PRODUCTION OF BIOGAS BY ANAEROBIC DIGESTION PROCESS AND PROCESS SIMULATION

Prepared By:

Muhammad Nazmul Hasan Khan (091415)

&

Md. Abdullah Hil Baky (091420)

Supervised By:

Dr. Md. Faisal Kader
Associate Professor MCE Department

&

Habibullah Amin Chowdhury
Assistant Professor MCE Department

Department of Mechanical and Chemical Engineering
Islamic University of Technology (IUT)
The organization of Islamic Co-operation (OIC)

CERTIFICATE OF RESEARCH:

The thesis title 'PRODUCTION OF BIOGAS BY ANAEROBIC DIGESTION PROCESS AND PROCESS SIMULATION' submitted by Muhammad Nazmul Hasan Khan (091415) and Md. Abdullah Hil Baky (091420), has been accepted as satisfactory in partial fulfillment of the requirement for the Degree of Bachelor of Science in Mechanical and Chemical Engineering on October, 2013.

Supervisor

Assoc. Prof. Dr. Md. Faisal Kader
Department of Mechanical and Chemical Engineering
Islamic University of Technology (IUT), Gazipur

Supervisor

Asst. Prof. Habibullah Amin Chowdhury
Department of Mechanical and Chemical Engineering
Islamic University of Technology (IUT), Gazipur

Head of the Department

Prof. Dr. Abdur Razzak Akanda
Department of Mechanical and Chemical Engineering
Islamic University of Technology (IUT), Gazipur

DECLARATION:

This is to certify that the work presented in this thesis is an outcome of experiment and research carried out by the authors under the supervision of Assoc. Prof. Dr. Md. Faisal Kader & Asst. Prof. Habibullah Amin Chowdhury .

Author

_____	_____
Muhammad Nazmul Hassan Khan	Md. Abdullah Hil Baky
091415	091420

Supervisor

_____

Associate Prof. Dr. Md. Faisal Kader
MCE Department

Supervisor

_____

Assistant. Prof. Habibullah Amin Chowdhury
MCE Department

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ABSTRACT

The objective of the paper is to study the production of biogas from an existing biogas plant using food waste. As food waste only rice is used. Also process simulation of methane production and comparison of simulated result with experimental result are done to optimize the methane production. The simulation is done in PRO II process simulation software. A 6 pilot scale wet digestion plant was constructed for the purpose of biogas production. The duration of the study period was 120 days. In this system an average specific gas production of 31 kg-mol/hr was obtained for .05 kg-mol/hr of starch loading rate where process simulation gives the value of gas production as 49 kg-mol/hr for the same loading rate of starch. The percentage of methane in the biogas obtained from the plant is 69% & the percentage of carbon-di-oxide is 29%. So it is found feasible to use rice as food waste in biogas plant.

Content

Chapter 1

Introduction:

Concerning the treatment of solid waste, the anaerobic digestion of solid waste has been studied in recent decades, trying to develop a technology that sum up advantages for volume and mass reduction as well as for energy and sources recovering. Anaerobic digestion, besides aerobic composting can be an alternative strategy for the reduction of municipal solid waste. In contrast of aerobic composting, anaerobic digestion of solid waste does not require air and produce biogas with high volumetric fraction of methane (50-70%). Furthermore anaerobic digestion possesses better handling of wet waste and area requirement (Baldasano et al. 2000; Hartmann et al. 2006). Anaerobic digestion (AD) was commonly used only in the wastewater treatment plants waste management (Palmisano at al. 1996) until 1970's. The amount of generated solid waste continuously increases and due to the large environmental impacts of its improper treatment, its management has become an environmental and social concern.

Rapid biodegradation of the organic fraction of the MSW is of key importance to identify environmental more responsible way to process it rather than landfilling or composting it. Anaerobic digestion has the advantage of biogas production and can lead to efficient resource recovery and contribution to the conservation of non-renewable energy sources.

Furthermore, anaerobic digestion is closed and controlled process and based on fugitive emissions is more preferable than landfilling and aerobic composting (Levis et al. 2010). Even though proven to be effective for treating organics, anaerobic digestion plants are facing difficulties in obtaining fairly clean feedstock that results in technical difficulties with the equipment and poor compost quality. Furthermore, the economic feasibility of these plants has been questioned due to the high investment and operation costs. Also there are more than 40 different AD technologies available on the market and it is challenging to identify the best one (Kelleher 2007). In this study we have reviewed the anaerobic digestion reactions and examined the AD technologies that are available on the market, in order to identify the most efficient one.

Having in mind the difficulties AD plants are facing in practice and the increased interest in finding a sustainable supplemental carbon source for denitrification in the wastewater treatment plants (WWTP), we have also tested the possibility to link these two processes by means of laboratory. This experimental study investigated the possibility to use the volatile fatty acids (VFA), naturally produced in the process of anaerobic acidogenesis from the food waste, as supplemental carbon source for denitrification in the waste water treatment plants (WWTP). Furthermore we tested the product of this experiment as a supplemental carbon source for denitrification of wastewater. The methods, materials and detailed results are elaborated in this study. All tons reported in this study refer to metric tons.

Chapter 2:

Literature Review

2.1 ANAEROBIC DIGESTION PROCESS

Microbial decomposition of organic matter into methane, carbon dioxide, inorganic nutrients and compost in oxygen depleted environment and presence of the hydrogen gas is anaerobic digestion (AD). Anaerobic digestion (AD) is also known as bio-methanogenesis. It occurs naturally in wetlands, rice fields, intestines of animals, manures and aquatic sediments, and is responsible for the carbon cycle in the ecosystems.

Every year 30 and 70 % of the total methane released in the atmosphere are from Natural and anthropogenic sources respectively. Wetlands and animal guts (mainly insects and ruminants) are the Major natural sources of methane while the main anthropogenic sources have been identified in the fossil fuel processing industries, rice fields and landfills. Biological activity has been identified to be the cause for more than 80% of the flux of the atmospheric methane (Palmisano et al. 1996).

In general there are three different methanogenic ecosystems in the nature (Figure 1) : (a) in lacustrine and marine sediments, marshes, swamps, rice soils, sludge and digesters where the organic matter is completely degraded; (b) in ruminants and intestinal tracts of almost all living creatures (e.g. humans, insects, termites), where the process of mineralization is incomplete and most of the intermediate products (e.g. volatile fatty acids) are absorbed into the bloodstream; (c) in absence of organic matter (e.g. hot springs) where methanogenesis occurs only from geochemical hydrogen formed as part of the geological process (Garcia et al. 2000).

Generally three main reactions occur during the entire process of the anaerobic digestion to methane: hydrolysis, acid forming and methanogenesis. Although AD can be considered to take place in three stages all reactions occur simultaneously and are interdependent.

In the experimental study to be described later, we shortened the AD process at the end of the acid forming stage, because the goal was to produce volatile fatty acids and avoid methane production. Methanogenesis was not important in our experimental study but is described below in order to provide the complete picture of the AD process.

2.2 HYDROLYSIS

Hydrolysis is a reaction that breaks down the complex organic molecules into soluble monomers (constituents), Figure 2, Stage 1. This reaction is catalyzed by enzymes excreted from the hydrolytic and fermentative bacteria (cellulase, protease and lipase). End products of this reaction are soluble sugars, amino acids; glycerol and long- chain carboxylic acids (Ralph & Dong 2010). Approximate chemical formula for the organic fraction of the municipal solid waste (MSW) is C6H10O4 (Shefali & Themelis 2002).

Hydrolysis reaction of the organic fraction of the MSW can be represented by the following reaction:

(Ostrem & Themelis 2004)

2.3 ACID-FORMING STAGE

This stage is facilitated by microorganisms known as acid formers that transform the products of the hydrolysis into simple organic acids such as acetic, propionic and butyric acid as well as ethanol, carbon dioxide and hydrogen. (Figure 2, Stage 2) Acid forming stage comprises two reactions, fermentation and the acetogenesis reactions. During the fermentation the soluble organic products of the hydrolysis are transformed into simple organic compounds, mostly volatile (short chain) fatty acids such as propionic, formic, butyric, valeric etc, ketones and alcohols.

Typical reactions occurring at this stage are the following:

- Conversion of the glucose to ethanol:
- Conversion of the glucose to propionate:

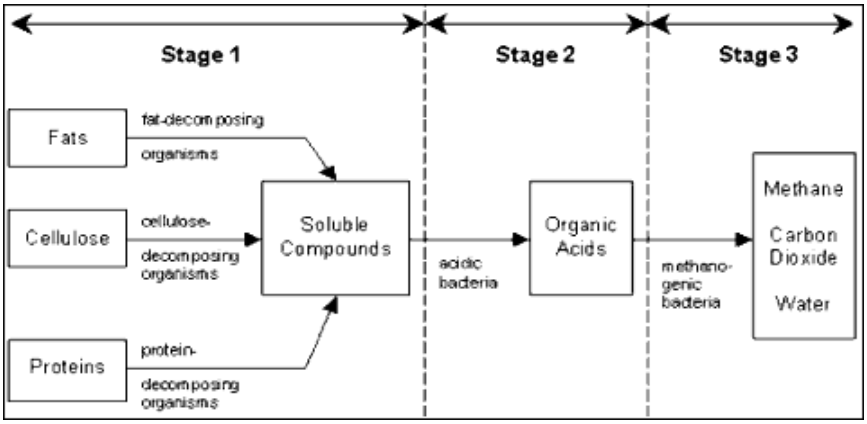

Fig 2.1: Stages of Acidogenesis

The acetogenesis is completed through carbohydrate fermentation and results in acetate, CO2 and H2, compounds that can be utilized by the methane is of critical importance in acetogenesis of compounds such as propionic and butyric acid. These reactions can only proceed if the concentration of H2 is very low. Thus the presence of hydrogen scavenging bacteria is essential to ensure the thermodynamic feasibility of this reaction (Ostrem & Themelis 2004).

- Conversion of glucose to acetate:
- Conversion of ethanol to acetate:
- Conversion of propionate to acetate:
- Conversion of bicarbonate to acetate:

2.4 METHANOGENESIS:

Methanogenesis is a reaction facilitated by the soluble mater into methane. Two thirds of the total methane produced is derived by converting the acetic acid or by fermentation of alcohol formed in the second stage, such as methanol. The other one third of the produced methane is a result of the reduction of the carbon dioxide by hydrogen. Considering that the methane has high climate change potential the goal is to find an alternative in order to lower the environmental foot print of the organic waste treatment. Therefore in the experimental part we avoided this stage and instead of methane we targeted the production of volatile fatty acids.

The reactions that occur during this stage are as follows (Ostrem & Themelis 2004):

- Acetate conversion:

$$2CH_3CH_2OH + CO_2 \leftrightarrow 2CH_3COOH + CH_4$$

Followed by: $CH_3COOH \leftrightarrow CH_4 + CO_2$

- Methanol conversion

$$CH_3OH + H_2 \leftrightarrow CH_4 + H_2O$$

- Carbon dioxide reduction by hydrogen

$$CO_2 + 4H_2 \leftrightarrow CH_4 + H_2O$$

The amount of methane that can be expected to be produced can be calculated as (Parkin & Owen 1986):

$$C_nH_aO_bN_c + \left[n - \frac{a}{4} - \frac{b}{2} + 3\left(\frac{c}{4}\right)\right]H_2O \rightarrow \left[\frac{n}{2} - \frac{a}{8} + \frac{b}{4} + 3\left(\frac{c}{8}\right)\right]CO_2 + \left[\frac{n}{2} + \frac{a}{8} - \frac{b}{4} - 3\left(\frac{c}{8}\right)\right]CH_4 + cNH_3$$

In the case of the organic fraction of the MSW this reaction would be as follows:

$$C_6H_{10}O_4 + 1.5H_2O \rightarrow 0.75CO_2 + 3.25CH_4$$

2.5 BIOCHEMICAL REACTIONS IN ANAEROBIC DIGESTION:

The conversion of complex organic matter to methane and carbon dioxide is possible only by the common action of at least four different groups of microorganisms (MO). The essential microbial complex is comprised of hydrolytic bacteria, fermenting bacteria, acetogenic bacteria and methanogenic Archaea. These groups of MO have established syntrophic relationships where the later members of the food chain depend on the previous for their substrates, but also they may have significant influence on the earlier members in the chain by removing the metabolic products (Garcia et al. 2000). The first group of MO consist the hydrolytic bacteria. These organisms catalyze the hydrolysis reaction through the extracellular hydrolytic enzymes they excrete. The resulting monomers from this reaction undergo fermentation directly to acetate, or through the pathway of the volatile fatty acids and alcohols facilitated by the so-called secondary fermenters or obligate proton reducers (Ralph & Dong 2010). These bacteria convert their substrates to acetate, carbon dioxide, hydrogen, and perhaps formate, which are subsequently used by the methanogens (Schink 1997).

2.6 HYDROLYTIC BACTERIA

Biodegradable polymers found in the MSW include lignocelluloses, proteins, lipids and starch. Specialized microbial population of hydrolytic bacteria is responsible for depolymerization of these organic polymers towards their building compounds, monomers. Usually this is found to be the slowest and the rate limiting step in the overall anaerobic digestion process. Furthermore, the ultimate methane yield is directly dependant on the efficiency of this reaction (Palmisano & Barlaz 1996).

Lignocellulose refers to the three major components of the plant tissue: cellulose, hemicelluloses and lignin. The cellulose and hemicelluloses are biodegradable and make up over 90% of the biochemical methane potential of the MSW, while the phenolic groups in lignin are even inhibitory to the enzymes. Cellulose is degraded by hydrolyses to yield a soluble disaccharide, cellobiose, which on further hydrolysis results in D-glucose. The cellulolytic enzyme system is composed of endoglucanases, exoglucanases, and glucosidases. The main anaerobic bacteria degrading cellulose include Bacterioides succinogenes, Clostridium lochhadii, Clostridium cellobioporus, Ruminococcus flavefaciens, Ruminococcus albus, Butyrivibrio fibrosolvens, Clostridium thermocellum, Clostridium stercorarium and Micromonospora bispora (Palmisano & Barlaz 1996).

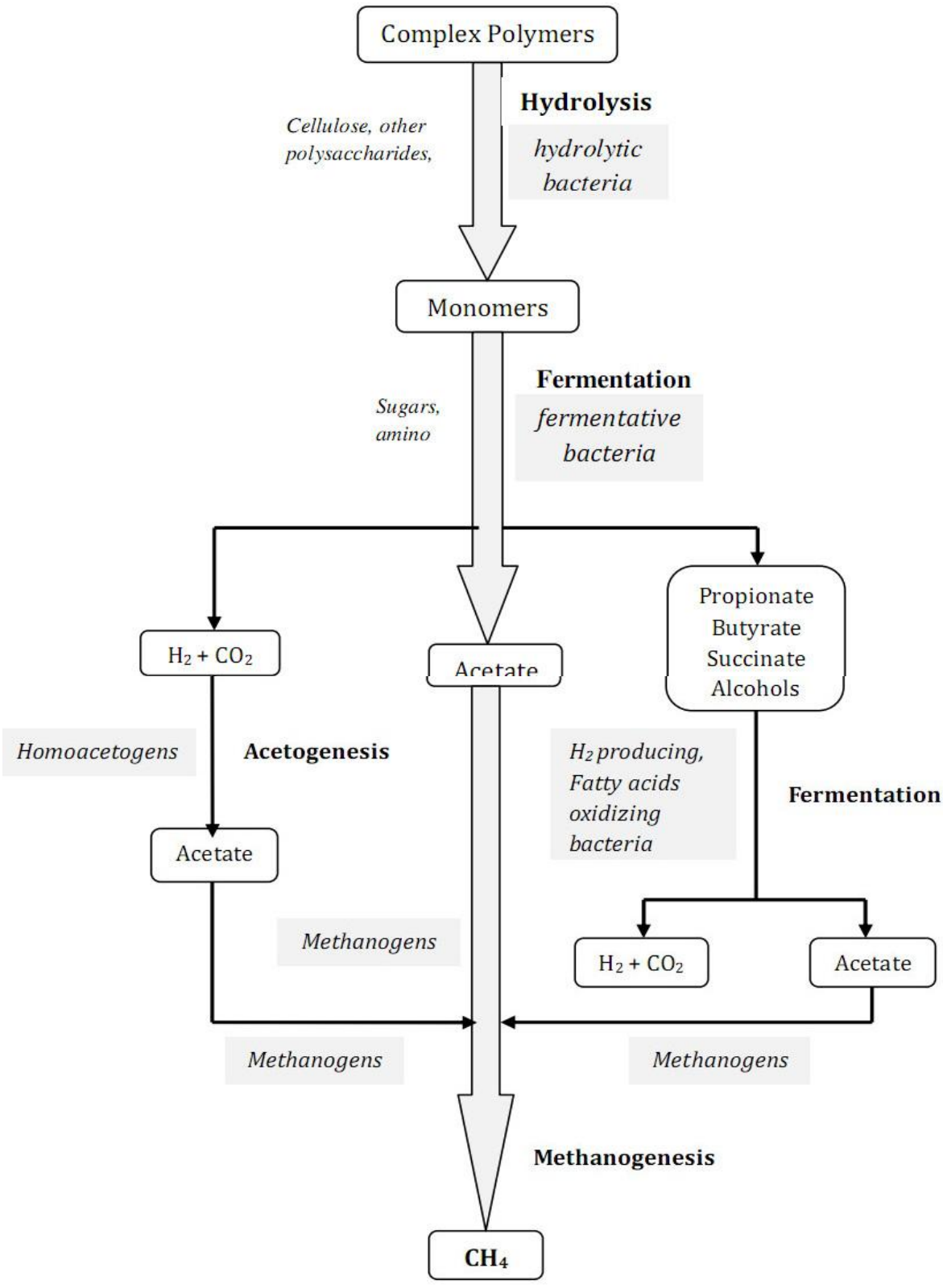

Fig 2.2: Overall Process Diagram of AD system

2.7 ACETOGENIC BACTERIA/HYDROGEN-PRODUCING ACETOGENS (OHPA):

Acetogenesis is the stage when the products of the hydrolysis are processed to hydrogen, carbon dioxide, formate and acetate. This pathway occurs naturally in well balanced methanogenic systems. However, in practice, there are cases of electron or hydrogen accumulation (e.g. when methanogenesis is inhibited) when numerous other fermentation products may be formed (e. g. propionate, butyrate, lactate, succinate, and alcohols) as a mechanism to remove the excess electrons or hydrogen. Organisms that convert these fermentation products to acetate, generally exhibit obligate proton- reducing metabolism and are obligatory dependent on the hydrogen removal as referenced in Archives of Environmental Protection. Because of this the acetogenic bacteria are also called obligatory hydrogen-producing acetogens (OHPAs).

2.8 METHANOGENIC MICROORGANISMS:

The main route of methane production is through a syntrophic relationship between acetate-oxidizing bacteria and hydrogen-utilizing methanogenic Archea. The acetoclastic and hydrogenotrophic methanogens contribute 70% and 30%, respectively, to the methane production in industrial wastewater treatment.

Numerous methanogens have been isolated and described so far, but the studies, mainly based on 16S rDNA cloning analyses, suggest that the most commonly found methanogens genera, in the biogas reactors, are Methanobacterium, Methanothermobacter (formerly Methanobacterium), Methanobrevibacter, Methanosarcina, and Methanosaeta (formerly Methanotrix) as referenced in Archives of Env. Protection. Among the acetoclastic methanogenic organisms, Methanosarcina and Methanosaeta species has been reported to be dominated in large-scale mesophilic and thermophilic digesters treating wastewater and sewage sludge. Its dominance comes mainly due to its wide tolerance for environmental factors such as nutrients and temperature (Palmisano & Barlaz 1996).

2.9 INTERACTIONS BETWEEN DIFFERENT MICROBIAL CONSORTIA IN THE AD REACTORS:

The overall reaction anaerobic degradation is a reaction with very low energy yield comparing to the aerobic degradation. The main reason is that the electron acceptor in this case is the carbon dioxide and not oxygen like in the aerobic degradation. Carbon in the carbon dioxide is in the most highly oxidized state with a COD: C ratio of zero. Since the energy available depends on the oxidation state of the substrate and indicates the electrons available for removal as it is oxidized, with carbon dioxide as electron acceptor the amount of free energy available is very low. As shown in the case of the glucose, anaerobic degradation yields around 15 % the energy that would be released through aerobic degradation:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O \quad Free\ energy\ kJ/mol\ glucose\ -2{,}880$$

$$C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4 \quad Free\ energy\ kJ/mol\ glucose\ -428$$

The syntrophic association between fatty-acid-oxidizing microbes, hydrogen-consuming methanogens, and acetate-consuming methanogens represents one syntrophic example in the methanogenic community. Fatty acids are converted by syntrophic oxidizers to acetate and hydrogen/CO2, and these products are subsequently utilized by the two types of methanogens to form methane

- Conversion of propionate to acetate:
  $CH_3CH_2COO^- + 3H_2O \leftrightarrow CH_3COO^- + H^+ + HCO_3^- + 3H_2$
  free energy value: +76.1 kJ
- Conversion of butyrate to acetate:
  $CH_3(CH_2)_2COO^- + 2H_2O \leftrightarrow 2CH_3COO^- + H^+ + 2H_2$
  free energy value: +48.3 kJ

In particular, hydrogen is the most important intermediate and the hydrogen-scavenging reaction makes the whole reaction energetically feasible. The following reactions occur as referenced in the Environmental Microbiology (Ralph & Dong 2010):

- Acetogenic reactions
  $2HCO_3^- + 4H_2 + H^+ \leftrightarrow CH_3COO^- + 4H_2O$ free energy value: −104.6 kJ
- Methanogenic reactions
  $CH_3COO^- + H_2O \leftrightarrow CH_4 + HCO_3^-$ free energy value: −31.0 kJ
  $4H_2 + HCO_3^- + H^+ \leftrightarrow CH_4 + 3H_2O$ free energy value: −135.6 kJ

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CHAPTER 3

PARAMETERS AFFECTING THE ANAEROBIC DIGESTION OF FOOD WASTE:

3.1 pH value:

The pH value of the reacting material is a pivotal factor in the AD of food waste. The importance of the pH is due to the fact that methanogenic bacteria are very sensitive to acidic conditions and their growth and methane production are inhibited in acidic environment. In batch reactors pH value is closer dependent of the retention time and loading rate, as will be described later. Different stages of the AD process have different optimal pH values. Also the pH value changes in response to the biological transformations during different stages of AD process. Production of organic acids during the acetogenesis can lower the pH below 5 what is lethal for methanogens and cause decrease in the methanogens population. Constant pH is crucial in the start-up phase because fresh waste has to go first thru the stage of hydrolisys and acidogenesis before any methane can be formed, which will lower the pH. In order to keep the value of pH on the equilibrium buffer has to be added into the system, such as calcium carbonate or lime. Although it has been proven that the optimal range of pH for obtaining maximal biogas yield in anaerobic digestion is 6.5–7.5, the range is relatively wide in the plants and the optimal value of pH varies with substrate and digestion technique (Liu et al. 2007). The pH value is a function of volatile fatty acid (VFA) concentration, bicarbonate concentration, and alkalinity of the system as well as the fraction of CO2 in digester gas. In order to fix constant pH value it is crucial to adjust the relationship between the VFA and bicarbonate concentrations (Liu et al. 2007).

The expression of relationship between pH and methane yield is:

$$\frac{d\mathrm{CH_4}}{dt} = \left(\mathrm{Vm_{max}Xm}\frac{\mathrm{Ac^{-1}x10^{-pH}}}{\mathrm{Ac^{-1}x10^{-pH}} + \mathrm{KaKm}}\right) X \left(\frac{\mathrm{KimKa}}{\mathrm{KimKa} + \mathrm{Ac^{-1}x10^{-pH}}}\right)$$

3.2 COMPOSITION OF THE FOOD WASTE:

The composition of food waste is habits, region etc. It is important to know the composition of the food waste in order able to predict both the bio- design. The bio-methanization potential of the waste main components: proteins, lipids, carbohydrates, and cellulose. Bio-chemical characteristics of the highest methane yields have systems with retention time. The methanization the reactors with excess of cellulose and carbohydrates respe also inhibitory effects observed due to the VFA accumulation and ammonium nitrogen respectively hydrolysis are the assays with an excess of lipids and cellulose, indicating that when these components are in excess, a slower hydrolysis is induced decomposition of food waste is variable depending on the time of the year, cultural habits, region etc. It is important to know the composition of the food waste in order to be methanization potential and the most efficient AD facility potential of the waste depends on the concentration proteins, lipids, carbohydrates, and cellulose. This is due to the difference of these components (Neves et al. 2007). highest methane yields have systems with excess of lipids but with the longest methanization is fastest in systems with excess of protein with excess of cellulose and carbohydrates respectively. However there are effects observed in the assays with excess of lipids and excess of proteins due to the VFA accumulation and ammonium nitrogen respectively.

3.3 LOADING RATE:

Organic loading rate is a measure of the biological conversion capacity of the AD system. It determines the amount of volatile solids feasible as an input to the AD system. Overloading of the system can result in low biogas yields. This happens due to accumulation of inhibiting substances such as fatty acids in the digester slurry.

The event that would occur in the case of overloading the system are shown in the figure 4. It would cause proliferation of the acidogenic bacteria further decreasing the pH in the system and disturbing the population of the methanogenic bacteria. Also there is a definite relationship between the biogas yield and the loading rate. This is the concept that we used in the design of experimental part of this study. The loading rate was at the point in favor of the acidogenesis avoiding the methane production and maximizing the VFA production in it.

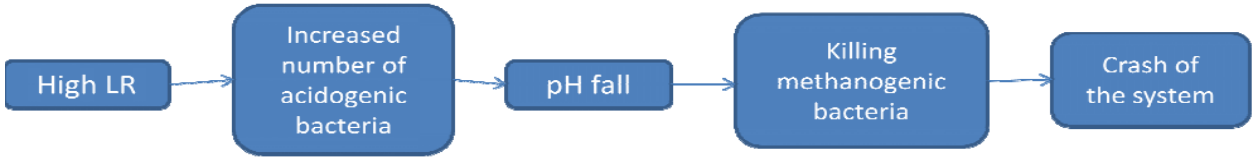


Fig3.1: Effect of loading rate

3.4 RETENTION TIME:

Retention time (residence time), in the AD reactors, refers to the time that feedstock stays in the digester. It can be calculated using the following equation:

$$Retantion\ time\ \boldsymbol{\theta}\ (days) = \frac{Operating\ volume\ \boldsymbol{V}\ (m^3)}{Flow\ rate\ \boldsymbol{Q}\ (\frac{m^3}{day})}$$

It is determined by the average time needed for decomposition of the organic material, as measured by the chemical oxygen demand (COD) and the biological oxygen demand (BOD) of the influent and the effluent material. The longer the substrate is kept under proper reaction conditions, the more complete its degradation will be. However, the rate of the reaction decreases with longer residence time, indicating that there is an optimal retention time that will achieve the benefits of digestion in a cost effective way (Viswanath et al. 1991). The appropriate time depends on the type of feedstock, environmental conditions and intended use of the digested material (Ostrem & Themelis 2004) Furthermore retention time in the AD system depends on process temperature and total solid content. Mesophilic digesters have longer retention time (10-40 days) then thermophilic digesters. Also the high solid content systems ("dry" processes) have longer retention time then low solid content systems ("wet" processes). Commonly used method for shortening the residence time in AD reactors is mixing the digester. Usually it is done by recirculation of the produced biogas back in the reactor.

3.5 OPERATING TEMPERATURE:

Operating temperature is the most important AD reactors because it is an essential condition for microbial consortia. Despite the fact that they can survive a wide range of temperature bacteria have two optimum range temperatures. Mesophilic digesters have an operating temperature 25-40 °C and thermophilic digesters have the rate of AD process shown in growth rates, and substrate degradation.

According to the reported experimental results as well as the operating performances of commercial scale AD plants, mesophilic and thermophilic reactors have advantages and disadvantages. Thermophilic digesters allow higher loading rate and yield higher methane production, substrate degradation and pathogen destruction. Also, the higher temperature shortens required retention time because it speeds up the reactions of degradation of the organic material. However, the thermophilic anaerobic bacteria are very sensitive to toxins and small environmental changes. Furthermore, these bacteria need more time to develop redox population. These systems are harder to maintain and are less attractive application because they require additional energy input for self-heating.

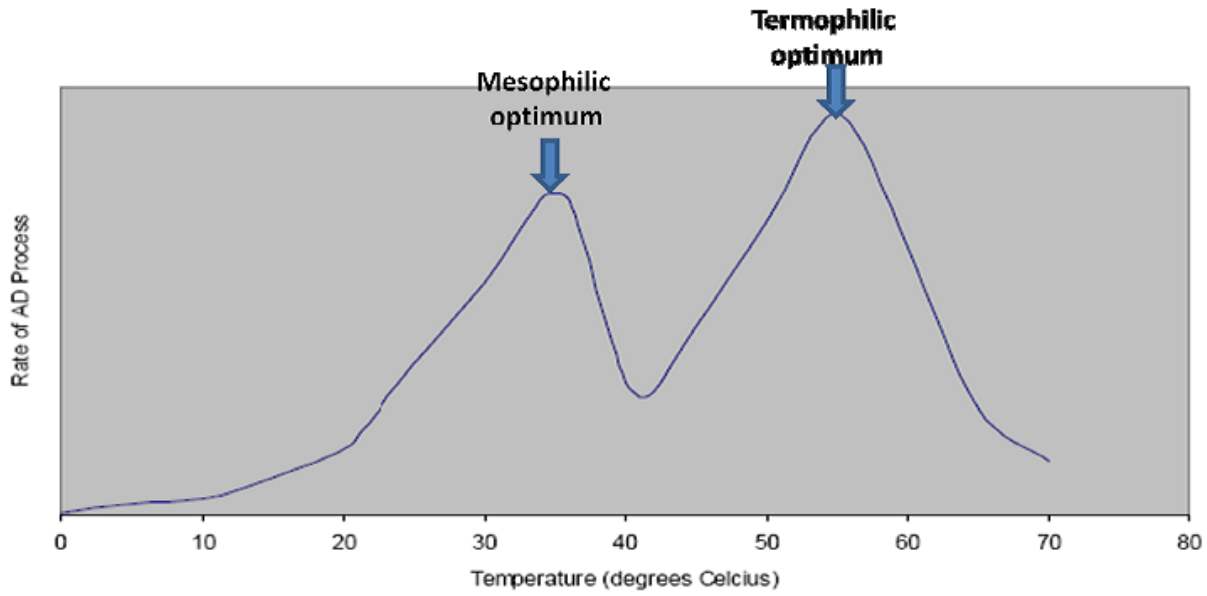


Figure 3.2: Rate of AD Process vs. Temperature (Ostrem & Themelis 2004)

Mesophilic AD reactors operate with robust microbial consortia that tolerate greater changes in the environment and are more stable and easier to maintain. Another advantage is that usually these systems do not need any additional energy input for heating the system.

CHAPTER 4

CLASSIFICATION OF THE AD SYSTEMS

There are many different technologies on the market that are used for AD treatment of the organic fraction of the MSW. These systems differ based on the design of the reactor and the operating parameters.
The design of the reactor depends on the feedstock that is going to be processed and varies from very simple and easy to maintain AD digesters used in rural China and India to very complex and automatic systems used lately in the developed world for treatment of the organic fraction of the solid waste (OFMSW). The feedstock also determines the need and type of pretreatment. In the case of OFMSW the pretreatment is usually big part of the AD plant and is necessary in order to clean up the feedstock to the required level as well as to separate as much as possible recyclable materials.
Characterization of the AD systems based on the operating parameters is done by the following criteria:

1. *LOADING RATE IN TOTAL SOLIDS CONTENT:*

- Low-solids content (<15%Total Solids) sometimes also called "wet digestion";
- High-solids content (25-30 % TS) also known as "dry digestion".

When the feedstock used is the organic fraction of the MSW both systems apply and have been proven successful. In both cases water needs to be added in order to lower the content of total solids. The "dry digestion" requires smaller and therefore less costly digesters on one side but more costly additional equipment for mixing and material flow on the other side (Ostrem & Themelis 2004)".

2. *OPERATING TEMPERATURE*:

- Thermophilic AD processes operate in the temperature range of 50°C-65°C ;
- Mesophilic AD processes operate at about 37°C.

Anaerobic digestion of the OFMSW is possible in both temperature ranges. Thermophilic AD digesters have been shown to be more efficient in biogas production, faster rate of decomposition but with higher maintenance costs.

3. *NUMBER OF REACTORS USED IN SERIES*:

- Single stage digester: All reactions take place in one reactor and environmental conditions are maintained at levels that suit all types of bacteria. Therefore, operating conditions for a particular stage are not optimal.
- Multi-stage digesters have physically separated biochemical reactions of hydrolysis and acidogenesis in different reactor vessels. Each vessel maintains the optimal environmental conditions for the microorganisms that facilitate the specific reaction that is happening inside.

4. *METHOD OF INTRODUCING THE FEED INTO THE REACTOR:*

- Continuous flow reactors have feed and discharge flows in continuous or semi-continuous manner. This is the most common form of industrial scale reactors.
- Batch reactors are loaded and allowed to react for a certain period (usually two weeks). Digestion of the OFMSW is possible in both types of systems although there are advantages and disadvantages in both cases. For example the batch reactors need to be bigger in volume due to the long retention time while in the case of the continuous flow reactor the effluent is a mixture of partly and completely digested material (Ostrem & Themelis 2004).

5. *FEEDSTOCK MATERIALS USED IN ANAEROBIC DIGESTION:*

The most suitable feedstock for Anaerobic Digestion is:

- Animal waste and biowaste from wastewater treatment plants
- Food and kitchen wastes from restaurants, canteens, food markets, and municipal source- separated food wastes.
- Organic waste from food processing industry, slaughter houses, etc.

CHAPTER 5

DESIGN OF THE PLANT

5.1 SOLID VIEW OF THE PLANT

By using solid works software we designed the biogas plant.

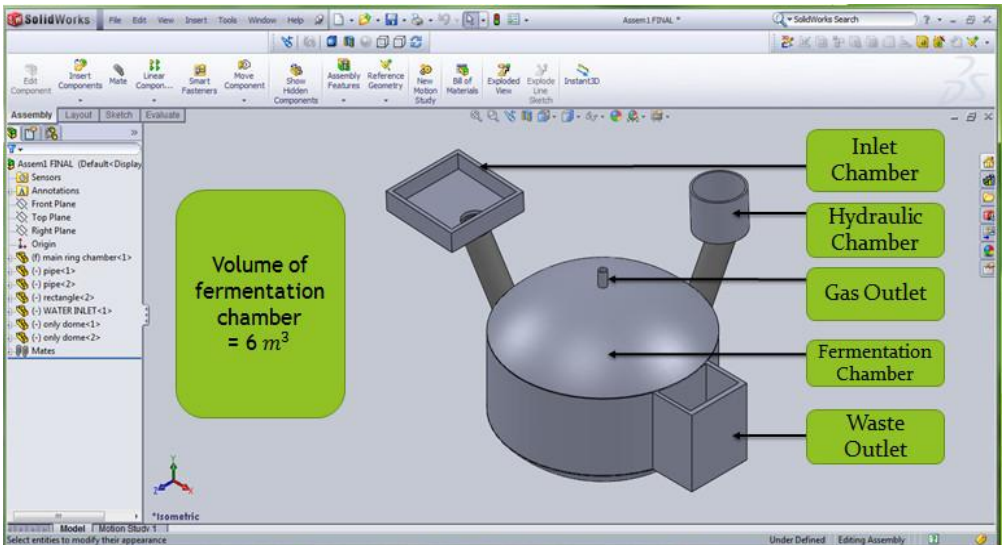


Fig5.1: Solid View of the Plant

5.2 TRANSPARENT VIEW

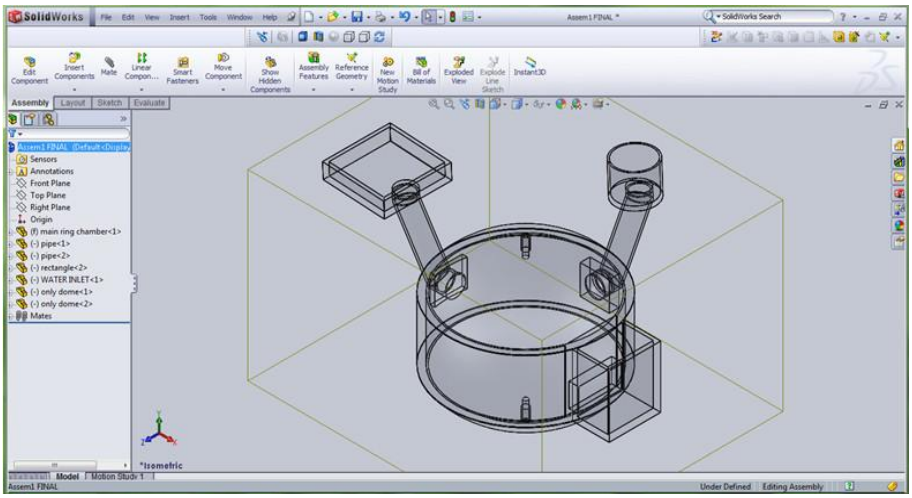


Fig5.2: Transparent View of the Plant

CHAPTER 6

PROCESS SIMULATION

6.1 PURPOSE OF PROCESS SIMULATION

- Process simulation is used for the design, development, analysis, and optimization of thermodynamic processes and is mainly applied to chemical plants and chemical processes.
- To obtain a model-based representation of chemical, physical, biological and unit operations in software
- To describe processes in flow diagrams where unit operations are positioned and connected by product streams.
- The goal of a process simulation is to find optimal conditions for particular process.

6.2 MAIN EQUATIONS RELATED TO PROCESS SIMULATION

- Hydrolysis: (*starch*)+ 2
- Acedogenesis: (*acetic acid*)
- Methanogenesis:

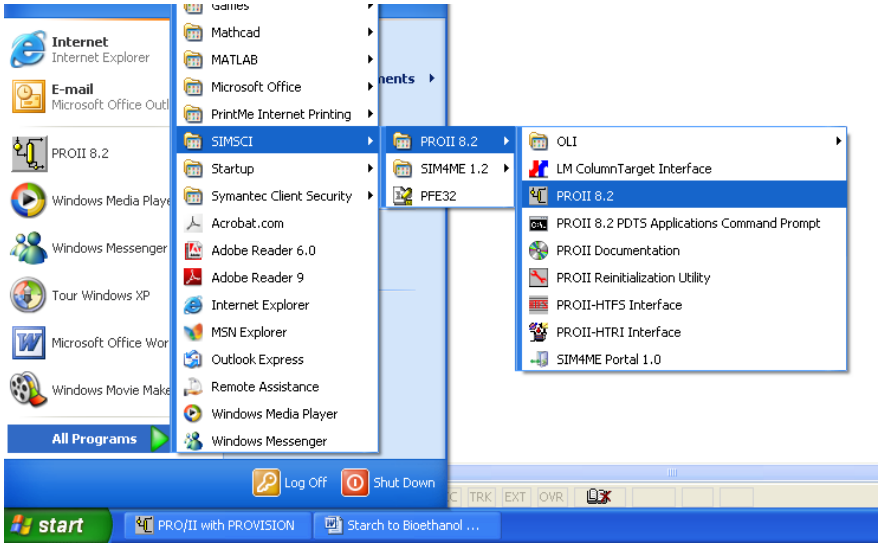
6.3 PROCESS FOR SIMULATION IN PRO II SOFTWARE

PART 1: CREATING A NEW FLOW SHEET

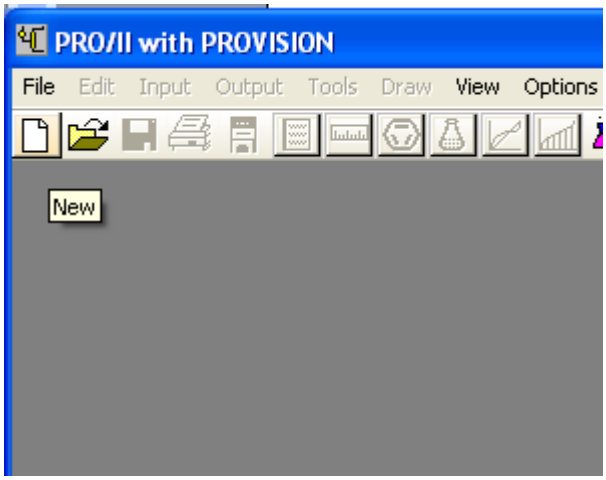
Step 1:

Open ***PROII 8.2*** icon by clicking start / All Programs / SIMSCI / Pro II 8.2 /PROII 8.2. The welcome window tells what operations are required by color designation: Red borders mean data and action required. Green border means user may override this field. Blues borders mean that the data you filled in the entry field. Yellow borders mean that you supplied data outside the normal range of values for a field.

Click OK on ***Welcome to PRO/II***



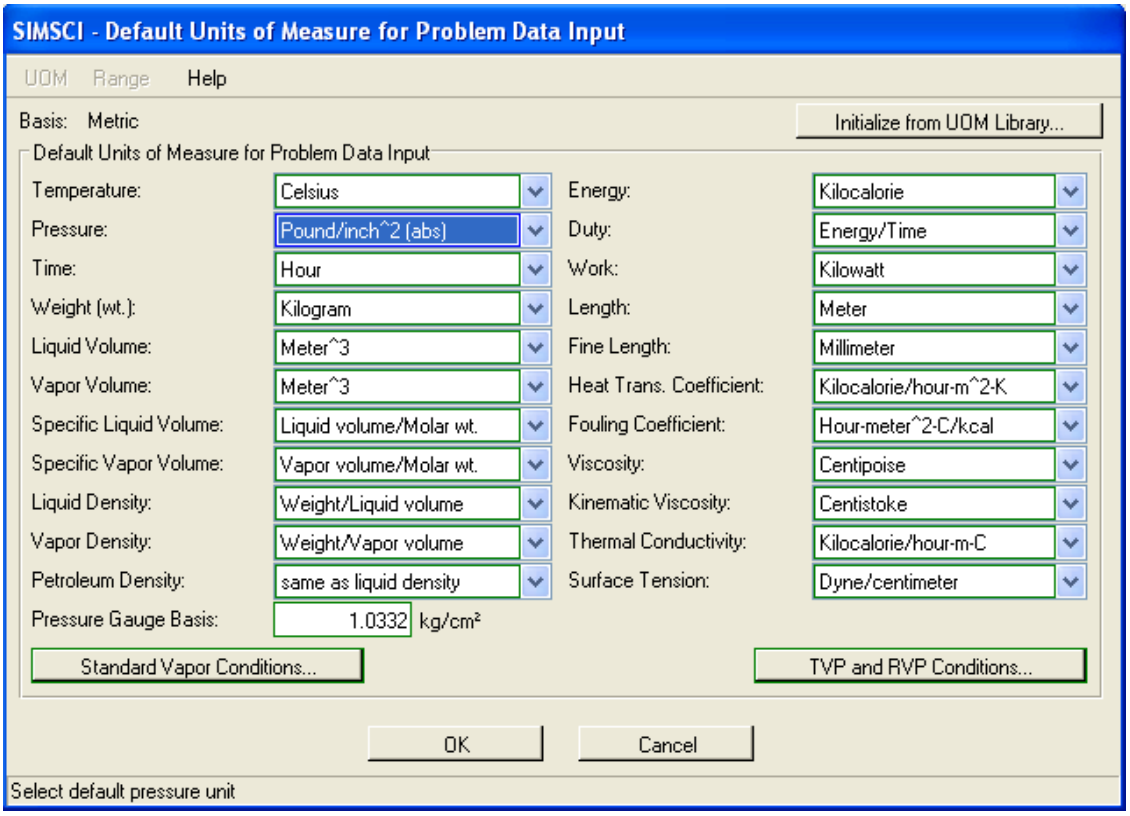
Step 2: Open new flow sheet. By clicking  icon.



Step 3: Save project by clicking icon. Name the file ***Bioethanol from Starch*** and click ***Save.***
Step 4: To change units of measurements there are two options.

Option A: Changes units for entire PFD.

To set the units that will be used through out the PFD either select "**Units of Measure**" under the "Input" tab or click the icon. Change **Temperature** to **Celsius**, **Pressure** to **Pound/inch^2(abs), Weight(wt)** to **Kilogram, Liquid Volume** to **Meter^3,** and **Vapor Volume** to **Meter^3.** Click ***OK.***

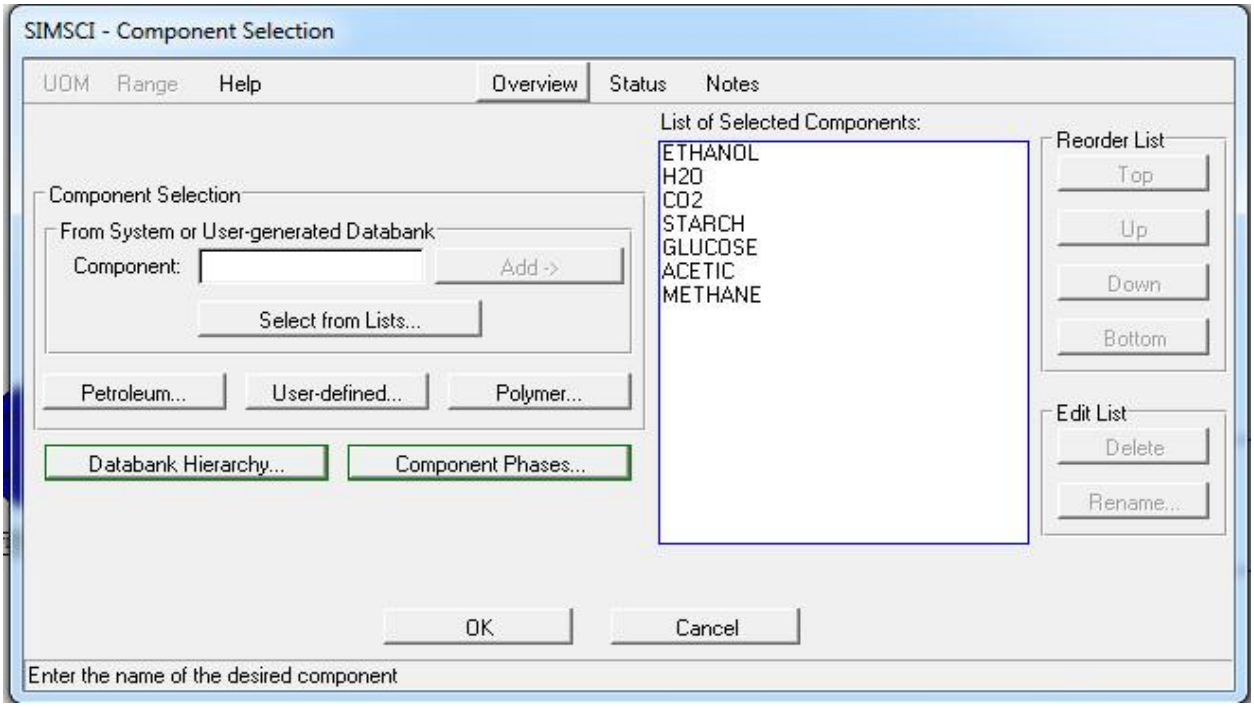


Option B: Change units for each process unit (See Part 2A below Step 15)

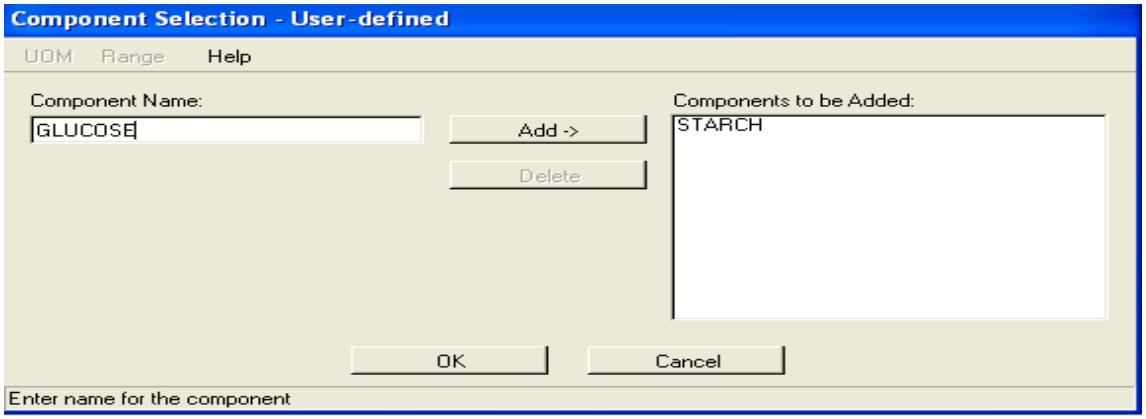
PART 2A: SETTING UP LIBRARY AND HYPOTHETICAL COMPONENTS

Step 1: Add new component by pressing on  icon.

Entering Library components: Type "**Ethanol**" in the ***Component Selection*** window. Click ***Add***. Repeat the process for "**Water**" and "**CO_2**".

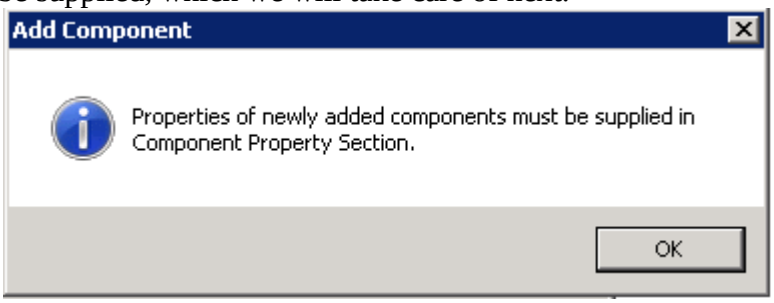


Entering Hypothetical components: Enter two components that are not in the system by clicking on ***User-defined*** tab in the "**Component Section**" window. Type "**Starch**" in the "**Component Name**" box. Click "**Add**". Repeat for "**Glucose**".



NOTE: Starch and glucose under the "Components to be Added"

You will get an alert when you press OK, warning that properties of the newly added components must be supplied, which we will take care of next.



Step 2: Click ***OK*** twice

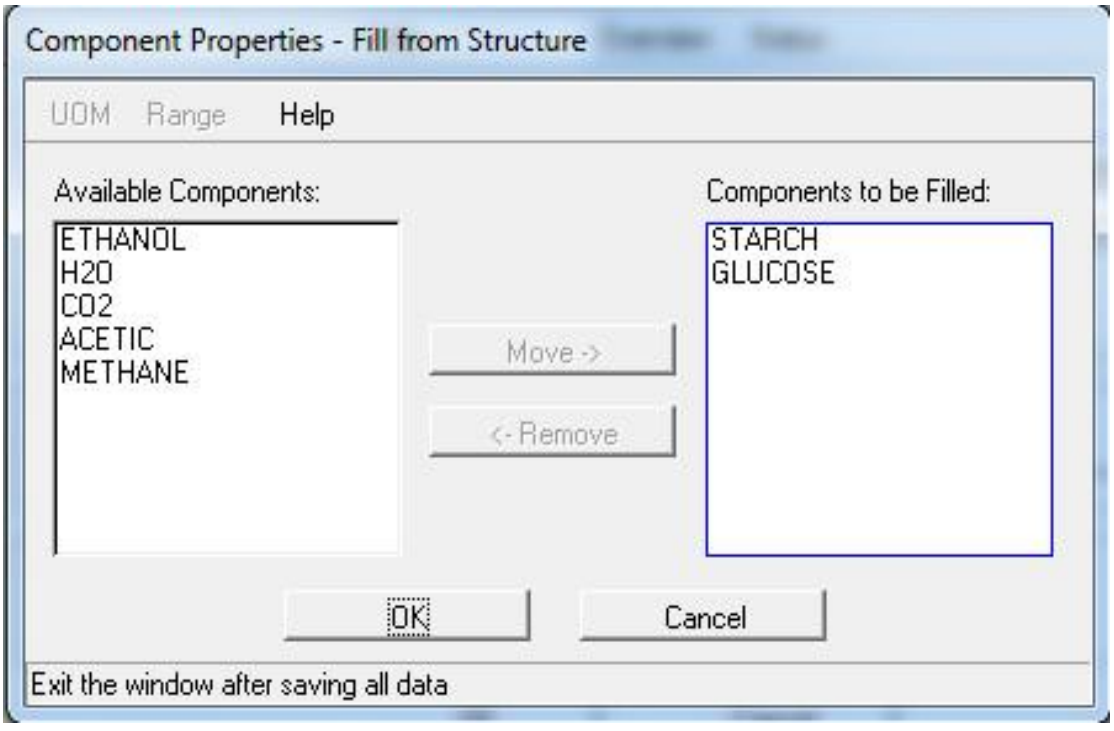
NOTE: We can see five components in the list: ETHANOL, WATER, CO_2, STARCH, and GLUCOSE.

Step 3: Click ***OK***

Step 4: Click on component properties  icon

Step 5: Click on "**Fill from structure**" in the "**Thermophysical properties**" section.

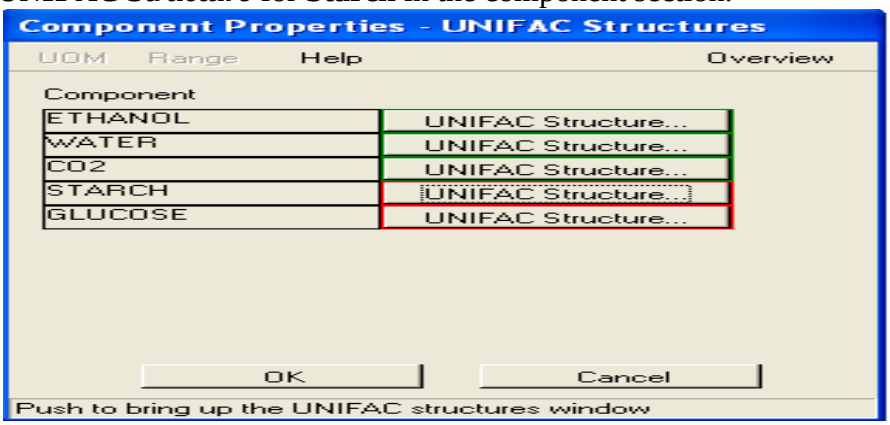
Step 6: Select Starch from "**Available Components**" and Click ***Move*** to "**Components to be Filled**". Repeat for **Glucose**.



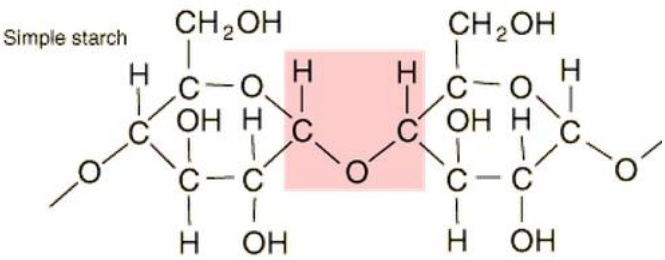
Step 7: Click ***OK***

Step 8: Click ***UNIFAC Structures***

Step 9: Click ***UNIFAC Structure*** for **Starch** in the component section.



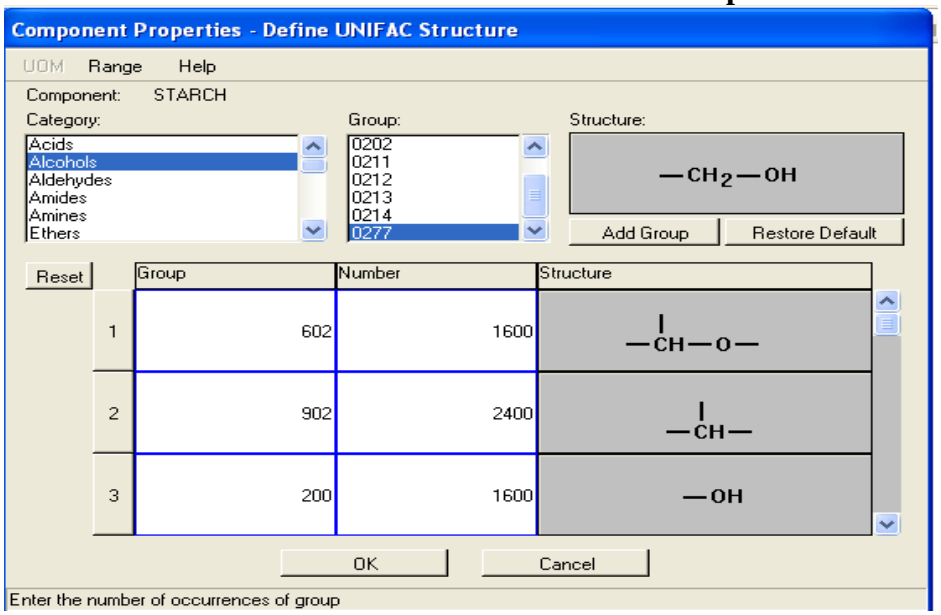
Step 10: Enter components of the STARCH from the table below. Note starch is a polymer of D-glucose and has the following structure and we want to mimic it. Basically this is a polymer of Maltose molecules we call amylose. Hydrolysis of amylose takes place with enzymes that break down or hydrolyze starch into the constituent sugars. These enzymes are known as amylases and such α-amylases are found in plants and in animals. For example, human saliva is rich in amylase, and the pancreas also secretes the enzyme. These polymers typically have very high but indefinite molecular weights of 10,000 or so, and can be broken down through chemical pulping to 500 – 2000 MW molecules. These undergo liquefaction with amylase to maltose which is then converted to glucose with maltase. The following appears to be based on a MW of 800 repeating glucose units, i.e. 800 alcohols of the CH_2OH type, 1600 alcohols of the –CHOH type, 1600 ethers (two per glucose, one on each end), and 2400 –CH paraffin groups (i.e. 4 –CH groups per glucose).



a. Under **Category** select "**Alcohols**"
b. Under "**Group**" select **0200**
c. Click Add Group
d. Under "**Number**" column change "**1**" to " **1600**"
e. Repeat steps (a-d) until all the values have been inputted.

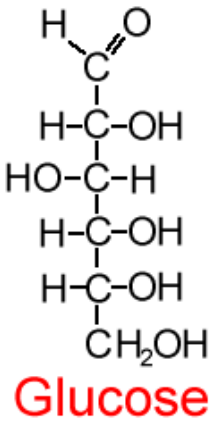
Category	Group	Number
Alcohols	0200	1600
Alcohols	0277	800
Ethers	0602	1600
Paraffins	0902	2400

NOTE: The window below should look similar after the completion of the table



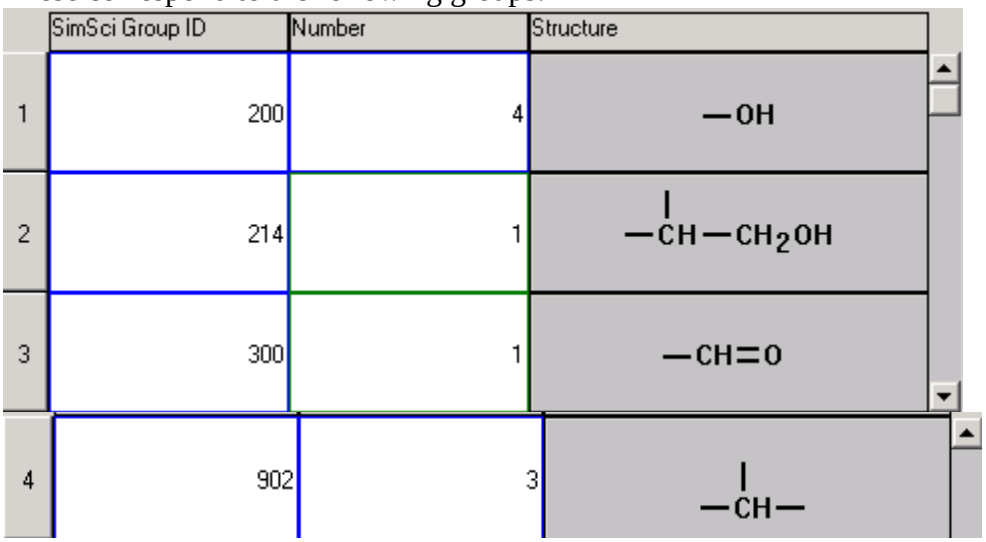
Step 11: Click ***OK***

Step 12: Repeat Step 10 and Step 11 for **GLUCOSE** by using the values in the table below. Note glucose has the following structure and we want to mimic it with sub-molecular categories.

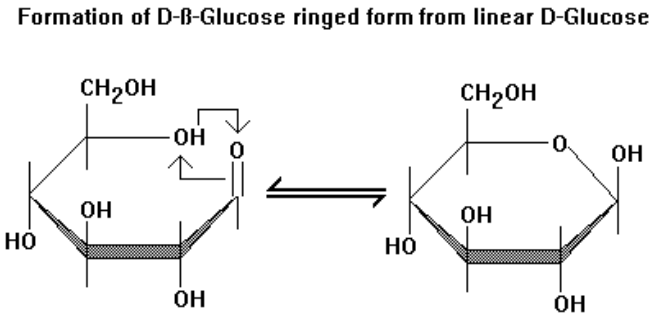


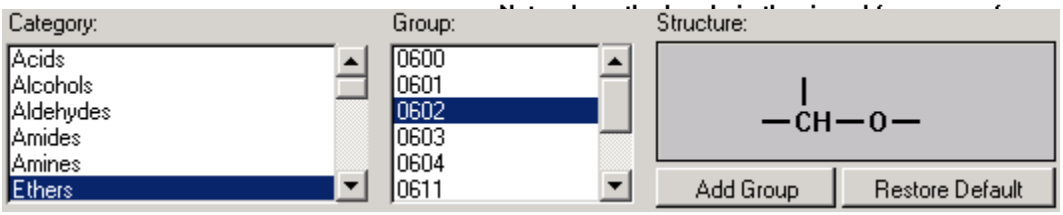
Category	Group	Number
Alcohols	0200	4
Alcohols	0214	1
Aldehyde	0300	1
Paraffins	0902	3

These correspond to the following groups:



In reality glucose in solution forms a ring structure (99.98% with only 0.02% in the straight chain form) so we really want to correct our sub-molecular components based on the following structure. We would simply replace the aldehyde group (=O) structure with an ether structure (-CH-O-C-), probably with No. 602 or perhaps No. 688.

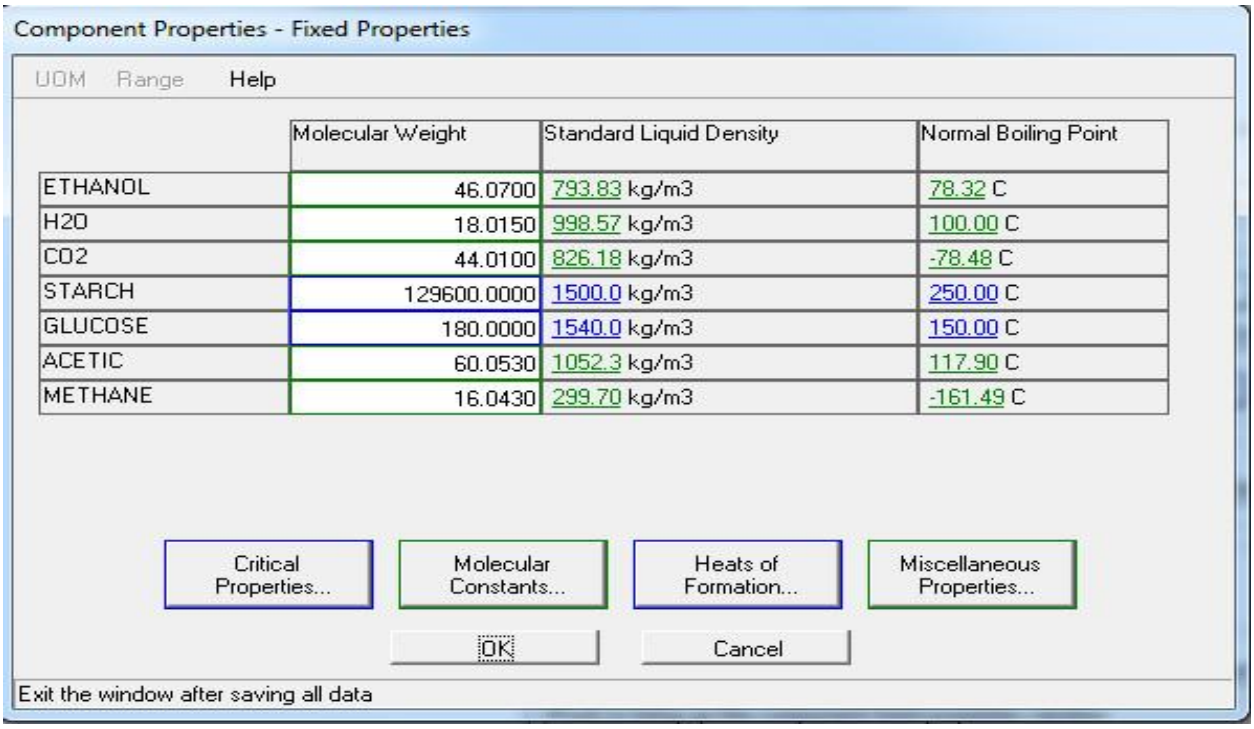




Step 13: Click ***OK***

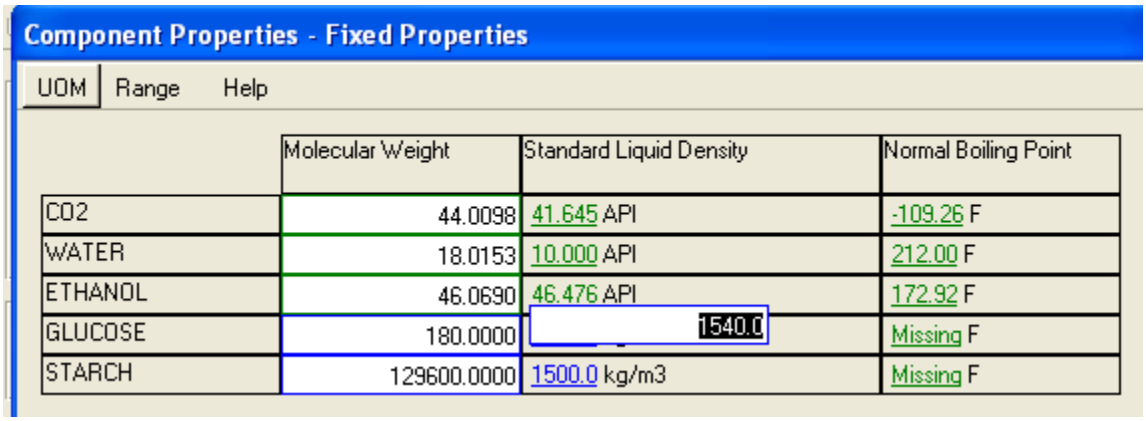
Step 14: Click **Fixed** in "**Thermophysical properties**" section. Enter the component properties of **STARCH** and **GLUCOSE** from the table below.

Component	**Molecular Weight (g/mol)**	**Standard Liquid Density (kg/m^3)**	**Normal Boiling Point (^oC)**
Starch	129600	1500	250
Glucose	180	1540	150



Step 15: Click ***OK*** twice.

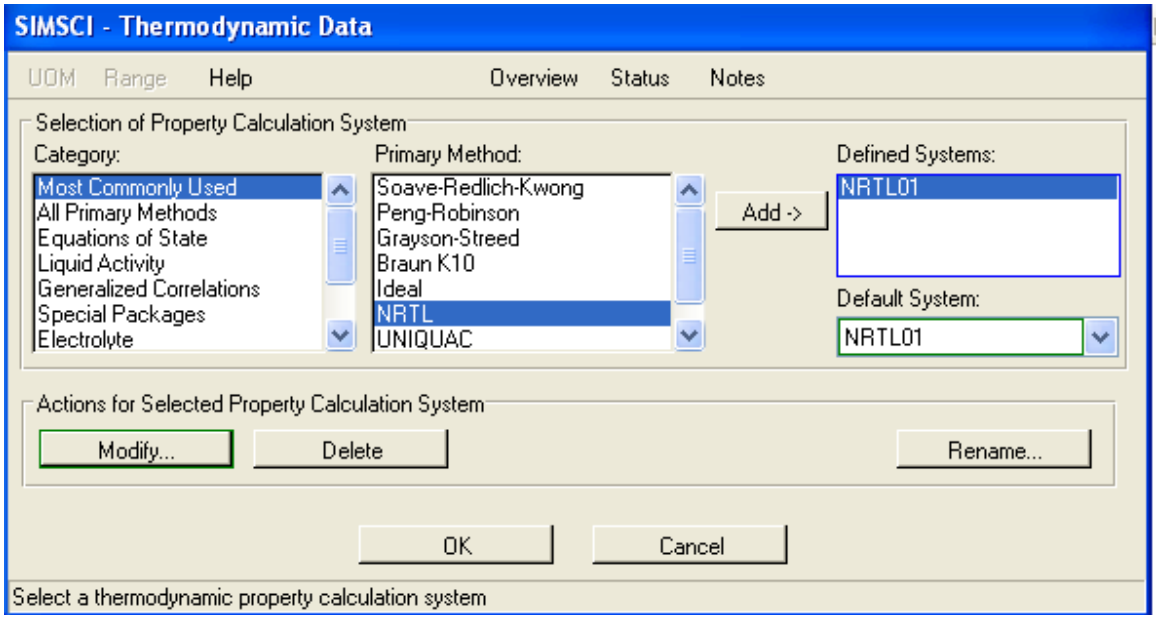
Important Note: The other option to change units is click the value under "**Standard Liquid Density**". Then click **UOM** (Unit of Measurement), finally select desired units**: kg/m^3**.



Step 16: Select the thermodynamic package for the process calculations by either selecting ***Input*** tab on the menu bar and then click **Thermodynamic Data** or press the  icon on the tool bar.

Step 17: Under "**Category**" select **Most Commonly Used**

Step 18: Under "**Primary Method**" Select **NRTL**
Step 19: Click **Add**

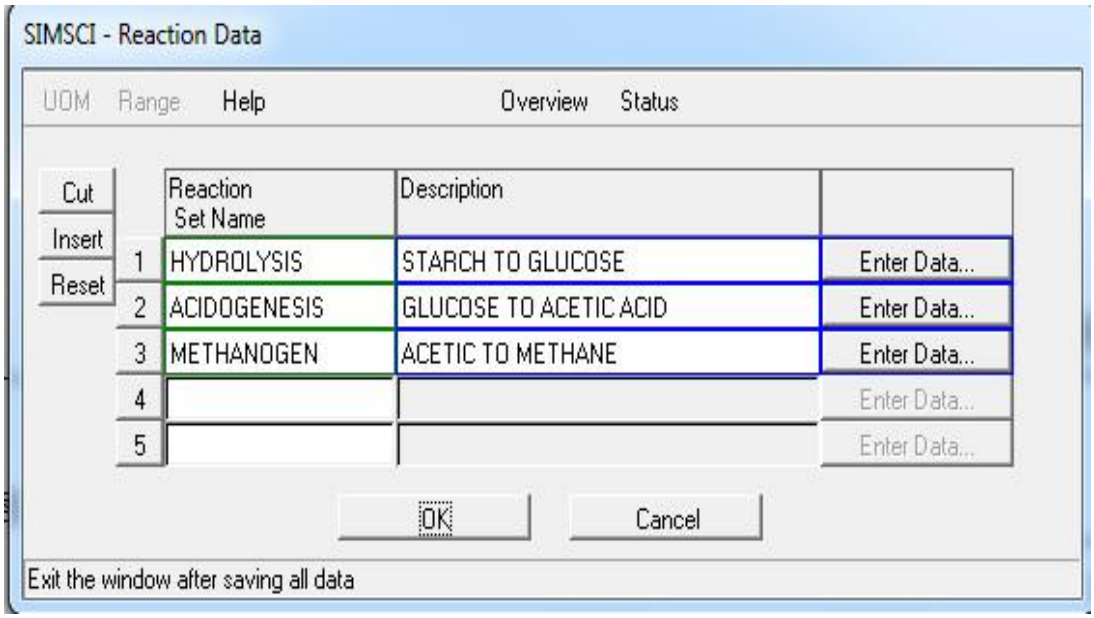


Step 20: Click **OK** twice

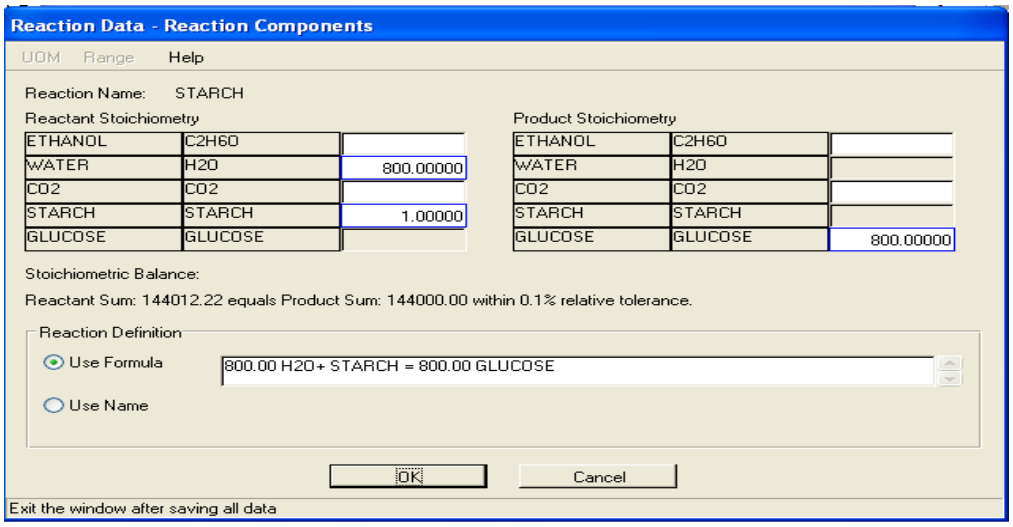
PART 2B: DEFINING REACTIONS

Step 1: Click ***Input*** (menu bar) the select ***Reaction Data***

Step 2: Under "**Reaction Set Name**". Type "**STARCH**", and then give a description. Repeat for **ETHANOL**. See screen below.



Step 3: Click **Enter Data** for STARCH reaction.
Step 4: Click Red Box under "Name". Enter "Starch" and click Red highlight letters "Reactants = Products".
Step 5: Type **"800"** in the white box next to H20. Type **"1"** for **STARCH** and **"800"** for **GLUCOSE**.
Note: Then balance the reaction: Starch + 800 H_20 = 800 Glucose



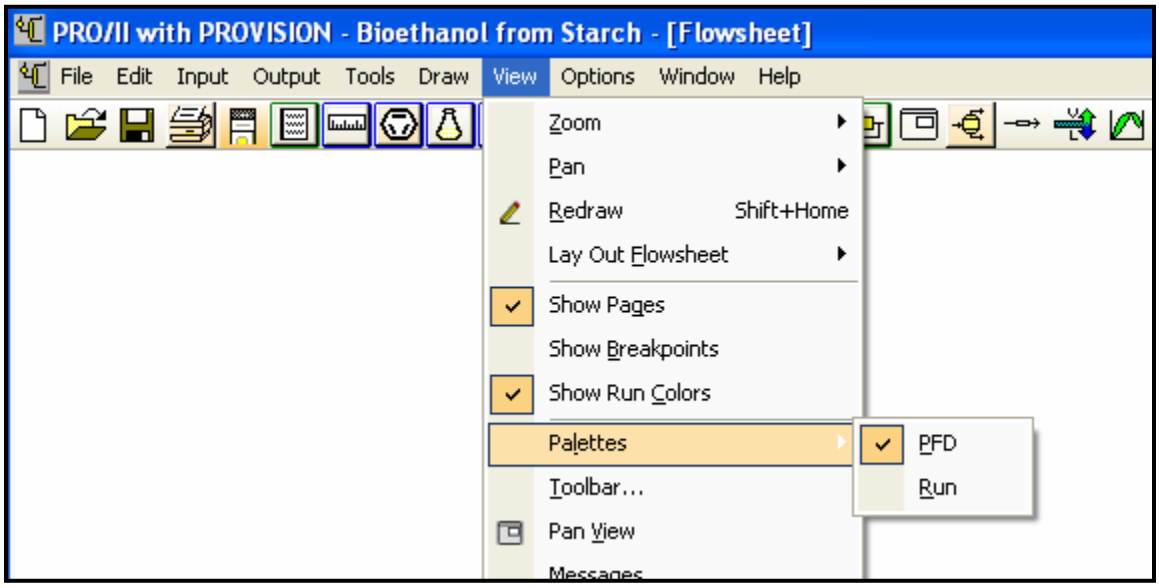
Step 6: Click ***OK*** twice

Step 7: Repeat steps 3-6, except type "ETHANOL" and in STEP 5, type **"1"** in the white box next to **GLUCOSE**. Type **"2"** for **C_2H_6O**, and **"2"** for **CO_2**.

Note: Then balance the reaction: Glucose = 2 C_2H_6O + 2 CO_2

PART 3: CREATING A PROCESS FLOW DIAGRAM (PFD)

Step 1: Click ***View / Palettes / PFD***



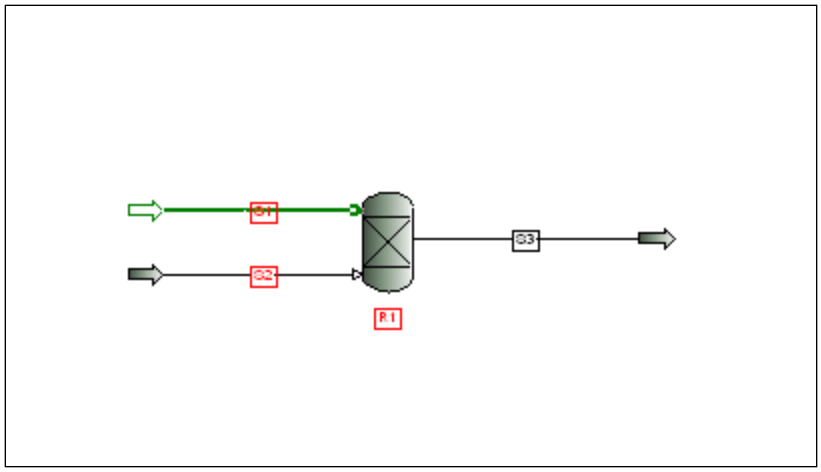
PART 4A: CREATING CONVERSION REACTOR (R1)

Step 1: Click on **Conversion Reactor R1** from the PFD pallet

Step 2: Click **Steams** from the PDF pallet

Step 3: Connect inlet stream by dragging head of arrow to the left side of the reactor. Repeat the process for another inlet stream (total of two inlet streams).

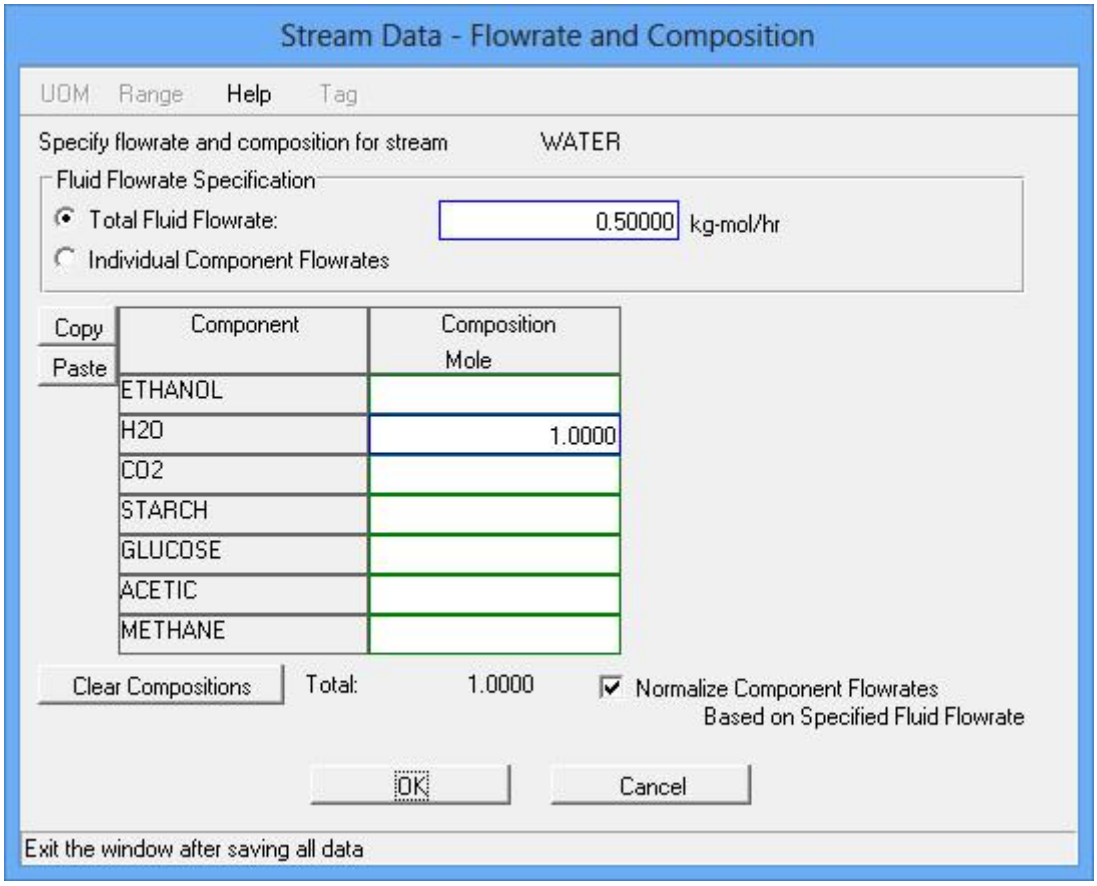
Step 4: Repeat the process, except use only one stream (outlet) and drag from the tail end of the arrow to the right side of the reactor.



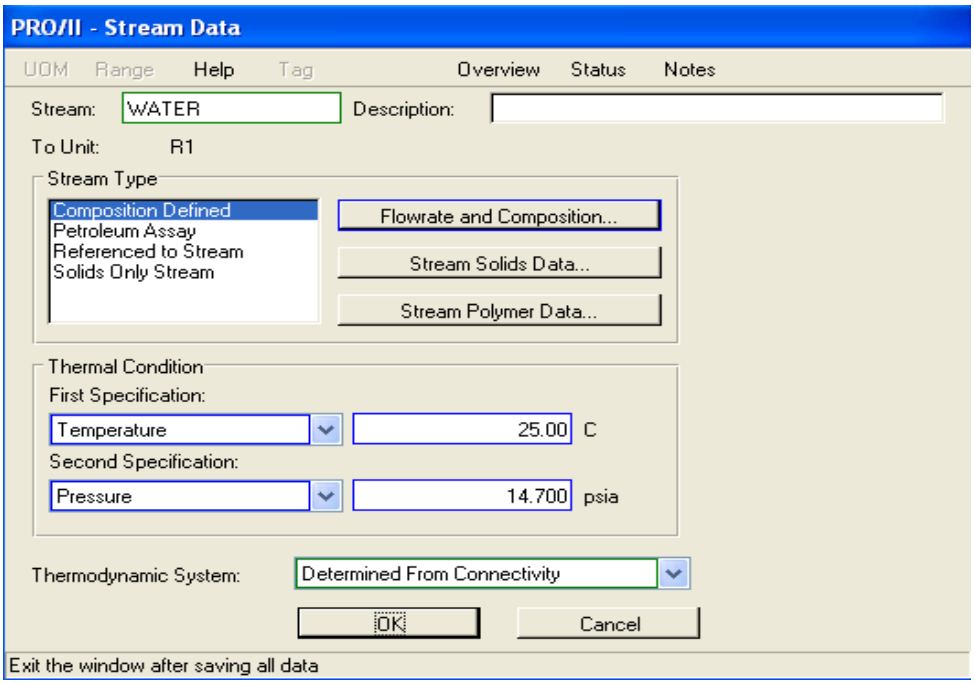
Step 5: Double click the input stream **S1** and rename "**WATER**". Then click on **Flowrate and Composition** under "**Composition Defined**" section.

Step 6: Click **Total Fluid Flowrate**. Input "**0.5kg-mole/hr**", and then under the "**Composition Mole**" section, input "**1.00 Mole**" for **WATER.**

Step 7: Click on **OK**.

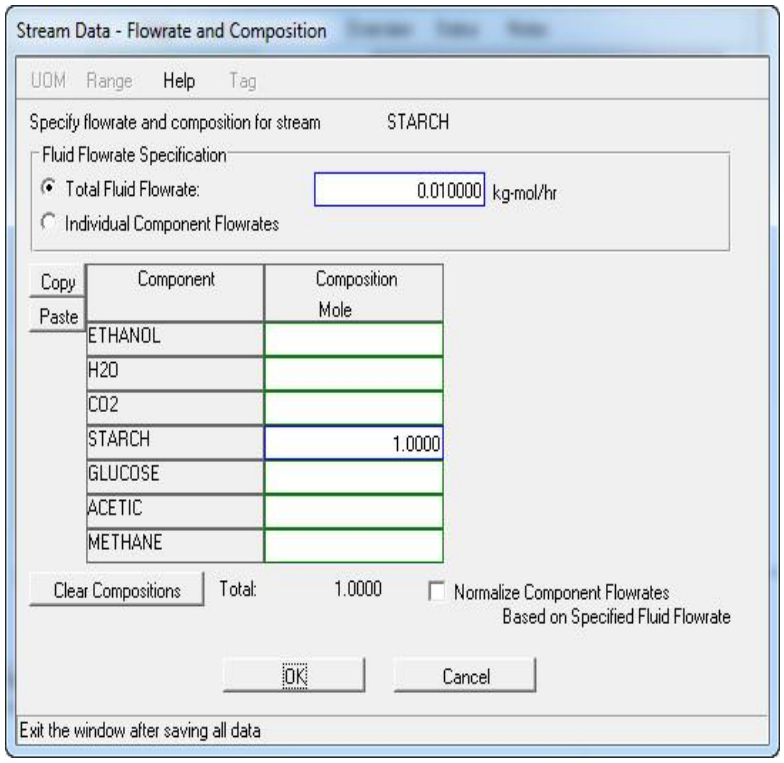


Step 8: Under "**Thermal Condition**", make "**First Specification**" to be Temperature, and input "**25 ^{o}C**"; "Second Specification" to be Pressure and input "**14.7 psia**".



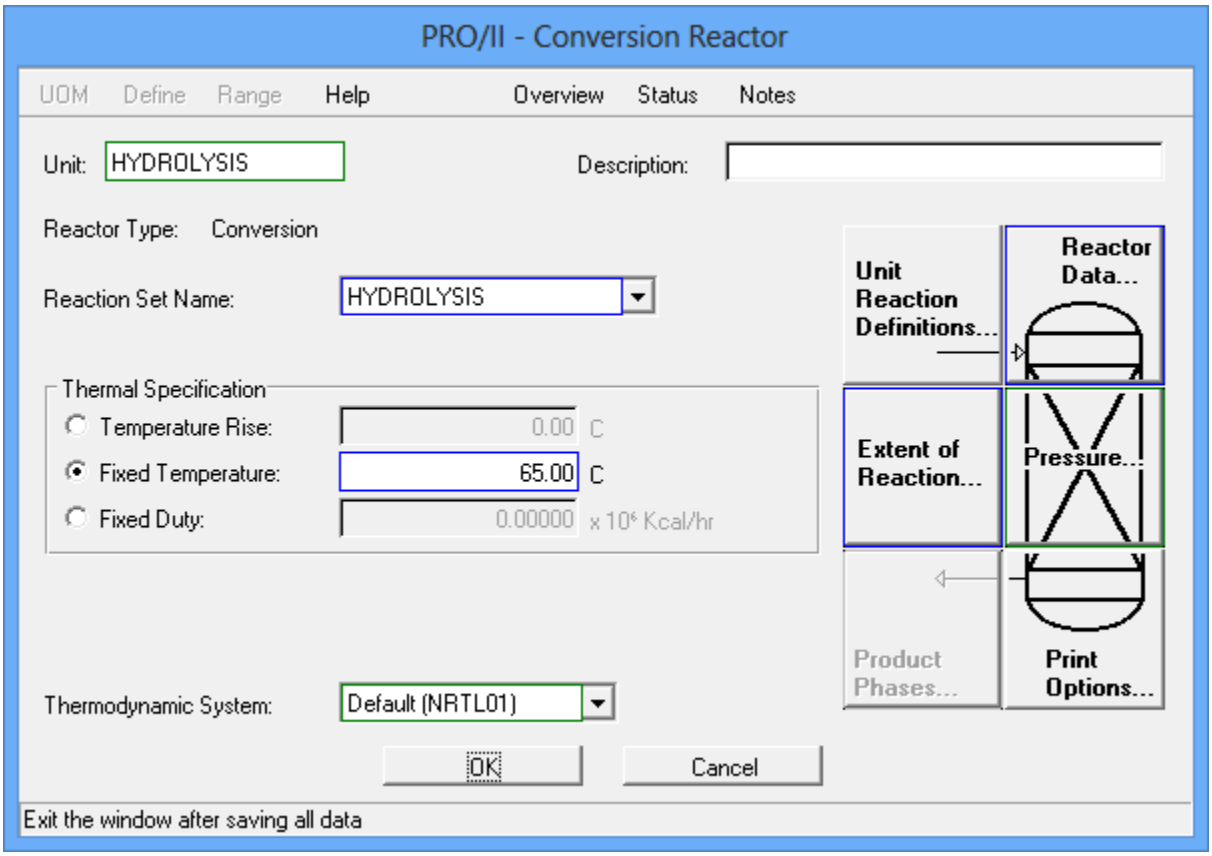
Step 9: Click **OK**

Step 10: Double click stream **S2** and repeat step 5-9, except stream name "**STARCH**", Total flow rate "**0.01 kg-mole/hr**", Composition for starch "**1 mole**".



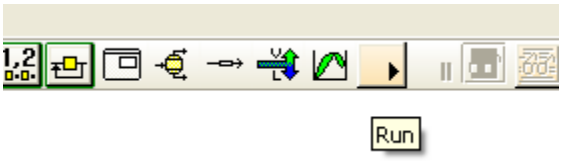
Step 11: Double click stream **S3**, and rename "**Glucose**".

Step 12: Click on the reactor **R1** and under "**Reaction Set Name**" click **STARCH**. Type **"65^{0}C"** for "**Fixed Temperature**". Click on "**Extent of Reaction**" and under "**Base Component**" select **Starch**, and input **"0.89"** under **conversion coefficient A**.



Step 13: Click **OK** twice

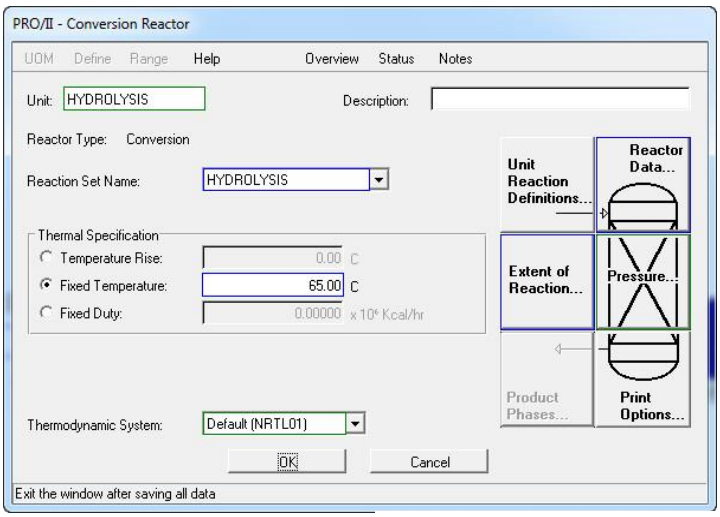
Step 14: Click **Run** on the tool bar

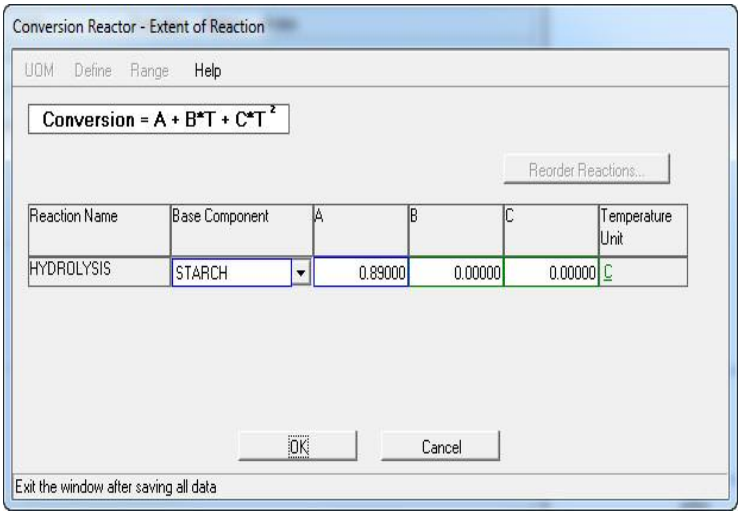


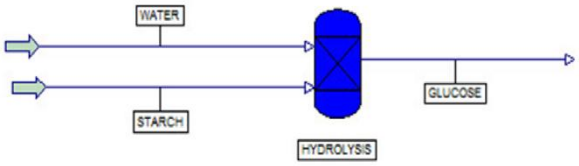
<u>Note: If reactor is blue then process to next step otherwise repeat PART: 3A</u>

For 3 processes conversion reactor are shown below

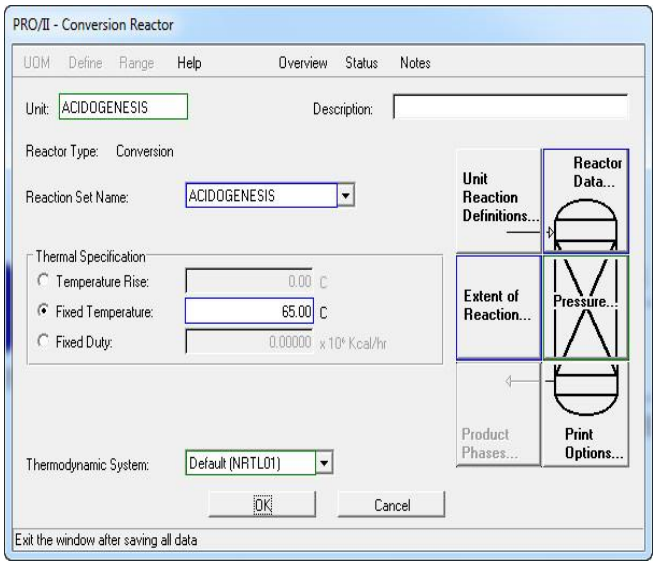
1. For Hydrolysis:

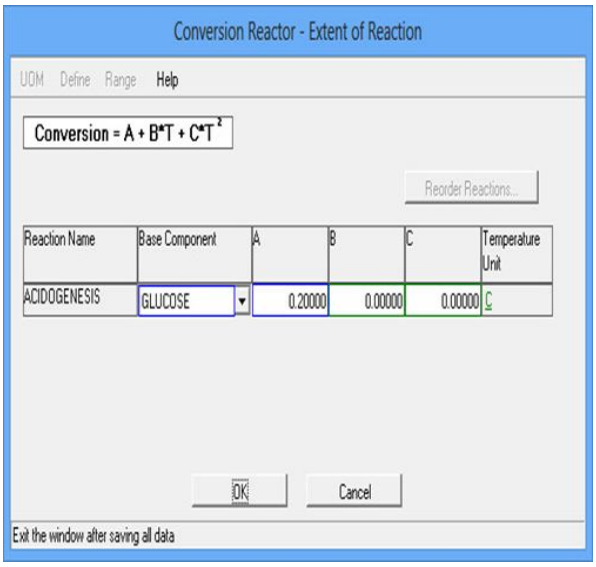




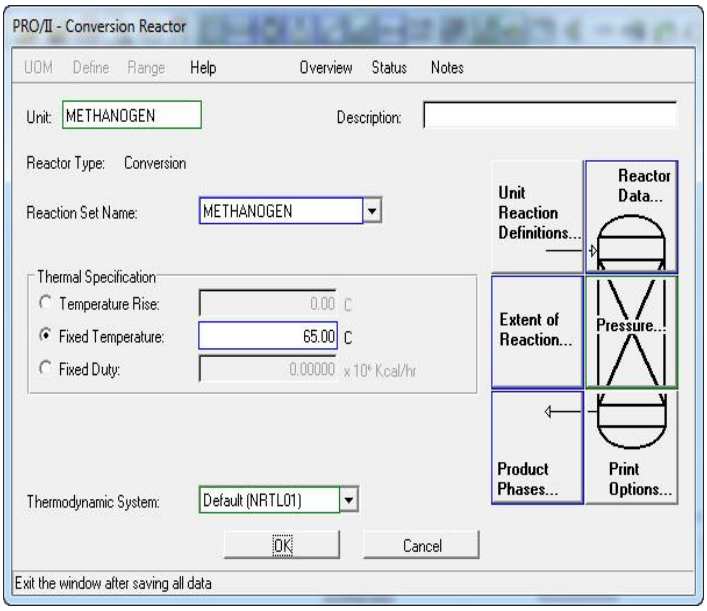


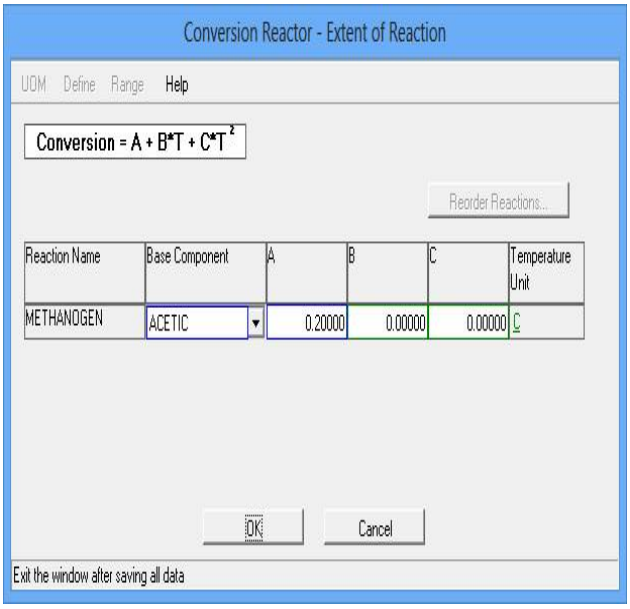
2. For Acidogenesis:

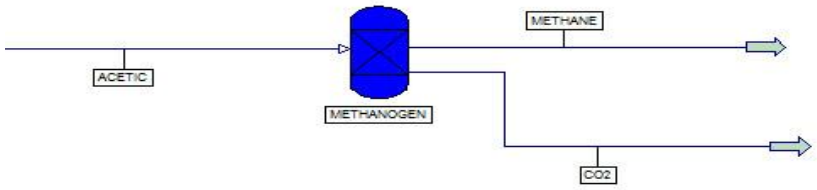




3. For methanogenesis:







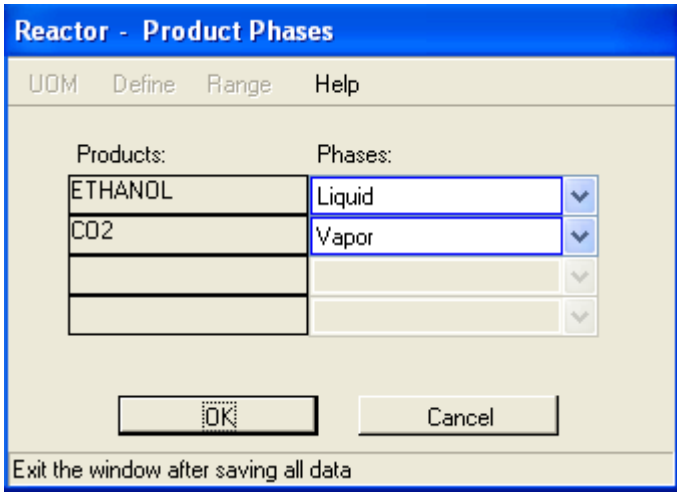
PART 4B: CREATING CONVERSION REACTOR (R2)

Step 1: Select another conversion reactor from the PFD pallet, then connect **GLUCOSE** stream to **R2**.

Step 2: Select two more stream from the PDF pallet and connect on the right side of R2 (outlet streams). Rename upper outlet stream "**CO_2**" and lower stream "**ETHANOL**".

Step 3: Double click **R2.** Under "Reaction Set Name" click **ETHANOL**. Type **"35^{0}C"** for "**Fixed Temperature**". Click on "**Extent of Reaction**" and under "**Base Component**" select **GlUCOSE**, and input **"0.687"** under conversion coefficient A.

Step 4: Click on **Product Phases**. Change phases according to the screen bellow. Under "**Phases**" select **Vapor** for **CO_2** and select **Liquid** for **ETHANOL**.



Step 5: Click **OK** twice.

Step 6: Click Run  icon

<u>Note: If reactor is blue then process to next step otherwise repeat PART:4B</u>

6.4 PROCESS SIMULATION FLOW DIAGRAM:

Through hudrolysis the complex polymer becomes monomer. From this monomer we can get methane through three different ways. The ways are indicated in the overall process diagram by number 1, 2, 3.

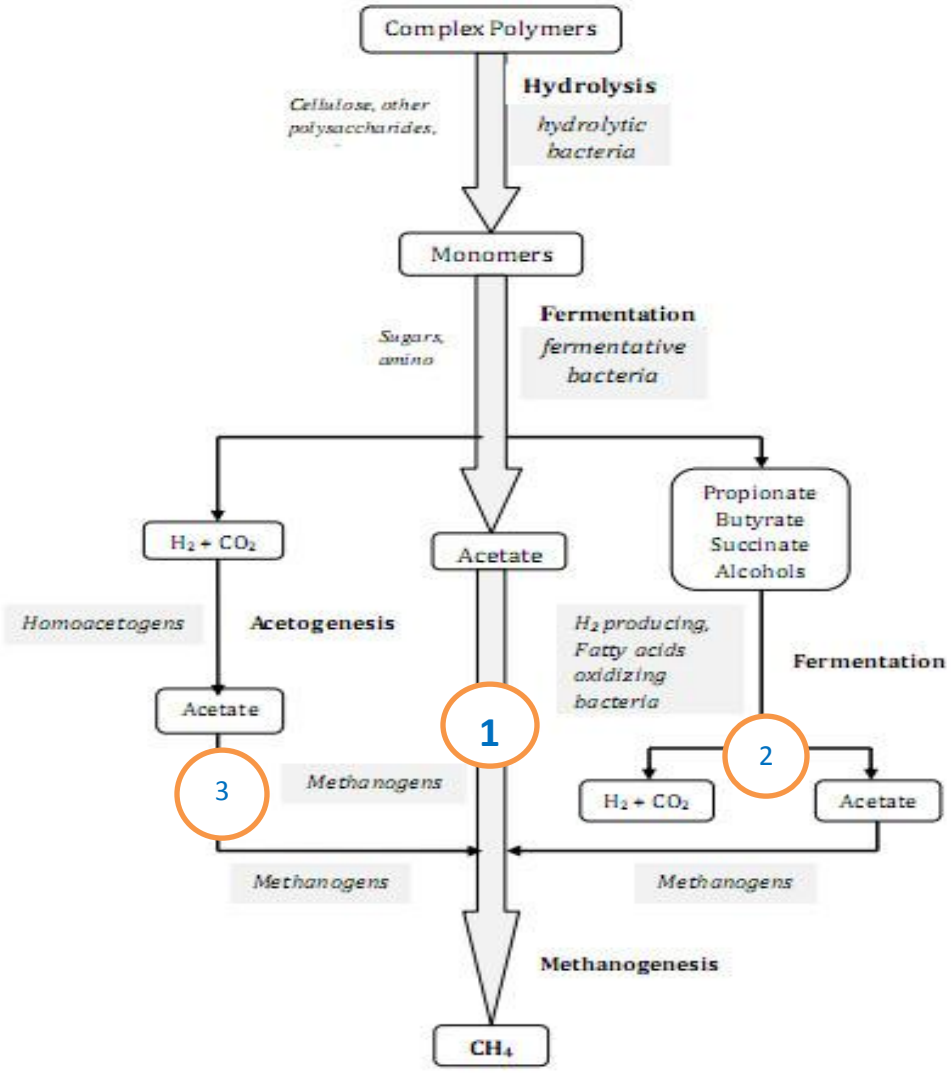
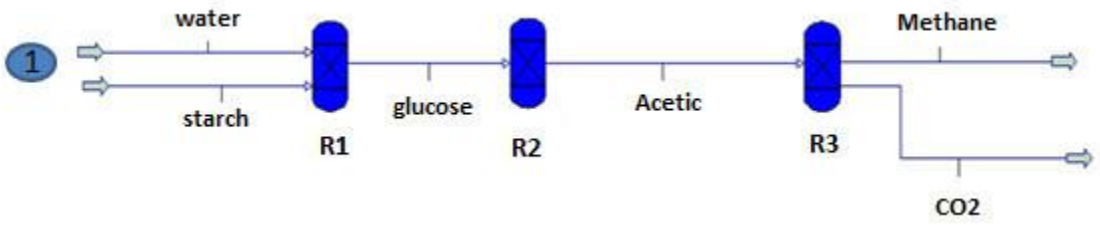


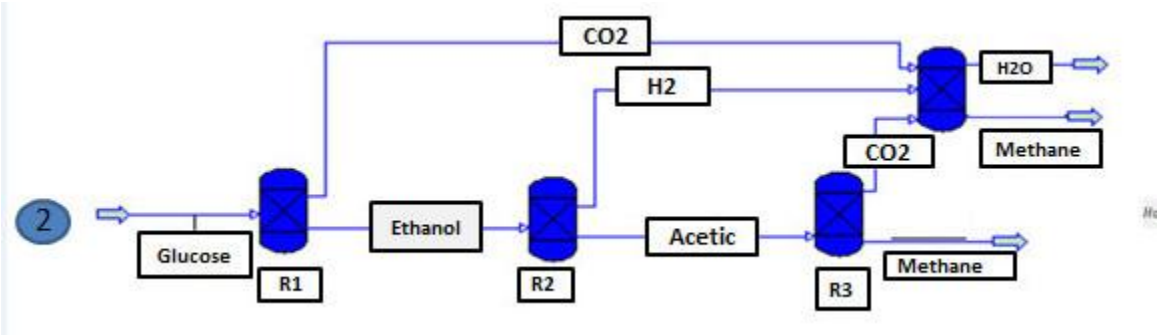
Fig 6.1: Overall Process Diagram for Anaerobic Digestion

For these three ways the respective process simulation diagrams are shown below.

For no 1:



For no 2:



For no 3:

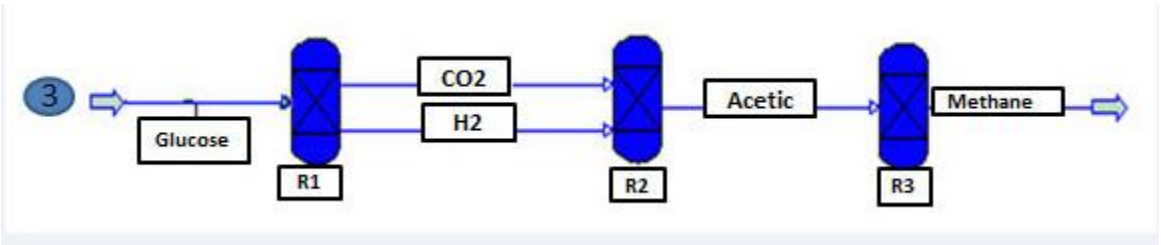


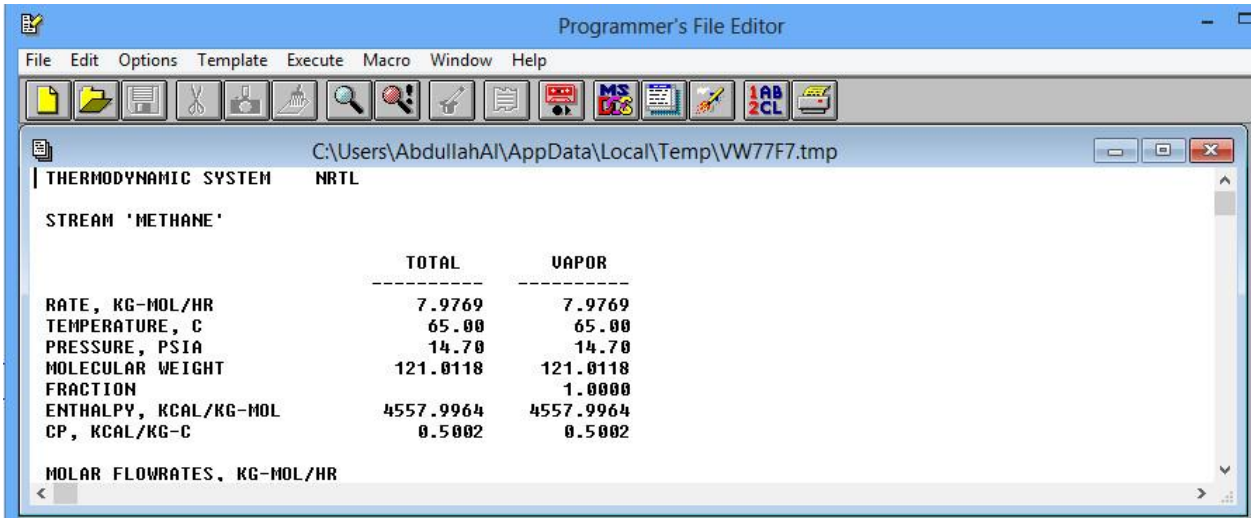
Fig 6.2: Flow streams from PRO II software for different process

CHAPTER 7

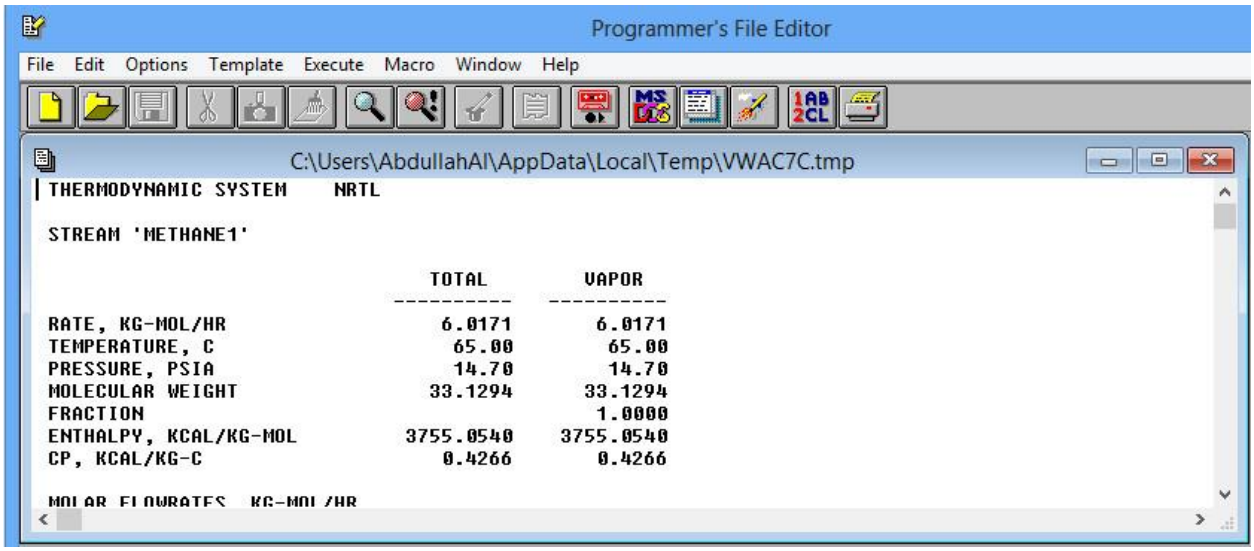
RESULT

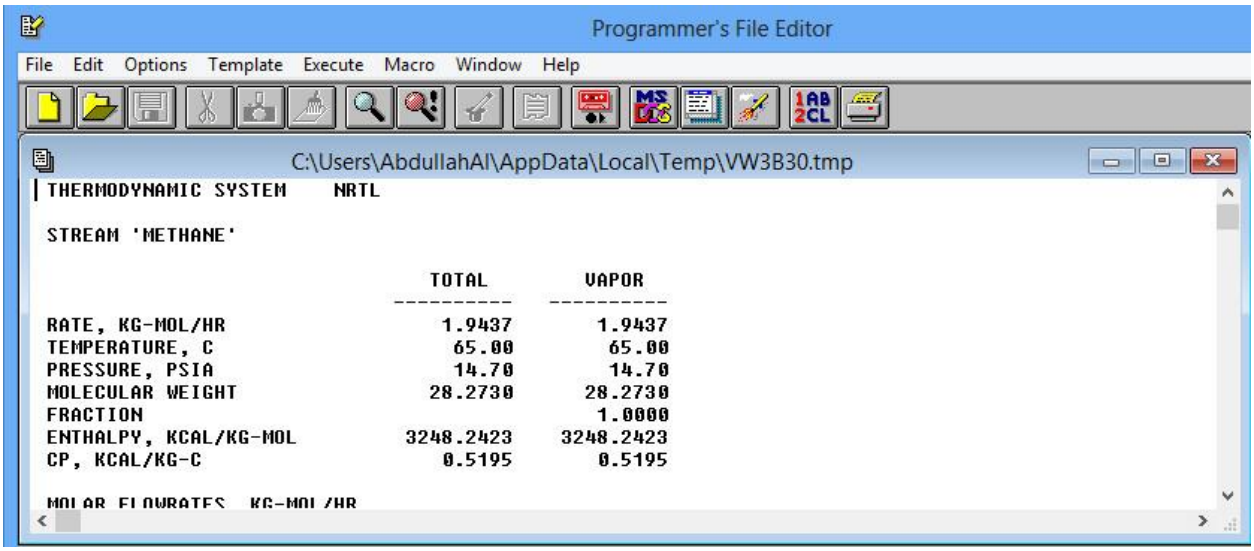
The simulated flow rate from pro II software, for different ways(1,2,3) as shown above, for starch loading rate 0.05 kg-mol/hr are shown below.

1) For no 1 the result is:

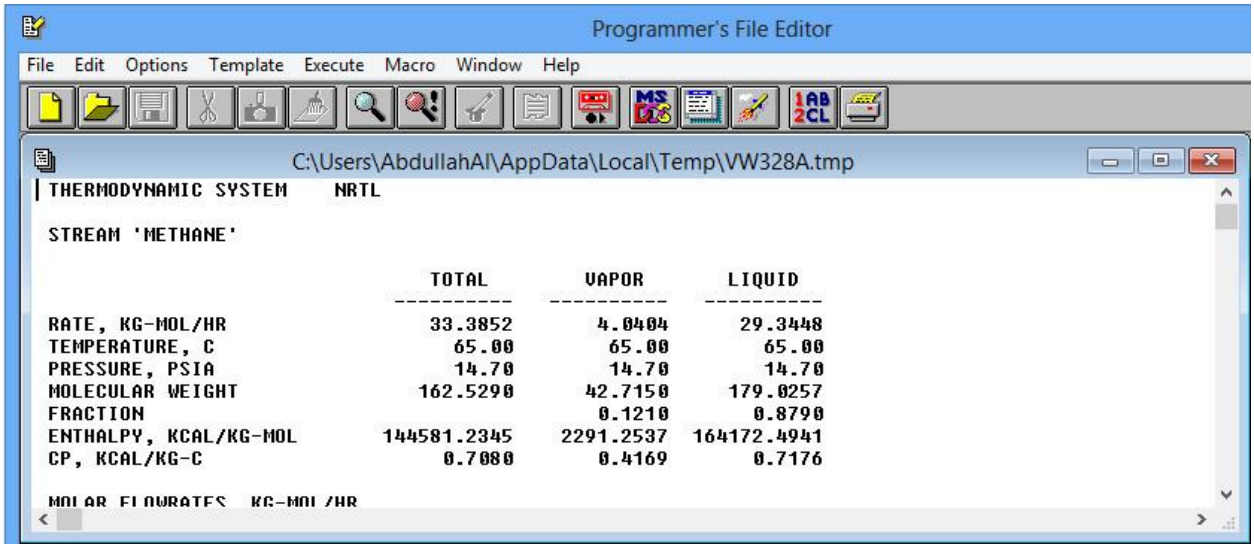


2) For no 2 there are two streams we get methane from. The results for both streams are shown in two dialog box below:





3) For no three the result is:



So, in total the flow rate is = (7.9769+6.0171+1.9437+33.3852) kg-mol/hour

= 49.3229 kg-mol/hour

From simulation for different loading rate the flow rates obtained are as follows:

Loading Rate (starch) kg-mol/hr	Flow Rate of Methane Kg-mol/hr
0.01	13.3517
0.03	32.0865
0.05	49.3229
0.075	75.3647

EXPERIMENTAL RESULT:

Sample calculation for loading rate 0.05 kg/hr

- Density of Methane , ρ = .668 kg/
- Diameter of Pipe , D = 18 mm
- cross sectional area of pipe, A=π/4 π/4( )= 2.5*
- Velocity of flow, V= 52 m/s
- Mass flow rate = ρAV =.668 * 2.5 * * 52

  = 8.684* kg/s

  = 31.2624 kg/hr

From experiment using the continuity equation the chart of flow rate and loading rate is shown below:

Loading Rate(starch)	Velocity (m/s)	Flow rate (kg-mol/hr)
0.01	18	10.8216
0.03	38	22.8456
0.05	52	31.2624
0.075	57	34.2684

Comparison in graph between simulated result and experimental result:

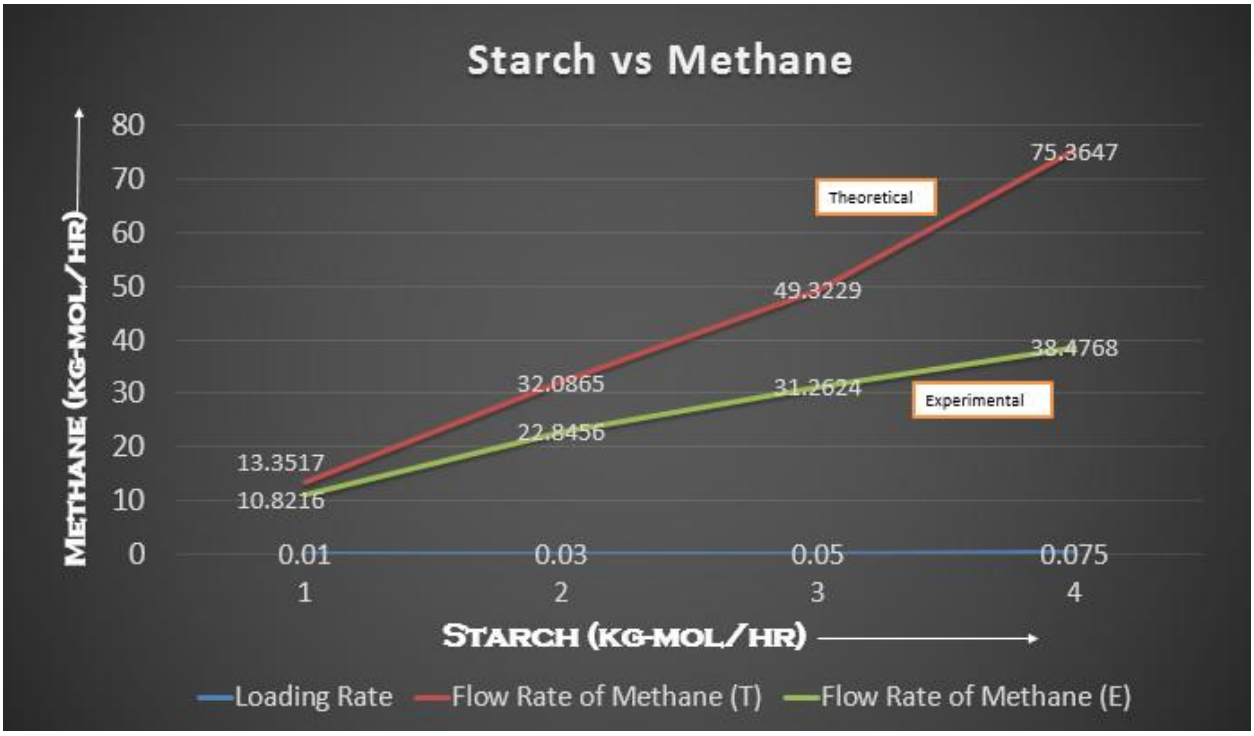


Fig 7.1: Comparison between Starch loading rate vs. Methane flow rate of theoretical and experimental result

pH Variation Diagram:

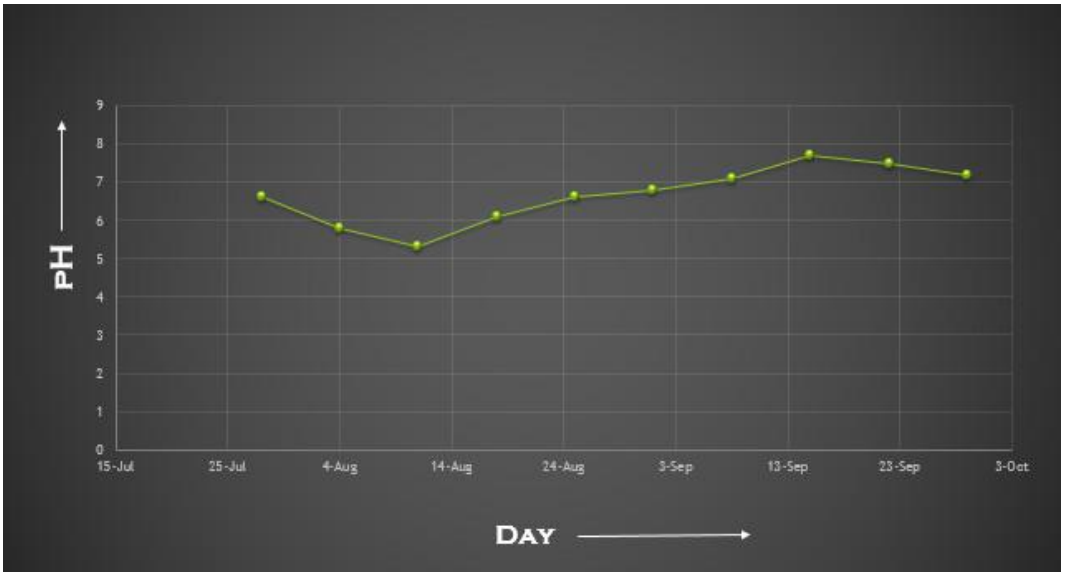


Fig 7.2: variation of pH in weekly basis

GAS COMPOSITION:

- Percentage of C
- Percentage of C : 29%

CHAPTER 8

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