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**Research Paper**
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# Conditioning of Producer gas by dosing in Hydroxide solution

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***Abstract*** - Producer gas is the mixture of combustible ($H_2$, CO, $CH_4$) and non-combustible gases ($CO_2$, $N_2$) along with Tar, SPM, water vapor, mineral vapor etc. A number of methods has been designed and developed and successfully implemented for removal of Tar and SPM from producer gas, however these methods are uneconomical. Apart from that most of the developed technologies, for improving the quality of producer gas, removes only Tar and SPM from producer gas.

The present research work deals with the cleaning as well as conditioning of producer gas. A Chemical hydroxide dosing based technology was developed and tested successfully. Study reveals that sodium hydroxide chemicals at 30% concentration and dosing with producer gas can increase the energy content of producer gas up to 11% by absorbing the non-combustible gases ($CO_2$). In addition to that heating of hydroxide solution and increasing of residence time of producer gas with hydroxide solution, not only increases the cleaning efficiency (90% and 87%) of Tar & SPM present in producer gas, it also conditioned the producer gas by absorbing the $CO_2$ at a tune of 17%, respectively.

***Keywords:*** Producer gas, Hydroxide solution, Producer gas quality, Tar & SPM, Ccalorific value

## I. INTRODUCTION

Due to the continuous rise in energy demand and rapid depletion of fossil fuels, the utilization of biomass has attracted global attention. Among different routes of biomass energy conversion, the gasification is considered a valid process to obtain a fuel gas [11, 14]. Biomass gasification is a thermo-chemical conversion technique which is capable to convert biomass into producer gas. These gasses could be used either for thermal or power generation application.

Producer gas is the mixture of combustible ($H_2$, CO, $CH_4$) and non-combustible gases ($CO_2$, $N_2$) along with Tar, SPM, water vapor, mineral vapor. Sulfur compounds such as hydrogen sulfide ($H_2S$) and nitrogen compounds ($NH_3$, HCN) in producer gas are undesirable as their condensates are corrosive and pollutants in exhaust gases [12]. A number of methods has been designed, developed and successfully tested. Among the different constituent of producer gas only combustible gases delivered energy for power generation. However these components contribute maximum 40% of the total component of producer gas [3, 7, 18]. Percentage of inert gases and other contaminants in producer gas are major (about 60%). Most of the work done to improve the quality of producer gas, removes only Tar and SPM from producer gas. Although producer gas free from tar and SPM and cooled up to the ambient temperature, increases it's application, however, it does not affect much on energy content of producer gas [13].

No work or very limited work has been reported in the literature related to conditioning of producer gas using hydroxide. However, few has been reported for cleaning and conditioning of producer gas, which could be broadly classified into five methods such as Mechanical methods, Self modification, Catalytic cracking, Thermal cracking and Plasma methods [12]. Among all the method catalytic cracking and plasma method were most prominently used for conditioning purpose. The catalytic cracking is the most widely used method due to its capable of reforms non-combustible gases into combustible gases. However, due to high cost of the catalyst, it is not feasible. Although, plasma technologies sharply decrease the formation of tar and also effectively remove fly ash, NOx and $SO_x$, however they are uneconomical [8]. The concept of dosing of hydroxide for conditioning of producer gas may solve the above said problem. The significant feature of this technology is cheap and easily available in nature.

## II. MATERIAL AND METHODS

The commercial hydroxides (NaOH and KOH) were used for conditioning of Producer gas. The experiment performed on available Updraft gasifier (fixed bed counter-current) to obtain producer gas at School of Energy and Environmental Studies (SEES), Devi Ahilya Vishwavidyalaya, Indore, Madhya Pradesh (India). Temperature measured by Portable K-type thermocouple and pitot tube connected with flue gas analyser used for velocity of producer gas.

The proximate analysis of biomass was carried out as per ASTM standard, however; bomb calorimeter used to determine the energy content of biomass [6, 17]. Orsat apparatus and Gas chromatography was used to analyse the composition of producer gas [4,5].

**A. Experimental Design**

The producer gas obtained from gasifier was passed through different concentrations (10%, 20%, 30%, 40%, 50%, and 60%) of hydroxide solution. Latter it was collected in gas sampling bottle before and after passing through hydroxide solution, at every interval of 15 minutes of dosing. Sampling of gas was done by water displacement method [3] with the help of vacuum pump (Fig.1). An isokinetic conditions was maintained during sampling of raw and clean gas. Collected gas sampling bottles was kept overnight in deep freezer maintaining 5-6$^{o}$C temperature [2]. At this temperature Tar and SPM condensed at the inner surface of gas sampling bottle. Later gas sampling bottle washed using 2-5 ml of acetone. Then it was poured in known weight of cotton. Cotton was kept in hot air oven to evaporate the acetone maintaining oven temperature as $110\pm5^{\circ}$C. Left out material subtracted from weight of cotton measures the quantity of Tar and SPM present in the producer gas [1]. Later raw and cleaned gases were taken in especially designed gas sampling bottle with septum, to analyse the composition of producer gas with the help of Orsat apparatus, further checked with gas chromatography.

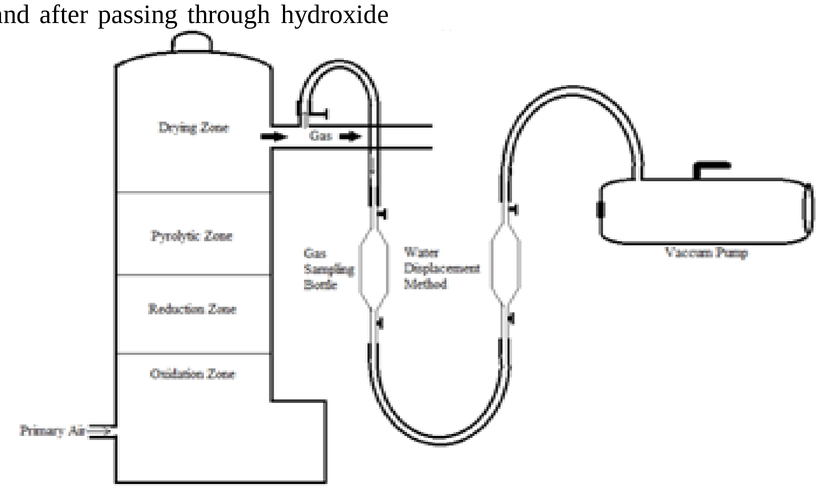


Figure.1: Sampling of producer gas through water displacement method

## III. RESULT AND DISCUSSION

Proximate analysis of biomass includes moisture content (5.366 %, wb), Volatile matter (77.14 % db), Ash content (0.86% db), Fixed carbon (21.53 % db), and Calorific Value (4445.22 kCal/kg). Proximate analysis indicates that fire wood obtain from open markets are suitable for thermal application.

The removal efficiency of Tar and SPM, at different NaOH and KOH concentration dosing, dosing solution temperatures and resistance times of producer gas on producer gas quality was optimize and same is discussed under following sub-heads.

**A. Effect of Hydroxide Concentration on Cleaning Efficiency of Producer Gas**

To achieve the optimized concentration of hydroxides (NaOH and KOH), producer gas was passed through different concentration (10% to 60%) of hydroxide solution. It was observed that at atmospheric temperature, 30% NaOH concentration gives maximum (82.7%) cleaning efficiency. Similarly KOH gives the maximum cleaning efficiency (69%) with 40% KOH concentration. The cleaning efficiency of NaOH is higher than KOH. Cleaning efficiency of producer started suffering at below and above 30% concentration for NaOH and 40% concentration of KOH respectively. It may be due to the fact that above 30% NaOH and 40% KOH concentrations, both solutions started losing its dissolution capacity or it may be due to pressure of the gas in the system decreases, gas becomes less soluble in the solvent [9].

Critical analysis of both optimized concentration of hydroxides indicate that NaOH is better and chipper than KOH for conditioning as well as removal of Tar and SPM from producer gas. It is also important to note that the concentration of both hydroxide (NaOH and KOH) is still alkaline in nature even when it reacts with Tar (acidic nature); it may be due to high basic nature of hydroxides. Thus it can be safely concluded that after adding of small quantity of hydroxides flacks, concentration of used solution can be maintained to desire level.

The calorific value of producer gas increased up to 12% after conditioning with hydroxides (Table 2 and 3). For raw producer gas it was about 1048 kCal/ $Nm^3$, and 1079.35 kCal/ $Nm^3$ whereas for conditioned producer gas with NaOH & KOH it was noted as 1174.93 and 1200 kCal/ $Nm^3$ respectively. The calorific value of producer gas increases due to absorption of $CO_2$ from the producer gas, which was in the range of 13.0- 13.4% and reduced up to 3.4 and 2.5% respectively with application of NaOH and KOH. Although removal efficiency of $CO_2$ from producer gas with KOH is better than NaOH however, cleaning efficiency of Tar and SPM with NaOH was higher. Hence it is concluded that the Tar and SPM removal efficiency of NaOH is higher than KOH whereas, $CO_2$ removal efficiency of KOH is greater than NaOH. It may be due to higher concentration of KOH.

Table 2: Composition and calorific value of raw and Conditioned Producer Gas with NaOH

| Sample NO. | Producer gas composition | | | | | Calorific value of producer gas, kCal/ $Nm^3$ |
|---|---|---|---|---|---|---|
| | CO | $H_2$ | $CH_4$ | $CO_2$ | $N_2+O_2$ | |
| Raw Producer Gas | | | | | | |
| 1 | 14.45 | 9.51 | 2.81 | 13.3 | 59.93 | 1028.42 |
| 2 | 14.39 | 9.76 | 2.65 | 13.41 | 59.79 | 1018.70 |
| 3 | 15.48 | 10.52 | 2.86 | 13.2 | 57.94 | 1097.42 |
| | Average | | | | | 1048.18 |
| Conditioned Producer Gas with NaOH | | | | | | |
| 1 | 16.06 | 10.57 | 3.12 | 3.4 | 66.58 | 1142.73 |
| 2 | 16.21 | 10.85 | 2.96 | 3.5 | 66.48 | 1140.51 |
| 3 | 17.15 | 12.56 | 3.14 | 3.25 | 63.9 | 1241.54 |
| | Average | | | | | 1174.93 |

Caloric values of standard CO, $H_2$, & $CH_4$ were taken as 13.1, 13.2 and 41.2 $MJ/m^3$ respectively (Read & Das, 1988). 1 $MJ/m^3$ ≈ 238.8459 $kCal/m^3$

**B. Effect of temperature and residence time of hydroxide solution with producer gas on quality of producer gas**

It is believed that if absorber and absorbent gets more residence time and temperature, their reactivity could be increased. As per the literature, the rate of reactivity increases considerably with an increase in temperature. In other words, rate of reaction is directly proportional to temperature. Retention time (RT) is a measure of the time taken for a sample to pass through any medium. Considering that effect of hydroxide solution's temperature and its residence time with producer gas on producer gas quality was studied.

Table 3: Composition and calorific value of raw and Conditioned Producer Gas with KOH

| Sample NO. | Producer gas composition | | | | | Calorific value of producer gas, kCal/ $Nm^3$ |
|---|---|---|---|---|---|---|
| | CO | $H_2$ | $CH_4$ | $CO_2$ | $N_2+O_2$ | |
| Raw Producer Gas | | | | | | |
| 1 | 15.68 | 10.45 | 2.74 | 13.1 | 58.03 | 1089.68 |
| 2 | 14.61 | 9.74 | 2.66 | 13.3 | 59.69 | 1025.94 |

 

| | | | | | | |
|---|---|---|---|---|---|---|
| 3 | 16.05 | 10.81 | 2.84 | 13.0 | 57.3 | 1122.43 |
| | Average | | | | | 1079.35 |
| Conditioned Producer Gas with KOH | | | | | | |
| 1 | 17.42 | 12.25 | 2.86 | 2.43 | 65.04 | 1212.66 |
| 2 | 16.53 | 10.86 | 2.85 | 2.6 | 67.16 | 1140.01 |
| 3 | 18.02 | 12.63 | 2.91 | 2.5 | 63.94 | 1248.34 |
| | Average | | | | | 1200.34 |

Caloric values of standard CO, $H_2$, $CH_4$ were taken as 13.1, 13.2 and 41.2 $MJ/m^3$ respectively (Read & Das, 1988). 1 $MJ/m^3 \approx$ 238.8459 $kCal/m^3$

Optimized concentrations of hydroxide solutions (NaOH and KOH) were heated at randomly selected temperatures (60°C, 70°C and 80°C) before dosing it with producer gas. Temperatures of hydroxide solutions were maintained with the help of water bath. The residence time of hydroxide solutions with producer gas was enhanced by using pebbles (20-25 mm size) up to a height of 9-10 cm and 14-15 cm respectively in 2,000 ml conical bottle (before putting pebbles the height of solution was 6 cm).

The result shows that optimized NaOH concentration gave maximum cleaning efficiency at higher temperature ($80^oC$) and was noted about 92.0% however, optimized KOH concentration (40%) at same temperature gave only 78.05% cleaning efficiency of producer gas. In fact cleaning efficiency of producer gas (at optimized concentration of hydroxide solution) increases with increasing temperature of hydroxide solution. Temperature of hydroxide solution was kept up to $80^oC$, as further increment in hydroxide solution temperature, may increase the cleaning cost of producer gas without much increase in cleaning efficiency (Fig.2 and 3). Study indicates that at higher temperature the cleaning efficiency of NaOH is more than KOH. Similarly, it also noted that the effect of residence time on optimized NaOH for cleaning of producer gas was 87.21% whereas with optimized KOH it was only 72.97%. Critical analysis of data for increasing residence time of producer gas with optimized hydroxide solutions and increased hydroxide solution temperature later dosing of producer gas, clearly indicate that increasing of Hydroxide solution temperature is more effective than increasing of residence time of producer gas with optimized hydroxide solution for cleaning of producer gas. However, the solubility of gases generally decreases with increasing temperature [10].

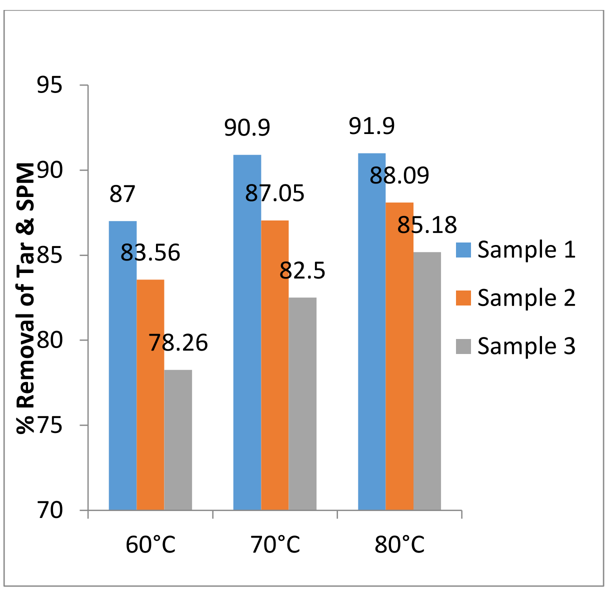


Figure.2 Removal of Tar & SPM with heated NaOH solution

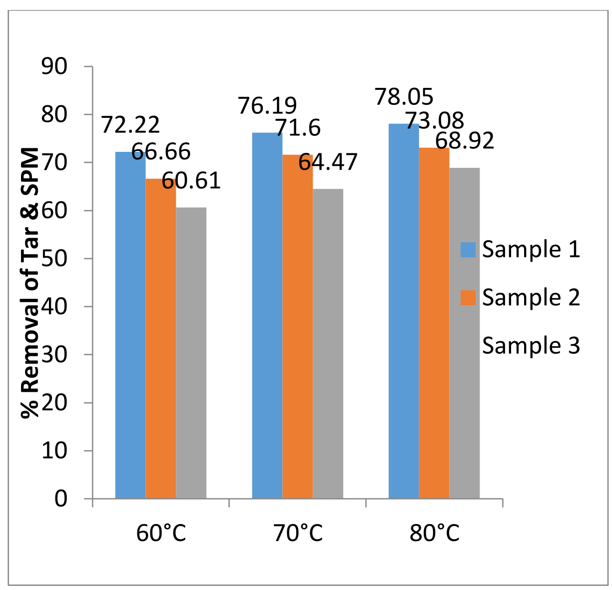


Figure. 3 Removal of Tar & SPM with Heated KOH solution

Clean producer gas obtained through residence time of hydroxide solution, further analyzed with gas chromatograph and very encouraging result was found. The calorific value of producer gas increased up to 17% after conditioning with optimized hydroxide solution and higher residence time of hydroxides solution with producer gas (Table 4 and 5). Although both hydroxides gave significant cleaning which statistically (T-test) proved, however cleaning efficiency of NaOH at higher temperature is better than and KOH. Hence, it could be safely concluded that NaOH concentration give economical cleaning as compared to KOH [5].

It was also noted that although the cleaned producer gas fuel properties does not met the specification of the IC engine conditions, however it is able to conditioned and reduced maximum quantity of (92%) tar & SPM from the producer gas at very nominal cost.

Table 4: Composition and calorific value of raw and Conditioned Producer Gas with NaOH

| Sample NO. | Producer gas composition | | | | | Calorific value of producer gas, kCal/ $Nm^3$ |
|---|---|---|---|---|---|---|
| | CO | $H_2$ | $CH_4$ | $CO_2$ | $N_2+O_2$ | |
| Raw Producer Gas | | | | | | |
| 1 | 14.55 | 9.56 | 2.91 | 13.35 | 59.63 | 1043.01 |
| 2 | 14.69 | 10.16 | 2.95 | 13.48 | 58.72 | 1070.25 |
| 3 | 15.68 | 10.02 | 2.96 | 13.29 | 58.05 | 1097.79 |
| | Average | | | | | 1070.35 |
| Conditioned Producer Gas at optimized & more residence time with NaOH solution | | | | | | |
| 1 | 16.53 | 11.55 | 3.31 | 1.30 | 68.61 | 1200.76 |
| 2 | 16.69 | 11.35 | 3.35 | 1.40 | 67.21 | 1209.70 |
| 3 | 17.18 | 11.39 | 3.37 | 1.25 | 68.06 | 1228.27 |
| | Average | | | | | 1212.91 |

Table 5: Composition and calorific value of raw and Conditioned Producer Gas with KOH

| Sample NO. | Producer gas composition | | | | | Calorific value of producer gas, kCal/ $Nm^3$ |
|---|---|---|---|---|---|---|
| | CO | $H_2$ | $CH_4$ | $CO_2$ | $N_2+O_2$ | |
| Raw Producer Gas | | | | | | |
| 1 | 15.86 | 10.54 | 2.77 | 13.15 | 58.03 | 1101.12 |
| 2 | 14.68 | 9.94 | 2.86 | 13.32 | 59.69 | 1054.15 |
| 3 | 16.15 | 10.38 | 2.80 | 13.20 | 57.3 | 1108.10 |
| | Average | | | | | 1088.12 |
| Conditioned Producer Gas at optimized & more residence time with KOH solution | | | | | | |
| 1 | 18.23 | 12.25 | 3.39 | 0.86 | 65.27 | 1290.20 |
| 2 | 16.53 | 10.86 | 3.56 | 0.85 | 68.20 | 1209.91 |
| 3 | 18.02 | 12.63 | 3.62 | 0.71 | 65.02 | 1318.24 |
| | Average | | | | | 1272.78 |

Caloric values of standard CO, $H_2$, $CH_4$ were taken as 13.1, 13.2 and 41.2 $MJ/m^3$ respectively [15]. 1 $MJ/m^3 \approx 238.8459$ $kCal/m^3$

 

## IV. CONCLUSIONS

From the above study it can be safely concluded that, 30% NaOH concentration gives maximum cleaning efficiency (82.7%) of producer gas as compared to 40% KOH concentration (69%). The cleaning efficiency of optimized concentration could be further enhanced by increasing the temperature and residence time of the dosing solution. The result shows that NaOH concentration gives maximum cleaning efficiency (92.0%) at higher temperature (80$^o$C). The cleaning efficiency of heated NaOH concentration was found higher than KOH for Tar and SPM removal. Although both hydroxides give significant cleaning efficiency, which was proven by statistically (T-test), however cleaning efficiency of NaOH is better than KOH. The calorific value of producer gas increased up to 10% after conditioning with hydroxides. The calorific value of producer gas could be further increased up to 17% after conditioning with optimized and higher residence time of hydroxides solution. Tar and SPM removal efficiency of NaOH is higher than KOH whereas, $CO_2$ removal efficiency of KOH is greater than NaOH.

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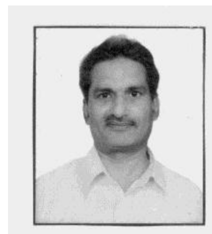

**R N Singh, Professor,** has completed his B Tech & M Tech in Agricultural Engineering and Ph.D. in Energy. He has more than 88 research paper and 2 Book chapters in his credit. He is life member of 4 society engaged in Energy & Environment. Guided 4 Ph.D. and more than 50 PG students. 3 Ph.D. research scholars are continuing.
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