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Sustainable Energy Production From Biomass: A Case Study On Tasmanian Blue Gum Eucalyptus Gasification.

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Abstract:
The global transition to renewable energy sources is a crucial response to the urgent need to reduce global warming and its negative environment consequences. One feasible approach within this paradigm is to generate steam from syngas produced by biomass gasification.
Background: *Gasification is a thermochemical process that transforms organic materials into combustible gas mixtures, provides a sustainable and renewable way to generate energy, chemicals and fuels. This technology helps to minimize greenhouse gas emissions and reliance on fossil fuels.*
Materials and methods: *In this experiment, Tasmanian blue gum eucalyptus sawdust is used to generate pellets which will subsequently be processed into syngas using downdraft gasifier. The experiment investigates the effect of increasing air velocities specifically 10, 15, 20 and 25 M/sec as a gasifying agent to the gasification process.*
Results: *The air velocity is measured at 10, 15, 20 and 25 m/s resulting in the time taken of 2280, 1860, 1560 and 1380 with efficiency increases of 41.11, 47.73, 49.62 and 54.67, respectively. This implies that optimizing air velocity is crucial for improving the overall performance of biomass gasification. The proximate and ultimate results of pellet are some better compared to the raw eucalyptus by researcher Filomena Pinto [16]. The efficiency is slightly high compared with the researcher R. Ravi Kumar [25]. The generated syngas may eventually replace the fossil fuel LPG for domestic purposes.*
Conclusion: *The time taken for the gasification decreases with the increase of air velocity up to 25m/s. As the result the efficiency increases.*
Keywords: *Biomass; Pellets; Downdraft Gasifier; Gasification; Cyclone separator; Syngas.*

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I. Introduction

India's forest which covers around 28.3% of the country's total area, stores approximately 2800 million metric tons of carbon in forest biomass [1].Carbon dioxide (CO_2) emissions are mostly caused by burning solid waste, forests and fossil fuels [2]. Globally the capacity for renewable energy has grown gradually, with an annual growth rate of 8%, reaching 820 GW in 2016 [3].The renewable energies are

Solar energy: Solar radiation is directly converted into electrical energy by photovoltaic solar cells [4]. In 2002, solar energy percentage of total energy was between 1.7% - 1.8% in 2007, and it reached 2.1% in 2007 in Jordan which save about 16 million DRs [5].

Hydropower: Hydropower uses the energy in falling or swiftly flowing water to produce electricity. Hydropower projects reduce flooding, offer recreational opportunities and don't produce garbage that contributes to greenhouse gas emissions or air pollution [6].

Wind energy: Asia is the largest capacity which counts 43.2% [7].The future of the wind energy is offshore wind power.

Ocean thermal energy: The heat, currents, waves and tidal found in the ocean have enormous potential for energy [8].

Biomass Energy: The word "biomass" is a compound of the word's "bio", which means "living", and "mass", which denotes "weight". When biomass is used instead of fossil fuels, greenhouse gas emissions are reduced. Biomass has a potential to store solar energy through photosynthesis. Plants develop in the response to sunlight, this energy is kept in the plants and referred as biomass energy (wood, straw, dung and other plant waste). Biomass can be processed into liquid or gaseous fuels, or burned to generate power or gasses [4]. The forth-largest energy source ion the world is biomass. It makes up about 14% of the total energy consumed worldwide [9]. The types of biomass waste that can be seen in the environment in daily life are

Municipal Solid waste: The concept of "trash" as it exists in systems created by humans' does not exist in natural ecosystems. The term municipal solid state (MSW) refers to the organic and inorganic waste that homes and buildings discharge [3].

Agricultural waste: Organic elements left over from agricultural activities that are usually regarded as waste or by-products are referred to as agricultural waste biomass [3].

Sewage sludge (SS): A substantial amount of SS is produced by the physical, chemical and biological wastewater execution methods. In anaerobic digestion (AD) sewage sludge has the highest potential for producing biogas [3].

Livestock manure (LM): A consistent by product of the livestock yard is LM. The livestock is collected can be dried for several days, and the dried material is then utilized s fuel for the gasification process.

Forest residue: The most important lignocellulose raw materials for the production of bioenergy is forest residue [3].

Industrial residue: The material left over from food industries, petrochemical and pharmaceutical sectors. The agricultural and food sectors produce enormous amount of organic waste from the processed feedstock materials as well as biodegradable solid or liquid wastes [3].

Bioenergy is produced from biomass, plants (food and energy crops) may cultivated one essential resource for the development of bioenergy is biomass. It is mostly employed in the production of heat, electricity and biofuels [10]. The palm oil sludge which almost produces the 10% of oil and the rest 90% can be treated as biomass [11]. Waste from kitchens and sewage systems can contaminate waster. Physical treatment techniques are a possible source of biomass since they remove waste and particulates which can also be as source of biomass [12].

Types of technologies for biomass

There are three methods exist for utilizing biomass are physicochemical (such as the two or three trituration used to produce vegetable oils from oil plants seeds), biochemical (such as the anaerobic digestion of wet biomass and fermentation and hydrolysis of sugar plants) and thermochemical (such as pyrolysis, combustion and gasification and torrefaction) [13].

Thermochemical conversion technologies

Direct ignition: Direct ignition is the process of burning biomass directly into chemical energy that is stored as heat and power. Steam is produced when the biomass is burned in the oven to create thermal power.

Pyrolysis: Pyrolysis is a process that occur when organic compounds are exposed to high heat (400-700 .) in the absence of oxygen. Slow pyrolysis produces (250-400) produces more bio-char with longer residue durations. Flash pyrolysis (400-600) yields more bio-oil and bio-fuels due to short residence times. Catalytic pyrolysis increase the production of hydrogen, methane, ethane and propone by improving the gaseous fraction [14].

Gasification: Gasification is a thermochemical process that converts biomass into gas mixture, mainly carbon dioxide (CO_2), hydrogen (H_2) and carbon monoxide (CO). This process occurs at high temperatures (973 to 1773 k). The resulting gas also contains small amounts of methane (CH_4), nitrogen (N_2) as well as char, ash, tar and oils [15].

Torrefaction: Torrefaction, also known as mild pyrolysis, is a thermochemical process that enhances biomass properties subjected it to slow heating temperatures 200 and 300 (392 to 608) in an inert atmosphere. This technique reduces moisture and decreases the O/C ratio, increasing the energy content. Torrefaction allows biomass to retain approximately 70% of its original mass and 90% of its initial energy. Classification of Torrefaction are Light torrefaction (up to 230), Mild torrefaction (up to 260), and Severe torrefaction (up to 290)[16] It is preferable to use pellets made from torrefied biomass to enhance heating value, grindability, combustion performance, storage, transportation and handling [16].

Gasifiers: Gasifiers particularly fixed-bed or moving- bed types are among the simplest and most widely used for pilot-scale production. They are categorized into updraft and downdraft based on the direction of feedstock slow and gas flow. In fixed bed downdraft gasifiers, both the solid biomass and gas move downward, operating at temperatures around 1000 [3]. In fixed bed updraft gasifiers have a gas flowing upward while biomass moves downward, also operating near 1000 , but the syngas produced typically contains higher levels of tar. It has been discovered that the downdraft gasifier can produce 18.21 MJ/kg of power when coconut shells are used as fuel [17].

Thermochemical conversion technology for utilizing tea waste biomass and water hyacinth:

Bio char is produced through the process of pyrolysis when the tea debris which includes trimmed branches, seed shells and leftovers residue is treated. The produced bio char has many benefits such as Bio-adsorbents, Soil Amendment, and Precursor for catalysts and Energy storage devices [18]. The process of making water hyacinth biomass pellets involves exposing the materials to the light until its moisture content drops from 84.48 % to 10.57%. The texture of the pellets becomes hard and stiff as the temperature drops from 90 to 25 [19].

Biochemical/ Biological conversion technologies:

Biochemical conversion is the process of converting organic matter (such as biomass and agricultural waste) into useful energy sources by use of natural process like enzymes and microorganisms.

Composting: Composting is a natural recycling mechanism in which microorganisms such as bacteria, actinomycetes and fungus break down organic waste including leaves, yard trimming and kitchen waste in oxygen rich aerobic environment. The outcome is nutrient-rich compost, also known as "black gold" which nourishes soil [3]. Experiment like vermicomposting which uses banana leaves and cow manure in varying amounts aid in the composting process [20].

Bioethanol fermentation: Bioethanol fermentation yields bioethanol (CH_3CH_3OH) a renewable fuel generated from sugar-rich crops such as fruits and sugarcane. Ethanolgenic and saccharolytic microbes are essential to this process, turning sugars into ethanol via fermentation. The resulting ethanol is a clean burning fuel option [3].

Anaerobic digestion: The anaerobic digestion AD is like creating energy from waste organic compounds. Anaerobic digestion is a very effective method of producing methane (CH_3) also referred as biogas, from organic waste. We can use this biogas as a green energy source. Besides producing energy AD aids in the deactivation of dangerous pathogens that are present in the waste materials [3].

Pellets and Briquettes:

Pellets*:* These cylindrical solid biofuels are usually between 6 and 8 mm in dimeter and up to 40mm I length. They are frequently seen in smaller appliances like gasifiers and stoves in homes.

Briquettes: Briquettes which are larger and have diameters between 5 and 90mm lengths between 75 and 300 mm are used in big and medium sized industrial settings. The Preprocessing is to improve the pellets qualities size reduction, torrefaction, steam explosion, and hydrothermal carbonization are for preprocessing techniques that enhances biomass handling qualities, bulk density and energy density [21]. Waste cooking oil (WCO), waste lubrication oil (WLO) and recovered polyvinyl alcohol (rPVA) are combined to create fuel pellets from biomass. Important pellet characteristics like calorific value (CV), strength and durability can all be improved by adding a binder [22].

Pellets made from rice straw are one popular kind of biomass solid fuel. But because of their high ash content and low gross calorific value they have difficulties. The pellets made by combining rice straw and moso bamboo in different propagations. The pellets calorific value and strength and durability is raised with the 2:3, and 3:2 weight ratios [23].

Van Hoang Nguyen et al. [24] produced activated carbon with ultrahigh surface area was made from sawdust using a simple one-step chemical activation. The resulting sawdust activated carbon (SACs) is porous, with aggregated nanoparticles measuring 10 to 20 nm in diameter. The activated carbon demonstrates the potential as an absorber for the practical treatment of dye-containing wastewater.

Ravi Kumar R. et al. [25] tested a producer gas cleaning system for a downdraft gasifier that uses a combination of segregated Dry Municipal Solid Waste (SDMSW) and biomass with ratio propagations. The blending ratio of 60:40 (Biomass: SDMSW) showed the highest efficiency with calorific value 3428.62 kcal/kg and efficiency of 54.28%.

Albara Mustafa et al. [26] investigated the manufacture of liquid biofuels from biomass to meet the demand for public transportation in Narvik, Norway. The biomass waste from woods and municipalities was employed and the energy produced from trash was three times greater than the fuel need, with the excess biofuel used to generate heat. The density of the syngas is 0.95 kg/m3. It is concluded that the payback period could be completed within four years.

Objectives

Gathering sawdust from fields and turning it into pellets.
By utilizing the pellet as fuel to create syngas in a downdraft gasifier.
The produced syngas eventually replace the LPG for domestic purposes.
To enhance the efficiency and decreases the time with the change of air velocity such as 10, 15, 20, 25 M/sec.

II. Material And Methods

Sawdust Extraction and Making Them into Pellets

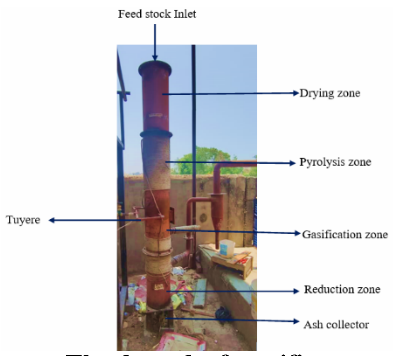
The experiment was conducted using the sawdust gathered from Tasmanian blue-gum eucalyptus (Neelagiri) trees harvested for the paper manufacturing sector. These trees are recognized for increasing the strength and longevity of paper are commonly used to make books, packaging and personal care products. The gathered sawdust was taken to pellet factory in Hyderabad, where it was sun dried to reduce the moisture before crushed uniform particles with a wood crusher. Pellet are then produced Using pellet machine, with waste lubricating oil added to increase the calorific value, strength and durability. A total of 82 kg of pellets were generated with the samples collected for both ultimate and proximate analysis.



The collected sawdust **Pellet making machine** **Tasmanian blue-gum eucalyptus pellets**

The gasifier

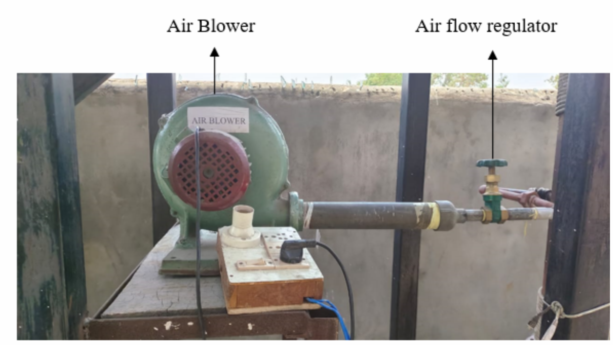
The gasifier is designed in the vertical cylinder shape. The gasification setup consist of four zones the drying zone, pyrolysis zone, gasification zone and reduction zone. The temperatures are denoted as T1 for Drying Zone, T2 for pyrolysis zone, and T3 for Gasification zone and T4 for reduction zone. The feedstock is been installed from the top by opening the plate and the feedstock is settled at the pyrolysis stage. The ash collection is been done from the bottom next after reduction zone is shown.



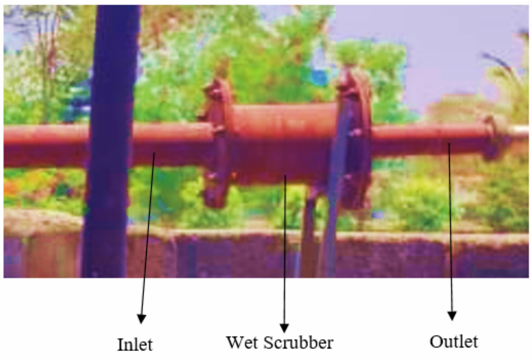
The downdraft gasifier

Air Blower and wet scrubber

An air blower is used to supply the air which acts as gasifying agent for gasification process. The connection is done with Tuyere in opposite direction and air flow regulator is fixed to adjust the air velocities. A specialized tool called a wet scrubber is used to extract the contaminants when they pass through the water or solvent from exhaust gas before it prepare for its usage. In addiction temperature of gas decreases. The outlet provide cleaner gas as these elements must be handled efficiently.



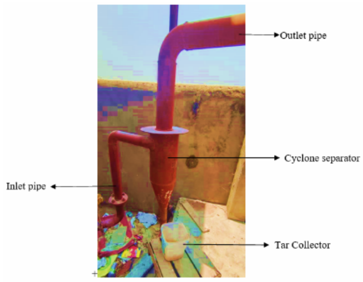
Air blower



Wet scrubber.

Cyclone separator

A cyclone separator is a necessary instrument for removing the particulate matter. The inlet is located at the lateral side, the air which is dense with solid particles enters. The denser, bigger particles are forced outward by centrifugal force. The particles collide with the vessel wall and fall down to bottom. Afterwards the smaller particles are collected in the tar collector. The clean syngas leaves from the top with the high velocity.



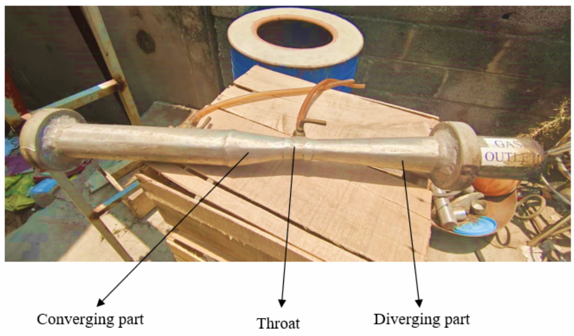
The cyclone separator

The specific dimensions of the cyclone separator.

Parameter	Dimension in mm
Diameter of the cyclone body (barrel)	152.5
Length of the body	304.8
Length of the cone	304.8
Total length of the cyclone	609.6
Diameter of the gas exit	76.2
Diameter of the dust outlet	38.1
Width of the inlet	38.1

Venturimeter

A venturimeter is a tool for measuring the rate at which fluid flows through the pipe. The venturimeter consist of a Converging part, Throat and Diverging part. A U-tube manometer is a simplest pressure measurement device. It consist of the U-Shaped glass tube filled with liquid. When the venturimeter is coupled to a U-tube manometer in gasification process, we can measure the pressure difference between the two sections. The pressure differential measured by the manometer is used to calculate the flow rate of fluid through the pipe.

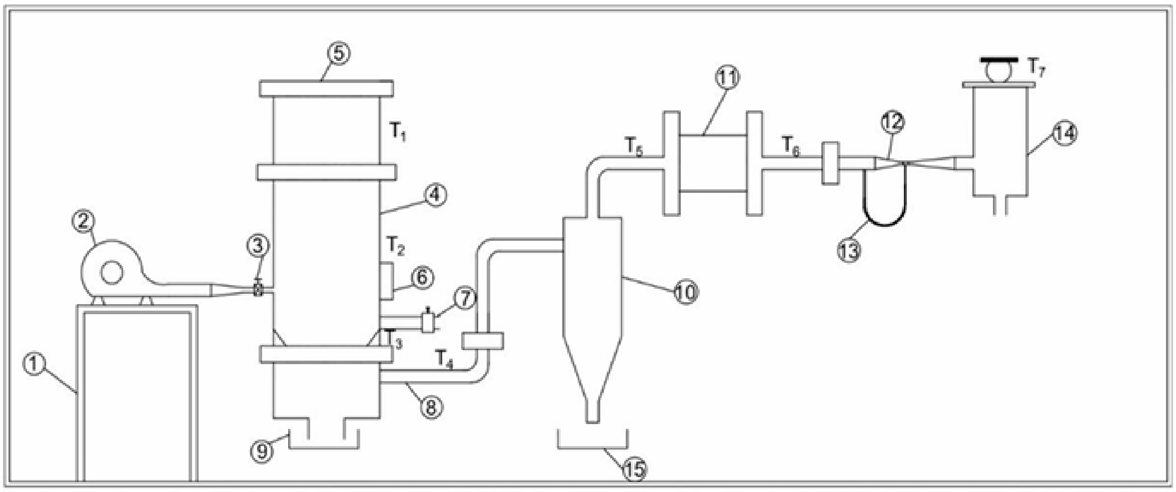


Venturimeter

U-tube manometer connection with venturimeter

The experiment setup of biomass downdraft gasifier

The downdraft gasifier for biomass is located in Maturi Venkata Subba Rao Engineering College, Hyderabad. The downdraft gasifier setup consist of the various components are 1) A support stand for the air blower, (2) the air blower, (3)the airflow regulator (4) the gasifier (5) feed stock (6) the fire door (7) gas blow-off pipe (8) gas outlet pipe (9) tar collection unit (10) cyclone separator (11) wet scrubber (12) gas flow meter (13) manometer (14) gas burner (15) ash collection as shown in figure by the researcher [25].



The schematic layout of the experimental setup with cyclone separator [25]

The setup of the downdraft gasifier is been designed such a way that

1. Feedstock Installation: The feedstock which is the fuel for the gasifier is been installed from the upper side of the gasifier as shown in figure 5 component.
2. Drying process: This process is done after the pellets are installed and before the fire ignite takes place from the fire door. The air blower is connected as shown in figure 2 component. And it is controlled by the airflow regulator shown in figure 3 component to set the velocity of air inlet as gasifying agent. The air blower should run for the 3-5 minutes. So that the pellet becomes as much as moisture free condition.
3. Fire door: The fire is ignited from the fire door after the drying process is done. To catch the fire a small fire bed is needed in some cases with the available sources to catch the fire properly. The precautions are taken while opening as there is a chance of pellet leakage. So a small necessary gap is sufficient from half opening.
4. Pyrolysis process: This process is done in pyrolysis zone and the combustion takes place in the complete absence of oxygen and the temperature range is higher. The volatile gases and solid char are comes as a byproduct. The gasifying agent is not necessary here so the air blower should be off for this process. Depending on the gas coming out from the gas outlet the next step continues.
5. Gasification zone: The volatile gases and bio char here treated by using the gasifying agent. The air is supplied. Hence the fire ignites here until the bio char completely turns into gas and ash. The temperatures are almost the peak of this process. The more generation of gas is been seen here according to runtime. The process goes continues and followed by reduction.
6. Reduction zone: Here the gas particles and solid ash gets separated. The gas is sent to the cyclone separator through the gas outlet pipe and the remaining solid ash falls down. From here onwards the temperature decreases for further process.
7. Tar collector: The tar collector is been placed next down to reduction zone as shown in figure 9 component to collect the solid ash.
8. Cyclone separator: The gases which comes from the gas outlet pipe is connected to the cyclone separator as shown in figure 10 component. The gas contains some fly ash particles up to here. The fly ash particles gets into the ash collector.
9. Wet scrubber: This is followed up process after the cyclone separator as the other contaminated and other small particles get removed by passing through wet scrubber. The temperature of syngas almost reaches to atmospheric condition.
10. The venturimeter: The mass flowrate of the syngas flowing through the equipment is measured with the venturimeter connected to u-tube manometer.
11. Gas outlet: The gas outlet is connected at the end for capturing the syngas.

The same experiment is done with the variation in the air velocities as 10, 15, 20, 25 m/sec in four different days. The feed stock inlet for every reading is taken as a constant feedstock 20 kg's. The temperature is taken as T1, T2, T3, T4, T5 and T6.and the runtime of experiments is taken in seconds. The recording the pressure head difference from U-tube manometer and the further steps follows by data reduction.

Formulas used
The formulas are taken from the standard textbook of fluid mechanics Rajput
The discharge formula (Q)
$Q_{act}=C_d\times A_1\times A_2\times sqrt\ (2gh)/sqrt\ (A_1^2-A_2^2)$ ….. (1)
Q_{act}= Actual discharge.
Where C_d is the coefficient of 0.98.
A_1 is the cross section of inlet= (π/4) $d_1^{2.}$
A_2 is the cross section o at the throat= (π/4) d_2^2.
Where d_1= 2 inch = 0.0508 meters.
d_2 = 1 inch = 0.0254 meters and g= 9.81.
h= Venture head (differential pressure head),
$h=x/1000(S_{water}/S_{gas}-1)$ …..(2)
By substituting the equation 2 in equation 1 we will get the actual discharge.
Where x=differential manometer reading in terms of meters of manometric fluid.
S_{water}= Specific gravity of manometric fluid.
S_{gas}=specific gravity of fluid in pipe and considering standard fluid is water.
Mass flow rate = density of syngas * actual discharge.
$M_f=\rho*Q_{act}$. ….. (3)
By substituting the equation 1 in equation 3 we will get the mass flow rate.
Mass of the gas = mass flowrate * time in seconds.
$M=M_f$*time. ….. (4)
By substituting the equation 3 in equation 4 we will get the mass of syngas.
Output= mass of syngas/ calorific value of gas.
Input= mass of pellet/ calorific value of pellet.
By taking all the values substitute in equation 5 the efficiency is calculated
Efficiency =η
(η)% = (output/input)*100. ….. (5)

III. Results

Test reports
Proximate analysis report

Table no 1: The proximate analysis report of pellet

S.NO	Parameters	Units	Results
A	**Proximate analysis**	-	-
1	Moisture content	% by mass	7.70
2	Ash content	% by mass	2.40
3	Volatile matter	% by mass	71.40
4	Fixed carbon	% by mass	18.50
B	Gross calorific value	K Cal/ kg	4250
C	Bulk density	g/cc	0.4244

Ultimate analysis report

Table no 2: The ultimate analysis report

S.NO	PRAMETERS Ultimate Analysis	VALUES Repetition 1	VALUES Repetition 2	VALUES Delta	VALUES Mean value
1	CARBON, C	46.48	46.23	0.25	46.36
2	HYDROGEN, H	6.314	6.306	0.008	6.310
3	NITROGEN, N	0.46	0.47	0.01	0.47
4	SULPHUR, S	0.000	0.000	0.000	0.000
5	OXYGEN, O				44.46

Table no 3: The result after calculation.

S.no	Air Velocity from blower	T1	T2	T3	T4	T5	T6	Time in second	Mass of syngas	Mass of pellets	Calorific value of syngas	Calorific value of pellet	Efficiency (%)

	(Mt/sec)												
1	10	52	282	455	230	115	52	2280	10.09	20	3463	4250	41.11
2	15	48	297	566	255	127	56	1860	11.64	20	3485	4250	47.73
3	20	55	311	595	268	146	59	1560	11.95	20	3527	4250	49.62
4	25	55	333	642	282	168	63	1380	12.95	20	3587	4250	54.67

The atmospheric temperature is ±45 centigrade. Air velocity from the air blower to gasification zone is been operated by valve (Full opening 10 revolutions 25 m/sec). T1 – Drying zone temperature, T2- Pyrolysis zone temperature, T3- gasification zone temperature, T4- reduction zone temperatureT5- reduction to cyclone separator temperature, T6- gas out temperature.(T1, T2, T3, T4, T5, and T6) all the temperature reading are taken in centigrade. Time is taken in seconds of syngas production start to end.

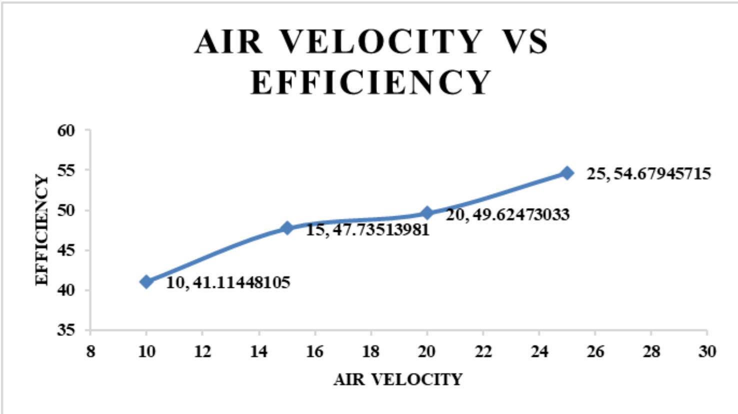


Fig no 1: Air velocity vs Efficiency

The figure 1 shows variation of efficiency with air velocity, as the Air velocity increases the efficiency increases which means the gasifying agent (air) supply to the gasification zone.

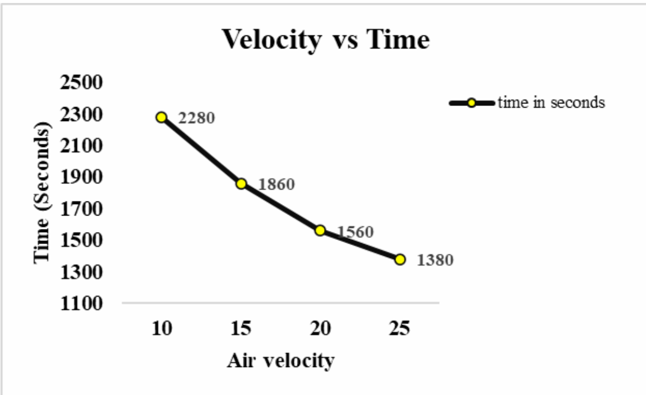


Fig no 2: Air velocity vs Time

The time taken for the gasification decreases as the Air velocity increases as shown in fig 2. The air is supplied as the gasifying agent to the gasification process which helps in the complete combustion the time taken for the process is decreases.

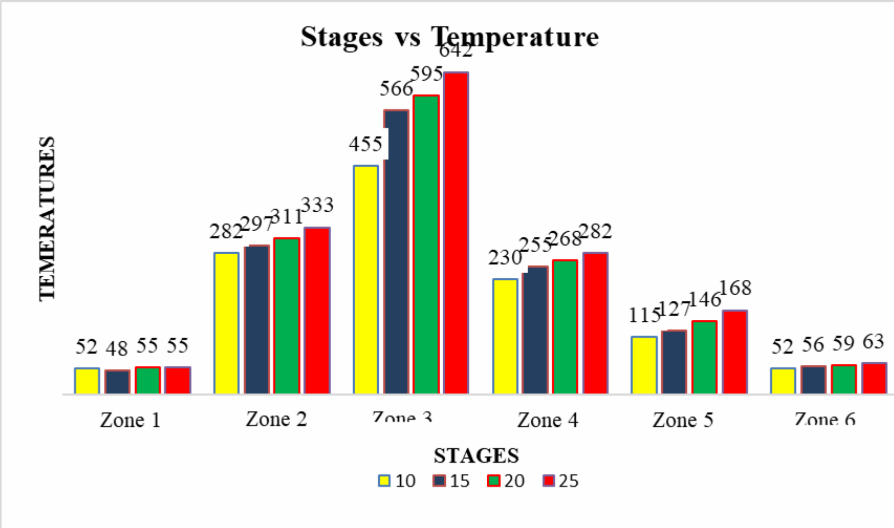


Fig no 3: Temperature versus stages of downdraft gasifier at different velocities

The different zones of temperatures of downdraft gasifier process is shown above in figure 3. As the air velocity increases the temperatures for mainly pyrolysis, gasification, reduction zone increases this is because the high temperature are attain with velocity increases hence the time decreases.

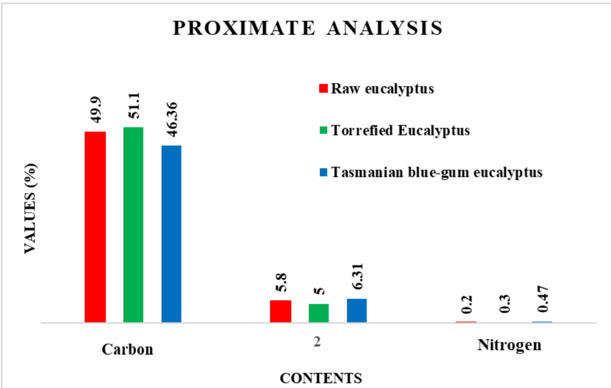


Fig no 4: The proximate analysis Comparison with Filomena Pinto [16]

The carbon, hydrogen and nitrogen content values compared with the literature **Error! Reference source not found.** with my experiment values as shown in figure 4. As a result compared to the raw eucalyptus the pellet used for experiment shows the better contents and compared to the torrefied eucalyptus my fuel have an additive of waste lubricating oil which is cost effective.

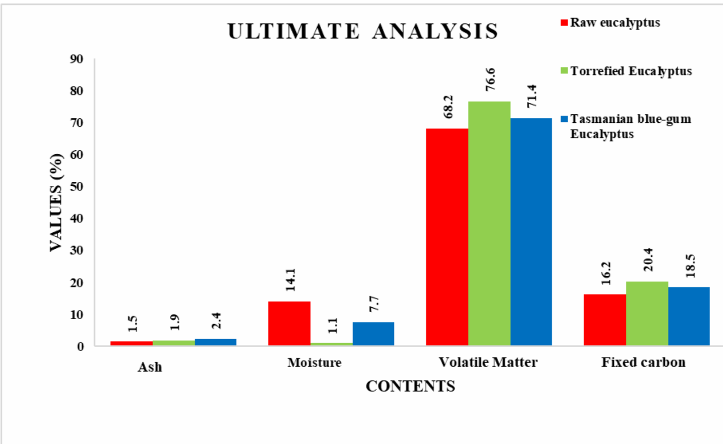


Fig no 5: Ultimate analysis Comparison with Filomena Pinto [16]

The ash, moisture contents, volatile matter and fixed carbon values compared with the available literature [16]. As a result compared to the raw eucalyptus the pellet used for experiment shows the better contents and compared to the torrefied eucalyptus my fuel have an additive of waste lubricating oil which is cost effective.

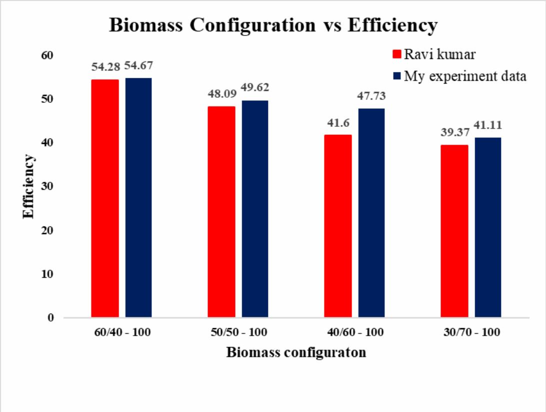


Fig no 6: Comparison of experiment efficiency with R. Ravi Kumar [25]

The comparison of data from the available literature [25] as the researcher follows to do the experiment with two different biomass configurations by ratios and the efficiency is shown in figure 7. From my experiment data the air velocity variations such as my best data is 25, 20, 15 and 10 m/sec observed with the data of available literature from his best configuration. Hence from maintaining only single biomass with variation in air velocity also gives the better efficiency.

IV. Discussion

The pellets that are used for the experiment is better than the raw eucalyptus sawdust and also the proximate and ultimate analysis of the pellets are better than compared with the raw eucalyptus pellets compared with the [16].

As the experiment is done by using the downdraft gasifier with the variation of the air velocity we can see that as the air velocity increases the time taken for the gasification process decreases and the efficiency increases.

As we can see while supplying the air velocity 10 m/s the time taken is 2280 seconds and efficiency is 41.11 with the increases of the air velocity 15 m/s the time is 1860 seconds and efficiency is 47.73 and with the increases of the air velocity 20 m/s the time is 1560 seconds and efficiency is 49.62and also with the increases of the air velocity 25 m/s the time is 1360 seconds and efficiency is 54.67.

Form the theoretical study if the air velocity increases beyond 30m/s, the time is not sufficient for the complete burning at gasification process because of the insufficient time of burning the tar content will increases. Hence the efficiency will decreases.

Table shows the Air velocity vs Time vs Efficiency

Air velocity	Time	Efficiency %
10	2280	41.11
15	1860	47.73
20	1560	49.62
25	1380	54.67

V. Conclusions

- Raw sawdust is collected and processed into pellets using waste lubricating oil. Proximate and ultimate analysis are performed.
- The test results strongly favor gasification over raw eucalyptus according to previous literature [16]. As the comparison with torrefied eucalyptus, the fuel used is not torrefied but the results shows slight differ change.
- As air velocity increases, efficiency increases because the gasifying agent (air) is provided to the gasification zone, allowing for easier fuel combustion
- Hence shortening the time required for gasification, resulting in a more efficient process.
- Air velocity enhances efficiency by almost 40%.

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