COMPARISON OF ENERGY CONSUMPTION BETWEEN RECYCLE AND CONVENTIONAL PROCESS OF FLOUR MILLING: AT BREAK SYSTEM

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ABSTRACT

The amount of energy used for the milling process is an important economical consideration. Increasing the energy usage will increase the operating cost or reduce the mill's profits. The aim of this study is to reduce the usage of energy in a break system of a flour milling process. The strategy was to introduce a recycle grinding circuit in the break system in order to reduce the amount of energy used. The method of determining the amount of energy used was made through the electrical power used. A comparison of energy usage between the recycle and conventional processes at break system of flour milling was made. However, this study has limitations and only concentrated on the calculation of energy used by the main equipments in the break system such as roller mill, sifter, purifier and bran finisher. With similar target production, 60 tonnes white flour per day, the energy used in recycle process was found to be 713.30 kW and conventional process was 893.01kW. The results showed that the conventional process consumed more energy that was 25% higher compared to the recycle process. It was concluded that the recycle process successfully reduces energy consumption at the break system compared to the conventional milling process.

Keywords: *Recycle Grinding Circuit, Break System, Energy, Roller Mill, Sifter*

INTRODUCTION

Flour milling is the process by which wheat is ground into fine particles and through which the wheat grain is separated into its constituent parts: bran, germ and endosperm. The germ and bran are largely discarded while the endosperm is then further reduced into fine powder that we call flour. Flour is a versatile and valuable food source that contains nutrients including vitamins. The best known use of flour is for making bread, but it is also an important ingredient in biscuits, cakes, pies and much more. Majority of flour sold is white [1], this means it consists almost entirely endosperm.

Many millers have flour specifications that must be met, where overall milling value of a wheat sample is determined not only by flour yield, but also flour refinement [6]. A commonly used index of flour refinement in wheat milling is ash content, which shows the quality of the product (flour). Ash is used to determine the degree of separation between endosperm and bran. The ash content of flour is an indicator of the amount of mineral matter present. The bran has a higher mineral content (about 6-7%) than endosperm. The pure starchy endosperm has approximately 0.35% ash.

Hinton [7] showed that the gradient of ash increased from inner to outer layers of the endosperm of the grain. As flour extraction from the wheat grain increases, a higher percentage of bran ends up in the flour. The bran ash is always relatively much higher than that of the endosperm; the miller considers good performance of wheat and efficient operation of the mill to be the production of low ash flour at a high extraction level [8]. Practically, it is impossible to mill a flour completely free of bran contamination.

In principle the milling process is established in three stages that are break, purification and reduction systems. The break system is used to break open the wheat kernel and continue to scrape endosperm from the bran, step by step, by sequential passages. The purification system is to separate the outer branny material from inner white endosperm. The aim of this purification system is to purify the milling material that almost no flour is produced. The reduction system is used to deliberately mill the center particles of the wheat grain into flour.

In a conventional flour milling, the structure of the process and flow of the material streams are arranged in a very linear way (containing only inlet and outlet streams) and have very few combined streams. As a result, the milling process involves many unit operations. This is where engineers can be involved in improving the flour milling process, to reduce the number of operations, as there are likely to be streams that could be combined or recycled.

A typical concept in an engineering process is to incorporate processes with a recycle system. The function of recycle system is to recycle the 'unreacted' feed that effluent from the earlier steps in the process. The unreacted feed is usually too valuable to be disposed of and is therefore recycled to the earlier process. Thus, this study is to incorporate the recycle process circuit into the flour milling process. The recycle process is expected to reduce the number of equipments used which will reduce the energy usage as well as the mill's cost.

Mill cost is the most important factor when designing a flour mill. Thus, lowering the mill's cost factor automatically improves the mill's profit ratio [4]. One of the most important mill cost factors is energy consumption. Electrical energy costs in milling are usually the third largest item of plant operating expense, next to raw material and labour [3]. Energy use varies from mill to mill; however, the big power consumer of energy in the milling process is grinding [2]. Main equipments that involved in grinding process are roller mill, sifter and purifier. Thus, reducing the number of use of these equipment items subsequently reducing the electrical energy cost.

Measuring the electric or energy power consumption should be related to the production rate or wheat ground. Thus, the better flour mill is the one that can produce constant production with less energy. Methods to reduce energy uses may range from changing the mill flow to changing the type of light bulb used [5]. In this study the strategy was to introduce the recycle concept at break system in flour milling process, mainly at second break. The main objective of this study was to compare the energy consumption of the recycle and conventional processes at the same production rate, without affecting the quality of finished product (flour).

MATERIAL AND METHODS

Preparation of Wheat

The type of wheat used was *Mallaca*, a hard wheat with a moisture content of 10.23%. Prior to milling, the wheat had to be conditioned up to standard. For this study the raw material (wheat) was conditioned for 24 hr to reach 16% moisture content. Wheat samples were mixed in a rotating mixer at 45 rpm for 15 minutes.

Experimental Mills and Ancillary Equipment

The Satake STR-100 roller mill was used for the milling experiments. This machine utilizes is a single pass system, which uses full-scale diameter rolls (250mm diameter) to mimic commercial flour milling operations. It is a versatile laboratory mill on which the parameters (roll configuration, roll speed, roll gap, roll differential, roll pressure and feed rate) can be quickly and accurately altered. The roller settings for this experiment are listed in Table 1.

Table 1: Experiment roller mill setting

Roll Parameter	Break system	Setting
Fast Roll Speed		550 rpm
Differential		2.5:1
Roll Gap	1st break	0.5 mm
	2nd break	0.2 mm
	3rd break	0.07 mm
Roll Profile	1st break	4 flutes cm^{-1}
	2nd break	6 flutes cm^{-1}
	3rd break	8 flutes cm^{-1}

The Simon laboratory plansifter that oscillates at approximately 200 rpm, which mimics commercial continuous flow sifting operations, was used for sieve analysis. Samples were sieved for 3 minutes using a sieve stack comprising wire mesh sieves of size: 2000, 1700, 1400, 850, 500, 212 and through the 212 μm (at bottom pan).

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A bran finisher was used after the third break sifter in a recycle process, and after the third and fourth break sifter in a conventional process. These machines remove the small amount of endosperm found close to the bran skin which the fluted rolls have missed and recover it as flour.

Methods of milling

The target production for recycle and conventional process for this milling plant was 60 tonnes of white flour per day. The milling process was run based on the flow sheet that was developed for recycle and conventional process. The milling process was performed in batch wise. The milling results were expressed as an average of duplicate runs. However, if two consistent results were not achieved, the process was repeated until consistent results were obtained.

Milling flow sheet

Milling flow sheet for recycle process at break system for laboratory and industrial scale. Figure 1shows the flow sheet in laboratory scale, which consists of three pairs of break rolls, three sifters, a purifier and a bran finisher.

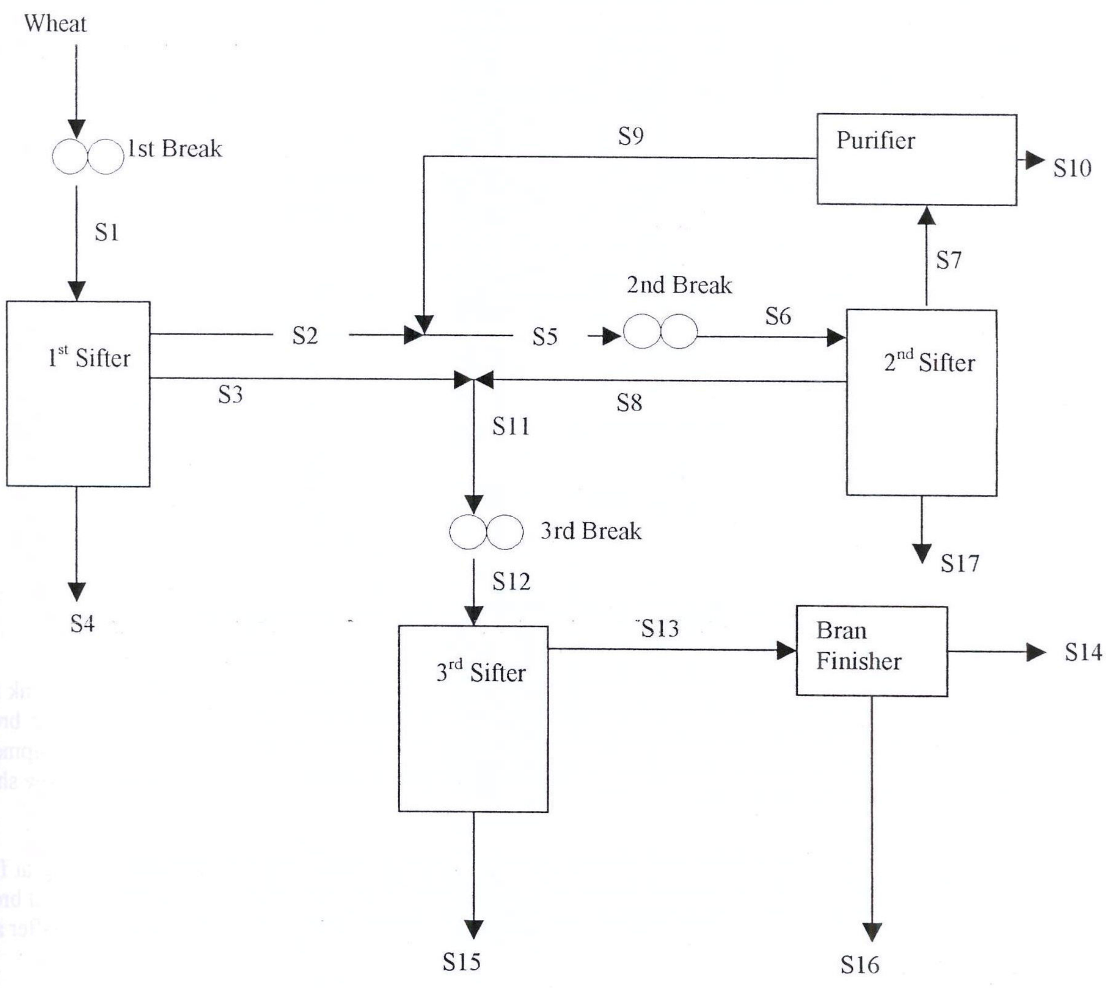

Figure 1: Flow sheet for Recycle process at Break system: Laboratory scale

The recycle flow sheet in Figure 1 was limited to a small scale or laboratory process. Milling experiment based on this flow sheet was performed where the objective was to investigate the whole process at break system by incorporating a recycle stream (at second break). Based from the flow sheet (Figure 1), the milling and sieving processes were divided into 3 sections. Milling at first break was operated first, followed by the second break with the incorporated recycle stream and finally the third break section. After performing the milling process, the flow sheet was re-evaluated for industrial scale. Some other factors need to be considered in large scale, such as the feed amount and the large particle size range being handled by the rolls that are sent to third break will be huge, and it will not be practical to use just a pair of roller mills. Figure 2, shows the flow sheet for recycle process for industrial scale, which consists of four pair for break rolls, three sifters, a purifier and bran finisher. In general, this recycle process required nine pieces of main equipments.

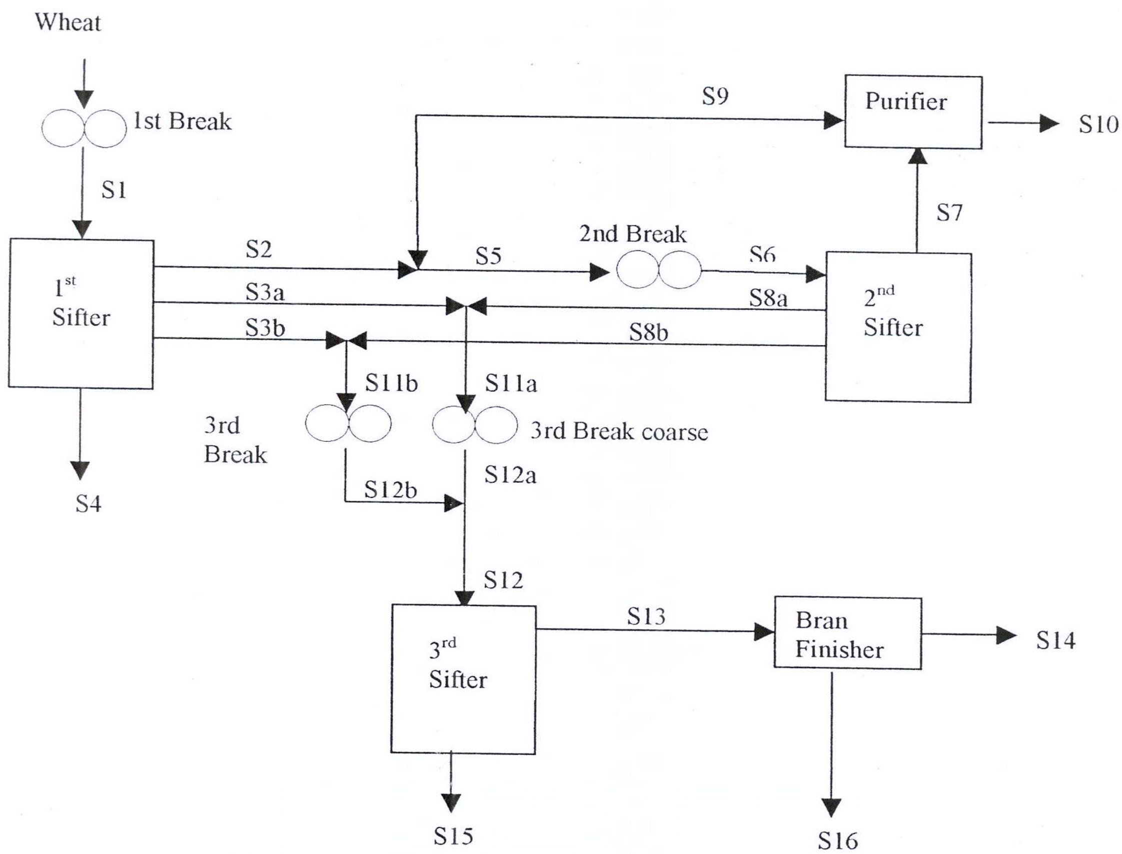

Figure 2: Flow sheet for Recycle process at Break system: Industrial scale

Milling flow sheet for conventional process at break system. This conventional process employs four break roll functions; first break roll, second break coarse and fine rolls, third break coarse and fine rolls and fourth break coarse and fine rolls. Overall this conventional flour milling process required thirteen pieces of main equipment, which have four extra unit operations compared to the recycle grinding process. Figure 3 shows the flow sheet for conventional process at break system.

In this conventional process, the milling and sieving processes were divided into four sections. Milling at first break rolls and sifter, followed by the second break rolls (coarse and fine) and sifter, then milling at third break rolls (course and fine), sifter and first bran finisher, and finally the fourth break rolls (course and fine), sifter and second bran finisher.

Ash (Laboratory) Analysis

These ash experiments were carried out to determine the quality of stocks produced by recycle grinding. The ash content indicates the amount of mineral presence in the particles. Ash analysis was performed using a laboratory programmable furnace (oven) and the analysis was based on the American Association of Cereal Chemistry (AACC - 1995) method followed for this ash analysis was used. Two repeat ash contents were performed on each particle size and if two consistent results were obtained, the average result was used. If two consistent results were not achieved, the process was repeated until two consistent results were obtained.

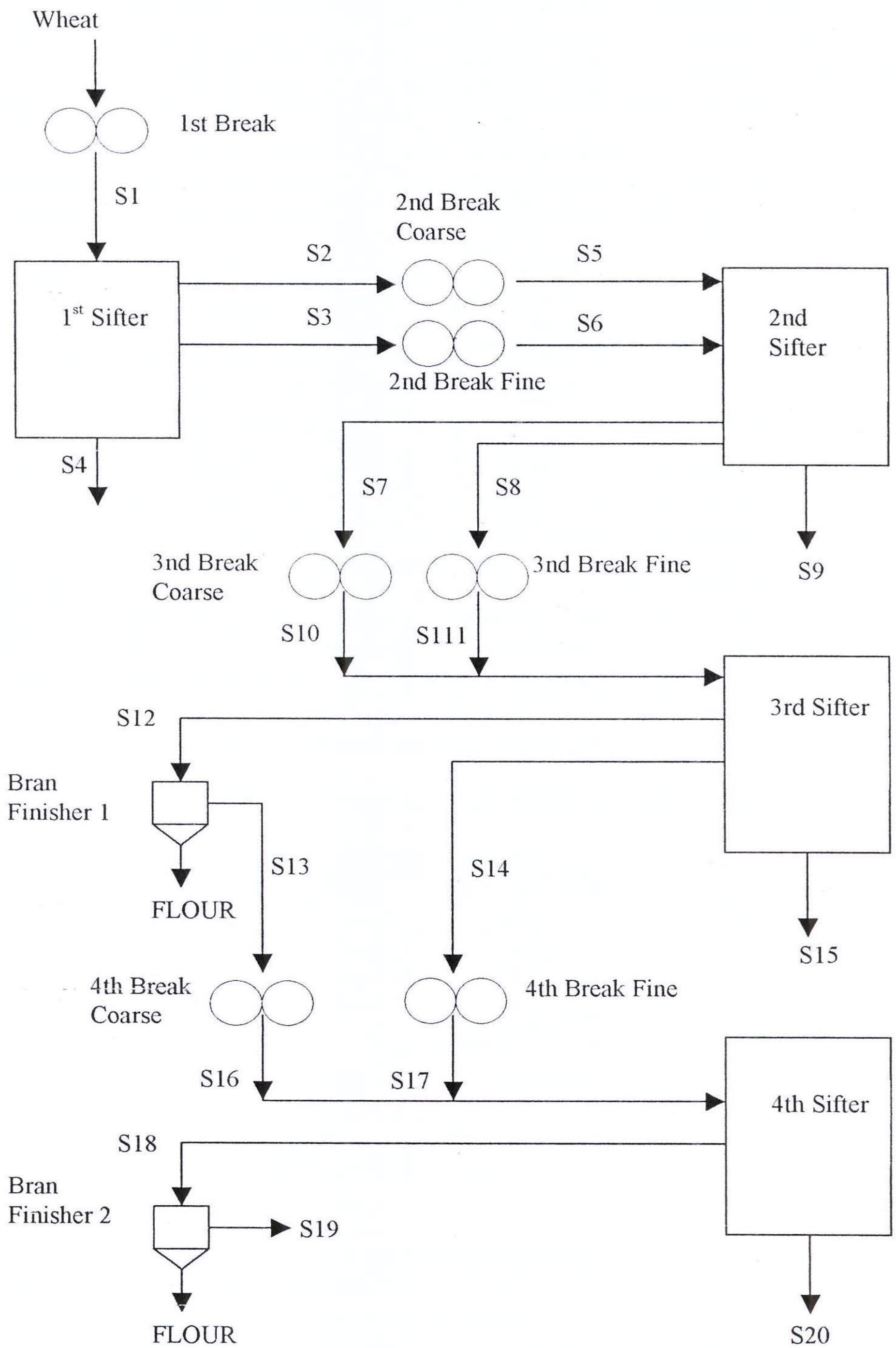

Figure 3: Flow sheet for conventional process at break system

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RESULTS AND DISCUSSION

Ash Analysis for recycle grinding process

Ash analysis was made after performing the whole milling process based on the flow sheet in Figure 1. The ash content of each size classification separated was measured for first break, second break, recycle grinding and, for third break only size below 1140μm was measured. Figure 4 shows the ash content for all grindings, from first break to recycle grinding. The ash content for each particle size at first break was lower compared to other grinding system. This might be because the coarsest particles like bran still contain large amounts of endosperm. When measured at this stage, the ash content will be low as the endosperm still appears in the coarsest particles.

Ash content at second break and recycle grinding shows the same pattern, where it decreased steadily and significantly after passing through 1180μm sieve. The decrease was steepest for particle size through 850μm, which showed the finer particle size becoming cleaner or the content being more endosperm and less bran. The quality of particles above 2000μm at second break was lower compared to all recycle grindings, this particle was the produce of grinding the material at second break which is considered as fresh feed (particle size above 2000μm outlet from first break sifter) in the recycle grinding process. For the recycle grinding process, the feed was a mixture of fresh feed and feed from recycled product, and this means the output material from recycle grinding would be expected to have more bran. This ash content result means that the efficiency of the purifier was not 100% and some bran flakes will appear in the feed recycle circuit.

At third break grinding, ash content was above 3% for particle size over 1180μm but for finer particle size (through 500μm) it was still lower and less than 1%. This grinding results in the production of more endosperm and more finer bran fragments. Therefore, the percentage of ash tends to be higher for particle size through 1180μm because of contamination with finer bran particles. Although the ash content was higher compared to the other grinding system it is still possible to separate this finer bran when it is sent through the next system (purification and reduction system). From all the grindings, ash content for particle size through 212μm was less than 0.6 %, relatively low. Particle that pass thru 212μm is considered as a break flour or finished product. It can be concluded that the recycle grinding process at break system was successful without deteriorating the quality of the product.

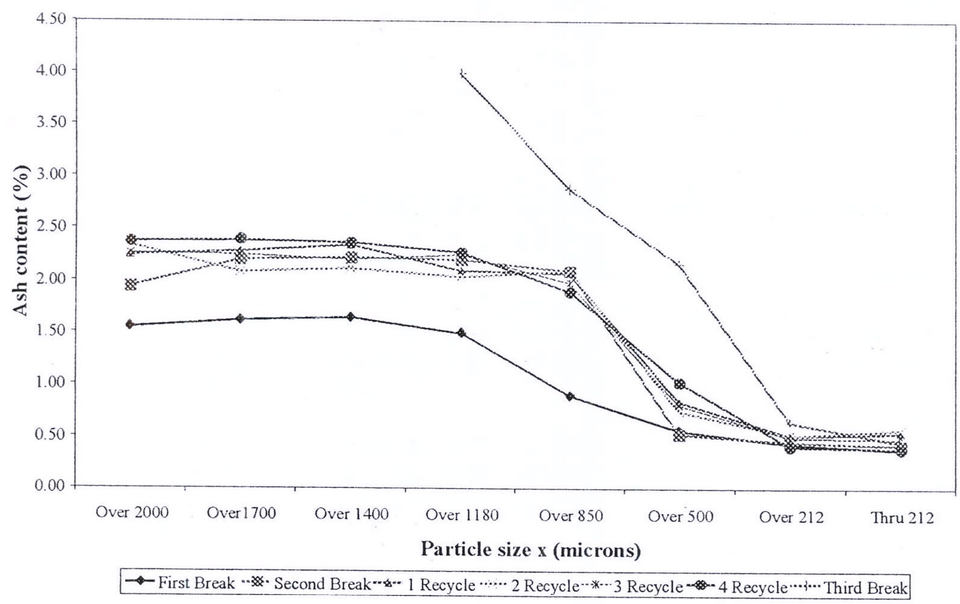

Figure 4: Ash content of Size Fractions for Recycle Grinding Process

Consideration of break recycling on industrial scale

Figure 2 shows the flow sheet of recycle process for industrial scale, and some modification was made based on figure 1. The only difference in this flow sheet is at third break section. The feed quantity to third break will be

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large and a large particle size range will be handled by the third break rolls. Excessive quantities of stock (input) to break roll will result in overfeeding of the passages. Eventually good stock will find its way to by-product (wheat feed or bran) and a poor extraction will result. These excessive quantities of stock can also result in blockages being caused in the machines and conveying equipment handling the stock quantity.

From experimental investigation, ash content for particles over 1180μm for third break were high compare to first break, second break and recycle grinding. This might be because the grinding has produced more fine bran fragments from large particles. It is practical to separate the feed input (stock) to third break into two sections, fine and coarse. This means third break coarse rolls will handle particle size over 1700μm to over 1400μm and third break fine rolls will handle particle size over 1180μm. It is common in the flour milling industry to use two break rolls (fine and coarse) in the third break section. The arrangement will reduce the production of more fine bran fragments and less ash content for particle size over 1180μm and through 1180μm. Using two pairs of rolls in this section will also reduce the quantity of stock handled by a pair of rolls.

Energy usage within the recycle circuit

The total break release[1] was obtained from the result of the milling process at laboratory scale. Table 2 shows that the total break release obtained (in percentage) was 77.64%.

Table 2: Total break release of the recycle process at break system

	Release (%)	*Of (%)*	*Leaving (%)*	*Stage*	*% to stock*
First Break	36.00	100.00	25.00	To Second Break	36.00
			39.00	To Third Break	
Second Break and Recycle	37.00	25.00	8.75	To be recycle	10.30
			7.00	To Third Break	
Third Break	67.00	46.00			31.34
Total release					77.64

Assuming that 9% from 77.64% at break system will be rejected via the purification and reduction system, thus the final extraction[2] rate for this plant is 68.64%. Based from the extraction rate, the total wheat required to produce 60 tonnes of flour per day was calculated and found to be 87.6 tonnes per day.

Table 3 shows the nine pieces of equipment used in a break system that incorporated a recycle circuit.

Table 3: Main equipment for recycle process at Break System

Equipment	Unit required	Power*(kW/ton)	Power (kW/kg)
Roller mill	4	7.2	0.0072
Sifter	3	1.0	0.0010
Purifier	1	1.0	0.0010
Bran Finisher	1	2.0	0.0020

* The power given is the maximum value.

The energy used for main equipment at break system was calculated based on the equation below:

Energy used = Power of the equipment X % of power used during milling X amount of wheat processed per day. (1)

The energy used by the main equipment in break system incorporating recycle circuit was calculated and shown in Table 4 which consists nine main equipments.

[1]Break release is the percentages of stocks released at each break stage and sieved through a known sieve aperture, they are then sent to purification or reduction system.
[2]Extraction is the amount of material extracted from the raw material, e.g. white flour extraction from wheat.

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Table 4: Energy used at break system for Recycle Process

Equipment		*Energy (kW)*
Roller Mill	First Break roll	378.43
	Second Break roll	88.78
	Third Break coarse roll	73.93
	Third Break fine roll	73.93
Sifter	First Break	43.80
	Second Break	12.33
	Third Break	20.53
Purifier	Second Break	4.32
Bran Finisher	Third Break	17.25
Total energy used		713.30

Energy usage in conventional process

The milling flow sheet for conventional process that was illustrated in Figure 3 represents a typical flow sheet for a flour milling plant. The total break release of the break system for conventional process is shown in Table 5.

Table 5: Total break release of break system for conventional process

	Release (%)	*Of (%)*	*Leaving (%)*	*Stage*	*% to stock*
First Break	36	100	64	To Second Break	36
Second Break	50	64	32	To Third Break	32
Third Break	22.7	32	25	To Fourth Break	7.26
Fourth Break	9.6	25	22		2.37
Total release					77.64

The extraction rate for this conventional process was assumed to be similar to the recycle process, 68.64%. Thus, the total wheat required was 87.6 tonnes per day in order to produce 60 tonnes of flour per day. Based on the power given for each equipment in Table 3, the energy used by the main equipment used in a break system for conventional process was calculated and shown in Table 6.

Table 6: Energy used in Conventional Process

Equipment		Energy (kW)
Roller Mill	First Break roll	378.48
	Second Break roll (course and fine)	201.83
	Third Break roll (course and fine)	100.92
	Fourth Break roll (course and fine)	78.01
Sifter	First Break	43.80
	Second Break	28.03
	Third Break	14.02
	Fourth Break	10.83
Bran Finisher	Third Break	16.52
	Fourth Break	20.33
Total energy used		893.01

CONCLUSIONS

The experiment for the whole recycle grinding process (lab-scale) at break system based on the developed flow sheet (Figure 1) was performed. The work determined that the recycle grinding process was successfully applied at break system and produced an acceptable range of break release percentage, 77.64%. Analysis of the quality also was performed and showed good quality of the finished product (break flour). However, the flow sheet was refined in order to be implemented in large (industrial) scale and the total main equipment required was nine unit of main equipment. The energy usage by the main equipment was determined, 713.30 kW for the production of 60 tonnes of white flour per day.

The conventional process required thirteen unit operations at break system and the energy usage was found to be 893.01kW. This result shows that the conventional process consumed more energy that was 25% higher compared to the recycle grinding process.

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It was concluded that the recycle grinding process is successful and potentially can produce the target production without compromising the quality of the finished product. Besides, the recycle grinding process also reduces the unit operations and energy used in the break system in milling process compared to the conventional process.

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