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RESEARCH ARTICLE

C++ Software Program for Downdraft Gasifier Design and Development

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Abstract
Biomass gasification is an important process of converting biomass into a gaseous fuel through a sequence processes of thermochemical reactions. Prototype of down draft gasifier was designed to generate synthesis gas for house hold applications. C++ Software Program for the design and development of downdraft gasification system was done.

Keywords: Downdraft gasifier; Biomass; Synthesis gas; Software calculation

Introduction

Downdraft gasifiers reactors are the most suitable for rural areas using both small and medium sizes. The system can serve both the household and agriculture applications. The performance of gasification processes in a downdraft gasifier is affected by different factors including residence time, type of reactors, properties of the biomass feed, air to steam ratio and the addition of catalyst. These parameters are affecting on the performance of the gasifier.
The gas produced from gasification processes will be used for different application in rural areas such as drying, domestic cooking, irrigation pump and small scale industrial process. Downdraft gasifier has been applied in China for domestic cooking. Downdraft gasifier of 6-7 kw was designed and constructed in India. Many gasifiers system has been applied in India for heating and small industrial processes (1-8).
The present article deals with software program C++ for design and development of downdraft gasifier .

Processes in downdraft gasifier

In the downdraft gasifier both biomass and air move in the downward direction in the lower part of the gasifier system. Down draft consists from four zones. The zones of gasification process such as drying, pyrolysis, oxidation and reduction is shown in Fig. 1.
The fed biomass is dried in the top of gasifier. The dried biomass moves downward to the upper-middle zone, enabling the pyrolysis and the tar conversion reactions to occur.

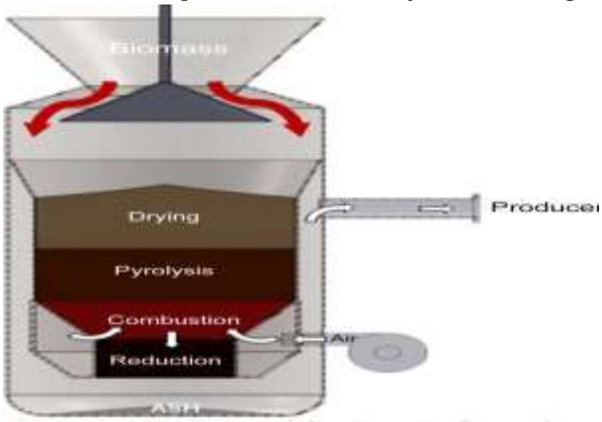

Figure 1. Schematic diagram of downdraft gasifier

The unconverted tars and gases then evolve toward the oxidation zone, where the combustion takes place at higher temperature of 1000-1400 °C.
The chemical species formed finally move through a reduction zone where the H_2 and CO contents are enriched.
The product gas contains a low amount of particulates and tars (~ 1 g/Nm^3) because most of the tars are combusted in the oxidation zone.
The downdraft gasifier is particularly well adapted when a clean syngas gas with a low content of tar and particulates is required.

Advantages & Disadvantages of Downdraft gasifier
Advantages

Downdraft gasifier is very attractive for biomass gasification due to its easy fabrication and operation, and also due to low tar content in producer gas.

Disadvantages

Drawbacks such as grate blocking, channeling, and bridging are found in the downdraft gasifiers, typically for feedstock with low bulk density.
Another disadvantage is that the downdraft gasifiers only suitable for feedstock with low moisture content.

DESIGN OF DOWNDRAFT GASIFIER

The design of the gasifiers is an important parameter that affects their performance. Various works on design improvements have been done for enhancing the performance of the gasifiers (1-12).

Important Parameters in Design

Following parameters must be understood first before starting design of downdraft gasifier.

Equivalence Ratio (ER)

ER is defined as the ratio of oxygen supplied per kg feedstock to the stoichiometric requirement. ER fixes the amount of air supplied for gasification. A value of 0.2-0.4 ER is generally recommended depending on the size of the unit and retaining of heat in the combustion zone. From our studies we recommend, ER 0.25 for medium size gasifier.

Specific Gasification Rate (SGR)

SGR is the volumetric flow rate of gas per unit area based on throat area, the gas volume being measured at the standard conditions. Generally, The recommended SGR value falls in the range of 1920-2640 m^3/m^2 -hr. A mean value of 2000 m3/m3.hr is recommended in our study.

Relative Cylinder Storage Capacity (RCC)

RCC is the mass flow rate of biomass per unit area based on the diameter of the upper cylinder. The recommended RCC value falls in 250-300 m^3/m^2 –hr.

Specific Solid Flow Rate (SSR)

SSR is the mass flow of fuel measured at the throat. It is a derived parameter since it can be obtained from SSR. As **one kg** of biomass approximately gives **2.4 m^3** of gas, SSR can be related to SSR as SGR/2.4.

$$SSR = \frac{SGR}{2.4}$$

Design Procedure

Some parameters are required to decide first for the design purpose which are as follows:

The capacity of gasifier

Capacity of the gasifier is decided first as **Po kW** thermal output power. While gasifier design procedure is based upon its capacity.

Syngas Yield (Y):

As per literature **1 kg** of biomass will yield **2.4 m^3** of syngas.

High Calorific Value (HCV) of Syngas:

High Calorific Value of produced syngas from most biomass and agricultural residues, is about 4000 KJ / m^3.So, Required syngas generation rate for Qg output thermal power is, $Q_g = \frac{P_\circ}{HCV} m^3/h$.

Air Flow Rate Calculation:

For the calculation of air flow rate, ultimate analysis of biomass is required. (Tables 1-2) shows the proximate and elemental analysis of biomass residues.
Optimum equivalence ratio is considered as 0.25 from our technical studies.

Table-1. Proximate analysis of biomass samples (wt%).

Biomass type	**%Moisture content**	**%Total volatile matter**	**%Fixed carbon**	**%Ash**
Cotton stalk	8.9	81.24	14.48	4.28
Rice straw	8.04	69.24	16.7	14.42
Corn stalk	7.96	76.6	19.12	4.27

Table- 2. Elemental analysis of biomass samples (wt%).

Biomass type	**C %**	**O %**	**H %**	**N %**	**S %**
Cotton stalk	44.8	43.8	5.8	1.09	0.57
Rice straw	33.86	39.18	4.5	1.045	0.945
Corn stalk	40.3	46.93	4.2	2.3	Nil

The stoichmetric requirement for the combustion of different biomass materials is determined in Table 3.

Table 3. Air requirement for stoichiometric combustion of biomass

Biomass	**Stoichiometric oxygen required (Kg/kg)**	**Stoichiometric air required $m_{a\,comb}$(kg/kg)**
Cotton stalks	1.2	5.3
Corn stalks	0.94	4.1
Rice straw	0.86	3.8

Air required for combustion=$Q_{acomb} = m_{acomb}/\rho$

Actual air mass required for gasification$m_{agasification=0.25m_{acomb}}$

From which the air rate required for gasification can be determined

$$Q_{ag\ gasification=-0.25m_{acomb/\rho}}$$

Throat Design

Throat diameter of the gasifier is designed based on specific gasification rate (SGR) value. SGR value of downdraft gasifier falls in between 1920-2640 **N**m^3/m^2 -hr. SGR value for downdraft gasifier is taken as SGR = 2000 Nm^3/m^2 -hr.

From the definition of Specific Gasification Rate,

SGR =$\frac{Qg}{A_{th}}$

Where, A_{th}= Area ofthroat

$A=\pi d^2_{th/4}$

So, from which (d_{th}) can be determined

Diameter Combustion Chamber

The combustion chamber is one of the main parts of the gasifier. It should be insulated to retain the heat of combustion. It generally consists of three zones; medium, combustion, higher pyrolysis and the lower is reduction.

The diameter of the combustion chamber is generally taken 2-3 the throat diameter.

In our case we recommend the higher ratio to assist for insulation of the chamber

$d_{Comb=\ 3.0}d_{th}$

Where d_{comb} is the diameter of combustion chamber

Height of Combustion Chamber

There are wide variety of relations for estimation of the height of combustion chamber . The more reasonable is to relate the height to the throat area.

A value of 2-3 is mostly used. For our study we recommend 2

$$H_{Comb=\ 2.0}d_{th}$$

Reduction Zone Height (**H_r**).

The relation between reduction zone height and diameter of the throat is used to calculate reduction zone height below throat. For medium size gasifier.

$\frac{H_r}{d_{th}}$=2.0

Diameter of air distributor

The recommended velocity of air in the distributor is 6-10 m/sec. (Kumar &Ojolo).The cross section area of the air distributor can be obtained based on the volume of air required for gasification

Take the velocity of the air = 6 m/sec

Q_{ag} Gasification =V*A

$=6*\pi/4\ d^2$

From which diameter (d) of air distributor can be determined

Determination of number and size of nozzles

The number of nozzles for medium size gasifier (dt 150-300) ranged between 5-8 nozzles.

For even distribution of air we recommend 6 nozzles

Number of nozzles = 6

Diameter of nozzles

The velocity of air in the nozzles should be not less than 30 m/s.In order to have good combustion of the whole cross section but not adjacent to the walls.

V= 30m/s

Using the velocity V= 30 m/sec, and knowing the airflow rate (Q_{ag}) and number of the nozzles n. The area of the nozzlecan be determined from equation.

$V=30= Q_{ag}/(6*A_{nozzle})$

$= Q_{ag}*4/(6*\pi d^2)$

From which diameter of the nozzle (d) can be determined

Fuel Storage Upper Cylinder Diameter ($d_{stoarge}$).

For calculation of diameter of fuel storage upper cylinder, Relativecapacity of cylinder (RCC) is used. Which is 250 kg / hr.$m^2$for downdraft Gasifier.

RCC= $\frac{\dot{m}f}{A_{cylinder}}$ =250 kg / hr. m^2

Where, $\dot{m}_f$= actual mass flow rate of biomass in kg/hr

$\dot{m}_f=\frac{Qg}{2.4}$

$A_{cylinder}$ = Area of the upper cylinder for storage of biomass in m^2.

So, the diameter of storage cylinder, $d_{cylinder}$**)** can be determined.

$$A_{Cylinder} = \pi d^2 cylinder\ /4$$

The Height of Upper Cylinder.

The bulk density of pelletized biomass, 300-600 kg/m^3.

Let's take **500** kg/m^3. So, calculating storage of biomass for **3**hrs operation of gasifier, which is sufficient for the consumption of half a day.

Volume required for 3 hrs operations

$V_3=h * \pi r^2$

To calculate height of storage cylinder "upper part"

$$\mathbf{V_3=\pi \quad r^2 \quad h_c}$$

Where, r = radius of fuel storage cylinder in, m.

h = height of fuel storage upper cylinder in, m.

Mass of fuel = $(Q_g/2.4)$

Volume of fuel = $(Q_g/2.4)$ *3hr/ρ

C^{++} Software Program for downdraft gasification design

```
//

//Design calculation of Downdraft Gasifier for Biomass Gasification

//shown in Fig.2

#include <iostream>

#include <math.h>

using namespace std;

int main()

{

float Po, Y, HCV, Qg;

float ma, SGR, rho, Dn, An;

floatAth, Dth, HDR, Hth, Qairg;

floatHr, RCC, Dcy, Acy, vol, Nz;

float W, Vcy, Hcy, Dch, Hch, BD, V;

cout<<
"*******************************************
******" <<endl;

cout<<
"*******************************************
*********" <<endl;

cout<< "******** 1- Calculate Syngas Generation Rate,
Qg  ***********" <<endl;

cout<<
"*******************************************
***********" <<endl;

cout<< " >> Enter the Capacity of Gasifier(Thermal Output Power,Po = kW)==" <<endl;

cin>> Po;

cout<< " >> Enter Syngas Yield,Y;'1kg biomass will yield 2.4 m3 of syngas' ==" <<endl;

cin>> Y;

cout<< " >> Enter High Calorific Value HCV of Syngas ==== 4000 KJ/m3    ==" <<endl;

cin>> HCV;

Qg = Po*60*60/HCV;

cout<< " 1-  Syngas Generation Rate, Qg = " <<Qg<< "m3/hr" <<endl;

cout<<
"*******************************************
****" <<endl;

cout<<
"*******************************************
****" <<endl;

cout<< "***** 2- Calculate Air Flow Rate, Qair
*******" <<endl;

cout<<
"*******************************************
****" <<endl;

cout<<
"*******************************************
****" <<endl;

cout<< " >> Enter the mass air required for combustion (ma) from table according type of biomass)==" <<endl;

cin>> ma;

cout<< " >> Enter air density at stp = 1.29' ==" <<endl;

cin>> rho;

Qairg = 0.25*ma/rho;

cout<< " 2-  Air Flow Rate for gasification, Qairg = " <<Qairg<< "m3/hr" <<endl;

cout<<      "*********************************"
<<endl;

cout<<      "*********************************"
<<endl;

cout<< "**3-Throat Diamater, Dth ***********"
<<endl;
```

```
cout<<        "***********************************" <<endl;

cout<<        "***********************************" <<endl;

cout<< " >> Enter Specific Gasification Rate SGR from 1920 to 2640 Nm3/m3.hr" <<endl;

cin>> SGR;

Ath = Qg/SGR;

cout<< " 3-1- Area of Throat, Ath = " <<Ath<< "m2" <<endl;

Dth = sqrt(4*Ath/3.14);

Dth = Dth * 100;

cout<< " 3-2  - Diameter of Throat, Dth = " <<Dth<< "cm" <<endl;

cout<<
"************************************************"
<<endl;

cout<<
"************************************************"
<<endl;

cout<<     "**4-Combustion     Chamber,     Dcb, Hcb***********" <<endl;

cout<<
"************************************************"
<<endl;

cout<<
"************************************************"
<<endl;

Dch = 3*Dth * 100;

Hch = 2*Dth * 100;

cout<< " 4-1- Diameter of Combustion Chamber, Dch = " <<Dch<< "cm" <<endl;

cout<< " 4-2- Height of Combustion Chamber, Hch = " <<Hch<< "cm" <<endl;


cout<<
"******************************************"
<<endl;
cout<<
"******************************************"
<<endl;
cout<<  "**  5-Reduction  Zone  Height,(Hr)******" <<endl;
cout<<
"******************************************"
<<endl;
cout<<
"******************************************"
<<endl;
Hr = 2.5 * Dth;
cout<< " 5- Height below Air inlet, Hr = " <<Hr<< "cm" <<endl;
cout<<
"************************************************"
<<endl;
cout<<
"************************************************"
<<endl;
cout<< " **6-Fuel Storage Cylinder Diameter, Dcy **" <<endl;
cout<<
"************************************************"
<<endl;
cout<<
"************************************************"
<<endl;
cout<< " >> Enter Relative Capacity Of Cylinder, RCC 250 kg/hr.m2" <<endl;
cin>> RCC;
Acy = Qg /(Y*RCC);
Dcy = sqrt(4*Acy/3.14)*100;
cout<< " 6- Diameter of fuel Storage Cylinder, Dcy = " <<Dcy<< "cm" <<endl;
cout<<
"*********************************************
****" <<endl;
cout<<
"*********************************************
***" <<endl;
cout<< " ** 7- Height of Fuel Storage Cylinder, Hcy ****" <<endl;
cout<<
"*********************************************
****" <<endl;
cout<<
"*********************************************
***" <<endl;
cout<< " >> Enter bulk density (BD) of pelletized biomass from 300-600 kg/m3" <<endl;
cin>> BD;
cout<< " >> Enter number of operating hour, Hr, take = 3hr" <<endl;
cin>>Hr;
vol = (Qg*Hr)/BD;
Hcy = 4*vol*1000000/(3.14*Dcy*Dcy);
Hcy = Hcy/100 ;
cout<< " 7- Height of fuel Storage Cylinder, Hcy = " <<Hcy<< "m" <<endl;
cout<<
"*********************************************
****" <<endl;
```

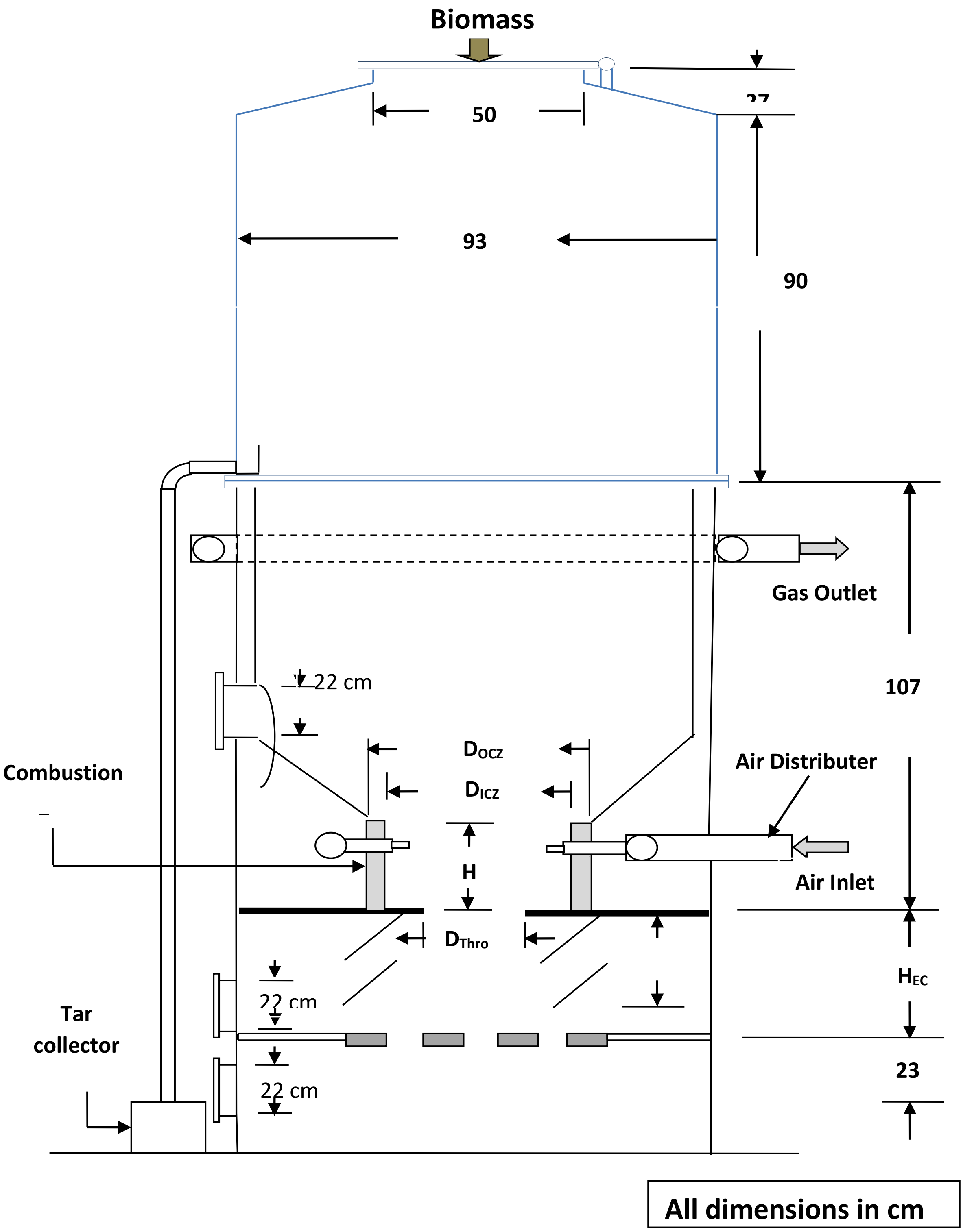

Fig. (2) Gasifier internal details

```
cout<<
"**********************************************
****" <<endl;
cout<< " *********** 8- Nozzle Diameter, Dn
************" <<endl;
cout<<
"**********************************************
****" <<endl;
```

```
cout<<
"*********************************************
****" <<endl;
cout<< " >> Enter number of Nozzles, Nz" <<endl;
cin>>Nz;
cout<< " >> Enter air velocity, V = 30 m/sec" <<endl;
cin>> V;
    An = Qairg/(Nz*V);
Dn = sqrt(4*An/3.14)*100;
cout<< " 8- Diameter of nozzle, Dn = = " <<Dn<< "m"
<<endl;
return 0;
}
```

Conclusions

1.The following conclusions were drawn:
Downdraft gasification is more suitable processes for converting of biomass for synthesis gas
2.Thermochemical and physical characteristics of biomass together with the optimal design of downdraft gasifier was done.
3.C^{++} Software Program for Downdraft Gasifier Design and Development was established.

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