

Experimental Analysis of a Wood Gasifier Based Engine

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Abstract

In this project a FEMA style, Stratified Downdraft gasification system was built. This system was used to convert a 16 HP internal combustion engine into a system that only uses the syngas emitted from gasifying wood as its fuel rather than gasoline. The gasification system used consisted of a downdraft fire tube where wood pellets were gasified and routed through two filters before the gas entered the carburetor of the engine. There were some challenges that were faced such as choosing the right materials for the system that could tolerate moderately high temperatures and also designing a vacuum tight system. After the design and construction of the gasification system, we were able to successfully run the engine on gasified wood pellets and show that wood, a renewable resource, can be used as a fuel for an internal combustion engine.

Introduction

Our group has researched and studied a system known as “wood gasification.” From our research, we found that this system was developed in the late 1800s and was used heavily in Europe during World War II due to a petroleum shortage. After studying the basics of how the system works, we were able to design and construct a system that would work best with our riding mower and convert it from running on gasoline to running on the gases emitted by gasifying wood. The process of the wood gasification system begins with wood burning inside of a downdraft style fire-tube where vacuum from the engine pulls the flame down and only allows enough oxygen to start the combustion process, but not enough to complete the reaction. The gases that emerge from burning wood with an insufficient amount of oxygen are known as a syngas. The syngas consists of hydrogen, carbon monoxide, nitrogen and a small amount of methane which form a fuel that is combustible. However, there is a downside to burning wood with an insufficient amount of oxygen. This problem results in a “dirty” gas that consists of ash, sulfur, and moisture which can be harmful to an internal combustion engine. In order to clean the syngas and reduce the impurities for a longer running engine, we constructed two filtration systems. Initially we developed a water filter in combination with a “dry” filter; however, after testing the system for the first time, we were unable

to produce enough vacuum to pull the syngas through the water. We then redesigned the water filter where we removed the water and used a cone filter that can be found on the intake tube of an automobile. The dry filter we developed contains wood chips that will help reduce the moisture content of the gas before entering the carburetor of the engine along with trapping the remaining impurities of the gas that went through the first cone filter. By designing a system that includes two filters, it will help improve the life of the engine.

Background

Wood gasification is not a new concept. As early as the 1840's, gasification systems were used to create a "producer gas" which was used for heating households [1]. The peak popularity of wood gasification was during the Second World War in Europe. During World War II, access to petroleum in Europe was very limited. In the absence of petroleum, they relied very heavily on Wood Gasification to power their automobiles and farm equipment. At the time, 95 percent of all farm equipment, boats, and stationary engines were operated by a gasification system in Denmark, which was occupied by the axis forces during World War II [1]. Even in neutral countries, such as Sweden, as much as 40 percent of all automobiles were operated on a gasification system [1]. The low efficiency, inconvenience of stopping to load the gasifier with wood, and the health risks from the deadly carbon monoxide gas produced, caused gasification to become unnecessary after the war ended and petroleum became available again [1].

Theory

In a spark ignition internal combustion engine, fuel is vaporized in the carburetor and pulled into the engine during the intake stroke, or vaporized by the injectors as it is injected into the cylinder. Since it operates on vaporized fuel, almost any combustible gas can be used to operate a spark ignited internal combustion engine. Wood gasification operates by burning wood and running the engine off of the smoke that is produced from the reaction, which is also called syngas. The syngas is made up of approximately 20 percent Hydrogen (H₂), 20 percent Carbon Monoxide (CO), small amounts of methane (CH₄), and 50 to 60 percent Nitrogen (N₂) [1]. In a typical set up, there is the fire-tube, in which the fuel is burnt and a filtration system to filter tars and particulates out of the syngas. In the FEMA Stratified Downdraft gasifier, there are four zones in which reactions take place inside of the fire-tube. The first zone is where the fuel is stored, and also dried. The second zone is the pyrolysis zone. The third zone is the combustion, and the fourth zone is the reduction zone [2]. In the first zone, the wood fuel is dehumidified and as the process continues, will be drawn down into the other three zones. In the second zone, pyrolysis occurs. Pyrolysis breaks organic materials down chemically in the absence of oxygen [3]. The resulting producer gas from the pyrolysis reacts in the later stages to form the syngas [2]. In the third zone, the combustion occurs. In the reduction zone, the following reactions occur; The Boudouard reaction, and the Water Gas Shift reaction. The Boudouard reaction is $C + CO_2 \rightarrow 2CO$ and the Water Gas Shift reaction is $C + H_2O \rightarrow CO + H_2$ [2]. The gas produced is then filtered, as it may contain ash and tar which are harmful to engines. The filtered gas is then routed into the engines air intake, which is mixed with air as it is being pulled into the engine.

Table 1: FEMA chart to determine fire tube size

Table 2-2. Fire tube dimensions

Inside diameter (inches)	Minimum length (inches)	Engine power (horsepower)	Typical engine displacement (cubic inches)
2*	16	5	10
4*	16	15	30
6	16	30	60
7	18	40	80
8	20	50	100
9	22	65	130
10	24	80	160
11	26	100	200
12	28	120	240
13	30	140	280
14	32	160	320

EQUIPMENT

The materials and supplies that are used to build a wood gasification system are simple and range in a large variety based on the specific design you want to build. There are some things to consider before designing the system such as; fire tube diameter which is based on engine horsepower, finding materials that can withstand a high temperature until the gas is cooled, filtration systems that will catch the impurities of the syngas, initial vacuum that can be ran until the fire tube is at operating conditions, and a completely air tight system. After considering these initial guidelines we were able to determine what supplies we would use that would work best with the riding lawnmower. The schematic drawing is shown in Figure 1.

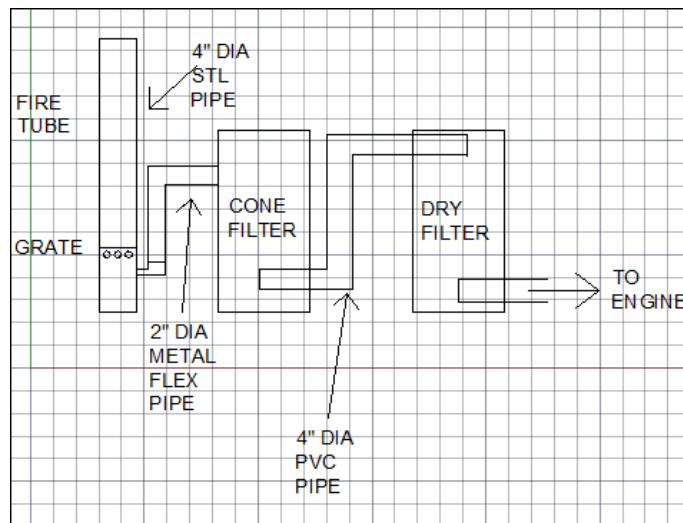


Figure 1: Schematic Drawing of System.

Since the engine of our mower was 16HP, we followed the chart given by FEMA (Table 1) and found that the required fire tube diameter was four inches which can be shown in Figure 2.



Figure 2: Four inch diameter fire tube with grate.

Knowing that the gas coming from the fire tube would be at high temperatures, we used 1/4" steel pipe for the fire tube along with the pipe that connected the first filter to the fire tube which required brazing shown in Figure 3.



Figure 3: Brazing metal pipe to filter.

After the gas travels through the long pipe, the temperature will decrease once it enters the filters so we were able to use PVC pipe to route the gas through the rest of the system Shown in Figure 4.



Figure 4: Filters and PVC Piping.

For the filters we used five gallon metal buckets with a gasket sealed lid for an air tight seal. The internal view of the filters is shown in Figure 5 and 6. For the connections where the PVC pipe joined into the filters, silicone was used to keep the system vacuum tight. The next thing we looked at was a way to regulate the fuel to air ratio and this was done using a ball valve shown in Figure 7.

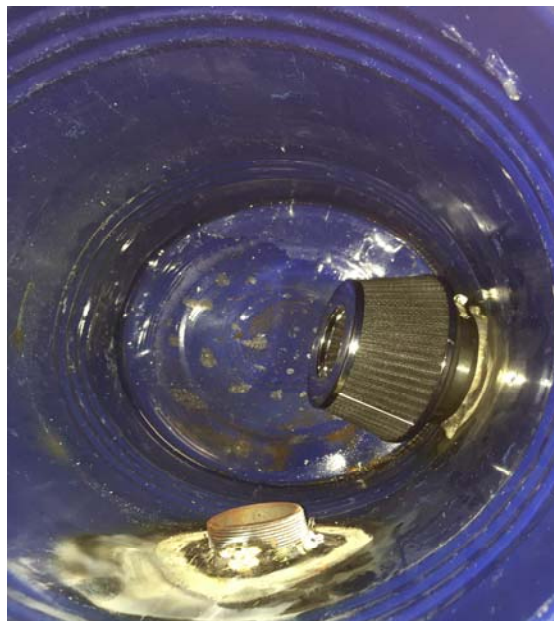


Figure 5: The first filter of the system, which uses an air filter that would be used on an automobiles air intake system.



Figure 6: Second Filter, “dry filter”. Once filled with wood chips, the gas will be pulled through the wood chips where they will act as a filter.



Figure 7: Ball valve and electric fan.

Attached to the ball valve, we installed an electric fan (also shown in Figure 7) that is mounted in a way that when running, it will pull the syngas through the system and dispose of it into the atmosphere until the fire tube is at operating temperatures. Once the fire tube reaches its operating temperature, we will be able to start the engine and turn the fan off since the engine will provide the vacuum to the system. As the gas travels through the system, it will finally reach the carburetor where it will be routed through a 90 degree PVC bend shown in Figure 8.



Figure 8: 90 degree PVC pipe routed into the carburetor.

Since the gasification system consists of many components, we designed and fabricated a platform that would attach to the rear of the riding lawnmower for our system to be mounted on shown in Figure 9. The final assembly was completed and can be shown in Figure 10 during our test trials.



Figure 9: Metal Platform.



Figure10: Complete and Operational System.

PROCEDURE

Before starting the engine there are some steps that need to be followed. First, the electric fan must be running while the starting procedure takes place in order to pull the gas down through the fire tube and exit out of the fan shown in Figure 11.



Figure 11: Syngas exiting the fan.

As mentioned earlier, it is important to pull the flame downwards in order to only allow enough oxygen to start the combustion process, but not enough to complete the reaction. As the fan is running, a hand full of wood pellets was added to the fire tube and was lighted by dropping a lit piece of paper or wood into the bottom of the tube. Once there is a flame in the fire tube, the tube was filled up with wood pellets. Initially, the syngas produced in the fire tube cannot be used until it reaches the operating temperature. We found from our experiments that the fire tube must reach a temperature of 1000°F before the syngas can be used to power the engine. The time required for the fire tube to reach the operating temperature is 30-35 minutes depending on the ambient temperature. Once the operating temperature has been achieved, the reaction has now started and the four zones have been established inside of the fire tube. The gas is now ready to be used in the internal combustion engine. The next step would be to close the ball valve to the “run” position which is marked on the valve. This position was found from experiments which allows for the correct fuel to air ratio. Once the valve is in the operating position, the electric fan was turned off. It is now time to start the engine by turning the ignition key.

OBSERVATION

During the period of design and construction of our wood gasification system, we have developed a very clear understanding of how the system works. During the build period, we found various things that needed to be changed from the original design that was developed on paper and in AutoCAD. An example would be the water filtration system that was later changed after testing and replaced with what we believe is a cleaner and more functional filter. After continuing on and fixing the small things in our design, we were able to develop a complete gasification system that operated well enough to run our internal combustion engine.

RESULTS

When it came time to test our system, we followed the procedure stated above in order to start our engine. In order to find out when the fire tube was at operating temperature, we developed an experiment where we recorded the temperature every two minutes at different locations of the fire tube which were two inches apart shown in Figure 12.



Figure 12: Fire tube with marks that are two inches apart.

To find the temperature at the marked locations on the fire tube, we used a non-contact infrared thermometer to measure the temperature every two minutes until the fire tube reached a steady state of temperature. We found that it takes 30 minutes to reach the steady state at an ambient temperature of 50°F. The maximum temperature of 1000-1100°F was found at the mark 10 inches from the bottom of the fire tube where the wood pellets are gasified. The temperature data that was recorded can be shown in Figure 13. Using the infrared thermometer we also recorded the maximum temperature of our filters where we found the maximum temperature for the first filter to be 220°F and the second filter to reach 150°F leading to a temperature loss of 70°F between the two filters. This temperature loss is beneficial to our system since we would like the gas to cool before it enters into the engine.

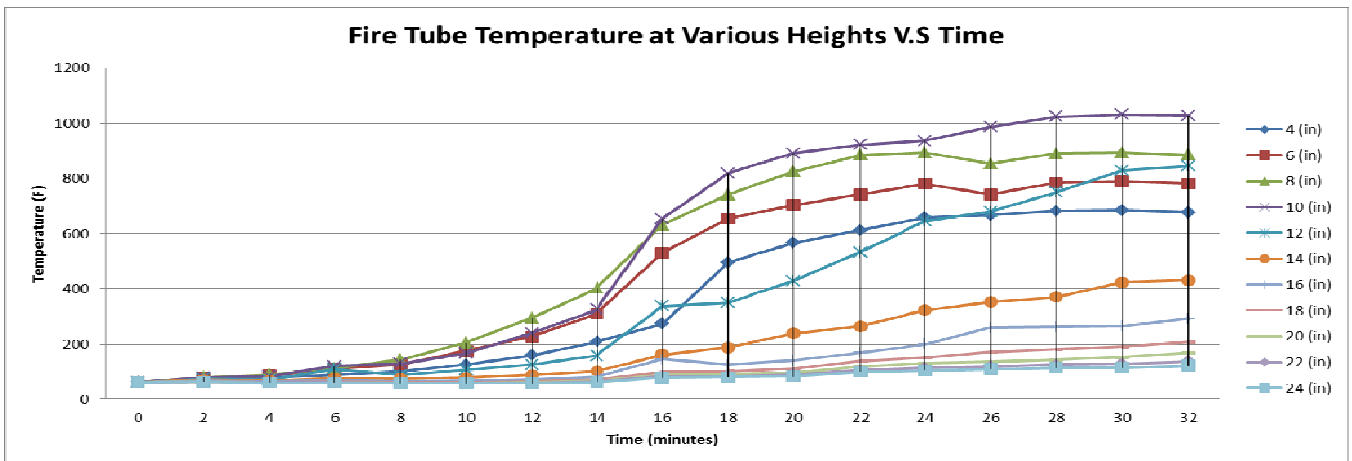


Figure 13: Graph of Fire Tube Temperature V.S Time.

After the gas left the second filter, the temperature reduced to 120-122°F before entering the carburetor.

Initially, it took many tries in order to find the right fuel to air ratio in order to keep the engine running in which we did using the ball valve in Figure 7. After finding the proper ball valve position, we were able to run the engine using only gasified wood as our fuel. Once started, we let the engine idle at 60-65% throttle for thirty minutes before applying the power from the engine to the mechanical drive of the mower. From there, we were able to verify that the system operated at 60-65% throttle the same as it would if it were operating on gasoline. We noticed no power loss from using the gasification system at this throttle position. Unfortunately we were unable to increase the engine speed to 100% throttle without the engine shutting off. We found that the recommended four inch diameter fire tube did not produce enough fuel for our 16HP engine to run at the maximum throttle position.

CONCLUSION

At this time, we have successfully designed and built a wood gasification system that can be used to run the internal combustion engine of the riding lawnmower. We were able to prove that, with the right system it is possible to convert wood into a combustible gas and that wood is a renewable resource that can be used as fuel. We found that we were able to run the engine at 60-65% of its maximum potential with no signs of power loss when compared to the engine running on gasoline. However, we were not able to perform any performance tests in order to measure the exact difference in power between the system operating on gasoline and the system operating with wood gasification. We were also not able to calculate the efficiency of the system while running on wood gasification, as we ran out of time.

FUTURE WORK

In the future we plan to replace the 4in diameter fire tube with an 8in in order to run the engine at 100% throttle, add a thermometer to the new fire tube that will allow us to monitor the temperature as it increases to the operating temperature, and add an intercooler after the fire tube to reduce the inlet temperature into the filters and also the carburetor. After making these improvements, we believe we will have a system that can operate at any throttle position and also allow for a more convenient startup for the operator. We also plan to redesign the system to reduce its startup time. Furthermore, we would like to design a control system and perform performance test on the system.

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