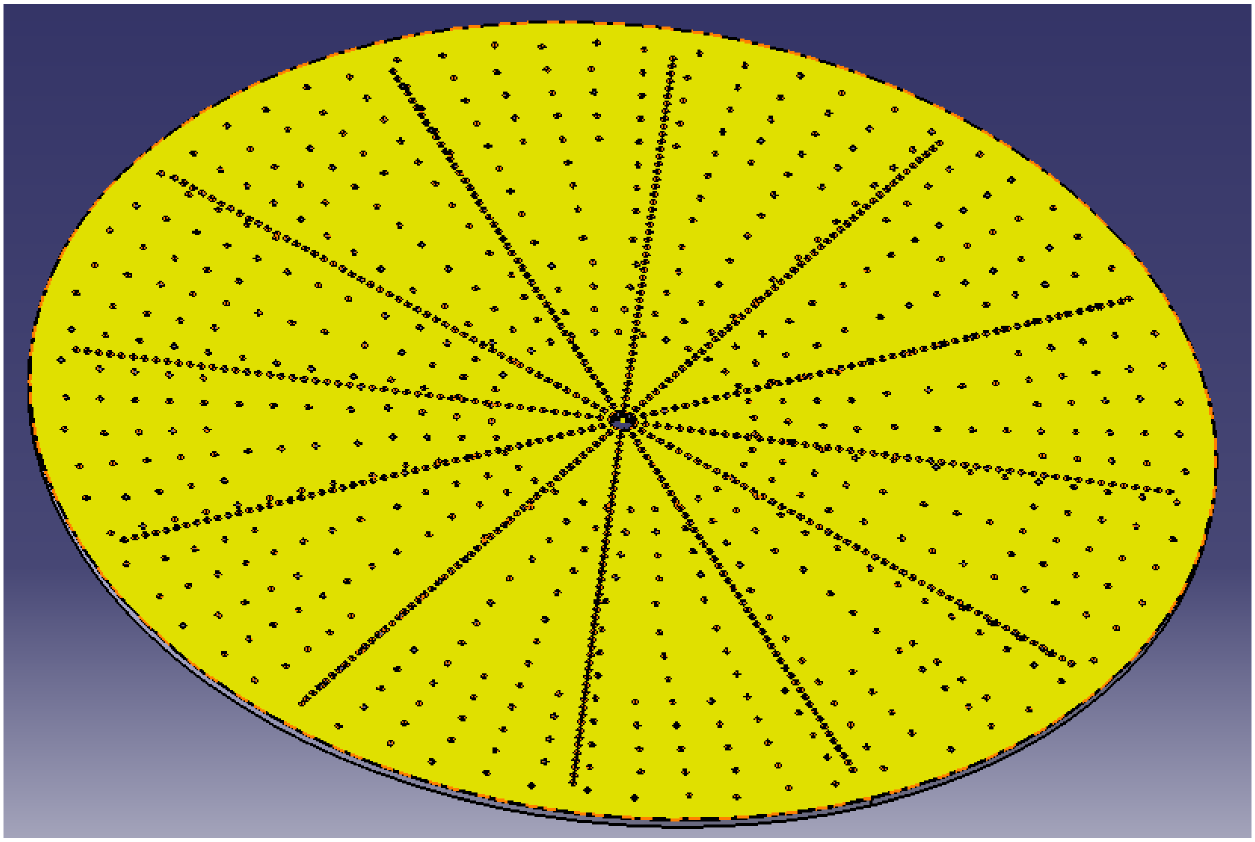


Figure3-.6: Burner port of baking pan

3.12.1 Secondary airport/hub

Secondary airport is the hole that supplies air into the combustion chamber for accomplishing complete combustion in addition to this which enables to assemble injectors/orifice to the mixing tube the design analysis relays on design of orifice so that its diameter based on secondary airport and orifice diameter. Hub has a conical chamfered surface end for a reason of delivering secondary airs to the combustion chambers due to velocity variation effect. The schematic or drawing of designed hub is as shown below. for determining the hole of secondary air entrainment relays on ratio of secondary air to primary air that enables to obtain optimum heat according to papers of Dijan Supramano and Dan Farah Inayati performance of mass gas stove, insufficient supply of secondary air results in soot particles in large numbers causes for emissivity of flame to be high results in high radiation heat transfer so that the ratio of secondary air to primary air expected to be 2.44 in order to get high efficiency for the pan.so that determination of diameter of secondary air hole can be.

Therefore secondary air/primary air=2.44

Secondary air hole=2.44*primary air

Quantity of primary air is calculated as of 0.30552m/s from previous analysis.

Secondary air hole=2.44*primary air

Secondary air hole=2.44*0.30552m/s

Secondary air hole=0.7454688m

Qsecon

air=2ndl/4………………………………………………………3.3.8

d= 4*0.7454688/$2\pi n$, where n is the number of hole around the manifold taken to be 120 for delivering uniformly hence

d= 4*0.7454688*0.5/$\pi * 120$

d= 4*0.7454688*0.5/$\pi * 120$

d=0.00395684m

d=3.95684mm=4mm

Top lid cover

Clay pan

Baking pan lid cover is used to reduce energy waste during baking conducted. But it also has an effect on the texture of the *injera*. Traditionally it is conically shaped structure made of mud and cattle dung. It is effective in insulating the heat transfer but it is not good for the baking *injera*. It also has low durability. Therefore, aluminum or galvanized low carbons steel are used in most of electric *injera* baking stoves today. In this project aluminum lid that is available in the market will be used for this part. The thickness of the aluminum sheet is 1mm other dimension is as follow. Top lid cover is an essential component because it enables to close the baked *injera* until it becomes well baked by enclosing it to overcome the loss of energy to have better *injera* front structure. Therefore the overall structure of top lid cover could be as shown below.

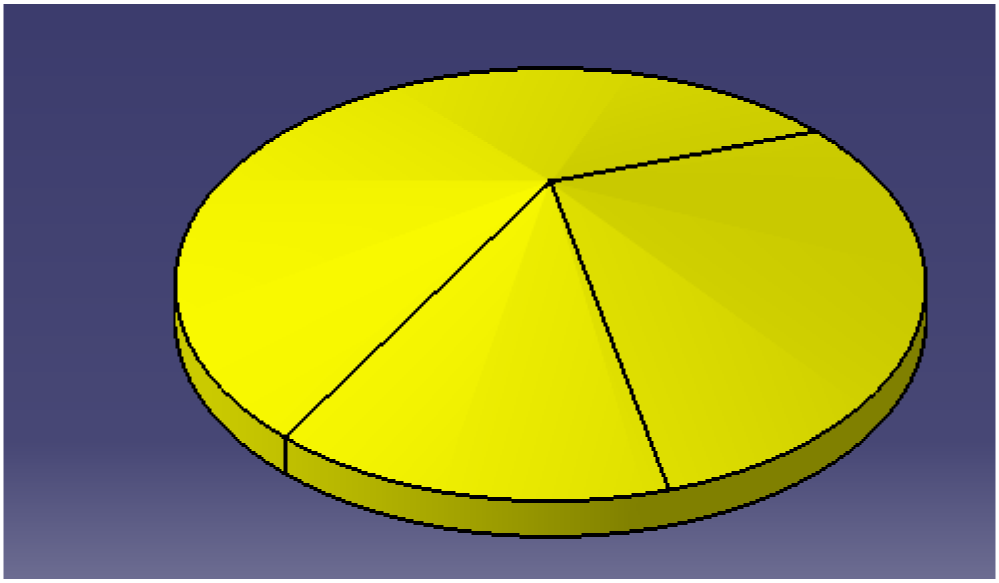


Figure 3-7: Ttop lid cover baking pan

Mitad support

The support of *mitad* is integrated into the wall by grooving the inside of the wall of house. This is for a reason of space utilization. Where footing is landed on the floor while the *mitad* and footing are assembled together, finally which are disassembled during the time of baking. The analysis of support and total assembly is as shown below.

$F_1=F$ $F_2=F$

$F_1+F_2=mg=\sum\rho_i v_i g$, $F_1=F_2=F$

Therefore

$$F1 + F2 = mg = \sum \rho\ ivig$$

$$F + F = mg = \sum \rho\ ivig$$

$$2F = mg = \sum \rho\ ivig$$

$$2F = mg = \sum \rho\ ivig$$

$$2F = mg = \sum \rho\ ivig$$

$$F = mg/2 = \sum \rho\ ivig/2$$

$$F = \frac{mg}{2} = \sum_{i=1} \rho \frac{ivig}{2} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 3.3.9$$

materials that has been held by support during baking solely is *injera* batter, *mitad*/clay, lid cover, insulation, gypsum plastic insulator, mixing tube, burner ports…etc.

Therefore

$$F = mg/2 = \sum \rho\, ivig/2$$

$F= (1175*0.264+1746*5.652*10^{-3} {}^{+}2700*2.826*10^{-3} {}^{+}7800*1.127*10^{-4} +7800*5.652*10^{-3})/2$

F= (310.2+9.8684+7.6302+0.87906+44.086)/2

F=372.66/2

F=186.33N

Once we calculate the force that exerts on the stand we are going to calculate the dimension of the support or chain. By considering that the cross section of the stand is circular hence from Shigley we take this relation as shown below the material which uses for standing have better modulus and yield strength. Therefore we had better to select the cheapest as well as good strengthen materials.

Where ρ and v is density respectively, volume of part of mitad component material required for constructing *mitad*.

Height the gas in a flame must be at a high temperature for the combustion Reaction to proceed. If the flame is cooled, the reactions are "quenched" And the reactions are incomplete. Biogas burning in air will produce Carbon monoxide and carbon particles (soot) if the reaction is quenched.

The back-flow phenomenon, which is caused by a built-up pressure in the preheating chamber, needs to be checked in order to ensure effective flow of the liquid fuel for complete combustion. A sudden expansion is introduced along the pipe flow line, as illustrated.

Quenching is useful, as it prevents lighting back in burner ports that are of the correct size. The flame cannot pass through the port as the metal cools it. The correct positioning of the object to be heated (e.g. a pot of food to be cooked) above the flame is therefore important. If the object is too close to the flame, the flame is quenched and the combustion is incomplete and the efficiency of the stove is reduced. If the object is too far away from the flame, heat is lost to the atmosphere and the stove is again less efficient. The best position for the base of the object being heated is just above the tip of the visible flame, just outside the outer mantle, above the hottest part of the flame. The flame height, though, and depends on a variety of factors. A key variable is the velocity of the gas/air mixture through the burner ports, which in turn depends on the size of the burner ports and the gas pressure. The degree of primary aeration of the burner affects both the mixture velocity and the height of the inner cone of the flame, which in turn affects the full flame height. Greater primary aeration will reduce the flame ("Biogas Stove Design," 1996).

Skirt air bucket

It is the component responsible for holding by assembling *mitad* clay, pan as well as other accessories. The material used for skirt is selecting regarding to light weight low thermal conductivity so that for this design aluminum is selected so that the design procedure is as shown.

The heat transfer from skirt to the atmosphere is mainly by conduction hence

$Q=-kdT/dr$

$Q=-2\pi kldT/dr$, rearranging this equation and introducing integration on both sides will result in

$\int^{ro}_{riQdr}=-\int^{To}_{Ti}2\pi kldT$……………………………………………..3.4

$Q\ (r_o-r_i)=-2\pi kl\ (T_o-T_i)$

$r_o-r_i=-2\pi kl(T_o-T_i)/Q$

$r_o-r_i=-2\pi kl(T_o-T_i)/Q$

$r_o=-2\pi kl(T_o-T_i)/Q+r_i$

$r_o=-2*3.14*204*(126-26)/45590+300$

$r_o=5+300=305mm$

Therefore, the thickness of skirt is going to be the difference of outer and inner radius

I.e. t=ro-ri

t= 5mm

Where T_o is the atmospheric temperature

Ti is the combustion temperature of biogas

Q is the generated heat energy from biogas

K thermal conductivity of aluminum 237

L is length of height of skirt 110mm

ri $_{is}$ the inner radius of *mitad* 300mm

r_o is the outer radius of *mitad* skirt 305mm

Manifold

manifold is one of the components of biogas *injera* baking pan that has been asserted inscribing all the main components to be inside as well as holding holes that are available for the entrance of airs compensating in addition to primary air acting as secondary air in order to make complete combustion also holds additional wider holes to tips of the manifold that serve as exhaust line to lead exhaust gases from combustion chamber after oxidation conducted drives to smoke filter finally to chimney and then to the atmosphere. The design of manifold is primarily depends on the size of *mitad* and it is better to use low thermal conductivity materials else if it must be insulated to minimize heat wastage.

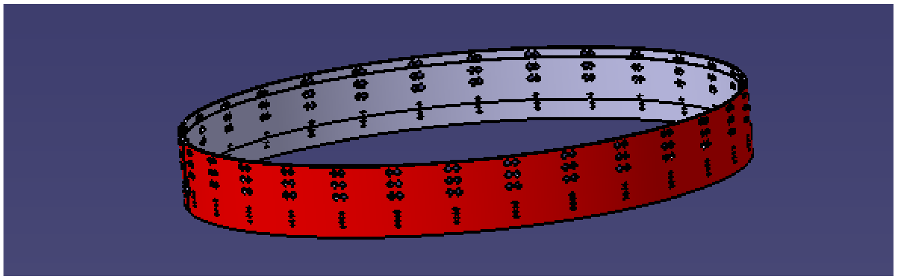


Figure 3-.8: Manifold of baking pan

Flame type

So as to categorize combustion phenomena in-different appliances, it is better to introduce two types of flames: premixed and diffusion flames. These flames will be reviewed taken into account of a laminar regime only, in which velocity is ideally parallel to the wall axis with a parabolic distribution as a function of the distance from the wall, while pressure is a function of stream wise distance. For laminar flames issuing from a tube burner these two models of combustion are obtained. If fuel and air are already mixed within the tube, as in the case of a Bunsen burner, and the gas is ignited downstream, a premixed flame front will propagate towards the burner until it reaches its steady state position in the form of the well-known Bunsen cone. Behind the flame front, as yet un burnt intermediates such as CO and H 2 will mix with the air entrained from outside the burner and lead to post flame oxidation and radiation. Therefore, the unburnt fuel stream is supplied with air (known as primary air) before combustion occurs. If all the air required for complete combustion is provided as primary air, then the flame is said to be fully aerated or fully premixed. If only part of the total air required is supplied with the primary air, the flame is said to be partially aerated, and the remaining air (known as secondary air) diffuses into the hot combustion gases downstream of the flame front. The other mode of combustion is that in a diffusion flame or non-aerated flame. Here no air is mixed with the fuel within the tube of the burner.   Therefore, only fuel issues from the tube

Flame type plays a vital role for designing the right burner as well to achieve better cooking biogas stove. The burner expected to be designed with the flame of flame lift of achieved when velocity of gas and air mixture exiting a port is higher than the laminar flame speed. Even though Flame lift off cause’s emission of carbon dioxide as well as incomplete combustion, it has a great advantage for achieving effective heat transfer to the pot.

Flash back results when the reverse occasions happened.

Heat transfer characteristics

In *injera* baking system all mode of heat transfer are incorporated as shown on the figure hence the thermal circuit is drawn as shown as well as the heat transfer is supposed to be approximated as steady state one dimensional heat transfer.

The energy transfer from heating element to the baking clay, side and bottom insulations is through conduction heat transfer. On the other hand the stove experienced a considerable natural convection and radiation heat losses from its surfaces to the surrounding room. The heat loss during baking can be described in different three direction as shown below the following figure the heat flow via assembly of biogas baking pan considered as heat transfer as of cylindrical objects standing from this assumption this paper makes the following heat transfer characteristic analysis through each component and finally the heat dissipated to the surrounding environment.(Kebede & Kiflu, 2014,)

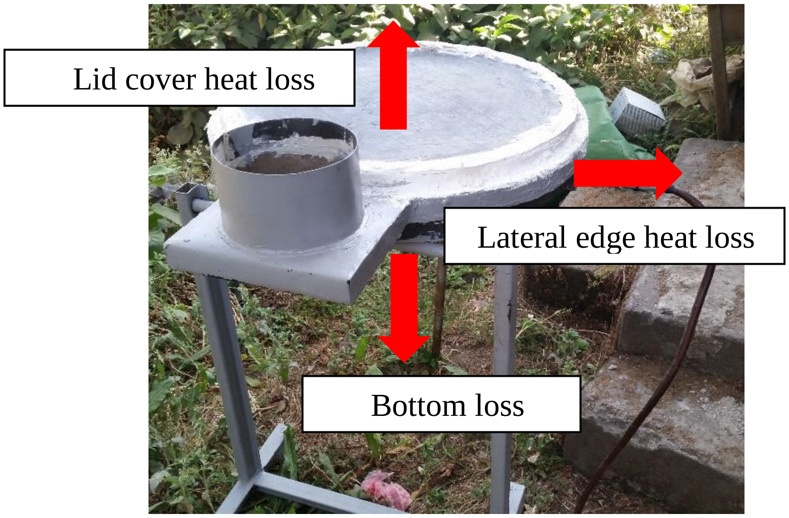


Figure 3-.9: Heat loss from injera mitad

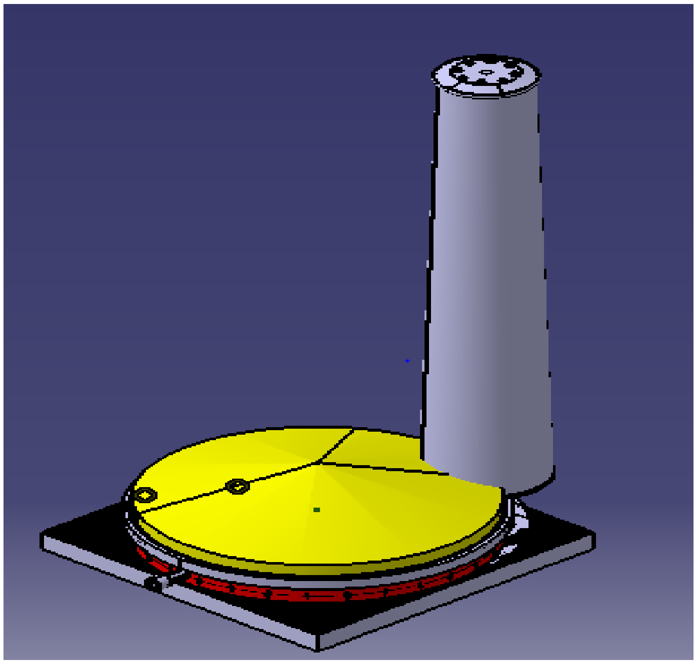


Figure 3-10: Assembly drawing of stove

Figure 3-.11: Prototype

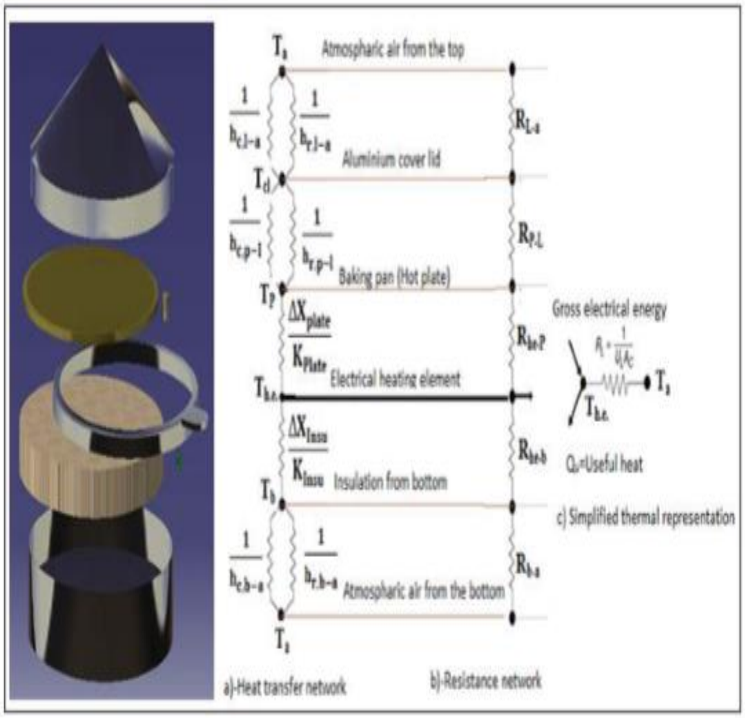


Figure 3-.12: Thermal circuit of the stove (Mesele Hayelom, 2017)

Even though the heat transfer in *injera* baking process is in three different direction it can be considered to be only into two directions by restricting the lateral side heat transfer introducing proper insulation in order to allow simplicity of calculation as shown below. Here consider that the heat transfer is assumed to be predominantly from the bottom of pan as well as from the top of lid cover

for this analysis the paper consider that temperature of the flame as of 800^{o}c and internal temperature of stove taken as 400^{o}c as well as external cover of the stove to be$26^{o}{}_{c}$equivalent to the atmospheric temperature.[6]

From the above thermal resistance circuit we be able to determine the overall heat transfer, here the paper supposed that the heat transfer is considered to be one dimensional steady state heat transfer even though the reality is transient so that Q can be given by the following equation here for simplicity of analysis neglect side heat transfer by insulating we considered that the transfer of heat via lateral side wall of *mitad* is insignificant as a result we be able to discard it.

$Q=U\ (\Delta T)$

U=ΔT/Q=L/K 3.4.1

R=1/ L/K A

Likewise the overall heat $_{\text{transfer}}$ resistance can be given as shown below

$$Req1 = 1/R12 + 1/R21 = Rcn + Rcd/RcdRcn$$

$$Req2 = 1/Rcdn + 1/Rcnd = Rcdn/RcndRcdn + Rcnd/RcndRcdn$$

Therefore the total thermal resistance can be the sum of all resistance.

$Rtot = Req1 + Req2 + R_{\text{eq3}}$...3.4.2

$Q_X= (T_i-T_o)/R_{tot}$

$Q_X= (T_i-T_o)/ Req1 + Req2 + Req3$

$Q_X= (T_i-T_o)/R_{tot}$

$45.59= (800-26)/R_{tot}$

$45.59= (774)/R_{tot}$

$R_{tot=16.977}\cong_{17\ \Omega}$

$Q_X= (T_i-T_o)/R_{equ1}$ rearranging this equation will give us

$R_{equ1}= (T_i-T_o)/ Q_X$

$R_{equ1}= (800-40)/ Q_X$

$R_{equ1}= (800-40)/ 45.59$

Requ1 =16.67Ω

3.13 Chimney Design

Chimney is a channel with a certain height that used to generate induce natural air draught. The length of chimney is the vertical distance that will be measured from the bottom of combustion chamber to the end of chimney. Length of chimney is simply the height is considered as one of the major geometric parameters of the stove combustion system which describes to the vertical length from the source of hot flue gas to the exit of this flue gas i.e. the atmospheric air.

Chimney provides several uses advantages in areas of fuel burning as well as system of combustion by facilitating drawing of sustainable or continuous flow of draught via the combustion system which will be able to provide air for combustion requires more amount of air to get enough burning air/gases for effective combustion process. even though air includes other elements that elements in air is inert towards combustion in addition leaves the system with high amount of heat energy i.e absorbs too much generated heat for instance nitrogen. Introducing to much amount of air into the combustion chamber causes loss of heat, due to the fact that the inert gas that gets in with air from the atmospheric has a challenge of heat absorption as well as causes to discharge to eject to the atmosphere via the chimney with the content of heat energy. The natural draught of chimney serves to expel the flue gas in addition it also acts as mitigating factors the problem associated with smoke pollution in the combustion system. Introducing chimney into the combustion system to facilitate the draught as well as mitigate emission

The pressure responsible for natural draught can be given by the following mathematical correlation.

$$\Delta P_{induced}=gh_{chim}\ (\rho_{amb}-\rho_{hot})\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..3.4.3$$

$$=gh_{chim}\rho_{amb}\ (1-T_{amb}/T_{hot})$$

The natural draught value of chimney is determined by the height of chimney as well as e temperature gradient of flue gas in the chimney and atmospheric air. The pressure gradient described on the above equation is converted into the mass flow rate flowing via the combustion system which relays on the height of chimney cross sectional area of chimney, the loss coefficient (LC), the temperature of combustion gas and atmospheric temperature. The correlation is given as shown below the equation. The loss coefficient in this mathematical relationship stands for the loss associated with friction and viscosity of flue gas due to the system geometry and the loss of heat via chimney wall. Therefore, here we can consider the value of loss coefficient as of LC=0.5with pots and LC=0.35with the pots on the stove. Now the mass flow rate of draught can be given by the following equation

$$\dot{M}=LCA\ (\Delta Pinduced/RsThot)\frac{\sqrt{2gh_{chim}(T_{hot}-T_{ambient})}}{T_{ambient}}\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.4.5$$

Draft is produced by natural convection of hot flue gas through the chimney; this may be enhanced in some cases with draft chimney fans. An appliance may require draft applied at the flue gas outlet to draw air into the combustion chamber. Another type of appliance with a draft hood does not require a draft at the combustion chamber outlet and the combustion process is isolated from chimney draft variations. A third type of appliance may produce a positive pressure at its outlet. Theoretical draft Dt is the draft due to buoyancy of the hot flue gases. This is a function of chimney height and mean gas temperature difference. Available draft Dais the draft needed at the appliance outlet. If the height of the chimney is too high or the flue gas temperature is greater than anticipated there will be surplus available draft and draft control may be required.

The draft required to overcome chimney flow resistance is equal to the difference between theoretical drafts and available draft.

$\Delta p - Dt = Da$……………………………………………………..3.4.6

Flue gas velocity in a chimney is usually in the range1.5 to 15 m/s. A cone is required at the top to increase

Velocity and achieve effluent dispersal. During analysis of a chimney system one must first determine the mass flow ratio of flue gases per kg of fuel burned. Then, the theoretical draft should be determined (depends on buoyancy force) which is a function of chimney height and flue gas temperature. Based on an assumed diameter, the flow velocity is then determined as well as the flow pressure drop. The difference between theoretical draft and flow pressure drop is the available draft

Consider the analysis of a chimney system for a biogas considering the released or generated energy in the combustion analysis of45.59 kW boiler and considering the mean chimney gas temperature equal to 295^{o}C and an ambient temperature of 26 ^{o}C. (For properties and theory see ASHRAE 1996)CO2

15.08%CO2 in flue gases for biogas fuel from combustion analysis

$CH_4 + 9.56\ \text{air} \longrightarrow CO_2 + 2H_2O + 7.56N_2 + \text{Energy}$

Therefore, based on molecular mass of flue gas % CO2 will be:

Total molecular mass of flue gas is

Mass of CO2+massof $2H_2O$+mass of N_2

44+36+7.56*28

291.68

% CO2=mass of CO2*100/total mass of flue gas

% CO2=44*100/291.68

15.08

First determine the mass flow ratio (kg flue gases/MJ fuel burned) M which depends on fuel type and %

CO2:

M= · 0.314(0 .12 + 14.4/CO2 M= 0.5332 kg/MJ

M= · 0.314(0 .12 + 14.4/15.08 M=0.337 kg/MJ

I =45.59 kW input of combustion chamber/furnace

w = I .M/1000g/s mass flow rate of fuel

w =45.59 .0.337/1000 g/s mass flow rate of fuel w= 0.01538

B =101000 atmospheric pressure, Pa

Tm + 273.317 mean chimney gas temperature (K) To =273 ambient T

The chimney gas temperature is equivalent to flue gas temperature so that which can be determine from energy balance i.e. the top heat transfer is exhausted via chimney as a result is equal to carried by chimney gas energy loss, hence the chimney temperature initially equal to the atmospheric temperature of 26^{o}c and temperature of flue gas could be T_{fg} from this hypothesis we be able to determine this temperature.

$Q_{fg}=Qt_{op}$

$Q_{fg}=k_{stcm}A_{cm}\Delta T=k_{stcm}A_{cm}(T_{fl}-T_{amb})$……………………………………3.4.7

Q_{top} is already calculated from heat loss analysis and which is about 1076.4^{o}c

$Q_{fg}=k_{stcm}A_{cm}\Delta T=k_{stcm}A_{cm}(T_{fl}-T_{amb})= Q_{top}$ is already calculated from heat loss analysis and which is about 1076.4^{o}c

$k_{stcm}A_{cm}\Delta T=k_{stcm}A_{cm}(T_{fl}-T_{amb})=Q_{top}$……………………………………….3.4.8

$T_{amb}=20^{O}$ C

k_{stcm} is obtained from table which is 12.1-45 we take the average value for this analysis so that which is about 28.55 w/mk

$A_{cm}=\pi\times H_{C}\times d= \pi\times 6\times 0.11 =2.0724m^{2}$

$k_{tcm}A_{cm}\Delta T=k_{stcm}A_{cm}\ (T_{fl}-T_{amb}) = 1076.4w$

$28.55\times2.0724m^2\times\ (T_{fl}-T_{amb}) = 1076.4w$

$28.55\times2.0724m^2\times\ (T_{fl}-26) = 1076.4w$

$28.55\times2.0724m^2\times T_{fl}-26 = 1076.4w$

$28.55\times2.0724m^2\times T_{fl}-26) = 1076.4w$

$59.1T_{fl}-26) = 1076.4wa$

$59.1T_{fl}-1534) = 1076.4w.$

$59.1T_{fl}) = 1076.4w + 1534$

$59T_{fl} =2610.4$

$T_{fl} =2610.4/59$

$T_{fl} =44.3^{O}\ C=317^{O}k=111.6^{O}f$

First, we may obtain chimney height using the following mathematical manipulation first we have to suppose that the flue diameter based on the following condition simply select the diameter regarding chimney design for stove hence for stove design the stack diameter is given as 120<D<150 as a result for this stove design the paper is selects about a diameter of 100mm. having this diameter height of chimney could be evaluated as shown below according to the Rankine of the height that has been proposed. The Rankine height determination supposed that the following conditions are in compliance.

1. The gas in the chimney expected to be uniformly hot.
2. The gas move in parallel sections through the chimney
3. The density of gas in the chimney is uniform as well as not differs sensibly from that of air at identical pressure and temperature.

As a result height could be: H_C

$$HC = 13Vo2.\frac{\left(\frac{w}{\S n}\right)2\left(\frac{T1}{To}\right)2}{\left[0.96\left(\frac{T1}{T2}\right)-1-\frac{0.06b}{2Acg\left(Vo2\,.\frac{w}{\S n}.\frac{T1}{To}\right)2}\right]}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.4.9$$

Where H_C is chimney height

V_o is volume of air at 32°F $=1.82\times10^{-3}m^3/s$

W is weight of fuel burned or combusted i.e1.71kg/s

n is ratio of combustor area to that of chimney area 0.034

§ is weight of cubic meter of gases in the chimney=0.0807NT_O/$V_O$$T_1$=0.0807.24.461/(112.4×0.00182) = 0.0474

A_c is section of chimney in square meter. $\Pi d^2_c/4=3.14(110)^2(0.25)$ =9498.5mm^2

b is width or diameter of chimney combustor is 600mm

T_o absolute temperature of ice melting 461^{o}F

T_1 absolute temperature of chimney gas.

T_2 is absolute temperature of external air 32^{o}F

$$HC = 13Vo2.(w/\S n)2(T1/To)2/[0.96(T1/T2) - 1 - 0.06b/2Acg(Vo2\,.w/\S n.T1/To)2]$$

$$HC = 13 \times 1.82 \times 10 - 3m2/s2 \times (1.71/0.047 \times 0.034)2 \times (317/461)2/[0.96(111.6/32) - 1 - 0.06b/2Acg(Vo2\,.w/\S n.111.6/3)2]$$

$$HC = 2.84/(2.34 - 4 \times 10 - 4)$$

$$HC = 2.84/2.34$$

$HC = 1.214m$=1214mm

2The following equation for theoretical draft does not consider cooling of flue gases during flow through the Chimney; this process will reduce Tm and Dt. The theoretical draft is the difference in weight between the Warm light air in the chimney and an equal column of ambient air (buoyancy)

Dt= 0.03413. BH (1/To— 1/Tcm) 3.4.9

Dt= theoretical draft

Dt= 0.03413. BH (1/293— 1/317) =8×10^{-7}×BH theoretical draft

Dt= 0.03413. BH (1/293— 1/317) =8×10^{-7}×101000×1.214theoretical draft

Dt= 2.79Pa theoretical draft

ρ=0 · 0.00348× B/Tm density of flue gases kg/m^3

$\rho = 0.00348\times 101000/317$ $\rho=1.109$ density of flue gases kg/m³

Assuming one 90-degree elbow (k=0.75), one Tee (1.25) and an exit cone (k=1), we determine the total k value (dimensionless system resistance coefficient) as follows:

$k = 0.75 + 1.25 + 1.0 + 0.033\,.\times H.\times 1000/\mathrm{di}$…………………………3.5

$k = 0.75 + 1.25 + 1.0 + 0.033 \times .1.214 \times 1000/100$

k =3.401 dimensionless system resistance coefficient of chimney

(The last term above is the coefficient accounting for friction losses in the straight duct)

$V= IM41000/ di2\rho\pi$……………………………………………………3.5.1

V= 1.4585 velocity of flue gases m/s (1.5-15 recommended range)

$V= \frac{45.59\times0.337\times4\times1000}{}/(1102.\rho\pi)$ V= 1.4585 velocity of flue gases m/s (1.5-15 recommended range)

$\Delta p = k\rho V2/2$ ……………………………………………………3.5.2

$\Delta p = 4.98 \times 1.109 \times 1.4585 \times 1.4585 /2$

$\Delta p = 8.49$

Δp= pressure drop in chimney & fittings (Pa)

Da – Dt= Δp Da = 11.28Pa available draft (Pa)

Da = Δp +Dt

Da =8.49 Pa +2.79Pa

Da =11.28Pa

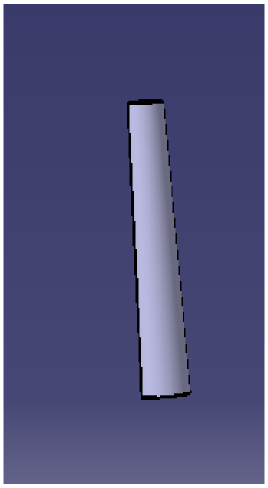


Figure 3-.13:Chimney

Stack

This technique enables to approximate the stack losses to estimate boiler efficiency. The parameter needed to calculate this technique is given below. These data are evaluated during source testing.

1. Stack T^{O} (T_{stack})
2. Dry oxygen in flue gas (o_2 dry %)

Summary of mathematical manipulation as shown

Evaluation of mass of dry gas per standard cubic meter of fuel

DG=14.7365o2 %/21%-o2 % +15.371

Evaluation of dry losses in chimney

L_{DG} (%) =0.001044× DG× (T_{stack} -70)

Evaluation of wet/moisture losses in chimney

L_{WG} (%) =9.482+0.004351×T_{stack}

From stoichiometric combustion of natural gas no of moles of dry flue gas is equal to the sum of the moles of N_2 and CO_2

$Mco_{2\,=}$ (1mole ofco$_{2/}$mole of fuel) × (44co$_2$ /1mole of co$_{2)\,\times}$ (mole fuel/volume of fuel)

MN_2 = (1mole of N$_{2/}$mole of fuel) × (44 N$_2$ /1mole of N$_{2)\,\times}$ (mole fuel/volume of fuel)

Chimney cap

Chimney exhaust must have an enclosure in order to overcome the problem of entrance of dust particle insects as so that it affects combustion indirectly hence to avoid such kind of difficulty we have to provide capes that have holes in order to minimize this problem. The design of chimney cape basically based on the outlet or exhaust of chimney.

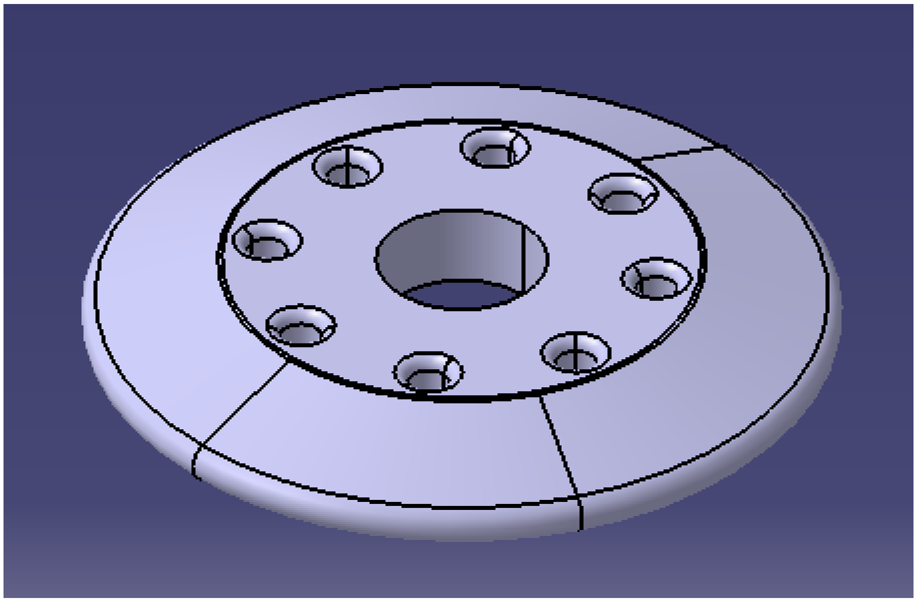


Figure 3-14:Chimney cape

Flame Height Determination

The flame height (Lf) correlated to heat released (Q) rate with diameter of flame Df. The determination of flame length will be as shown

$_{Lf =} 0.235\ Q\ 0.4-1.02*D$

$_{Lf =} 0.235\ Q\ 0.4-1.02*D$

$_{Lf =} 0.235\ *455.9\ *0.4-1.02*0.002$ $_{Lf =} 2.72$

$_{Lf =} 4.285=43mm$

Where Q is given by KW and D is given by m

3.14 *Material Selection*

Gas burner components are usually made of cast iron, as they must take high temperatures, be very robust and withstand corrosion. Many parts can be made from aluminum, except for those parts which might reach temperatures above its softening point (600°C). Cast iron is used for parts that reach higher temperatures, as it is fairly resistant to corrosion. Although it is brittle and can shatter if dropped onto a hard surface. Mild steel can take high temperatures, is not brittle, is easily welded and is very strong, so can be used for many components. However, steel is susceptible to corrosion so must be coated with a corrosion inhibitor that can withstand the temperature in which the steel is being used. There is aluminum based paints that are designed for high temperature use, as well as vitreous enamels that are baked onto the metal surface. Gas burner parts can also be made from ceramics, which are much cheaper than metals, easy to mold and can be baked in a furnace to give a hard material that can withstand high temperatures and is not susceptible to corrosion. The main disadvantage is that they are brittle and can shatter if dropped on a hard surface.

Table 3.16 Material selection

Material	**K(wm^{-1}/k^{-1})**	**Comments**
Silver	422	at room T^{o} metals feels cool
Copper	391	Great for pulling away heat
Gold	295	
Aluminum	205	
Stainless steel	10-25	Why cookware uses stainless steel
Glass concrete wood	0.5-3	
Many plastic	0.4	at room T^{o} plastic feel warm
G-10fiber glass	0.29	Strongest insulator choice
Stagnant	0.024	Usually moving
Styrofoam	0.01-0.03	Can be better than air

Chapter Four: Experimental Setup and Result

The experimental part of the project intention was to validate the output of the modeling tool and gain flame port design insight from off the shelf burner testing. The characteristics of cook stoves play a vital role to highly variable and interdependent combustion and heat transfer, which makes modeling these processes difficult and uncertain. Therefore, physical testing was conducted to validate the products of the modeling design tool.

4.1 Experiment Setup

The recently developed new biogas *injera* baking oven for thermal application/use was tested at biogas appliances testing laboratory located at Addis Ababa University Arat Kilo campus biogas sources and a nearby rural biogas digester user at north shewa of DebreBirhan located at SengaBeret.

4.1.1Biogas Supply

Difficulties may arise when carryout a validation experiment with biogas from digester. Variable environmental conditions and feedstock composition occur daily, leans to changes in the methane concentration, and thus energy content, of biogas.

Therefore, tests on multiple days may be conducted with biogas that has a range of energy contents. Another variable is biogas supply pressure. The pressure of biogas within a digester builds as gas is produced. Gas production in a digester is often outcompeted by the gas consumption of an appliance and thus the gas supply pressure decreases over the use period.

4.1.2Biogas Flow Control

The experiment set the mass flow rate to 0.052 grams per second, or the flow rate that correlates to the inlet velocity set in the modeling design tool (1.23 m/s).

$\dot{m}\ [kg\ s] = \rho biogas\ [kg\ m3] * v\ [m\ s] * Ainlet\ [m2]$ 4.1

$\rho biogas\ [kg\ m3] = P\ [Pa] * MWbiogas\ [kg\ kmol]\ R\ [J\ kmolK] * T\ [K]$

The mass flow rate was controlled and locked in at the set point through an iterative process. The difference in mass of the gas cylinder over a period of time was recorded and a mass flow rate was calculated. To hone in on 0.053 grams per second, the gate valve on the inlet regulator (Figure 15) was adjusted in a stepwise fashion while monitoring the change in mass of the cylinder over a set period of time.

4.1.3 Sampling Equipment and challenges that face during experimental investigation

The Advanced Biomass Combustion Laboratory at Colorado State University has established a robust suite of tools and instruments that allow for scientific collection of experimental data. This study leveraged the resources available to achieve the desired objectives of validating the modeling design tool.

Challenges that face during experimental investigation

While we carry out the experimental investigation we face too much difficulty beyond difficulties of manufacturing of flame port i.e. drilling port holes like obtaining biogas digester, flow meter.

It was also difficult to enter arat kilo campus due to security problem even if there exists the infrastructure access.

The major challenging problem was unabling to attain the baking temperature range due to several reasons for instance out burning of biogas due to presence of leakage from combustion chamber.

The other main difficulty was transporting the prototype from located site amist kilo to area where experimental analysis was carried out because of this I lost my PC and causes for head bleeding.

The major problem was arise due to the absence of thin clay mitad or thickness of mitad which we used were too thick about 2cm hence difficult to reach the baking temperature range of 180-200 but while we carry out at arat kilo campus the temperature at this mitad reaches to120.

Finally the experimental analysis was conducted at north shewa located at sengabert using getus mitad the baking temperatures were achieved effectively.

The other experimental setup also includes computer for recording of data thermocouple data, balance to measure the weight of the *injera* and the data logger to connect the thermocouple with the simulation software; energy meter for measurement of the energy consumption of the *Injera* baking *mitad* were also used. The additional experimental setup is indicated in figure below.

Figure 4-1:e Experimental setup with flow meter

4.2Efficiency of the pan analysis and result

4.2.1Efficiency of Baking Pans

The efficiency of a baking pan is the utilized energy divided by the total energy input (or the energy utilized during a baking session divided by total energy consumed by the baking pan).

Efficiency = $\frac{nEnergy\ utilized\ x}{Energy\ input1!}$ ×100% ……………………………………….4.2

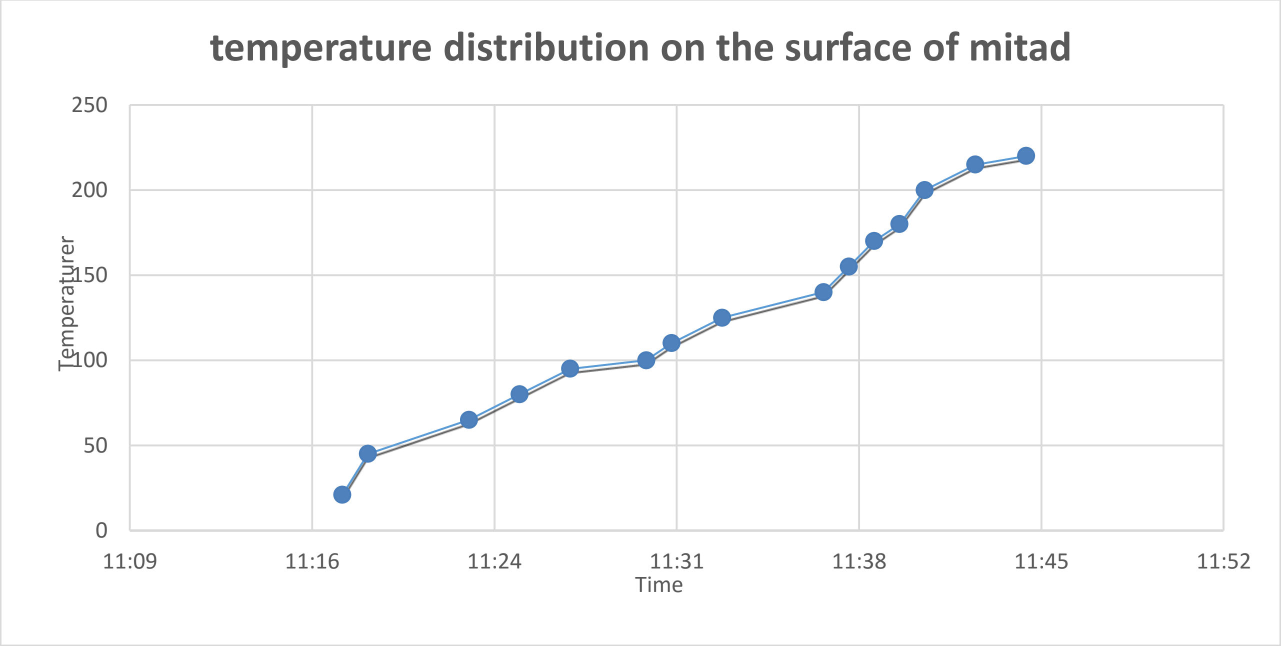
$$\eta_{th} = \frac{n \times Eutilized}{Einput} \times 100$$

even though biogas cooking stove is a smokeless or clean technology it is better to include or availing of chimney/draft is very essential this is because while we carry out the experimental investigation we observe that some leakage of biogas so that results in burning out side of the stove in turn causes wastage of energy this phenomenon was observed at the margin of prototype and *mitad* assembly margin though it was shield with ferrostiko and gesso when we conduct the test without chimney. but when we conduct the test with inserting the draft the leakage forced to be flow inside the targeted area as a result the chimney overcomes the problem of leakage and also facilitates combustion efficiency additionally prohibits wastage of energy outside of the stove

The new thermal efficiency, which is a measure of the proportion of the total energy which is usefully employed in a thermodynamic system. According to Clarke (1985) the thermal efficiency of a cooking stove depends largely on how gas of the fuel line to the pot or vessel on the stove (convective heat transfer). The burn rate and the net calorific value of the fuel were used in the calculation of this parameter.

Here we described that about the new novel biogas injera baking technology had the feature of radially arranged flame port holes for delivering biogas to the combustion chamber received from digester via mixing tube oriented radially over the circular sheet metals at an angle of 30 degrees. 45 holes were arranged radially out ward started from center of mitad at a distance of 5mm for a distance of 300mm. those flame port holes has a diameter of 2mm in confirmation with the biogas burner design guidelines. The total flame port holes that were arranged radially out ward from center to edge of mitad could be 544.the remaining holes were arranged according to the proximity of drilled holes that run from center to edge of burner port sheet metal so that we were provided flame port lines having 13 flame port holes at an angle of 5degree from neighboring flame port line and other 3 different short flame port lines having 5flame port holes at an angle of 5degree from the neighborhood port holes. This were done due to the fact that when two lines run from the center far away it goes diverging hence causes for non-uniform heating of mitad surfaces and causes in one surface for overcooked by doing so we were over cooking such kind of challenges. This new novel biogas injera baking pan had the thermal efficiency of22.1%.

The table and chart below shows the temperature distribution over the surface of mitad as can be seen from the chart temperature increases with time rapidly due to the distribution of fuel or proper orientation of flame port. Finally, this technology over comes several negative impacts that imparts by the existing injera baking technology in our home land Ethiopia or world like indoor air pollution, high energy cost, improper disposal of waste.



4.2 chart that shows temperature distribution of biogas injera baking pan with respect to time.

Table 4.1 temperature distribution on surface of mitad

Time	temperature
11:18	21
11:19	45
11:23	65
11:25	80
11:27	95
11:30	100
11:31	110
11:33	125
11:37	140
11:38	155
11:39	170
11:40	180
11:41	200
11:43	215
11:45	220

$$\eta_{th} = \frac{n\times Eutilized}{Einput}\times 100$$

$$E_{utilized}=M_{batter}\times C_{p}\times(T_{boiling}-T_{o})+h_{fg}(M_{batter}-M_{injera}) \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.3$$

$$\frac{EutilMbatter\times Cp\times(Tboiling-To)+\text{angedaccording to the proximity } hfg(Mbatter-Minjera\,)}{Q\text{vt}}\times 10\%$$

the remaining holes were drilled on sheet metal plates as drilled over the surface

Calculated

$$Eutil\ =nxM_{batter}\times C_{pbatter}\times(T_{boiling}-T_{o})\ +h_{fg}(M_{batter}-M_{injera}\,)$$

$$Eutil$$

$$Eutil\ = \frac{Mbatter\times Cp\times(Tboiling-To)+hfg(Mbatter-Minjera\,)}{Q\text{vt}}\times 100\%$$

$$Eutil\ \ = M_{batter}\times C_{p}\times\ (T_{boiling}-T_{o})\ +h_{fg}(M_{batter}-M_{injera}$$

M_{batter} *is mass of batter which can be measured usin gram* $_{so}$ *that 600gramor0.6kg*

$C_{pbatter}$ *is the specific heat capqacity of batter from table4.375kj*

$T_{boiling}$ *is boiling temperature of water i.e* $100^{o}{}_{C}$,$368^{o}k$

$T_{o\ ambient}$ *temperature of senga beret* $20^{o}C$;$298^{o}k$

h_{fg} *is the latent heat of evaporation of water at 8kPa is obtained or read from property table since there is no 8kpa in the table we obtain the value using linear interpolation between 7.5kpa and 10kpa as shown below.*

7.5kpa	*2574*
8kpa	h_{fg}
10kpa	*2583*

$(10-7.5)/ (8-7.5) = (2583-2574)/ (h_{fg}-2574)$

$2.5/0.5 = 9/ (h_{fg}-2574)$

$2.5\ h_{fg}-6435=4.5$

$2.5\ h_{fg}=7695.5+4.5$

$2.5\ h_{fg}=7695.5.5$

$h_{fg}=7695.5/2.5$

$h_{fg}=2595.8$

$M_{batter} =$ *600g, 0.6kg*

$M_{injera}=$ *0.36kg*

$Einput = 45.59kw$

$E_{util}= nxM_{batter}\times C_p\times (T_{boiling}-T_o) +h_{fg} (M_{batter}-M_{injera});$ *now substitute the value for each parameters*

$E_{util}= nxM_{batter}\times C_p\times (T_{boiling}-T_o) +h_{fg} (M_{batter}-M_{injera});$

$E_{util}=3x0.6x4.375x70+2575.8x0.24$

Eutil=9651.25+758.2)/420

*Eutil=1410*3/420=10.1Kw*

$$\text{Thermal efficiency}=\frac{Mbatter\times Cp\times(Tboiling-To)+hfg(Mbatter-Minjera)}{Q\text{vt}}X100$$

Thermal efficiency=3X1169.442+waste/45.59

Thermal efficiency=10.01 X 100/ 45.59

Thermal efficiency=22.1%

Time required for better cooking could be in second

h_{fg} *is in kJ/kgK*

Where:

$Einput$= energy input (J) QV_= rate of energy input (45590W),

t= total time taken during the baking session (S).

The total time taken for a baking session is the sum of, the heat up time, the total baking time, and

The total idle time [2].

$t=theat\ up+n\times tbaking+n$: 1_$\times tidle$ ……………………………………………….4.4

Where:

t= total time for the baking session 8 minute

$theat\ up$= heat up time

$tbaking$= baking time for a single injera,2.33minute

$tidle$= idle time 1minute

n=number of baking cycle; 3

Fig4.3 texturre of baked injera using this prototype

Fig4.4 front surface texture of baked injera

Chapter 5: Conclusion and Recommendation

5.1 Conclusion

Biogas cooking stove is an early existing technology yet now it is underutilization due to several factors. Bringing this technology to our home land will results several countable advantages for instance it provides a great income of foreign currency by substituting overcoming cooking of using electrical energy finally leads to sell the electrical energy to the nearby country, overcomes the problem of forest deforestation, mitigates or avoids health problem and also overcomes air pollution, ozone layer depletion.

The biogas *injera* baking pan developed in this research has an efficiency of 22.1 percent.this baking pan has the ability to bake *injera* with in an averagely time of 2.33 minute for a single *injera* and it takes about 7-8minute in order to bake 3 *injera* including an idle time that is time needed for opening as well as time needed for pouring the batter on *mitad* and closure time. The following picture shows the result of experimental investigation of baked *injera* on the pan.the temperature distribution over the surface of mitad can be shown below the given table. As we could have seen the temperature distribution looks uniform over the surface this could be achieved due to the special feature of flame port distribution and its number was too much makes the stove better than the existing injera baking pan.

5.2 Recommendation

In this research paper, we recommend the following main points because we observe as we carried out starting from design up to the end of experimental investigation via manufacturing.

1. In this research paper, we recommend that production or manufacturing of the prototype not only this research but also others shall be better to be produced with in the school workshop this is due to the fact that the external manufacturers or PLCs do not concern about the use of right materials for the design selection of the components as well as do not concern about the quality of prototype rather they concern about their profit and end of time of product development.
2. We recommend that for the next research around this area the researcher must focuses including the biogas *mitad* not only the combustion chamber burner port of the stove.
3. We also recommend that the researcher has to take into account for better utilization or performance of such kind of paper to work on concerning about design of mixing tube,

burner port hole as well as distribution of biogas after delivered to the manifold to exit each burner port hole.

4. It is also better to carry out the experimental investigation with respect to the design specification at 10MPa but the experimental investigation for this prototype was carried out at 8Kpa that is why its efficiency is lower.
5. The margin of prototype assembly with *mitad* must be sealed soundly or make the weld very fine or it is better to use oxyacetylene welding. As a result, we will enhance its efficiency much more.

Reference

(1). Article, R. (n.d.). porous radiant burner for household cooking purpose: A REVIEW.

(2) Areview of injerabakingtechnology in ethiopia :(Kamil Dino and Demiss Alemu (phd))

(3). Bansal, M., Saini, R. P., & Khatod, D. K. (2013). Development of cooking sector in rural areas in IndiaAreview*17*, 44–53. https://doi.org/10.1016/j.rser.2012.09.014

(4). Bansal, M., Saini, R. P., & Khatod, D. K. (2017). Optimal sizing of a solar – biogas-based cooking system for a cluster of villages, *6451*(November). https://doi.org/10.1080/14786451.2013.799469

(5). Biogas Stove Design. (1996), (August).

(6). Bond, T., & Templeton, M. R. (2011). Energy for Sustainable Development History and future of domestic biogas plants in the developing world, *15,* 347–354. https://doi.org/10.1016/j.esd.2011.09.003

(7). Brown, E., Leary, J., Davies, G., Bachelor, S., & Scott, N. (2017). eCook : What behavioral challenges await this potentially transformative concept *22,106*–115 https://doi.org/10.1016/j.seta.2017.02.021

(8). Chen, S., Chen, B., & Song, D. (2012). Bio resource Technology Life-cycle energy production and emissions mitigation by comprehensive biogas – digestate utilization, *114*, 357–364. https://doi.org/10.1016/j.biortech.2012.03.084

(9). Dahiya, D., Lather, R. S., & Bhatia, P. (2016). Improvement of the Domestic LPG Cooking Stoves: A Review, *9*(December), 1–8. https://doi.org/10.17485/ijst/2016/v9iS1/105856

(10). De, D. K., Nathaniel, M., & Olawole, O. (2014) Cooking g with Minimum m Energy y and Protection of Environment and.*IERI Procedia*, *9*, 148–155. https://doi.org/10.1016/j.ieri.2014.09.055

(11). Grima-olmedo, C., Ramírez-gómez, Á. & Alcalde-cartagena, R. (2014). Energetic performance of landfill and digester biogas in a domestic cooker, *134*, 301–308. https://doi.org/10.1016/j.apenergy.2014.08.032

(12). Haileselassie, A., Bayray, M., & Jørgen, O. (2014a). Design and development of solar thermal Injera baking: steam based direct baking, *57,* 2946–2955. https://doi.org/10.1016/j.egypro.2014.10.330

(13). Haileselassie, A., Bayray, M., & Jørgen, O. (2014b). Solar powered heat storage for Injera baking in Ethiopia. *Energy Procedia*, *57*, 1603–1612. https://doi.org/10.1016/j.egypro.2014.10.152

(14). Hou, S., & Chou, C. (2013). Parametric Study of High-Efficiency and Low-Emission Gas Burners, *2013*.

(15). Kadam, R., & Panwar, N. L. (2017). Recent advancement in biogas enrichment and its applications, *73*(January), 892–903. https://doi.org/10.1016/j.rser.2017.01.167

(16). Kebede, D., & Kiflu, A. (2014) design of biogas stove for injera baking appliction, *1*(1), 6–21.

(17). Kelebe, H. E., & Olorunnisola, A. (2017). Biogas as an alternative energy source and a waste management strategy in Northern Ethiopia, *7269*(November). https://doi.org/10.1080/17597269.2016.1163211

(18). Khan, M. Y., & Saxena, A. (2016). Performance Of LPG Cooking Stove Using Different Design of Burner Heads, (July 2013).

(19). Kurchania, A. K., Panwar, N. L., & Pagar, S. D. (2017). Design and performance evaluation of biogas stove for community cooking application, *6451*(November). https://doi.org/10.1080/14786460903497391

(20). Lohan, S. K., Dixit, J., Modasir, S., & Ishaq, M. (2012). Resource potential and scope of utilization of renewable energy in Jammu and Kashmir, India, *39*, 25–30. https://doi.org/10.1016/j.renene.2011.08.033

(21). Malico, I., & Mujeebu, M. A. (2015). Potential of Porous Media Combustion Technology for Household Applications, *1*(1), 50–69.

(22). Manon, L., & Bermúdez, E. (2016). Ethiopia â€™ s emerging domestic biogas sector: Current status, bottlenecks and drivers, *60*, 475–488. https://doi.org/10.1016/j.rser.2016.01.068

(23). Mechanics, A. (2013). Biogas Flameless Combustion: A Review, (June 2014). https://doi.org/10.4028/www.scientific.net/AMM.388.273

(24). Media, P., Universiti, A., Zailani, M., Bakar, A., Sains, U., Conference, I., Mujeebu, M. A. (2015). Development of premixed burner based on stabilized combustion within discrete porous medium begell, (January 2011). https://doi.org/10.1615/JPorMedia.v14.i10.60

(25). Mulugeta, B., & Demissie, S. W. (2017). Design, Optimization and CFD Simulation of Improved Biogas Burner for “ Injera” Baking in, *6*(1), 58–64.

(26). Muthukumar, P., Anand, P., & Sachdeva, P. (2011). International journal of Performance analysis of porous radiant burners used in, *2*(2), 367–374.

No Title. (1950), 144–149.

(27). Obada, D. O., Obi, A. I., Dauda, M., & Anafi, F. O. (2014). Design and Construction of a Biogas Burner, *2*(2), 35–42.

(28). Ogedengbe, E. O. B., & Ajibade, F. D. (2017). Improved Burner Efficiency and Fuel Consumption in Domestic Cooking Appliances Improved Burner Efficiency and Fuel Consumption in Domestic Cooking Appliances, *5639*(November). https://doi.org/10.1080/23815639.2017.1324331

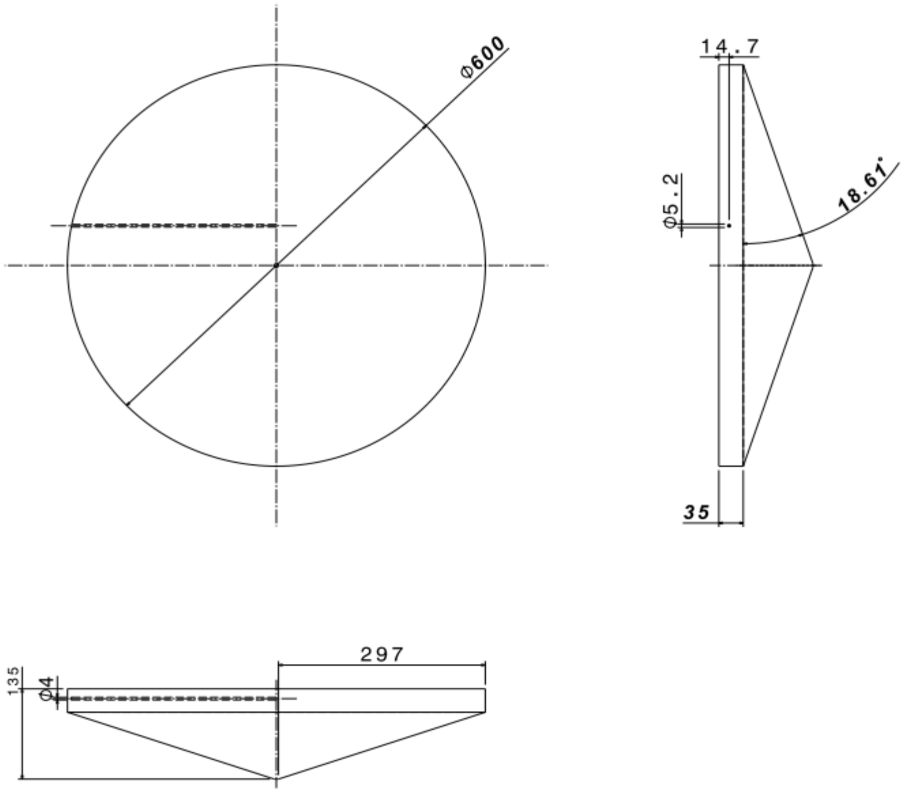
(29). Science, T. (2017). Experimental study of the effects of swirl and air dilution on biogas non-premixed flame stability, (January). https://doi.org/10.2298/TSCI130112157R

(30). Surjosatyo, A., & Ani, F. N. (2011). Study of Enhancing the Swirl Burner Performance on a Small Scale Biomass Gasification, (August).

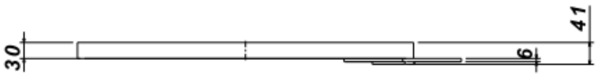
(31). Tumwesige, V., Fulford, D., & Davidson, G. C. (2014).Science Direct Biogas appliances in Sub-Sahara Africa, *0*. https://doi.org/10.1016/j.biombioe.2014.02.017

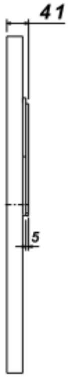
(32). Vaccari, M., Vitali, F., & Tudor, T. (2017). Multi-criteria assessment of the appropriateness of a cooking technology: A case study of the Logone Valley, *109*(May), 66–75. https://doi.org/10.1016/j.enpol.2017.06.052

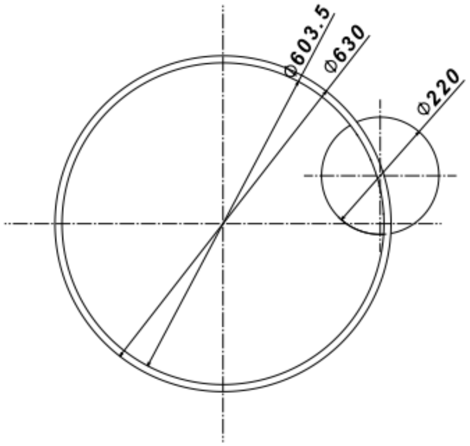
(33). Walecha, M., & Revaskar, V. A. (n.d.). Thermal Analysis of Gas Burner, 38–40.

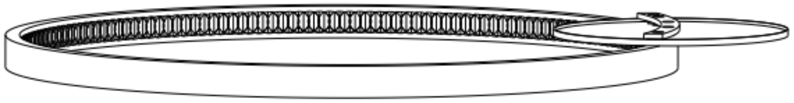


Dessie Gashay 11/17/2019 Dr.Abidulkadir Aman	**Addiss Ababa Univeristy** **Institute of technology**
A1	**Lid Cover**
1:1 | 0.00	Lid cover | 3







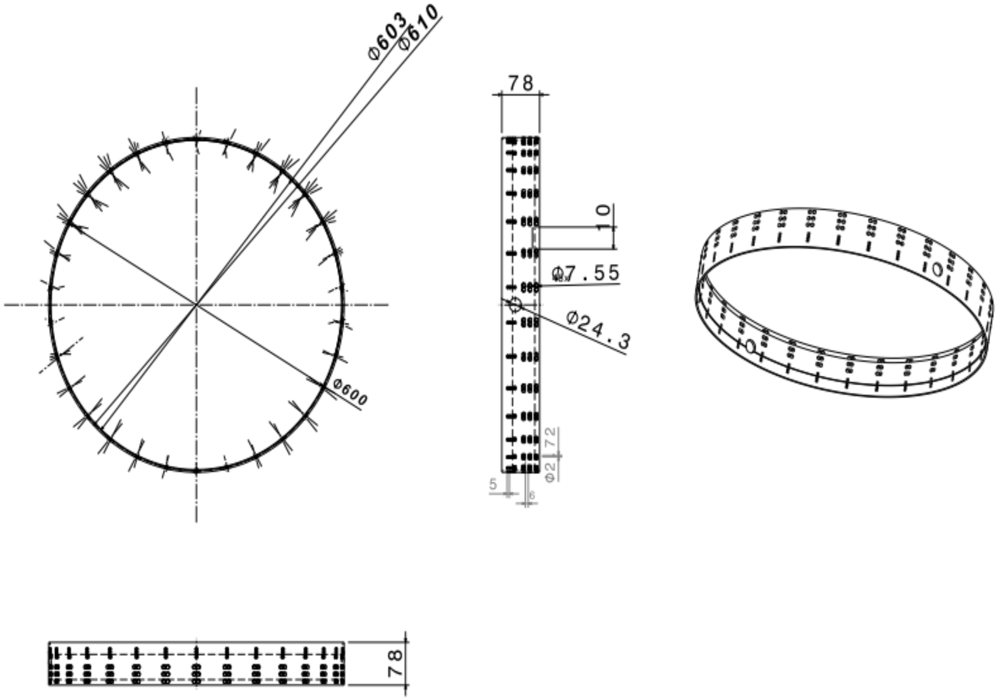


Dessie Gashay
11/12/2019
Dr.Abidulkadir Aman

SIZE		
A1		Smoke filter

SCALE	WEIGHT (kg)	DRAWING NUMBER	SHEET
1:4	0.67	smoke filter	7

P



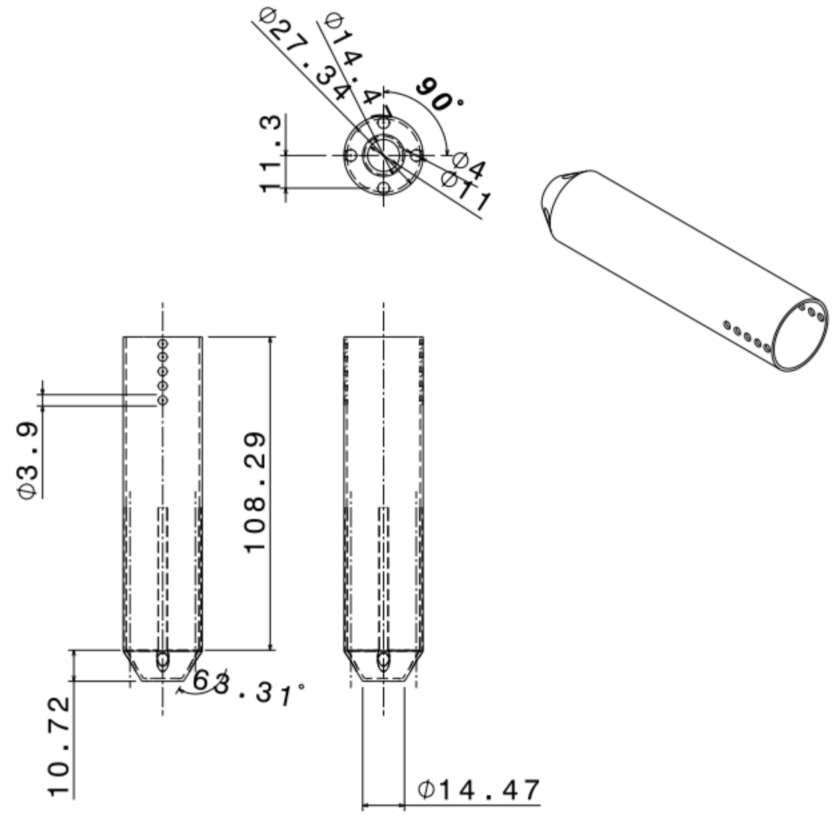
Dessie Gashay
11/16/2019
CHECKED BY:
Dr.Abdulkadi
r Aman

Addis Ababa
Univeristy Institute
of Technology

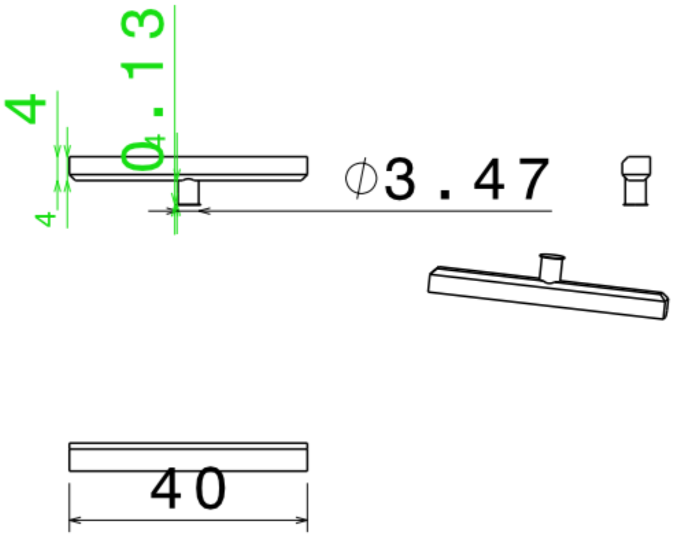
A1

manifold

1:1
0.59
manifold
4



DESIGNED BY:
Dessie GASHAY
DATE: 11/12/2019
CHECKED BY:
Dr.Abidulkadir Aman
DATE: XXX
SIZE A2
Mixing Tube
SCALE 1:1
DRAWING NUMBER *mixing tube*
SHEET 1/1



DESIGNED BY:
Dessie Gashay

CHECKED BY:
Dr.Abidulkadir Aman
DATE
XXX

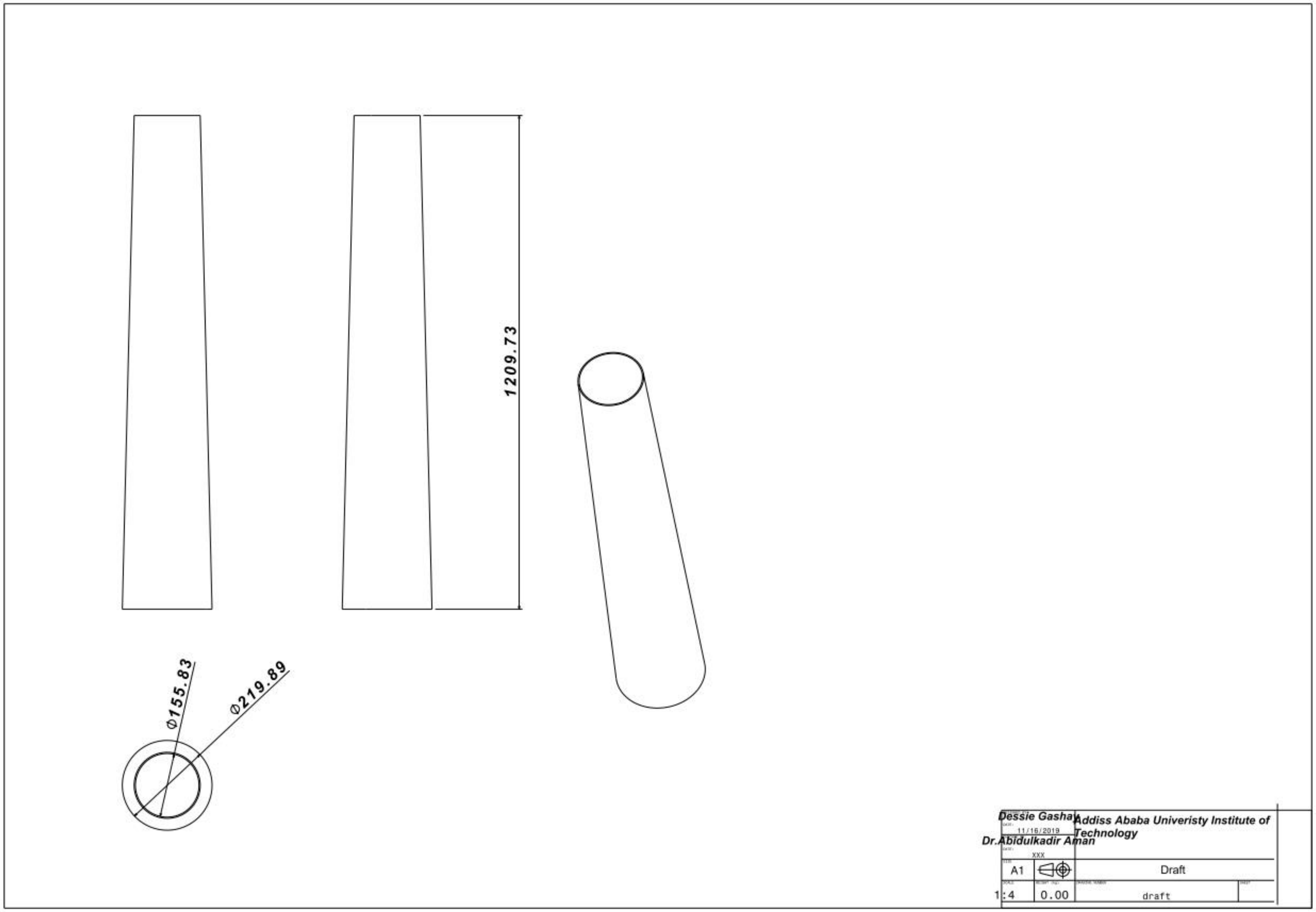
Addiss Ababa Univeristey
Institute of Technology

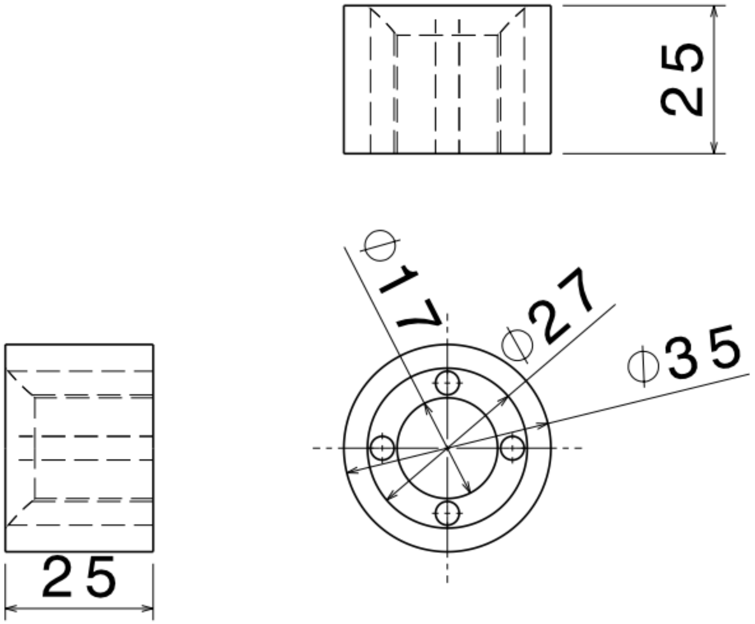
SIZE
A4

Lid handle

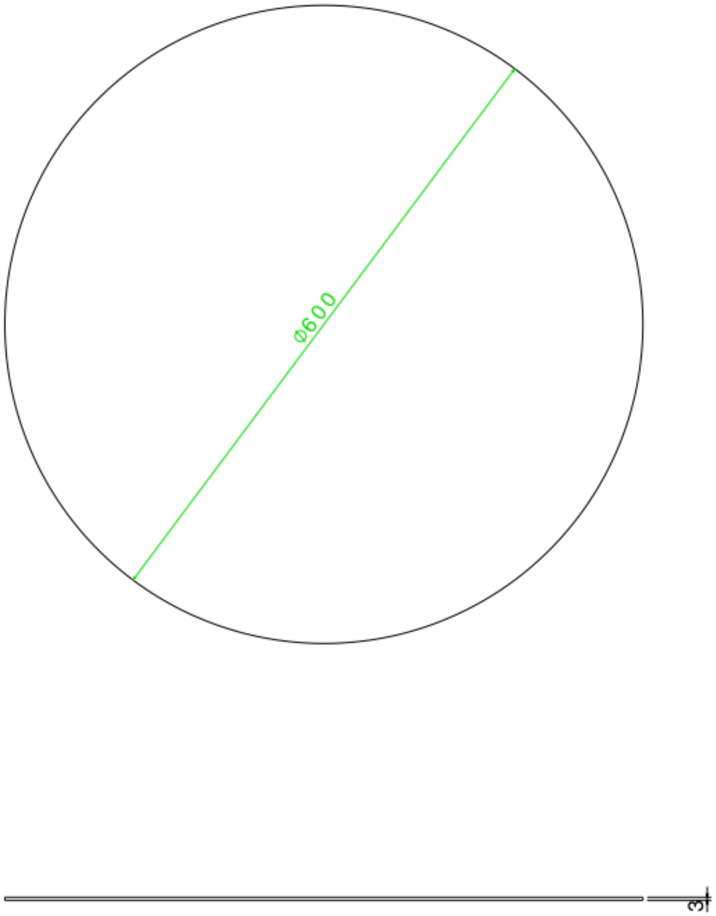
SCALE 1:1

DRAWING NUMBER
lid handle

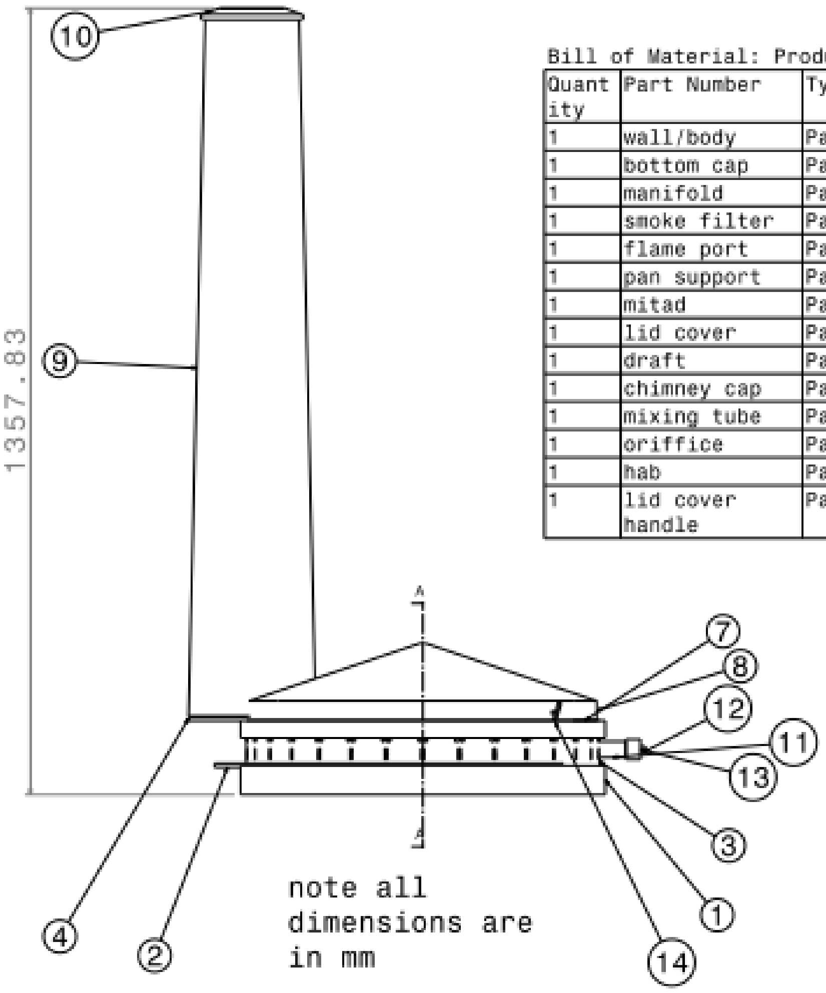

1209.73
Ø155.83
Ø219.89
Dessie Gashay
11/16/2019
Dr.Abidulkadir Aman
XXX
Addiss Ababa Univeristy Institute of Technology
A1
Draft
1:4
0.00
draft



DESIGNED BY: **Dessie Gashay**	Addiss Ababa Univeristy Institute of Technology
CHECKED BY: **Dr. Abidulkadir Aman**	
SIZE A4	Hab
SCALE 1:1	hab



DESIGNED BY: Dessie Gashay	Addis Abab a Univeristy Institute of Technology	
CHECKED BY: Dr.Abidulkadir Aman		
A1		MITAD
SCALE 1:2		DRAWING NUMBER mitad



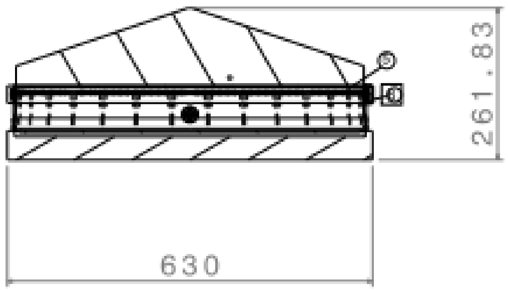
note all dimensions are in mm

Bill of Material: Product4

Quantity	Part Number	Type	Nomenclature	Revision
1	wall/body	Part		
1	bottom cap	Part		
1	manifold	Part		
1	smoke filter	Part		
1	flame port	Part		
1	pan support	Part		
1	mitad	Part		
1	lid cover	Part		
1	draft	Part		
1	chimney cap	Part		
1	mixing tube	Part		
1	oriffice	Part		
1	hab	Part		
1	lid cover handle	Part		

Recapitulation of: Product4
Different parts: 14
Total parts: 14

Quantity	Part Number
1	wall/body
1	bottom cap
1	manifold
1	smoke filter
1	flame port
1	pan support
1	mitad
1	lid cover
1	draft
1	chimney cap
1	mixing tube
1	oriffice
1	hab
1	lid cover handle



DESIGNED BY: Dessie Gashay	Addis Ababa Univeristy Institute of Technology		
CHECKED BY: Dr.Abdulkadir Aman			
SIZE A2		biogas baking pan section view	
SCALE 1:5	41.24	section view	1/11