Original Research Article

Effects of acyclone dimensions onquality of syngas producedwith awood-firedbiomassgasifier

ABSTRACT

Charcoalgasificationwaswidelyusedduring the secind World War to dial withpetrolumscarcity. Whenpetrolumwasagainavailaibleafter the wargasificationwasneglectedafterwards [1]. However, fossilsresources are nowadays know as non renewable and there are severalreseachcarried out all over the world to developrenewable sources of energy. Under that scope gasifiers are of greatinterest in the developing countries for developpingindividual or decentralised sources of energy. Even in developped countries, developpement of gasificationprojectsis in progress.

In a previouswork, wedesigned and fabricated a downdraftbiomassgasifierwith a relativelybig cyclone and filtration units. Producedsyngaswas full of moistureand carbon dioxyde (CO_2) when the gasifierwasfeedwithwood, but moisture content waslesserwithcharcoal. However in a sahelian country as Burkina Fasowithlimitedwood ressources, traditionnal production of charcoalfromhigh densitywoodexhibitlow conversion efficiency. Thereforefurtherworkshouldbe donne to use lowdensitywooditselffrom agricultural, furnituremakers or sawmillwastes.This paperadresses the design, fabrication and testingof asmaller cyclone separotor unit to replace the first oneformerlyfabricated.Weobtainedlessmoisture content, almost no carbondioxide in the producedsyngas and better combustion fromwoodwaste of the same initial humidity content.

Keywords : Gasifier, Syngas, Wood, Moisture, Cyclone,Design

1. INTRODUCTION

In Burkina Faso, the total consumption ofprimaryenergywasestimatedequal to nearly 2625 ktoein 2008 with a strongdependence on biomasswhichrepresents more than 80% of consumedenergy[2], [3].On year 2019, total consumption of primaryenergyraised to 4657 ktoewith 99% frombiomasswhereashydropower and solarphotovoltaicrepresentslessthan 1% [4].

Biomassgasification, verylittleused in Burkina Faso, is one of the most efficient methods for convertingbiomassinto thermal and electricalenergy.Despite the abundance of waste of agricultural, vegetable and householdorigin, the large-scale exploitation of this conversion process isverylittledeveloped in Burkina Faso.In a bibliographicreview made in 2014, itwasestablishedthatgasification of wastemaybean interesting alternative for Burkina Faso [5].BARRY [6] statedthat: “*The syngas production sector by gasification of mobilizableresidues can onlybecompetitivewith the butane gasmarket if the technologyismanufacturedlocally.*” In factgasificationunitswhereinstalled at Dano, Po and Bama in Burkina Faso. But theseprojectsdidn’tfullysuccess, even iftheyhadgasificationunits technologies that are in production elsewhere in the world. Howevergasificationstillappears as feasible in Burkina Faso, providedsomeeconomical and technicalconsiderationsbetaken in account [7]. Therefore, we have a challenge to locally manufacture gasificationunits for electrical power generation in Burkina Faso.

Withtheseconsiderations inmind, weare in the process of designing and thoroughlytestingsmall-scalegasifiers in order to better master the gasificationtechnologywithlocallymanufacturedunits. Wehave previouslydesigned and fabricated a laboratory-scalegasifierwith the aim of convertingbiomass, mainlywastefrom the city of Koudougou, into a gasthat can beused as fuel. This paper report workaimed to improving the first syngas purification stage of thatgasifier.

2. MATERIALS AND PROCESS

2.1 Materials

Components of the gasification unit are essentiallygroupedintotwo parts namely the reactor body and the auxiliaryequipments. The cyclone separator, part of the auxiliaryequipements constitue the subject of thiswork.

2.1.1 Syngasgenerator

The gasifierusedhere(or in this case)is a co-currentdowndrat type fuelledwithwood. The body of the gasgenerator (or the reactor) is made up of twoparts : an upper part whichincludes the hopper and the combustion chamber, and a lower part consisting of the gasoutlet pipe, the ignition and cleaning ports.

2.1.2 Auxiliaryequipments

The auxiliaryequipmentsmainly comprise acyclone, a gaz expansion chamber, afilter and an air blower.

a) The cyclone

At the outlet of the reactor, the synthesisgascontainsparticles in suspension and water vapour. Severalauthors have used a cyclone separator as a first syngaspurication stage [8], [9] and [10].

The separatorusedin ourgasification process are cyclonesconstructedwithdimensions given in table 1 below. In the first fabrication, the synthesisgasproduced in the reactionchamberwas input in the cyclone through a 6cm diameter pipe.In the second fabrication, diameter of the admission pipe to the cyclone wasreduced to 4cm.

Bothtwo cycloneshelped us eliminate of heavyparticles (tar) and partial condensation of water vaporcontained in the synthesisgases.

b) The burner

Through a tube, the gases are channeled to the generating set for itsoperation. Beforeinjecting the syngas into the engine's combustion chamber, a pilot burnerisbuilt to ensurethat the syngas is combustible. The first burnerweconstructedwassimplyfabricatedwithempties camping gas cannes as illustrated in figure 1.abelow.

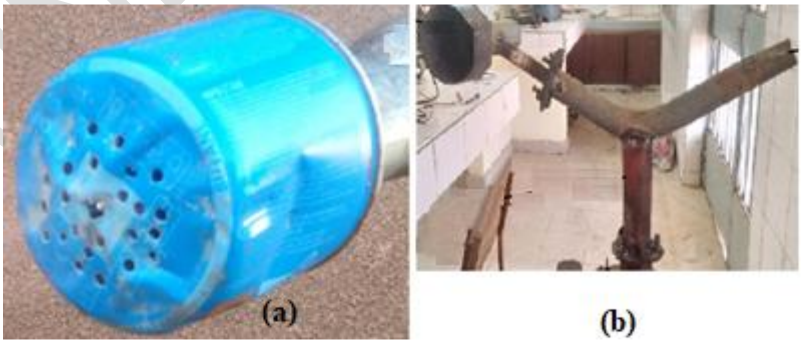


Figure 1 : Test burnersusedupfront the internal combustion engine

Later,webuiltanotherburnerusing the“venturyeffect” as illustrated on figure 1.b above.

2.1.3 Expérimental setup

Parts of the biomassgasifier, namely: the reactor, the cyclone, the gas expansion chamber, the filter and the burner are thenassembled by screws and nuts. This setup allows to separatedifferents parts of the gasifierduring maintenance. Figure 2 belowillustrates the experimental setup wecreatedduringthiswork. This gasification unit, made according to the Imbert model is a “downdraftgasifier ”.

Figure 2 : Experimental setupwith first and second cyclone

2.2 Process

Gasificationis a process thatwaswidelyusedduring the Second World War to deal with the shortage of hydrocarbons.Nowadays, in the face of climate change and the lack of oilresources, the urgent need for this process, abandonedafterseveralyears, isresurfacing. From an energy point of view, the termbiomassrefers to all organicmatterthatcan beused as energy sources [11], [12].Thus, the existence of a high variability in the composition of biomasspromotes the development ofvarious technologies for itsenergyrecovery[13].Gasificationis a thermal conversion process of carbonaceous or organicmaterials in the presence of an oxidizing agent (oxygen, carbondioxide, water vapour) into a synthesisgas.In otherwords, gasificationis the process of convertingbiomassinto a mixture of combustible gases by partial oxidation atvery high temperatures [14], [15].

3. METHODS

At the reactoroutlet, syngas contains combustible gases, water vapor, and solidparticles (tar, ashresidue). It isadvised to purifysyngasbeforeusingit in an ICE (Internal Combustion Engine) for electrical power generation. Purification methodsincludeseparation, filteringamongmanyothers.

3.1 Assembly of newcyclone

3.1.1 Cyclone

Cyclones have been usedsince the late 1800's to removedustfromindustrialgasstreams. Their simple design, low capital and maintenance costs, and adaptability to a wide range of operating conditions have made cyclones the mostwidelyusedindustrialdust collectors [16].

The first cyclone webuilt [17] haveproved to bepoorly effective, hence the need for itsimprovement.

In a cyclone, the gases arrivestangentially to the body of it. Heavy particlesare retained by the cyclone and settle to the bottomwhile light onesrise and emergevertically.

Cyclone collection efficiency, η, isdefined as the fraction of particles of a given size thatisretained by the cyclone. Severaltheories have been developed to predictcollection efficiency. Unfortunately, thesegreatlydiffer in complexity. While a general agreement seem to bethat operating parameters of the system shouldbeused to predict performance, thereisless agreement on the effects of cyclone dimensions and geometry [18].

Leith [19] has identifiedthreegeneralapproaches to predicting cyclone collection efficiency. Wewillonlyconsider one of the these : the Critical Diameter.

This method assumes thatparticles enter the cyclone at certain radial distance from the cyclone axis. Particles must traveloutwardfromthis position to the wall to becollected; the criticalparticleis the size thattravelsexactlythis distance duringitsresidence timein the cyclone. Differentassumptions about initial radial position and residence time lead to differentapproximate solutions.

The Lapple[20]cutdiametertheoryis the mostwidelyusedexample, alsocalled « the timedflight approach ». Lappleassumedthatdustentering the cyclone wasevenlydistributedacross the inletopening. The particle sizethattravelsfrom the inlethalfwidth to thewallduring the time in the cyclone iscollectedwith 50% efficiencyiscalled the cutdiameter. Lapplecalculatedthisparticle size, the cutdiameter, as :

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

With

- μ : gaz vicocity(Pa.s)
- b : cyclone inletwidth (m)
- ρ_p : particlesdensity (kg/m^3)
- υ_i : gaz inletvelocity (m/s)
- N : number of revolutions gaz makes in the cyclone (dimensionless)

The "staticparticle" theory of Barth [19] to predict d_{50}gives :

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

Where :

- μ : gasviscosity
- Q : gas flow
- ρ_p : particlesdensity
- Z_c : vortex corelength
- V_{tmax} : maximum tangentialvelocity

Tangentialvelocity of particles and gas areassumedequal.

Iozia and Leith [21] developedequations to predictthesetermsfrommeasurements of the gas flow pattern within cyclones of various dimensions and foundthat maximum tangentialvelocityisgiven [22] by expression :

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

Corelengthwasdetermined[17] withtwodimensionnalassumptions :

$z_c = H - S$ 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 $d_c > B$

Corediameterisgiven [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 aredepicted in figure3 fromIoza and Leith [21]below :

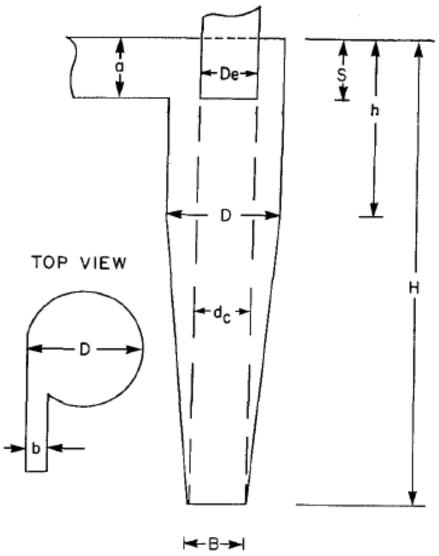


Figure 3 : Cyclone parameteraccording to Donna Lee Iozia& David Leith [21]

For a givensyngasreactor, if we let the gas flow Q, particlesdensity and gasviscosity all contants, wecould group their values in one constant cte and seethat collection effiencycouldbeexpressed as :

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

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

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

where
μ = gasviscosity
W = cyclone inletwidth
D = cyclone barrel diameter
ρ = particledensity
U = gasvelocity at inlet
t= averagegasresidence time

Gas residence time isgiven by :

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

where
V = cyclone volume
h= cyclone inletheight

Thesethree formula suggested us that the biggerV_{tmax}, the lessercutdiameter, hopefullybetterparticlesremoval.

Because for a given partial pressure in the reactor, particles exitfrom the reactorshouldbehigherwhen the exit surface, ie the pipe diameterdecrease.

Considering the relative costcalulated by Stermand [24] as depicted in figure 4below, wedefinitelyopted for a smaller cyclone compared to the first onewebuilt.

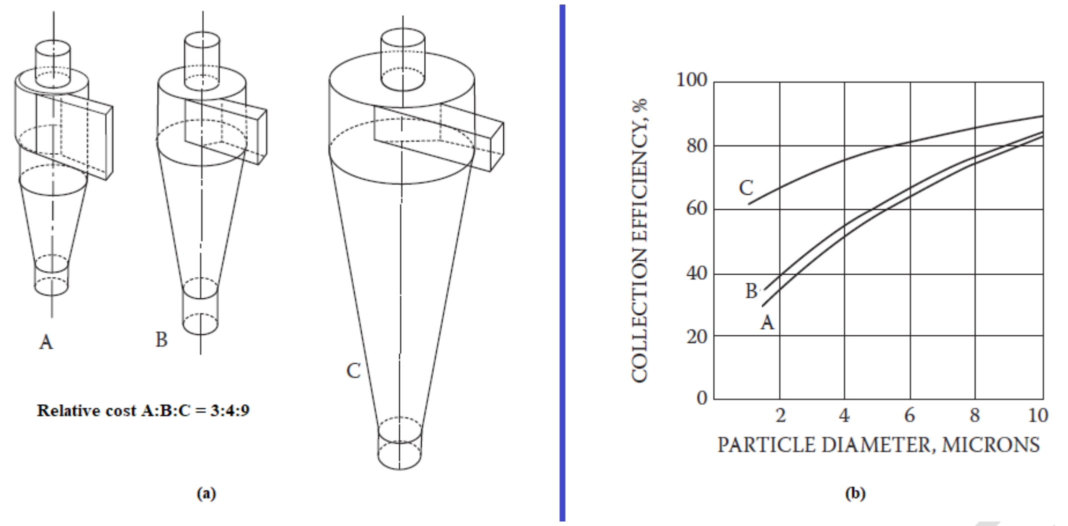


Figure 4 : Geometrical dimensions, relative cost and effiency. AdaptedfromIoza& Leith [21] and Stermand[22]

3.1.2 Manufacturing of the second cyclone

The cyclone weusedisconstructedusing 2mm thicksheetmetal. Dimensions are given in table 1 below :

Table 1 : Compared dimensions of the two cyclones

Item	Hauteur (cm)		Radius (cm)		Volume (cm^3)		Volume (L)	
Cyclone	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Highercylinder	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	
Lowercylinder	16	10	R = 6	R = 5	1808.64	875	1.81	0.86
Condensatecone	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 thenbendit to form a cylinderwith a radius of 12cm and a height of 20cm
2. We close the upper part of the cylinderthenweperforateit.
3. Weintroduce and weldtangentially and verticallytwo tubes of 4cm in diameter in the twoholes
4. Webuildanothercylinderwith a radius of 3cm and a height of 10cm. This cylinderisterminated by a cone of height 10cm and radius R_1 = 3cm; R_2 = 1.5cm. A condensed water and particleevacuation valve isscrewed to the end of this unit.
5. Weproperlyweld the differentelementsconstructedpreviously.
6. Airtightnessisalwaysbecheckedduringassembly.

The finished second cyclone isshown at the right of the first onein figure 5below :

Figure 5 : Comparision of the twocyclonesseparators

3.2Power on and testing of the gasifier

3.2.1Power on procedure

For the very first launch of the gasifier, weaddedcharcoal to the gratelocatedunder the combustion port. Thenwefill the combustion tube withcoal to a height of 4 inchesabove the grate. Additionally, weneed to fill the fuel hopperwith air-driedwood and then follow the followinginstructions:

1. Sensors for measuringparameterssuch as temperature, humidity and gasanalyzers are placedduring the assembly of the experimentaldevice to monitor the evolution of theseparametersduring the operation of the reactor

2. After checking the tightness of the experimentaldevice, weadapt the blower thenturnit on full blast for a few minutes to evacuate the gases in the differentunits.

3. In addition, fireisintroducedfrom the ignition tube to initiate combustion. Diesel fuel can beused 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, weincrease 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 gasessuch 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. Wealways check the permanence of combustible gases at the outlet of the reactorbeforeusingit in the engine. To do this, the speed of the blower must beadjustedso as to have a permanent production of combustible gas.

3.2.2Power on and running the gasifier

Afterswitching on the gasifier, the blower speeds must beadapted inorder to keep the syngas production rate stable. Next, weneed to refill the hopperbeforeitiscompletelyempty. Finally, weshake the gridregularly to make the ashesfall. To turn off the gasifier, the hopper must beclosedso as to avoidany entry of air whichcouldbeused to maintain combustion.

3.2.3 Maintenance procedures

Duringoperation of the gasifierwe must regularly check the junctions and tightening to avoidanygasleaks. In addition, we must remove the ashesfrom the cleaning module everydayaftershaking the grid for a few minutes. Wealso open the filter and cyclone evacuation valve to remove the condensedliquidbeforestarting the gasification. Maintenance carried out everyweekfollowing the followingprocedure:

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 beplaced in the hopper and used as fuel.

4. Use high temperature silicone gasket to seal all pipes and the relatively to ambiant air

4. RESULTS AND DISCUSSION

Cyclones are one of the cheaper and simplerdustcollectors available, but they have a relativelylowefficiencyunlessusedwithcoarsedust[23]. By reducing the diameter of the inlet tube in the second cyclone, wehoped to have a greatergas entry speed into the cyclone.By reducingits volume, you have reduced the residence time in the cyclone.The total volume of the cyclone wasbring down from19.9L to 3.26 L. This workismainly qualitative due to technical limitations.Wewanted to achievebettersyngasquality at the exit of the purification units in terms of the combustion flamequality.Due to leak of wellworkinggasanalysers, results are onlyqualitativelyappreciated.

4.1Testingwith the first cyclone

4.1.1 Preliminarytestingexperiments

The first test of the gasification unit webuiltwascarried out on June 19, 2022 at the Physicslaboratory of Norbert ZONGO University. Paper and cardboardwereused to operate the gasifier. Duringthis test, wenoticed the release of white smoke and a flow of black liquid at the leaky joints. During the experiment, wefindthat the gasesproduced are verypoor in fuels (carbonmonoxide, methane, dihydrogen, etc.). Produced syngas wasflamable, butits combustion wasbarelysteady.

4.1.2 Testingwithwood as fuelwith first cyclone

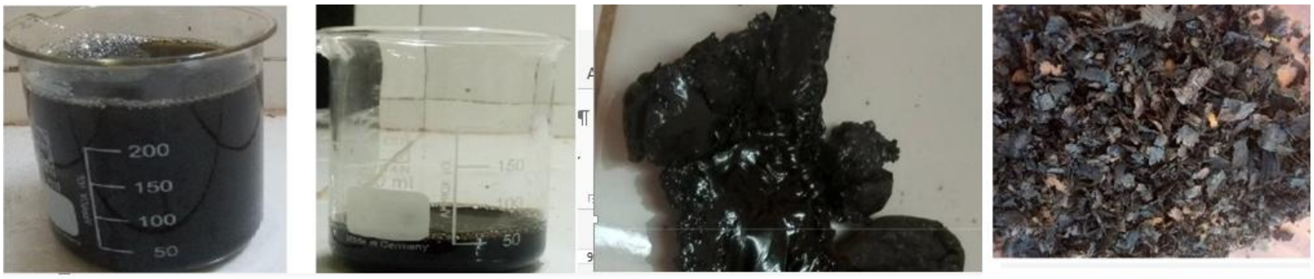
After the first preliminary test of the device, we made several adaptations. The reactorwhichwas of the stratifieddowndraft type wasmodified to a non-stratifiedgasifier. Then a cyclone wasbuilt to removedustfromthe syngas. A blower isalsosuitable for injecting air directlyinto the reactionchamber. On Sunday October 16, 2022 in the physicslaboratory, weuseddampwood for the first time to operate the deviceafterseveral adaptations of the reactor. Duringtheseexperiments, weobtained a yellowflame as evidenced in figure 6 below and the formation of a very large quantity of water mixed with condensable liquid in the cyclone and in the filtration unit.

(a): Charcoal with first cyclone

(b) Wood with first cyclone

Figure 6 : Syngas combustion with first cyclone withcharcoal and wood as combustible

At the end of the reaction, weobserved a deposit of tar in the pipes as show on figure 7.c. Additionally, the wood chips in the filtration unit becomewet (d). Figures 7 illustrate the state of the wood chips aftergasification (d), the water vaporcondensed in the first (a)and that in the second cyclone (b). Weseethatthereismuchtary water with the first cyclone thanwith the second one.



(a) (b) (c) (d)

Figure 7 : Byproducts of the gasification process

4.1.3 Testingwithwood as fuel withthe second cyclone

Afterwerepalced the cyclone separator, wefollowed the sameexperimentalprotocol as with the first cyclone in order to compare the quality of syngaz. Figure 8 belowillustrate the color of the flamewith the second cyclone, respectivelywithcharcoal and wood.

(a) Charcoal with second cyclone

(b) Wood with second cyclone

Figure 8 : Combustion flamequalitywith the second cycloneseparator

4.2Syngas composition evolution over time

Duringourvarious tests, weintroducedtemperaturesensorsabove and at the outlet of the reactor to monitor the evolution of the temperature in the reactor and that of the syngas as they exit the reactor. Humiditysensorswerealsointroduced to monitor the evolution of the humidity of the syngas at the outlet of the differentunits of the experimentaldevice. Furthermore, gasanalyzers, such as the Bacharach"Monoxor III", Bacharach"Fyrite INTECH 110" and a "Testo 325" are used to monitor the evolution of carbonmonoxide, methane, dioxygen and temperature.

The resultsobtainedafter the various tests show that the syngas at the outlet of the device are made up of carbonmonoxide (CO) and other combustible gasessuch as methane (CH_4) and dihydrogen(H_2).

Withwood as fuel, the maximum quantity of COmeasuredisestimated at 2200 ppm on the other hand, withcharcoalcoal, this value can go up to 2300 ppm.

a) Whenweusedwood chipswith the first cyclone :
   - the gasesobtainedwherepoorlyflammable, nearlynon-combustible,
   - syngasobtainedwas of white color like smoke,
   - gasanalysersshowed high moistureand CO_2content in the produced syngas,
   - onlycharcoalproducedflammablegaseswith the first cyclone as evidenced in figures 6 above.

b) Whenweusedwood chips with the second cyclone withwood fuel of nearly initial moisturecontent:

- The gasesobtainedwhereflammable

- Syngasobtainedwasalmosttranparent
- Gasanalysersshowedlowmoisture content and almost no CO_2 in the produced syngas
- No more need to use charcoalas fuel with the second cyclone as evidenced in figure 7 above.

On the other hand, weobtain combustible gaseswith a flame of the samecolor as that of wood if wemake a mixture of wood and wood chips.

5.CONCLUSION

This workis part of a largerprojectwith the main objective of designing and creating a gasifierpowered by biomassfrom the town of Koudougou. This paperadressed the design, fabrication and testing of a second separator cyclone. In the first fabrication, the synthesisgasproduced in the reactionchamberwasadmitted in the cyclone through a 6cm diameter pipe. In the second fabrication, diameter of the admission pipe to the cyclone wasreduced to 4cm. This enabled us to divide the volume of the cyclone by 5.5 and resulted inbetter syngas qualityevidenced by the combustion flamecolor and extent.

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