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*RESEARCH ARTICLE*

# A CLOSED MODEL OF PRODUCTION SYSTEM FOR INDEPENDENT ENERGY IN CORN FLOURS INDUSTRY.

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## Abstract

Corn flours industry consumes large amounts of energy (98 kWh/ton) in the processing of corn to corn flours. The main source of energy have been fossil fuel which availability is declining overtime. A continued dependency on this energy source would become constraining factor in the very near future. In addition, the production of corn flours produced wastes that can be used as a source of alternative sustainable energy. The purpose of this research was to develop a model of the mass balance and energy of corn flours processing industry as an energy independent system so as to minimize dependence on fossil energy. The results are expected to be a reference to the development of independent or more efficient energy corn flours industry. The model was developed to depict the actual situation of corn flours production process. The output of the model showed that obtained yield of corn flours is 31%. The wastes are cobs and corn husk that can be utilized to generate energy as much as 3,870 kWh from combustion technique with boiler at 68% efficiency. Therefore, corn flours industry can be energy independent.



## Introduction:-

Morphologically, corn consists of 68.86% corn seeds, 17.53% corn husk, and 16.32% corn cob (Indradewa *et al*. 2005). Good quality corn that is clean then processed to separate skin, endosperm, embryo, and tip cap to produce corn flours (SNI 01-3727-1995). Corn flours is a semi-finished product of dried corn kernels (Suryawijaya 2009). As much as 40 to 50% (total weight) of corn parts are underutilized, especially corn cobs and corn husks. Wastes must be treated and added the production process cost by establishing waste processing unit and disposal. It is usually done by the end of pipe approach (Christina *et al*. 2007). This solution is becoming not effective because still generating waste and more costly.

Corn flours industry consumes considerable energy in the production process, at a capacity of 182 tons/day requires electrical energy of 8,568 kWh/day (Syanto 2011). Prime source of energy used for the production process is fossil fuel that is of non-renewable sources. The use of non-renewable fuel can cause a great impact when it runs out of supply and corn flours industry cannot survive.

The problem of waste and energy use are existing in corn flours industry. This problem requires the development of a new system for their solution (Christina *et al*. 2007). The new approach is needed in the form of an industrial

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system that integrate with surrounding of mutual support in order to optimize material cycles as an input to be processed into products (Gamer 1995).

The corn cobs and corn husks consist of lignocellulose (38.99% fiber content) containing highest xylan (12.4%) compared to other agricultural wastes (Richana *et al*. 2004). Therefore, the wastes can be utilized as a source of energy in the production process of corn processing. Within an industrial ecology perspective, the utilization of waste containing energy can overcome the problems of waste handling and energy supply in the industry.

Energy generation from corn cobs and corn husks may be utilized to develop a closed production system without any energy input from outside of the system. Based on environmental engineering rules, closed system means a system that all input and output flows are known (Davis and Cornwell 2013). This research refers to this rule and used mass balance modeling to describe material flows and calculate energy potency of the wastes. Bantacut and Pasaribu (2015) developed the model for closed mass flow and energy sufficiency in CPO production, Bantacut and Novitasari (2016) developed and applied the model to analyze energy and water self-sufficiency in white sugar production, and Bantacut and Nurdiansyah (2017) developed closed production process for energy sufficiency in rice mill. Therefore, the developed closed system is expected to integrate corn flours production and by-products utilization as an energy resource to meet energy need in the corn flours industry.

**Research Objective:-**

The purpose of this research was to develop a model of a closed system energy independent of corn flours production. The research goal was achieved through:

1. Development of mass balance model of corn flours industry.
2. Calculation of the energy needs of corn flours industry.
3. Calculation of the energy potential for corn flours industry wastes.
4. Development of closed system models development for corn flours industry.

**Scope of Research:-**

Inputs used in the model consisted of whole corn (intact), corn husks, corn fiber, corn cobs and corn kernels. The basis of calculating the mass balance model was 12 tons of corn per day. Development of industrial closed system model consisted of simple and complex models. The complex model were made based on each process step that considering to be a separate compartment.

## Method:-

**Data Collection:-**

Data used in this research were primary and secondary data. Primary data was obtained from direct observation of the production process, energy needs and energy sources used. The Secondary data used were taken from journals, research and academic papers, and statistical reports.

**Model Description:-**

Mass balance model was developed based on the process flow in and out of compartment to describe the actual production process. The model was developed to determine internal flows using ratio values (coefficient of efficiency) of the independent and dependent variables based on the principles of a linear equation. Microsoft Excel was used as calculation tool. Results of the model calculations then compared with actual data from production process of corn flours industry. Similar calculation was also applied to identify and calculate the amount of by-products that potential to be a source of energy to meet the needs of the production process. This model has a high degree of accuracy and in accordance with the actual production process forms the basis of analysis of potential energy of by-products to develop an energy independent production process.

**System Boundary:-**

Corn flours industry has a complex production system that involves many interconnected factors. The factors are material and energy (input) required in the production process (input), and product (as well as by-product) (output) generated from the production process. These factors require a comprehensive approach to find the optimal solution to energy used. Therefore, the systems approach was used to analyze the flow of mass, energy needs, including energy potential of by-products in the production process of corn flours.

**Mass Balance:-**

Mass balance model was created by identifying compartments that can describe the production process. Then, the model was built by establishing mass balance equations that connect the inputs (corn and supporting materials) and outputs (corn flours and by-products). The mass balance model was developed from a simple model to the complex one. The simple model was formed based on the assumption that the system has a single compartment without specific flow of input and output.

Mass balance equations solved by building a matrix that is based on the efficiency factor (the ratio of the variable value) from secondary data onto the mass flow of corn processing industry. After identifying the mass flows and efficiency factor, then the value of the efficiency equations was determined and mass balances were constructed.

**Energy Content of By-Product:-**

Based on a mass balance model that describes the actual condition of the corn flours processing industry, the potential energy of by-products can be calculated with the equation:

$$\text{Potential Energy (kcal)} = \text{Mass (kg)} \times \text{Caloric Value (kcal/kg)}$$

Where the mass of by-product was obtained from the calculation model, while the caloric values were obtained from the literature.

**Process Flow of Self-Sufficient Energy:-**

The by-product of corn flours processing industry was examined as main energy sources to meet energy needs. Analysis of the energy usage began with the calculation of the mass input-output flows of the system. The potential energy of resulting by-products were determined then compared with the energy needs which were obtained from tools and machines energy consumption. Table 1 shows typical machine electrical energy consumption of corn flours industry of 12,000 kg corn per day capacity.

**Table 1:-** Machines energy consumption of corn flours processing

| Process | Type of machine | Energy need (KWh/ton) |
|---|---|---|
| Corn husk removing | Corn husk remover | 22 |
| Corn in Cob drying | Tray dryer[a] | 10 |
| Corn seed shelling | Corn seed sheller | 22 |
| Corn kernel drying | Flat bed dryer[b] | 15 |
| Corn hulling | Corn huller | 40 |
| Corn Milling 1 | Multi mill[c] | 22 |
| Corn Milling 2 | Disc mill[c] | 20 |
| Corn oil extraction | Screw presser[c] | 7.5 |

Source: [a] Ogechukwu 2012; [b] Balitsereal 2015; [c] Koeswara 2009

**Mass Balance Model:-**

Mass balance is mathematical representation of input and output mass flows in a system. It can be applied for modeling on production, transportation and fate of pollutants in the environment. Bantacut and Novitasari (2016) developed and recommended a complex mass balance model for assessing material inflows, outflows and internal flows of agroindustry by taking a case of sugar mill. It shows every flow in the system and also every accounted component in the closed system. Many researcher have also been applying similar modeling such as Davis and Cornwell 2013, Bantacut and Pasaribu 2015, and Bantacut and Nurdiansyah 2017. The model in this study consists of variables and efficiency values in corn flours production process.

**Simple Model:-**

A simple Mass Balance Model assumes production process of a single compartment (Figure 1). This model simply identifies the amount of material entering and leaving the system generally. Corn seeds to compose of 68.86% of corn intact (Indradewa *et al*. 2005). Processing corn with dry milling method will produce corn flours of 44.5% (dry basis) (Syanto 2011) to 48.4% (Ryan, 2010; Syanto 2011) of corn intact. The simple model calculated the flours yield was 32.36% of the total corn intact.

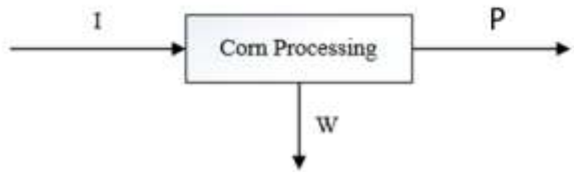


**Figure 1:-** Simple Mass Balance Model

Where I = input, P = Product, W = Waste and I = P + W

**Complex Model:-**

The Complex Model follows main steps of corn flours processing to describe all inputs and outputs of each compartment of the whole production processes. This Model has balance equations as many as the number of compartments (14 compartments). It consists of 5 independent variables ($I_1$,$I_2$,$I_3$,$I_4$,$I_5$) and 28 dependent variables ($X_1$, $X_2$, $X_3$, $X_4$, $X_5$, $X_6$, $X_7$, $X_8$, $X_9$, $X_{10}$, $X_{11}$, $X_{12}$, $X_{13}$, $X_{14}$, $W_1$, $W_2$, $W_3$, $W_4$, $W_5$, $W_6$, $W_7$, $W_8$, $W_9$, $W_{10}$, $W_{11}$, $W_{12}$, $P_1$ and $P_2$). The independent variables are consistence which has a given value (12 ton of Corn Intact) while the dependent variables have various values depending on efficiency values (Figure 2).

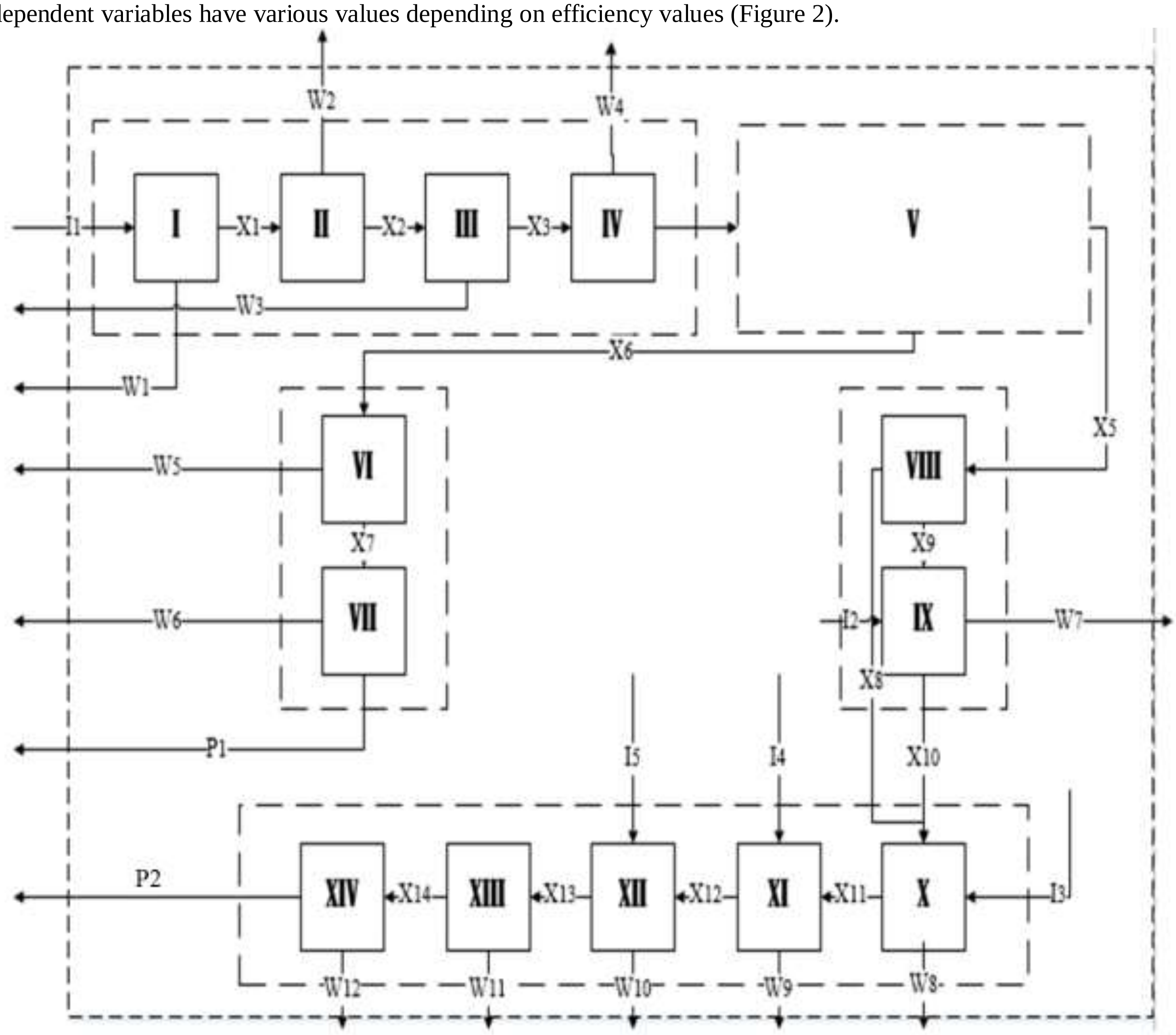


**Figure 2:-** Complex Mass Balance Model (symbol explanation in Table 2)

**Table 2:-** Explanation of symbols in Figure 2

| Compartment | | Explanation | |
|---|---|---|---|
| I | | Corn husk removing | |
| II | | Corn cob drying | |
| III | | Shelling | |
| IV | | Corn kernel drying | |
| V | | Hulling | |
| VI | | First milling | |
| VII | | Second milling | |
| VIII | | First extraction | |
| IX | | Second extraction | |
| X | | Degumming | |
| XI | | Netralization | |
| XII | | Bleaching | |
| XIII | | Winterizing | |
| XIV | | Deodorization | |
| Input | | Output | |
| $I_1$ | = Corn intact | $P_1$ | = Corn flours |
| $I_2$ | = Solvent (Hexan) | $P_2$ | = Corn oil |
| $I_3$ | = Water | | |
| $I_4$ | = Alkali | | |
| $I_5$ | = Bleaching earth | | |
| Waste | | Internal Flow | |
| $W_1$ | = Corn husk | $X_1$ | = Corn without husks |
| $W_2$ | = Evaporated water | $X_2$ | = Dried corn without husk |
| $W_3$ | = Corn cob | $X_3$ | = Corn kernel |
| $W_4$ | = Evaporated water | $X_4$ | = Dried Corn kernel |
| $W_5$ | = Corn groats | $X_5$ | = Germ, tip- cap, pericarp |
| $W_6$ | = Corn groats | $X_6$ | = Corn from hulling process |
| $W_7$ | = Corn dregs | $X_7$ | = Corn after 1st milling |
| $W_8$ | = Posphorus | $X_8$ | = Crude corn oil |
| $W_9$ | = Dirt | $X_9$ | = Husk |
| $W_{10}$ | = Dirt | $X_{10}$ | = Crude corn oil |
| $W_{11}$ | = Wax | $X_{11}$ | = Degummed corn oil |
| $W_{12}$ | = Volatile substances | $X_{12}$ | = Neutralized corn oil |
| | | $X_{13}$ | = Bleached corn oil |
| | | $X_{14}$ | = Winterized corn oil |

**Mass Balance Model Equations:-**

In accordance to process compartment (Figure 2), there is 14 mass balance equations can be created. Some 14 additional equations are needed to solve 28 dependent variables.

**Mass Balance Equations:-**

| | | | |
|---|---|---|---|
| Compartment 1 : | $I_1 - W1 - X_1$ | = 0 .......................... | (1) |
| Compartment 2 : | $X_1 - X_2 - W_2$ | = 0.......................... | (2) |
| Compartment 3 : | $X_2 - X_3 - W_3$ | = 0.......................... | (3) |
| Compartment 4 : | $X_3 - X_4 - W_4$ | = 0.......................... | (4) |
| Compartment 5 : | $X_4 - X_5 - X_6$ | = 0.......................... | (5) |
| Compartment 6 : | $X_6 - X_7 - W_5$ | = 0.......................... | (6) |
| Compartment 7 : | $X_7 - P_1 - W_6$ | = 0.......................... | (7) |
| Compartment 8 : | $X_5 - X_8 - X_9$ | = 0.......................... | (8) |
| Compartment 9 : | $I_2 - W_7 - X_9 + X_{10}$ | = 0.......................... | (9) |
| Compartment 10 : | $X_8 + X_{10} + I_3 - W_8 - X_{11}$ | = 0.......................... | (10) |
| Compartment 11 : | $X_{11} + I_4 - X_{12} - W_9$ | = 0.......................... | (11) |

| | | |
|---|---|---|
| Compartment 12 : | $X_{12} + I_5 - X_{13} - W_{10} = 0$........................................ | (12) |
| Compartment 13 : | $X_{13} - X_{14} - W_{11} = 0$........................................ | (13) |
| Compartment 14 : | $X_{14} - W_{12} - P_2 = 0$........................................ | (14) |

**Efficiency Equation:-**

**Corn husk removing efficiency ($E_1$)**

$$E_1 = \frac{X_1}{I_1} = \frac{Corn\ without\ husk}{Corn\ Intact} \quad (15)$$

Harvested corn is left for a few moments, then the husk is removed. Corn on cob without the husk is about 86.4% of the weight of intact corn (Indradewa *et al.* 2005), then $E_1$ is 0.864.

**Corn on cob drying efficiency ($E_2$)**

$$E_2 = \frac{X_2}{X_1} = \frac{Dried\ corn\ with\ cob}{Corn\ without\ husk} \quad (16)$$

Corn is generally harvested during the rainy season in high rainfall conditions and humid. These circumstances causing fresh harvested corn have high moisture content of 25-35% (Firman *et al*. 2006). The fresh corn crop needs to be dried to reduce moisture content not higher than 18% (Thahir *et al*. 1988) or in range 17- 20% (Wijandi 2003). Drying of the corn is to avoid damage to corn when shelling process (Handerson and Perry 1982) at efficiency of 87.5%, then $E_2$ is 0.875.

**Corn seeds shelling ($E_3$)**

$$E_3 = \frac{X_3}{X_2} = \frac{Corn\ kernel}{Dried\ corn\ with\ cob} \quad (17)$$

Corn kernel (grain) is about 85.2% of the weight of the dried corn with cob (Indradewa *et al.* 2005), then $E_3$ is 0.852.

**Corn Kernel drying efficiency ($E_4$)**

$$E_4 = \frac{X_4}{X_3} = \frac{Dried\ Corn\ kernel}{Corn\ kernel} \quad (18)$$

Moisture content of corn kernel of shelling process is about 17-20% (Wijandi 2003). For further usage and storage, the corn should be dried until the moisture content of 12 – 14% (Brooker *et al*. 1974) and maximum moisture content is 17% (Firmansyah *et al.* 2005). Grain drying efficiency values is about 91% (Handerson and Perry 1982), then $E_4$ is 0.91.

**Hulling efficiency ($E_5$)**

$$E_5 = \frac{X_6}{X_4} = \frac{Hulled\ corn}{Dried\ corn\ kernel} \quad (19)$$

Corn husking is the process of corn grinding to separate the germ, tip-cap and pericarp. The hulling process has a value of 70% efficiency (Widayanti *et al* 2011), then E5 is 0.70

**First milling efficiency ($E_6$)**

$$E_6 = \frac{X_7}{X_6} = \frac{Rough\ milled\ corn}{hulled\ corn} \quad (20)$$

At this stage, corn milling process is done roughly and produces grits yield as much as 86% (Widayanti *et al.* 2011), then $E_6$ is 0.86.

**Second milling efficiency ($E_7$)**

$$E_7 = \frac{P_1}{X_7} = \frac{Corn\ flour}{Rough\ milled\ corn} \quad (21)$$

The second stage of milling to produce fine corn flours by 87% of processed material (Widayanti *et al.* 2011), then E7 is 0.87.

**First extraction efficiency ($E_8$)**

$$E_8 = \frac{X_8}{X_5} = \frac{Crude\ corn\ oil}{germ, tip-cap, pericarp} \quad (22)$$

Part of the corn kernel is composed of germ, tip-cap and pericarp that obtained from milling process has a relatively high oil content. Oil from these sections can be extracted to produce corn oil by means of compression. This extraction process uses screw press to produce corn oil yield by 4.4% of the extracted portion (Koswara 2009), then $E_8$ is 0.044.

**Second extraction efficiency ($E_9$)**

$$E_9 = \frac{X_{10}}{X_9+I_2} = \frac{Crude\ corn\ oil}{Husk+Solvent} \quad (23)$$

Corn residual slag from first extraction still containing a small amount of corn oil. This corn oil content can be further extracted using solvent extraction (hexan). The oil yield of this extraction is about 1.4% of the husk and solvent (Koswara 2009), then $E_9$ is 0.014.

**Degumming efficiency ($E_{10}$)**

$$E_{10} = \frac{X_{11}}{X_8+X_{10}+I_3} = \frac{Deggumed\ corn\ oil}{Crude\ corn\ oil+water} \quad (24)$$

A refining process is needed to improve quality of the oil. The first stage of the refining process is degumming which is carried out to remove impurities. The gum is diluted in hot water to form into 1-3% of total oil. Refining yield is as much as 96% of the total crude corn oil (Corn Refiners Assosiation 2006), then $E_{10}$ is 0.96.

**Neutralization efficiency ($E_{11}$)**

$$E_{11} = \frac{X_{12}}{X_{11}+I_4} = \frac{Neutralized\ corn\ oil}{Degummed\ corn\ oil+Alkali} \quad (25)$$

The second stage of the purification process is neutralization. This purification process aims to neutralize the corn oil by alkali treatment, the addition of alkali is 1% of total oil. This process will produce corn oil into 97% of the processed materials (Corn Refiners Assosiation 2006), then $E_{11}$ is 0.97.

**Bleaching efficiency ($E_{12}$)**

$$E_{12} = \frac{X_{13}}{X_7} = \frac{Bleached\ Corn\ oil}{Neutralized\ corn\ oil+Bleaching\ earth} \quad (26)$$

Corn oil is bleached using bleaching earth to eliminate color of the oil. The refining process will yield corn oil 97% of the processed materials (Corn Refiners Assosiation 2006), then $E_{12}$ is 0.97.

**Efficiency winterization ($E_{13}$)**

$$E_{13} = \frac{X_{14}}{X_{13}} = \frac{Winterized\ corn\ oil}{Bleached\ corn\ oil} \quad (27)$$

Process of winterization is done to separate the wax from the oil content of corn. This process will produce winterized oil at 98% of the total processed materials (Corn Refiners Assosiation 2006), then $E_{13}$ is 0.98.

**Deodorization efficiency ($E_{14}$)**

$$E_{14} = \frac{P_2}{X_{14}} = \frac{Refined\ corn\ oil}{Winterized\ corn\ oil} \quad (28)$$

Deodorization process is carried out to eliminate smell of the corn oil. This process is done by heating the oil to evaporate volatile compounds. This stage is the final process of the corn oil refining to produce pure corn oil as much as 98% of the total corn oil processed (Corn Refiners Assosiation 2006), then $E_{14}$ is 0.98.

## Results and Discussion:-

The closed system model is intended to describe actual situation of the corn industry that processes corn intact to corn flours. The simple and complex models were developed to see the complexness necessity level and model accuracy. From the results comparison, the complex model is the most suitable for describing and analyzing mass and energy balances of corn flours production systems.

**The Simple Model:-**

The simple mass balance model with 12 tons of intact corn resulted 32.64% yields to corn flours. The corn kernels is 68.86% of the total intact, then the yield is equivalent 48% of corn kernels. This simple model can not describe the actual process conditions and is not enough to illustrate the process. However, the model showed the input and ouput relationship. Waste produced is not identified clearly cause difficulties in energy potency analysis. Figure 3 shows input and output of the simple model.

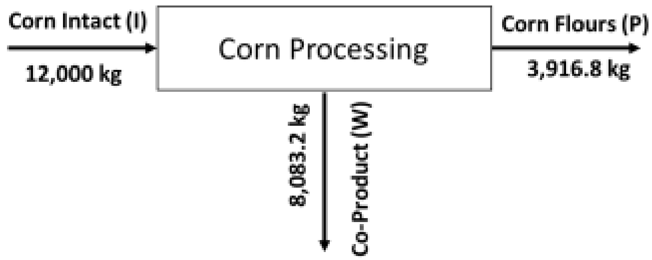


**Figure 3:-** The simple model output

**The Complex Model Outputs:-**

Development of the complex model was based on the compartment division into several sections to detailing mass flows within the system. The yield of corn flours was 31% and corn oil yield was 0.87%. Table 3 shows the model outputs which then used to draw the mass flow of Figure 4.

**Table 3:-** The complex model outputs

| Symbol | Explanation | Weight (kg) | Symbol | Explanation | Weight (kg) |
|---|---|---|---|---|---|
| $X_1$ | Corn without husk | 10,368.00 | $W_1$ | Corn husk | 1,632.00 |
| $X_2$ | Dried corn with cob | 9,072.00 | $W_2$ | Evaporated water | 1,296.00 |
| $X_3$ | Corn seeds | 7,729.34 | $W_3$ | Corn cob | 1,342.66 |
| $X_4$ | Dried corn seeds | 7,033.70 | $W_4$ | Epavorated water | 695.64 |
| $X_5$ | Tip-cap, germ, pericarp | 2,110.11 | $W_5$ | Corn groats | 640.07 |
| $X_6$ | Hulled corn | 4,923.59 | $W_6$ | Corn groats | 599.69 |
| $X_7$ | Course milled corn | 4,283.53 | $W_7$ | Corn dregs | 1,997.31 |
| $X_8$ | Crude corn oils | 92.84 | $W_8$ | Phosphorus | 4.85 |
| $X_9$ | Husk | 2,017.27 | $W_9$ | Dirts | 3.49 |
| $X_{10}$ | Crude corn oils | 28.36 | $W_{10}$ | Dirts | 3.39 |
| $X_{11}$ | Degummed corn oils | 116.36 | $W_{11}$ | Wax | 2.19 |
| $X_{12}$ | Neutalized corn oils | 112.88 | $W_{12}$ | Volatile substances | 2.15 |
| $X_{13}$ | Bleached corn oils | 109.50 | $P_1$ | Corn flourss | 3,683.83 |
| $X_{14}$ | Winterized corn oils | 107.31 | $P_2$ | Corn oil | 105.16 |

The outputs of both models are very close that the yield was 32.64% (simple model) and 31% (complex model) respectively. This little different could be caused by level of calculation details. To some extent, the addition of variable increases the accuracy of the model, but more than that the complexity does not increase accuracy. Regardless the difference, which is neglectable, the complex model were used for further analysis based on identified internal mass flows.

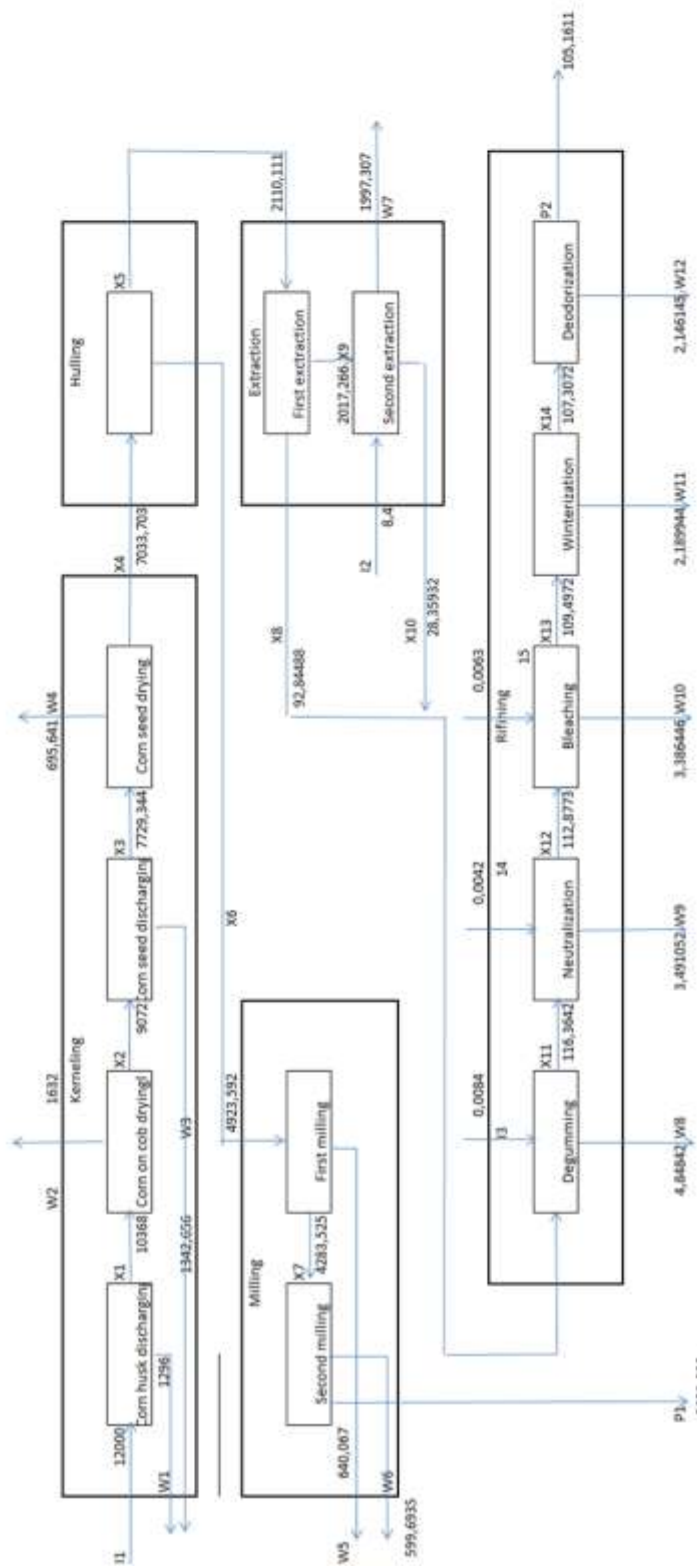


**Figure 4:-** Mass flows in the corn flourss production process

**Utilization of By-product of Corn Flours Industry:-**

The corn flours production system produces by-products in the form of evaporated water, corn husks, corn cobs, corn groats and corn dregs. The evaporated water can be reused for watering degumming process. By-products such as corn groats and corn dregs can be used as addition for animal feed. Other by-products containing energy such as corn husks and corn cob can be used as sources of energy input. A utilization model of by-products in the corn flours industry can be seen in Figure 5.

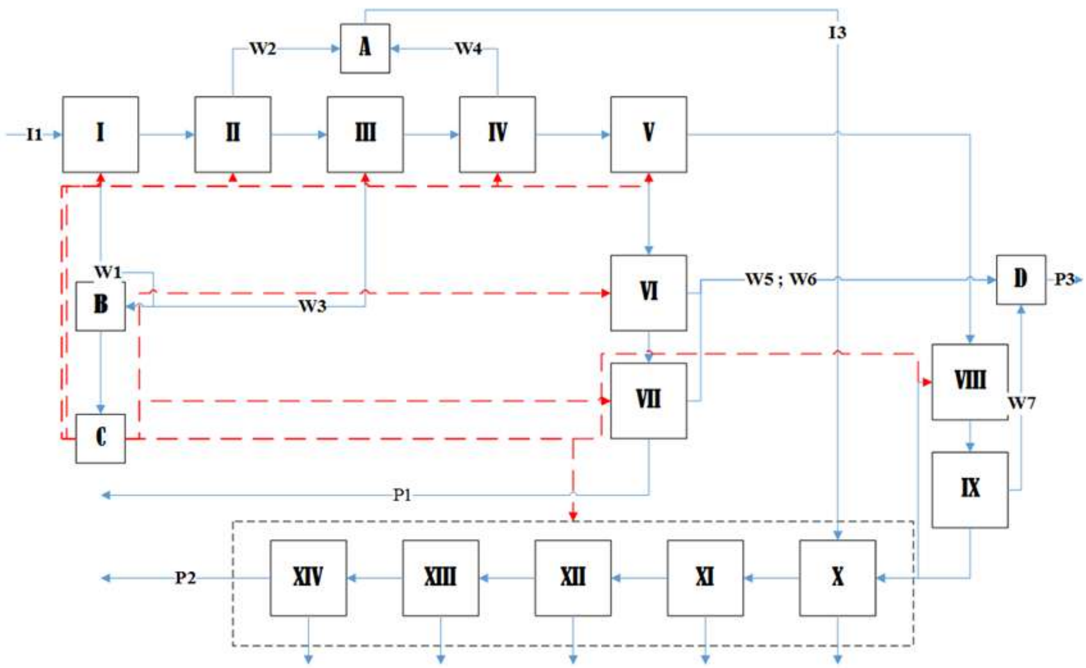


**Figure 5:-** Energy independent model of corn flours industry (symbols explanation in Table 4)

**Table 4:-** Symbols of Figure 5

| Symbol | Definition | Symbol | Definition | Symbol | Definition |
|---|---|---|---|---|---|
| I | Corn husk removing | XI | Neutralization | $W_1$ | Corn husk |
| II | Corn on cob drying | XII | Bleaching | $W_2$ | Evaporate water |
| III | Corn seed shelling | XIII | Winterzation | $W_3$ | Evaporate water |
| IV | Corn kernel drying | XIV | Deodorization | $W_4$ | Corn cob |
| V | Hulling | A | Condenser | $W_5$ | Corn groats |
| VI | 1st milling | B | Furnace/boiler | $W_6$ | Corn groats |
| VII | 2nd milling | C | Steam turbine co-generation | $W_7$ | Corn dergs |
| VIII | 1st extraction | D | Animal's feed Production | $P_1$ | Corn flours |
| IX | 2nd extraction | I1 | Corn intact | $P_2$ | Corn oil |
| X | Degumming | I3 | Water | $P_3$ | Animal's feed |

**Corn Flours Indusry Energy Independent:-**

The corn flours industry needs a large amount of electrical energy for production process. The main processes are corn husk removing, drying, shelling, hulling, milling and oil extraction. Each process uses electrical powered machines. The type of machine and the specification shown in Table 1 from which corn flours industry with capacity 12 ton of corn per day needs electric energy as much as 1,177 kWh (Table 5).

**Tabel 5:-** Energy needs for processing 12 ton corn intact

| Process | Total Material | Energy needs (kWh/ton) | Total energy needs (kWh) |
|---|---|---|---|
| Corn husk removing | 12 | 22 | 264 |
| Corn in cob drying | 10.4 | 10 | 104 |
| Corn shelling | 9.1 | 22 | 200 |
| Corn kernel drying | 7.73 | 15 | 116 |
| Corn hulling | 7.03 | 40 | 281 |

| | | | |
|---|---|---|---|
| Corn milling 1 | 5 | 22 | 110 |
| Corn milling 2 | 4.3 | 20 | 86 |
| Corn oil extraction | 2.1 | 7.5 | 16 |
| Total | | | 1,177 |

Corn husk is an outer skin of the corn, while corn cob is part of the kernels of corn that both have a high potency to use as renewable energy materials. There are several methods to use corn waste for energy generation. Generally, they are divided into two paths, thermochemistry and biochemistry. Thermochemistry paths are combustion, gasification and pyrolysis while biochemistry paths are fermentation and esterification.

A simple and proper way to convert corn cobs and corn husk into energy is through thermal gasification process. Calorific content of the corn cobs is 13.4 MJ/kg. Carbonization process can improve the calorific value of corn cobs from 3,500-4,500 kcal/kg or 14-18.9 MJ/kg to 32 MJ/kg (Watson, 1988 in Prostowo, *et al*. 1998; Mochidzuki *et al*. 2002).

Although gasification of the corn cobs has already been very common method, still encounter some obstacles. One of the most visible obstacle is its low calorific value and density. Therefore, Urono (2010) recommended carbonization process to increase carbon content and calorific value of the corn cobs. The carbonization increased calorific value of corn cobs by about 65% and carbon content of 67%. At a temperature of 380ºC, carbonization improved carbon content and calorific value by 52.6% and 7,128 kcal/kg respectively. Without carbonization, at low calorific value and density, the gasification process will very quickly and unstably burn corn cobs so that the gas cannot be utilized optimally that is only about 12%.

Alternatively, corn waste can be processed into ethanol and butanediol by fermentation. This fermentation process will result ethanol with an energy value of 122 MJ/kg, while the 2,3-butanediol energy value of 114 MJ/kg (Anon, 2002; Lachke, 2002).

For technical reasons which are easier and simpler, thermochemistry path was chosen in this study. Direct combustion to produce steam power for electricity generation using fluidized bed combustion (FBC) boiler is applied for calculation. It is proper technology for low density biomass conversion to energy since it has good mass and heat transfer characteristics (Jiang *et al*. 2003; Loha *et al*. 2013). FBC also offers multiple benefits, such as compact boiler design, flexibility with fuel used, higher combustion efficiency and reduced emissions of noxious pollutants such as SOx and NOx. The fuels burnt in these boilers include coal, washers rejects, and other agricultural wastes (UNEP 2007).

Electricity production efficiency of turbine generator is about 33-35% and it can be increased to 74.13-86.40% in isentropic condition (Batt and Rajkumar 1999). Steam production uses FBC boiler at efficiency of 68% (Yadav and Singh 2011). The potential energy independency through corn waste use is shown in Table 6 and the detailed calculation in Table 7.

**Table 6:-** Energy of corn flours industry independence level

| Type of energy | Value (kWh) |
|---|---|
| Energy obtained from biomass | 3,870 |
| Energy Needs | 1,178 |
| Energy Surplus | **2,692** |

Based on the above calculation, corn flours industry can be energy independent by applying closed production system through utilizing corn waste as energy resource.

**Table 7:-** Detailed calculation of energy independence level

| Parameter | Unit | Total |
|---|---|---|
| Plant capacity | kg corn/day | 12,000 |
| Corn husk | kg/day | 1,632 |
| Corn cob | kg/day | 1,298 |
| Energy Content | | |

| | | |
|---|---|---|
| Corn husk | kcal/kg | 3,500 |
| Corn cob | kcal/kg | 4,500 |
| Total Energy of Biomass | | |
| Corn husk | kcal | 5,712,000 |
| Corn cob | kcal | 5,841,000 |
| Heat to produce steam (derived from steam table for saturated condition at 30 Barr) | kcal/kg | 669.93 |
| Boiler Efficiency | % | 68 |
| Actual Steam | | |
| Steam from corn husk | kg/day | 5,798 |
| Steam from corn cob | kg/day | 5,929 |
| Total generated steam | kg/day | 11,727 |
| Steam turbine co-generation (33%) | kWh | 0.33 |
| Total Electrical Energy | | |
| Generated electrical energy | kWh | 3,870 |
| Plant energy need | kWh | 1,178 |
| Surplus Energy | kWh | 2,692 |

## Conclusion and Recommendation:-

**Conclusions:-**

The corn flours industry can be self-sufficient in energy if the processing started from shelling process. The shelling process produces corn husk and corn cob that can be used as energy source of corn flours industry.

The corn flours industry with 12 ton capacity of corn intact per day, produces corn husks 1,632 kg and corn cobs 1,298 kg. These by-products can generate electrical energy as much as 3,870 kWh per day. Electrical energy needed for the production is 1,178 kWh so that the corn flours industry can be energy independent. In addition, corn flours industry can also produce water from drying process that can be utilized in degumming process. Corn flours industry also produces corn groats and corn dregs that can be utilized as animal feed.

**Recommendations:-**

The corn flours industry must be designed to perform process from shelling to corn flours so it can supply enough biomass as energy source. This research indicated that the corn flours processing can be developed into an energy independent industry by starting from the shelling process.

Further research to apply this system needs to be done to more accurately adjusting the energy needs. This adjustment is needed in respect of various technologies and machines to use so that a more comprehensive data base would be available for better production process design.

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