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Experimental Study of Coconut Shell Fluidized Bed Gasification for Production of Fuel Gas for End-Use Applications

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Abstract

The coconut shell fluidized bed gasification features for production of fuel gas have been studied experimentally. The objective of the study is to investigate the influence of steam to biomass ratio [SBR] varied from 0 to 2.6 on gas composition, equivalence ratio [ER], biomass particle size of 1mm and inert gas particle size of 1.2 mm and reactor temperature varied from 600 to 900 °C for the production of fuel gas. The gas composition for H_2, CO, CO_2, and CH_4 was analyzed and found that the H_2 gas production is high 37 % with temperature than other gases. The calorific value [HHV], carbon conversion and gas yield were increased to 5 MJ/Nm^2, 1.32 Nm^2/kg and 86% with a variation of temperature. The variation of gas composition with steam to biomass ratio shows that the CH_4 has high percentage 45% and 51% of the bed temperature of 710 ^{0}C and 780 ^{0}C respectively than other gases. The maximum carbon conversion increased from 76 to 82% between the temperature range from 650 ^{0}C to 900 ^{0}C. The composition of H_2 with temperature was found to be a very vital factor. The methane and hydrogen contents were increased with a variation of temperature. The results reveal that steam reforming improved the fuel gas quality than biomass air gasification. However, too much supply of steam would reduce the temperature of gasification which reduces the quality of fuel gas.

Keywords: Coconut shell Biomass, Fluidized bed, Gasification, Equivalence Ratio [ER], Steam to Biomass Ratio [SBR], Higher Heating Value [HHV], Gas Yield [GY] and Carbon Conversion Efficiency [CCE]

INTRODUCTION

In current years, utilization of fossil fuel has vulnerable to the supportable growth of the humanity due to energy shortage and environment problems. Pyrolysis, gasification, and hydrolysis are called as thermal–chemical technologies, which was used to change biomass into gas energy or chemicals like renewable sources [1]. The sulfur content up to 90% could be reduced using the fluidized bed for the gasification. The fluidized beds subjected to serious corrosion of vessels and pipes from scratch by pulverized elements of biomass [2]. The pyrolysis technology is better for bio-oil production from biomass than other conversion processes. The bio-oil energy density by volume is ten times higher than the biomass so it was more preferred for transport purposes. However, the bio-oil has high viscosity, low heating value, high water content, and corrosiveness. Therefore, bio-oil utilization was limited for pyrolysis but it is suitable for syngas production processes and steam reforming for hydrogen gas. The steam and bio-oil reforming has limitations for hydrogen and syngas production and the deactivation of the catalyst due to deposition of carbon [3–5]. Hence, an effective catalyst such as Ni-based catalysts, oxide catalyst and metal-loaded noble catalysts and highly active elements such as Rh, Ru, and Pt have been investigated for reforming of steam and bio-oil [6]. However, the applicability of noble metals was decreased due to rare availability and high cost. Ni-based catalysts were utilized to harvest hydrogen-rich gas at high yields due to activities of high reforming with gas-solid gasification, biomass pyrolysis and catalytic reforming processes, [7 and 8]. The use of Ni has limitations such as cost, sulfur poisoning and toxicity which affect the environmental and safety measures. Therefore, Fe/olivine catalysts are used for reforming of steam and bio-oil, for the environmental and economic motives. The complexity of bio-oil challenges the researchers and, many studies have been done on model compounds such as glycerol, acetic acid, m-cresol and ethanol such as the fodder materials on bio-oil reforming [9 and 10].

The bio-oil obtained coconut shell by pyrolysis process was used in a rotary kiln heated electrically at 450 ^{0}C, which yield a maximum of liquid products [11]. When Fe content is increased from 5 % to 10 % in biomass, the CO_2 and H_2 concentration increases due to water gas shift (WGS) reaction is gambled, it was found that iron was auspicious metal for WGS reaction and reached maximum carbon conversion to 97.2% however, concentration of CO reduces [12]. The main crystalline phase was Mg_2SiO_4 at fresh and in the used condition of catalysts. After steam reforming reaction the intensity of Mg_2SiO_4 diffraction increases to peak. The Fe_2O_3 presents in the fresh catalyst as diffraction pattern and vanishes after reaction of catalyst [13]. The reforming of steam and bio-oil from pyrolysis of coconut shell over olivine catalyst in fixed-bed quartz reactor has been studied [14]. The influences of iron loading, calcination temperature, steam to carbon ratio, reaction temperature, bio-oil weight hourly space velocity [BWHSV] in gas composition and conversion of carbon were explored to enhance the activity of the catalyst.

From above literature review, it was found that the effective catalysts, noble metals and few varieties of fuels have been burnt in a fluidized bed. The biomass products of bio-oil by pyrolysis, syngas by gasification, and sugar by hydrolysis have been produced by above thermal–chemical technologies. Therefore, the present study is focused on fluidization and gasification of biomass using steam and air as the working fluid and bubbling fluidized bed gasifier was developed experimentally to explore the influence of SBR, temperature, and ER on the performance of gasification and reactor scale up in commercial applications.

The maximum coconut production was found in Indonesia than other countries. Also, plenty of coconut biomass is available in India, especially in southern coast pan of the country. More biomass plants have been established in India for production of fuel gas. Table 1 shows the quantity of coconut produced in the world.

Table 1. Coconut producing countries in the world

Country	**Production (Tonnes)**
Philippines	20,600,500
Indonesia	16,312,400
India	12,994,500
Brazil	3,659,144
Sri lanka	2,506,300
Thailand	1,821,540
Mexico	1,346,300
Vietnam	1,186,100
PapuaNew Guinea	767,200
Malaysia	656,320
Tanzania	380,200
World	62,230,504

Table 2 Proximate analysis

Characteristics Parameters	**Percentage (%)**
Moisture content	7.02
Ultimate Analysis (Wt. = % wet basis)	
Carbon (C)	54.03
Hydrogen (H)	6.25
Volatile matter	73.03
Oxygen (O_2)	38.55

Table 3. Ultimate analysis

Characteristics Parameters	**Percentage (%)**
Fixed carbon	19.58
Nitrogen (N)	0.87
Ash	0.62
Sulphur (S)	0.19
Higher Heating Value	20,889 kJ/kg

MATERIALS AND METHODS

The coconut shell was dried naturally in air and pulverized and used as biomass for the experimental study. The coconut shells were analyzed in the proximate and ultimate analysis for its moisture content. Table 2 shows proximate analysis of biomass and composition of coconut shell. Table 3 shows coconut shell ultimate analysis of dry and without ash condition. The analysis yields the gas composition of 38.45% oxygen 53.73% carbon and 6.15% hydrogen by mass and remaining part contained hints of Sulphur and Nitrogen. The fuel has been represented on a molar basis as $CH_{1.36}\,O_{0.54}$ by considering the major elements. A typical sample of pulverized coconut shell used in present study is shown in Figure 1.

Figure 1. Sample of pulverized coconut shell

Experimental setup

The layout of fluidized bed gasification system used for the present study is shown in Figure 2. The experimental setup consists of different components such as air blower, motor, hopper, generator, thermocouple, scrubber, cyclone, burner, filter and fluidized bed gasifier with a column size of 108 x 1500 mm. The fuel and air were supplied through screw feeder and blower. The cyclone, dry filter, water scrubber, and burner attached with probes were located on the downstream side of the setup. The heater was located in bed base and insulated entire bed with refractories. Thermocouples were fixed to measure the temperature at various points in the setup. The fuel gas and ash particles were detached in cyclone separator after gasification process. Before operating the reactor bed, pressure drop, particle size measurement, and preparation of setup would be accomplished. The experiment was conducted systematically to confirm the steadiness of the process and consistency of measured data from the experiment.

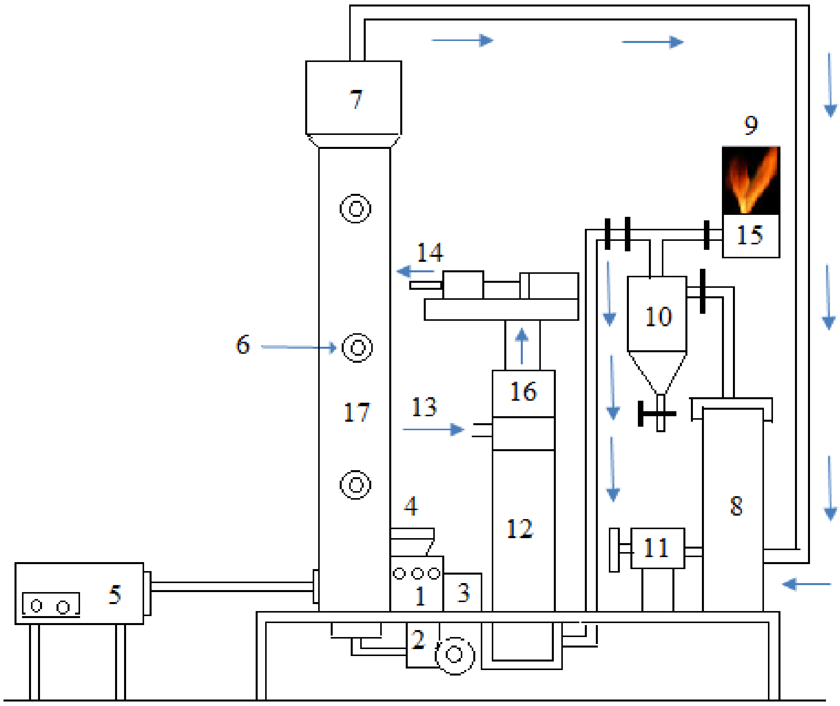

Figure 2. Fluidised Bed Gasification System – Experimental Setup

1. Control Pannel, 2. Air Blower, 3. Variable Displacement Drive Motor, 4. Biomass Hopper, 5. Steam Generator, 6. Thermocouple, 7. Free Board, 8. Suction Blower, 9. Flame, 10. Cyclone, 11. Blower Motor, 12. Water Scrubber, 13. Water Inlet, 14. Supply to Gas Chromotography, 15. Burner, 16. Dry Filter, 17. Fluidized Bed Gasifier

Initial startup of the bed

The inert solid bed has been preheated electrically about 550^0C before supplying biomass fuel to burnt in the fluidized bed. After the required temperature was reached in bed, screw feeder was operated to gradually supply the biomass particles to inert bed. The biomass feed rate was preserved up to stable temperature was attained by the bed. After reaching stable bed temperature of 500 to 600^0C initiated the fuel feed and about 2 to 3 hours were required for observing smoke and emissions. The gas composition and temperature were analyzed and measured with gas analyzers and thermocouples at various locations (T_1 to T_{10}). Water filed U tube manometer is used to measure the airflow and velocity through the Orifice air flow meter.

RESULTS AND DISCUSSION

Influence of temperature on gas composition

The gas composition with the influence of temperature has been investigated for fluidization and gasification of coconut shell biomass for the reaction temperature reactor varied from 650 to 900^0C as shown Figure 3. The result depicts that the gas composition has high Hydrogen (H_2) concentration of 39% by volume for gasification temperature at 900^0C. When gasification temperature increases, contents of CO, and CO_2 decreased from 21 to 16% and 18 to 16 % by volume and then increase slightly, also CH_4 contents slightly decreased from 7.5 to 5 %. at equilibrium condition of gasification and a similar trend was noticed in the literature [16].

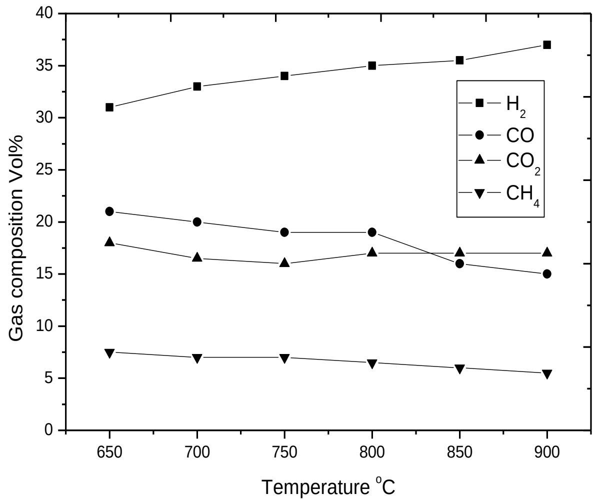

Figure 3. Influence of temperature on gas composition

Influence of temperature on HHV and gas yield

The variation of HHV and gas yields with the influence of temperature is shown in Figure 4. The result reveals that the gas yield increase from 122 to 132 Nm^3/Kg with the influence/increase of temperature at 850^0C then slightly decrease with temperature. Similarly, the gasification process yields fuel gas having a heating value of 4.86 MJ/m^3 at maximum gasification temperature of 900 ^{0}C. The solid fuel is converted into gaseous products at a higher heating value with the increase of temperature.

The heat losses through the gasifier walls, close to the exit, and cyclone could be endorsed at lower temperatures of the freeboard. The gas yield was high at maximum temperature but it didn't favor gas heating value always. The hydrogen and carbon dioxide in the fuel gas is high at maximum temperature due to gasification pressure and temperature which agree well with the literature [18].

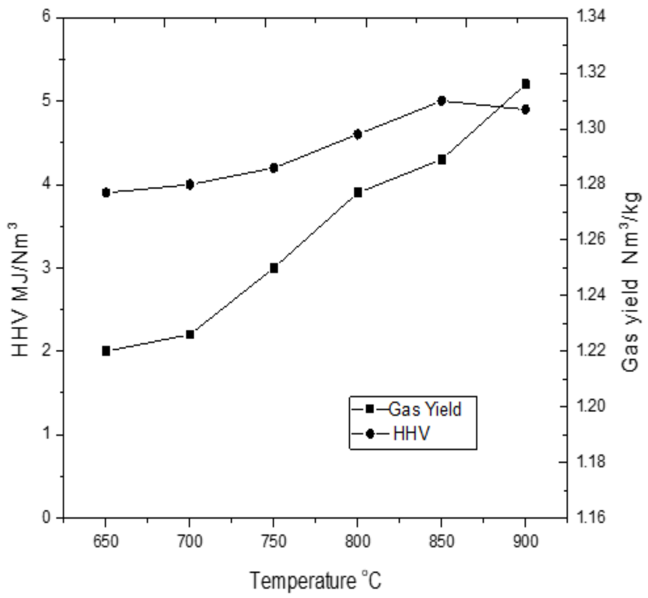

Figure 4. Influence of temperature on HHV and gas yield

Influence of temperature on carbon conversion efficiency

The gas carbon conversion efficiency [CCE] variation with gasification temperature is shown in Figure 5. The carbon conversion efficiency has been determined from feed data and product gas composition during gasification process. The factors considered in the study have a substantial influence on carbon conversion efficiency at different temperatures. The result reveals that carbon conversion efficiency increased from 76 to 82% between the temperature range of 650^0C and 900 ^{0}C and the present result agree well with the result in the literature [18].

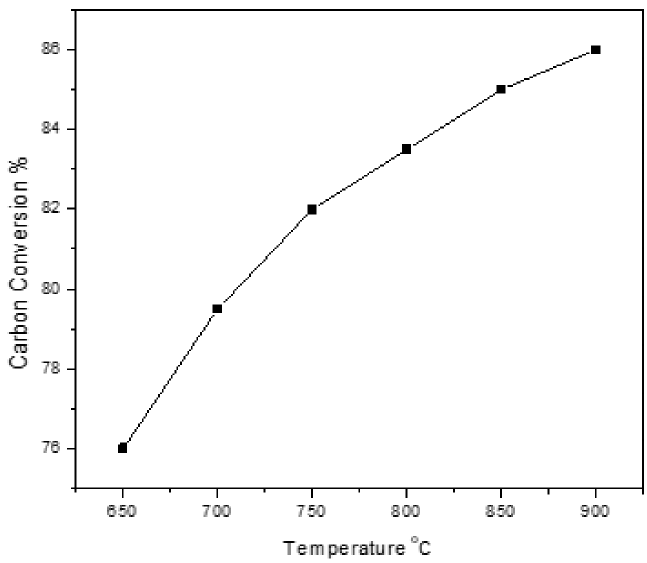

Figure 5. Influence of temperature on Carbon conversion efficiency

Influence of equivalence ratio [ER] on gas composition

The gas composition variation with equivalence ratio [ER] is shown in Figure 6. ER was evaluated with the ratio between the actual air supplied and stoichiometric air required per kg of fuel. ER is an important parameter in biomass gasification with air. A part of the fuel was ignited to produce energy to withstand the endothermic gasification reactions during the process of gasification. The lower value of ER for a fluidized bed gasifier was determined by various features such as reactor temperature, fuel feed rate, and fluidization velocity. Similarly, the maximum value of ER was determined by reactor temperature, tar quantity, gas quality and thermal perspective of material. It is observed from the result that the hydrogen concentration is high 37% than other elements at ER 0.12. Similarly, at ER 0.2, 0.25, 0.3 and 0.35 the concentration of CO is high than other elements in the gas composition. Also, the portion of fuel burnt in the fluidized bed and portion of fuel gasified in the reactor was determined by ER and a similar trend was found in the literature [15].

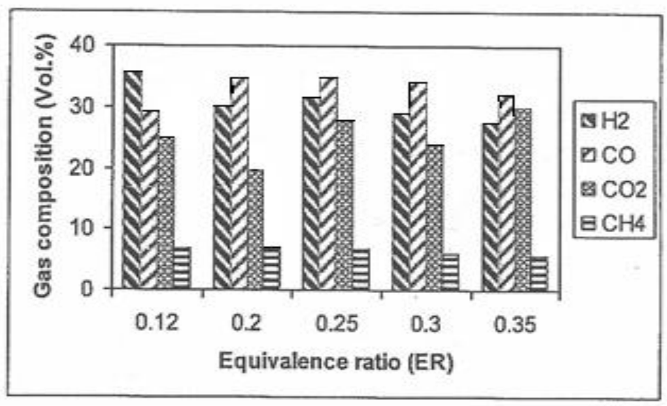

Figure 6. Influence of equivalence ratio on gas composition volume %

Influence of steam to biomass ratio on gas composition

The influence of steam to biomass ratio on gas composition at bed temperature 710 ^{0}C is shown in Figure 7. The steam flow rate was increased from 0 to 2.6 kg/h and kept all other conditions constant during the experiment.

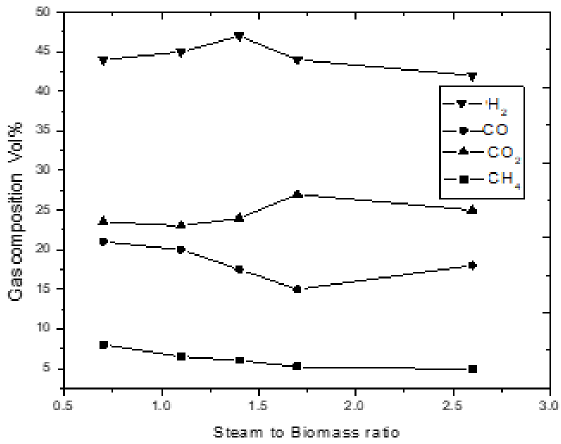

Figure 7. Influence of steam to biomass ratio on gas composition at a bed temperature of [710^{0}C]

The result reveals that the high concentration of H_2 47% attained at SB 1.5. The trend of hydrogen concentration slightly increases and then decrease with a variation of SB. The CO_2 concentration increased from 24 to 27% then slightly decreased. Similarly, the concentration of CO and CH_4 decreases from 21 to 17 % and 8% to 5 % with an increase of SB from 0.7 to 2.6.

The influence of steam to biomass ratio on gas composition at a bed temperature of 780 ^{0}C is shown in Figure 8. The result reveals that the high concentration of hydrogen 50% at SB 1.5. The hydrogen concentration slightly increases from 47.5 % and then decrease with a variation of SB. The CO concentration decreased from 22.5 to 17%. Similarly, the concentration of CO_2 increases from 18 to 24 % and CH_4 decreases from 8.5 to 5% with an increase of SB.

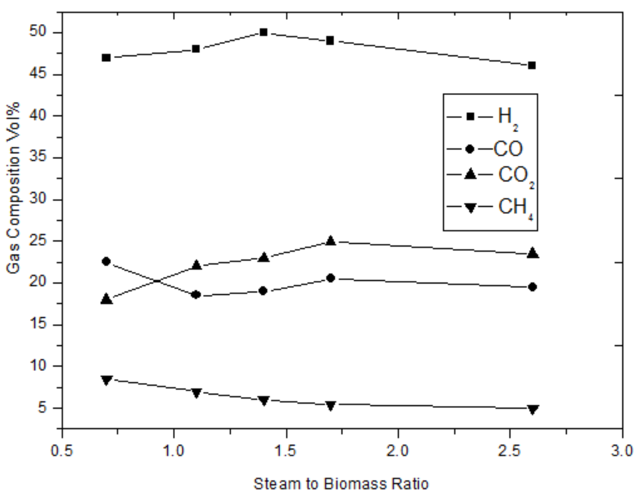

Figure 8. Influence of steam to biomass ratio on gas composition at a bed temperature of [780^{0}C]

It was evident from Figures 7 and 8 that the supply of steam has a great impact on the improvement of hydrogen concentration at maximum temperature. Further over the SBR range from 1.65 to 2.6, the composition of CO, CO_2 decreased, which depends on the supply of an excess quantity of steam, which reduces the temperature of reaction, it degrades the gas quality and the present results agree with result found in the literature [16].

Table 4. Hydrogen Production with temperature for different biomass

Temperature (^{0}C)	Hydrogen Production (mol %)	Reference
650	72	[6]
850	40	[8]
900	71	[4]
900	82	[5]
900	37	Present

Figure 9 illustrates the hydrogen production (mol %) with temperature for different biomass obtained from the literature reference shown in Table 4. The result shows that hydrogen production was high 82 (mol %) at 900 ^{0}C. The similar result for the catalyst deactivation and steam reforming of bio-oil for hydrogen production was found in the literature [5]. However, in the present investigation the hydrogen production 37 % (mol %) at temperature 900 ^{0}C which is higher than that of other gases in the composition [Fig. 3].

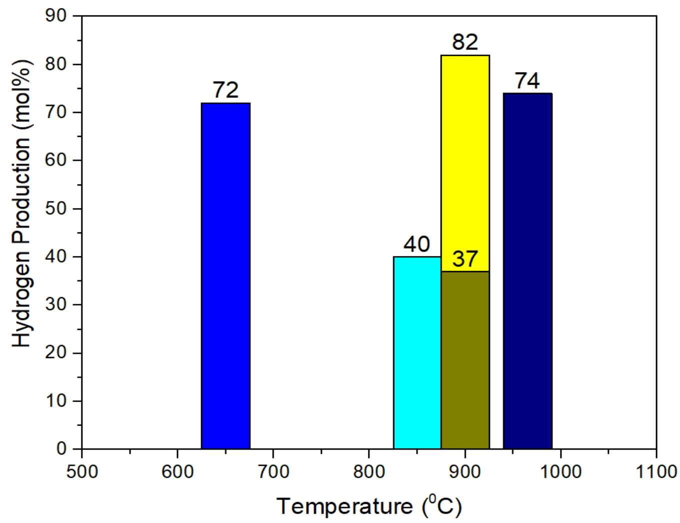

Figure 9. Hydrogen gas energy production for various biomass

CONCLUSIONS

The study on coconut shell fluidized bed gasification for the production of fuel gas for end use applications performed experimentally. The coconut shell steam-air gasification has been employed in a gasifier with a fluidized bed to produce fuel gas for end use applications. The equivalence ratio played a vital role than other parameters in the gasification process, which influence more on gas composition. The result shows that the hydrogen concentration is high 37% than other elements at ER 0.12. Similarly, at ER 0.2, 0.25, 0.3 and 0.35 the concentration of CO is higher than other elements. According to end use of gas produced in the gasification process, the suitable equivalence ratio would be considered. The complex effects on test results would be formed at higher equivalence ratio (ER). The optimal value of ER changed with respect to temperature, HHV and gas yield and carbon conversion. The performance of a gasifier depends on the influence of reactor temperature because of the reactor dependent of ER. The efficiency of carbon conversion was increased from 76 to 82% between the temperature range from 650 ^{0}C to 900 ^{0}C. The introduction of steam greatly improved the hydrogen at highest temperatures. The gas yield and higher heating value increased for higher temperatures. The cost of coconut shell is low and availability is high compared to other biomass. Therefore, coconut shell biomass would be the best source for fluidized bed gasification for energy conversion.

NOMENCLATURE

Abbreviations

SBR Steam to Biomass Ratio

ER Equivalent Ratio

HHV Higher heating value

Molecular Formula

H_2 Hydrogen

CO Carbon Monoxide

CO_2 Carbon Dioxide

CH_4 Methane

C_2H_4 Ethylene

C_2H_2 Acetylene

C_2H_6 Ethane

N_2 Nitrogen

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