Process layout evaluation in the production of ethanol fuel

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Abstract. Due to depletion of petroleum reserves and environmental impact of fossil fuels, an alternative solution is introduced in form of ethanol fuels. Ethanol fuels have promising potential in the transport sector and in the generation of electricity. In addition, very few researches highlighted the production electricity cost of ethanol fuel for the transportation sector. Therefore, this study will focuses on finding the effective process layout in the production of ethanol fuel. The first main objective of this research is to simulate the layout of ethanol fuel plant using DELMIA QUEST software. The second objective is to determine the most efficient process layout in the production of ethanol fuel. The layout of ethanol fuel plant was simulated and the most efficient layout in terms of ethanol production was suggested from the simulation. At the end of this research, the efficient process layout is highlighted between the dry mill and wet mill process layout. It was found that dry mill layout offers lower electricity cost for ethanol production.

1. Introduction

Renewable energy comes from the repetitive currents of energy that occurs naturally in the environment. Examples of renewable energy sources are solar, hydropower, wind, tide and waves, and non-carbon technologies. Non-carbon technologies include geothermal heat and biomass. The supplies of these renewable energy are affected by various factors such as technological innovation, policies and cost [1]. The field of renewable energy received the global attention due to depletion of fossil fuels caused by increasing demand and the growth of automotive industry [2]. Besides, environmental issues such as air pollution and global warming also contributing towards this attention [3].

As discussed by Chen et al. [4], the automotive industry must attempt to allocate all its resources efficiently in order to achieve the standard requirements of emission reductions derived from the vehicles. Emission reduction from the combustion engine will further reduce the impact on the environmental issues and air pollutions. This can be achieved by using the alternative sustainable fuels such as alcohol, natural gas and biodiesel where it has lower NOx, CO, HC, CO₂ emissions.

In recent years, biofuels have captured most of the attention in the transportation sector since they are environmentally friendly, clean and safe. Generally, biofuels are produced from the conversion of biomass which well known for their renewable characteristics. In comparison with fossil fuels, biofuels were found having [5]:

1. Superposition
2. Low emissions
3. Renewable source
4. Cost efficiency
5. Social contribution
6. Sustainable technology

The use of ethanol as a fuel for transportation has attracted attention due to its various advantages over conventional fuels. Ethanol is derived from renewable sources such as sugarcane, corn, and other agricultural products. It is a clean, sustainable, and renewable energy source, and it has lower emissions compared to fossil fuels. Ethanol can be blended with gasoline to create an alternative fuel that can be used in vehicles. The use of ethanol in transportation can help reduce greenhouse gas emissions and improve air quality, making it an attractive alternative fuel.

In this study, the authors aim to evaluate the process layout for the production of ethanol fuel using DELMIA QUEST software. They focus on simulating the layout of an ethanol fuel plant and determining the most efficient process layout in terms of ethanol production. The study highlights the difference between dry mill and wet mill process layouts, with the dry mill layout being found to offer lower electricity cost for ethanol production.

The introduction of renewable energy sources such as ethanol has gained significant attention due to the depletion of fossil fuels and the environmental impact of conventional fuels. Biofuels derived from renewable sources provide an alternative solution to meet the energy demand while reducing emissions. The research presented in this paper contributes to the understanding of the process layout evaluation in the production of ethanol fuel, which can further support the transition to sustainable energy sources.
a) lower emission of gas that reduce the greenhouse effect,
b) lower impact of sulfur dioxide (SO2) emissions due to the low contents of sulfur in biomass,
c) lower usage of non-renewable sources such as fossil fuels, and
d) sustainable biofuels can be developed with the aid of the advance power systems through biogas combustion.

One of the alcohol types that has captured the attention of the researchers is ethanol. It was said that ethanol has the potential to replace gasoline due to higher octane number, broader flammability limit, higher flame speed and higher heat of vaporization. These characteristics can lead towards higher compression ratio, shorter burn time and leaner burning engine. Thus, combustion in spark-ignition engine using the bioethanol can be said more complete than using gasoline [5].

Ethanol can be produced from sugar cane or starch, molasses, sugar beets, cereals, cellulosic biomass, shale oil and natural gas [6]. These resources are fermented, and then distilled up until purification. The production cost of biofuels can vary with respect to the feedstock, region, scale of production and conversion process. Currently, ethanol is more expensive to be produced than gasoline in all regions considered [7]. Other than that, cost for large-scale production of bio-based products is currently more expensive in developed countries. Conversely, in developing countries, the biofuels production cost is much lower and very near to the world market price of petroleum fuel. Besides, the simultaneous production of bioethanol appears economically attractive in locations where hydroelectricity is available at very low cost.

There were also studies conducted on the mixture of ethanol and gasoline in spark-ignition engine in the transportation sectors. Surprisingly, the results were very convincing as one of the study states that the blending of alcohol and gasoline showed a positive improvement in terms of performance of the engine and smooth operation under different operating conditions [8]. Although many studies have been performed to find the best methods to produce the alcohol fuels and their performance in spark-ignition engine, still only few researches have highlighted on the production electricity cost which is one of the most important factor to implement ethanol fuels in the transportation sector. Thus, this study is investigating the efficiency of the ethanol fuel production process layout with respect to the electricity cost that simulated using DELMIA QUEST software.

2. Materials and Methods
2.1 Process Layout of Ethanol Fuel Production
There are two layouts investigated in this study. They are dry mill and wet mill process layout. The explanation on each layout are as follows.

2.1.1 Layout 1 – Dry Mill
During dry milling process, the corn kernel was first ground into flour and called as meal. Water is then added to the meal to produce slurry. Next, conversion of starch to dextrose, a simple sugar was done by adding enzymes that from switchgrass, corn stover (corn stalks, leaves and other leftovers). In order to control the pH value, ammonia and nutrient for the yeast were added. The mixture was processed with high temperature to reduce levels of bacteria before its being cooled and transferred to fermenters. During this process, yeast was added, and the sugar was converted to ethanol and carbon dioxide.

2.1.2 Layout 2 – Wet Mill
In wet mill, the corn grain was soak in a dilute combination of sulfuric acid and water for several hours to separate the grain into few components. The slurry mix was then grinded purposely to separate the corn germ. The byproduct from this process is corn oil than can be sold to gain profit. Meanwhile, the remaining components which consist of fiber, gluten and starch were separated using a series of separators.
2.2 Part Class Creation

Part class was an important element before starting the simulation. A part class can be introduced to create several parts having similar properties. A part is an entity that moves between elements and is processed by the system. Parts are generated at sources or as a result of a machine process. Sinks will consume parts and parts act as a result of a process of a machine. The part class parameters were identified and shown in Table 1.

| Part Class Name | Color | By-Product | Machine Involved |
|-----------------|-------|------------|------------------|
| Part1           | White | Corn       | Milling          |
| Part2           | Grey  | Corn grits | Milling and mashing |
| Part3           | Black | Corn mash  | Mashing and cooking |
| Part4           | Red   | Liquefied mash | Cooking and fermentation |
| Part5           | Green | Fermented mash | Fermentation and ultrafiltration |
| Part6           | Blue  | Filtrate   | Ultrafiltration and Pervaporator 1 |
| Part7           | Yellow| Impure ethanol | Pervaporator 1 and Pervaporator 2 |
| Part8           | Cyan  | Ethanol    | Pervaporator 2   |

Table 2. Dry milling parameters

| Process         | Rate (kg/s) | Simulation Time |
|-----------------|-------------|-----------------|
|                  | Input       | Output          |                   |
| Dry milling      | 9.84 (corn) | 9.84 (corn grits) |                     |
| Mashing          | 9.84 (corn grits) | 24.84 (corn mash) | 8 working hours or 28800 seconds |
| Cooking          | 24.84 (corn mash) | 25.22 (liquefied mash) |                     |
| Fermentation     | 25.22 (liquefied mash) | 21.53 (fermented mash) |                     |
| Ultra-filtration | 21.53 (fermented mash) | 19.03 (filtrate) |                     |
| Pervaporator 1   | 19.03 (filtrate) | 3.36 (impure ethanol) |                     |
| Pervaporator 2   | 3.36 (impure ethanol) | 3.20 (ethanol) |                     |

Table 3. Wet milling parameters

| Process         | Rate (kg/s) | Simulation Time |
|-----------------|-------------|-----------------|
|                  | Input       | Output          |                   |
| Wet milling      | 19.9 (corn) | 9.84 (corn grits) |                     |
| Mashing          | 9.84 (corn grits) | 24.84 (corn mash) | 8 working hours or 28800 seconds |
| Cooking          | 24.84 (corn mash) | 25.22 (liquefied mash) |                     |
| Fermentation     | 25.22 (liquefied mash) | 21.53 (fermented mash) |                     |
| Ultra-filtration | 21.53 (fermented mash) | 19.03 (filtrate) |                     |
| Pervaporator 1   | 19.03 (filtrate) | 3.36 (impure ethanol) |                     |
| Pervaporator 2   | 3.36 (impure ethanol) | 3.20 (ethanol) |                     |

2.3 Simulation Procedures

The simulation process starts with the identification of the simulation elements. The element class can be defined to create a few elements having similar properties. Elements act as the basis of QUEST models systems. The elements needed in the simulation were divided into three different parts; source, machine and sink.
Once the elements of the simulations have been defined, the simulation process flow was developed. Process flow is an important element for simulating process layout in DELMIA QUEST software. The process will start with milling before it goes to mashing and cooking. After that, the process will enter the fermentation and ultra-filtration. Next process is Pervaporator 1 and Pervaporator 2 before it end at the storage.

Lastly, the simulation was performed. In this study different factors have been considered which are simulation time, types of machines and machine rate. All scenarios were considered as the flow of production which starting from the raw material to the final product. In order to achieve the objectives of this study, different parameters have been conducted in the simulation. Table 2 and Table 3 concluded the simulation parameters for both dry and wet milling ethanol production.

2.4 Method of Result Analysis
DELMIA QUEST is a tool to simulate the process layout of any production process. The results produced from this simulation that will be included are number of finished parts and average processing time. These results will be further analyzed and compared to each other in terms of efficiency in producing ethanol fuel.

Additionally, to further analyze the comparison between the process layouts, the cost of electricity of the machine involved in the production of ethanol fuel for both dry and wet milling layout will be calculated using the simple mathematical formula as follow:

\[
\text{(Wattage x Operation Hours) x kWh Rate = Electricity Cost}
\]

where Electricity cost (RM), Wattage (kW) = wattage of dry/wet milling machine, Operation Hours = 8 working hours per day, kWh Rate = Tariff charges, based on 38.00 cent per kWh [9].

3. Results and Discussion
3.1. Finished Product

| Type of milling process | Finished parts |
|-------------------------|---------------|
| Dry milling             | 348           |
| Wet milling             | 174           |

Based on Table 4, dry milling layout produced higher number of ethanol when compared to wet milling layout. This result is supported by the fact that ethanol is the primary product of the dry mill plant and produced high protein caloric animal feed and carbon dioxide as the co-products. Meanwhile, wet mills are slightly less effective in producing ethanol and it produce high protein animal feeds, and corn gluten feed as the byproducts. Thus, the production electricity cost to run a dry mill ethanol plant will be much lower than that of a wet mill plant. This is because dry milling machine is less capital intensive [10]. Besides that, dry milling machine has far less components and features when compared to wet milling machine [11].

Although the capital for wet milling machine is high, wet mill plant is more flexible and can produce not only ethanol, but other valuable products such as corn sweeteners, starch, and oil. Due to the flexibility of the wet mill plant, it allows better reaction and adjustability to the market demands for corn products as compared to dry mill plant. Furthermore, the wet mill process also possesses many other advantages such as the ability to recycle yeast cells batch by batch and has lower usage of water per gallon during the ethanol production [10]. However, the amount of ethanol produced by wet mill plant is lower than dry ill plant. Nevertheless, the flexibility and adjustability of the wet mill plant products to the market demand will affect the production cost of ethanol.
3.2. Average Processing Time

From Table 5, dry mill layout has faster overall average processing time as compared to wet mill layout at the same parameters besides the rate of corn supply that can be processed at a time by the milling machine. Wet milling machine has higher processing rate which is 19.9 kg/s of corn as compared to 9.84 kg/s for the dry milling machine. Thus, it can be said that the processing rate of milling machine affect the average processing time. The higher processing rate is due to wet milling involves with soaking the corn to assist in separation of the corn kernel. Unlike wet mill plants, dry mill plants have shorter average processing time and rate because the corn milling process is much simpler and does not require extra time to be completed.

Table 5: Comparison of average processing time

| Process     | Dry Mill Average Processing Time (s) | Wet Mill Average Processing Time (s) |
|-------------|-------------------------------------|--------------------------------------|
| Dry milling | 248.109                             | 496.218                              |
| Mashing     | 248.118                             | 496.236                              |
| Cooking     | 248.126                             | 496.253                              |
| Fermentation| 248.135                             | 496.270                              |
| Ultra-filtration | 248.144                            | 496.287                              |
| Pervaporator 1 | 248.152                          | 496.305                              |
| Pervaporator 2 | 248.161                          | 496.322                              |

3.3. Cost of Electricity Consumption

Table 6. Wattage and tariff rates

| Machine     | Wattage (kW) | Tariff Rates |
|-------------|--------------|--------------|
| Dry milling | 3            | 38.00 sen per kWh |
| Wet milling | 11           |              |

Figure 1. Cost of Electricity against Type of Machine

The wattage of dry and wet milling machine was estimated based on correlations found in previous literatures. Meanwhile, the tariff rates of electricity for industrial usage were taken from the updated tariff on 9 August 2020. All currency values were considered in Ringgit Malaysia. Table 6 shows the comparison between wattage of dry and wet milling machine and the tariff rates.

Based on the Figure 1, the estimated electricity cost of dry milling machine was lower than wet milling machine. One of the reasons is dry milling machine operated at lower wattage than wet milling. The cost of electricity of the equipment in the facility can be said to be having an impact on the production
cost of ethanol. The lower cost of electricity basically means lower operational cost that lower the production cost. From the results obtained, dry milling machine in a dry mill layout can save up to 70% of electricity cost when compared to the wet mill layout.

4. Conclusion
Using the multi-functional DELMIA QUEST, the simulations were successfully conducted. Featuring crucial information from written articles, the simulation process was made easier and relevant results were produced. The following conclusion can be drawn:

- Dry mill layout was the best technique in producing lower cost ethanol.
- The layout using dry mill produced higher amount of ethanol and has lower average processing time than wet mill layout.
- Even though wet mill process layout was found less effective in producing ethanol, the adjustability and flexibility to market demand is far more superior.

However, there are still many improvements and research needed to be done especially by introducing the information and parameters regarding the modification and reduction of enzyme used in production of ethanol.

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