Fall 12-6-2019

USING BIOMASS TO DUAL FUEL A 4.5 KW DIESEL GENSET TO INVESTIGATE REDUCING WASTE DISPOSAL COSTS FOR A SMALL U.S. MUNICIPALITY

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by

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A dissertation
submitted in partial fulfillment
of the requirements for the
Doctor of Philosophy Degree
State University of New York
College of Environmental Science and Forestry
Syracuse, New York
December 2019

Department of Paper and Bioprocess Engineering

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Acknowledgments

I would like to thank Dr. Klaus Dölle for serving as my academic mentor. He has supported and worked with me throughout my extended pursual of my doctorate degree. He helped me transform my gasification hobby into an academic pursuit. I would also like to thank Steve Giarusso for his invaluable support in my research. My research would not have been possible without the support of the Research Foundation for the State University of New York.

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OBJECTIVE STATEMENT

The object of this research was to investigate whether it would be feasible for a small U.S. municipality wastewater treatment plant to save money by gasifying the biosolids it produces along with other biomass entering the plant and use the resulting producer gas to power a genset to generate electricity. Some work has been done on gasifying sewage sludge and biomass for large municipalities and generating electricity with the resulting producer gas or syngas but investigating gasifying biosolids and biomass entering and generating electricity with the resulting producer gas for a small U.S. municipality to save on disposal costs is novel.

ABSTRACT

R. P. Bates. Using Biomass to Dual Fuel a 4.5 kW Diesel Genset to Investigate Reducing Waste Disposal Costs for a Small U.S. Municipality, 89 pages, 10 tables, 23 figures, 2019. Council of Science Editors style used.

This study explores dual fueling a diesel genset with producer gas made from biosolids , wastepaper and woodchips generated at or brought into the Minoa (a village in New York) Wastewater Treatment Plant (MWTP) and the possibility of a dual fueled genset and gasifier reducing the MWTP operating costs. The producer gas resulted from gasifying the biomass in a downdraft Imbert style gasifier. Gasification of woodchips was first studied in the gasifier using two different sizes and types of woodchips. It was found that the denser hardwood chips 2 cm x 2 cm x 0.6 cm gave better performance than less dense willow chips 1 cm x 1 cm x 0.15 cm. The smaller, less dense chips restricted air flow and reduced temperatures in the gasifier oxidation and reduction zones. Particle size distribution from samples taken vertically through the gasifier also indicated restriction of air and fuel flow through these zones with the smaller, lighter chips. Dual fueling of the genset with the larger, denser woodchips reduced diesel consumption by approximately 75%.

Wastepaper, primarily newspaper, was then studied as gasifier fuel. It was first pulped, then the wet pulp was formed into 60 cm^3 chunks, then dried and gasified. The wastepaper fuel was generally difficult to gasify because of its low density and tendency to hang up in the gasifier. Dual fueling the genset with producer gas from wastepaper only reduced diesel consumption by approximately 30%. Since wastepaper can be recycled by Minoa at no cost, gasifying its wastepaper was not recommended.

Biosolids were then studied as gasifier fuel. Copious ashes were removed from the gasifier oxidation and reduction zones. Dual fueling the gasifier with producer gas from biosolids reduced diesel consumption by 70% - 90%. Biosolids first processed through a filter press then pressed into roughly 15 cm^3 chunks and dried gasified easily as long as the grate was continuously agitated. By generating electricity and the potentially valuable soil amendment biochar dual fueling a diesel powered genset with producer gas generated from biomass could save Minoa more than $14580 annually.

Keywords: Dual fueling, gasification, down draft, biomass, biosolid

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CHAPTER 1: INTRODUCTION

Modern civilization depends on using the abundant material resources provided by nature. Today fuel energy stored in solid, liquid and gaseous form is the most needed resource in today's world economy. During US colonial times, wood was the dominant fuel resource, surpassed by coal in 1885. Coal was then surpassed by petroleum in 1949 and natural gas in 1957. The use of petroleum and natural gas then quadrupled in a single generation[1]. The change from biomass fuel to fossil fuels at the end of the 19th century was necessary to fulfill the ever-growing energy demand of the increasing population and fast-growing industry. This all resulted in a global temperature rise, known as global warming, over the past 140 years[2]. Associated with global warming, a rise in the CO_2 level in the atmosphere can be noticed[3].

In 2016 the US consumed a total of 13,504 thousand barrels of crude oil per day[4]. Therefore, US independence from foreign sources of energy is of great national interest.

According to the Unites States Census Bureau Energy, the U.S. population increased by nearly 204% from 1950 to 2010 to over 308.7 million and is expected to reach 439.0 million in 2050[5]. Energy consumption has increased by 280.5% to a total of 28.556 trillion kWh/day[6] and is expected to increase by 5% by 2040, whereas an increase of 11% is expected in a high economic growth case[7]. Data from EIA[8]show that in 2016, 78.5% of the energy consumed was supplied by fossil fuels, with petroleum accounting for nearly 35.9%, natural gas for 28.4% and coal for 14.2%. 8.4% of the consumed energy was supplied by nuclear energy and about 10.2% from the renewable energy sector. Biomass feedstock accounts for 47% of the total US renewable energy consumption, making biomass the single largest renewable energy source in the U.S.[9]. Indeed, photosynthesis converts solar energy into biomass of up to 220 billion metric tons a year. This biomass can be converted into approximately 10 times today's world energy consumption[10]. A

U.S. joint study between the Department of Energy (DOE) and the U.S. Department of Agriculture (USDA) identifies sources for biomass feedstock and estimates an annual biomass of 1,366 million dry tons available for the production of biofuels and energy from forest and agricultural resources[11]. Depending on how exactly carbon neutrality is defined, power from biomass is generally considered carbon neutral in that none of the carbon contained in the biomass comes from fossil sources such as coal or petroleum[12].

The increasing costs of energy and material resources are leading industrial, commercial, farm-based and municipal enterprises in the U.S. and many other nations to develop more sustainable modes of operation[13], because fossil fuels, the current primary sources of energy on earth, are finite [14]. Many studies suggest that the costs of fossil fuel exploration and extraction will continue to rise, perhaps to unprecedented levels [14-17]. In both the United States and the developing world there is an increasing need for low-tech, low-cost solutions to our energy, resource, and waste management challenges. Finding ways to utilize appropriate technologies for alternative energy systems will be among the solutions that will remediate the impacts of fossil fuel utilization[18]. Biomass energy is not in an ideal form for direct use and requires conversion technologies such as: 1) biochemical (the use of enzymes and yeast - which is costly and time-consuming), or 2) thermochemical which is the fastest, cleanest and most efficient[19]. The thermochemical conversion of biomass includes: pyrolysis, combustion and gasification of the biomass. Gasification with air results in producer gas, a mixture of carbon monoxide, hydrogen, methane, carbon dioxide and nitrogen gases[20]. Gasification can potentially convert 60%-90% of the biomass energy into a gas that can then be burnt to produce industrial or residential heat, run engines for mechanical or electrical power, or to produce synthetic fuels[21]. Various designs exist for gasification, most commonly fixed bed, fluidized bed, updraft and downdraft gasifiers. These designs are based upon the input of oxidizer flow and the direction of gas output in the system.

The downdraft gasifier has been proven to be the most successful design for small scale power generation due to its low tar production, an inhibiting by-product of the process. Downdraft gasification has not yet been successful for large scale (MW) power production. The downdraft gasifier has 5 major zones: 1) drying, 2) conversion, 3) charring, 4) oxidation, and 5) reduction zones. The Imbert design is a downdraft design in which the gasifier contains a throated combustion zone such that the diameter for the pyrolysis zone decreases into and through the combustion zone and increases again through the reduction zone[18]. Figure 1 shows a diagram of an Imbert gasifier. A pilot-scale downdraft, Imbert-type gasifier shown in Figure 2 below was designed and constructed to be used at a municipal wastewater treatment plant, CERF, in Minoa, NY. Figure 3 below is a design sketch for the CERF gasifier.

Gasifiers are relatively simple devices. The mechanics of their operation, such as feeding and gas cleanup, also are simple. The successful operation of gasifiers, however, is not so simple. No neat rules exist because the thermodynamics of gasifier operation are not well understood. Yet, nontrivial thermodynamic principles dictate the temperature, air supply, and other operating variables of the reactors that we build[21]. Biomass largely consists of hydrocarbons. Hydrocarbons combined with the proper amount of oxidizer break down largely into the fuel gases hydrogen, carbon monoxide and methane starting at temperatures above 600 deg C (1112 deg F) [21]. Reaction times at this temperature are comparatively slow and the breakdown of hydrocarbons at lower temperatures tends to produce larger amounts of tar. For these reasons gasifiers are generally operated such that the temperatures in the combustion and reduction zones are 700 deg C (1292 deg F) to 1000 deg C (1832 deg F)[21]. Prolonged operation at temperatures above 1000 C requires that the gasifier be built from more expensive heat resistant materials.

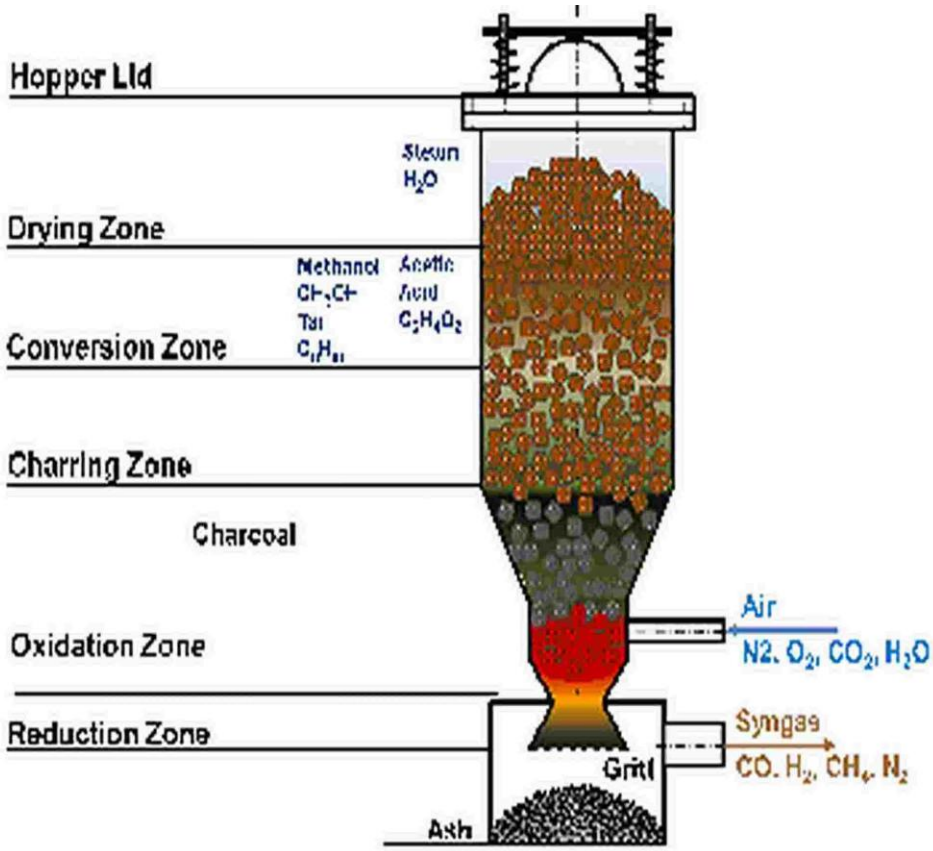

Figure 1. Imbert Style Gasifier Image by Klaus Dölle, Imbert Style Gasifier, pdf-file

A pilot-scale downdraft, Imbert-type research gasifier shown in Figure 2 below was designed and constructed to be used at Clearwater Educational Research Facility (CERF), located at the municipal wastewater treatment plant of Minoa, NY[22]. Figure 3 below shows a design sketch for the CERF gasifier[22]. This research is a study of the pilot scale gasifier located in Minoa. Initially dual fueling the diesel powered genset with the gasifier fueled with woodchips was investigated[22]. The objectives were to determine the feasibility and savings of diesel fuel in dual fueling the genset with producer gas produced from sewage sludge and other biomass entering the plant along with the avoidance of waste disposal costs for the sewage sludge. However, the MWTP doesn't have a large or steady supply of woody biomass and gasifying the small and erratic wood waste supply would not reduce yard waste disposal fees so woodchip dual fueling the genset was not considered as a way for the MWTP to save money at this time.

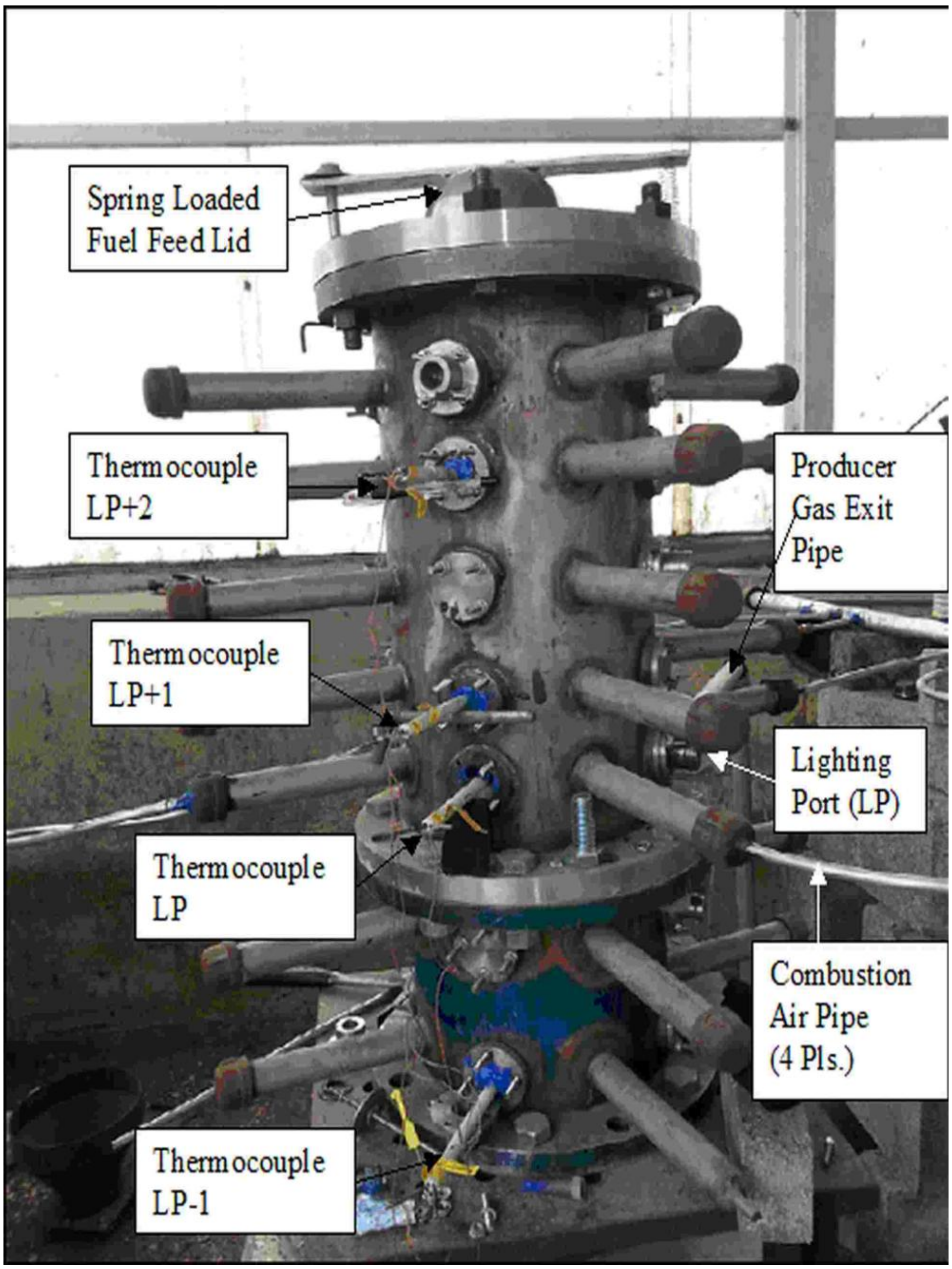

Figure 2. CERF Gasifier

According to the EPA, the average person in the US generates about 1/8 kg (dry basis) of sewage sludge per day, with approximately 13,000 to 15,000 publicly owned treatment plants generating 110 – 150 million tons of wet sludge annually[23]. Given the projected US population increase of 42% by 2050, these numbers may increase to 150 – 215 million tons annually by 2050. The vast majority of municipalities, approximately 15,000, have populations of less than 15,000 according to the US census[24]. Disposal of sewage sludge, the biosolid end product of sewage treatment, is a major expense for small municipalities like Minoa, NY, population 3345[25]. Small municipalities pay a premium price for disposal of sewage sludge, for example, the village of Minoa, NY,

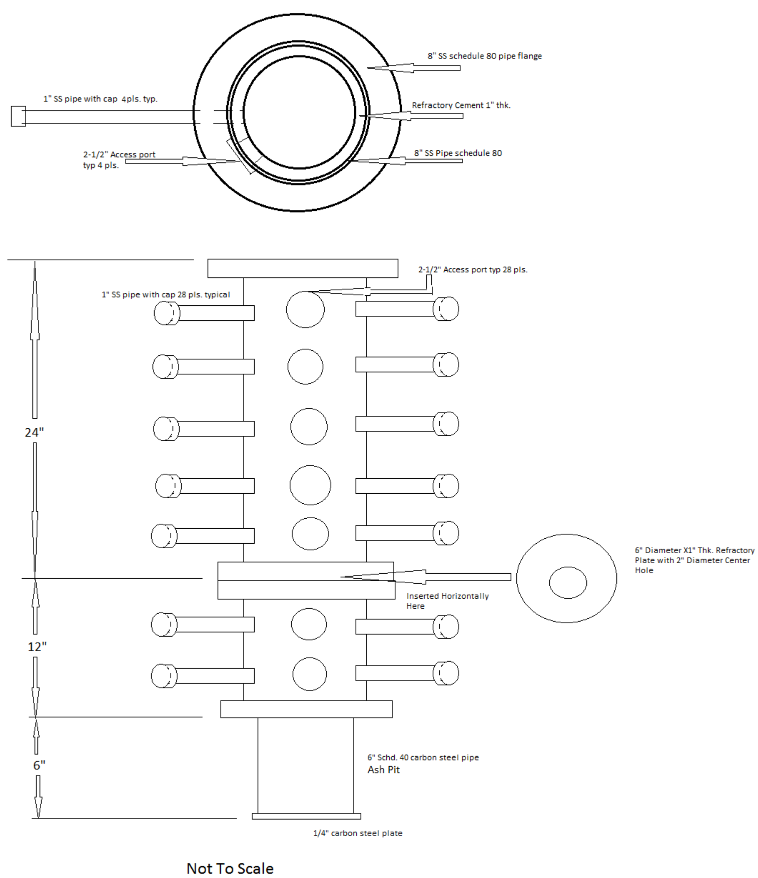

Figure 3. CERF Gasifier Design Sketch

pays $60 per ton to landfill wet (80% MC) sludge and it generates 230 – 250 wet tons per year[26] for an annual cost of $13800 - $15000, not including the cost of transporting the sludge to the landfill facility. By generating electricity from the sludge small municipalities can avoid much of the cost of disposal of what is considered hazardous waste and in addition can offset the cost of electricity used by the municipality.

Wastepaper (paper and cardboard products) as determined experimentally using a bomb calorimeter has a higher heat of combustion, 3.66 watt-hours (wh)/g, than sewage sludge, 3.04 wh/g, and burns more readily in the calorimeter. This study explores dual fueling a small diesel powered genset with producer gas from a sewage sludge and paper fueled gasifier. Producer gas is generated from a gasifier when the oxidizing agent is air, its main constituents are carbon monoxide, hydrogen and nitrogen. Syngas is produced from a gasifier when the oxidizing agent is steam or oxygen, its main constituents are carbon monoxide and hydrogen[27] . Producer gas has a lower heating value (LHV) of 4 – 7 MJ/NM^3 , syngas has a higher LHV of 10 – 28 MJ/NM^3 [28]because it is not so heavily diluted with inert nitrogen.

The average person in the US generated approximately 1.25 lbs. of waste paper per day in 2015[29]. According to the EPA, approximately 40% of a typical landfill in 2007 was made up of paper products[30], showing that ample waste paper is available to mix with sludge for gasification without reducing the amounts of paper currently recycled for making paper or energy via combustion. The goal of this project is to explore the feasibility and cost effectiveness of gasifying and producing electricity from the biosolids and wastepaper Minoa produces and avoid much of the cost of disposal of what is considered hazardous waste and in addition offset the cost of electricity used by the municipality.

CHAPTER 2: LITERATURE REVIEW

The two main technologies presently used to convert biomass into energy are thermo-chemical and biochemical. Gasification and the production of syngas or producer gas is one of the four main processes of thermochemical conversion of biomass to energy, the others being combustion, pyrolysis and liquefaction[31]. Brusca et al. [32]propose using gasification to generate energy from glycerol, a major byproduct of the production of biodiesel, a biochemical process. The glycerol undergoes steam reformation and is gasified in this thermo-chemical process.

Gasification is heating a carbonaceous material with a limited amount of a gasifying agent, typically oxygen, air or steam to produce syngas if the gasifying agent is steam or oxygen or to produce producer gas if the gasifying agent is air. It is a thermochemical process that increases the hydrogen to carbon content content of the feedstock [33]. Most of the fuel energy in syngas or producer gas is derived from its CO and H_2 content. Syngas and producer gas also usually contain lesser amounts of CO_2 and CH_4, producer gas also contains approximately 50% N_2. Other names for syngas depending on the feedstock, gasifying agent or time and place of production include town gas, water gas and blast furnace gas. Producer gas is sometimes known as wood gas if the feedstock is wood. Gasification has four stages that take place in different locations in the gasifier; drying, pyrolysis, oxidation and reduction [34]. Heat generated in the oxidation stage drives the other three stages, it dries the fuel out in the drying stage, drives out the combustible gases from the fuel in the pyrolysis stage and produces syngas or producer gas in the reduction stage. Syngas or producer gas is mainly formed by the following chemical reactions [35]:

CHxOy (biomass) + O2 (21% of air) + H2O (steam) = CH4 + CO + CO2 + H2 + H2O (unreacted steam) + C (char) + tar (1)

2C + O2 = 2CO (partial oxidation reaction) (2)

C + O2 = CO2 (complete oxidation reaction) (3)

$C + 2H_2 = CH_4$ (hydrogasification reaction) (4)

$C + H_2O = CO + H_2$ (water gas reaction) (5)

$C + CO_2 = 2\ CO$ (Boudouard reaction) (6)

$CO + H_2O = CO_2 + H_2$ (watergas shift reaction) (7)

$CO + 3\ H_2 = CH_4$ + H2O (steam reformation reaction) (8)

Temperature and residence time of the reactants determine the fractions of the products. Temperature and residence time are affected by the amount of gasifying agent introduced and gasifier design. By breaking down all the biomass to mostly simple gases gasification avoids complex treatments and conditions typical of fuels derived from pyrolysis, liquefaction and biochemical processes. However, syngas and producer gas often contain contaminants such as ash, sand, char and tar. Internal combustion engines (ICEs) are more tolerant of contaminants than turbines and hence are better suited for use with syngas or producer gas, particularly for smaller systems where equipment cost is a major concern as they do not require as extensive a clean up train as turbines would [36-38]. Tar is a major problem as a contaminant in syngas or producer gas used in any engine as it tends to stick and plug pores in filters and engine components it comes in contact with [39]. In small engines using a downdraft gasifier such as the Imbert gasifier using appropriately sized fuel with a low moisture content and operating it at a appropriately high combustion temperature is a good way to avoid tar problems [21, 40]. Imbert gasifiers were used extensively during petroleum fuel shortages in WWII to power motor vehicles, even airplanes[41]. Figure 4 below shows a block diagram for producing producer gas. Most of the energy in producer gas usable in an ICE is provided by its hydrogen and carbon monoxide content.

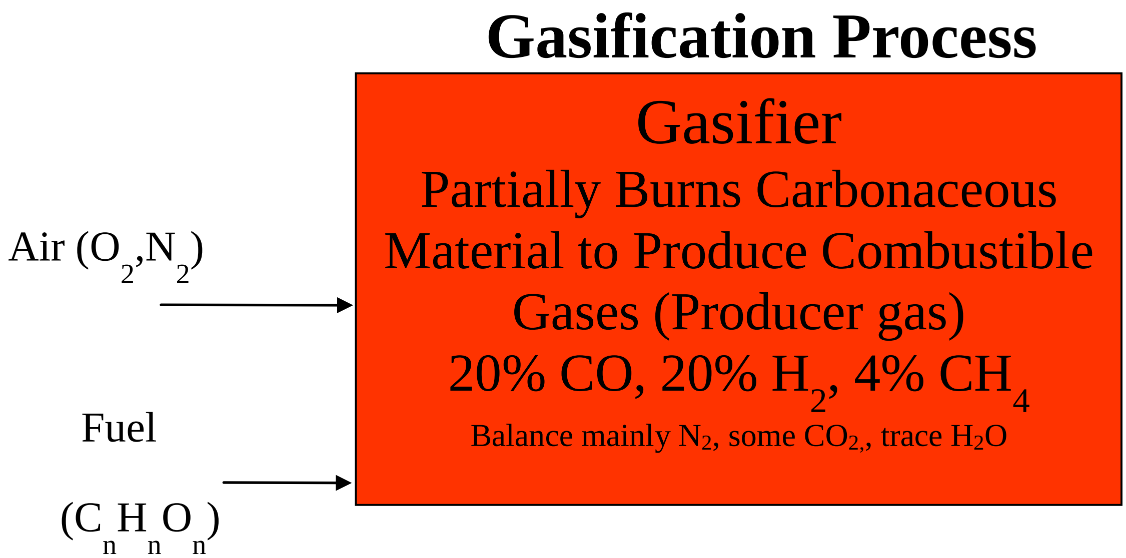

Figure 4. Gasification

Producer gas composition varies widely due to biomass type and gasifier conditions. Typical composition of producer gas is, by volume, 18–20%H_2, 18–20%CO, 2%CH_4, 11–13%CO_2, traces of H_2O and balance N_2 [42]. The lower heating value (LHV) of carbon monoxide is 10 MJ/kg, the LHV of hydrogen is 120 MJ/kg [43]. Thus, any process that generates producer gas or syngas aims at maximizing the amount of hydrogen.

Airflow rate is one of the key parameters effecting gasifier performance. Airflow rate in gasifiers is usually stated as Equivalence Ratio (ER) or Superficial Velocity (SV) [35]. Equivalence Ratio is the ratio of the amount of air entering the gasifier to the amount needed for the complete combustion of the burning biomass. Superficial Velocity is the airflow rate (volume/ sec) divided by the area of the narrowest portion of the gasification zone resulting in a velocity (length/ sec). Increasing the ER from a minimal value towards 0.5 generally increases temperature but decreases residence time, increases gas production but decreases the LHV of the gas (because more of the fuel value of the biomass is combusted), and lowers the tar content of the producer gas or syngas [35]. Generally for gasification there is an optimal ER in the range of 0.2 –0.4 [35, 44]that results in a fairly energetic gas with low tar content. SV also seems to have an optimal range of 0.4 – 0.6 m/s, a SV of 0.7 m/s increases tar production, probably due to a lower residence time [35].[35, 44]

Table 1. Properties of Producer Gas (PG) Compared with Pure Combustible Fuel Gases + Air, from [45].

Gas	Fuel LCV, Lower Calorific Value, MJ/kg (MJ/Nm3)	Air/ Fuel @ Φ =1 mass (mole)	Mixture, MJ/kg (MJ/Nm3)	Fuel-air Equivalence ratio (Φ), Limit		Laminar burning velocity (S_L), (Limit) cm/s		S_L Φ =1, cm/ s	Peak Flame Temp, K	Product/ Reactant Mole Ratio
				Lean	Rich	Lean	Rich			
H_2	121 (10.8)	34.4 (2.38)	3.41 (3.2)	0.01	7.17	65	75	270	2400	0.67
CO	10.2 (12.7)	2.46 (2.38)	2.92 (3.8)	0.34	6.80	12	23	45	2400	0.67
CH_4	50.2 (35.8)	17.2 (9.52)	2.76 (3.4)	0.54	1.69	2.5	14	35	2210	1.00
C_3H_8	46.5 (91.3)	15.6 (23.8)	2.80 (3.7)	0.52	2.26	-	-	44	2250	1.17
C_4H_{10}	45.5 (117.7)	15.4 (30.9)	2.77 (3.7)	0.59	2.63	-	-	44	2250	1.20
PG	5.0 (5.6)	1.35 (1.12)	2.12 (2.6)	0.47	1.60	10.3	12	50	1800	0.87

Gasification temperature also greatly effects producer gas composition. Generally, gasification at temperatures between 800 C and 900 C favor CO and H_2 production (higher heating value), higher producer gas yields and less tar [35]. Unfortunately, gasification at 800 C or higher also favors the formation of slag or clinkers from ash [46].

At first glance it would appear that power derating for a gasoline or diesel engine operating on producer gas would be severe given the disparity of the fuel's LHV values. However, the derating is mitigated by the disparity of stoichiometric air/fuel ratios for the two fuels, 1.2 for producer gas and 14.9 for gasoline or 14.5 for diesel fuel [42, 47, 48]. Thus, the amount of energy burned in the engine per revolution is not as different when operating on producer gas or petroleum fuel as the difference in LHV would imply. Typically, ICEs are derated by approximately 30 – 40% when operated on producer gas rather than petroleum fuels [40, 49].

Compared to combustion of the same biomass, gasification generally results in lower emissions of carbon monoxide, sulfur and nitrogen compounds such as NO [37]. Trading off nitrogen compound emissions with exhaust gas recirculation and retarding of the injection/ignition timing may lead to an optimal condition where nitrogen compound emissions and engine power and operation are acceptable[50]. Integrated gasification combined cycle (IGCC) systems for power and heat production have been shown to offer better energy efficiency and environmental performance than conventional combustion-based technology [37]. IGCC systems extract power from surplus heat generated by the gasification and burning of fuel via steam powered turbines.

Electrical generation using a producer gas powered engine is applicable to the developed world as a means of reducing greenhouse emissions and to the developing world as a means of providing electricity in rural areas which typically have available biomass [42]. A big advantage of producer gas use in spark ignition (SI) engines as opposed to compression ignition (CI) or diesel engines is the ability to run on producer gas fuel alone rather than in the dual fuel mode necessary in CI engines operating with producer gas, thus eliminating the need for any petroleum fuel. High thermal efficiency is possible with producer gas fueled SI engines resulting from higher compression ratios allowed by the high antiknock characteristics (low flame speed) of CO and CH4 and diluents N2 and CO2 in producer gas compared to those possible in gasoline powered SI engines [42]. These counteract the knocking tendencies (high flame speed) of the hydrogen in syngas and also decrease the cylinder temperatures and pressures and lower NO_x emissions [42]. It should be noted, however, that much of the energy in producer gas comes from its hydrogen content. Without increasing the compression ratio a SI gasoline engine running on producer gas is estimated to have a thermal efficiency of 10% - 15% as opposed to 15% - 20% running on gasoline due to the lower energy content of the syngas – air mixture compared to the gasoline- air mixture [51]. However, milling of the engine block and/or cylinder head and/or changing the engine pistons is necessary to increase the compression ratio of a gasoline SI engine.

Producer gas is used as fuel in diesel or compression ignition engines in the dual fuel mode in which diesel fuel is used as the pilot fuel and producer gas is introduced through the engine intake air and provides the bulk of the fuel charge. Figure 5 shows a typical carburetor for mixing and introducing air and producer gas to a diesel engine for dual fueling. The pilot fuel is necessary to ignite the producer gas as the producer gas auto-ignition temperature (500°C) is higher than is achieved by the fuel charge in the diesel engine on the compression stroke [52, 53], although Reed reports that a slow speed, single cylinder, direct injection diesel engine was able to run on 100% producer gas for extended periods when operating conditions allowed [21]. Dual fueling diesel engines with a compression ratio greater than 17:1 may not be practical [54]. The amount of diesel fuel necessary as the pilot fuel is variable and largely depends on the quality and energy content of the producer gas [49]. The Food and Agricultural Organization of the United Nations (FAO) recommends a minimum of 8 – 9 cubic mm of diesel per cycle as pilot fuel for stable combustion [55]. Producer gas is able to substitute 60% - 90% of the diesel fuel required to run a diesel engine at a specific power level [21, 56]. Dual fueling a diesel engine allows use of a lower energy producer gas or one that varies more in energy content[49] than would be practical in a spark ignition engine. The diesel engine governor in dual fuel mode increases or decreases the amount of diesel fuel injected as necessary to maintain engine output in the face of decreasing or increasing producer gas energy content.

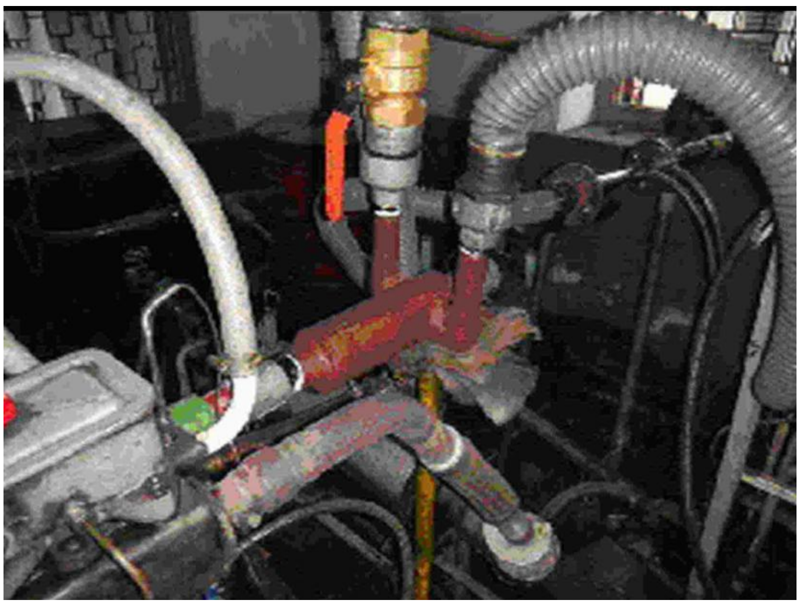

Figure 5. Carburetor Used to Mix and Introduce Air – Producer gas Mixture to Dual Fuel Engine[57]

Raman and Ram report that diesel engine dual fuel energy efficiency is generally about 20% using producer gas but stipulate that this efficiency is only achieved when the engine is run at full power and that efficiency falls off rapidly at partial load and throttle settings [58]. They state that at full load diesel engine power generation efficiency is about 28%, this falls off to about 17% when the diesel engine is operated at 20% load. Producer gas power generation efficiency is reported as 21% at full load and only 9 % at 20% load [58], a much steeper drop in efficiency than for the diesel engine power generation efficiency going from full to partial load.

Emissions from dual fueled (producer gas and diesel) compression ignition (CI) engines are generally less than when running on diesel alone. Greenhouse CO_2 is reduced by the degree of substitution of biomass-based producer gas for diesel as biomass generally is considered carbon neutral [51], depending on the definition of carbon neutrality [12]. SO_2 and SO_3 are considered culprits in acid rain production[51] and are reduced from levels emitted from a diesel engine running on 100% diesel when the engine is dual fueled with producer gas[37]. According to Whitty et al producer gas has a much wider ignition range than conventional hydrocarbon fuels so it can be burned leaner, reducing CO emissions over levels obtained from burning diesel [37]. Particulate matter (PM) emission levels are also reduced from diesel levels when the engine is dual fueled with producer gas[33, 59]. In a well tuned dual fuel system VOC (volatile organic compound) emission levels are reduced from those obtained from a CI engine running on 100% diesel[37].

Nitrogen oxide (NO_x) compounds are considered the major cause of ecosystem acidification[51]. They are generated from the oxidation of N_2 which can happen in engines at combustion temperatures greater than 2500 F[37]. NO_x emissions increase with increasing flame temperatures, also with the amount of excess air and with the degree of fuel-air mixing[37]. NO_x emissions increase with higher ratios of nitrogen containing fuel and sulfur containing fuel[37]. Thermal effects dominate, however,[37 51 59]so controls that lower combustion temperatures including those developed for other gas fired technologies such as water injection and exhaust recirculation can be effective[37] using producer gas as fuel. Some balancing of emission controls may be necessary to achieve acceptable emission levels for different pollutants. For example, higher compression ratios raise combustion temperatures increasing NO_x emissions but decrease CO emissions.

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CHAPTER 3: MATERIALS AND METHODS

3.1 GASIFIER STARTUP WITH WOOD CHIPS

Wood chips for gasification were obtained from two sources. The first source consisted of willow woodchips of approximately 1 cm X 1 cm X 0.15 cm in size. The batch was air-dried to approximately 15% moisture content in a sunny room. The chips were small and potentially would excessively reduce air flow through the char-combustion zone. As a potential improvement, larger, denser hardwood chips were obtained. These woodchips were approximately 2 cm X 2 cm X 0.6 cm in size. The larger wood chips were dried to a moisture content of approximately 7%.

Omega type K thermocouples (serial: SC-GG- K-- 30- 36-PP) were soldered to extension thermocouple probes (McMaster-Carr K8R-12Z [Z773]) containing ceramic insulation and sealed into gasifier ports at various heights of the gasifier using silicone sealant as shown in Figure 2 above. Airflow sufficient to maintain a combustion zone temperature of 1000 deg C was provided by a 1 hp. shop vac. A vertically oriented radiator to cool the syngas was boxed in and piped to capture some of the gasifier heat of combustion and return it as warmed combustion air to the gasifier to maximize the combustion temperature. The boxed-in radiator with piping and shop vac are shown as components in the complete gasifier system in Figure 6 below.

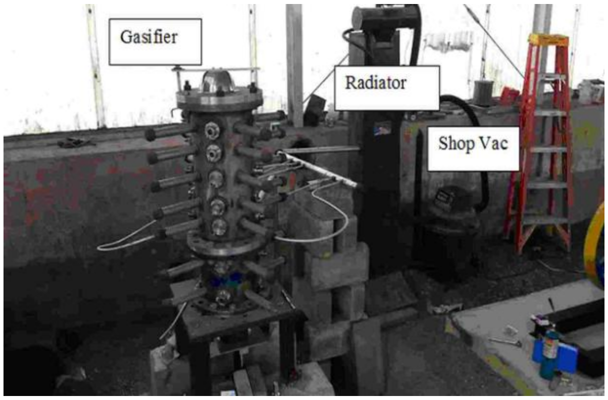

Figure 6. CERF Gasifier System

Wood chips were fed into the gasifier from the top until they were approximately 2.5 cm below the top. Woodchips were pushed down with a 1 cm diameter x 1 meter long steel rod (rodded) in intervals of approximately 10-20 minutes during the run (when temperature of the material was generally stable). The pushing down of wood chips was to ensure that the chips dropped down into the combustion zone from the drying zone, to prevent or correct any bridging and/or channeling of the chips as the chips in the combustion zone were consumed. The gasifier was run in batches for a duration of 40-60 minutes (time taken to consume woodchips until reaching just above lighting port) consuming approximately 1 kg. of woodchips each run. Shutdown of the gasifier occurred by shutting off the vacuum in order to stop drawing in air. During the gasifier run, the extension pipe on the vacuum was occasionally changed between 2 different diameter pipes to control the amount of air being drawn into the gasifier.

A high temperature- data logger (Omega HH147) was used to view and manually record temperature. Due to difficulties with the datalogger, temperature data could not be obtained for the port near the top of the gasifier. Temperatures were recorded at three different ports and reported in relation to the location of the lighting port (LP). The remaining ports are reported as above or below LP as LP+1 and LP -1 respectively. During preliminary and initial gasification experiments, temperatures were difficult to record (manually) due to measurement fluctuations of up to 200 F within 30 seconds – 1-minute intervals. Temperatures were recorded in 2- or 3-minute intervals for the majority of experiments.

Samples of particles were collected after the system was cooled (next day or longer) from ports corresponding to heights of the temperature ports. A sample was retrieved from four different heights, the height just above the lighting port (LP+1), the height of the lighting port (LP), the height of the port below the lighting port (LP-1), and finally from the ash pit. These particle sizes were analyzed using sieve analysis. These particles were sieved using a W.S. Tyler RX-29 Sieve Shaker using 4 ASTM E-11 US Standard meshes (4mm, 2mm, 300um, 150um). Material retained within each mesh was reported by weight using a Denver Instrument SI-234 analytical scale.

3.2 WOOD CHIP DUAL FUELING

The genset (engine and generator) has a Basant 4.5 kW (6 horsepower) Lister design engine driving a 5.6 kW (7.5 horsepower) Baldor 3 phase squirrel cage induction motor fitted with capacitors and configured as a generator. Figure 7 shows the genset. Figure 8 shows the gasifier – genset system. Producer gas from the gasifier passed through a cyclone filter to remove particulates, was cooled in the radiator, further filtered in a hay filter and mixed with a small amount of outside air in the engine carburetor before entering the engine. The engine governor controlled the amount of diesel introduced to the engine so that the engine speed remains constant when the engine ran on diesel alone, reducing the amount of diesel injected to a minimum of 0.382 l/hour[1] or 19.6 cubic mm per cycle, in excess of the 8 –9 cubic mm recommended[2] as a minimum to maintain stable combustion. The governor introduced more diesel to make up for insufficient or weak syngas to bring the engine up to set speed. However, if the producer gas introduced into the engine would cause the engine to exceed the set speed the governor became ineffective. Load to the generator was a 1500-watt 120 V portable electric heater.

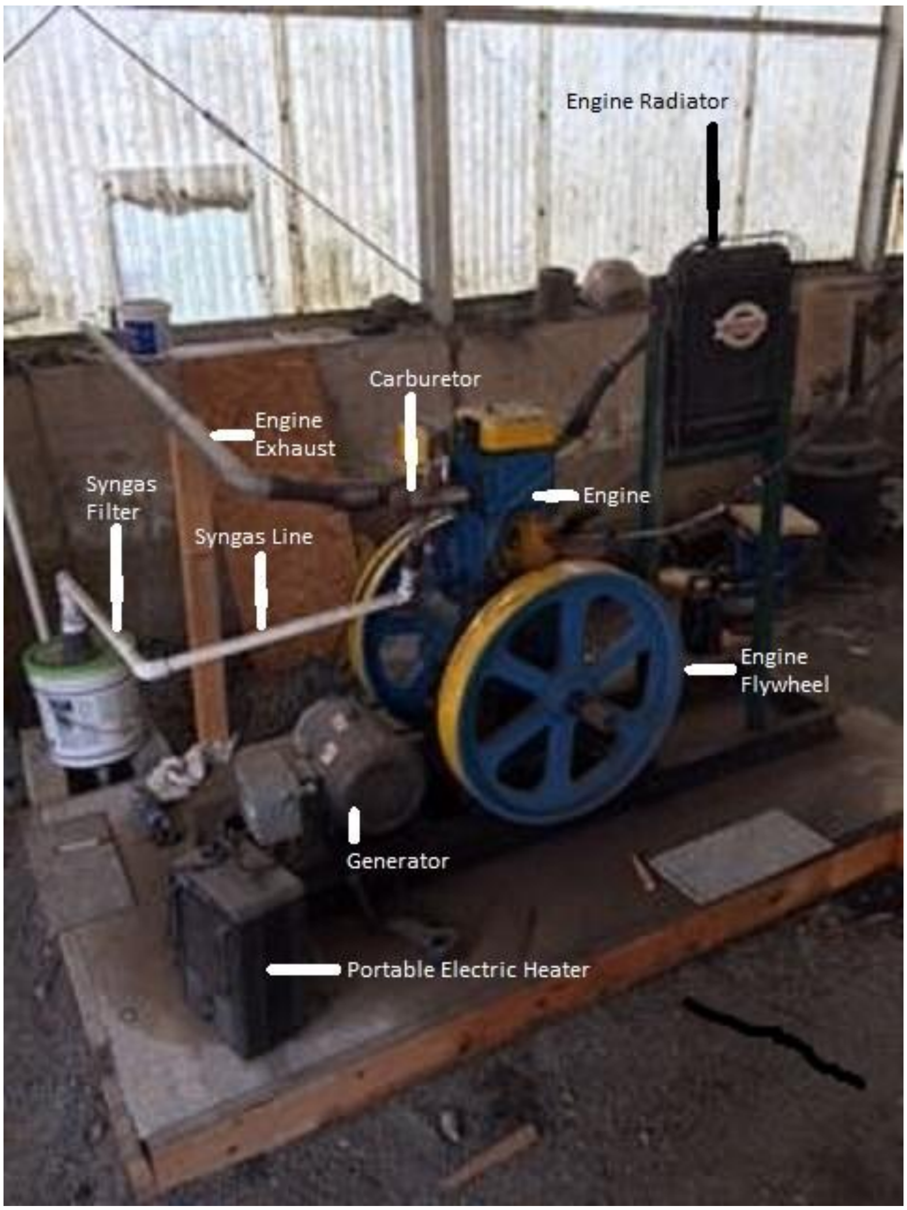

Figure 7. CERF Genset[3]

Figure 8. CERF Gasifier Genset System

Hardwood woodchips approximately 2 cm square and 0.3 cm thick at approximately 12.5% MC, oven dry basis, fueled the gasifier. During each 30-minute run approximately 1 kg. of chips were used. Successful operation of the gasifier requires an adequate char bed for each run that is formed from leftover pyrolyzed fuel from the previous run. The char bed should extend to the level of the combustion air nozzles or lighting port to minimize the formation of tar. Ideally the char bed is not overly disturbed beyond a moderate tamping to shake down the ashes from the bed to the ash pit. To prevent tar forming and entering the engine while the gasifier was at a lower temperature starting vacuum to the gasifier was provided by a 1 hp (0.75kW) Shop Vacuum Cleaner (shop vac) and the gasifier lit by momentarily touching a propane torch flame to the fuel through the lighting port. The diesel engine was then started, and generator load applied. Once the gasifier temperature at the lighting port reached 1400 F the shop vac was turned off and engine vacuum applied to the gasifier by opening carburetor and producer gas line valves to the gasifier and closing the carburetor outside air valve until it was 95% closed. Engine fuel level in the graduated cylinder diesel fuel reservoir was noted as well as volts and amps supplied by the generator to the generator load, the portable electric heater. The gasifier top was opened approximately 15 minutes into the run and the fuel tamped down with a steel rod (rodded). At the same time and at the end of the run voltage and amperage supplied to the heater were noted. Also at the end of the run diesel fuel level in the fuel reservoir was noted.

Energy content of the diesel fuel used by the engine during the run, D_{en}, was calculated by:

$$D_{en} = \text{milliliters of fuel consumed X 40.7 kWh/gallon X 3785 ml per gallon} \qquad (9)$$

where 40.7 kWh is the energy content of 1 gallon of diesel fuel[4].

Energy provided to the generator load (heater), G_{en}, was calculated by:

$$G_{en} = \text{Avg. volts measured X Avg. amps measured / 1000 watts per hour x 2 runs per hour} \quad (10)$$

Genset efficiency, G_{eff}, for each run was calculated from:

$$G_{eff} = 100 \text{ X } G_{en} / D_{en} \quad (11)$$

Baseline runs for determining genset efficiency with the engine operating on diesel fuel alone were first conducted[5]. The average genset efficiency running on diesel alone, G_{effd}, was used to calculate the quantity of diesel, d_{alone}, the genset would require to generate G_{en} for dual fuel runs if the genset were operated on diesel fuel alone by:

$$d_{alone} \text{ (ml)} = G_{en} / G_{effd} \text{ x 40.7 kWh per gallon/ 3785 ml per gallon} \quad (12)$$

Diesel fuel savings (%), D_{fs}, for a dual fuel run were calculated from:

$$D_{fs} = 100 \text{ X } (d_{alone} - \text{actual quantity of diesel used (ml)})/ d_{alone} \quad (13)$$

Cold gas efficiency for small downdraft gasifiers experimentally determined is 30% -60%[6, 7], 40% is used for the woodchip fuel energy calculation. The woodchip fuel energy was calculated from:

Wood Energy (kWh/kg) = (100/ Geff) X Diesel Fuel Savings (ml) X

0.01076 diesel energy content (kWh/ml) X (1/weight of wood used (kg)) X 1/cold gas efficiency factor 0.4 (14)

3.3 PAPER DUAL FUELING

The genset and gasifier system used was the same as used for the woodchip dual fueling above. Wastepaper consisting of newspaper, light cardboard, magazine and printer type paper, was pulped in a high consistency mixer, partially dewatered, formed into chunks approximately 60 cubic centimeters as shown in Fig. 9 below, oven dried and used at approximately 6% Moisture Content (MC), oven dry basis. The chunks fueled the gasifier for each run. Runs lasted 6 minutes or 0.1 hours to ensure an adequate char bed for the next run. The gasifier was operated as it was with woodchips. Previous to the three runs using 60 cubic centimeter chunks trial runs with chunks of approximately 20, 40, 60 and 80 cubic centimeters were conducted to determine the best size of chunks to be used in this gasifier. During each run approximately 825g of chunks were used except as noted. As noted above, successful operation of the gasifier requires an adequate char-bed for each run that is formed from the leftover fuel from the previous run. Once the gasifier temperature at the lighting port reached 1400°F the vacuum from the shop vac was turned off, its inlet valve closed and the engine vacuum was applied to the gasifier by opening carburetor and producer gas line valves to the gasifier and closing the carburetor outside air valve until it was approximately 66% closed. It should be noted that during Run 11 in Appendix B that I forgot to close the inlet valve to the shop vac after shutting the shop vac off, letting too much air get mixed with the producer gas. This run was not used in any further analysis. The carburetor outside air valve was adjusted throughout the run, typically once or twice, to maximize engine speed. Since the paper runs were typically only 6 minutes long the gasifier was not opened and rodded during the run. The engine governor setting was not changed during the run. At the start of each run engine fuel level in the graduated cylinder diesel fuel reservoir (+/- 1 ml) was noted as well as volts and amps supplied by the generator to the generator load, the portable electric heater. At three minutes into each run and at the end of the run voltage and amperage supplied to the heater and diesel fuel level were noted again. The amount of paper chunks consumed in each run was determined by noting the fuel level in the gasifier before and after each run.

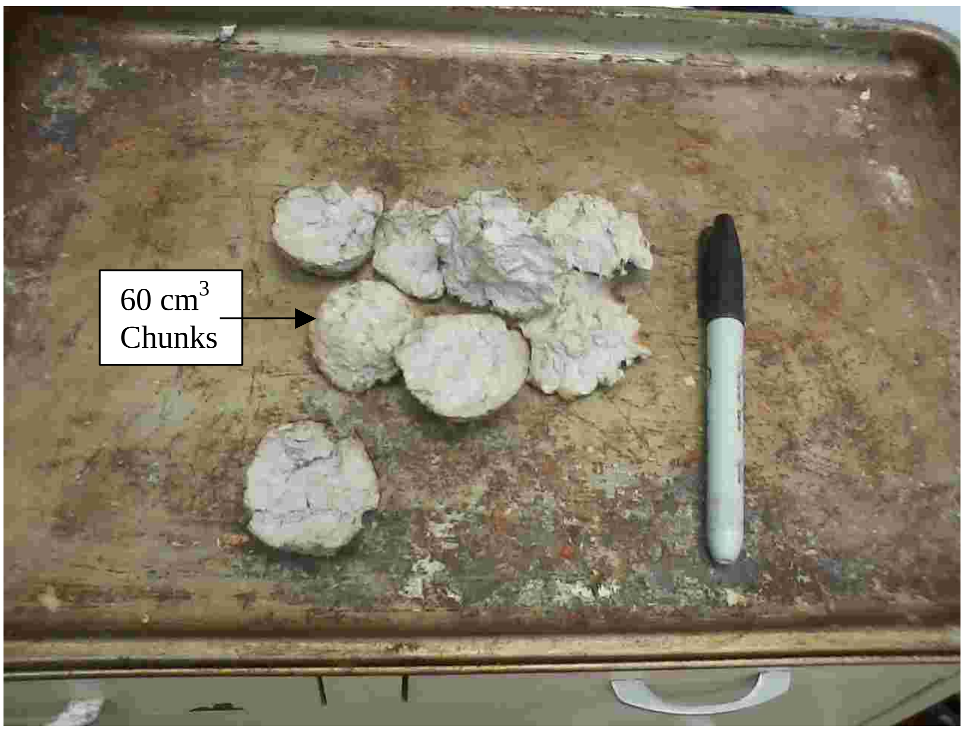

Figure 9. Paper Chunks Used in Gasifier

Diesel fuel energy content, energy provided to the generator load, genset diesel efficiency, equivalent quantity of diesel and diesel fuel savings were calculated as for woodchip dual fueling above.

As a check, calculated wastepaper fuel energy content from each run was compared to that determined by bomb calorimeter testing, 3.67 kWh/kg (5647 Btu/lb)[8] and the measured density of the fuel, 0.08 g per cubic centimeter (chunks as loaded in gasifier). Engine efficiency with wastepaper producer gas as fuel is assumed to be 17%, the same as the engine with diesel fuel. Given that the gasifier volume was 10309 cc, a full gasifier load of paper fuel weighed 825 g. Cold gas efficiency was assumed as 40%, the same as for the woodchip runs above, for the wastepaper fuel energy calculation. The wastepaper fuel energy was calculated from:

Paper Energy (kWh/kg) = (100/ Geff) X Diesel Fuel Savings (ml) X
0.01076 diesel energy content (kWh/ml) X (1/ Paper Usage (fraction of full load used)
X 0.83 kg (weight full load)) X 1/cold gas efficiency factor 0.4 [15]

The effects of the paper fuel 6% moisture content are assumed to be negligible as effects of fuel moisture content on gasification reported in the literature are not significant until much higher levels[9, 10].

3.4 MIXED PAPER AND BIOSOLID DUAL FUELING

The genset and gasifier system used was the same as used for the woodchip dual fueling above except that a shaker rod was added connecting the engine to a grate shaker fork as shown in Fig. 10 below after the engine slightly stuck, indicating some tar contamination of the engine, after a run including straight biosolids with a high percentage of fines. The shaker rod translated engine vibration to the gasifier grate to help prevent buildup and clogging of the oxidation and reduction zones with ash and fines. This is especially important with biosolids or sewage sludge as its ash content is very high, approximately 40% -50%[11-13]. Paper fuel was prepared as described above in the paper dual fueling procedure. Biosolids, the residue from sewage that has been aerobically digested with microbes followed by aerobic endogenous digestion of the microbes in a wastewater treatment plant for a total period of 25 – 30 days[14], were, after one or more of a variety of treatments subsequently described, formed into chunks of approximately 60 cubic centimeters and oven dried. Fig. 11 below shows some of the biosolid

Figure 10. Shaker Rod

fuel after oven drying. Biosolid chunks that were oven dried without further treatment crumbled into fines and would not retain their shape as can be seen in Fig. 11. Treatments that were tried to help the dried chunks retain their shape included: 1. air drying for at least a period of a week, forming into chunks, then oven drying, 2. processing through the filter press, a Belt Filter Press by Alrick Press Co., Inc., followed by a 2% by volume quantity of hemp fiber being sprinkled on the biosolid surface as it exited the filter press, then oven drying. Also tried were manually pressing biosolids off the filter press at 160 kg. into approximately 2.5 cm. cubes with a press and mold built by the author shown in Fig.12 below and 1. & 2. above followed by pressing. Fig. 13 shows some of the pressed and hemp fortified biosolids just before being oven dried.

Diesel energy, energy provided to the generator, genset efficiency and diesel fuel savings were calculated as above for the paper runs but the fuel energy for the combined paper and biosolid fuel were calculated from:

Biosolid and Paper Energy (kWh/kg) = (100/ Geff) X Diesel Fuel Savings (ml) X

0.01076 diesel energy content (kWh/ml) X

(1/ (dried paper weight + dried biosolid weight)) X cold gas efficiency factor 2.5 (16)

Figure 11. Biosolid fuel after oven drying

Figure12. Biosolid press and mold [15],[16]

Figure 13. Pressed and Hemp Fortified Biosolids Before Drying

Biosolid energy content determined by calorimeter testing[8] was 3.04 kWh/kg, within 21% of the 3.67 kWh/kg measured for paper so for a rough check the difference was ignored.

After oven drying the biosolids and paper chunks were weighed, mixed and used as fuel in the gasifier for each run. Biosolids have a very high ash content and any fuel bridging or channeling is likely to cause cool spots in the oxidation and/or reduction zones of the gasifier and allow tar to pass through to the engine without any immediate engine degradation or noticeable change in engine performance. Only after the engine cools down will tar contamination be evident with the engine being stuck or the crankshaft not being able to rotate. It is recommended that any run dual fueling with producer gas from biosolids be immediately followed before the engine cools by a ten to twenty minute period of running on diesel fuel alone to burn any tar deposits in the combustion chamber away.

3.5 BIOSOLID DUAL FUELING

Biosolid fuel was prepared as described above in the Paper and Biosolid Dual Fueling section and used to fuel the gasifier for the biosolid dual fueling runs. Dried manually pressed biosolids not fortified with fiber are shown in Fig. 15 below. To prevent tars in the producer gas care was taken to not introduce more fines than necessary into the fuel and to ensure residual ash was removed from the char bed by rodding the char bed before each run. Even with thorough rodding slight engine sticking indicating some tar contamination of the engine occurred after the second biosolid run so after the third biosolid run the shaker rod was removed and a more positive shaker shown in Fig. 14 below installed. It used a form of a crank powered by an electric drill motor connected by a stiff spring attached to the end of the shaker. Even with a more vigorous grate shaker tar reaching the engine is possible and following any dual fueling run with biosolids immediately before the engine cools with a 10 – 20 minute period of running on diesel alone as described in section 3.4 above is recommended.

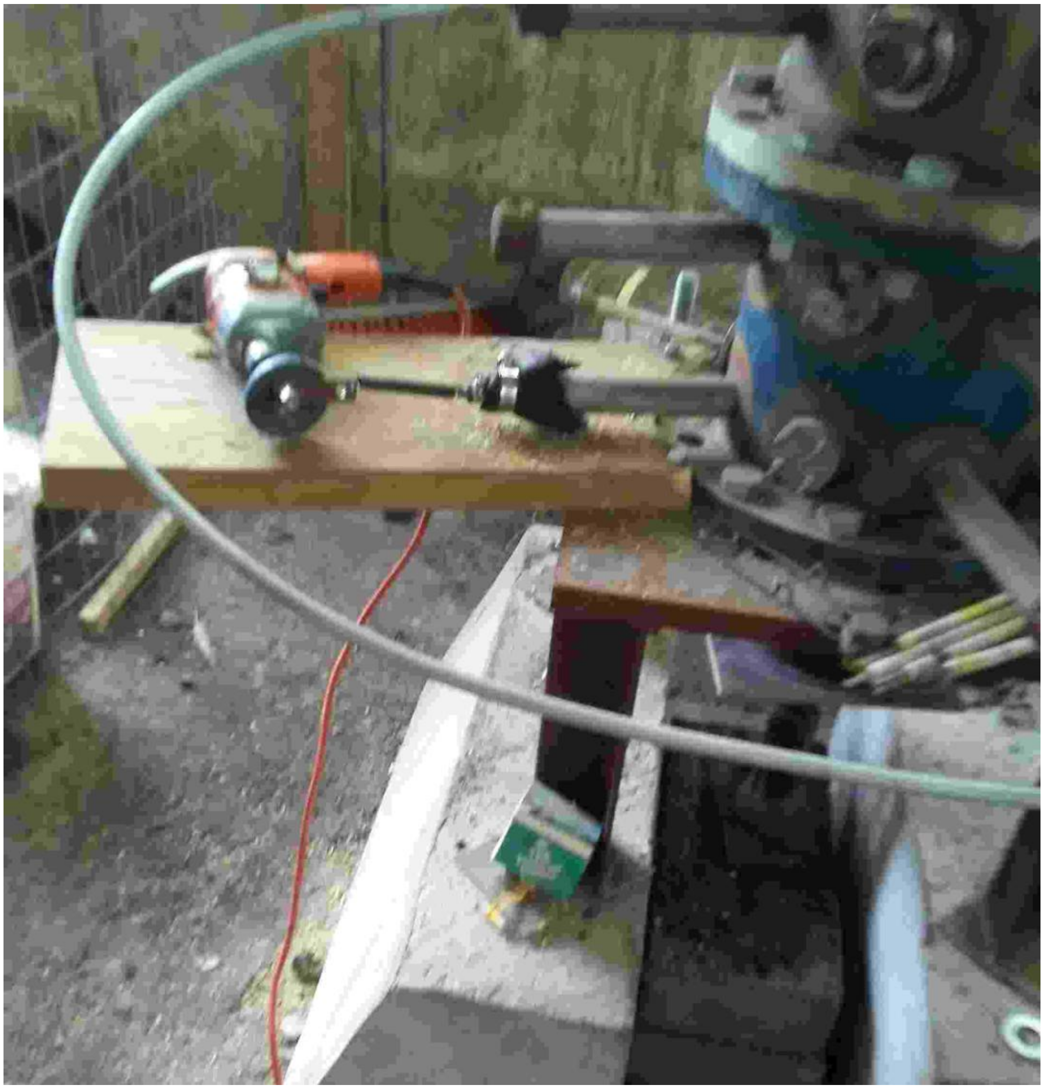

Figure 14. Modified Gasifier Grate Shaker

Figure 15. Dried Pressed Biosolids with no Hemp Fiber

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CHAPTER 4: RESULTS AND DISCUSSION

4.1 WOODCHIP STARTUP

Nomenclature for this section are shown in Table 2 below.

Table 2. Nomenclature for Wood Chip Startup

Location	Abbreviation (based on location relative to lighting port [LP])
Ash Pit	LP-1
Lighting Port	LP
Port just above Lighting Port	LP + 1
Port near top of gasifier*	LP + 2

*Temperatures were not reported for the thermocouple at the port near the top of the gasifier due to difficulties with the datalogger memory and display.

Run 1 used the small willow woodchips. The temperature profile for gasification run 1 shown in Figure 16 below indicates that pyrolysis temperatures are achieved immediately in the gasifier; however, gasification and combustion temperature zones were marginal. This may have been due to the small wood chips reducing air flow through the char-combustion zone. Fuel chunk size has been found to be one of the key factors in successful gasification. Too large a chunk size promotes good air flow through the oxidation and reduction zones but not enough surface area for good producer gas production. Too small a chunk size as noted above provides inadequate air flow in areas of the oxidation and reduction zones and allows tars to pass through.

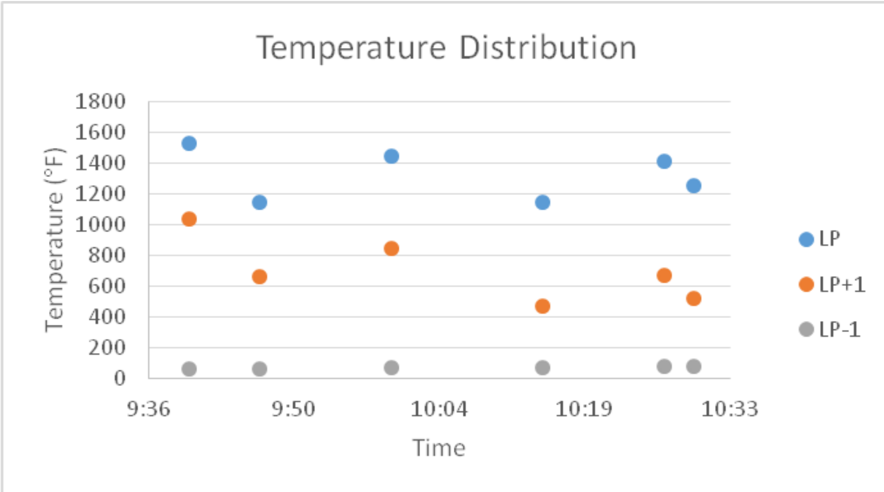

Figure 16. Temperature Distribution Along Gasifier during Gasification Run 1.

For Run 2, approximately 1/4 of the wood chips in the gasifier were willow wood chips from the first experiment and 3/4 of the wood chips were newly dried wood chips from the second source (the larger, more homogeneous chips). The temperatures clearly indicate clogging of the gasifier with reduced or no downdraft. The region above the lighting port quickly reached the highest temperatures indicating blocked air flow (little downdraft) as shown in Fig. 17 below.

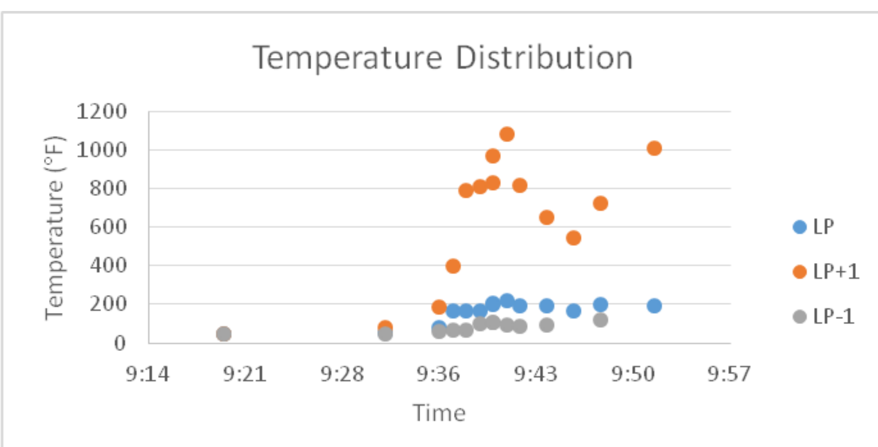

Figure 17. Temperature Distribution Along Gasifier during Run 2

For Run 3, the larger wood chips were added into the gasifier but some of the residual smaller pieces from the willow wood chips may have bridged above or clogged up the gasifier below the lighting port zone. Good gasification temperatures at the lighting port level were reached for a brief period; however, the low temperature recordings at the lighting port level and high temperatures above and below the lighting port level starting at time 9:28 as shown in Figure 18 below demonstrate insufficient downdraft air flow due to bridging and clogging in the gasifier with hot material stuck above the lighting port and then dropping through a void at the lighting port level to a level below it as the material at the lighting port level is consumed.

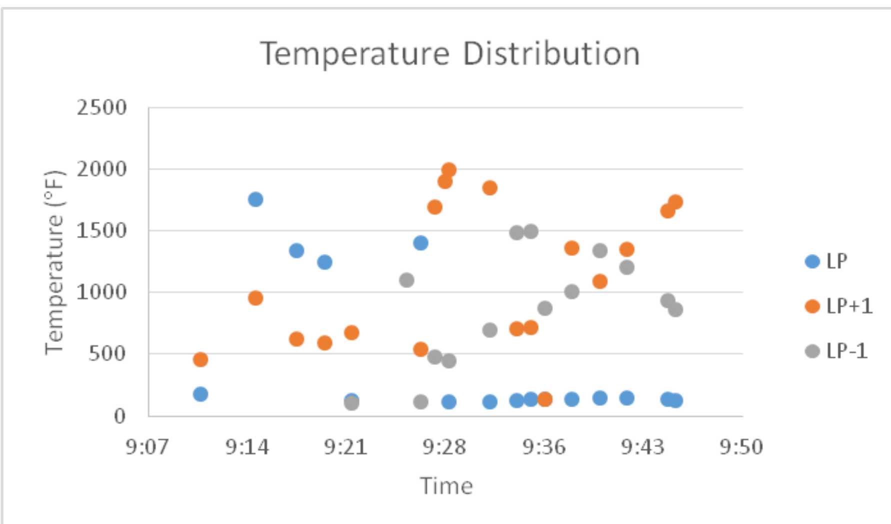

Figure 18. Run 3 Temperature Distribution Along Gasifier

The temperature distribution profile for Run 4 as shown in Figure 19 below shows temperatures relatively stable once achieving gasification and combustion temperature ranges with no evidence of clogging. Temperatures ranged up and down as the shop vac adapter pipes were changed. Some smoke was seen at approximately time 9:33 that may have been a result of excess air leaking into the combustion zone.

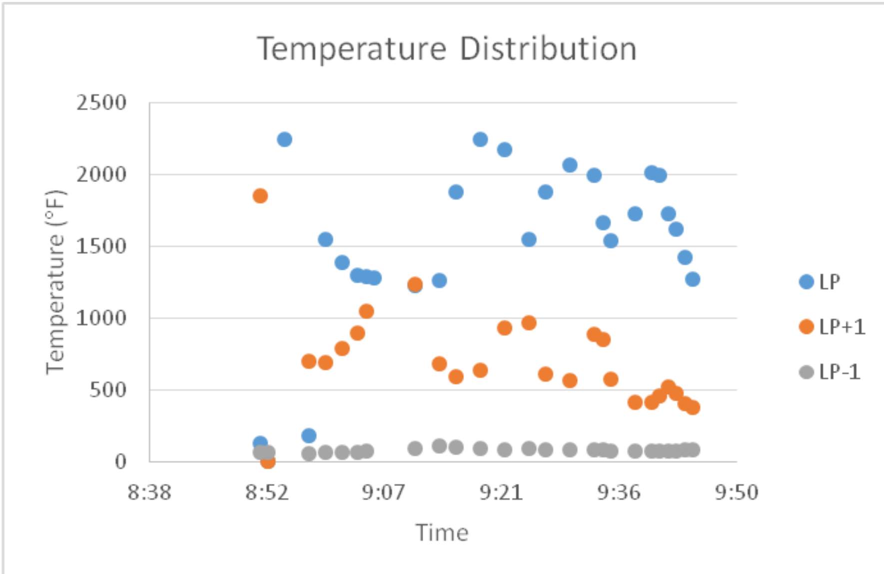

Figure 19. Run 4 Temperature Distribution Along Gasifier

Run 5 temperatures are shown in Figure 20 below. Gasification temperatures at the lighting port level were reached almost immediately and maintained over the majority of the course of the experiment. Drops in temperature can be attributed to cold woodchips being released into the charring and oxidation zones when the wood chips were rodded down.

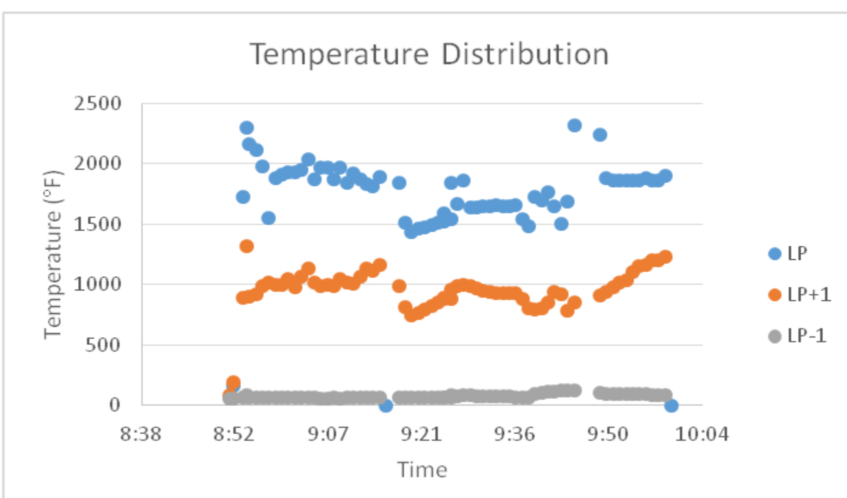

Figure 20. Run 5 Temperature Distribution Along Gasifier

The tables below provide the sieve analysis for each zone of the gasifier. Percentages shown in Tables 3 – 6 represent the percent material retained at a given sieve size of the material passing through from the sieve of next larger size above it. For the top 4mm sieve the percentage is of the total sample.The data does not include samples of Run 4 to prevent skewing of data as for that run some of the wood chips were pushed down into the gasifier for the following run just before collection. Run 3 where temperatures indicated clogging in the gasifier, exhibited a larger percentage of smaller material at the lighting port level as shown by the presence of material passing through the 300um sieve retained by the 150um sieve in Table 4, to be expected with the clogging . Larger chips would normally settle at or below the lighting port. It seems counterintuitive that the largest pieces of fuel were found in the lowest parts of the gasifier below the lighting port and in the ash pit. One would expect the chunks to be consumed as they pass through the charring, oxidation and reduction zones. What happens, however, is that fuel particles fall into the charring, oxidation and reduction zones as fuel is consumed beneath it but is buoyed up by friction with adjacent fuel particles that have not yet fallen. Bigger particles fall sooner as they are heavier and friction with adjacent particles is proportionately less. When the bigger particles fall they fall further than smaller particles because of their greater momentum and impact with the layers below. Bigger fuel particles are less likely to be consumed in traveling from the hopper to the ash pit because their residence time in any given zone is less and because all things being equal a bigger particle takes longer to oxidize and be reduced than a smaller fuel particle.

Quantities shown are in grams. Quantities of material collected in the gasifier level above the lighting port are shown in Table 3 below.

Table 3. Material just above Lighting Port (% Cumulative Wt Retained in Sieve)

LP+1	Run 1	Run 2	Run 3	Run 5
4mm	0.155	0	88.36018	N/A
2mm	0.0253	0	49.78038	N/A
300um	0.0067	0	37.4817	N/A
150um	0	0	0	N/A

The samples from the lighting port contain larger material; however, the evidence of clogging in the lighting port region on Run 3 can be seen here as well where ~92% of the cumulative weight is retained in the 300um mesh compared to 0-5% in the other gasification experiments. Material quantities collected from the lighting port level are shown in Table 4 below.

Table 4. Material from Lighting Port (% Cumulative Wt Retained in Sieve)

LP	Run 1	Run 2	Run 3	Run 5
4mm	77.9281	95.89744	32.67045	36.16208
2mm	45.99923	53.23077	70.17045	12.23242
300um	1.546193	0	91.71402	5.198777
150um	0	0	100	0

Below the lighting port, an increase in particle sizes on Run 2 indicates the clogging may have begun during this gasification run. The temperature profiles demonstrate lower temperatures in the lighting port which may have resulted in inadequate pyrolysis leaving larger wood chip pellets in the zone. No sample material resided in the zone just below the lighting port after the Run 3 gasification experiment. Possibly there was bridging at the lighting port or above and the material below burned out. Material quantities collected from below the lighting port are shown in Table 5 below.

Table 5. Material just below Lighting Port (% Cumulative Wt Retained in Sieve)

LP-1	Run 1	Run 2	Run 3	Run 5
4mm	66.36528	90.74476	N/A	62.37482
2mm	41.59132	73.31887	N/A	38.8269
300um	1.808318	26.3919	N/A	10.58655
150um	0	6.507592	N/A	0

Sample material collected from the Ash pit typically contained the largest amount of material and greatest portion of larger material as it is at the bottom. Limited oxygen and short residence time at combustion or gasification temperatures allow some of the biomass to pass through the gasifier to the ash pit as biochar. The ash pit generally contains up to 20% or so of biochar, a reactive charcoal that is highly desirable as a soil supplement. The downdraft pulling the producer gas through the hot reduction zone breaks down or cracks the larger complex hydrocarbons (tars) that can be so damaging to downstream filters and equipment. Material quantities collected from the ash pit are shown in Table 6 below. Fig. 23 below shows a sample of the ash and biochar collected from the ash pit and cyclone.

Table 6. Ash (from Ash Pit) (% Cumulative Wt Retained in Sieve)

Ash	Run 1	Run 2	Run 3	Run 5
4mm	55.37256	60.64119	67.40227	84.8607
2mm	26.77765	29.45624	39.72608	50.07331
300um	3.976958	0.531171	10.08827	10.44721
150um	0	0.061797	0	0

Plotting the data from Tables 5 and 6 as graphs of percentages of the material sample from the port resulted in the graphs in Figures 21 and 22 below, respectively. The distributions of percentages of material collected at each sieve mesh size appear to be exponential distributions.

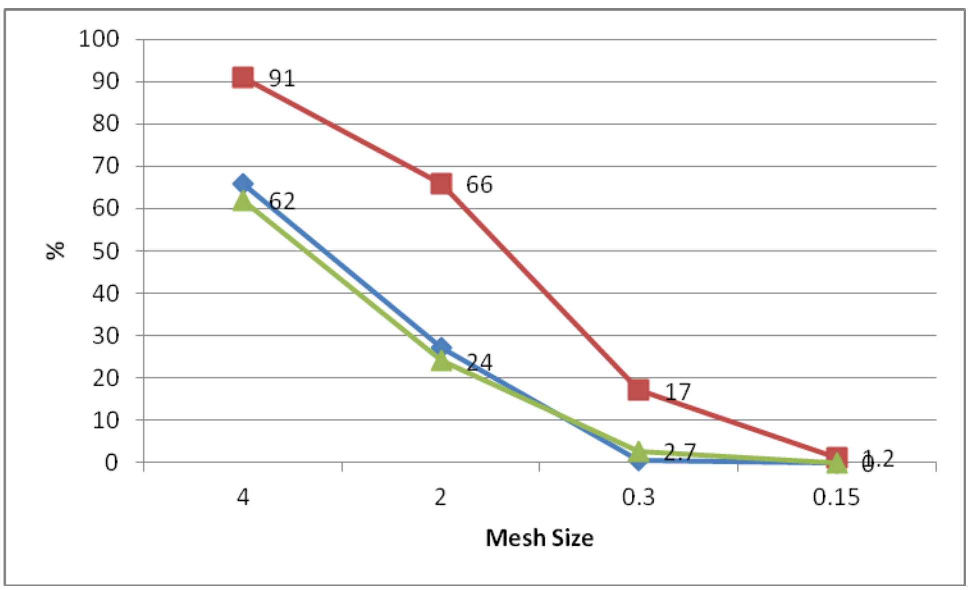

Figure 21. Graph of Percentage of Material Sample vs. Mesh Size for

LP-1 (Table 5)

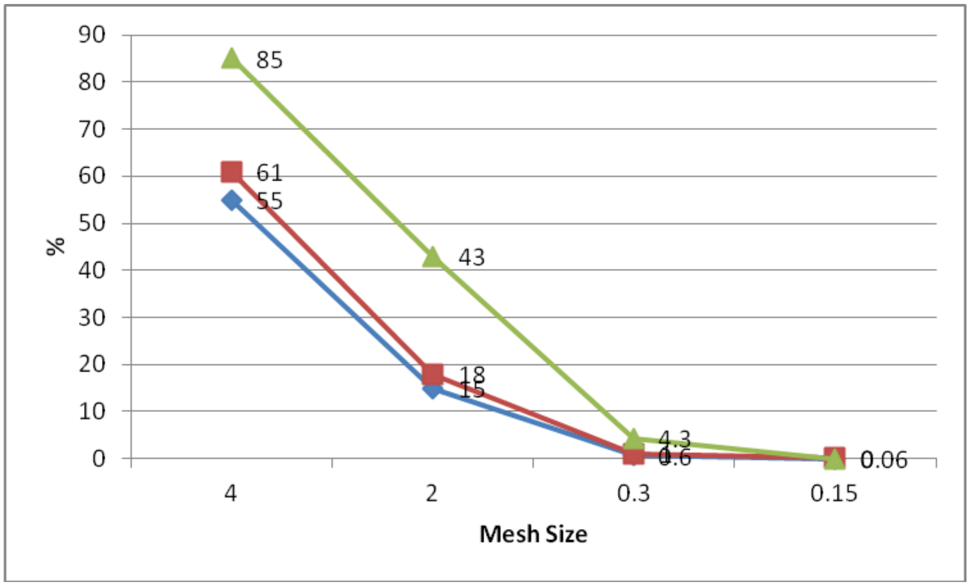

Figure 22. Graph of Percentage of Material Sample vs. Mesh Size for

Ash Pit (Table 6)

Figure 23. Ash and biochar collected from the ash pit and cyclone

4.2 WOODCHIP DUAL FUELING

Results from 5 diesel alone runs and 3 dual fuel (diesel and gasified woodchips) runs are shown in Table 7 below. Runs 1 – 5 were with the engine fueled by diesel alone. Runs 6 – 8 were with the engine dual fueled.

Table 7. Genset Run Results

Run	diesel used (ml)	Average Volts	Average Amps	woodchips used (kg)	G_{en} (kWh)	D_{en} (kWh)	G_{eff} (%)	d_{alone} (ml)	D_{fs} (%)	Wood Energy (calculated) kWh/kg
1	340	115	10	0.0	0.6	3.6	16.1	NA	NA	NA
2	320	115	10.6	0.0	0.6	3.4	18.1	NA	NA	NA
3	305	115	9.8	0.0	0.6	3.2	17.6	NA	NA	NA
4	365	125	10.6	0.0	0.7	3.8	17.3	NA	NA	NA
5	310	114	9.8	0.0	0.6	3.3	17.1	NA	NA	NA
6	131	151	12.5	2.3	0.9	1.4	68.5	515.9	74.6	1.8
7	120	152	10.3	2.3	0.8	1.3	62.1	427.9	72.0	1.7
8	125	149	13	2.3	1.0	1.3	73.7	529.5	76.4	1.6

As can be seen above, values for G_{eff} for Runs 1 – 5 appear low for the thermal efficiency of a diesel engine which generally is reported to be about 30% for small diesel engines. Raman and Ram[1] state that in their testing diesel thermal efficiency dropped from 28% to about 17%, the same as the average genset running on diesel alone efficiency G_{eff} in Table 7 above (Runs 1-5), when the engine was operated at partial load as was the case in these runs rather than at full throttle or 100% loading. It is apparent from the d_{alone} and D_{fs} columns in Table 7 that dual fueling with woodchips can save a considerable amount of diesel fuel in operating the genset. The 69% - 74% diesel savings reported above are within the 60% - 90% range of savings reported by Malik et al. and Martinez et al.[23]Unfortunately reporting the overall thermal efficiency of the dual fueled runs was impractical because of the necessity of having a relatively undisturbed char bed from the previous run before starting a given run. Measuring the amount of woodchips consumed in a run would have required emptying, weighing and replacing the char bed before each run which would have disturbed the char bed structure and led to difficulty in producing adequate, tar free producer gas during the next run. Instead an approximate value of 2.3 kg was used. This was calculated using the average density of the woodchips times the gasifier volume. Maple wood fuel energy as measured in calorimeter testing[4]was 4.86 kWh/kg, not very close to the 6.1 – 6.9 kWh/kg values in Table 7. Most of the discrepancy is probably due to assumptions of the consumed woodchip weight and cold gas efficiency.

The governor on the Basant diesel engine is a spring-loaded device working with spinning centrifugal weights that reduces or increases the amount of diesel injected into the combustion chamber if the engine speed increases or decreases from the set point. In dual fueling a minimal amount of diesel is needed to ignite the producer gas drawn into the combustion chamber. As producer gas is drawn into the engine running on diesel the engine speed will increase and the governor will decrease the amount of diesel injected proportionally but not necessarily to the point where less producer gas is ignited so the governor is not completely effective in preventing over-revving of the engine when dual fueled. A higher generator rpm produces a higher voltage. This is seen in the higher average voltages reported in the dual fueled runs in Table 1. For operating a portable resistance heater the higher voltages were not a great problem but for other applications the higher voltages may not be allowable. For these cases the governor may need to be adjusted occasionally or changed to a different type such as an electronic or an electrochemical governor that would control the position of the throttle plate.

4.3 PAPER DUAL FUELING

Results from dual fuel (diesel and gasified wastepaper) runs with 20, 40 and 80 cubic centimeter paper chunks and 3 dual fuel runs with 60 cubic centimeter paper chunks are shown in Table 8 below. Runs 1 – 3 were done with the engine fueled by 20, 40 and 80 cubic centimeter paper chunks and diesel. Runs 4-6 were conducted with the engine dual-fueled with 60 cubic centimeter paper chunks and diesel. It can be seen that the genset efficiency, G_{eff}, was higher on the average with the 60 cubic centimeter chunks. Calculated paper energy was not very consistent nor very close generally to the calorimeter measured value of 3.67 kWh/kg. However, the higher paper energy numbers were not far from the bomb calorimeter determined number, only 11.5% less. Without being able to measure the amount of material in the char bed for each run the weight of paper chunks for each run was an approximation at best and probably explains the bulk of the discrepancy. Other potential sources of error include the average voltage and amp readings and the assumptions of a constant 17% engine efficiency with diesel and producer gas. Also, the cold gas efficiency was only estimated.

Wood is the ideal biomass for gasification as its energy content and density are relatively high and its ash content very low. Almost every other type of biomass will have a lower energy content and/or density and a much higher ash content causing more potential oxidation and reduction zone cool spots associated with tars passing out of the gasifier and fuel flow problems as well as a higher potential for slagging problems.

Table 8. Genset Wastepaper Run Results

Run	Chunk Size (cm^3)	Diesel Usage (ml)	Average Volts	Average Amps	Paper Usage (fraction of full gasifier load)	G_{en} (kWh)	D_{en} (kWh)	G_{eff} (%)	d_{alone} (ml)	D_{fs} (%)	Paper Energy (calculated) (kWh/kg)
1	20	60	124	11.2	0.6	0.14	0.63	22.02	75.92	20.97	4.10
2	40	50	125	11.3	0.5	0.14	0.53	26.87	77.22	35.25	5.01
3	80	55	125	11.3	0.8	0.14	0.58	24.43	77.22	28.77	3.13
4	60	40	137	11.3	0.7	0.15	0.42	36.82	84.63	52.74	3.92
5	60	55	130	11.8	0.8	0.15	0.58	26.53	83.86	34.42	3.40
6	60	40	134	12.2	0.7	0.16	0.42	38.88	89.37	55.24	4.14

As discussed in prior work[5] G_{eff} for the genset powered by diesel alone was approximately 17%. It is evident that if calculated from diesel usage alone genset efficiency improves with dual fueling using gasified wastepaper but gains were not as dramatic as when the genset was dual fueled with gasified woodchips, where average diesel fuel savings were 74%[5]. The dried paper pulp chunk fuel was very low density, approximately 1/3 that of the woodchips used in the prior study[5]. This caused the fuel to be exhausted very quickly, necessitating 6-minute runs instead of 30-minute runs as when the gasifier was fueled with woodchips. In addition, the paper fuel's low density made bridging and channeling more of a problem because its low weight and friction with the gasifier interior wall made it more prone to hanging up[67]. Bridging is a clog in the fuel preventing flow of the fuel downward through the gasifier. Channeling is the formation of large passages through the fuel allowing most of the airflow to pass through them and only a little to pass through the remainder. Bridging and channeling result in non-uniform gasifying conditions in the oxidation and reduction zones of the gasifier making the quality of the producer gas and tar control erratic[6]. Fuel densification may be explored as a way to avoid this problem. However, it is apparent from the d_{alone} and D_{fs} columns in Table 8 that dual-fueling with low density wastepaper chunks can save a considerable amount of diesel fuel in operating the genset even under less than optimal conditions.

As discussed in the Woodchip Dual Fueling section above the governor on the Basant diesel engine is a spring-loaded device working with spinning centrifugal weights that allows higher engine rpm and generator voltage at a given setting for dual fueling than when running on diesel alone. For operating a portable resistance heater the higher voltages and amperages allowed by this governor as described above were not much of a problem but for other applications the higher voltages and amperages may not be allowable. For these cases the governor may need to be adjusted occasionally when dual fueling or changed to a different type that controls the amount of producer gas allowed into the engine.

4.4 PAPER AND BIOSOLID DUAL FUELING

Table 9 below shows the results of 8 runs with mixed paper and biosolid gasifier fuel. The first three runs were conducted with the gasifier air inlet valve 12.5 % open, the last 5 runs were with the gasifier air inlet valve 25% open. The first four runs were 6 minutes long, the second four runs were 4 minutes long. Biosolids from runs 1,2,5,6,7 were unprocessed from the drying shed, biosolids from runs 3,4 and 8 were processed through the filter press. The dried biosolids tended to disintegrate into small chunks and fines, especially those from the drying shed. The engine on Run 6 was slightly stuck upon startup indicating the gasifier on Run 5 allowed some tar through to the engine. This is not surprising considering that the bulk of material gasified during Run 5 was biosolids from the drying shed. The fines and ash from the biosolids probably restricted airflow through the combustion and reduction zones creating cooler pockets allowing tars to pass uncracked through the gasifier. In light of subsequent testing with biosolids alone the paper chunks helped flow of air and ash through the oxidation and reduction zones of the gasifier. As noted above in 4.3 inaccuracies in measuring the weight of material in each run probably caused most of the inconsistencies and lack of agreement with measured calorimeter energy content.

Table 9. Genset Paper and Biosolid Run Results

Run	Diesel Usage (ml)	Average Volts	Average Amps	paper used (kg)	biosolids used (kg)	G_{en} (kWh)	D_{en} (kWh)	G_{eff} (%)	d_{alone} (ml)	D_{fs} (%)	Paper and Biosolid Energy (calculated) (kWh/kg)
1	55.0	131.0	10.1	0.3	1.1	0.13	0.59	22.36	72.33	23.96	2.16
2	50.0	135.0	11.5	0.3	1.1	0.16	0.54	28.86	84.87	41.09	3.37
3	45.0	140.0	11.4	0.2	0.3	0.16	0.48	32.96	87.25	48.42	9.23
4	40.0	131.0	11.4	0.2	0.4	0.15	0.43	34.70	81.64	51.01	7.29
5	20.0	154.0	12.9	0.2	1.2	0.13	0.22	61.48	72.33	72.35	2.34
6	15.0	149.0	11.3	0.1	0.8	0.11	0.16	69.17	61.03	75.42	2.75
7	30.0	149.5	11.6	0.1	0.9	0.12	0.32	35.78	63.14	52.49	3.44
8	15.0	144.3	11.3	0.2	0.4	0.11	0.16	66.68	58.83	74.50	4.41

4.5 BIOSOLID DUAL FUELING

It was expected that biosolids would be very difficult to gasify alone based on earlier calorimeter testing[4] as they were comparatively difficult to burn and had a high ash content[8]. I expected to have to blend wastepaper with the biosolids in order to be able to gasify the biosolids. Instead I found the paper harder to gasify alone, the biosolids alone provided a larger quantity of more stable, combustible producer gas that produced much electricity when fueling the genset. Despite frequent rodding of the gasifier and installation of the shaker rod tar remained a problem when fueling the gasifier with biosolids alone. It is suspected that the large amounts of ash produced and not completely shaken down into the ash pit created areas in the oxidizing and reduction zones that the air could not adequately reach leading to cool spots and tars not completely cracked contaminating the producer gas. Replacing the shaker rod with a more vigorous positive shaker shook most of the ash into the ash pit and rectified the tar situation at least some of the time. Table 10 below shows the biosolid run results. Run 1 was with biosolids from the filter press that tended to disintegrate into small chunks and fines after drying. Run 2 biosolids were from the drying shed and also tended to disintegrate into small chunks and fines after drying. While no tar formation was noted from these runs the gasifier needed to be heavily rodded after Run 2 to enable it to be lit for the next run indicating that it was clogged with fines and ash. Runs 1 and 2 were not very impressive as far as fuel savings, either, indicating that the clogging reduced the quantity and/or quality of the producer gas as well. Runs 3 – 6 were with manually pressed biosolids previously processed through the filter belt formed into chunks of roughly 15 cubic centimeters. Runs 3 and 4 were fortified with fiber, Runs 5 and 6 were not fortified. The chunks from runs 3-6 all remained relatively coherent after drying so fortification with fiber was not necessary. Runs 3 –6 were very impressive both from how steady and stable the engine ran while being dual fueled and also from how much power was generated. The electric heater overheated and shut down at the end of Run 5 and 4 minutes into Run 6 necessitating Run 6 being shortened to only 4 minutes. The engine was slightly stuck and the gasifier needed severe rodding upon startup of Run 4 and after Run 6 indicating tar was generated and allowed to pass to the engine during Runs 3 and 6. The shaker rod was exchanged for the more vigorous shaker for Runs 5 and 6. The ash pit was checked before Run 4 and before and after Run 6. The ash pit was empty when checked before Run 4 and after Run 6 indicating that during Runs 3 and 6 agitation of the grate was insufficient to shake the ash and fines through the grate. No signs of tar reaching the engine were seen for Run 5 and a large amount of ash, 584 grams, was present in the ash pit after the run indicating that for that run grate agitation was sufficient to ensure that the ash generated during Run 5 migrated through the grate to the ash pit which ensured adequate air circulation through the gasifier oxidation and reduction zones to prevent any tars migrating into the engine.

Given during Run 6 that grate agitation was not sufficient to shake ashes in the gasifier oxidation and reaction zones through the grate into the ash pit and tar consequently reached the engine a more powerful and positive grate shaker is needed for any future runs with biosolids with this gasifier. The ashes must be removed from the oxidation and reduction zones to ensure adequate air circulation in and to keep fuel flowing through those zones. The CERF experimental gasifier grate only can move laterally approximately 0.25 cm so potential agitation is limited, especially if during the run some ash or char particles fall behind the grate supports and temporarily jam or reduce motion of the grate. Any gasifier CERF would consider using in the future should have a grate with at least 1 cm range of lateral motion and an agitator capable of shaking it at least twice a second.

Table 10. Biosolid Run Results

Run	diesel used (ml)	Average Volts	Average Amps	biosolids used (kg)	G_{en} (kWh)	D_{en} (kWh)	G_{eff} (%)	d_{alone} (ml)	D_{fs} (%)	Biosolid Energy (calculated) kWh/kg
1.0	50.0	127.0	10.6	0.3	0.1	0.5	20.5	58.9	15.1	1.0
2.0	100.0	122.0	10.4	1.0	0.2	1.1	20.1	115.4	13.3	0.4
3.0	25.0	147.5	14.2	0.8	0.2	0.3	79.7	114.5	78.2	3.2
4.0	25.0	158.0	15.0	0.7	0.2	0.3	90.2	129.6	80.7	4.3
5.0	10.0	151.0	14.5	0.8	0.2	0.1	208.3	119.7	91.6	3.5
6.0	5.0	165.0	15.6	0.7	0.2	0.1	328.1	94.3	94.7	3.6

4.6 COST SAVINGS OF CERF DUAL FUELING A GENSET USING ALL THE BIOSOLIDS PRODUCED BY THE MINOA WASTEWATER TREATMENT PLANT (MWTP)

4.6.1 COST TO MWTP OF TRUCKING AND LANDFILLING BIOSOLIDS

Biosolids (wet tons) produced by MWTP – 230 to 250/ yr.[9]

Tons per truckload - 11[9]

Truckloads per year = (230 tons per year/11 tons/ truckload) to (250 tons per year/11 tons/ truckload) = 21 to 23 (17)

Labor cost per hour for truck driver - $50[9]

Hours per truckload - 3[9]

Trucking labor cost per year = (21 truckloads per year x 3 hours/truckload x $50 per hour) to (23 truckloads per year x 3 hours/ truckload x $50 per hour) = $3150 - $3450 (18)

Landfill cost for wet sludge - $60/ton [9] MWTP biosolid landfill cost per year = ($60/ton x 230 tons per year) to ($60/ton x 250 tons per year) = $13800 to $15000 (19)

Total cost to MWTP to truck and landfill biosolids per year = ($3150 + $13800) to ($3450 + $15000) = $16950 to $18450 (20)

A case might be made that since the truck driver is a salaried employee the labor cost should be discounted since it is not an additional cost incurred by MWTP. In that case the total cost is from (19), $13800 to $15000.

4.6.2 COST TO MWTP TO DUAL FUEL GENSET WITH GENERATED BIOSOLIDS

Biosolids are to be formed into briquettes, air dried and then further dried by reclaimed heat from the gasifier and engine.

Biosolids (dry tons) produced by Minoa Wastewater Treatment Plant– 47/yr.[10]= 47 x 907.2 kg/ton = 42,638 kg/ yr. (21)

Genset will be running 40 hours/ wk. X 50 weeks/ yr. = 2000 hrs./ yr. (22)

Genset will use 42,638 kg/yr. / 2000 hrs./yr = approx. 22 kg/hr.

Current gasifier uses .8 kg/ .1 hr. = 8 kg/hr.

So to use 22 kg./hr. fuel gasifier needs to be approx. 3 times as big.

Engine needs to be 3 times as big, also.

Least expensive way:

Lister 16 hp engine coupled with 12.5 kva generator cost delivered to NYC (Appendix A)-$2500

Gasifier from China 25 – 30 kg/hr throughput - $3000 (Appendix A)

Briquette machine from China - $4800 (Appendix A)

Total equipment cost = $10,300 + shipping for gasifier and briquette machine and genset from NYC

More expensive but perhaps less set up, maintenance and operator time:

PP30 Power Pallet from All Power Labs (Appendix A)- $50,000

PP30 will not handle manure without voiding warranty but says nothing about sludge briquettes.

Briquette machine from China - $4800 (Appendix A)

Shipping additional for briquette machine

Total equipment cost for more expensive option = $54800 + shipping

For both options labor estimated at 1 hour/ day plus periodic maintenance of 1 day/month @$50/hr.

Operator labor for 5 days/week x 50 wks./yr = 250 days/yr. X 1 hr. day = 250 hrs./year (23)

Maintenance labor = 8 hrs./day/month x 12 months/yr. = 96 hrs./yr. (24)

Total labor cost = (250 hrs./yr. + 96 hrs./yr.) x $50/hr. = $17300/ year (25)

Genset currently generates 0.2 kwh/0.1 hr. = 2 kwh/hr. (26)

If genset and gasifier are tripled in capacity output should be 6 kw or 6 kwh/hr. (27)

Genset should run 40 hrs./wk x 50 wks./yr = 2000 hrs./yr. (28)

Cost of electricity to MWTP is $0.0375[11] per kWh.

Therefore, genset can offset electricity costs 2000hrs./yr x $0.0375/kwh x 6kw = $450/yr. (29)

If equipment is assumed to last 15 yrs., discounting interest, least expensive equipment option annual cost is if shipping is assumed to total $5000 = $15,300/15 = $1020 (30)

More expensive equipment annual cost becomes $59800/15 = $3987 (31)

If labor costs are discounted least expensive equipment option annual savings become:

($13800 - $1020 + $450) to ($15000 - $1020 + $450) = $13230 to $14430 (32)

If labor costs are discounted more expensive equipment option annual savings become:

($13800 - $3987 + $450) to ($15000 - $3987 + $450) =$10263 to $11463 (33)

If labor costs are not discounted least expensive equipment option annual savings become:

($16950 - $17300 - $1020 +$450) to ($18450 -$17300 - $1020 +$450)= -$920 to $580 (34)

If labor costs are not discounted the more expensive equipment option annual savings become:

($16950-$17300-$3987+$450) to ($18450-$17300-$3987+$450)= -$3537 to -$2387 (35)

So if labor costs are discounted both equipment options save on the order of $10000 annually. If labor costs are not discounted the least expensive equipment option loses on the order of $1000 annually if sludge production is at the low end and saves on the order of $1000 annually if sludge production is at the high end. The more expensive equipment option loses on the order of $2000 - $3000 annually if labor costs are not discounted. However, the more expensive equipment option may save an additional amount in saved operation and maintenance labor.

Wastepaper was more difficult to gasify and did not generate much additional power. It was more laborious to convert to fuel than biosolids. It does not incur any costs to Minoa to dispose of[16]. So there are very little savings to be incurred to Minoa presently in dual fueling a genset with gasified wastepaper. Wood waste from Minoa is sporadic and never present in a large quantity. It is currently included with yard waste and trucked to a compost facility for a flat yearly fee that will not change if wood waste is gasified instead. It is not recommended that Minoa gasify wastepaper or wood waste in an attempt to save money at this time.

An additional potential source of income from gasification of biosolids is biochar. Biochar is the solid carbon residue of pyrolysis, gasification or other processes that heat biomass while limiting its access to air[12-14]. Biochar can be a very valuable soil amendment that increases its organic content, decreases bioavailability of heavy metals, increases soil water retention , soil aeration and permeability and decreases soil density[13]. Biochar and ash derived from gasification of biosolids can be seen in Fig. 21 above. Biochar yields from gasification range from 5% to 15%[15]. Assuming the yield from the CERF gasifier is 10% and CERF produces 47 dry tons of biosolids annually[10], CERF should be able to produce 4.7 tons/ year of biochar. Biochar may be applied to the soil along with the ash, the ash performing a liming effect in increasing soil pH[13]. Assuming that ash makes up 50% of the dry biosolids, CERF should be able to produce 23.5 tons of ash annually. Biochar produced at higher temperatures such as those achieved in gasification are good at adsorbing soil contaminants[15]. As this is a comparatively new product and biochar properties vary considerably with how it is produced, market prices are extremely variable, from $80 per ton to over $13,000 per ton[14]. Experimentation with ash and biochar from the CERF gasifier on wetlands or crop growing soils may be warranted before any marketing of this product is conducted.

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CHAPTER 5: CONCLUSIONS AND FUTURE WORK

5.1 CONCLUSIONS

If labor costs can be discounted then it is clear gasification of MWTP biosolids and dual fueling a diesel powered genset with the resulting producer gas can save Minoa up to $14430 annually, possibly more with the sale of biochar from the gasifier and/or if the cost of electricity to MWTP rises and/or sludge tipping fees increase. If labor costs cannot be discounted then savings only become possible with current costs and no income from biochar if the maximum amount of biosolids is gasified, the least expensive equipment is purchased and operator and maintenance costs do not escalate. If the cost of landfilling biosolids rises to $75 per wet ton or the cost of electricity to MWTP rises to $0.30 per kWh or the sale of biochar brings in more than $721 per ton then even the more expensive equipment option can offset the calculated possible annual loss of $3537 and save Minoa money.

Given that wastepaper can be disposed of at no cost and given the difficulty of gasifying wastepaper and making high quality producer gas, it is not recommended that MWTP try to dual fuel the genset with producer gas from wastepaper. If in the future wastepaper disposal costs Minoa money then dual fueling a genset with producer gas made from wastepaper can be revisited. If gasification of wastepaper is considered in the future some method of densifying the dried fuel chunks is recommended. Possibly processing the wet pulp through a briquette machine followed by drying would be sufficient.

5.2 FUTURE WORK

As discussed in the results section, any gasifier that CERF uses for gasifying biosolids to make producer gas for use in an internal combustion engine needs to have a vigorous grate shaker to ensure adequate air flow and fuel flow through the oxidation and reduction zones.

CERF has also been experimenting with biodigesters making biogas, mostly methane. Triple fueling the diesel genset with biogas and producer gas or dual fueling with biogas and producer gas alternately may give the genset more flexibility and the ability to generate more electricity by running longer hours and/or by having the capability of running a larger genset.

As mentioned above, there may be a large income potential for the sale of biochar and ash produced by biosolid gasification. Investigation of the amount, quality, quantity and value of these gasification byproducts may lead to a significant additional income stream from biosolid gasification.

APPENDIX A. GENSET, GASIFIER, BRIQUETTE MACHINE QUOTES

PREM ENGINEERING PVT. LTD.
to me

Dear Richard

15kva with 20hp can be made but the engine will be under power by 2 hp.

12.5kva 240, 60 Hz, 1800 Rpm single phase.
Coupled with 16hp 850 Rpm Lister Type Water Cooled Diesel Engine Handle Start On Base Frame with V Pulley and V Belts packed in wooden case .
Price USD 2500.00 CNF New York Port USA.

Delivery time for Shipping appox . 45 to 60 days after receipt of advance payment in our bank.

Kindly provide us details for Performa Invoice

Thanking You,

Jaydeep N Dave / Ankur N Dave
Mobile: +9199099 99069 / Mobile +9199099 42372
Director / Director

PREM ENGINEERING PVT. LTD.
334, GIDC. AJI INDUSTRIAL ESTATE PHASE- II,
RAJKOT -360003. GUJARAT - INDIA.
Phone : +91-281-2387164 ,2387295 Fax +91-281-2227573
Email : info@premengineering.co.in
Website : www.premengineering.co.in
FACEBOOK : https://www.facebook.com/premengineering
INSTAGRAM: premengineering

An ISO 9001:2015 Certified Company
(CIN NO : U27109GJ1995PTC025100)

All Power Labs Gasifier Power Pallet

All Power Labs Power Pallet 30 (25 kw) $2 per kw - $50000
All automated, great heat recovery
BUT says manure of any kind incompatible, void warranty – low power, slagging

Power Pallet PP30 (25 kW)

The Power Pallet is a complete biomass power generation solution that converts woody biomass into electricity. It is a compact and fully automated system–from biomass in–to electricity out–delivered at a price point of $2 per watt equipment cost.

The **Power Pallet PP30** is our most recent version of the Power Pallet biomass genset, with many enhancements and improvements from the prior Power Pallet PP20. It comes standard with *grid-tie electronics* for taking advantage of applications such as microgrids, feed-in tariffs, and net energy metering, as well as heat exchangers for heating water for *combined heat and power* (CHP) applications. The PP30 is also much quieter; the engine is now enclosed, and the cooling fans are low-noise electric fans that only turn on as the engine coolant needs cooling, such as when it is not being used to heat water. Power output has increased nearly 50% over the PP20, and the session runtime has been extended as well.

Why it's different The Power Pallet is distinguished among biomass power generation systems by its compact size and affordable price. Its integration of CHP capabilities with power generation and woody biomass disposal make it a perfect candidate for applications which find value in heat, electricity, and wood or nutshell disposal.

View larger image

biomass gasifier price /small gasifiers generator

FOB **Reference** Price:Get Latest Price

$500.00 - $3,000.00 / Sets | 1 Set/Sets (Min. Order)

More

Product Details

Company Profile

Report Suspicious Activity

Overview

Quick Details

Condition:

New
Place of Origin:
Henan, China
Brand Name:
Shuliy
Model Number:
SLQ series
Voltage:
220V/380V
Power(W):
80w
Weight:
500kg
Dimension(L*W*H):
1400*850*1450mm
Certification:
ISO
Gas utput:
20m3/h
Quality:
top level
How to buy:
just contact me
Package:
wood case
Service:
best
After-sales Service Provided:
Overseas service center available
Warranty:
One day

Supply Ability

Supply Ability:
600 Set/Sets per Week

Packaging & Delivery

Packaging Details
wooden box
Port
qingdao

biomass gasifier price /small gasifiers generator

contact person: Ms amy
skype:amyshuliy
whatsapp/viber/mob:0086-15838059105

China best quality Biomass gasifier for sale

Introduction:

Due to the rapid increase in the need of energy source, more people start to become interested in Renewable & Eco-friendly Energy especially for agricultural countries.

SLQ Downdraft Biomass Gasifier is our new renewable product which can generate clean and useful gas with the materials of agro-wastes and wood wastes, such as straw, cotton stalk, corn stalk, peanut shell, wood shavings, wood chips etc.

Features:

1. New design, advanced technology, scientific and compact structure, high efficiency, simple operation.
2. Only 2 minutes to generate gas. And it takes 8-12 minutes to boil 4.5kgs water same as the natural gas.
3. Feeding raw material, generating gas, using gas can realize simultaneously.
4. Good cleaning device to control the tar content, ash content, water content and guarantee the gas clean and good.
5. The occupy area is not over 1 square meter. Gasifying efficiency can get to 70%.

The heat value of gas is 4600-5200KJ/m3.

6. And we can design the suitable power according to customer's electricity situation.

Technical parameters :

Model	SLQ-10	SLQ-20	SLQ-30A
Gas output	10m3/h	20m3/h	30-50m3/h
Gas calorific value	4600-5200KJ/m3	4600-5200KJ/m3	4600-5200KJ/m3
Efficiency of gasification	>70%	≥80%	≥85%
Draught fan Power	220V	220V	220V
Material amount	3~5kg/h	6-10Kg/h	25-30Kg/h
Size(mm)	1030*630*1185	1400*850*1450	2100*800*1500

Product show:

Website: https://www.alibaba.com/product-detail/biomass-gasifier-price-small-gasifiers-generator_2018300052.html?spm=a2700.7724857.normalList.129.148472ceajjJ0b

Briquette Machine:

https://www.alibaba.com/product-detail/Gold-supplier-manure-briquette-press-machine_60829945080.html?spm=a2700.7724857.normalList.12.69355546CWwP8o&s=p

View larger image

•

Share

Gold supplier manure briquette press machine

- 1-2 Sets

$4,800.00

Shipping fee:
Contact supplier for shipping cost to United States
Lead Time:
10 day(s) after payment received
Customization:
Customized logo (Min. Order: 1 Sets)
Customized packaging (Min. Order: 1 Sets)
More
Start Order Contact Supplier
More

Overview

Quick Details

Type:
Briquette Machines
Condition:
New
Production Capacity:
500-4000kg/h
Motor Type:
AC Motor
Place of Origin:
Henan, China
Brand Name:
Sharing International
Dimension(L*W*H):
Depends on models
Certification:
CE ISO SGS
Warranty:
1 Year
After-sales Service Provided:
Online support, Video technical support, Field installation, commissioning and training, Field maintenance and repair service
Name:
Gold supplier manure briquette press machine
Application:
Briquette production for heating cooking BBQ ,etc
Briquette shape:
Round cylinder Square Hexagonal Pillow or customized
Briquette size:
20-220mm customized
Materials:
coal/charcoal/coke/mineral powder/biomass materials
Voltage:
220V/380V/415V/460V /Customized
Pressure type:
Mechanical Pressure&hydraulic pressure
Motor:
7.5kw-15kw
Installation:
Provide Technique Support
Color:
Green/blue/red/Client's Required

Packaging & Delivery

Selling Units:
Single item
Single volume:
3 cm^3
Single gross weight:
1500.0 kg
Package Type:

Seaworthy and long distance transportation sustainable packaging:
1.Sand blasting, coat with high quality paint;
2.Naked packed for heavy and large parts,but wrap by PP-Bubble.
3.Non fumigation wooden box for small parts,spare parts, tools, CNC/PLC.
4.Or as clients request.
(Gold supplier manure briquette press machine)

Lead Time :

Quantity(Set)	1 - 1	2 - 3	4 - 5	>5
Est. Time(days)	10	15	20	To be negotiated

Video Description

Product Description

Gold supplier manure briquette press machine

Brief Introduction of honeycomb briquette press machine:

It is maily used to process coal/charcoal powder into cylinder shape briquette with high density and standard looks,and marked with a number of holes inside the cylinder makes it seems like honeycomb,because it can increase the surface area of coal.make the full combustion of coal, to reduce rsource waste. Also our briquette machine now widely used to produce new-type ignited briquette.

Parameters of honeycomb briquette press machine models:

(Gold supplier manure briquette press machine)

Model	Capacity	Motor power	Diameter of model	Pressure
LFM140	45-50 pieces/minute	7.5kw	140mm	20-35 tons
LFM160	45-50 pieces/minute	7.5kw	160mm	20-35 tons
LFM170	20-26 pieces/minute	11kw	170mm	35-45 tons
LFM220	20-26 pieces/minute	11kw for coal 15kw for charcoal	220mm	30-40 tons
Shapes of final briquettes: Round cylinder, square, flower shapes ,heart shapes,hexagonal shape,etc. Or we can custom the related moulds as clients' requests.				

APPENDIX B: RUN DATA

Run	Gasifier input air valve% open	Run time hours	Average Volts	Average Amps	Generated Power (Wh)	diesel used (ml)	wood used (kg)	paper used (kg)	biosolids used (kg)	Ash (k
1	100	0.5	115.0	10.0	575.0	340.0				
2	100	0.5	115.0	10.6	609.5	320.0				
3	100	0.5	115.0	9.8	563.5	305.0				
4	100	0.5	125.0	10.5	656.3	365.0				
5	100	0.5	114.0	9.8	558.6	310.0				
6	100	0.5	151.0	12.5	943.8	135.0	2.3			
7	100	0.5	152.0	10.3	782.8	120.0	2.3			
8	100	0.5	149.0	13.0	968.5	125.0	2.3			
9	100	0.2	130.0	11.6	256.4	95.0	char	0.6		
10	12.5	0.1	125.0	11.3	141.3	50.0		0.5		
11	12.5	0.1	127.0	11.5	146.1	60.0		0.5		
12	12.5	0.1	124.0	11.2	138.9	60.0		0.4		
13	12.5	0.1	137.0	11.3	154.8	40.0		0.6		
14	12.5	0.1	125.0	11.3	141.3	55.0		0.7		
15	12.5	0.1	130.0	11.8	153.4	55.0		0.7		
16	12.5	0.1	134.0	12.2	163.5	40.0		0.6		
17	12.5	0.1	127.0	10.6	107.7	50.0			0.3	
18	12.5	0.2	122.0	10.4	211.1	100.0			1.0	
19	12.5	0.1	131.0	10.1	132.3	55.0		0.3	1.1	
20	12.5	0.1	135.0	11.5	155.3	50.0		0.3	1.1	
21	12.5	0.1	140.0	11.4	159.6	45.0		0.2	0.3	
22	25	0.1	131.0	11.4	149.3	40.0		0.2	0.4	
23	25	0.1	154.0	12.9	132.3	20.0		0.2	1.2	
24	25	0.1	149.0	11.3	111.6	15.0		0.1	0.8	
25	25	0.1	149.5	11.6	115.5	30.0		0.1	0.9	
26	25	0.1	144.3	11.3	107.6	15.0		0.2	0.4	
27	25	0.1	147.5	14.2	209.5	25.0			0.8	
28	25	0.1	158.0	15.0	237.0	25.0			0.7	
29	25	0.1	151.0	14.5	219.0	10.0			0.8	

Gasifier volume - 6" ID X 22-1/4" D to grate = 629 cubic inches = 10309 cc

Measured density of paper fuel - 500ml = 40g = .08g/cc — weight of full gasifier of paper fuel = 825

Measured density of wood fuel - 500ml = 112g = .224g/cc — weight of full gasifier of wood fuel = 2309

Run	diesel efficiency(%)	overall efficiency (%)	diesel to generate power @17% efficiency	diesel savings(ml)	diesel savings (%)	diesel savings (Wh)
1	15.7		314.3			
2	17.7		333.2			
3	17.2		308.1			
4	16.7		358.8			
5	16.7		305.4			
6	65.0	17.0	515.9	380.9	282.2	4098.9
7	60.6	17.0	427.9	307.9	256.6	3313.5
8	72.0	17.0	529.5	404.5	323.6	4352.1
9	25.1	17.0	140.1	45.1	47.5	485.8
10	26.3	17.0	77.2	27.2	54.4	292.9
11	22.6	17.0	79.8	19.8	33.1	213.5
12	21.5	17.0	75.9	15.9	26.5	171.3
13	36.0	17.0	84.6	44.6	111.6	480.2
14	23.9	17.0	77.2	22.2	40.4	239.1
15	25.9	17.0	83.9	28.9	52.5	310.6
16	38.0	17.0	89.4	49.4	123.4	531.2
17	20.0	17.0	58.9	8.9	17.8	95.5
18	19.6	17.0	115.4	15.4	15.4	165.6
19	22.4	17.0	72.3	17.3	31.5	186.5
20	28.9	17.0	84.9	34.9	69.7	375.2
21	33.0	17.0	87.3	42.3	93.9	454.6
22	34.7	17.0	81.6	41.6	104.1	448.1
23	61.5	17.0	72.3	52.3	261.7	563.1
24	69.2	17.0	61.0	46.0	306.9	495.3
25	35.8	17.0	63.1	33.1	110.5	356.6
26	66.7	17.0	58.8	43.8	292.2	471.7
27	77.9	17.0	114.5	89.5	358.0	963.1
28	88.1	17.0	129.6	104.6	418.3	1125.1
29	203.5	17.0	119.7	109.7	1097.0	1180.3

Run	gasifier fuel energy (Wh/kg)	gasifier fuel energy (Wh/kg) accounting	gasifier fuel energy (kWh/kg.)	
1	diesel	for 40% thermal		
2	savings/gasifier fuel	efficiency		
3	weight. Assumes fuel			
4	energy goes to generated			
5	power with same engine efficiency			
6	1782.1	4455.3	4.5	
7	1440.7	3601.6	3.6	
8	1892.2	4730.5	4.7	
9	796.4	1991.0	2.0	char from wood runs
10	552.6	1381.5	1.4	
11	402.9	1007.2	1.0	* vacuum cleaner port not closed, small chunks
12	417.9	1044.8	1.0	small chunks
13	800.4	2001.0	2.0	big chunks
14	341.5	853.9	0.9	even bigger chunks
15	443.6	1109.1	1.1	big chunks, same as 9/6
16	885.4	2213.5	2.2	big chunks, same as 9/6
17	382.0	955.1	1.0	fuel from wet filter press material
18	165.6	414.0	0.4	fuel from drying shed - broken up with shovel
19	138.1	345.4	0.3	biosolids from drying shed, formed into patties and dried
20	278.0	694.9	0.7	biosolids from drying shed, formed into patties and dried
21	869.3	2173.2	2.2	biosolids from filter press formed into patties and dried
22	722.7	1806.7	1.8	biosolids from filter press and drying bed formed into patties and dried. Shop vac left on 4 minutes into run
23	411.6	1029.0	1.0	biosolids from drying bed, gasifier only run 4 minutes, then puff of smoke and engine rpm and gen VA declined
24	543.1	1357.7	1.4	biosolids from drying bed. Engine slightly stuck from last run.
25	351.7	879.2	0.9	biosolids from drying bed
26	840.7	2101.8	2.1	biosolids treated with polymer, predried for 3 hours, then formed and dried overnight. Amp average assumed, volts accurate.
27	1284.1	3210.2	3.2	manually pressed biosolids from the filter press with hemp
28	1731.0	4327.4	4.3	manually pressed biosolids from the filter press with hemp, engine very slightly stuck, clogged, needed to be rodded from ash pit
29	1401.8	3504.6	3.5	manually pressed biosolids, no fiber, heater blew at end of run

RESUME

Date and Place of Birth: March 5, 1952 and Oceanside, NY

Education:

9/70 – 5/74 Cornell University B.S. Vertebrate Anatomy and Physiology

9/83 – 5/87 Syracuse University B.S. Mechanical Engineering

9/92 – 5/95 SUNY Environmental Science and Forestry M.S. Wood Processing

1/10 – present SUNY Environmental Science and Forestry doctorate candidate Bioprocess Engineering

Work Experience:

5/86 – 1/87 Co-op at Carrier Corporation, Syracuse, NY chiller mechanical engineer

5/87 – 5/92 General Electric Corporation, Syracuse, NY radar mechanical engineer

9/92 – 5/95 SUNY ESF research assistant

9/95 – 6/97 New Zealand Forest Research Institute, Rotorua, New Zealand engineer/ scientist wood drying

9/97 – 9/09 Cooper Industries, Cortland, NY steel plate lifting clamp design engineer

1/10 – 3/12 SUNY ESF research assistant

3/12 – 3/14 Pall Corporation, Cortland, NY alternate fuels engineer

3/14 – present SUNY ESF research assistant

Selected Publications:

Bates R, Dölle K. Dual fueling a diesel engine with producer gas produced from woodchips. Advances in Research 2018;14(1):Article no.AIR.39431.

Bates R, Dölle K. Producer gas use in internal combustion engine – A practical approach. International Journal for Innovative Research in Multidisciplinary Field (IJIRMF) 2017;3(7):157-65.

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Patents

US Patent 7,819,448 10/26/2010 Plate Lifting Clamp

US Patent Pending 1992 Cable Reel Deployer