THERMODYNAMIC SIMULATION OF BIOGAS COMPOSITION IN AGRICULTURAL WASTE GASIFICATION

MUHAMMAD SYAFIQ BIN AZIZ

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ABSTRACT

Being one of the world's largest producers of palm oil, Malaysia has an abundant supply of oil-palm fronds due to the large plantation areas in the country. Considering the large and consistent supply, oil-palm fronds could be a promising source of biomass energy through gasification. In this work, the study is conducted by thermodynamic simulation to determine the biogas composition of oil palm fronds (OPF). Computer simulation using MATLAB is performed to predict composition of the synthesis gas. A preliminary gasification of oil palm fronds is conducted to understand the process and to improve the study in the future. It is proven that oil palm fronds are feasible for gasification and have a good potential as a renewable energy source. Biomass gasification is a thermochemical process of converting biomass into the producer gas or synthesis gas which can be subsequently used for heat, power and liquid fuels production through various synthesis processes. The major objective of this study was to identify the biogas composition from oil palm fronds (OPF) by thermodynamic simulation using thermodynamic equilibrium model as suit to the Gibbs equations and formulations. Few assumptions were made as to ease the analysis of data. Results obtained were tabulated and graphs were sketched. Different temperature with range of 650˚C to 1200˚C is the manipulate variable. The composition of combustible gases was decreasing as the temperature increase. Also as the moisture content is increase, the composition of CO decrease, while other gases were slightly increases and decreases.

SIMULASI TERMODINAMIK UNTUK KOMPOSISI BIOGAS DALAM PENGEGASAN SISA BUANGAN PERTANIAN

ABSTRAK

Sebagai salah satu pengeluar minyak sawit terbesar di dunia, Malaysia mempunyai banyak bekalan pelepah kelapa sawit kerana kawasan ladang yang besar di negara ini. Disebabkan itu, ianya boleh menjadi sumber yang menjanjikan tenaga biomas melalui pengegasan. Dalam kertas kerja ini, kajian dijalankan menggunakan simulasi termodinamik bagi menentukan komposisi biogas pelepah kelapa sawit (OPF). Simulasi komputer menggunakan MATLAB dilakukan untuk meramalkan komposisi gas terhasil. Kajian ini membuktikan bahawa pelepah kelapa sawit sesuai untuk pengegasan dan mempunyai potensi yang baik sebagai sumber tenaga yang boleh diperbaharui. Pengegasan biomas adalah satu proses termokimia, menukar biomas kepada gas sintesis yang boleh kemudiannya digunakan untuk tenaga haba, kuasa dan pengeluaran bahan api melalui pelbagai proses sintesis. Objektif utama kajian ini adalah untuk mengenal pasti komposisi biogas dari pelepah kelapa sawit dengan simulasi termodinamik menggunakan model keseimbangan termodinamik yang bersesuaian dengan rumusan dan persamaan Gibbs. Beberapa andaian telah dibuat untuk memudahkan analisis data. Graf telah dilakarkan berpandukan data yang telah diperolehi. Suhu yang berbeza antara 650˚C hingga 1200˚C adalah pemboleh ubah yang dimanipulasikan. Komposisi gas mudah terbakar telah berkurangan dengan peningkatan suhu. Juga dengan meningkatnya kandungan kelembapan, komposisi gas CO menurun, manakala gas lain sedikit bertambah dan berkurangan.

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NOMENCLATURE

a – g	Coefficient for gibbs free energy empirical relation
C, H, O, N, S	Carbon, hydrogen, oxygen, nitrogen and sulfur fraction in biomass (dry basis)
C*, H*, O*	Carbon, hydrogen and oxygen fraction in biomass (wet basis)
$c_1 - c_4$	Coefficient for specific heat capacity
ΔG_T	Gibbs free energy (KJ/kmol))
$\Delta_{gf,T,i}$	Change in Gibbs free energy for individual gas with temperature
HHV	Higher heating value (MJ/kg)
H_{bio}	Heat of formation (kJ/kmol)
H°_{f}	Enthalpy of formation (KJ/kmol)
K_1	Equilibrium constant for water-gas shift reaction
K_2	Equilibrium constant for $C + 2H_2 \rightarrow CH_4$
LHV	Lower heating value (MJ/kg)
M_{bio}	Molecular weight of the biomass
m	Moisture content in biomass (% dry basis)
m_w	Number of moles of water vapor (dry basis)
n_i	Number of moles of species i
n_{tot}	Total number of gaseous moles in the reactor
P_x	Partial pressure of species of I inside the reactor

P_i	Products of complete combustion of biomass (kmol) for species i
w	Stoichiometric coefficients of water vapor
x, y, z	Normalized coefficient of atomic hydrogen, oxygen and nitrogen for biomass molecule
$x_1 - x_2$	Number of moles of H_2, CO, CO2, H_2O, CH_4 respectively
x_g	Number of moles of oxygen for gasification

CHAPTER 1

INTRODUCTION

1.1 General Overview

The high prices of fossil fuels and environmental concerns have driven many interests for the field of biomass gasification. A large number of organizations and countries around the world nowadays are investing development dollars in an attempt to get place in this critical market. As we all know, biomass is an indigenous, environmental friendly, often cheap and the most important it is renewable fuel. Besides that, so many agricultural wastes that either been destroyed or left to rot, although the wastes have so many other benefits as important as for biogas production. Handbook of Biomass Downdraft Gasifier Engine Systems mentioned that the benefits gain from biomass for energy use include low cost by-product of agriculture, low ash and sulfur content, and also decreasing the level of CO_2 in the atmosphere.

Palm oil industry waste provides the biggest potential for biomass energy utilization in Malaysia. It is because they are abundant, easily available and moreover there is a need to be disposed of cost effectively. Today, 3.88 million hectares of land in Malaysia is under oil palm cultivation. These palm oil plantations yield a large amount of harvestable biomass that is about 50 to 70 tons per hectare per year. 10% of this total results in the finished products as palm oil and palm kernel oil. While the remaining 90% are Empty Fruit Bunch (EFB), trunks, kernels, and palm oil mill effluent that will be discarded as waste or left to settle in waste ponds, as well as Oil Palm Fronds (OPF) that are left to rot for soil nutrition (S. Prasertsan et. al., 2006)

Table 1.1 Biomass stock in Malaysia (Abdulmuin et al., 2001)

Year	Felled Trunks (mil. tones, dwb)	Felled Fronds (mil. tones, dwb)
2006	9.7	2.5
2008	9.0	2.4
2010	10.5	2.7
2012	11.2	2.9
2014	10.2	2.7
2016	10.0	2.6
2018	10.6	2.8
2020	11.1	2.9

The present research focuses on OPF, as they are easier to collect, store and to prepare as feedstock. Table 1.1 shows the projected availability of the field residue of trunks and fronds in Malaysia (Abdulmuin et al., 2001).

Gasification as the matter of fact already had been used for almost 200 years ago, in various types and forms. It is essentially an oxygen limited thermochemical conversion of carbonaceous material to a useable gaseous fuel. The wide range of sources including energy crops, agricultural waste, and municipal solid waste, create easy accessibility to low cost fuel sources for gasification almost anywhere in the world. Small scale (20-250 kWth) downdraft gasifiers are a valuable source of energy for populated rural areas. These units are cheap, easy to use, require minimal maintenance and support. It also can drastically improve the lives of rural communities that don't have electricity or gas for cooking. This potential for future growth gives rise to the need for an accurate model for predicting the heating value and composition of the synthesis gas produced from many different biomass sources.

1.2 Previous Developments and Motivation

Several models have been proposed in literature to predict downdraft gasifier synthesis gas composition and heating value from the ultimate and proximate analysis of the fuel source. Zainal et al., (2001) had proposed using a thermodynamic equilibrium model for such predictions and concluded reasonable agreement with experimental data. From the other journal, Sharma (2008) compared a kinetic model to a thermodynamic model. That study concluded that the kinetic model is limited because it uses rate constants based on the difference from the equilibrium value, so for gas composition the equilibrium model is a reasonable alternative to the complexity of the kinetic model. The equilibrium model computes the gas composition, for complete thermochemical conversion, at a specified temperature. In any small scale commercial downdraft gasifier, there will not be a single reaction temperature or complete thermochemical conversion. The equilibrium model compared well against experimental data in (Zainal et al., 2001) but for an actual downdraft gasifier the inhomogenous reaction zone causes fluctuating reaction temperatures and conversion efficiencies. These factors lead to inaccuracies in the prediction of composition and heating value of expected synthesis gas. An accurate model of gas composition and heating value is critical for the optimal selection of biomass sources in various parts of the world.

1.3 Research Background

The research of biomass has been conducted a decade ago till now, in various ways, samples and methods. The research will be more focus on the composition of biomass. To be more specific, Oil Palm Frond (OPF) had been chosen as the subject. Plus, thermodynamic equilibrium by using Gibbs formulations is necessarily applied.

Recently a number of studies were made by final year students of Universiti Teknologi Petronas [(Kimin, 2008), (S. Balamohan, 2008)], on the feasibility of OPF as a feedstock for gasification and preparation of the feedstock. Their scope for chemical property was studied by Ultimate Analysis, Calorific Test, and Proximate Analysis. The results they obtained show that OPF has a higher quality in terms of lower ash content, higher calorific value and acceptable moisture content, compared to other biomass resources as shown in Figures 1.1 and 1.2. Figure 1.1 shows the comparison of ash content of OPF with other biomass resources. While Figure 1.2 shows the comparison of energy content of OPF with other biomass resources. From the analysis also Balamohan found out that the OPF has average density of 712.8kg.m^{-3}, which is more suitable as compared to other feedstock materials in terms of bulk handling (S. Balamohan., 2008).

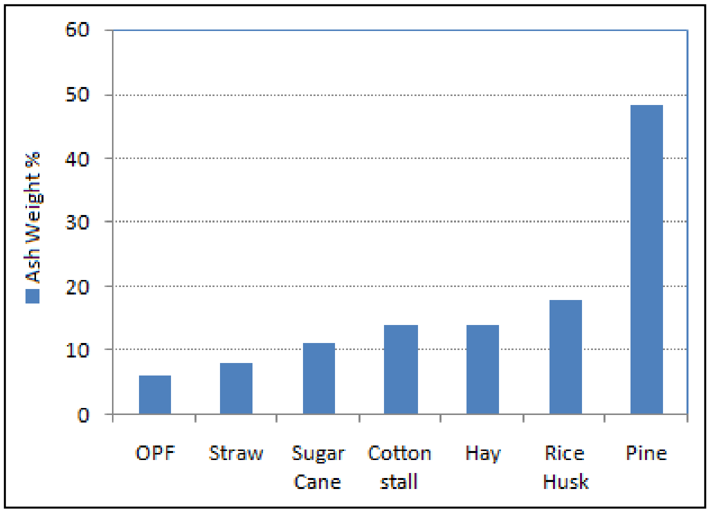

Figure 1.1 Ash content in biomass samples (S. Balamohan, 2008)

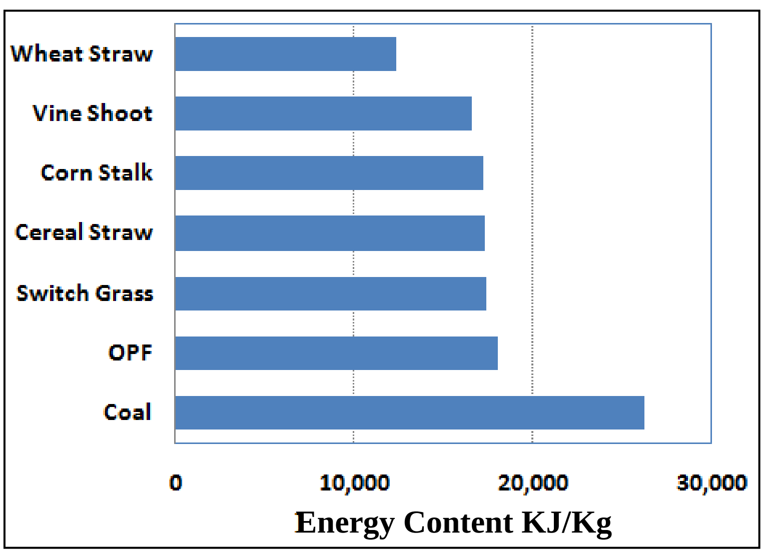

Figure 1.2 Energy content in biomass samples (S. Balamohan, 2008)

A few another studies have been conducted to determine synthesis gas composition and heating value of synthesis gas using thermodynamic equilibrium modeling on limited biomass types. Watkinson et al., (1991) have developed a thermodynamic equilibrium model and compared their result with various types of gasifiers used for coal. Their research found the best prediction for entrained bed gasifier but a lower degree of accuracy while predicting synthesis gas composition from fluidized bed and moving bed gasifiers. Meanwhile, Jarungthammachote and Dutta (2007) and Melger et al. (2007) predicted synthesis gas composition from various biomass types using thermodynamic equilibrium modeling at a fixed equivalence ratio. Their researches predicted gasification temperature through an iterative process and the synthesis gas composition at a given equivalence ratio. It is stated that the composition of temperature is varies with the temperature for the gasification. Thus, this research was to identify how far can this be true.

1.4 Research Objectives

- To identify the composition of biogas in agricultural wastes (oil palm fronds) by thermodynamic simulation.
- To study the agricultural wastes gasification process.

1.5 Research Project

1.5.1 Introduction

In order to manage this research successfully, 3 stages had been planned earlier. The stages are as below:-

1.5.1.1 Stage 1

Firstly, collects any data and journals that related to the research in order to understand the core and concept of the research. With the data and journals collected, introduction for the proposed research have been made where it will clearly stated the objectives that want to be achieve accompanied with literature review that will relate the finding and the entire journals together. After that, the methodology will be plan. For simulation, the software will be identified and the how to use the software will be learned further. Furthermore, the problem statement also will be identified.

1.5.1.2 Stage 2

During the second stage, the basic concepts are already mastered and will focus more on the experiment methodology. Also, in order to do the simulation, software chosen is MATLAB that fit the best for the models and simulation. In this stage, it will be more on preparing models and equations for the simulation so the simulation can be run smoothly so that successful result can be obtained. Other than that, all the variable and parameter will be identified so that the objectives will be more cleared.

1.5.1.3 Stage 3

With all the variables and parameters have identified, the model will be constructed using MATLAB coding software while referring to the governing equations, which are mostly related to Gibbs. Then the simulation will be run repeatedly as to achieve the objectives of this research. The results are taken and will be analyzed.

1.5.2 Research Scope

In this proposed project, a thermodynamic simulation of biogas composition in agricultural waste gasification will be conducted. For the specific sample of the agricultural waste, Oil Palm Fronds (OPF) is chosen. This is because Malaysia has a very large amount of OPF produced as referred to Table 1 (Abdulmuin et al., 2001). This simulation will be run by using MATLAB. The model chosen are thermodynamic equilibrium. It is because this technique is easier and also the simplest compare to other technique such as kinetics-free, steady-state, semi-transient and transient. Plus more, this technique give more accurate result of gas composition value (Reed, 1985). Some assumptions are made or retrieved from journals. Moreover, Gibbs equations and formulations are necessarily needed as for the calculation in order to run a complete simulation and achieving the objectives of this research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This literature is based on the objectives and scopes of this research. As for the research is focusing on the biogas composition in agricultural waste, that is OPF. Besides that, the thermodynamic simulation and the software used, that is MATLAB also discussed. This includes the modelling and governing equations. A reports will be made at the end of the experiment and the results of MATLAB analysis, backed up by published experimental data, where there are applicable will be presented.

2.2 Biomass Gasification

Modern agriculture is an extremely energy intensive process. However the high agricultural productivities and subsequently the growth of green revolution have been made possible only by large amount of energy inputs, especially those from fossil fuels (Leach, 1976). Rajvanshi (1978) mentioned that there has been a trend towards use of alternative energy due to recent price rise and scarcity of these fuels. As example of alternative energy sources are solar, wind, geothermal and other renewable energy. However these energy resources have not been able to provide an economically viable solution for agricultural applications (Dutta and Dutt, 1981).

Solar Energy Research Institute (SERI) mentioned that one biomass energy based system, which has been proven reliable and had been extensively used for transportation and on farm systems during World War II is wood or biomass gasification.

Biomass gasification on the other hand means incomplete combustion of biomass that resulting in production of combustible gases. The gases are consisting of Carbon monoxide (CO), Hydrogen (H_2) and traces of Methane (CH_4). This mixture is called producer gas. Producer gas can be used to run internal combustion engines. It also can be used as substitute for furnace oil in direct heat applications. The most important is it can be used to produce methanol in an economically viable way. Reed et al. (1982) mentioned that methanol is an extremely attractive chemical which is useful both as fuel for heat engines as well as chemical feedstock for industries. Since any biomass material can undergo gasification, this process is much more attractive than ethanol production where only selected biomass materials can produce the fuel.

2.3 Gasifier Types And Processes

Warnecke (2000) had classified the gasifiers into four different categories which are based on the fluid and solid movement inside the reactor. The types of gasifiers are as follow:-

i. Quasi non-moving or self-moving feedstock

ii. Mechanically-moved feedstock

- a. Downdraft gasifier
- b. Updraft gasifier
- c. Cross-draft gasifier

iii. Fluidically-moved feedstock

- a. Bubbling bed (BB) gasifier
- b. Circulating fluidized bed (CFB) gasifier
- c. Entrained-bed gasifier

iv. Special reactors

- a. Spouted bed gasifier
- b. Cyclone gasifier

Among of all the gasifiers stated, it is proven that downdraft (Figure 2.2), updraft (Figure 2.1), bubling bed fluidized (Figure 2.3) and circulating fluidized bed (Figure 2.4) gasifiers are the most well known and widely used (Knoef, 2000). However, bubling bed and circulating fluidized bed both are conclude as one section, that is as fluidized gasifier due to only slight different between them. Figure 2.1 to 2.4 show schematics of various gasifiers that are commonly used in the commercial market.

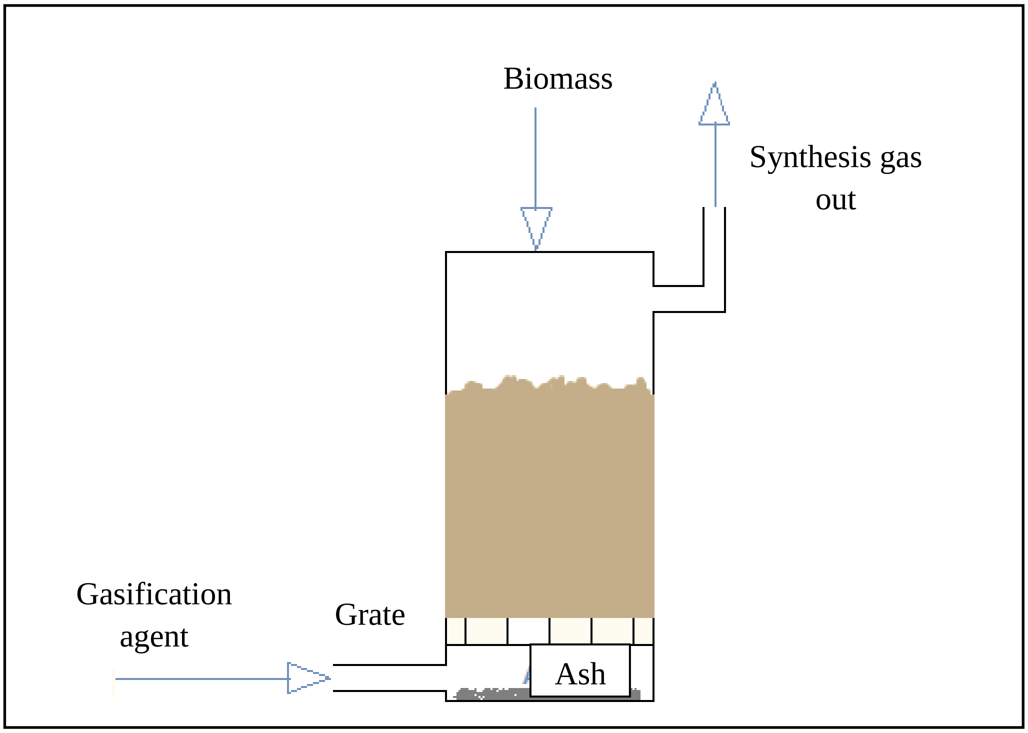

Figure 2.1 Updraft gasifier

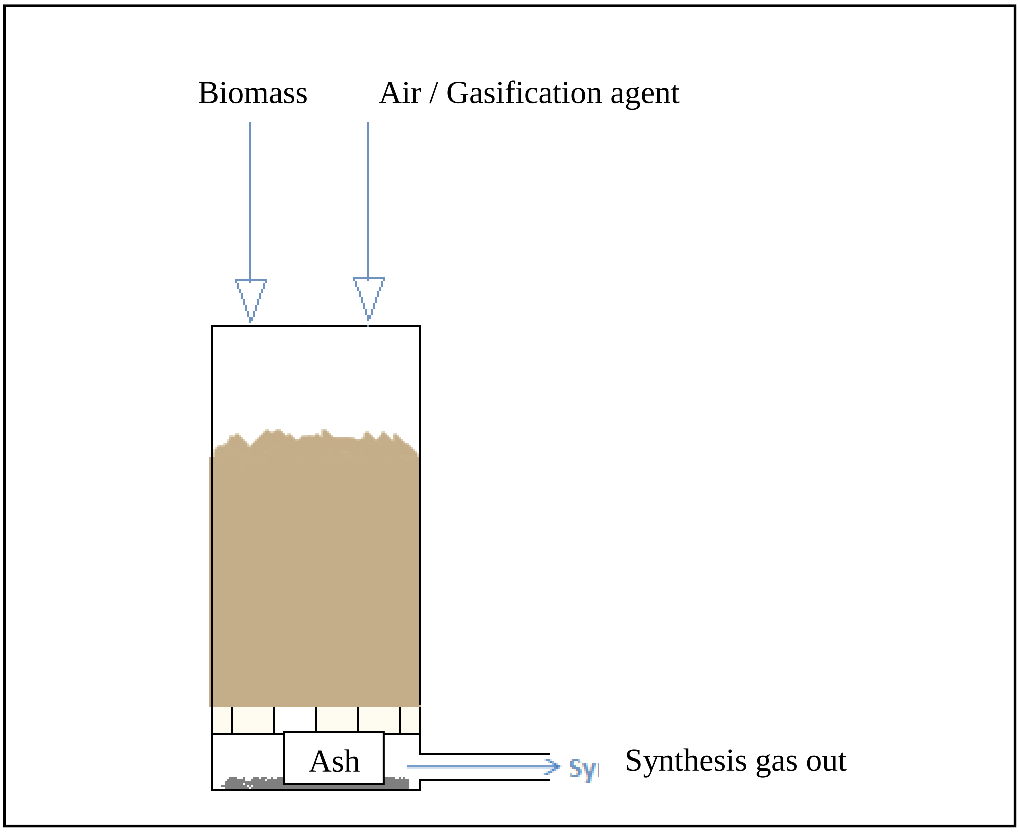

Figure 2.2 Downdraft gasifier

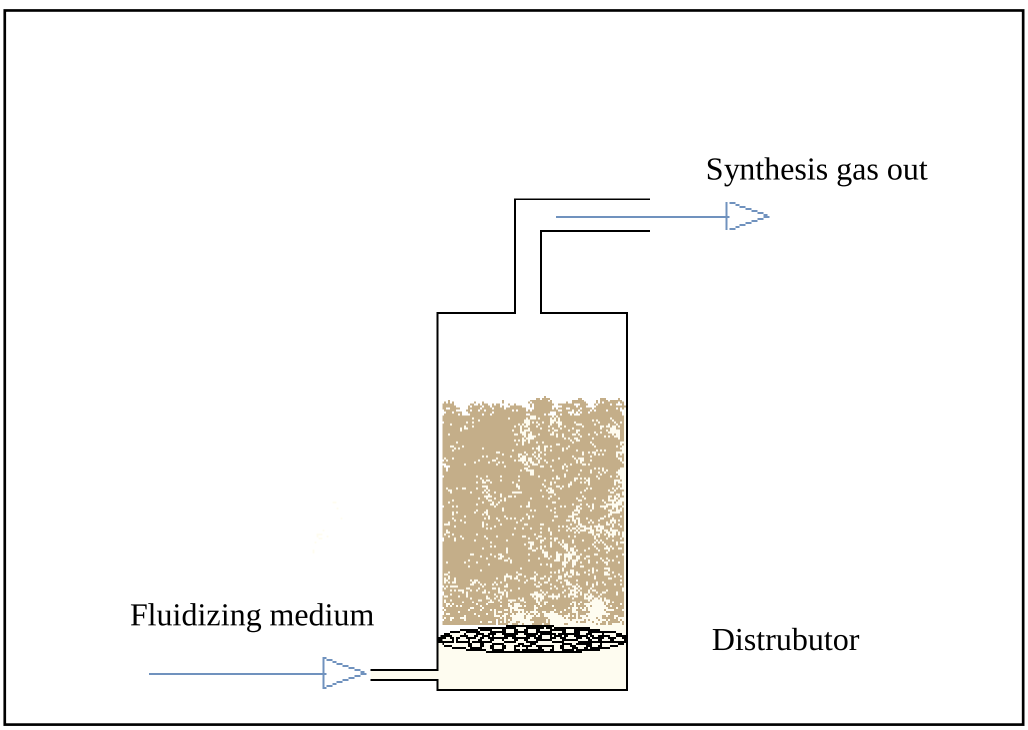

Figure 2.3 Bubling bed fluidized