بسم الله الرحمن الرحيم

Building a gasifier uses biomass

By

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Abstract

At the present project, a design of small-scale gasification unit for producing Methane was presented. Several types of biomass were used in order to investigate the quality and quantities of Methane generated units. It was found that the Methane from the wood pellets has the highest rate of Methane. Gasification of biomass is one of the most attractive methods for producing Methane-rich gas. we have built a gasification unit for producing electricity to supply a small house. Using biomass gasification to produce combustible gas is one of the promising sustainable energy options available for many countries. At present, a few small-scale community-based power generation systems using biomass gasifiers are in operation in Palestine. However, due to the lack of proper knowledge, these systems are not being operated properly at full capacity. This stands as an obstacle for further expansion of the use of gasifier technology. The production of energy from biomass reduces the dependence of developing countries on fossil fuels, And this unit will be generating electricity up to 1 kw.

الملخص

في هذا المشروع ، تم تقديم بناء وحدة تغويز صغيرة لإنتاج الميثان. تم استخدام عدة أنواع من الكتلة الحيوية من أجل التحقق من جودة وكميات وحدات الميثان المولدة. وجد أن الميثان من رقائق الخشب لديه أعلى معدل من الميثان. يعتبر تغويز الكتلة الحيوية أحد أكثر الطرق جاذبية لإنتاج غاز غني بالميثان. قمنا ببناء وحدة تغويز لإنتاج الكهرباء لتزويد منزل صغير. يعد استخدام تغويز الكتلة الحيوية لإنتاج غاز قابل للاشتعال أحد خيارات الطاقة المستدامة الواعدة المتاحة للعديد من البلدان. في الوقت الحالي ، هناك عدد قليل من أنظمة توليد الطاقة على مستوى المجتمع المحلي والتي تستخدم مفاعلات تحويل الكتلة الحيوية تعمل في فلسطين. ومع ذلك ، ونظراً لعدم توفر المعرفة الصحيحة ، فإن هذه الأنظمة لا يتم تشغيلها بكامل طاقتها بكامل طاقتها. هذا يقف عقبة أمام مزيد من التوسع في استخدام تقنية التغويز. إن إنتاج الطاقة من الكتلة الحيوية يقلل من اعتماد الدول النامية على الوقود الأحفوري ، وسوف تولد هذه الوحدة طاقة تصل إلى 1 كيلو واط

الإهداء وشكر

بسم االله الرحمن الرحيم (قل اعملوا فسيرى االله عملكم ورسوله والمؤمنون) صدق االله العظيم

إلهي لا يطيب الليل إلا بشكرك ولا يطيب النهار إلى بطاعتك .. ولاتطيب اللحظات إلا بذكرك .. ولا تطيب الآخرة إلا بعفوك .. ولا تطيب الجنة إلا برؤيتك

"االله جل جلاله"

إلى من بلغ الرسالة وأدى الأمانة .. ونصح الأمة .. إلى نبي الرحمة ونور العالمين

"سيدنا محمد صلى االله عليه وسلم "

إلى ملاكي في الحياة .. إلى معنى الحب وإلى معنى الحنان و التفاني ..

إلى بسمة الحياة وسر الوجود إلى من كان دعائها سر نجاحي وحنانها بلسم جراحي إلى أغلى الحبايب

إلى من نـفـتـخر دوماً بأننا أبناؤها... إ لى من أ سكنتنا بين ثنايا الضلوع...إ لى ينبوع الدفء والحنان.

إلى التي سهرت و تعبت وقدمت الغالي والنفيس

أمي الحبيبة

إلى من كلله االله بالهيبة والوقار .. إلى من علمني العطاء بدون انتظار ..

إلى من أحمل أسمه بكل افتخار ..وإلى الابد

إلى الرجل الذي وهبني حياته، وشدّ على يدي وأنا أحبو أول خطوة لي في حياتي ،

إلى الرجل الذي كان يرى بي دوماً ما لا يراه أحد. وينتشلني كلمّا سقطت لأعود من جديد...

إلى الرجل الذي أردته هنا معي لأخبره أنني رغبت فقدّمت فأنجزت فاستطعت

فها أنا ابنك وصلت لما أردت ان اكون منذ صغري ، ،

إليك والدي الحبيب

إلى من رافقوني منذ أن حملنا حقائب صغيرة ومعكم سرت الدرب خطوة بخطوة وما تزالون ترافقوني حتى الآن..

إلى شمعة متقدة تنير ظلمة حياتي ..معكم أكون أنا وبدونكم أكون مثل أي شيء

إلى من أرى التفاؤل باعينهم والسعادة في ضحكتهم..

في نهاية مشواري أريد أن أشكركم على مواقفكم النبيلة إلى من تطلعتم لنجاحي بنظرات الأمل

أخوتي واخواتي (عائلتي الحبيبة)

أعوامٌ قد قضيناها وسرنا بها خطوة بخطوة، أشخاصٌ كانوا معنا ولا زالوا. شجعونا بحبّ و أمل

أعادونا للصواب كلّما حدنا عنه وكانوا هم القدوة المختارة ، و الإلهام المقدّم .

واليوم ونحن نخطو خطواتنا قبل الأخيرة في حياتنا الجامعية نتقدم لهم بما في الكون من كلمات شكرٍ وتقدير،

و لهفات حبّ و عرفان .

فأرقّ الشكر بداية لجامعتنا التي احتضنتنا دوماً. التي رسمت لنا خطوات الحياة و أساس كل علم

فمنها كان الإبداع.

وأيضا للذين قبلونا كأبناء فكانوا معنا خطوة بخطوة ، لمشرفنا القدير

الدكتور الفاضل ماهر مغالسة

الشكر موصول للذي كان عونا في الطريق كلما احتجنا إليه

الدكتور الفاضل فؤاد الزرو

على ما قدّموه لنا من دعمٍ وإرشادٍ ومساعدات وما بذلوه لنا من عطاء لنكون نحن بهم ومنهم .

والشكر يصل لكلِّ مدرّس آمن بنا وأخبرنا بأنّا نستطيع، فلولاهم ما خطونا خطوة النجاح هذه...

إلى طلاب عائلتنا الثانية , إلى شعبتنا بكل من فيها... فشكراً لكم من القلب وبعضٍ من الروح لكم.

إلى من تحلو بالإخاء وتميزوا بالوفاء والعطاء إلى ينابيع الصدق الصافي إلى من معهم سعدت ،

وبرفقتهم في دروب الحياة الحلوة والحزينة سرت إلى من كانوا معي على طريق النجاح والخير إلى من عرفت كيف أجدهم وعلموني أن لا أضيعهم

أقول لكم: أنتم وهبتموني الحياة والأمل والنشأة على شغف الاطلاع والمعرفة

إلى كل من وهب لنا ولو كلمة.

أصدقـائي

والله وليّ التوفيق.

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Chapter One

Introduction

1.1 Introduction

In the present scenario demand for electricity increases, day by day but the power sector cannot fulfill this demand completely. having a huge amount of biomass like wood, bio-waste. At present to fulfill the shortage of power supply diesel generators are extensively used to produce electricity in rural and hilly areas. These generators produce a great amount of emission which affects the surrounding environment. In this quest, it is our need to use clean and eco-friendly bio-fuel which will not harm the environment and help to produce electricity independently without the need for external power supply sources[1,2].

Biomass is formed from living species like plants and animals. It is a collection of organic and inorganic materials mostly consists of by-products and wastes form animals and agriculture. Biomass is considered renewable because of unlike fossil fuel and can be reproduced plant through crop harvesting and consumption of food by the animals. Plants absorb carbon dioxide for their growth and return back to the atmosphere it means it will not disturb carbon dioxide level in the atmosphere and therefore biomass is considered as "Carbon Neutral Fuel" [1,2].

1.2 Renewable Energy in Palestine

1.2.1 Solar Power

Solar energy can be a major contributor to the future Palestinian energy supply, with its high potential in the area. Palestine receives about 3,000 hours of sunshine per year and has an average solar radiation of 5.4 kWh/m. Domestic solar water heating (SWH) is widely used in Palestine where almost 70% of houses and apartments have such systems. In fact, Palestine is one of the leading countries in the field of SWH for domestic purpose. SWH is made locally in the West Bank and Gaza Strip with a production rate of about 24,000 units per year which is considered to be sufficient for the Palestinian market. Solar thermal and photovoltaic systems are yet to take off in Palestinian areas due to high costs associated with such systems[3].

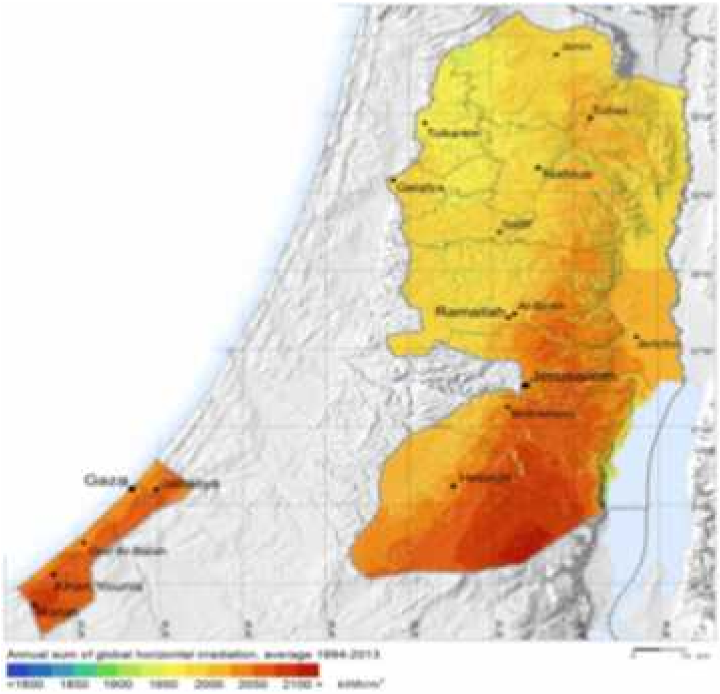

Figure 1.1 Horizontal Irradiation - long-term yearly average[3].

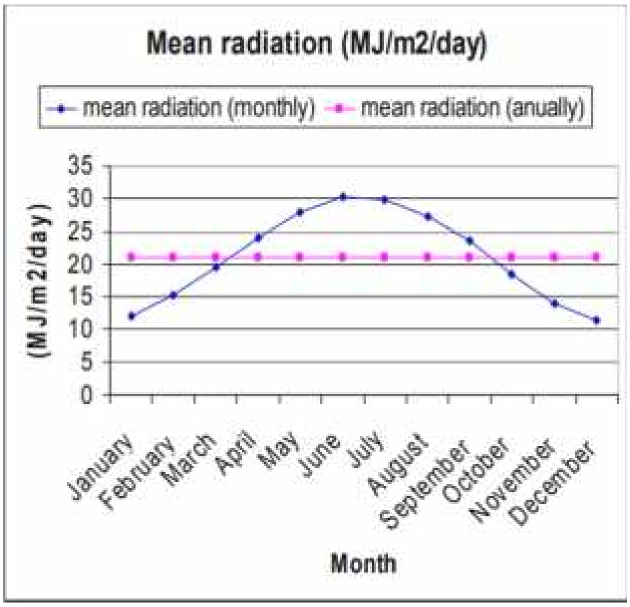

Figure 1.2 Mean monthly and annual daily global radiations (MJ/m2 /day) [3].

1.2.2 Wind Power

Wind power is the use of air flow through wind turbines to mechanically power generators for electric power. Wind power, as an alternative to burning fossil fuels, is plentiful, renewable, widely distributed, clean, produces no greenhouse gas emissions during operation, consumes no water, and uses the little land. The net effects on the environment are far less problematic than those of non-renewable power sources.

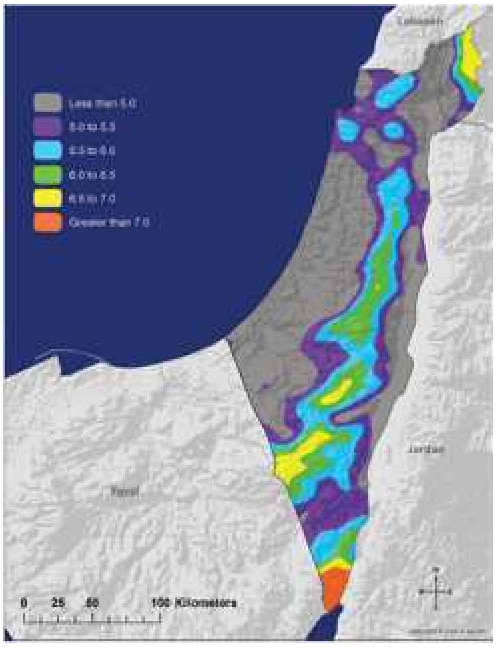

Figure 1.3 Wind speed in Palestine[4].

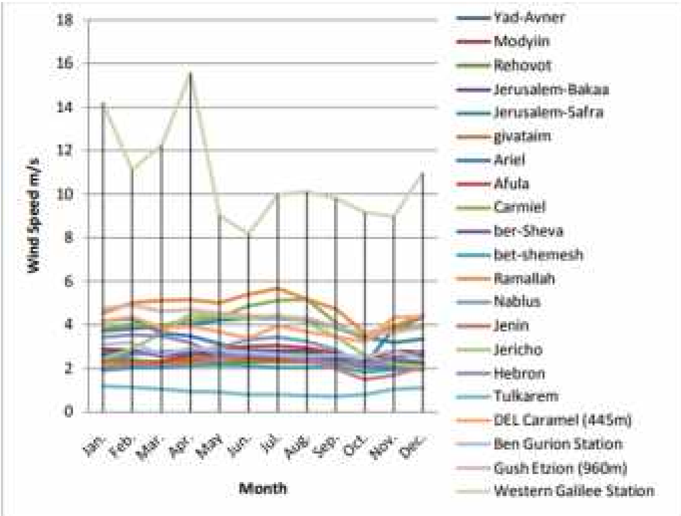

Figure 1.4 Wind profile in each one of the stations monthly[5].

1.2.3 Biomass

Biomass is an industry term for getting energy by burning wood, and other organic matter. Burning biomass releases carbon emissions, but has been classed as a renewable energy source in the EU and UN legal frameworks, because plant stocks can be replaced with new growth. It has become popular among coal power stations, which switch from coal to biomass in order to convert to renewable energy generation without wasting existing generating plant and infrastructure. Biomass most often refers to plants or plant-based materials that are not used for food or feed, and are specifically called lignocellulosic biomass. As an energy source, biomass can either be used directly via combustion to produce heat or indirectly after converting it to various forms of biofuel. Conversion of biomass to biofuel can be achieved by different methods which are broadly classified into thermal, chemical, and biochemical methods[6].

Figure 1.5 Biomass fuel.

Biomass as fuel

Biomass as a fuel can lead to disagreements about the viability of using cropland for fuel production. Ethanol and biodiesel production can divert corn and soybeans from the food and feed market and into the fuel production industry. Contrary to this biomass gasification can be tailored to avoid such conflicts.

Biomass gasification can utilize a wide range of fuel sources including materials suggests that other biomass sources include agricultural residues are good candidates for gasification. Normally agricultural residues are under or unutilized materials leftover following crop production.

Residues include corn stover, rice hulls, rice straw, wheat straw, cotton stalks, and bagasse. Agricultural residue collection is possible after the crop is harvested for its primary use and would not take away from food and feed cropland.

According to previously applied methods for generating power, the Biomass fuel method is chosen for completing present work due to:

- This method is a suitable way to generate power.
- Biomass fuel is environmentally friendly.
- Biomass fuel is available frequently and cheaper.
- This method for generating power is new at Palestine.

1.3 Problem Statement

The project idea came up from the status of recycling the biomass waste to thermal and electric power. In this project, a small gasification unit will be designed and implemented in order to recycle the waste of small farms and Carpentry to electricity. Such project will give a good solution for the projects in the rural areas and off-grid villages.

1.4 Objectives

This research project was designed to evaluate the use of farm and forestry grown biomass for producer gas generation. A smaller scale gasification system can offer greater flexibility and is more cost-effective in research testing gasifier operation and various biomass for producer gas. The goal of this project is to utilize existing knowledge in designing downdraft gasifiers for biomass to producer gas processes. Specific objectives were to:

1) review and compile existing knowledge on downdraft gasification theory to support the generation of unique design ideas.

2) design and fabricate a gasification system capable of generating producer gas streams from multiple solid fuel types with varying physical characteristics.

3) evaluate the function of a unique research-scale gasifier and investigate processing parameters and physical characteristics significant to effective gasification operation.

1.5 Time Table

The following timetable displays the project implementation-flow divided into fifteen weeks of the first semester as following.

Table 1.1 Time Table

Weeks / Tasks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Introduction Chapter (1)															
Gasification process Chapter (2)															
System Design Chapter (3)															
Project Implementation															
Testing and Calibration															
Conclusions and Recommendations Chapter (5)															

2

Chapter Two

Gasification process

2.1 Overview

The gasification process is the thermochemical conversion of biomass into a gaseous fuel, Gasification occurs in a reactor called a gasifier, which contains the solid fuel while it converts to producer gas. Gasifiers can be divided into four reaction zones as illustrated in figure 2.1.

- Drying and storage

- Pyrolysis

- Combustion/Oxidation

- Reduction

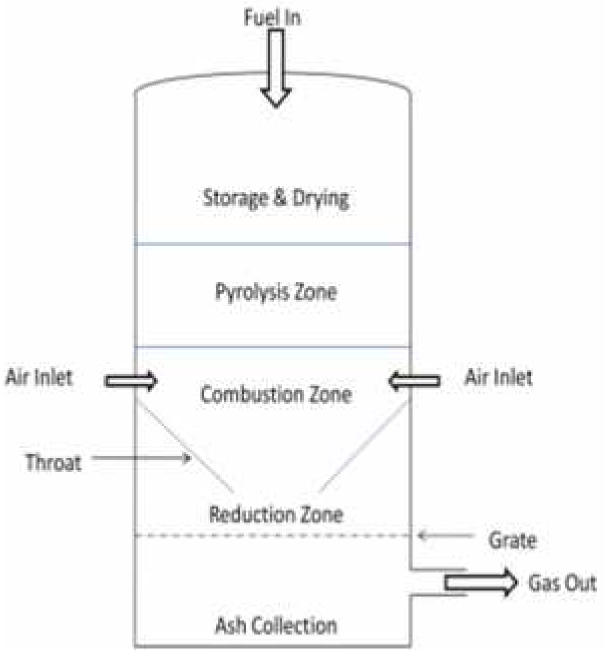

Figure 2.1 Gasification process [7]

Gasifiers alone are only a small part of a gasification process which also includes filtration, cooling, and storage systems. Gasification has been shown to be an endothermic process and for conversion to proceed energy must be added to the system[7].

Providing the necessary energy can be accomplished through the addition of sensible heat into the gasifier.

One way of heat addition comes from an external heating, source similar to Murdoch's teapot demonstration. Through external heating, the temperature in the gasification chamber is increased to initiate and sustain producer gas generation.

The second, more common method is through partial combustion of the solid fuel Sensible heat released during combustion provides the necessary energy to start and maintain gasification reactions[7].

Partial combustion, unlike complete combustion, occurs in an oxidizing agent limited environment. Common sources of oxidizing agent (gasifying agent) are air, steam, pure oxygen, and hydrogen[7].

2.2 Reaction Zones

2.2.1 Drying and Storage

Solid fuel loads are stored and prepared in the drying and storage zone for the lower gasifier zones.

In the drying zone, with high temperatures and moisture are driven from the solid fuel generating steam for subsequent zone reactions[8-10].

2.2.2 Pyrolysis

Pyrolysis is defined as the conversion of biomass in an oxygen-deprived environment. During gasification temperatures in the pyrolysis zones will vary depending on fuel sources, During pyrolysis, combustible gas products are released from the solid fuel include H_2, CH_4, CO, and CO_2). Other products of pyrolysis include tars, which can collect and obstruct the entire gasification system or become trapped in the producer gas and residual charcoal [8-10].

2.2.3 Combustion/Oxidation

If an external heating source is not used sensible heat needed for gasification is introduced to the gasifier through partial combustion that occurs in the combustion/oxidation zone. Temperatures within the combustion zone vary depending on gasification system and can be manipulated by gasifying agent selection, and flow rate.

Complete combustion of carbon with oxygen yields primarily CO_2 and is characterized by the exothermic carbon-oxygen reaction which provides some of the necessary energy for gasification. Comparatively partial combustion yields primarily CO with 28% of the energy released from complete combustion. Carbon Varying the gasifying agent flow rate can directly affect the composition of the producer gas as supported by Bhattacharya and Dutta. This phenomenon occurs in the presence of excess oxygen where combustion reactions move toward completion and producer gas generated is consumed during combustion. Conversely, in the absence of oxygen, the necessary energy will not be generated to initiate gas production. Optimal gasifying agent delivery rate is crucial to the successful operation of a gasifier.

Reactant choice is also critical in the combustion/oxidation zone. For example, using air as the gasifying agent introduces oxygen and inert diluents (e.g. N_2) which are incombustible. Diluents lower system temperatures and generally pass through the gasifier and exit as part of 8 the producer gas stream.

In certain cases, due to the high temperatures of the combustion zone, nitrous oxides (NOx) can form. Using air as the gasifying agent has advantages of being readily available and free. Unfortunately, air generates the lowest heating value fuel when compared to a steam/oxygen, steam/heat, and hydrogen/heat. Heating value differences for various fuels per gasifying agent are described Generally, gasifying agents that raise producer gas heating value also increases the complexity of the gasification system[8-10].

2.2.4 Reduction

The majority of producer gas CO is generated in the reduction zone. Most defined chemical reactions within the reduction zone are endothermic. Temperatures leaving this zone are usually less than that of the combustion zone. Depending on the design and operational parameters of the gasifier the temperatures is high ,The reduction of post-combustion products is generalized by:

-Boudouard reaction

-Carbon-water-gas reaction

-Water-gas shift

-Methanation reactions

Reduction by-products include ash particles and char. Ash, when entrained in the producer gas, is undesirable due to its abrasive nature. High gasifying agent velocities and producer gas generation rates can lead to ash and char particulate entrainment within the producer gas[11].

2.3 General Block Diagram

The following Function block diagram as illustrated in figure 2.2 clarify system stages.

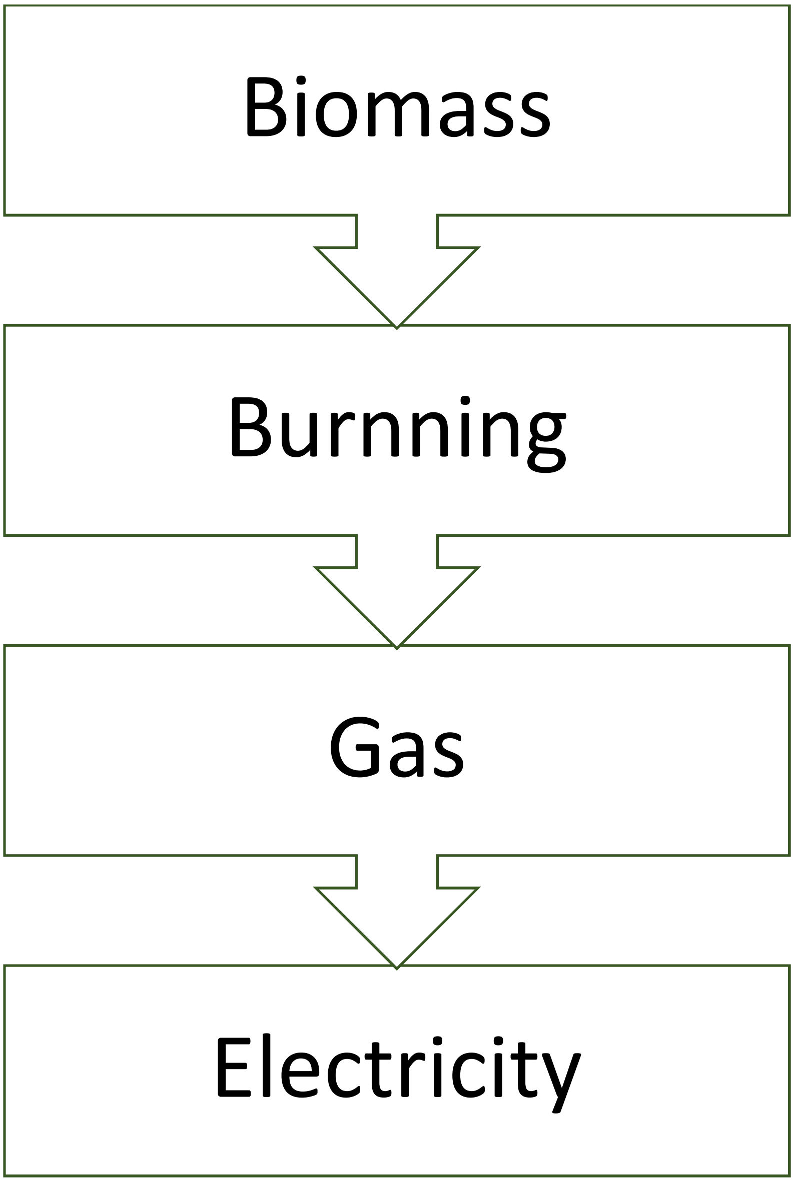

Figure 2.2 Functional Block Diagram

2.4 Block Diagram

The following block diagram as illustrated in figure 2.3 shows the principle of machine operation.

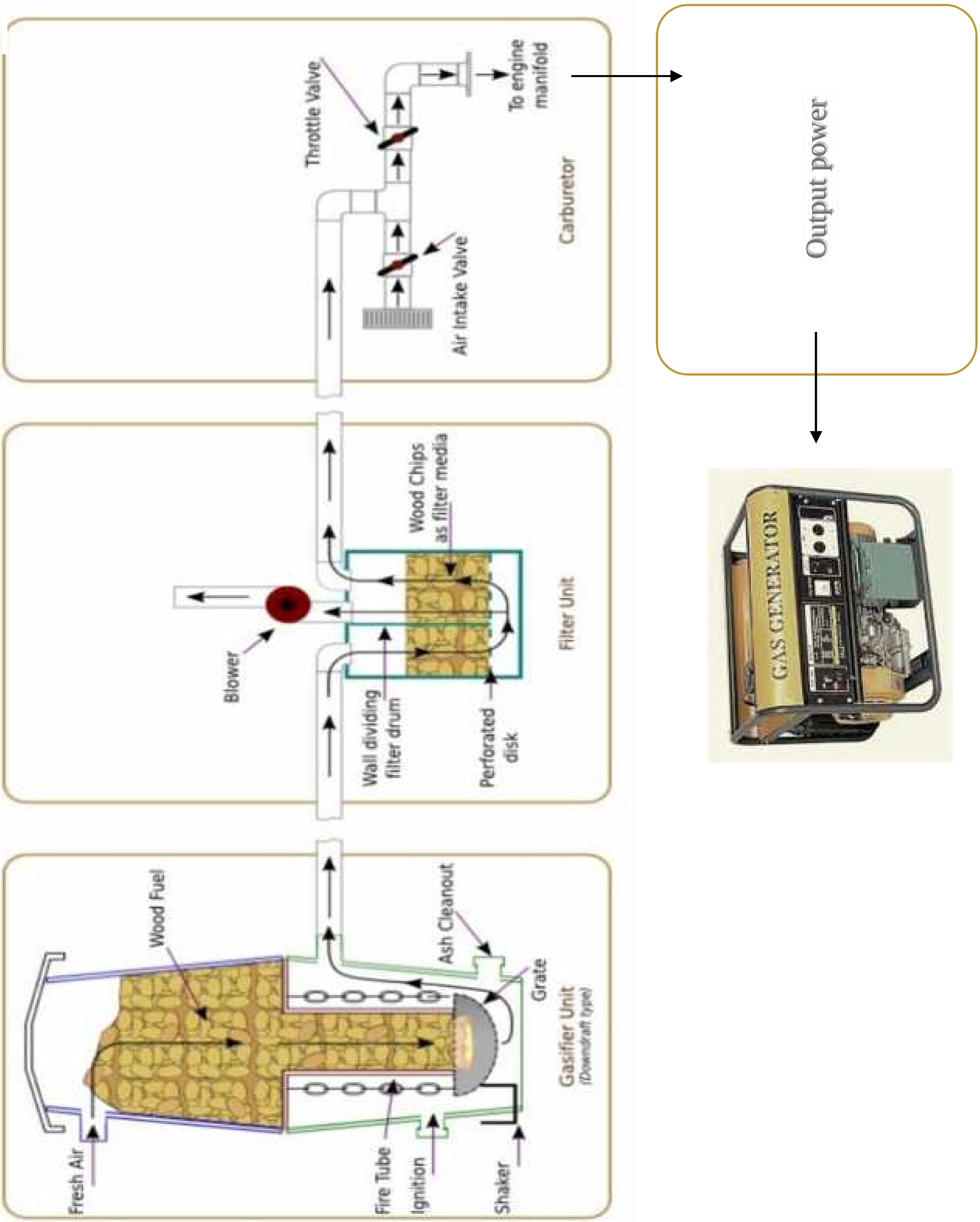

Figure 2.3 Block Diagram[12].

3

Chapter Three

System Design

3.1 Introduction

This chapter will include the all system design electrical and mechanical.

3.2 Electrical design

3.2.1 Load profile

When the grid is not nearby, electricity becomes much more valuable with the extra cost and complexity of a self-sufficient, stand-alone power system can provide enormous benefit.

We have limited solutions, one of that, the competition with the cost of bringing the grid to the site, which may run many thousands of dollars per mile. Instead of use utility power, using a gas gasification system.

The design process for stand-alone systems begins with an estimate of the loads that are to be provided. To achieve a reduction in electricity consumption, it is vital to have current information about household electricity use.

The project data was collected according to a house located in Hebron city.

Power needed by a load, as well as the energy required over time by that load, is important for system sizing. In the simplest case, energy (watt-hours or Kilowatt-hours) is just the product of some nominal power rating of the device multiplied by the hours that is used.

January and July were chosen as the two months were peak consumption of electric power through a year.

$E=P*T$

P: power consumption (kW).

E: energy consumption (kWh).

T: The period of time that the appliance was operated (hour).

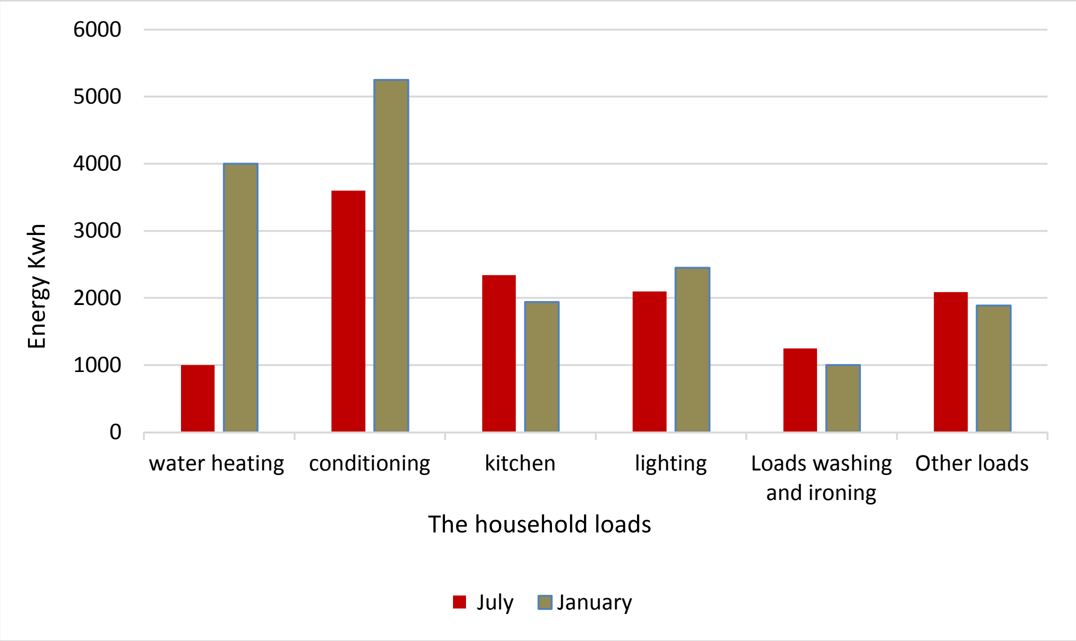

Figure3.1 The comparison of the proportion of major household loads between winter and summer.

According to the figure (3.1), we find that the amount of energy consumed in the winter more than the summer, and this is due to several reasons.

The year is divided into two main seasons summer and winter, There is two peaks of energy consumption during the year, one in the middle of winter in the month of January, the second peak in the middle of the summer in July.

The total average consumption of 12 months is **3116** kWh/year, so, after we know the amount of energy consumed.

3.3 Mechanical Design

The 3D design for all the machine stages using CATIA software.[13]

3.3.1 Gas generator unit and the fuel hopper

This unit contains eight parts as following:

1-Fire Tube

Using the displacement or horsepower rating of the engine to be fueled by the gasifier unit, determine the dimensions (inside diameter and length) of the fire tube, Metal pipe, open-ended metal cylinder; diameter and length from Appendix B Table B-1; the minimum wall thickness of 1/2 cm. [14,15].

2-Metal Plate

The circular top plate should be cut to a diameter equal to the outside diameter of the Gasifier housing drum at its top. A circular hole should then be cut in the center of the top plate. the diameter of this hole must be equal to the outside diameter of the fire tube.

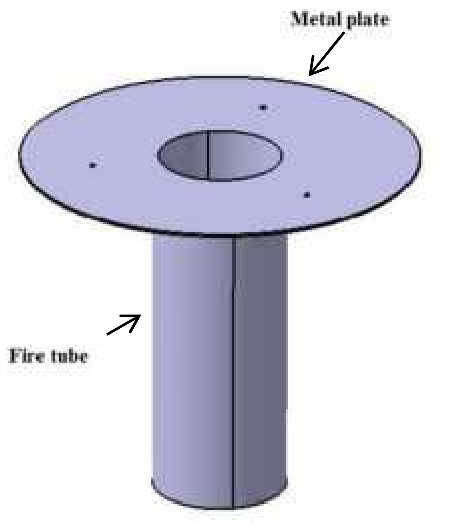

Figure 3.2 Fire Tube and Metal Plate.

3-Grate

The grate should be made from a stainless-steel mixing bowl or colander. Approximately 125 holes with diameters of 1.3 cm. should be drilled in the bottom and up the sides of the mixing bowl. [14,16]

Figure 3.3 Grate.

4-Housing Drum

Metal oil drum or metal container with approximate dimensions of 45.5 cm. diameter and 73.5 cm. height. the container must have a bottom.[14,15]

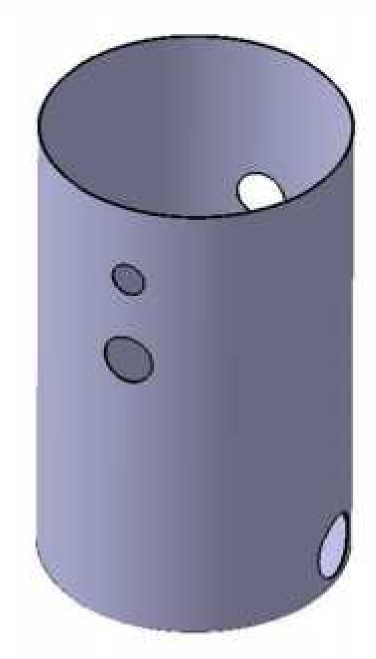

Figure 3.4 Housing Drum.

5-Fuel Hopper

20-gal metal garbage can or metal container with approximate dimensions of 45 cm.top diameter and 61 cm. height. the bottom is not required.[14,15]

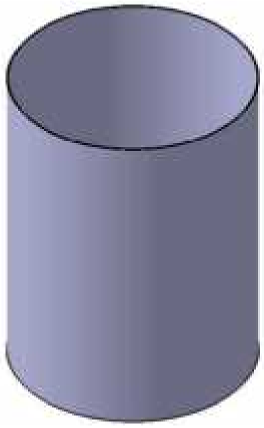

Figure 3.5 Fuel Hopper.

6-Housing drum lock ring

Lock ring for 30-gal oil drum.[17]

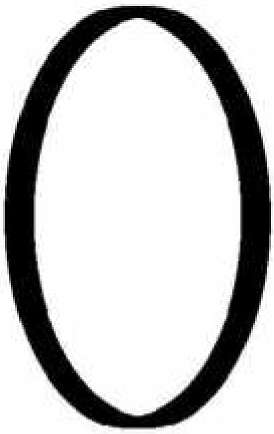

Figure 3.6 Lock ring.

7-Connecting Pipe

The connecting pipe between the Gasifier unit and the filter unit should be attached to the gasifier housing drum at a point 15.2 cm. below the top of the drum and having 180 cm minimum length.[14]

Figure 3.7 Connecting Pipe.

3.3.2 The Primary Filter Unit

This unit contains five parts as following:

1-Metal Can

5-gal metal can or another metal container with minimum dimensions of 29 cm. diameter and 33 cm. tall. [17,18]

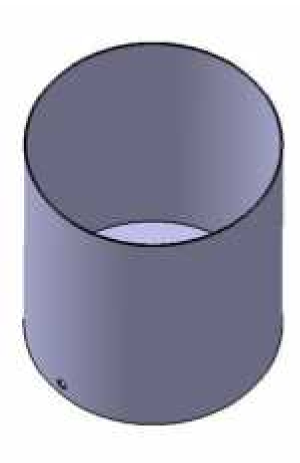

Figure 3.8 Metal Can.

2-Metal Plate

Circular metal plate; diameter equal to 1.25 cm. smaller than inside diameter of metal can the thickness of 0.3 cm. 1 cm. bolts, 7.5 cm. length with two nuts for each bolt.[17-19]

3-Rectangular Metal plate

Width equal to 0.5 cm. smaller than inside diameter of metal can height equal to 6.5 cm. smaller than internal height of metal can, 0.3 cm. thickness.[17-19]

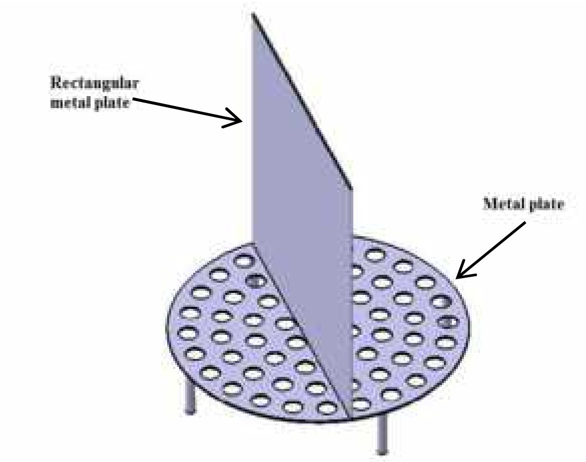

Figure 3.9 Metal Plate and Rectangular Metal Plate.

4-Circular Metal Plate

Circular metal plate; diameter equal to outside diameter of metal can, the thickness of 0.3 cm.[19].

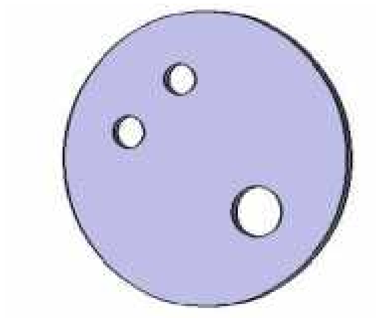

Figure 3.10 Circular Metal Plate.

5-Pipe

(between filter and generator) 3.2 cm. metal pipe, electrical conduit, automotive exhaust pipe, or another metal tubing. [14]

Figure 3.11 Pipe.

6- Steel Structure Base

Base for filter unit to handle it and Make it suitable for the whole system, it has 150cm length and 50cm width.

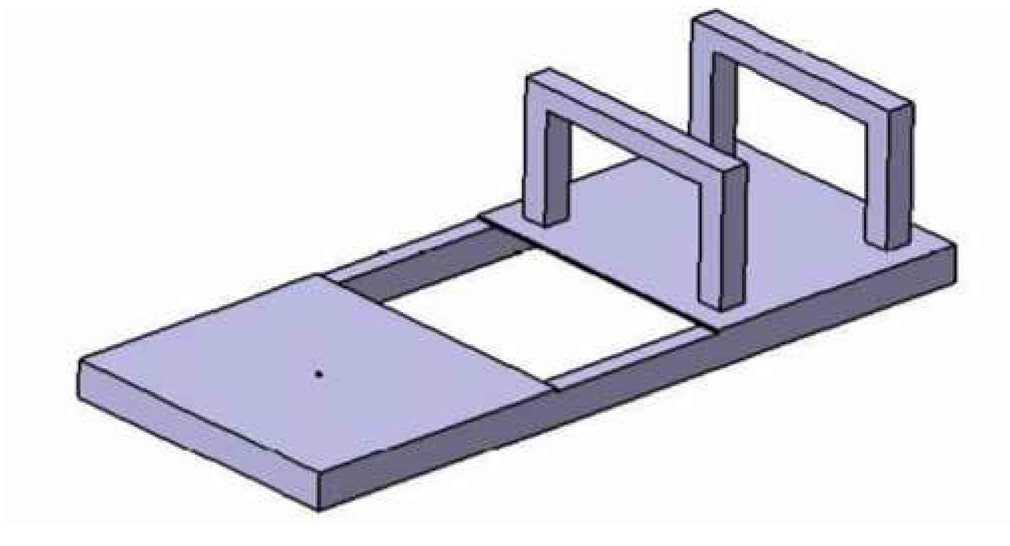

Figure 3.12 Steel Structure Base.

3.4 Assembly

The following figure shows all up mentioned outage parts assembled together in one design.

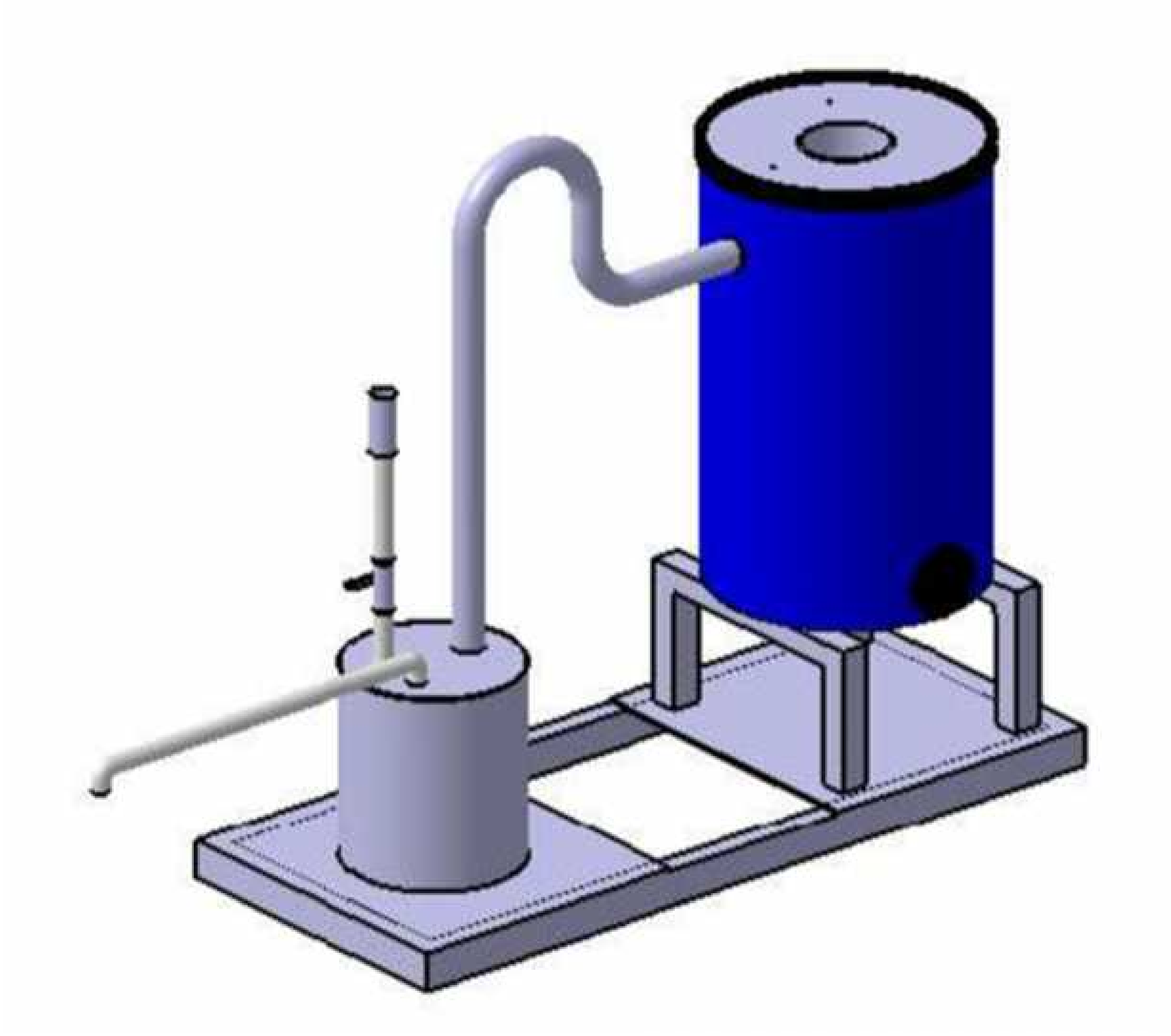

Figure 3.13 Outage shape of machine assembly.

The following figure shows all up mentioned internal parts assembled together in one design.

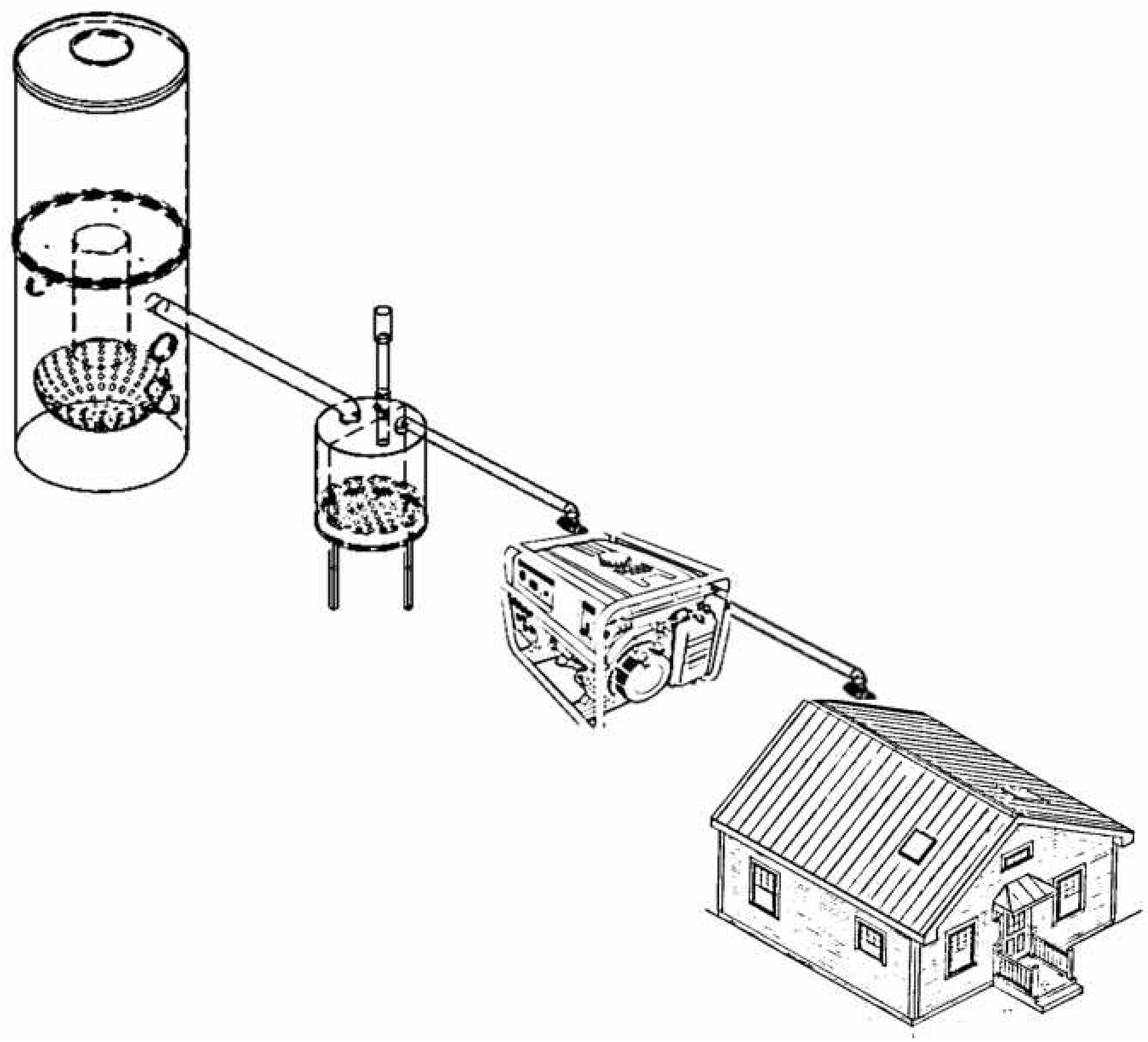

Figure 3.14 Schematic diagram of the system.

4

Chapter Four

Results and Current applications

4.1 Introduction

4.2 Experimental Results.

4.3 Current applications.

4.1 Introduction

This chapter provides experimental results and Current applications .

4.2 Experimental Result

In In this section, some experimental results will be presented for some types of biomass.

The following readings have been taken from various amounts of some kinds of biomass.

Table 4.1: Experimental Results

type	pellets	wood residue	olive mill pomace
Weight (gm)	450	350	500
Time (m)	15	15	15
Flam Status	Very good	Very good	Acceptable
Ignition Status	Some difficulty	Easy	Some difficulty

From the upper table, we conclude that the best material for produce gas from biomass is pellets and wood residue in our prototype for gasification.

4.3 Current applications

Wood gas can be used for heat production and for generation of mechanical and electrical power. Like other gaseous fuels, producer gas gives greater control over power levels when compared to solid fuels, leading to more efficient and cleaner operation.

4.3.1 Heat

Gasifiers offer a flexible option for thermal applications, as they can be retrofitted into existing gas fueled devices such as ovens, furnaces, boilers, etc., where wood gas may replace fossil fuels.

4.3.2 Electricity

Currently Industrial-scale gasification is primarily used to produce electricity from fossil fuels such as coal, where the wood gas is burned in a gas turbine. Gasification is also used industrially in the production of electricity, ammonia and liquid fuels (oil) .

4.3.3 Transport fuel

Gasoline engines can be operated on dual fuel mode using producer gas. Gasoline substitution of over 80% at high loads and 70–80% under normal load variations can easily be achieved. Spark ignition engines and solid oxide fuel cells can operate on 100% gasification gas.[21]

5

Chapter Five

Conclusions and Recommendations

5.1 Project Cost

The following table represent the final cost of the project.

Table 5.1: Cost Table

Item Name	Items No.	Total Cost (NIS)
Fire tube	**1**	**100**
Metal plate	**4**	**300**
Housing drum	**2**	**350**
Grate	**1**	**40**
Chains	**3**	**30**
Pipe	**3**	**200**
Blower	**1**	**100**
Battery	**1**	**100**
Gas generator	**1**	**1000**
System base	**1**	**200**
Overall Machine Body Cost	**1**	**2000**
Total Cost		**4420±10% NIS**

Note: All machine pictures are attached in Appendix C.

5.2 Conclusions

After the several times with firstly implementation the system and secondly running the system ,we find this topic is a grateful topic from where the economy of the cheapest fuel and for a clean green environment and for doing something unusual that makes us proudly, and the results of the test on some kind of biomass was great and provide a great demand of gas, we conclude that when start burning the air flow in the system should be strong so we need a perfect blower to do this and should have check valve to prevent any leak flame from entering the housing drum .

5.3 Recommendations

The main purpose of this project is to design gasification unit uses biomass to produce gas.

If any future projects consider adding modifications for the same machine we recommend the following:

- The thickness of the housing drum should be at least 0.5cm.
- The leaking status should be taken into account, we advise to use proper thermal silicone which can deal with a high-temperature degree.
- The output gas from our prototype has a high rate of tar, so we have to add more filter part such as cyclone filter to reduce tar rate because the high rate of tar cause damage to the generator (reduce the generator life).
- We recommend using temperature sensor for the system.
- We recommend using pressure sensor for the system.

Appendix A

“Heat Exchanger Performance”

Heat Exchanger Performance A tube and shell heat exchanger was installed on the gas-insulated downdraft gasifier to cool the producer gas stream prior to gas sample collection. Two type-K thermocouple probes (M12KIN-1/8-U-6-D, Omega Engineering Inc., Stamford, CT) were used to acquire producer gas temperatures from the inlet and outlet sides of the heat exchanger.

Temperature was recorded by gasifier control system along with temperature data coming from the gasifier. The heat exchanger removed an average of 101.6°C and 93.4°C from the charcoal runs at 25.48 and 50.97 m3 h -1, respectively, while average ambient temperatures were similar .

For field chopped sorghum tests there was an average of 63.5°C and 61.7°C removed for the 25.48 and 50.97 m3 h -1 runs, respectively with similar ambient temperatures.

. Maximum average heat exchanger inlet temperatures ranged between 160.2°C and 296.7°C depending on fuel source and air flow rate. Heat exchanger outlet temperatures, on average, were below 123.4°C.

Appendix B

“Fire tube dimensions”

.Table B Fire tube dimensions.

Engine power (hp)	Inside diameter (cm)	Minimum length (cm)
3-5	5	40.5
15	10	40.5
30	15	40.5
40	17.5	45.5
50	20	50.5
65	23	55.5
80	25.5	61
100	28	66
120	30.5	71
140	33	76
160	35.5	81

Appendix C

"Pictures of gasification unit"

References

1-Ciferno, J.P., J.J. Marano. 2002. Benchmarking Biomass Gasification Technologies for Fuels, Chemicals and Hydrogen Production. USDOE. Washington, D.C.

2- Butterman, H. C., & M. J. Castaldi. 2009. CO2 as a Carbon Neutral Fuel Source via Enhanced Biomass Gasification. Environ. Sci. Technol

3- Gai, C., and Y. Dong. 201. Experimental study on non-woody biomass gasification in a downdraft gasifier. Hydrogen Energy 37(2012)

4- Foley, G., and Barnard, G., Biomass Gasification in Developing Countries. Technical Report No. 1, Earthscan, London

5- Heesch, E. J. M., A. J. Pemen, M. Keping, S. V. B Yan, S. V. B. Paasen, and K. J. Ptasinski. 1999. Experimental program of the pulsed corona tar cracker. In Proc. 12th IEEE Intl. Pulsed Power Conf.Piscataway, N.J.: IEEE

6- Wei, L., J. A. Thomasson, R. M. Bricka, W. D. Batchelor, E. P. Columbus, & J. R. Wooten. 2006. Experimental Study of a Downdraft Gasifier. ASABE Paper No. 066029. Portland, OR.

7- Skov, N., and M.L. Papworth, PEGASUS (Petroleum Gasoline Substitute Systems), published by the Pegasus Publishing Co., Miami, FL.

8- Jameel, H., D. R. Keshwani, S. F. Carter, & T. H. Treasure. 2010. Chapter 10: Thermochemical Conversion of Biomass to Power and Fuels. In Biomass to Renewable Energy Processes, 436-489. J. Cheng, Boca Raton, F.L.: CRC Press/Taylor & Francis

9- Reed, T.B., and A- Das, Handbook of Biomass Downdraft Gasifier Engine Systems,

SERI/SP-271-3022, Solar Research Institute, Golden, CO

10- Wei, L., J. A. Thomasson, R. M. Bricka, W. D. Batchelor, E. P. Columbus, and J. R. Wooten. 2009. Syngas quality evaluation for biomass gasification with a downdraft gasifier. Trans.

11- Maschio, G. A. Lucchesi, & G. Stoppato. 1994. Production of syngas from biomass. Bioresource Technology

12- Rajvanshi, A. K. 1986. Alternative Energy in Agriculture, 2nd ed.,CRC Press.

13- Catia three-dimensional interactive application.

14- Anonymous, 'Coast to Coast on Homemade Fuel,' The Mother Earth News (No. 73)

15- Anonymous, ''Mother's Woodburning Truck,' The Mother Earth News (No. 69)

16- Chatterjee, A.K., State of the An Report on Pyrolysis of Wood and Agricultural Biomass,

PN-AAK-818, U.S. Department of Agriculture

17- Eoff, K.M., and D.M. Post, 'How to Power a Gasoline Engine with Wood,' Technical Reprint No.1, The Mother Earth News, Hendersonville

18- Miller, B., State-of-the-Art Survey of Wood Gasification, EPRI-AP-3101, Fred C. Hart Associates, Inc., Washington, DC.

19- Kaupp, A., and J.R. Goss, State of the Art Report for Small Scale (to 50kW) Gas Producer-Engine Systems, USDA Contract No. 53-319R-O-141, University of California, Davis, CA

20- Masters, G.M., Renewable and efficient electric power systems. 2013: John Wiley & Sons.

21-Ph.D. Thesis by Florian Nagel, Swiss Federal Institute of Technology Zurich, 2008