

Original Research Article

Dual Fueling a Diesel Engine with Syngas Produced From Woodchips

ABSTRACT

The aim of this work was to study the diesel fuel savings in dual fueling a small diesel powered genset with a small Imbert style downdraft gasifier fueled with hardwood wood chips. Eight different runs were conducted, five with the engine fueled with diesel alone to characterize fuel consumption on diesel, three dual fueling the engine with diesel and syngas. Generator power to a portable electric heater was measured and diesel fuel savings calculated for the power generated. It was found that dual fueling the generator saved about ¾ of the diesel fuel needed.

Keywords: Dual fueling, downdraft Imbert style gasifier, gasification, wood chips, fuel savings

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 CO₂ level in the atmosphere can be noticed [3].

In 2016 the US consumed a total of 13,504.00 thousand barrels of crude oil per day [4]. Therefore, the US independence on foreign sources of energy is of great national interest.

According to the United States Census Bureau Energy, the U.S. Population increased from 1950 to 2010 by nearly 204.03% 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 97.444 quadrillion British thermal units (Btu)/day [6] and is expected to increase by 5% by 2040, whereas an increase of 11% is expected in an high economic growth case. [7]. Data from EIA [8] in Figure 1 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 But the potential of biomass 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]. to produce energy is much greater than its use. For example, 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]. The 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]. The increasing costs of energy and material resources are directing industrial, commercial, farm-based and municipal enterprises in the U.S. and many other nations to develop more sustainable modes of operation [12], because fossil fuels, the primary sources of energy on earth, are finite [13].

Many studies suggest that the costs of fossil fuel exploration and extraction will continue to rise, perhaps to unprecedented levels [13, 14, 15, 16].

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. Today, the U.S. forest industry produces approximately 67 million dry tons of Forest Residual Biomass (FRB) from harvesting and converting wood into consumer products, which equals approximately 3.4 million barrels of oil equivalent (BOE). Currently FRB is partially used to produce mulch or is left unused in the forest by

the harvesting operations and cannot be utilized for biofuel and/or value-added product production due to long transportation distances. [17].

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].

In order to utilize the biomass available for energy production, it is necessary to develop more scientific and applied knowledge of the process, using not only high-grade FB but also low grade FB and Forest Waste Biomass (FWB), e.g. infected trees, stumps, and other forestry and agricultural residues and/or waste biomass.

The production of bio energy and fuels from any biomass is very dependent on keeping constant process parameters throughout the production chain as well as throughout the year. Inconsistent biomass supply results in losses and low overall process performance. Seasonal growth and variations occurring during this period make it even harder to predict the energy output of the used biomass. To overcome the seasonal effect, a diverse portfolio of a biomass mixture, based on regional availability, needs to be developed to insure a consistent delivery of biomass with set quality parameters to the biorefinery. This will result in a consistent process and help maximize the biorefinery output and overall performance.

The present cost range of \$12 to \$24 per Barrel of Oil Equivalent (BOE) for Forest Biomass (FB) can be expected [19]. In addition pretreatment and conversion processes needed for the biochemical route typically raise production costs for biofuels to \$60–\$120 per BOE, making only high fuel prices, above \$50–\$75 per bbl. for the production of bioenergy from biomass economically feasible [20].

Gasification can effectively use FRB and other FB byproducts currently little utilized to reduce dependence on fossil fuel without requiring more forest to be cut for fuel.

The downdraft gasifier has been proven to be the most successful design for small scale power generation due to its low tar, an inhibiting by-product of the process, production. Downdraft gasification has not yet been successful for large scale power production at the megawatt scale. The downdraft gasifier consists of 5 major zones: 1) drying, 2) conversion, 3) Charring, 4) oxidation, and 5) reduction zone. The Imbert style gasifier design is one 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 [21]. Figure 1 shows a diagram of an Imbert style research gasifier we have built at the Cleanwater Educational research Facility (CERF) located at the Village of Minoa, New York Waste Water Treatment Plant (WWTP).

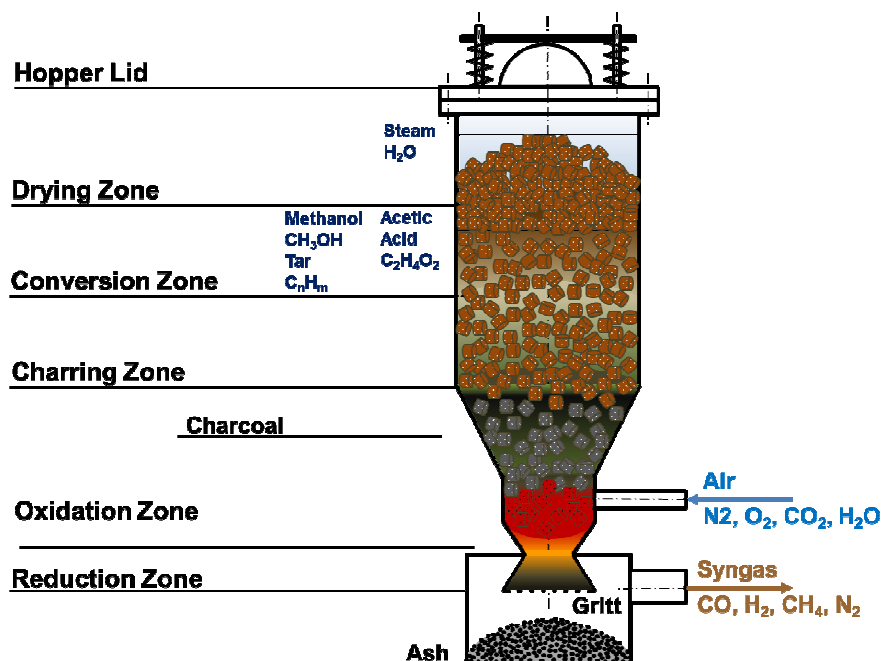
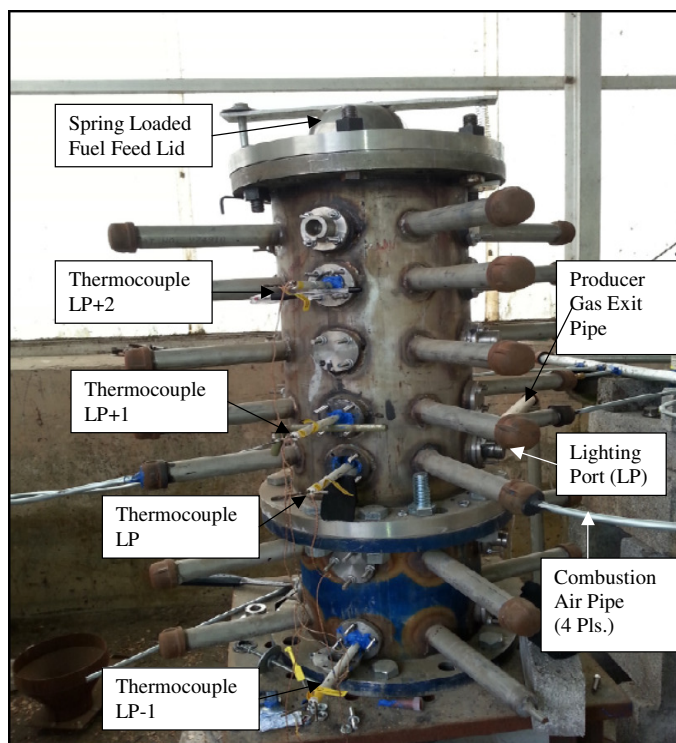


Figure 1: Imbert Style Gasifier [22]

A previous reported a pilot-scale downdraft, Imbert-type gasifier shown in Figure 2 below was designed and constructed to be used at CERF, located at the in municipal wastewater treatment plant

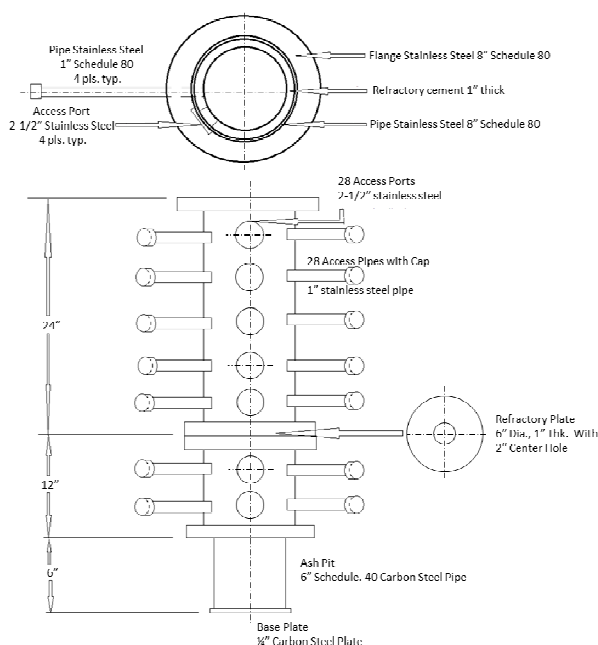
85 of Minoa, NY [23]. Figure 3 below shows a design sketch for the CERF gasifier [23]. This research is
 86 a continuation of the pilot scale gasifier located in Minoa. A pilot study of dual fueling a diesel
 87 powered genset with the CERF gasifier fueled with woodchips was performed. The objectives of this
 88 research are to determine the feasibility and savings of diesel fuel in dual fueling the genset with
 89 syngas produced from woodchips.
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92 **Figure 2: CERF Gasifier [23]**

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95 **Figure 3: CERF Gasifier Design Sketch [23]**

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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 [24].

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°C (1112°F) [24]. 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 zone are 700°C (1292°F) to 1000°C (1832°F) [24]. Operation at temperatures above 1000°C requires that the gasifier be built from more expensive heat resistant materials.

2. MATERIALS AND METHODS

The genset (engine and generator) was build using a Basant 6hp (4.5kW) horsepower Lister design engine driving a 7.5hp (5.6kW) Baldor 3 phase squirrel cage induction motor fitted with capacitors and configured as a generator. Figure 4 shows the genset. Figure 5 shows the gasifier and genset system. Syngas from the gasifier was cooled in the radiator, filtered in the hay filter and mixed with a small amount of outside air in the engine carburetor. The engine governor controlled the amount of diesel introduced to the engine so that the engine speed remains constant. The engine needed a minimal amount of diesel to ignite the syngas-air combustion charge. The governor introduced more diesel to make up for insufficient or weak syngas. As a load to the generator a 1500 watt 120 V portable electric heater was used.

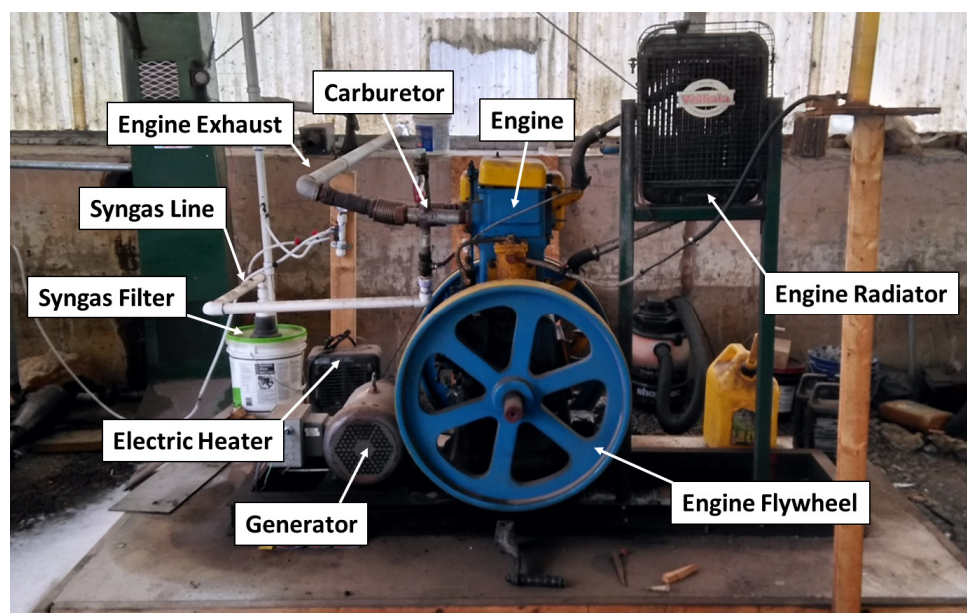


Figure: 4. CERF Genset [25]

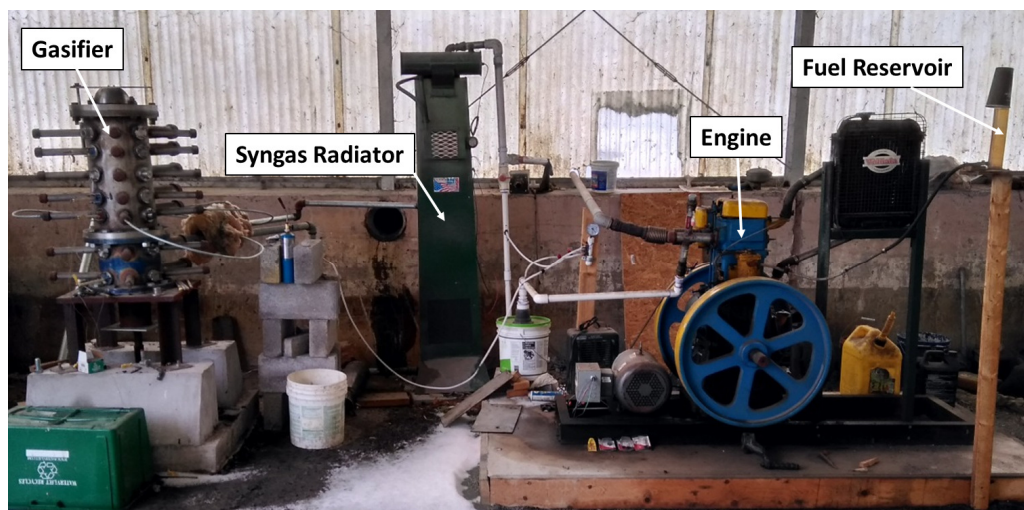


Fig. 5. CERF Gasifier Genset System [26]

Hardwood woodchips approximately $\frac{3}{4}$ " (19mm) square and $\frac{1}{8}$ " (3mm) thick at approximately 12.5% Moisture Content (MC), at a oven dry basis, fueled the gasifier for a 30 minutes run. During each run approximately 2.5lbs (1,134g). Of chips were used. Successful operation of the gasifier requires an adequate char-bed for each run that is formed from the leftover fuel from the previous run. Based on our experience operating the gasifier, 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 char-bed to the ash pit. 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 shortly thereafter the generator load was applied. Once the gasifier temperature at the lighting port reached 1800°F the vacuum from the shop vac was turned off and the engine vacuum was applied to the gasifier by opening carburetor and syngas 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. At the same time and at the end of the run voltage and amperage supplied to the heater were noted as well as gasifier temperature at the lighting port level. 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:

$$D_{en} = \text{milliliters of fuel consumed} \times 139,000 \text{ Btu/} 3785 \text{ ml per gallon} \quad [1]$$

where 139,000 Btu is the energy content of 1 gallon of diesel fuel [8].

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

$$G_{en} = \text{Avg. volts measured} \times \text{Avg. amps measured} / 3.412 \text{ Btu per watt hour} \\ \times 2 \text{ runs per hour} \quad [2]$$

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

$$G_{eff} = 100 \times D_{en} / G_{en} \quad [3]$$

Baseline runs for determining genset efficiency with the engine operating on diesel fuel alone were first conducted. 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:

$$d_{\text{alone}} (\text{ml}) = G_{\text{en}} / G_{\text{effd}} \times 139,000 \text{ Btu per gallon} / 3785 \text{ ml per gallon} \quad [4]$$

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

$$D_{\text{fs}} = 100 \times (d_{\text{alone}} - \text{actual quantity of diesel used (ml)}) / d_{\text{alone}} \quad [5]$$

3. RESULTS AND DISCUSSION

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

Table 1. Genset Run Results

| Run | Diesel Usage [ml] | Ave. Volts [V] | Ave. Amps [A] | G_{en} [Btu] | D_{en} [Btu] | G_{eff} [%] | G_{effd} [%] | d_{alone} [ml] | D_{fs} [%] |
|-----|----------------------|-------------------|------------------|--------------------------|--------------------------|-------------------------|--------------------------|----------------------------|------------------------|
| 1 | 340 | 115 | 10.00 | 1961.90 | 12486.13 | 15.71 | 16.84 | NA | NA |
| 2 | 320 | 115 | 10.60 | 2079.61 | 11751.65 | 17.70 | | NA | NA |
| 3 | 305 | 115 | 9.80 | 1922.66 | 11200.79 | 17.17 | | NA | NA |
| 4 | 365 | 125 | 10.60 | 2260.45 | 13404.23 | 16.86 | | NA | NA |
| 5 | 310 | 114 | 9.80 | 1905.94 | 11384.41 | 16.74 | | NA | NA |
| 6 | 131 | 151 | 12.50 | 3220.08 | 4810.83 | 66.93 | | 520.81 | 74.85 |
| 7 | 120 | 152 | 10.30 | 2670.91 | 4406.87 | 60.61 | | 431.99 | 72.22 |
| 8 | 125 | 149 | 13.00 | 3304.52 | 4590.49 | 71.99 | | 534.47 | 76.61 |

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 [27] state that during their testing the diesel thermal efficiency dropped from 28% to about 17%. The same is reported for our runs on average were the genset was running on diesel alone efficiency G_{effd} in Table 1 above, when the engine was operated at partial load as it 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 1 that dual fueling with woodchips can save a considerable amount of diesel fuel in operating the genset. The 72% - 76% diesel savings reported above are within the 60% - 90% range of savings reported by Malik et al. and Martinez et al. [28, 29, 30]. 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. Calculating 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 syngas during the run.

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 syngas drawn into the combustion chamber. As syngas 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 syngas 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 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.

4. CONCLUSION

This study shows that approximately $\frac{3}{4}$ of the diesel fuel required to operate a genset may be saved by dual fueling the diesel engine with syngas produced by gasifying woodchips. To prevent over-voltages when dual fueling the diesel engine governor may need to be adjusted or changed.

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