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PERFORMANCE ENHANCEMENT OF DOWNDRAFT GASIFIER WITH STEAM INJECTION

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Abstract: In India, ample amount of biomass is available. Gasification is thermochemical conversion in which biomass is converted in to producer gas with partial amount of air. In spite of being a century old technology, it is not fully developed especially for electricity generation because of its contaminants such as tar and particulate matter (PM). Saw dust briquettes and lignite were identified for the experimentation on 10 kWe downdraft gasifier. Effect of steam injection on performance of Downdraft gasifier was studied in present work. To im- prove quality of producer gas by steam injection, steam gasification system was developed. 6kW electrical steam generator was used to generate steam and this wet steam was heated with dry heater mounted on steam pipeline. Steam pressure (1 atm), temperature (121 °C) and flow rate (1.6 kg/hr(±0.1692 %)) were maintained with temperature – pressure sensor with controller and valve. Steam was decomposed at higher temperature in gasifier reactor cause lower yield of CO and higher yield of H2 & CO2. It was observed that H2 yield of product gas significantly increase and remain in the range of 16-21%. CO yield was reduced by 10%. Combustion zone temperature was reduced 25-50 °C. Gas calorific value was varying between 1200-1400 kcal/m3(±0.0000062 %) with steam injection. Cold gas efficiency was improved by 11%(±0.08017%). Tar is diminished significantly with steam injection because of complete combustion of fuel. Tar in producer gas in range of 60-160 mg/m3 (±0.0022%) which maybe the good alternative fuel for engine application. Particulate was in the range of 10-30 mg/m3(±0.0347%). Steam gasification helps to increase calorific value by increasing H2 yield and lower tar & particulates are the general conclusion from present study.
Keyword: Gasifier, Steam Injection

I. INTRODUCTION

1.1 Energy Scenario of India

The electricity sector in India had an installed capacity of 319.60 GW as of end March 2017. Renewable power plants constituted 30.3% of total installed capacity, in which share of Fossil Energy is 216.0496 GW (67.6%) and Renewable Energy is 96.8388 GW (30.3%). During the fiscal year 2015-16, the gross electricity generated by utilities in India was 1,116.84 TWh and the total electricity generation (utilities and non-utilities) in the country was 1,352 TWh or 1,075.64 kWh per capita. India is the world’s third largest producer and fourth largest consumer of electricity. Electric energy consumption in agriculture was recorded highest (17.89%) in 2015-16 among all countries. The per capita electricity consumption is low compared to many countries despite cheaper electricity tariff in India. Draft National Electricity \ Plan, 2016 prepared by GoI states that India does not need additional non-renewable power plants till 2027 with the commissioning of 50,025 MW coal based power plants under construction and additional 100,000 MW renewable power capacity.[1]

1.2 Introduction to Gasification Technology and Gasifier

Gasification is the process for converting the organic or fossil fuel based on Carbonaceous Organic or Fossil fuel in Carbon Dioxide, Hydrogen and Carbon Monoxide. This is done by reacting the material at high temperatures (>700 \textdegree C), without combustion and with controlled amount of oxygen and/or steam. The resulting gas mixture is called Syngas (from synthesis gas or synthetic gas) or Producer Gas and is itself a fuel. Gasifier is the closed vessel which is utilised for gasification process. The biofuel is fed in it and with less amount of oxygen the fuel is ignited and the fuel is converted into the gas. The power derived from gasification and combustion of the resultant gas is considered to be a source of renewable energy if the gasified compounds were obtained from biomass.[1]

1.3 Chemical Reactions inGasifier

In Gasifier the fuel undergoes in different chemical processes.

DehydrationorDrying:-
Itoccursat200^0C,resultingbiomassdriedoutandwater drivenoff.

Pyrolysis or Devolatization :-It occurs at $500 - 800^0$C. At $280\ ^0$C, H_2O, CO_2, and CH_3COOH. Between $280 - 500^0$C large quantities of tar and some CH_4isformed.

Combustion :- Complete combustion takes place at 1450^0C in which the volatile material and some portion of char reacts with oxygen to primarily convert carbon diox- ide and carbon monoxide, which provides the heat for subsequent reactions. The basic reaction is shownbelow.

$C + O_2 \rightarrow CO_2$

Gasification:-
Itoccursasthecharreactswithsteam/airtoproducecarbonmonox-ide andhydrogen.

$C + H_2O \rightarrow CO + H_2$

WhentheprocessreachesatthereverseblephaseitiscalledaWater GasShiftReaction equlibrium then the concentration of Steam, Carbon Monoxide, Carbon Dioxide and Hydrogen isbalanced.

$CO + H_2O \longleftrightarrow CO_2 + H_2$

Additionally with limited amount of oxygen or air is intoduced to burn some organic material to produce carbon dioxide and energy which is an exothermic reaction, which can be helpful in the reaction that converts further organic material to hydrogen and additional carbon dioxide. Another reactions occur when the formed carbon monoxide and residual water from the organic material react to form methane and excess carbon dioxide.

$4CO + 2H_2O \rightarrow CH_4 + 3CO_2$

Emission produced by gasification process is nearly zero and the by products are less hazardous and can be sold like sulfur and slag. Gasification plant uses significantly less water and produced CO_2can be captured for storage and sold for EOR (Enhanced Oil Recovery of petroleum reserves) and ECBM (Enhanced Coal Bed Methane) using available and commercially proven technologies.[2]

1.4 Advantages ofGasifier

- Emission control is easier thancombustion.
- Carbon capture utilisation and storage iseasybecause $CO_2$is captured and after processing on it the less harmful is released to theenvironment.
- Feedstockflexibilityishighsovariousfeedstockscanbeutilisedassolidwastesand other materials which are harmful to theenvironment.
- Producer Gas flexibility is also high due to produced syngas is further processed and different components can be extracted fromit.
- Higher Efficiency is obtained as compared to combustionprocess.[3]

1.5 Disadvantages ofGasifier

- Starting of gasifier needs sometime.
- Raw material is bulky, so carrying it to the Gasifier is difficult.
- Residue handling is dirty and time consumingwork.
- Obtaining producer gas in proper state is very difficult. It takes time to obtain it after various process.[3]

1.6 Application ofGasifier

1. Gasification based plants are very cost effective.
2. Generated producer gas can be utilised for generation of power from dual fuel engine.
3.Any kind of biomass can be utilised in the gasifier so the produced waste from different places like poltry, agriculture and other can be utilised
4.Pollution can be reduced due to pollution free syngas is produced.
5. Syngas from gasification is completely scrubbed before it is utilized as a part of an IGCC (Integrated gasification joined cycle) power plants. Accordingly, it is conceivable to for all intents and purposes dispense with emanations of criteria air contamination and dangerous toxins, for example, unstable mercury from coal-based power extends that utilize this innovation.
6. Not at all like regular gas or other coal frameworks, gasification-based power plants can be cost effectively configured (or retrofitted) to empower carbon dioxide catch if and when that is required to meet statutory or universal bargain commitments
7. Since gasification delivers a syngas of hydrogen and carbon monoxide, it is the just ordinary vitality innovation (other than atomic fission) equipped for creating the massive amounts of hydrogen that would be required to change over all or a real bit of the world's transportation fleet from gasoline and diesel fuel to hydrogen.[3]

1.7 Types ofGasifier

Several types of gasifiers are currently available for commercial use[6]. They are listed below.

Counter Current Fixed Bed Gasifier or Updraft Gasifier :- The biomass fed at the top of the reactor and moves in counter current to the gas flow passing through the Drying, Pyrolysis, Reduction and CombustionZones

Co-CurrentFixedBedGasifierorDowndraftGasifier:- Thebiomassisfed from the top and the air intkeis also from top or from the sides of gasifier. The gas leaves from the bottom of the reactor, so the fuel and gas moves inthe same direction.

CrossDraughtGasifier :-In this gasifier, the ash bin, fire and reduction zones are seperated. They operate well on dry fuel and dry air blast. But, they are not ideal due to designconstraints.

Fluidised Bed Gasifier :-In this type of gasifier both, Downdraft and Updraft gasifier's application can be fulfilled. The bed is originally extremely heated and thefeedstockisintroducedassoonasasufficientlyhightemperatureisreached.

II. LITERATURE SURVEY ON GASIFIER

From the Literature survey the conclusion is derived that Fluidised bed steam gasification is most effective between the temperature ranges of 650 ºC to 900 ºC and most effective Steam/Biomass Ratio is ranges 0.4 to 0.85 w/w as it gives a positive effect on hydrogen yielding, char gasification and tar reforming. When Steam/Biomass Ratio was in range of 1-2 it showed only a limited improvement. Increment in Reaction temperature leads to the increment of generation of hydrogen. Temperature has a positive effective on the com- position by increasing the H 2 content. Increment in temperature leads to improvement in 3 efficiency with maximum Carbon Conversion with 70% at 900 ºC and H 2 is increased by 38% at the same temperature. High gasification temperature and proper steam introduction led to higher yielding of dry gas and high Carbon Conversion Efficiency. Increment in temperature is helpful to increase the H 2 content. The content of charcoal from catalytic steam gasification ranges from 65 % to 75% at a temperature range of 750 ºC - 850 ºC in case of petroleum coke as it has highly disordered structure and becomes more strong and symmetric with the increase in char conversion efficiency. The catalyst that were impregnated showed greater results than natural catalyst in most of the cases for the steam gasification process.

III. METHODOLOGY

Towards achieving the objective the experiments were performed on 10 kWe Downdraft gasier. The methods and equipment used in the experiments are discussed in following section.

3.1 ExperimentalSetup

1.Gasifier
2.CycloneSeperator
3.Orifice Meter
4.Surge Tank
5.Ball Valve
6.Blower
7.Filter

3.2 Experimenta lMethodology

Before initializing the gasifier, the whole system is cleaned completely.Then prepared char is fed into the gasifier system from top to the bottom of air tuyeres. The K-Type thermocouple are inserted to measure the temprature of different zones and gas.The biofuel is fed after feeding of Char. The top cover is closed. In one of the air tuyers the flow of steam is also inserted with the help of branch conection. The pump is started for suck- ing the airfrom atmospher and the flame is inserted ith the help of Allegory (Mashal). The flame is sucked due to created pressure difference in the gasifier. The Allegory is removed when the inner part is red hot. The flow rate is maintained with the help of U tube manometer at the designed level and the temperature along the length of gasifier is recorded. Then the steam is inserted to the gasifier with the help of steam generator.The flowrate and temprature change is measured after injection of steam. With the help of steam and air, the condition of gas is improvised and the results of Tar and Particulate Matter is collected. If the results are satisfying the required conditions then the gas is further iserted to run the Dual Fuel IC Engine available[6].

3.3 Calorific Value ofFuel

Feedstock	Moisture Content (%)	Volatile Matter(%)	Ash (%)	Fixed Carbon	GCV (kcal/kg)
Sawdust Briquettes	4.87	78.74	4.87	11.8	4390
Wood	5.09	81.54	7.3	6.07	3164.14
Lignite	10.198	45.115	12.789	31.898	3778

Table 3.1: Results of proximate analysis, GCV for biomass briquettes, wood and lignite

The Calorific value of fuel is defined as the amount of heat evolved when a unit weight of fuel is completely burned and the combustion product are cooled at normal temperature. The calorific value of any given fuel is dependent on the moisture content and its density. The calorific value is determined by bomb calorimeter, we have taken from the literature as shown in table

3.4 Temperatur eProfile

Calibrated 6 nos. K-type thermocouple probe is use for measurement of temperature along the length of gasifier. The thermocouple probes are developed using 22 gauge K- type thermocouple wire. These wires were inserted in ceramic bids, which were placed inside the inconel tube of 8 mm diameter. The lead coming out of the tube is thoroughly sealed using asbestos powder so that atmospheric air in gas is minimized and there by permits more realistic measurement of temperature. Temperature profile of gasifier is prepared by taking temperature at different zone at regular time interval (15 minute). There are mainly four processes in gasifier. The Temperature should be taken in drying zone, Pyrolysis zone, Oxidation zone and reduction zone at seven different places along the length of gasifier.

3.5 Gas GenerationRate

Gas Generation rate can be measured by calculation with the help of various devices like U-Tube Manometer, Anemometer and Gas Flow Meter. Here in this project setup Hot Wire Anemometer model TMA-21HW is used and the area of the chimney pipe is kept constant. With the help of flow velocity measured from anemoneter and area of chimney, calculation of gas generation rate is done. The Hot wire amenometer is shown in fig.3.3

Flow is measured from the cross section area and flow from the anemometer.

$Q = A \times V$

Figure 3.3: Hot Wire Anemometer

3.6 Fuel Consumption

Gasifier is initially topped up with char and biofuel and then fired up and then with the help of Allegory and the combustion process is done. Fuel consumption is calculated with the help of Initial material topped up, Material added intervally, Material Remaining and time consumed while the experiment is running.

$$Fc = \frac{W_{im}+W_{mt}-W_{mr}}{t}$$

d

Equivalence Ratio
Equivalent ratio (ER) is very important term in gasication and combustion. In simple word, equivalent ratio means ratio of actual fuel air ratio to stoichiometric fuel air ratio. The equivalence ratio of a system is denoted as the ratio of the fuel-to-oxidizer ratio to the stoichiometric fuel-to-oxidizer ratio.[8] Mathematically,

$$ER = \frac{Fuel\ to\ Oxidizer\ Ratio}{Fuel\ to\ Oxidizer\ Ratio_{(Theoritical)}}$$

3.7.1 Effects on GasifierPerformance
Affects following parameters
1.Efficiency
2.Gas GenerationRate
3.Quality ofGas
4.Gas FlowRate

3.8 Calorific Value Estimation of Producer Gas
It is very important parameter to measure the efficiency of the gasifier. The composition of producer gas is found with the help of Gas Chrometograph. The concentration of Carbon Monoxide, hydrogen, Methane, Nitrogen and Carbon Dioxide is measured with the help of Gas Chrometography's results. The different peack are observed at the different retention time. With the help of the area the Percentage availability can be calculated with the help of equations available in literature. The CV of producer gas depends mainly on the concentration of Carbon Monoxide, hydrogen and Methane in producer gas.Producer gas is filled in Gas Collecting Baloon with the help of Vaccum Pump and then the sample taken from it is inserted in the Setup and GC is done. The setup is shown in fig.3.4

Figure 3.4: Gas Chromatograph

Components	Range of Components (%)
hydrogen	8-10
Nitrogen	45-60
Methane	2-5
Carbon Monoxide	5-20
Carbon Dioxide	5-15
H_2O	6-8

Table 3.2: Gas Composition range in Producer Gas

This Gas chromatograph (GC) set up is situated in Chemical Laboratory, NirmaUniversity. It is Gas chromatograph machine model SHIMANDZU GC-2010. Tubular led bed reactor of GC made of stainless steel tube of 18.05 mm inner, 19.05 mm outer diameter and tube length 500 mm. The producer gas products are analyzed using gas chromatographyequippedwiththermalconductivitydetector(TCD)andCarbosieves11 column or porupakk Q and 5 A modular sieve column with Ar, N2and He as thecarrier gas for the H2, CO, CH4, CO2gascomposition.

Name of Component	Formula	HHV(MJ/m^3)	LHV (MJ/m^3)
hydrogen	H_2	13.2*%H_2	11.2*%H_2
Carbon Monoxide	CO	13.1*%CO	13.1*%CO
Methane	CH_4	41.2*%CH_4	37.1*%CH_4

Table 3.3: Calculations for CV of Producer Gas Components 1 kcal=4.186 joule

3.9 Heat Generation Rate
Heat generation rate is the amount of heat generated from gasifier in unit time. It measures the capacity of gasifier. Heat generation rate calculate from calorific value of gas and gas generation rate of producer gas by following equation:
*HGR = CV of Producer Gas kcal/m^3 *Gas Generation Rate Nm^3/hr*

3.10 Efficiency of Gasifier
GasifierEfficiencyistheratiooftotalenergyinsupplyfuelandtotalenergyinproducer gas. So the gasifier efficiency is depending upon Calorific value of feedstock, Fuel consumption, Calorific value of producer gas and Gas flow rate. The efficiency is calculated by:

$$\eta = \frac{CV\ of\ gas\ in kcal/m^3 * Flow\ Rate\ in m^3/hr}{CV\ of\ biomass\ in kcal/kg * Fuel\ Consumption\ in kg/hr}$$

IV. RESULT AND DISCUSSION

Alltheexperimentswereconductedon10kWedowndraftgasifier withthetwofeed stocks to measure the available content of Tar and Particulate Matter on the Gas Generation Rate, Calorific Value of Producer Gas and Gasifier Efficiency. The method and equip- mentsutilised are discussed in the Chapter 3. Experimentation were done with Steam whichPressure,TemperatureandFlowRatemaintained1atm,121^{0}Cand1.6kg/hrre-spectively.Experimentwasconductedwiththetwofeedstockswithvariationsofcatalyst and steam listedbelow:
Feedstock 1:- Lignite
Feedstock 2:- Lignite (70%) + Briquettes(30%)
Feedstock 3:- Lignite (70%) + Briquettes (30%) +Steam 4.Feedstock 4:- Lignite + 7% $MgCO_3$+ Steam 5.Feedstock 5:- Lignite + 5% $MgCO_3$+ Steam 6.Feedstock 6:- Briquettes + 5% $MgCO_3$+Steam

4.1 Experimental Results
All the Experiments were conducted on the downdraft gasifier having cone angle 30^0, throat diameter 100 mm with different feed stocks. At each zone, temperature has

measuredwithKtypethermocouple.Thermocouplewasmounted atvariouslocationsacross the length of the gasifier and measures the temperature at an interval of 15 minutes. It was observed the initial temperature was higher. Temperature profile at different time withdifferentfeed stocksisDrying,Pyrolysis,CombustionandReductionzonesares hown below.

4.1.1 Temperature Profile

4.1.1.1 Drying Zone

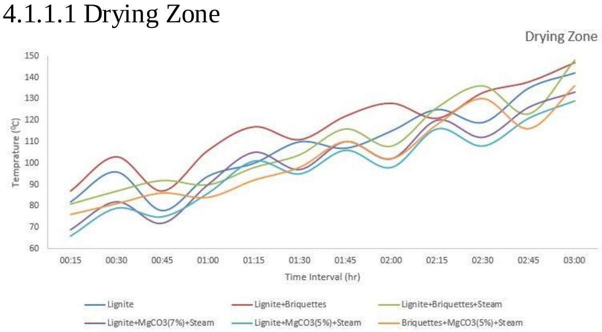

Figure 4.1: Temperature Profile at Drying Zone

As shown in fig.4.1. It is observed from the above figure that drying zone temperature at 180 min is in the range of 65 0C to 150 0C as per the feedstock used. This zone is away from combustion zone and in this zone moisture is removed from the fuel so temperature is low.

4.1.1.2 Pyrolysis Zone

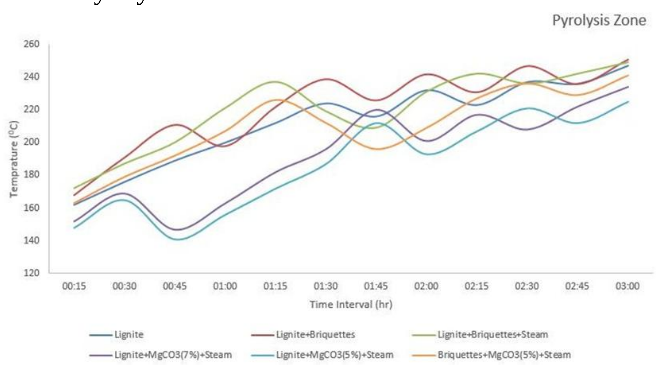

Figure 4.2: Temperature Profile at Pyrolysis Zone

Due to further decomposition of the fuel and removal of the moisture, tar are released. The temperature profile for Pyrolysis zone is shown in fig.4.2

4.1.1.3 Combustion Zone

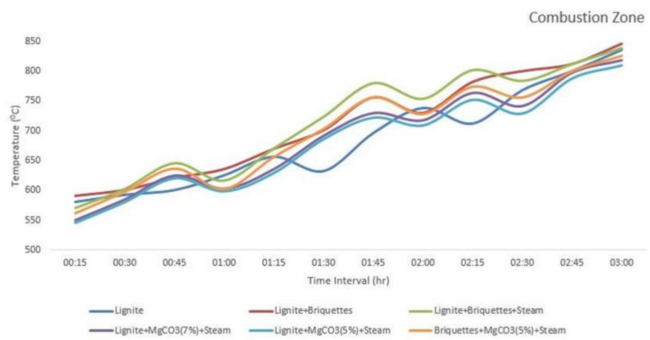

Figure 4.3: Temperature Profile at Combustion Zone

Due to thermal cracking of Tar and Exothermic Reactions, the complete combustions of feedstock takes place, thereby releasing large quantity of heat is released which results in increase of temperature. The temperature profile for Combustion zone is shown in fig.4.3

4.1.1.4 Reduction Zone

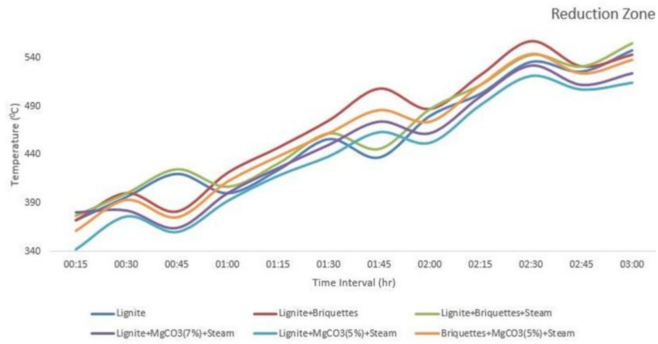

Figure 4.4: Temperature Profile at Reduction Zone

In this zone the products of partial combustion move down across the charcoal bed and thus result in formation of the producer gas. The temperature profile for Reduction zone is shown in fig.4.4

V. CONCLUSION

1. Fuel consumption for all different feed stocks for 10 kWe Downdraft Gasifier is varying from 9.95 kg/hr to 11.9 kg/hr. Lignite with Briquettes has maximum and Briquettes with 5% MgCO 3 and Steam has minimum Fuel Consumption.

2. Gas Generation Rate varies from 23.75 m 3 /hr to 26.73 m 3 /hr among all cases. Briquettes with 5% MgCO 3 and Steam has maximum and Lignite has minimum Fuel Consumption.

3. Efficiency varies from 65.716 % to 81.911 % for different feed stocks. Lignite with 7% MgCO 3 and Steam has maximum and has Lignite minimum Efficiency.

4. Tar content in Producer Gas varies from 60.8 mg/ m 3 to 607.80 mg/m 3 . Producer gas from Briquettes with 5% MgCO 3 and Steam has minimum value of Tar whereas from Lignite has maximum value of Tar.

5. Particulate Matter content in Producer Gas varies from 10.91 mg/ m 3 to 65.35 mg/m 3 . Producer gas from Briquettes with 5% MgCO 3 and Steam has minimum value of Particulate Matter whereas from Lignite has maximum value of Particulate Matter.

6. In steam gasification, better results were obtained as per higher Hydrogen yield and lower pollutants.

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