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Effects of a Cyclone Dimensions on Quality of Syngas Produced with a Wood-fired Biomass Gasifier

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Authors' contributions

This work was carried out in collaboration among all authors. Author NJF designed the study, conducted field testings and wrote the first draft of this paper. Author HS, revised this paper. Authors SBG and OF managed the analysis of the experiments. Author CH conducted field testing and followed up the construction of the two cyclones. All authors read and approved the final manuscript.

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ABSTRACT

Charcoal gasification was widely used during the second World War to deal with petroleum scarcity. When petroleum was again available after the war, gasification was neglected afterwards. However, fossils resources are know as non-renewable and there are several reseach carried out all over the world to develop renewable sources of energy. Under that scope gasifiers are of great interest in the developing countries for developing individual or decentralised sources of energy.

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Even in developed countries, several research and implementation of gasification units are in progress.
In a previous work, we designed and fabricated a downdraft biomass gasifier with a relatively big cyclone and filtration units. Produced syngas was full of moisture and carbon dioxyde (CO_2) when the gasifier was feed with wood, but moisture content was lesser with charcoal. Therefore further work should be carried out in order to use low density wood itself from agricultural, furniture makers or sawmill wastes.
We compared different cyclone separator design methods, adopted the Lapple's cutt of model and found that to obtain good removal efficiency of unwanted particles, it is better to work with small cyclones. The new cyclone that we built allowed us on the one hand to reduce the humidity of the synthesis gas obtained, and on the other hand to reduce the quantity of tars in the liquid collected at the bottom of the cyclone. These improvements have led to the production of cleaner and better fuel syngas.

Keywords: Gasifier; syngas; wood; moisture; cyclone; design.

1. INTRODUCTION

Until the start of the Second World War, oil and its derivatives were the main source of energy in Europe. Oil supplies having been severely disrupted by the war, several European countries, led by Sweden had developed the gasification of coal for the propulsion of motor vehicles [1].

In Burkina Faso, the total consumption of primary energy was estimated equal to nearly 2625 Kilotonne in 2008 with a strong dependence on biomass which represents more than 80% of consumed energy [2-5]. On year 2019, total consumption of primary energy raised to 4657 Kilotonne with 99% from biomass whereas hydropower and solar photovoltaic represents less than 1% [6-8].

Biomass gasification, very little used in Burkina Faso, is one of the most efficient methods for converting biomass into thermal and electrical energy. Despite the abundance of waste of agricultural, vegetable and household origin, the large-scale exploitation of this conversion process is very little developed in Burkina Faso [9,10]. In a bibliographic review made in 2014, it was established that gasification of waste may be an interesting alternative for Burkina Faso [11]. Other studies on the development of biomass energy in Africa agree with the main conclusions of this review [12-14].

Barry et. Al [15] stated that: "*The syngas production sector by gasification of mobilizable residues can only be competitive with the butane gas market if the technology is manufactured locally.*" In fact gasification units where installed at Dano, Po and Bama in Burkina Faso. But these projects didn't fully success, even if they had gasification units technologies that are in production elsewhere in the world. However gasification still appears as feasible in Burkina Faso, provided some economical and technical considerations be taken in account [16]. Therefore, we have a challenge to locally manufacture gasification units for electrical power generation in Burkina Faso.

We are in the process of designing and thoroughly testing small-scale gasifiers in order to better master the gasification technology with locally manufactured units. We have previously designed and fabricated a laboratory-scale gasifier with the aim of converting biomass, mainly waste from the city of Koudougou, into a gas that can be used as fuel. This paper report work aimed to improving the first syngas purification stage of that gasifier through the use of cyclones separators by observing the flame quality of syngas combustion at the flaring port and the state of wood filters chips.

2. MATERIALS AND METHODS

2.1 Materials

Components of the gasification unit are essentially grouped into two parts namely the reactor body and the auxiliary equipments. The cyclone separator, part of the auxiliary equipements constitue the subject of this work.

The wood used is cut from air-dried eucalyptus shrubs. For each experiment in this paper, we put approximately 8.5 kg of wood in the gasifier. The pieces of wood were cut with a machete and we tried to cut the large pieces further, so that the length of each piece of wood was approximately 7 cm at most for a width of 4 cm at most and a thickness of 2 cm. at most. The pieces of wood taken from the exterior part of the shrubs kept their bark. Under the sieve, we had left some coals from the previous gasification, just enough to fill the sieve and facilitate the igniting of the fuel.

2.2 Component of Gasifier

Fig. 1. give us the schematic of the overall gasification system :

2.2.1 Generator

The gasifier used here (or in this case) is a co-current downdrat type fuelled with wood. The body of the gas generator (or the reactor) is made up of two parts : an upper part which includes the hopper and the combustion chamber, and a lower part consisting of the gas outlet pipe, the ignition and cleaning ports.

2.2.2 Auxiliary equipments

The auxiliary equipments mainly comprise a cyclone, a gas expansion chamber, a filter and an air blower.

a. The cyclone

At the outlet of the reactor, the synthesis gas contains particles in suspension and water vapour. Several authors have used a cyclone separator as a first syngas purication stage [17-19].

The separator used in our gasification process are cyclones constructed with dimensions given in table 1. These are drawed and pictured on Fig. 2. In the first fabrication, the synthesis gas produced in the reaction chamber was input in the cyclone through a 6 cm diameter pipe. In the second fabrication, diameter of the admission pipe to the cyclone was reduced to 4 cm.

Both two cyclones helped us eliminate some heavy particles (tar) and allowed partial condensation of water vapor contained in the synthesis gases.

b. The filtering and expansion unit

The gases obtained after the separator cyclone may still contain dust and water vapor. The filter and expansion chamber, of which the operating diagram is given in Fig. 3c, is intended to ensure the purification and cooling of the gases under the effect of expansion. Thus, in this unit the gases undergo a first expansion in a cylindrical tube of 34,681 cm^3. They then pass through a first carpet of wood chips located at the bottom of this first cylinder and acting as a filter. Then, the gases continue their expansion at the bottom of the unit where a large volume of 35,501 cm^3 is offered to them. This expansion is accompanied by a drop in temperature according to the ideal gas equation: $PV = nRT$, where P is the temperature in Pa, V the volume in m^3, n the number of moles of gas in mol, R the constant ideal gas in $J.mol^{-1}.K^{-1}$ and T the temperature in K. Cooling the gases below 100°C, which is the vaporization temperature of water, causes the condensation of the water vapor contained in the gases that which is collected at the bottom of the filter and expansion chamber. Coming out through another cylindrical tube of volume 7,850 cm^3 filled with wood chips, the cooled gases are purified on the second belt of wood chips, before being used in the internal combustion engine intended for the production of electricity. Wood chips serve as a filtering mass for tars, water vapor by absorption and many other particles.

c. The burner

Through a tube, the gases are channeled to the power generation set for its usage. Before injecting the syngas into the engine's combustion chamber, a test burner used as a flaring port is built to ensure that the syngas is combustible. The first burner constructed was simply fabricated with empties camping gas cannes as illustrated in Fig. 3a.

d. Mesurement apparatus

Measurement apparatus whe have used in this study are depicted on Fig. 4 bellow. During our various tests, we introduced temperature sensors (4.a) and at the outlet of the reactor to monitor the evolution of the temperature in the reactor and that of the syngas as the exit the reactor.

Humidity sensors (4.b) were also introduced to monitor the evolution of the humidity of the gas at the outlet of the different units of the experimental unit.

Gas analyzers, such as the Bacharach, Fyrite Intech (4.e) and Monoxor III (4.f) and "Testo 310" (4.d) were used to monitor the evolution of carbon monoxide. Unfortunately, CO display from Testo 310 was erratic (rapid increase up to out of range), even when put at the same sampling point with the Monoxor III. We therefore concluded that its CO sensor was bad.

"Testo 325" was also aimed to mesasure methane and dioxygen, CO_2, effiency, etc. But its O_2 sensor is clearly reported bad with an error code displayed at the startup.

Fyrite Pro 110 (4.c), have a bad O2 sensor. Nothing relevant other than the temperature would have been measured with it. So we used thermocouples reading on multimeters as thermometers (4.a) for sake of setup simplicity instead of the gaz analysers.

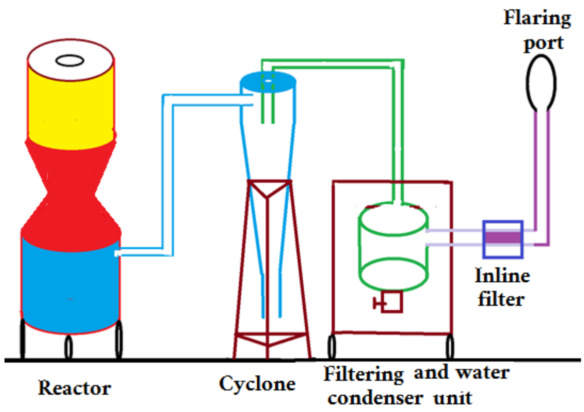


Fig. 1. Overall gasification system

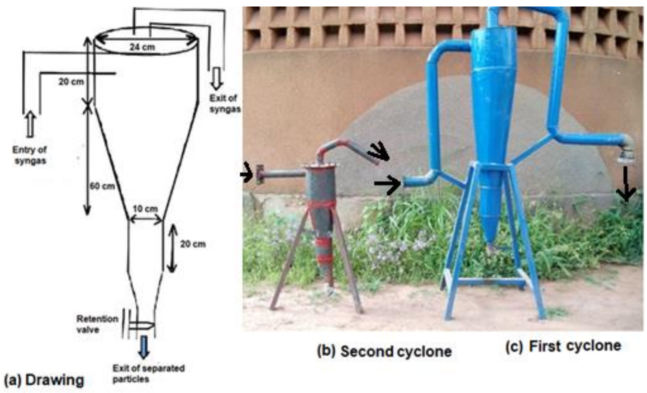


Fig. 2. Drawing and dimensions of the of the first cyclone and picture of both cyclones for comparison

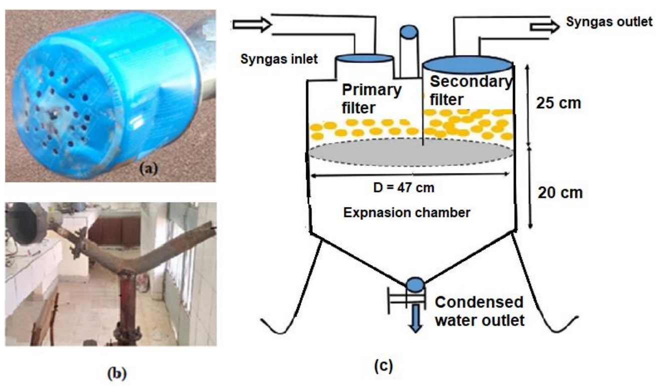


Fig. 3. Test burners (a) and (b) and expansion-filtering unit (c)

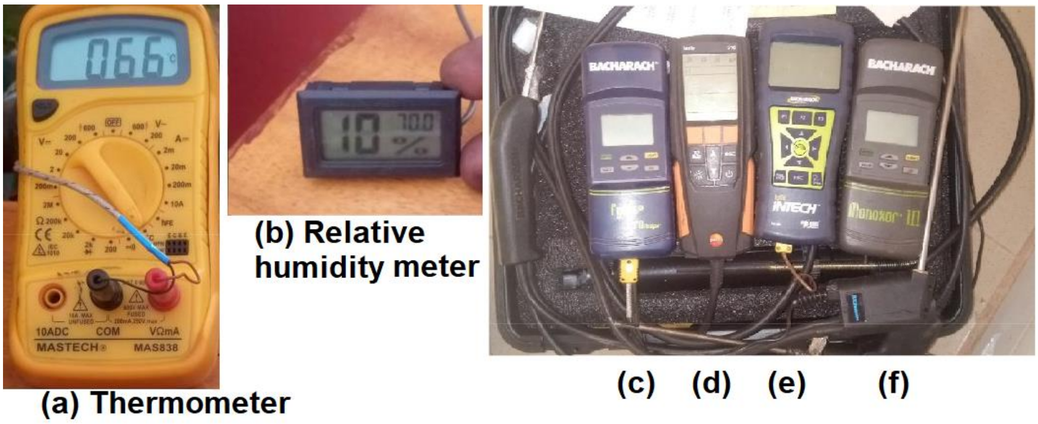


Fig. 4. Measurement apparatuses used in the study

2.3 Design Modelling of the Gasifier

Gasification is a process that was widely used during the Second World War to deal with the shortage of hydrocarbons. Nowadays, in the face of climate change and the lack of oil resources, the urgent need for this process, abandoned after several years, is resurfacing.

From an energy point of view, the term biomass refers to all organic matter that can be used as energy sources [20-22]. Thus, the existence of a high variability in the composition of biomass promotes the development of various technologies for its energy recovery [23]. Gasification is a thermal conversion process of carbonaceous or organic materials in the presence of an oxidizing agent (oxygen, carbon dioxide, water vapour) into a synthesis gas. In other words, gasification is the process of converting biomass into a mixture of combustible gases by partial oxidation at very high temperatures [24,25].

At the reactor outlet, syngas contains combustible gases, water vapor, and solid particles (tar, ash residue). It is advised to purify syngas before using it in an ICE (Internal Combustion Engine) for electrical power generation. Purification methods include separation, filtering among many others.

3. EXPERIMENTAL SET UP

3.1 The Gasification Unit

Parts of the biomass gasifier, as labeled on Fig. 5 bellow are: the reactor (a), the cyclone (b), the gas expansion chamber (c), the filter and the burner (d) that are then assembled by screws and nuts. This setup allows to separate differents parts of the gasifier during maintenance. This gasification unit, made according to the Imbert model is a “downdraft gasifier ”.

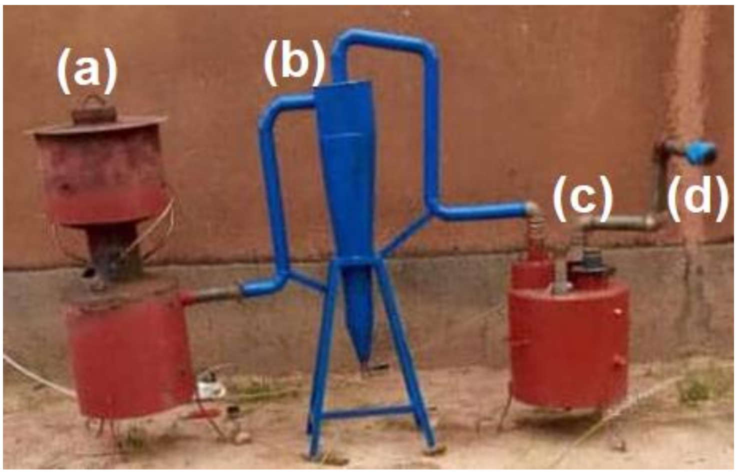


Fig. 5. Experimental setup with first and second cyclone

3.2 Power on Procedure

For the very first launch of the gasifier, we added charcoal to the grate located under the combustion port. Then we fill the combustion tube with coal to a height of 4 inches above the grate. Additionally, we need to fill the fuel hopper with air-dried wood and then follow the following instructions:

1. Sensors for measuring parameters such as temperature, humidity and gas analyzers are placed during the assembly of the experimental device to monitor the evolution of these parameters during the operation of the reactor
2. After checking the tightness of the experimental device, we adapt the blower then turn it on full blast for a few minutes to evacuate the gases in the different units.
3. In addition, fire is introduced from the ignition tube to initiate combustion. Diesel fuel can be used to initiate combustion. Using a cap, close the ignition tube by reducing the speed of the blower a little and then let it run. A few minutes later, we increase the speed by following the evolution of the temperatures.
4. As soon as combustion has started, we monitor, using the analyzers, the evolution of the proportions of combustible gases such as CO; CH_4 and H_2. When the CO proportion reaches 1060 ppm (part per million), let's test if the gases are combustible by approaching a flame.
5. We always check the permanence of combustible gases at the outlet of the reactor before using it in the engine. To do this, the speed of the blower must be adjusted so as to have a permanent production of combustible gas.

3.3 Power on and Running the Gasifier

After switching on the gasifier, the blower speeds must be adapted in order to keep the syngas production rate stable. Next, we need to refill the hopper before it is completely empty. Finally, we shake the grid regularly to make the ashes fall. To turn off the gasifier, the hopper must be closed so as to avoid any entry of air which could be used to maintain combustion.

3.2.3 Maintenance procedures

During operation of the gasifier we must regularly check the junctions and tightening to avoid any gas leaks. In addition, we must remove the ashes from the cleaning module every day after shaking the grid for a few minutes. We also open the filter and cyclone evacuation valve to remove the condensed liquid before starting the gasification. Maintenance carried out every week following the following procedure:

1. Clean the bottom of the gasification unit, the fuel hopper, and the filter.
2. Rinse the pipes and connections connecting the different components of the gasifier.
3. Replace the wood chips in the filter. Used shavings can be placed in the hopper and used as fuel.
4. Use high temperature silicone gasket to seal all pipes and the relatively to ambiant air

3.4 Design and Assembly of New Cyclone

3.4.1 Cyclone design

Cyclones have been used since the late 1800's to remove dust from industrial gas streams. Their simple design, low capital and maintenance costs, and adaptability to a wide range of operating conditions have made cyclones the most widely used industrial dust collectors [26].

The first cyclone we built [27] have proved to be poorly effective, hence the need for its improvement.

In a cyclone, the gases arrives tangentially to the body of it. Heavy particles are retained by the cyclone and settle to the bottom while light ones rise and emerge vertically.

Cyclone collection efficiency, η, is defined as the fraction of particles of a given size that is retained by the cyclone. Several theories have been developed to predict collection efficiency. Unfortunately, these greatly differ in complexity. While a general agreement seem to be that operating parameters of the system should be used to predict performance, there is less agreement on the effects of cyclone dimensions and geometry [26].

According to Leith et al. [28] three general approaches to predicting cyclone collection efficiency have been identified. We will only consider one of the these : the Critical Diameter.

This method assumes that particles enter the cyclone at certain radial distance from the cyclone axis. Particles must travel outward from this position to the wall to be collected; the critical particle is the size that travels exactly this distance during its residence time in the cyclone.

Different assumptions about initial radial position and residence time lead to different approximate solutions.

According to Lapple et al. [29] cut diameter theory is the most widely used example, also called « the timed flight approach ». Lapple assumed that dust entering the cyclone was evenly distributed across the inlet opening. The particle size that travels from the inlet half width to the wall during the time in the cyclone is collected with 50% efficiency is called the cut diameter. Lapple calculated this particle size, the cut diameter, as :

$$d_{50} = \sqrt{\frac{9\mu b}{2\pi\rho_p\ \upsilon_i N}}$$

With
μ : gas velocity vicocity (Pa.s)
b : cyclone inlet width (m)
ρ_p : particles density (kg/m^3)
υ_i : gas inlet velocity (m/s)
N : number of revolutions gas makes in the cyclone (dimensionless)

The "static particle" theory of Barth [30] to predict d_{50} gives :

$$d_{50} = \sqrt{\frac{9\mu Q}{\pi\rho_p\ Z_c V_{tmax}^2}}$$

Where :
μ : gas viscosity
Q : gas flow
ρ_p : particles density
Z_c : vortex core length
V_{tmax} : maximum tangential velocity

Tangential velocity of particles and gas are assumed equal.

Iozia and Leith [31] developed equations to predict these terms from measurements of the gas flow pattern within cyclones of various dimensions and found that maximum tangential velocity is given [32] by expression :

$$Vt_{max} = 6.1\ V_i\ \left(\frac{ab}{D^2}\right)^{0.61} \left(\frac{D}{D_e}\right)^{0.74} \left(\frac{D}{H}\right)^{0.33}$$

Core length was determined with two dimensionnal assumptions [33]:

$$z_c = H - S$$

When
$d_c < B$

$$z_c = (H - S) - \left(\frac{H-h}{\left(\frac{D}{B}\right)-1}\right)\left(\frac{\frac{D}{B}-1}{\frac{D_c}{B}-1}\right)$$

when
$d_c > B$

Core diameter is given [17] by expression :

$$d_c = 0.47D\left(\frac{ab}{D^2}\right)^{-0.26}\left(\frac{D_e}{D}\right)^{1/4}$$

Geometrical dimensions are depicted in Fig. 6 from Ioza and Leith [31].

For a given syngas reactor, if we let the gas flow Q, particles density and gas viscosity all contants, we could group their values in one constant cte and see that collection effiency could be expressed as :

$$d_{50} = \frac{cte}{V_{tmax}\sqrt{Z_c}}$$

This formula can be compared to that of given by Matsen [23] :

$$d_{50}^0 = 1.16\sqrt{\frac{\mu WD}{\rho U^2 t}}$$

where
μ = gas viscosity
W = cyclone inlet width
D = cyclone barrel diameter
ρ = particle density
U = gas velocity at inlet
t = average gas residence time

Gas residence time is given by :

$$t = \frac{V}{hWU},$$

where
V = cyclone volume
h = cyclone inlet height

These three formula suggested us that the bigger V_{tmax}, the lesser cut diameter, hopefully better particles removal.

Because for a given partial pressure in the reactor, particles exit from the reactor should be higher when the exit surface, ie the pipe diameter decrease.

By observing what happens when the pressure of a fluid to which an outlet is offered increases, we suspected that to have a high speed of gas exit at the level of the reactor, it would be good to have a diameter of the tube smaller output. This would give a greater entry speed of the U gases into the separator cyclone. Thus for a given partial pressure in the reactor, the speed of the particles leaving the reactor should be greater when the outlet surface, i.e. the diameter of the tube, decreases.

Considering also the relative cost calulated by Stermand [34] as depicted in Fig. 7, we definitely opted for a smaller cyclone compared to the first one we built.

3.4.2 Manufacturing of the second cyclone

The cyclone we used is constructed using 2 mm thick sheet metal. Dimensions are given in Table 1.

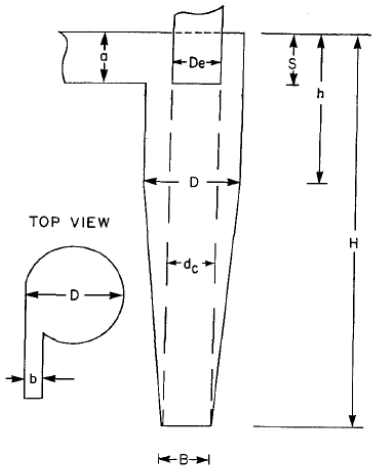


Fig. 6. Cyclone parameter according to Donna Lee Iozia & David Leith [31]

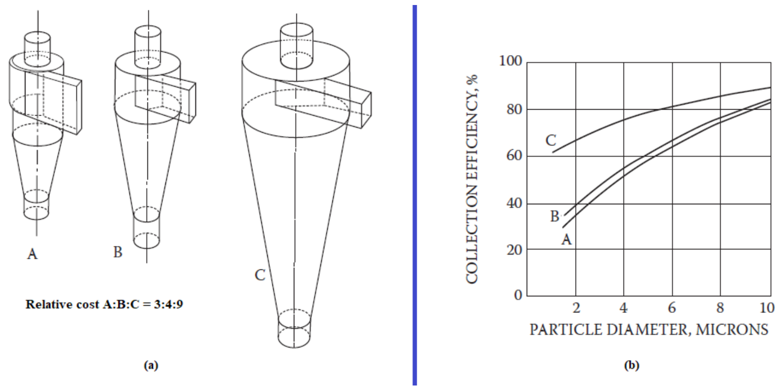


Fig. 7. Geometrical dimensions, relative cost and effiency. Adapted from Ioza & Leith [31] and Stermand [32]

Table 1. Compared dimensions of the two cyclones

Item	**Height (cm)**		**Radius (cm)**		**Volume (cm^3)**		**Volume (L)**	
Cyclone	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**
Higher cylinder	20	19.5	R=12	R = 7	9043.2	3000.07	9.43	3.00
Cone	60	20	R_{sup} = 12 ; R_{inf} = 6	R_{sup} = 7 ; R_{inf} = 5	8860.49	1539.13	9.05	
Lower cylinder	16	10	R = 6	R = 5	1808.64	875	1.81	0.86
Condensate cone	10	13	R_{sup} = 6 R_{inf} = 3	R_{sup} = 5 R_{inf} = 1.5	234.43	263.76	0.234	0.264
Total			**Not applicable**	**Not applicable**	**19946.8**	**3621.53**	**19.95**	**3.26**

The construction steps are as follows:

1. Cut the sheet and then bend it to form a cylinder with a radius of 12 cm and a height of 20 cm
2. We close the upper part of the cylinder then we perforate it.
3. We introduce and weld tangentially and vertically two tubes of 4 cm in diameter in the two holes
4. We build another cylinder with a radius of 3 cm and a height of 10 cm. This cylinder is terminated by a cone of height 10 cm and radius R_1 = 3 cm; R_2 = 1.5 cm. A condensed water and particle evacuation valve is screwed to the end of this unit.
5. We properly weld the different elements constructed previously.
6. Airtightness is always be checked during assembly.

4. RESULTS AND DISCUSSION

Cyclones are one of the cheaper and simpler dust collectors available, but they have a relatively low efficiency unless used with coarse dust [33]. By reducing the diameter of the inlet tube in the second cyclone, we hoped to have a greater gas entry speed into the cyclone.

We have installed two humidity sensors: one above the reactor and the other at the reactor outlet, before entering the cyclone. The idea was to see the humidity level of the fuel in the reactor and compare it to that of the outlet. After three tests, we had to realize that there was no relevant informant in measuring the humidity above the reactor, because it quickly increased to 70% relative humidity which is the measurement limit of the used sensors. This is logical because, since biomass always contains some moisture, the water contained in the fuel used is vaporized by the heat produced in the lower part of the gasifier in the oxidation zone.

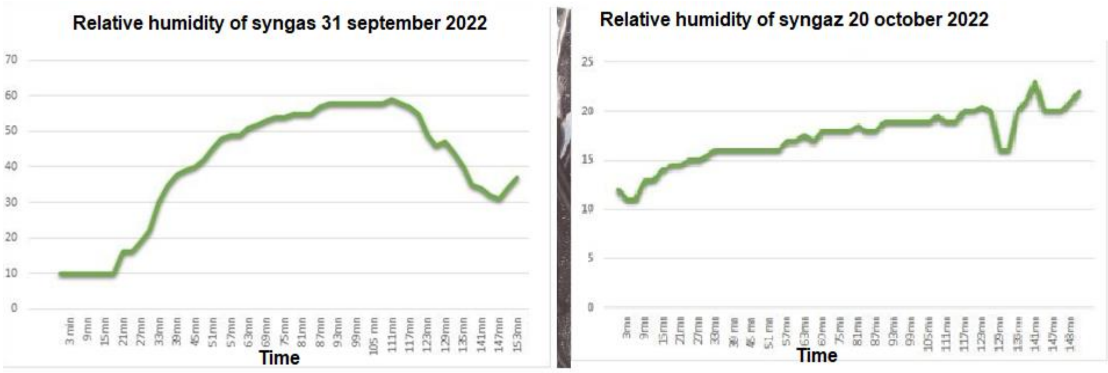
The first humidity sensor which was placed at the entrance to the cyclone was destroyed after the 3rd experimental test by heat and tar. So we put the second humidity sensor we had with us at the exit of the first and second cyclone. Unfortunately the reduction in humidity at the outlet of the second cyclone resulted in an increase in the temperature of the gases at its exit. The second humidity sensor was also destroyed by heat on the second cyclone, because their operating temperature limit was low (maximum 90°C).

The evolution of humidity during an experiment with the two cyclones before the destruction of the humidity sensor are given in the following Fig. 8.

We note that humidity at the entrance to the first cyclone rises up to 60% when the gasifier was feed with pieces of "dry" wood.

By reducing its volume, we have reduced the residence time in the cyclone. The total volume of the cyclone was bring down from 19.9 L to 3.26 L. The evolution of humidity during experiments done with the two cyclone before the destruction of the second humidity sensor as seen in Fig. 8 suggest that relative humidity was bring down from a maximum of 58% with the first cyclone to a maximum of 25% with the second cyclone.

This work is mainly qualitative due to the following technical limitations :



(a) First cyclone (b) Second cyclone

Fig. 8. Humidity mesures at the exit of the first and second cyclone

- The destruction of humidity sensors
- Lack of well working gaz analysers

We wanted to achieve better syngas quality at the exit of the purification units in terms of the combustion flame quality and chemical composition in combustible gases as CO, CH4 and H2. Due to lack of well working gas analysers, results are only qualitatively appreciated, the chemical composition of the three main elements of syngas over time was unfortunately not effectively recorded due to the failure of our second-hand gas analyzers.

We are confident that the visual syngas quality observation through the aspect of the combustion flame and filters wood chips state are sufficient enough to tell if syngaz is of better quality or not, because other parameters we would had measured with gaz analysers such as CO, CH4 and O2 content are not directly dependant of the cyclone. These gases yield merely depend on the operating conditions of the syngas generator and are non condensable gases in our context that always exit from the separator cyclone.

We agree that it is better to illustrate experimental results by field measurements of the elements on wich cyclone separators have an effect or depend on : inlet and outlet gases velocites, pressure drop, inlet and outlet gases viscosities, water condensates, tar and ash. This is why we have acquired six Humirel made HS1101-LF relative humidity sensors and more than ten industrial grade gaz sensors of the MQ serie. We are currently designing and aim to build our own in house gaz analysers at an affordable cost through the use of the MQ7, MQ4 and MQ8 sensors for respectively measuring CO, CH4 and H2 concentration in the syngas. For Oxygen, we have acquired two lambda O2 sensor that support high temperatures of internal combustion engines and are widely used in nowadays cars. All these sensors readings will be displayed on four 8-Bit Digital LED Tube Display Module for AVR and Arduino we already acquired and simulneaously output on USB ports of Arduino modules for use in a personnal computer. These combustibles gaz, Oxyden and humidity sensors are being programmed in the C language and an Arduino starter kit we have recently purchased for that purpuse. These programmed sensors will be tested, calibrated and assembled on protypying PCBs to form a kind of a data acquisition central driven by few of the eight 16F87 microcontrollers chips we have already purchased. More details about these sensors and microcontrollers can can be found on the Internet.

Thurthermore, we will considere buying pressure sensors and program them in orter to also investigate the effect of the geometrical dimensions on the pressure drop, since pressure drop is the second most important cyclones quality indicator as reported by Hsu et al. and Signgh et al. [35,36].

4.1 Initial Testing

Paper and cardboard were used to operate the gasifier. During this test, we noticed the release of white smoke and a flow of black liquid at the leaky joints. During the experiment, we found that the gases produced are very poor in fuels (carbon monoxide, methane, dihydrogen, etc.). Produced syngas was flamable, but its combustion was barely steady.

4.2 Initial Testing Using Wood

The reactor which was of the stratified downdraft type was modified to a non-stratified gasifier. Then a cyclone was built to remove dust from the syngas. A blower is also suitable for injecting air directly into the reaction chamber. On Sunday October 16, 2022 in the physics laboratory, we used damp wood for the first time to operate the device after several adaptations of the reactor. During these experiments, we obtained a yellow flame as evidenced in Fig. 9 and the formation of a very large quantity of water mixed with condensable liquid in the cyclone and in the filtration unit.

At the end of the reaction, we observed a deposit of tar in the pipes as show on Fig. 10.c. Additionally, the wood chips in the filtration unit become wet and of black color due to tar deposit (d). Fig. 10 illustrate the state of the wood chips after gasification (d), the water vapor condensed in the first (a) and that in the second cyclone (b). We see that there is much tary water with the first cyclone than with the second one.

4.3 Additional Testing

After we replaced the cyclone separator, we followed the same experimental protocol as with the first cyclone in order to visualy compare the quality of syngas. Fig. 11 illustrate the

Fig. 9. Syngas combustion with first cyclone with charcoal and wood as combustible

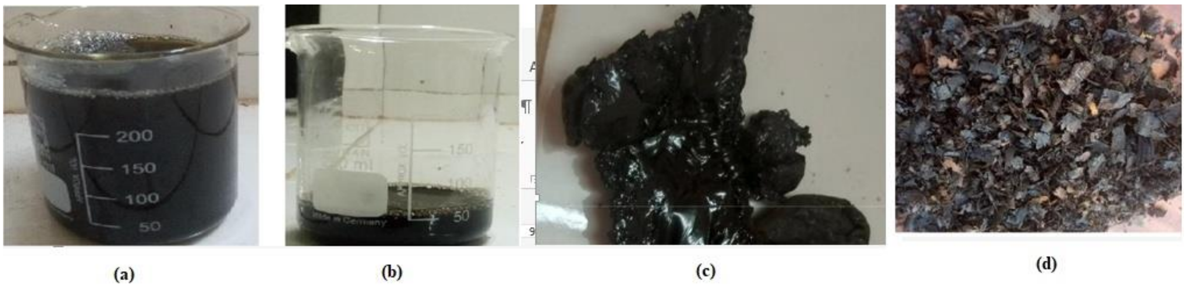


Fig. 10. Byproducts of the gasification process

Fig. 11. Combustion flame quality with the second cyclone separator

color of the flame with the second cyclone, respectively with charcoal (a), wood (b) and the state of filters wood chips with the two cyclones.

4.4 Syngas Composition Evolution Over Time

The results obtained after the various tests show that the syngas at the outlet of the device are made up of carbon monoxide (CO) and other combustible gases such as methane (CH_4) and dihydrogen (H_2).

With wood as fuel, the maximum quantity of CO measured is estimated at 2200 ppm on the other hand, with charcoal coal, this value can go up to 2300 ppm.

a) When we used wood chips as fuel with the first cyclone:

- the gases obtained where poorly flammable, nearly non-combustible,
- syngas obtained was of white color like smoke,
- wood saw used in the filter unit are wet (Fig. 11.c),
- only charcoal produced flammable gases with the first cyclone as evidenced in Figs. 9.a and 11.a.

b) When we used wood chips as fuel of nearly initial moisture content with the second cyclone

- the gases obtained where flammable,
- syngas obtained was almost tranparent,
- wood saw used in the filter unit are dry (Fig. 11.d),
- No more need to use charcoal as fuel with the second cyclone as evidenced in Fig. 11.b.

On the other hand, we obtain combustible gases with a flame of the same color as that of wood if we make a mixture of wood and wood chips.

We are suspecting that a big cyclone can partially act as expansion chamber, wich would explain why there is a big quantity of tar-water condensation in the first cyclone than in the second one. In that case, a smaller cyclone would also bear the advantage of dialing with less tar-water that is difficult to handle, because great quantities of tary water presents several environmental treats if it isn't properly handled [37,38].

5. CONCLUSION

This work is part of a larger project with the main objective of designing and creating a gasifier powered by biomass from the town of Koudougou. This paper adressed the design, fabrication and testing of a second separator cyclone. In the first fabrication, the synthesis gas produced in the reaction chamber was admitted in the cyclone through a 6 cm diameter pipe. In the second fabrication, diameter of the admission pipe to the cyclone was reduced to 4 cm. This enabled us to divide the volume of the cyclone by 5.5 and resulted in better syngas quality evidenced by the combustion flame color and length.

With a smaller cyclone, we obtained less moisture in the syngas at the exit of the second cyclone. Also we obtained a clearer condensated water color at the bottom of the the second cyclone, compared to that of the first cyclone. So we conclude that reduction in cyclone dimensions increased the quality of syngas by reducing its moisture content and the tar content of water recovered at the bottom of the cyclone. Our finding are in agreement with the work donne by Stairmand. Once we have finished seting up our acquistion central, we will also investigate the effect of cyclone size reduction on the pressure drop.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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