PRELIMINARY DESIGN OF METHANOL PLANT FROM COAL WITH GASIFICATION PROCESS CAPACITY OF 150,000 TONS/ YEAR

Asked to Meet Requirements Achieved Bachelor Degree in Strata 1 Engineering at Chemical Engineering Department Faculty of Engineering

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UNIVERSITAS MUHAMMADIYAH SURAKARTA

2018

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PUBLIKASI ILMIAH

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Preliminary Design of Methanol Plant from Coal with Gasification Process Capacity of 150,000 Tons/ Year

ABSTRACT

Methanol (CH_3) is one of the hydrocarbon compounds of the alcohol group (CnH_2n+2O) with an alkyl hydroxyl group (-OH). Dervative products of Methanol is acetic acid, MTBE, rubber, formaldehyde, etc. In Indonesia alone consumption of Methanol needs quite a lot, and raw material is very much. The raw material can take from Sumatera or Kalimantan. The plant is planned to establish in Sangatta area, East Kalimanatan in 2025, because near with raw material, utility, transportation. The land area is 3,800m^2 and hire 159 employees. The process of Methanol is in raw materials preparation stage, coal needed is 18,939.394 kg/hour, water 8,234.519 kg/hour, and oxygen 49,242.424 kg/hour. That will be heated in Gasifier Reactor with pressure 50 atm and temperature 600°C. Then input to Water Gas Shift Reactor (WGSR), at process stage will be react with water so CO_2 content will increase using catalyst CuO-ZnO-Al_2O_3 with pressure 49 atm and temperature 409°C. Then input to Fix Bed Reactor (FBR), CO and CO_2 will be react with hydrogen to produce methanol and water content using catalyst CuO-ZnO-Al_2O_3 at pressure 48 atm and temperature 200°C. At purification product stage, methanol and water are separated by distillation process. Methanol purification by distillation process to obtain methanol content is 99%. Supporting unit of the plant consist of water supply as much as 968,907 kg/hour which are processed from Mataram River, provision 21,038.298 kJ/hour of saturated steam, 34,970.805 kJ/hour of superheated steam, provision 998 kW of electricity, provision 236 liters/hour of diesel fuel, and provision 3,252 kg/hour of ammonia. Amount of working capital is USD $105,381,928 and Fix Capital Investment (FCI) is $12,184,852.33. The economic analysis shows that Return On Investment (ROI) before tax is 59.93% and after tax is 45.24%. Pay Out Time (POT) before tax is 1.43 years and after tax is 1.9 years. Break event-point (BEP) is 47.74% capacity, Shut down point (SDP) is amounted at 39.57% capacity, and Discounted cash flow (DCF) is 30.28%. From data results of feasibility analysis can be concluded that the plant is profitable and feasible to be established.

Keywords : Methanol, Gasifier, Fixed Bed Reactor.

ABSTRAK

Metanol (CH_3) adalah salah satu senyawa hidrokarbon dari kelompok alkohol (CnH_2n+2O) dengan kelompok hidroksil alkil (-OH). Contoh produk Metanol seperti asam asetat, MTBE, karet, formalin. Di Indonesia sendiri, kebutuhan Metanol cukup banyak, dan bahan baku yang melimpah. Bahan baku dapat diperoleh dari Sumatera atau Kalimantan. Pabrik ini direncanakan didirikan di kota Sangatta, Kalimanatan Timur pada tahun 2025, karena lebih dekat dengan bahan baku, utilitas, transportasi. Area tanah yang digunakan adalah seluas 3,800m^2 dan memiliki pekerja sebanyak 159 karyawan. Proses Metanol dalam tahap persiapan bahan baku memerlukan batubara sebanyak 18.939,394 kg/jam, air 8.234,519 kg/jam, dan oksigen 49.242,424 kg/jam. Yang kemudian akan dipanaskan dalam reaktor Gasifier dengan tekanan 50 atm dan suhu 600°C. Kemudian masuk kedalam Water Gas Shift Reaktor (WGSR) pada proses ini akan bereaksi dengan air sehingga kandungan CO_2 akan meningkat menggunakan katalis CuO-ZnO-Al_2O_3 dengan tekanan 49 atm dan temperatur 409°C. Kemudian masuk kedalam Fix Bed Reaktor (FBR), CO dan CO_2 akan bereaksi dengan hidrokarbon untuk menghasilkan Methanol dan air dengan menggunakan katalis CuO-ZnO-Al_2O_3 pada tekanan 48 atm dan temperatur 200°C. Pada tahap pemurnian, Metanol dan air akan dipisahkan dengan proses Distilasi. Didapatkan kemurnian Metanol dengan proses Distilasi adalah 99%. Unit pendukung pabrik terdiri dari pasokan air sebanyak 968,907 kg/jam didapat dari sungai Mataram, penyediaan uap jenuh 21.038,298 kJ/jam, penyediaan uap panas 34.970,805 kJ/jam, penyediaan listrik 998 kW, penyediaan bahan bakar diesel 236 liters/jam, dan penyediaan ammoniak 3.252 kg/jam. Jumlah modal kerja sebanyak USD $105,381,928 dan Fix Capital Investment (FCI) adalah $12,184,852.33. Analisis ekonomi menunjukkan bahwa Return On Investment (ROI) sebelum pajak 59,93% dan setelah pajak 45,24%. Pay Out Time (POT) sebelum pajak 1.43 tahun dan setelah pajak 1.9 tahun. Kapasitas Break event-point (BEP) adalah 47,74%, kapasitas Shut down point (SDP) adalah 39,57%, dan Discounted cash flow (DCF) adalah 30,28%. Dari hasil data analisis kelayakan dapat disimpulkan bahwa pabrik untung dan layak didirikan.

Kata kunci: Metanol, Gasifier, Fixed Bed Reaktor.

1. INTRODUCTION

1.1 Background of Plant

In Indonesia, the development of the chemical industry is growing quite rapidly. Along with the development of the chemical industry in Indonesia, resulting in the need for methanol (CH_3) which is a raw material and chemical supporting materials industry has increased. Methanol (CH_3) is one of the hydrocarbon compounds of the alcohol group (CnH_2n+2O) with an alkyl hydroxyl group (-OH). Derivative products of Methanol such as acetic acid, MTBE, rubber, formaldehyde. Methanol is a necessary chemical both domestically and abroad, in Indonesia alone consumption of methanol needs quite a lot. Based on the methanol requirement data above, the need for methanol import will increase every year. This is very possible considering the need for methanol by other factories producing derived compounds is expected to continue to grow. Coal in Indonesia is so much, the availability of coal in Indonesia reaches 120.338 million tons and reserves of 28,017 million tons (Ministry EMR, 2013). The amount is spread in the territory of Indonesia, namely Sumatra and Kalimantan, is the 2 regions that have the largest source and coal reserves among other regions. In total, resources and reserves in Sumatera and Kalimantan respectively reached 72,879 million tons and 49,526 million tons. Of the total coal resources, 1% is very high calorie coal, 10% high calorie coal, 67% medium calorie coal, 22% low calorie coal type (Sukandarrumidi,2005).

1.2 Capacity of Plant

In determining the capacity of the factory there are a few things to consider, among other, the needs of methanol on Indonesia, the capacity of existing factories and also the availability of raw materials.

Table 1. Data Import Methanol in Indonesia (BPS,2016)

Years	Import Methanol (kg)	Years	Import Methanol (kg)
2000	59,420,790	2008	63,102,359
2001	57,576,136	2009	76,973,648
2002	48,287,536	2010	192,223,851
2003	57,935,536	2011	275,947,247
2004	81,210,748	2012	261,865,693
2005	46,591,876	2013	341,455,237
2006	29,992,713	2014	557,361,725
2007	63,293,031	2015	628,257,845

(data.un.org, 2016)

The amount of methanol is expected to continue to grow, due to the need for methanol by other factories that produce derivative compounds. Raw material methanol is from PT. Kaltim Prima Coal. Taking into account thing as well as necessities methanol which will increase the design of the factory set then methanol 150,000 Tons/Year.

1.3 Loaction of Plant

Methanol plant with capacity 150,000 Tons/Year is planned to be established in the industrial area of Sangatta, Samarinda. The selection of the location based on the location of raw material, marketing, transportation, water resources to meet the water needs and availability of labor.

1.4 Review Library

Coal is a solid hydrocarbon rock formed from plants in an oxygen-free environment, and the effects of pressure and heat that last very long. So that coal can be regarded as fossil fuel. The main elements contained in coal are carbon, hydrogen, and oxygen. In general, coal is classified as 5 levels (in order of quality) are anthracite, bituminous, sub-bituminous, lignite, peat (peat). While the classification of coal based on calorific value is divided into 3 groups, namely as follows:

Table 2. Group of Coal based on Calor Content

(Sukandarrumidi, 2005)

Group	Calor Content (kkal/kg)	Type
High Quality	± 8300	Antrasit
Medium Quality	7000 – 8000	Bituminus
Low Quality	6000	Sub-Bituminus
	1500-4500	Lignit

1.5 The Usefulness of The Product

Methanol have many uses, especially in the chemical industry. Methanol uses among other as the raw material for formaldehyde, fuel, as raw material for plastic, heating material.

2. METHOD

2.1 Basic Reaction

2.1.1. Reaction of Product

2.1.1.1. Gasifier

$$C + H_2O \leftrightarrow CO + H_2$$

$$\Delta H°_{R(298)} = \sum\Delta H°_{f(product)} - \sum\Delta H°_{f(reactan)}$$

$$= (\Delta H°_{f(CO2)} + \Delta H°_{f(H2)}) - (\Delta H°_{f(C)} + \Delta H°_{f(H2O)})$$

$$= (-393.509 + 0) - (0 - 285.83)$$

$$= -107.679 \text{ kJ/mol}$$

The value of $\Delta H°_{R(298)}$ is negative, then the reaction takes place in an exothermic.

2.1.1.2. Water Gas Shif Reactor (WGSR)

$$CO + H_2O \leftrightarrow CO_2 + H_2$$

$$\Delta H°_{R(298)} = \sum\Delta H°_{f(product)} - \sum\Delta H°_{f(reactan)}$$

$$= (\Delta H°_{f(CO2)} + \Delta H°_{f(H2)}) - (\Delta H°_{f(CO)} + \Delta H°_{f(H2O)})$$

$$= (-393.509 + 0) - (-110.525 - 285.83)$$

$$= -41.154 \text{ kJ/mol}$$

The value of $\Delta H°_{R(298)}$ is negative, then the reaction takes place in an exothermic.

2.1.1.3. Fixe Bed Reactor (FBR)

Reaction 1 : $CO + 2H_2 \leftrightarrow CH_3OH$

Reaction 2 : $CO_2 + 3H_2 \leftrightarrow CH_3OH + H_2O$

Reaction 1

$$\Delta H°_{R(298)} = \sum\Delta H°_{f(product)} - \sum\Delta H°_{f(reactan)}$$

$$= (\Delta H°_{f(CH3OH)}) - (\Delta H°_{f(CO)} + 2x\Delta H°_{f(H2)})$$

$$= (-201) - (-110.525 + 2(0))$$

$= -90.475$ kJ/mol

The value of $\Delta H°_{R(298)}$ is negative, then the reaction takes place in an exothermic.

Reaction 2

$\Delta H°_{R(298)}$ $= \sum \Delta H°_{f(product)} - \sum \Delta H°_{f(reactan)}$

$= (\Delta H°_{f(CH3OH)} + \Delta H°_{f(H2O)}) – (\Delta H°_{f(CO2)} + 3x\Delta H°_{f(H2)})$

$= (-201 - 41.83) – (-393.509 + 3(0))$

$= -93.321$ kJ/mol

The value of $\Delta H°_{R(298)}$ is negative, then the reaction takes place in an exothermic.

2.1.2. Reaction equilibrium

2.1.2.1. Gasifier

$C + H_2O \leftrightarrow CO + H_2$

$\Delta G°_{R(298)}$ $= \sum \Delta G°_{f(product)} - \sum \Delta G°_{f(reactan)}$

$= (\Delta G°_{f(CO2)} + \Delta G°_{f(H2)}) – (\Delta G°_{f(C)} + \Delta G°_{f(H2O)})$

$= (-394.359 + 0) – (0 – 237.15)$

$= -157.009$ kJ/mol

From Van Ness (1997), equation (15.14)

$\ln K_{298} = [\ \frac{-\Delta G°f}{TR}\ ]$

$= 63.34$

$K_{298} = 3.2234 \times 10^{27}$

From Van Ness (1997), equation (15.17). At temperature 600 °C (873.15 K), equilibrium constant can be calculated as follows:

$\ln \frac{K}{K298} = \frac{-\Delta H°r}{R} x(\frac{1}{T} - \frac{1}{Treff})$

$K = 1.62 \times 10^{12}$

The value of equilibrium constant is 1.62×10^{12}, so the reaction is irreversible

2.1.2.2. Water Gas Shif Reactor (WGSR)

$CO + H_2O \leftrightarrow CO_2 + H_2$

$\Delta G°_{R(298)}$ $= \sum \Delta G°_{f(product)} - \sum \Delta G°_{f(reactan)}$

$= (\Delta G°_{f(CO2)} + \Delta G°_{f(H2)}) – (\Delta G°_{f(CO)} + \Delta G°_{f(H2O)})$

$= (-394.359 + 0) – (-137.168 – 228.59)$

$= -28.601$ kJ/mol

From Van Ness (1997), equation (15.14)

$\ln K_{298} = [\ \frac{-\Delta G°f}{TR}\ ]$

$= 11.54$

$K_{298} = 1.02 \times 10^5$

From Van Ness (1997), equation (15.17). At temperature 350 °C (623.15 K), equilibrium constant can be calculated as follows:

$\ln \frac{K}{K298} = \frac{-\Delta H°r}{R} x (\frac{1}{T} - \frac{1}{Treff})$

$K = 1.01 \times 10^5$

The value of equilibrium constant is 1.01×10^5, so the reaction is irreversible.

2.1.2.3. Fixe Bed Reactor (FBR)

Reaction 1 : $CO + 2H_2 \leftrightarrow CH_3OH$

Reaction 2 : $CO_2 + 3H_2 \leftrightarrow CH_3OH + H_2O$

Reaction 1

$\Delta G°_{R(298)} = \sum\Delta G°_{f(product)} - \sum\Delta G°_{f(reactan)}$

$= (\Delta G°_{f(CO2)}) – (\Delta G°_{f(CO)} + 2x\Delta G°_{f(H2)})$

$= (-162.5) – (-137.168 + 2(0))$

$= -25.332$ kJ/mol

From Van Ness (1997), equation (15.14)

$\ln K_{298} = [\frac{-\Delta G°f}{TR}]$

$K_{298} = 27556.67$

From Van Ness (1997), equation (15.17). At temperature 200 °C (473.15 K), equilibrium constant can be calculated as follows:

$\ln \frac{K}{K298} = \frac{-\Delta H°r}{R} x (\frac{1}{T} - \frac{1}{Treff})$

$K = 2.7 \times 10^4$

The value of equilibrium constant is 2.7×10^4, so the reaction is irreversible.

Reaction 2

$\Delta G°_{R(298)} = \sum\Delta G°_{f(product)} - \sum\Delta G°_{f(reactan)}$

$= (\Delta G°_{f(CH3OH)} + \Delta G°_{f(H2O)}) – (\Delta G°_{f(CO2)} + 3x\Delta G°_{f(H2)})$

$= (-162.5- 228.50) – (-394.359 – 3(0))$

$= -5.27$ kJ/mol

From Van Ness (1997), equation (15.14)

$\ln K_{298} = [\frac{-\Delta G°f}{TR}]$

$K_{298} = 3.76$

From Van Ness (1997), equation (15.17). At temperature 350 °C (623.15 K), equilibrium constant can be calculated as follows:

$$\ln \frac{K}{K298} = \frac{-\Delta H°r}{R} x\left(\frac{1}{T} - \frac{1}{Treff}\right)$$

K = 3.63

The value of equilibrium constant is 3.63, so the reaction is irreversible.

2.3 Step of Process

Methanol making process generally consists of 3 stages as follows:

2.3.1. Raw Material Treatment

Coal and water put into mixder (M-210), then streamed using pump to compresor (E-112) to raise the pressure being 50 atm will be drained into reactor gasifier (R-101). The air flowed into the filter (H-103) to clean air from dust and than come into membran to separate O_2 and N_2, then streamed to the compresor (E-111) to raise the pressure being 50 atm that will be streamed into reacto gasifier (R-101). In the gasifier (R-101), the incoming raw material is heated so that the phase is changes Solid-Liquid-Gas. With condition non isothermal, exothermics, temperature 600^oC and pressure 50 atm. The results come out then cooled with heat exchanger (R-101 and R-102). The streamed to the absorber (D-201) to remove H_2S content. Then streamed back to reactor Water Gas Shift Reactor (R-102) with the model fixed bed multitube. The usefulness of these reactors to obtain the content of CO_2 by adding H_2O with catalyst Cun-ZnO-Al_2O_3 and temperature 350 ^oC pressure 49 atm. Reaction of methanol formation takes place in the gas phase with condition operating is non isothermal, irreversibele, and exothermic of the reaction. Then cooled with heat exchanger (R-103 and R-104) and streamed into condensor (E-311) to lower the temperature on the current recycle. Then it is heated using heat exchangr (E-105) to 350 ^oC comet into reactor Fixed Bed Reactor (R-103).

2.3.2. Process of Product

The result of the product coming out of the reactor Water Gas Shift Reactor (R-102) is then inserted into the heat exchanger (E-106) for its temperature is lowered from 409 ^oC to 200 ^oC. Then streamed to the reactor Fixed Bed Reactor (R-103) with the model fixed bed multitube catalytic Cun-ZnO-Al_2O_3. This active catalyst at the temperature 200 ^oC and can be generated. Reaction of methanol formation takes place in the gas phase with condition operating is isothermal, irreversible, and exothermic of the reaction. The ouput temperature of the reactor about 200 ^oC. The product coes out, then streamed to the absorber (D-202) for methanol and water product taken his course. Later reduced to 1 atm pressure using expander (G-114).

2.3.3. Purification Process

Output of product expander (G-144) in the form of liquid phase, will be passed to a distillation tower (D-211) to separate water and methanol based on his boiling point. Top product from the distillation tower is methanol with 99% purity, then accomodateed temporarily in accumulator (A-144), and subsequently in the flush head into the condensor (E-313) before going into storage tank. While the result of the bottom product form of water will be channeled into the waste treatment unit for temperature is lowered, so that the water can be disposed of into the evironment.

3. RESULT AND DISCUSTION

3.1. The Main Tool Specification

3.1.1. Reactor Gasifier

Code	: R-101
Function	: Gasificationcoal become steam to produce crude gas
Type	: Fixed bed multitube
Operating condition	
- Pressure	: 50 atm
- Temperature	: 600°C
- Phase	: Solid – liquid - gas
- Material contruction	: High allow steel SA-167 grade 3
- Residence time	: 5 second
Hight reactor	: 4.790 m
Diameter reactor	: 4.5 m
Volume	: 94.031 m^3

Price : $ 111,130

3.1.2. Reactor Water Gas Shift (WGSR)

Code : R-102

Function : To added H_2 composition to make carbon dioxide

Type : Fixed bed multitube

Operating condition

- Pressure : 48.5 atm
- Temperature : 350°C
- Phase : Gas
- Material contruction : High allow steel SA-167 grade 3
- Residence time : 600 second

Specifications of shell

- IDS : 39 in
- Thickness : 5/16 in
- Baffle space : 9.75 in
- Number of passes : 1

Specifications of tube

- Number of tube : 700
- BWG : 16
- ID tube : 0.782 in
- OD tube : 1 in
- Pitch : 1 7/8 in
- Composition : Triangular

Reactor Diameter : 2.5 m

Total reactor height : 5 m

Price : $ 65,321

3.1.3. Reactor Fix Bed (FBR)

Code : R-103

Function : Process to make crude methanol

Type : Fixed bed multitube

Operating condition

- Pressure : 48 atm

- Temperature : 200°C
- Material contruction : High allow steel SA-167 grade 3
- Residence time : 600 second

Specifications of shell

- IDS : 39 in
- Thickness : 5/16 in
- Baffle space : 9.75 in
- Number of passes : 1

Specifications of tube

- Number of tube : 750
- BWG : 16
- ID tube : 0.870 in
- OD tube : 1 in
- Pitch : 1 7/8 in
- Composition : Triangular

Reactor Diameter : 3.75 m

Total reactor height : 7.5 m

Price : $ 105,626

3.1.4. Absorber 1

Code : D-201

Function : To absorb H_2S from mix gas product R-101 using solvent Dimethyl Ether Polyethylene Glycol (DEPG)

Type : Packed tower

Number stage : 11 stage

Temperature : 350°C

Pressure : 49 atm

Tray spacing : 0.3

Height tower : 13 m

Diameter : 2.342 m

Construction materials : Stainless steel SA 304

Dimensions of head

- Thickness : 0.005 m

- Height head : 0.586 m

Price : $ 83,149

3.1.5. Absorber 2

Code : D-202

Function : To remove gas impurities from crude methanol.

Type : Packed tower

Number stage : 10 stage

Tray spacing : 0.3

Height tower : 5.949 m

Diameter : 1.752 m

Temperature : 76.168°C

Pressure : 47.5 atm

Construction materials : Stainless steel SA 304

Dimensions of head

- Thickness : 0.005 m
- Height head : 0.438 m

Price : $ 64,068

3.1.6. Distillation Tower

Code : D-211

Function : To separate methanol as light component with water as heavy component.

Type : Tray-coloum

Number plate : 29 plate

Tray spacing : 0.3

Height tower : 9.186 m

Diameter : 1.1511 m

Construction materials : Stainless steel SA 285

Dimension

- Upper diameter : 1.387 m
- Lower diameter : 1.511 m
- Shell Thickness : 3/16 in

Dimensions of head

- Thickness : 0.188 in

- Height head : 0.255 m

Price : $ 162,482

3.2. Utility

Utility units available in methanol plant are as follows:

3.2.1. Water Procurement Unit

Water procurement unit provides sanitation water, water for boilers and cooling process.

3.2.2. Steam Procurement Unit

Steam procurement unit provides steam used in evaporation process and distillation towers.

3.2.3. Electricity Procurement Unit

Electricity procurement unit provide electric as driving force both on process equipments and lightings.

3.2.4. Fuel Procurement Unit

Fuel procurement unit provides diesel fuel for furnace boilers and generators.

3.2.5. Dowtherm A Procurement Unit

Dowther A procurement unit for cooling process.

3.3. Management

This company is an activity organized by the way regularly to seek profits by processing and produces a product, provide goods or services to the community. The form of the company on the design of Methanol plant is Limited Liability (PT). Limited liability company is a legal entity established under the agreement and conduct business. Activities with a capital base that is entirely divided into shares. The stock is the securities issued by the company or PT where people who have owned stock means has provided capital to the company and inderectly such person has company. In the limited liability company shareholders are only liable to deposit the full capital mentioned in each stock.

The Methanol plant is planned to be stablished has:

- The form of company : Limited Liability (PT)
- Field of business : Industry of Methanol
- The location : Sangatta, East Kalimantan

4. CONCLUTION

Dari hasil analisa kelayakan ekonomi dapat disimpulkan sebagai berikut:

1) Profit before tax = USD $ 6,618,072

   Profit after tax = USD $ 4,632,651

2) ROI (*Return On Investment*)

   - ROI before tax = 59.93%
   - ROI after tax = 45.24%

3) POT (*Pay Out Time)*

   - POT before tax = 1.43 years
   - POT after tax = 1.9 years

4) BEP (*Break Event Point*) = 447.74%

5) SDP (*Shut Down point)* = 39.57%

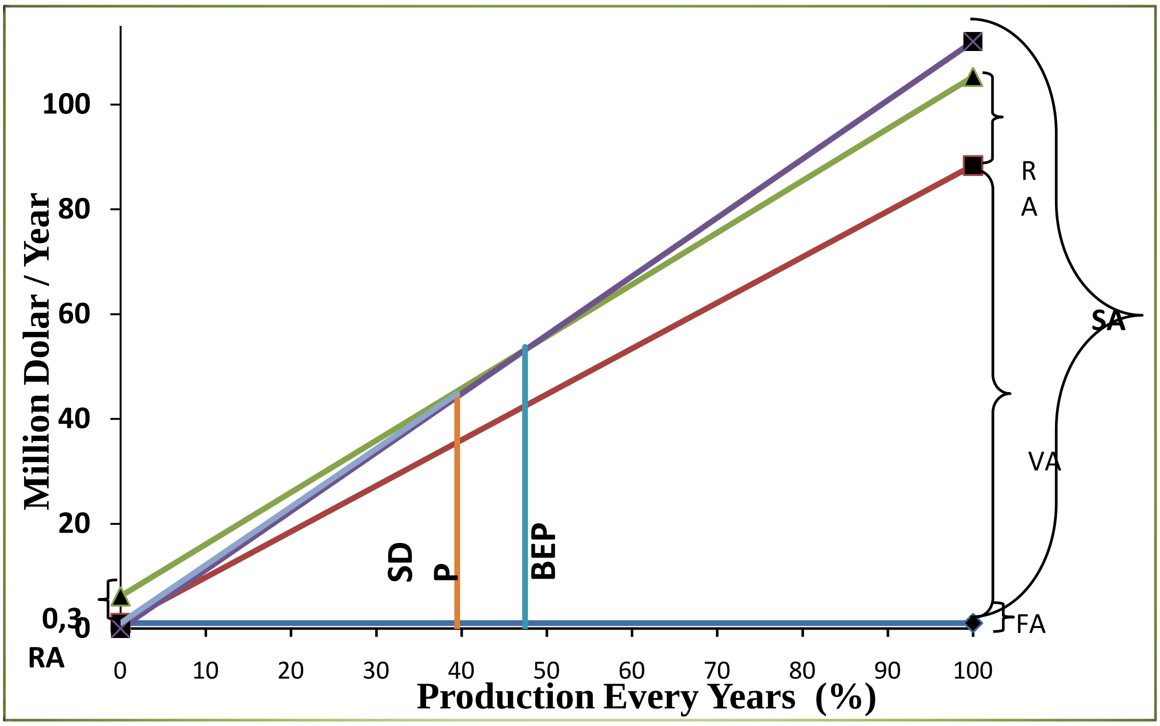

Figure 1. Feasibility Analysis

Based on results of economic feasibility analysis we concluded that Methanol plant is feasible to build.

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