QUALITY CONTROL OF CHEMICAL GRADE CALCIUM CARBONATE FROM LOPBURI LIMESTONE DEPOSIT IN THAILAND

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จุฬาลงกรณ์มหาวิทยาลัย
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การควบคุมคุณภาพของแคลเซียมคาร์บอเนตเกรดสูงจากแหล่งหินปูนจังหวัดลพบุรีในประเทศไทย

น.ส.พิมพิชชา เตียวพานิช

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                    CALCIUM CARBONATE FROM LOPBURI
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พิมพิชชา เตียวพานิช : การควบคุมคุณภาพของแคลเซียมคาร์บอเนตเกรดสูงจากแหล่งหินปูนจังหวัดลพบุรีในประเทศไทย. (QUALITY CONTROL OF CHEMICAL GRADE CALCIUM CARBONATE FROM LOPBURI LIMESTONE DEPOSIT IN THAILAND) อ.ที่ปรึกษาหลัก : รศ. สมศักดิ์ สายสินธุ์ชัย, อ.ที่ปรึกษาร่วม : ผศ.ดร.อภิสิทธิ์ น้ำประสานไทย

แคลเซียมคาร์บอเนต ($CaCO_3$) ในธรรมชาติพบในรูปของแคลไซต์ หินปูน ชอล์ก และหินอ่อน โดยสามารถนำไปใช้เป็นวัตถุดิบในหลายอุตสาหกรรม เช่น ปูนซีเมนต์ พลาสติก สี กระดาษ และยา ตัวอย่าง $CaCO_3$ เกรดต่ำจากโรงงานแคลไซต์จากตำบลโคกตูม อำเภอเมืองลพบุรี จังหวัดลพบุรี ประเทศไทย ได้ถูกนำมาศึกษา ตัวอย่างมีองค์ประกอบของ $CaCO_3$ มากกว่าร้อยละ 98 ในขณะที่ Fe_2O_3 มีค่ามากกว่าร้อยละ 0.1 และมีค่าเพิ่มขึ้นเมื่อเสร็จสิ้นกระบวนการ จากปัญหานี้ ทำให้ไม่สามารถขายผลิตภัณฑ์ได้เนื่องจาก Fe_2O_3 จำเป็นต้องมีค่าต่ำกว่านี้ (น้อยกว่าหรือเท่ากับร้อยละ 0.05 สำหรับเกรดสารเติมเต็ม และน้อยกว่าหรือเท่ากับร้อยละ 0.1 สำหรับเกรดอาหารสัตว์) การศึกษานี้มีเป้าหมายในการหาที่มาของสาเหตุในการเพิ่มขึ้นของค่า Fe_2O_3 ในโรงแต่งแร่ การลดค่า Fe_2O_3 โดยใช้เครื่องแยกแม่เหล็กแบบแห้ง และให้คำแนะนำในการเลือกเครื่องมือที่เหมาะสมในการติดตั้งเครื่องแยกแม่เหล็กแบบแห้ง รวมถึงการประเมินทางด้านการเงิน สำหรับการวิเคราะห์ตัวอย่าง องค์ประกอบทางเคมีของตัวอย่างถูกวิเคราะห์ด้วยเครื่องเอ็กซ์เรย์ฟลูออเรสเซนต์ (XRF) และเครื่องเลี้ยวเบนรังสีเอ็กซ์ (XRD) จากผลการวิเคราะห์ พบว่าเหล็กอยู่ในรูปของแร่แมกนีไทต์ แร่พิโรไทต์ และเศษเหล็ก จึงสรุปได้ว่า การเพิ่มขึ้นของเหล็กมาจากทั้งวัตถุดิบและเครื่องบดแร่แบบลูกบอล เครื่องแยกแม่เหล็กชนิดลูกกลิ้งเหนี่ยวนำถูกใช้เพื่อปรับปรุงคุณภาพของผลิตภัณฑ์ $CaCO_3$ โดยการลดค่า Fe_2O_3 เพื่อให้อยู่ในมาตรฐานที่กำหนด จากผลการทดลองพบว่าค่า Fe_2O_3 ลดจากร้อยละ 0.67 เป็น 0.08 และ $CaCO_3$ เพิ่มจากร้อยละ 98.06 เป็น 98.73 ณ สภาวะที่ดีที่สุด จากผลการทดลองดังกล่าว จึงแนะนำให้ติดตั้งเครื่องแยกแม่เหล็ก ณ ทางออกของเครื่องบดแร่แบบลูกบอล และผลิตภัณฑ์ส่วนหยาบของเครื่องคัดขนาดด้วยอากาศ เพื่อลดปริมาณเหล็ก การวิเคราะห์ทางการเงินพบว่า มูลค่าปัจจุบันของผลประโยชน์สุทธิ (NPV), อัตราส่วนลด (discount rate), อัตราการตอบแทนภายในการลงทุน (IRR), อัตราการตอบแทนภายในที่มีการปรับลด (MIRR), ระยะเวลาคืนทุน (DPP) คือ 17,992,947 บาท ร้อยละ 15 ร้อยละ 53 ร้อยละ 24 และ 1.6 ปี ตามลำดับ

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Pimpichcha Teawpanich : QUALITY CONTROL OF CHEMICAL GRADE CALCIUM CARBONATE FROM LOPBURI LIMESTONE DEPOSIT IN THAILAND. Advisor: Assoc. Prof. SOMSAK SAISINCHAI Co-advisor: Asst. Prof. APISIT NUMPRASANTHAI, Ph.D.

Calcium carbonate ($CaCO_3$) is naturally produced from calcite, limestone, chalk, and marble. It is being used as raw material in various industries (e.g., cement, plastic, paint, paper, and pharmaceutical industries). The low-grade $CaCO_3$ samples obtained from a calcite plant at Khoktum Sub-district, Muang Lopburi District, Lopburi Province, Thailand were used in this study. These samples contain more than 98% of $CaCO_3$ while Fe_2O_3 contents are higher than 0.1% and increased after finished the process. Because of this problem, the products could not be sold since lower Fe_2O_3 contents are required (e.g., ≤0.05% for filler grade and ≤ 0.1% for animal feeding). This study aims to find a source that cause the increasing of Fe_2O_3 content in the processing plant, removing the Fe_2O_3 content using a dry-type magnetic separator, and suggest the selection of suitable installation of dry-type magnetic separators in term the economic evaluation. For sample characterization, the chemical composition of the samples were analyzed using X-ray fluorescence (XRF) spectrometer, and X-ray diffractometer (XRD). The results showed that the phase of iron found in the sample were magnetite, pyrrhotite, and iron scrap, indicating that the increasing of Fe_2O_3 content was from both raw material and ball mill. Induced roll magnetic separator was used to improve the quality of $CaCO_3$ products by decreasing Fe_2O_3 content to achieve the standard requirements. The results showed that the Fe_2O_3 content was decreased from 0.67 to 0.08 wt% and $CaCO_3$ content was increased from 98.06 to 98.73 wt% at the optimum condition. From these results, magnetic separators are suggested to be installed at the point of ball milling discharge and underflow of air classifier to reduce the iron content. The financial analysis indicated that the net present value (NPV), discount rate, internal rate of return, modified internal rate of return, and discounted payback period are equal to 17,992,947 baht, 15%, 53%, 24%, and 1.6 years, respectively.

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Field of Study:	Georesources and Petroleum Engineering	Student's Signature	
Academic Year:	2021	Advisor's Signature	
		Co-advisor's Signature	

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CHAPTER 1
INTRODUCTION

1.1   General introduction

Calcium carbonate ($CaCO_3$) is a common mineral in the earth's crust that is usually found in marine deposits around the world. Naturally, $CaCO_3$ (e.g., calcite, limestone, chalk, and marble) is generally formed by the sedimentation of the shells of small fossils (e.g., snails, shellfish, and coral). The differences in their properties including whiteness, thickness, and homogeneity are based on the mineral formation as well as their mineral composition (Rohleder and Evelyn, 2012). It is being used as raw material in various industries (e.g., cement, plastic, paint, paper, and pharmaceutical industries). The chemical grade of $CaCO_3$ requires strict quality control in properties such as particle size, whiteness, and impurities such as iron oxide (Fe_2O_3) content. Therefore, $CaCO_3$ with trace impurities $> 0.1\%$ is difficult to use since the impurities could decrease the whiteness and durability of products (Oates, 2008).

The calcite plant in Khoktum, Muang Lopburi district, Lopburi Province, Thailand that is producing $CaCO_3$ and low-grade $CaCO_3$ have remained in the mining area. This low-grade ore contains less than 98% of $CaCO_3$ with a Fe_2O_3 content higher than 0.1%. After this, ores are fed into the process. The products showed a higher percentage of Fe_2O_3 content, which is unable to be sold. $CaCO_3$ quality requires Fe_2O_3 $\leq 0.05\%$ for filler grade and $Fe_2O_3 \leq 0.1\%$ for animal feeding.

In this study, the chemical composition of the samples obtained from this processing plant was analyzed to find the source that caused the increase in Fe_2O_3 content. Magnetic separation experiments using a dry-type induced roll magnetic separator were carried out to improve the quality of $CaCO_3$ products by decreasing Fe_2O_3 content to meet the market requirements. The experiments using an induced roll magnetic separator were carried out to improve the quality of $CaCO_3$ products by decreasing Fe_2O_3 content to achieve the standard requirements. Lastly, the project's financial evaluation was determined.

1.2   Objectives

1.   To find a source that cause the increasing of Fe_2O_3 content in the processing plant.

2.   To decrease the Fe_2O_3 content using a dry-type magnetic separator.

3.   To suggest the selection of suitable installation of dry-type magnetic separators with the project financial evaluation.

1.3   Scope and research methodology

The scope of this study is to decrease the Fe_2O_3 content in the low grade $CaCO_3$ from a calcite processing plant in Khoktum , Muang Lopburi district, Lopburi Province, Thailand by using a dry-type magnetic separator optimize the meet the requirement of $CaCO_3$. The schematic flowchart of this study is shown in Fig. 1.1.

The study started from the discussion about the state of the problem as discussed earlier. The background and literature review have been studied to understand the necessary information for this study, including the location and geology of the study area, calcium carbonate processing, magnetic separation, and recent studies about the removal of iron content from industrial minerals using a dry-type magnetic separator.

After that, the samples have been collected from various points in the processing plant, and these samples have been analyzed to determine the chemical composition and to find the source that caused the increase in Fe_2O_3 content in the processing plant.

Based on the results of the sample characterization, the sample that was collected from the point that Fe_2O_3 was increased was used for magnetic separation experiments to reduce Fe_2O_3 content.

Finally, suitable magnetic separators have been suggested for the installation at the proper points with the project financial evaluation including Net present value (NPV), IRR (Internal rate of return), Modified Internal rate of return (MIRR), and discounted payback period.

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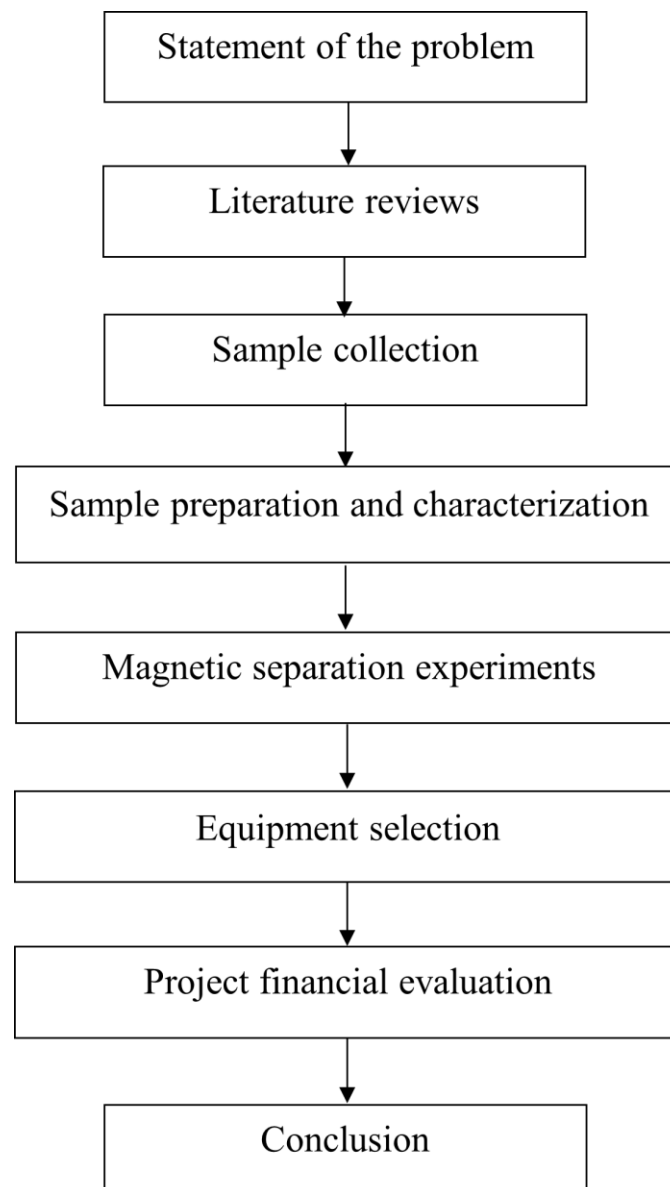
Fig. 1.1 Outline of this study

1.4   Order of presentation

In order to present this research and make it easy to understand for readers, the author has divided this research into the following 6 chapters.

Chapter 1 Introduction: general introduction; objectives; scope and research methodology; and order of presentation.

Chapter 2 Background and literature review: geological information of study area; calcium carbonate processing; magnetic separation; and recent studies about dry-type magnetic separators.

Chapter 3 Sample characterization: sample collection; quantitative analysis using X-ray fluorescence (XRF) spectrometer; qualitative analysis using X-ray diffractometer (XRD); and conclusion.

Chapter 4 The removal of iron content using induced roll magnetic separator: ore characterization; dry magnetic separation experimental methods; and result and discussion.

Chapter 5 Project financial evaluation: processing plant design; and financial evaluation.

Chapter 6 Conclusion and recommendation: conclusion and recommendation.

CHAPTER 2
BACKGROUND AND LITERATURE REVIEW

2.1   Geological information of study area

The calcium carbonate ($CaCO_3$) samples used in this study were provided by Sand and Soil Industry Co., Ltd., the second largest $CaCO_3$ manufacturer in Thailand. The company is located in Khoktum, Muang Lopburi district, Lopburi Province, Thailand. The mining area of this company is located far from the calcite processing plant (i.e., the study area) for 8 km, as shown in Fig. 2.1. Tantisukrit (1978) reported that the stratigraphy of this area consists of a thick bed of grey limestone, partly recrystallized limestone, marble, and calc-silicate in the Khao Khad Formation (PKd) of Saraburi Group that is covered by rhyolitic tuffs, andesite, and tuff in Permo-Triassic (PTrv) ages and then covered by Triassic-granites interbedded with limestone, marble, and/or calc-silicate. On top of these are covered by the quaternary sediment, which is caused by the erosion of limestone and tuffs by alluvial plain deposits.

Fig. 2.2 shows the general geological map (Series ND47-8 Ayutthaya Province) of the mining area provided by the Department of Mineral Resources (DMR). In the mining area, grey-white to white calcite is found. It occurred by the re-crystallization of limestone due to the contact metamorphism process of biotite-muscovite and granite. This process happened by the intrusion of magma in the Triassic ages. The purity of calcium oxide was increased due to this process. However, some impurities like iron-rich minerals remain. Most of the iron-rich minerals found in Lopburi Province are hematite and magnetite, which are usually found in the contact zone between diorite and limestone or sandstone and shale (Tantisukrit, 1978). Fig. 2.3 shows an aerial photograph of the mining area that has an area of around 116,800 m^2.

Geological map of Lopburi province

Scale

10 5 0   10
                              Km.
        2550

EXPLANATION

Sedimentary and Metamorphic rocks

Qa	Quaternary aluvial , conglomerate, sandstone, silt, clay,floodplain basin
Qc	Terrace sediment, weathering sediment, sand, silt, laterite
Qt	Terrace gravel, sand, silt, laterite soil
JKpw	Siliceous sandstone interbedded with gravel sandstone
Jpk	Purple siltstone, sandstone, conglomerate with calcreate
Trhl	Conglemerate, shale, mudstone, siltstone, limestone, greywacke, marl soil
Trl	Conglemerate, grey-shale interbeded siltstone and sandstone
Ps-1	Limestone, chert, shale, sandstone, volcanic sandtone
Ps	Limestone, chert, pillow basalt, ultrabasic, serpentinite

Igneous rocks

Tbs	Ultramafic basalt
Tv	Rhyolite, rhyolitic and andesitic tuffs
Trgr	Biotite granite, tourmaline, granodiorite, biotite muscovite granite
PTrv	Rhyolite, andesite, tuffs, rhyolitic and andesitic tuffs

สัญลักษณ์
SYMBOLS

●	Province		Fault
	Road		Anticline
	Rail road		Syncline
	River		Trust fault
	ขอบเขตประเทศ		Contact rock
	Dam and reservior		

Fig. 2.1 General geological map of Lopburi Province with the location of mining and study area (Department of Mineral Resources, 2002)
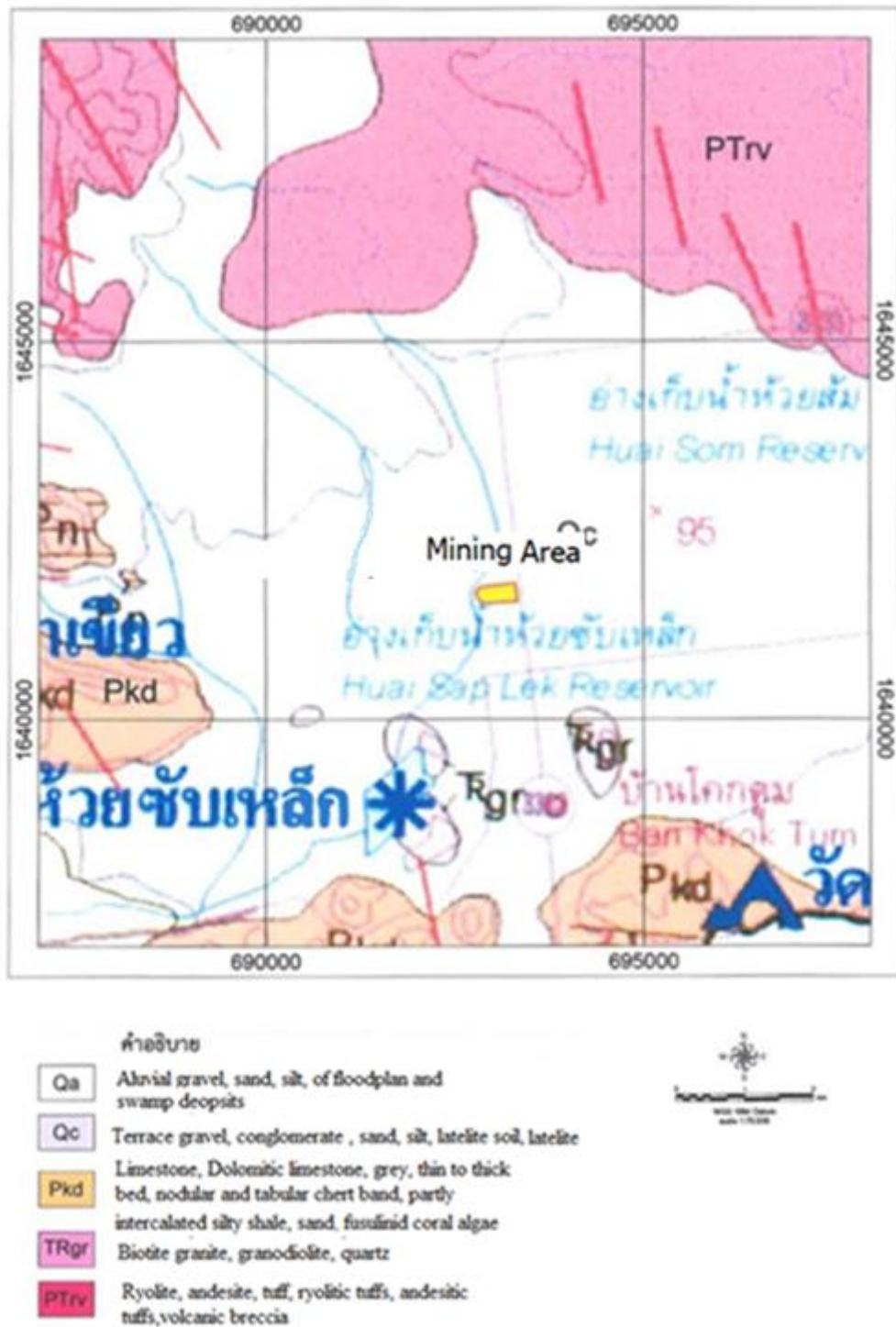
Fig. 2.2 General geologic map of mining area of Sand and Soil Industry Co., Ltd.
(Department of Mineral Resources, 2002)

Fig. 2.3 An aerial photograph of mining area

2.2 Calcium carbonate processing

The calcite processing plant of Sand and Soil Industry Co., Ltd., is far from the mining area by 8 km, as shown in Fig. 2.1. After the mining process, the calcite is carried to the processing plant and stored as a stockpile. The calcite in the stockpile was cleaned by water spray and separated by workers into 2 grades: (i) grade A (high quality calcite) that has a white color and (ii) grade B (low quality calcite) that has a grey-white color due to the large amount of gangue minerals. Fig. 2.4 shows the photograph of grade A and B calcite.

Table 2.1 shows the typical specification of calcium carbonate for each industry. since the calcite is usually sold as "calcium carbonate". Therefore, please note that after this, the word "calcium carbonate" will be used instead of "calcite".

The price of calcium carbonate depends on the properties of calcium carbonate (i.e., color, whiteness, particle size, $CaCO_3$ content, and Fe_2O_3 content). Normally, the chemical properties of high-grade calcium carbonate (e.g., filler grade) must contain at least 98.5% of $CaCO_3$ and less than 0.05% of Fe_2O_3. The main products of this

processing plant are grade A, having a particle size of –45 µm with a capacity of 168,000 metric tons per year. The application of products in this company is mainly a filler grade calcium carbonate for the chemical industry (i.e., cement, plastic, paint, paper, and pharmaceutical industry).

On the other hand, grade B which is grey-white in color due to its containing a large amount of gangue mineral, was focused. Since the $CaCO_3$ and Fe_2O_3 content are higher than 98% and 0.1%, respectively, which are not applicable or unable to be sold to any industry. In this study, grade B calcium carbonate from this processing plant was used as a sample to upgrade this product to be sold at least for animal feeding with Fe_2O_3 0.1%.

Fig. 2.4 Photograph of Grade A and B calcite

Table 2.1 Typical specification of calcium carbonate for each industry

Industry	Pharmacy Industry	Paint and Coating Industry	Paper Industry	Rubber Industry	Animal Food
Color of source rock	White				White grey
Whiteness (%)	>95			>94	
Particle Size	50 µm and 50 % less than 2 µm				Less than 100µm
$CaCO_3$ (%)	> 98.5			>98	
Fe_2O_3 (%)	< 0.01	0.01–0.02	0.02–0.03	0.03–0.05	≤0.1
Price (THB)	5000-8000	2500-5000	1000-2000	800-1000	600-800

Fig. 2.5 shows the processing flow chart of calcite processing plant of Sand and Soil Industry Co., Ltd. Grade A and grade B from mining with particle size less than 6 inches (–6'') are separately fed to the hoppers then, screened by grizzly feeder with 2" aperture. The –2" fraction is collected and sold as construction material while the –6+2" fraction is fed into jaw crusher to reduce the particle size into –1.5". After that, the products from jaw crusher are fed into impact crusher with 10 mm vibrating screen (closed-circuit) to reduce the particle size into –10 mm then, the product is collected in silo. Then, crushed products of grades A and B in the silo are blended using the belt conveyor installed below the silos. At this step, iron components could be removed using the permanent magnetic bars that are installed at the feed-end of silos.

The blended products are fed into two parallel lines of the grinding process: (i) vertical mill and (ii) ball mill. For the line of a vertical mill, 5 tons per hour of blended products are fed into a rotary feeder and then, fed into the vertical mill together with the circulating load from air classifier (R1) and blower classifiers (R2). The ground product from the vertical mill is classified using an air classifier. The +45 µm (R1) is fed into a rotary feeder for re-grinding using a vertical mill while the –45 µm fraction is classified into various sizes of products using blower classifiers and the fraction that does not meet the product requirement of particle size (R2) is fed into a rotary feeder for re-grinding.

For the line of the ball mill, 4.5 tons per hour of blended products are fed into the ball mill together with the circulating load from the air classifier (10.5 tons per hour). The ground product from the ball mill is classified using an air classifier. The +10 µm is fed into a ball mill for re-grinding as circulating load while the –10 µm fraction is classified into various sizes of products using another air classifier.

Table 2.2 shows the products generated from this processing flow chart. For the line of vertical mill, three products are generated that are (i) Calofil 30 (C–30) (ii) Calofil 60 (C–60), and (iii) Calofil 100 (C–100) with 10.0–45 µm, 7.0–9.0 µm, and 3.5–5.0µm size fraction, respectively. And for the line of ball mill three products are generated that are (i) Calofil 400 (C–400), (ii) Calofil 600 (C–600), and (iii) Calofil 800 (C–800) with 2.5–3.5 µm, 2.2–2.5 µm, and 2.0–2.2 µm size fraction, respectively.

Table 2.2 Size of calcium carbonate product at Sand and Soil Industry Co., Ltd.

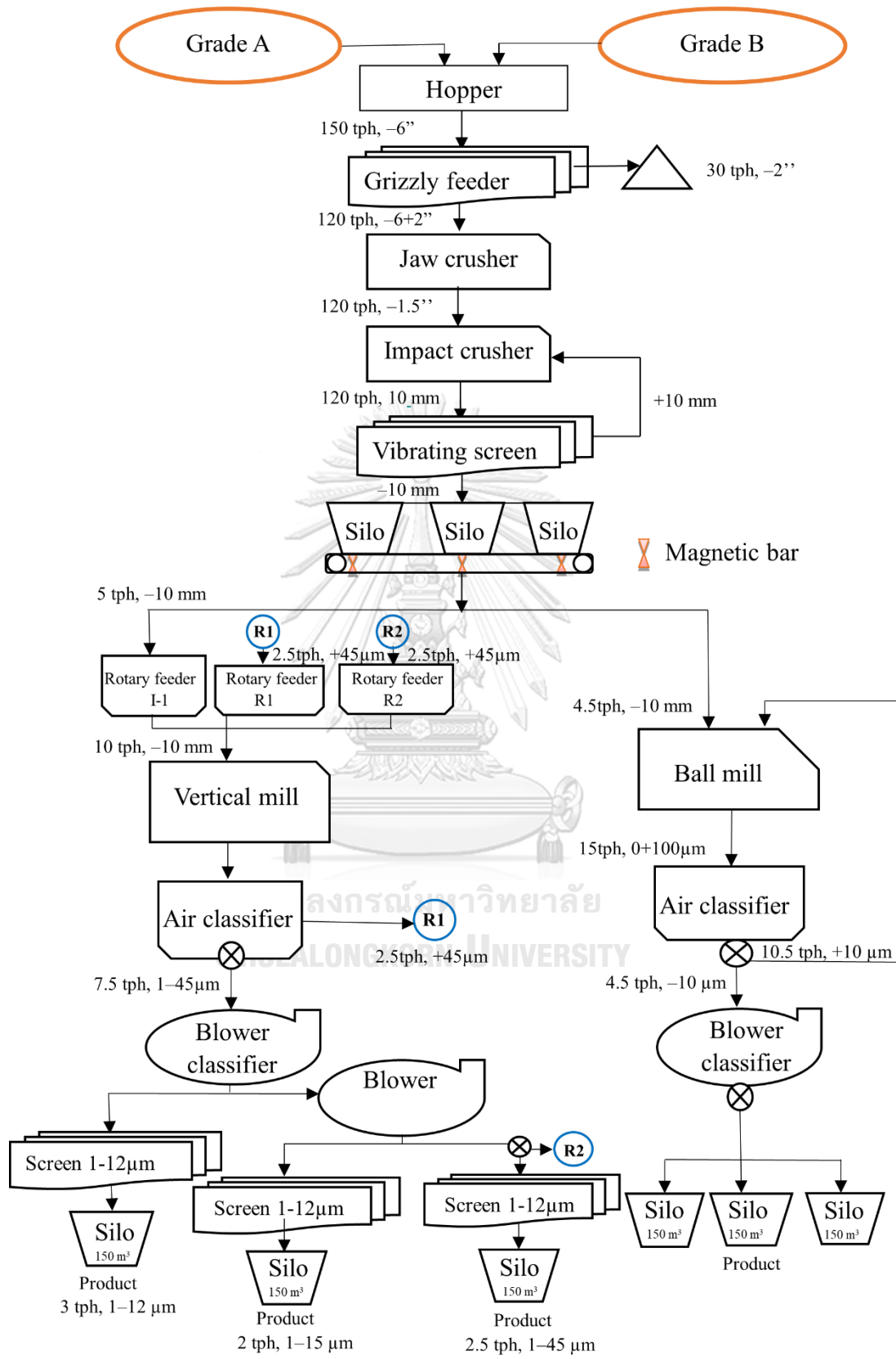|	Name of product	Particle sized (micron)
Vertical mill	Calofil 30 (C–30)	10.0–45
	Calofil 60 (C–60)	7.0–9.0
	Calofil 100 (C–100)	3.5–5.0
Ball mill	Calofil 400 (C–400)	2.5–3.5
	Calofil 600 (C–600)	2.2–2.5
	Calofil 800 (C–800)	2.0–2.2

Fig. 2.5 Flow sheet of calcite processing plant

2.3   Magnetic separation

Magnetic separation, the method that separates the material based on different magnetic susceptibilities, is one technique that has been widely used in mineral processing. The minerals can be categorized into three types based on different magnetic properties: ferromagnetic, paramagnetic, and diamagnetic. For ferromagnetic minerals, they are easily recovered and separated from diamagnetic minerals by using low magnetic intensity or permanent magnets. In contrast, paramagnetic minerals are more difficult to recover and separate, so high magnetic intensity is required (Norrgran and Mankosa, 2006; Tripathy, 2017).

Magnetic separation can be divided into two types: dry- and wet-type magnetic separation. Dry-type magnetic separators are suitable for coarse particles. The advantages of dry-type separation are, for example, lower energy consumption since no grinding process is required. However, for fine particles, the separation efficiency of dry-type magnetic separators is (i) water consumption is not required, (ii) solid/liquid separation is not required, and (iii) low energy consumption, which are more suitable for fine particles (Wills, 2006).

A dry induced roll magnetic separator (IRMS; Fig. 2.6), a kind of dry-type magnetic separator, is one of the most significant, simple, and efficient units for separating the paramagnetic elements from ore. It is widely used for the separation of wolframite, cassiterite, phosphate rocks, glass sands, and beach sands. The IRMS consists of a revolving phosphate steel laminated roll that is compressed with a non-magnetic stainless-steel shaft. The rotor is placed between specially shaped poles of an electromagnet. The two different laminations of roll and shaft with a serrated profile could promote high magnetic intensity up to 2.2 T. During the separation, the magnetic particles are attracted by the magnetic roll and are recovered into a magnetic compartment while the non-magnetic particles are thrown off into another roll or non-magnetic compartment. The important parameters that affect the separation efficiency of IRMS are magnetic susceptibility of the particles, the applied magnetic intensity, particle size, roller speed, and angle of the product collection splitter (Wills, 2006).
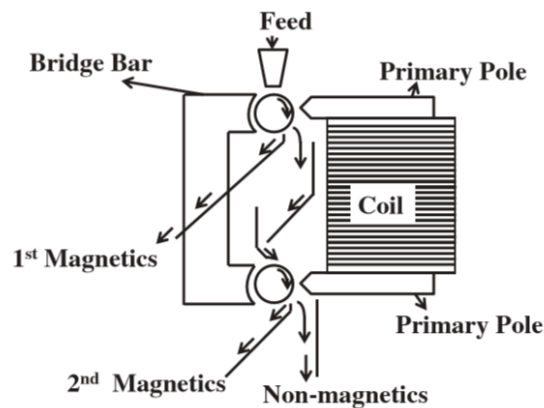
Fig. 2.6 Schematic diagram of particle separation in a double stage IRMS (Tripathy, 2014).

As mentioned above, the application of IRMS for the separation of other paramagnetic minerals in the mineral industry can be evaluated and broadened. Among the variables studied on IRMS, most of them are operating parameters, whereas design parameters, such as the diameter of the rotor that plays a significant role in the selection and sizing of the unit, have not yet been addressed. So, the application of this separator for different paramagnetic minerals as well as improvement of the separation efficiency for the existing industry will increase if an understanding of the gap areas can be narrowed down once (Tripathy, 2017).

2.4   Recent studies about dry-type magnetic separators

Table 2.3 shows the summary of the applications of IRMS for different mineral separations. It is shown that most of the research focused on adjusting the parameters to optimize the IRMS to be suitable for their samples. For the selective recovery of paramagnetic minerals using IRMS, there are three main parameters that are magnetic field intensity, feed rate, and rotor speed (Tripathy, 2017).

2.4.1   Effects of magnetic field intensity

Singh et al. (2011) studied the beneficiation and agglomeration processes to utilize low-grade ferruginous manganese ore fines. In this study, low-grade ferruginous manganese ore fines were recovered at various magnetic field intensities. The magnetic field intensity was between 1.1 and 1.7 T at a 1.2 kg/h feed rate and a 100–200 rpm rotor speed. The results showed that the optimum grade can be recovered by the highest

magnetic field intensity (1.7 T). In addition, at the lower magnetic field intensity (1.1 T), they found that the recovery can be increased by up to 40%.

Tripathy et al. (2017) studied the influence of particle size on dry high-intensity magnetic separation of paramagnetic minerals. In this study, the fine hematite was recovered at different magnetic field intensities. The results showed that there is an increase in the iron content of the magnetic product with the increase of the magnetic field intensity. Also, the optimum grade of iron content is found at the highest magnetic field intensity.

2.4.2 Effects of feed rate

Tripathy et al. (2017) studied the influence of particle size on dry high-intensity magnetic separation of paramagnetic minerals. In this study, the fine hematite was recovered at different feed rates. The results showed that at low rotor speed, the recovery of hematite was increased with the increase in feed rate. It is possible that single-layer particle flow passing through the rotor increases selectivity over multilayer passage at higher feed rates. In contrast, at high rotor speed, the recovery of hematite increased with the decrease in feed rate.

2.4.3 Effects of rotor speed

Naik et al. (2002) studied the quantification of induced roll magnetic separation of mineral sands. The separation of ilmenite and rutile from mineral sand concentrate has been investigated by using IRMS and found that the recovery of ilmenite increases with a decrease in rotor speed. Since high rotor speed could increase the centrifugal force of rutile, that would cause a reduction in the rutile recovery in the magnetic fraction.

Tripathy et al. (2014) studied the separation analysis of a dry high intensity induced roll magnetic separator for the concentration of hematite fines. In this study, the fine hematite was recovered at different rotor speeds. The rotor speed was adjusted at 30, 60, and 90 rpm. The highest grade (51.2% Fe) in magnetic products could be achieved by optimizing the process variables at a middle rotor speed of 60 rpm with the highest magnetic field intensity and lowest feed rate.

Table 2.3 Summary on the applications of IRMS for different mineral separation (Tripathy, 2017).

	Material used	Variables studied	Process
Naik et al., 2002	Mineral sand, India	Magnetic roll, roll speed, feed rate,	Used to separate ilmenite and rutile from sand
Singh et al., 2011	Ferruginous low-grade manganese ore, India	Magnetic field intensity and rotor speed	Used as two-stage separation in the flow sheet.
Tripathy et al., 2014	Hematite, India	Magnetic roll, roll speed, feed rate, splitter position	Used to separate hematite fines from the low-grade fines
Tripathy et al., 2017	Hematite, India	Magnetic roll, roll speed, feed rate, splitter position	Used to separate hematite fines from the low-grade fines
Ibrahim et al., 2017	Silica sand, Egypt	Particle size, belt speed, and splitter angle	Removal of Fe_2O_3

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CHAPTER 3
SAMPLE CHARACTERIZATION

3.1   Sample collection

To improve the quality of grade B calcium carbonate to be able to sell at least for animal feeding, Fe_2O_3 content that can be affected by the whiteness index should be reduced to meet the industry requirement, for example, less than 0.1% of Fe_2O_3 for animal feeding.

As described earlier in chapter I, this low-grade ore contains less than 98% of $CaCO_3$ with an Fe_2O_3 content of more than 0.1%. After that, the ore is fed into the process, and the Fe_2O_3 products are increased. In this chapter, the chemical composition, especially $CaCO_3$ and Fe_2O_3 content, at various points of the processing step was analyzed to evaluate a source that cause the increase of Fe_2O_3 content in the processing plant.

The samples used in this study were collected from a calcium carbonate processing plant of Sand and Soil Industry Co., Ltd. Fig. 3.1 shows the processing flow chart of the calcium carbonate processing plant of Sand and Soil Industry Co., Ltd. with the code of samples at the collecting points and Table 3.1 shows the details of these samples.

This low-grade ore contains less than 98% of $CaCO_3$ with Fe_2O_3 content higher than 0.1%, and after this ore is fed into the process, the Fe_2O_3 products are increased. Because of this problem, the products are not able to be sold to the customers that require high-quality $CaCO_3$ (Fe_2O_3 < 0.05% for filler grade and Fe_2O_3 > 0.1% for animal feeding).

Table 3.1 The code of samples at the collecting points at Sand and Soil Industry Co., Ltd.

Sample ID	Sampling points
S1	Calcium carbonate grade A ($Fe_2O_3 \geq 0.05$)
S2	Calcium carbonate grade B ($Fe_2O_3 < 0.05$)
S3	Product of impact crusher (grade A)
S4	Product of impact crusher (grade B)
S5	Feed of vertical mill
S6	Underflow of air classifier after vertical mill
S7	Product of vertical mill (C-30)
S8	Product of vertical mill (C-60)
S9	Product of vertical mill (C-100)
S10	Feed of ball mill
S11	Underflow of air classifier after ball mill
S12	Product of ball mill (C-400)
S13	Product of ball mill (C-600)
S14	Product of ball mill (C-800)

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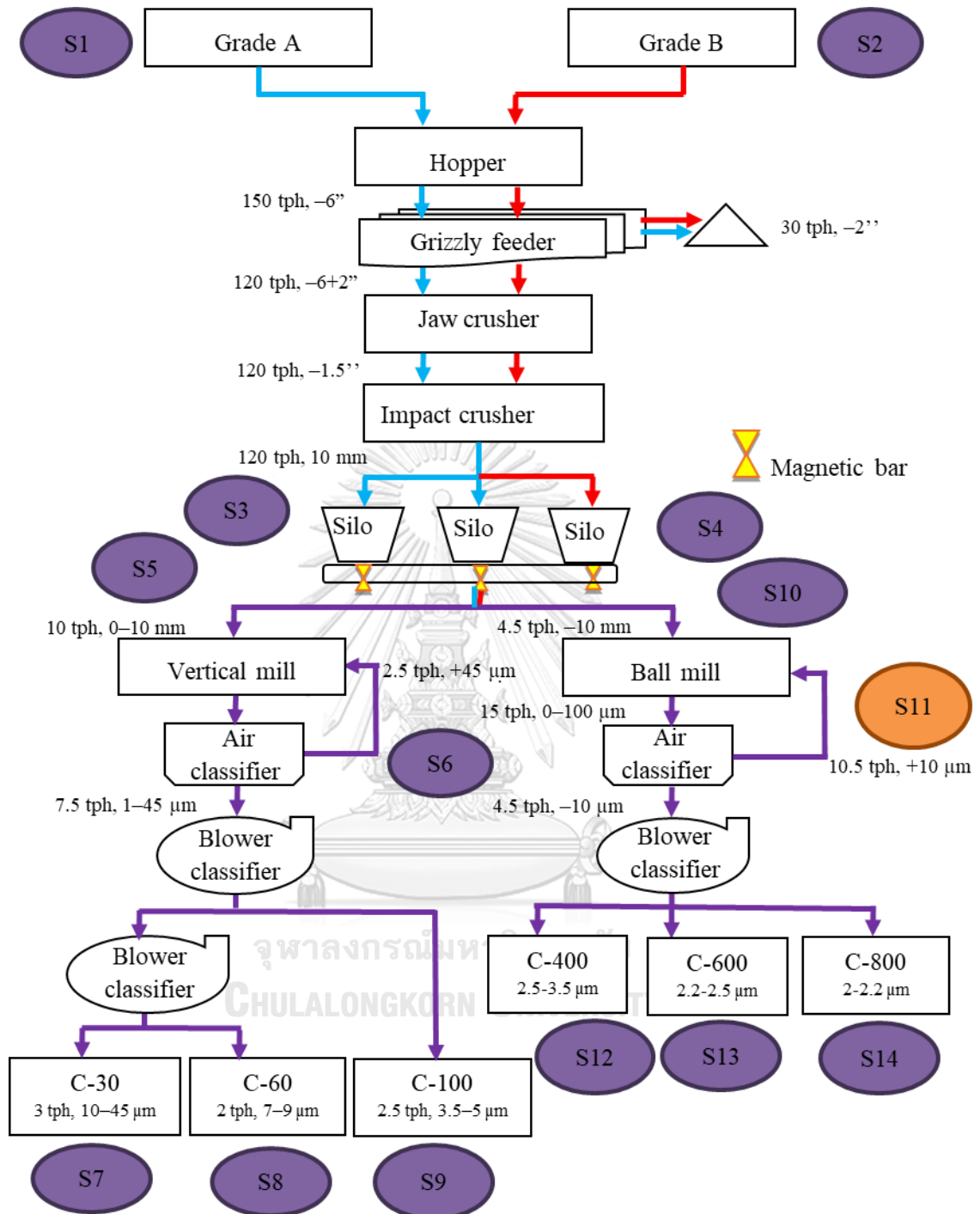CHULALONGKORN UNIVERSITY

Fig. 3.1 Flow chart of the processing plant of Sand and Soil Industry Co., Ltd. with the code of samples at the collecting points

3.2   Quantitative analysis using X-ray fluorescence (XRF) spectrometer

3.2.1   Methodology

The chemical composition of samples (Table 3.1) was analyzed using the X-ray fluorescence (XRF) fluorescence spectrometer (Rigaku Supermini 200, Rigaku, Japan).

3.2.2   Results and discussion

Table 3.2 shows the content of calcium and iron of samples in oxide form. The results showed that the S2, S4, S11, and S14 samples had iron oxide content equal to 0.46, 0.46, 0.67, and 0.07, respectively that higher than 0.05% of Fe_2O_3. It does not meet the required standard for sale. The results of S2 and S4 showed the same value of iron oxide content, indicating that iron content comes from the source rock or raw material, and the jaw and impact crushers do not increase the iron content. The iron oxide content was reduced to 0.05%, which meets the required standard at the S10 sample since the grade A and B rock are blended and some magnetic fraction is removed by the magnetic bar under the silo. The content of iron oxide increases at the S11 sample is the underflow product of the air classifier after the size reduction using a ball mill, indicating that the increase in iron content has also come from the process, especially the ball mill, which may be from the abrasive of grinding media (i.e., steel balls). For these reasons, the S14 sample that is the smallest product (C–800; 2–2.2 µm) also has an iron content of 0.07%, which exceeds the standard requirement. To confirm these results that iron content is from both the raw material and ball milling process, the S4 and S11 samples were analyzed using an X-ray diffractometer (XRD) to identify the amount of iron material contained in the samples.

Table 3.2 The mineral composition of calcium carbonate by XRF analysis.

Sample ID	Sampling points	% By weight	
		$CaCO_3$	Fe_2O_3
S1	Calcite grade A ($Fe_2O_3 > 0.05$) before crushing	99.22	0.03
S2	Calcite grade B ($Fe_2O_3 < 0.05$) before crushing	98.19	0.46*
S3	Product of impact crusher (grade A)	99.22	0.03
S4	Product of impact crusher (grade B)	98.19	0.46*
S5	Feed of vertical mill	99.09	0.05
S6	Underflow of air classifier after vertical mill	99.16	0.06
S7	Product of vertical mill C-30	98.97	0.06
S8	Product of vertical mill C-60	99.12	0.05
S9	Product of vertical mill C-100	99.10	0.04
S10	Feed of ball mill	99.09	0.05
S11	Underflow of air classifier from ball mill	98.06	0.67
S12	Product of ball mill C-400	99.10	0.05
S13	Product of ball mill C-600	99.20	0.04
S14	Product of ball mill C-800	99.06	0.07*

Note * means the iron oxide content are over the standard require

3.3 Qualitative analysis using X-ray diffractometer (XRD)

3.3.1 Methodology

To confirm the source of iron content, the S4 (product of impact crusher (grade B)) and S11 (underflow of air classifier from a ball mill) samples were analyzed using an X-ray diffractometer (XRD; PANalytical Aeris model, Netherland). Before the analysis, S4 and S14 samples were separated by IRMS to increase the magnetic minerals and make the peak of the XRD result easier to discuss.

1000 g of the samples were used in each experiment that was conducted at a rotor width of 13.5 cm, a tension of 100 V, an electrical current of 3 A, and a feed rate of 2.4 kg/h. After the separation, the magnetic fractions were analyzed by XRD as shown in Fig. 3.2.

The iron scrap from the surface of the grinding used in the ball mill was scrubbed using sandpaper (Fig. 3.3 (a)). Then, the magnetic product from the scrubbing process was recovered using a magnetic bar (Fig. 3.3 (b)). This iron scrub was analyzed by XRD to compare with the samples.
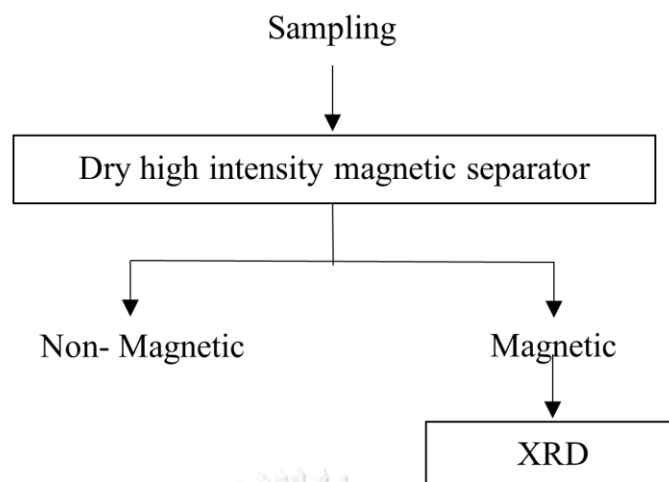
Fig. 3.2 Flow chart of XRD analysis used to determine the source of iron content.
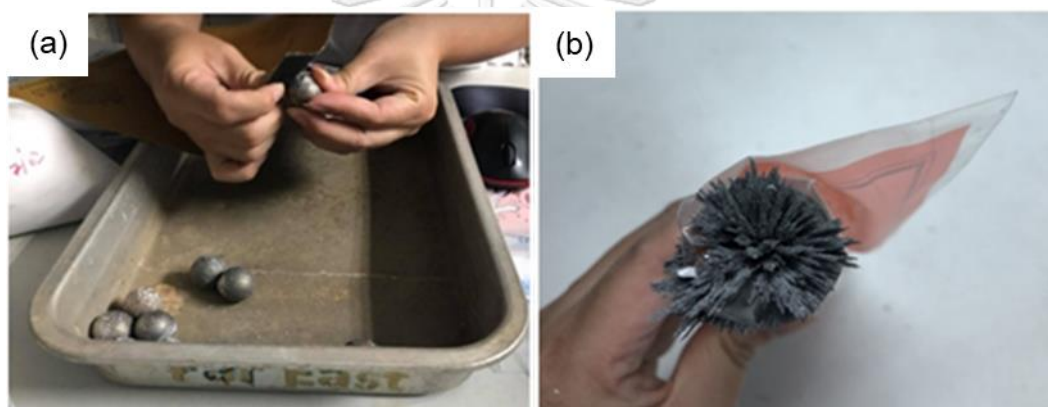
Fig. 3.3 (a) Attrition of grinding ball using sandpaper and (b) iron scrap from grinding ball surface

3.3.2 Results and discussion

Figs. 3.4, 3.5, and 3.6 show the XRD results of S4 (product of impact crusher (grade B)), S11 (underflow of air classifier from a ball mill), and the grinding ball from a ball mill, respectively. For S4, the results showed that the iron content in the sample is in the form of magnetite and pyrrhotite that come from the source rock. However, in the case of S11, sometimes magnetite and pyrrhotite were found similar to the S4 sample (Fig. 3.5 (a)) and sometimes synthesis iron was found (Fig. 3.5 (b)) similar to grinding ball from a ball mill (Fig. 3.6) indicating that both of iron form the source rock and ball mill are contained in this sample.

The iron impurity is in the form of magnetite and pyrrhotite, which come from the source rock. Magnetite occurs in most sedimentary, igneous, and metamorphic

rocks. It also occurs in contact with metamorphic zones. While pyrrhotite is a common trace constituent of mafic igneous rocks, it also occurs in contact with metamorphic zones. This mineral is often accompanied by pyrite and magnetite. In chapter 2, the geology of the study area revealed that the mining area found grey-white to white calcite. It occurred by the re-crystallization of limestone due to the contact metamorphism process of biotite-muscovite and granite. This process happens through the intrusion of magma bodies of granite intruding into limestone rock. The reaction between country rock and the fluid of magma makes the impurities into the calcite or country rock, such as magnetite and pyrrhotite.
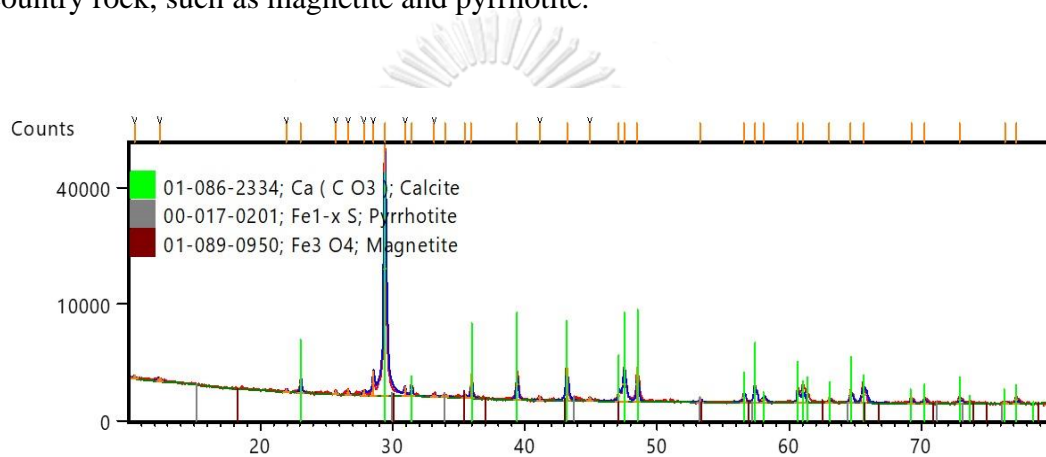

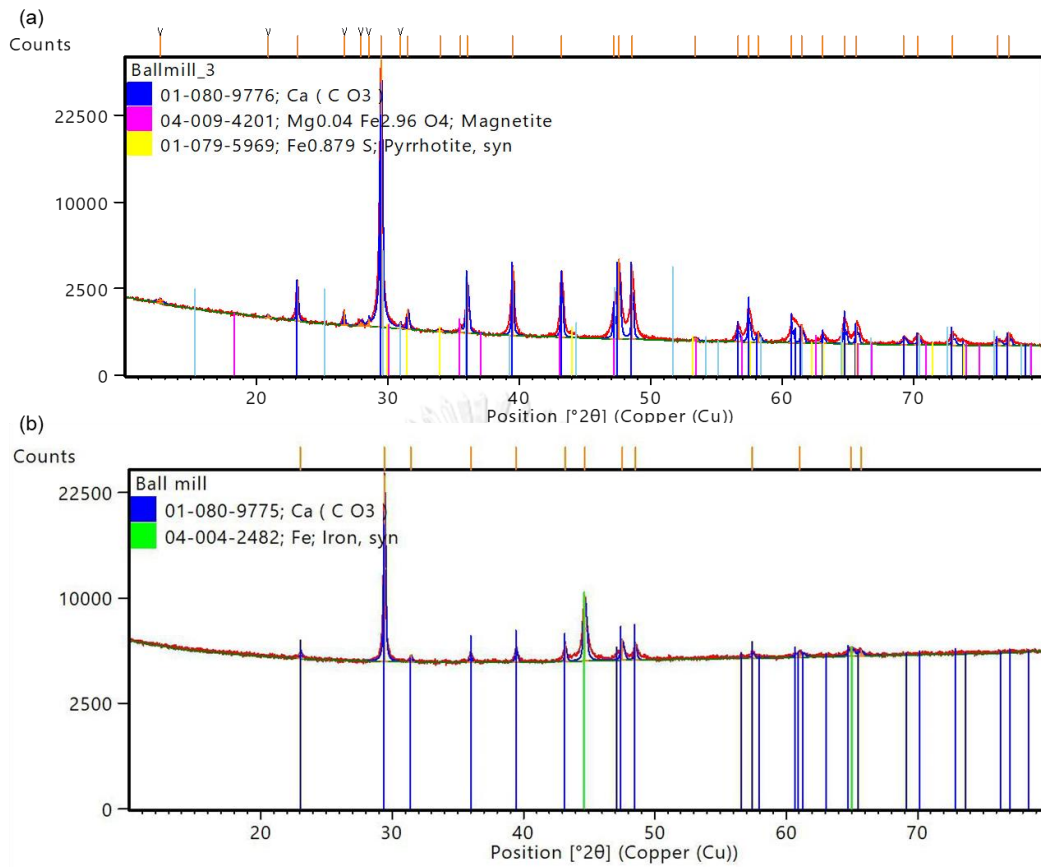**Fig. 3.4** XRD result of S4 (product of impact crusher (grade B))

Fig. 3.4 XRD result of S11 (underflow of air classifier from ball mill); (a) with the peak of calcite, magnetite , and pyrrhotite and (b) with the peak of calcite and synthetic iron.
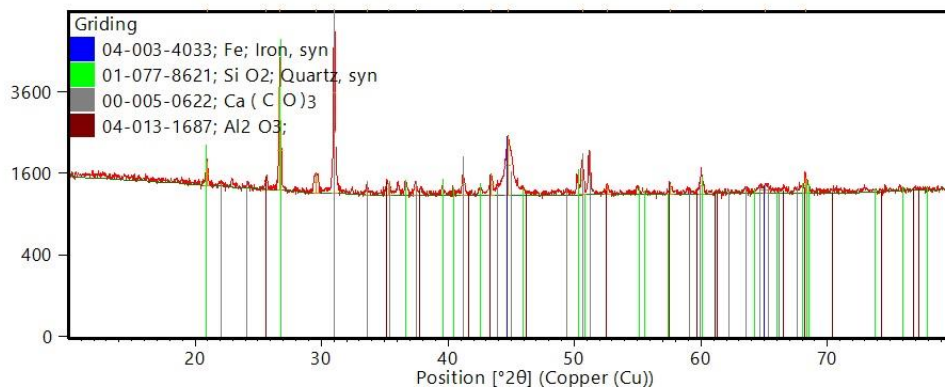

Fig. 3.5 XRD of grinding ball from ball mill

3.4   Conclusions

Fig. 3.7 shows the samples with the code at the collecting points and the processing flow chart of the calcite processing plant of Sand and Soil Industry Co., Ltd. The XRF result reveals calcium and iron content of samples in oxide form. The results revealed that the iron oxide concentration of the S2, S4, S11, and S14 samples did not meet the requirements for sale because the iron content of samples was greater than 0.05% Fe_2O_3. The results of S2 and S4 showed the same value of Fe_2O_3 content, indicating that iron content comes from the source rock or raw materials, the jaw crusher, and the impact crusher had no effect on increasing of the iron content.

The iron oxide content was reduced to 0.05%, which meets the required standard at S10 (grade A and B rock are blended). After size reduction using a ball mill, the content of Fe_2O_3 increases in the S11 sample, indicating that the increase in iron content also comes from the process, especially the ball mill, which could be due to the abrasiveness of the grinding media or the wall of the ball mill. As a result of these factors, the S14 sample, which is the smallest product (C-800; 2–2.2 µm), has an iron content that exceeds the standard requirement.

From the XRD result of S4 (product of impact crusher (grade B)), the result shows that the iron content in the sample is in the form of magnetite and pyrrhotite, which comes from the source rock grade B. However, in the case of S11 (underflow of air classifier from ball mill, sometimes magnetite and pyrrhotite were found similar to the S4 sample and similar to the grinding ball from the ball mill, indicating that both iron from the source rock and the ball mill are contained in this sample.
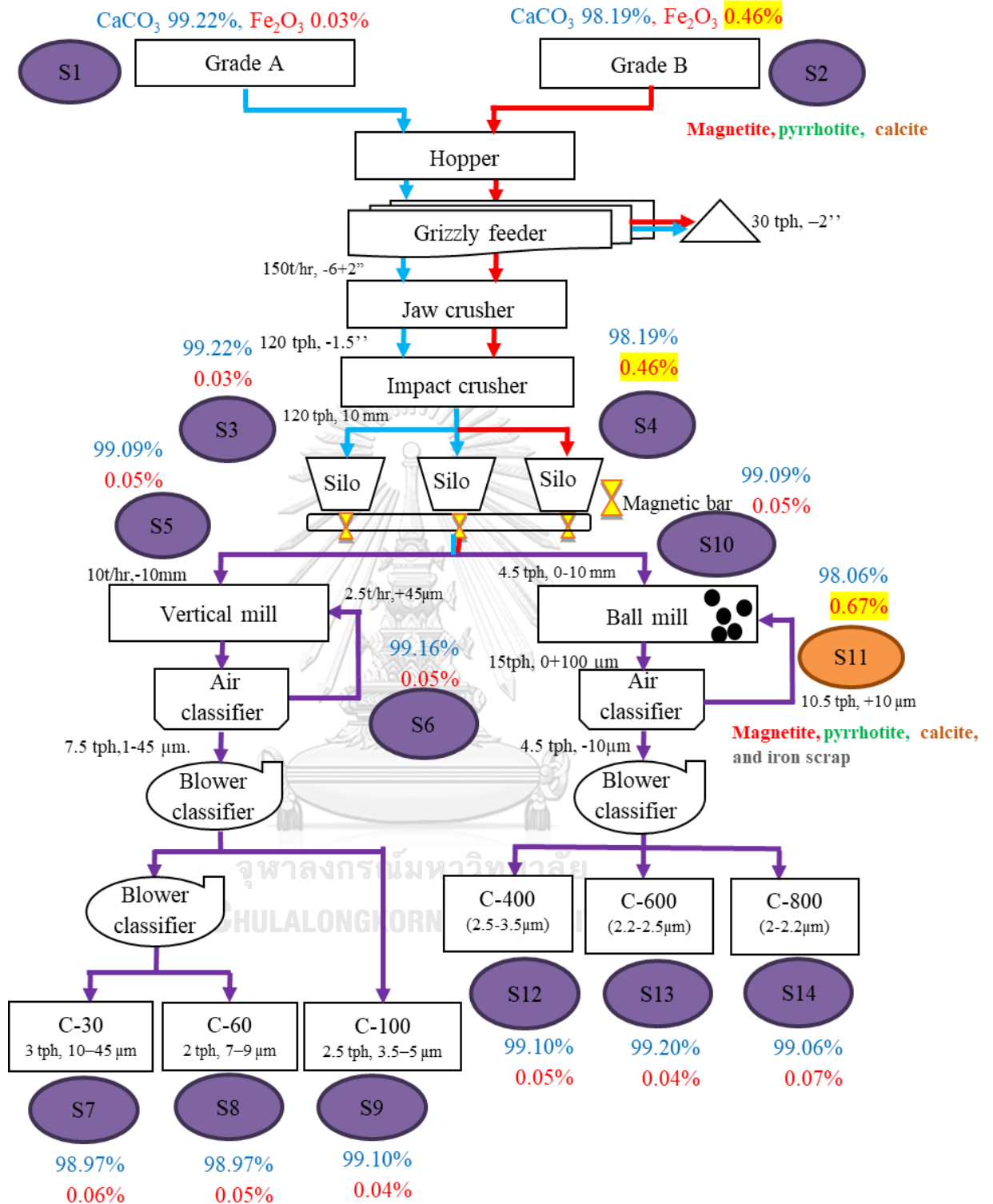
Fig. 3.6 Summary of XRD and XRF results in each points of processing plant

CHAPTER 4
THE REMOVAL OF IRON CONTENT USING INDUCED ROLL MAGNETIC SEPARATOR

4.1 Samples

The chemical composition of the S11 sample was measured through x-ray fluorescence (PANalytical, EPSILON4). The results of XRF illustrated that the S11 sample contains 98.06% of CaCO3, 0.67% of Fe_2O_3, and 1.27% of others. The Fe_2O_3 content of S11 exceeds the standard requirements as shown in Table 4.1.

Regarding the XRD results, the S11 (underflow of air classifier from a ball mill) sample indicated the impurities of magnetite, pyrrhotite, and iron scrap. Magnetite and pyrrhotite came from grade B of source rock, while the iron scrap came from the grinding balls of the ball mill. The impurities of magnetite, pyrrhotite, and iron scrap need to be removed using magnetic separation to meet the market requirement.

Table 4.1 Chemical composition of S11 sample (underflow of air classifier) from XRF analysis

Compound	CaCO$_3$	Fe$_2$O$_3$	SO$_3$	Al2O$_3$	SiO$_3$	P$_2$O$_3$	MgO	K$_2$O	SrO
(Wt. %)	98.06	0.67	0.28	0.08	0.36	0.04	0.44	0.04	0.03

4.2 Dry magnetic separation experimental methods

Since calcium carbonate is a non-magnetic or diamagnetic mineral at room temperature and the impurities like magnetite and iron scrap are ferromagnetic as well as pyrrhotite is moderately magnetic. Therefore, magnetite, pyrrhotite, and iron scrape have an average magnetic susceptibility higher than calcium carbonate. So, the impurities like magnetite, pyrrhotite, and iron scrap are easy to separate using dry magnetic separation because the susceptibility ranges are not close.

In this study, a bench-scale IRMS (ERIEZ MAGNETS CP887412 model, USA; Fig. 4.1), which has a width of induced rolls of 13.5 cm and an electrical voltage of 100 V, was used to remove the iron content of the S11 sample (underflow product of the air classifier after the size reduction using a ball mill) to meet the market requirement (e.g.,

Fe2O3 ≤ 0.05% for filler grade and 0.05 < Fe_2O_3 ≤ 0.1 for animal feed). The S11 sample contains 98.06% of $CaCO_3$ and 0.67% of Fe_2O_3.

1000 g of S11 sample was used for each condition. The magnetic field intensity was controlled using the variation of electrical current (i.e., 1, 2, and 3 A) and the feed rate was controlled at 2.4, 2.8, and 3.4 kg/h, as shown in Tables 4.2 and 4.3, to investigate the effects of magnetic field intensity and feed rate on the removal of iron content from the sample. After each experiment, three products (i.e., magnetic fraction, middling, and non-magnetic fraction) were obtained. The products were weighted, and the non-magnetic fraction was analyzed using an XRF spectrometer.

Fig. 4.1 Induced roll magnetic separator

(ERIEZ MAGNETS CP887412 model, USA)

Table 4.2 List of variables at different level

Variables	Units	Low	Center	High
Electrical current	A	1	2	3
Feed Rate	kg/h	2.4	2.8	3.4

Note Feed rate was mentioned based on the rotor width of 13.5 cm. and Tension (Volt) of 100 V.

Table 4.3 Experimental conditions used in magnetic separation experiments

Samples ID	Conditions	
	Electrical current (A)	Feed rate (kg/h)
D1	1	2.4
D2	1	2.8
D3	1	3.4
D4	2	2.4
D5	2	2.5
D6	2	3.4
D7	3	2.4
D8	3	2.8
D9	3	3.4

4.3 Results and discussion

4.3.1 Effects of magnetic field intensity and feed rate

Fig. 4.2 shows (a) yield percentage, (b) Fe_2O_3 content, and (c) $CaCO_3$ content of non-magnetic products after the separation using IRMS at different magnetic field intensities (at the electrical current of 1, 2, and 3 A) and feed rate (2.4, 2.8, and 3.4 kg/h). The results showed that most of the samples were recovered as non-magnetic products. The yield percentage of non-magnetic products was decreased when the magnetic field intensity and electrical current were increased while increasing with the increase in feed rate. So, the condition of electrical current and feed rate equal to 1 A and 3.4 kg/h (minimum magnetic field intensity and electrical current; maximum feed rate; D3) showed the highest yield percentage at 84.1%, while the condition of 3 A and 2.4 kg/h; (maximum magnetic field intensity and electrical current; minimum feed rate; D7) showed the highest yield percentage at 80.74% (Fig. 4.2 (a)).

In this study, to prepare a product that meets the standard requirements of animal feeding and filler grade, the Fe_2O_3 content must be less than 0.1 and 0.05%, respectively. Fig. 4.2 (b) showed that the Fe_2O_3 content of the non-magnetic product was between 0.239 and 0.285%, which was lower than the original feed with 0.67%. The lowest Fe_2O_3 content was obtained from the conditions of 3 A and 2.4 kg/h (maximum magnetic field intensity and electrical current; minimum feed rate; D7), followed by D4, D8, and D5 with 0.245, 0.252, and 0.261% of Fe2O3 content, respectively, indicating that high magnetic field intensity (high electrical current) and

low feed rate are required to achieve the low Fe_2O_3 content. In the case of $CaCO_3$ content, the range in the non-magnetic product was 98.35 to 98.60%, which was higher than that of the original feed with 98.06% (Fig. 4.2 (c)). These results showed the optimum condition (D7) showed the lowest Fe_2O_3 content with the lowest yield and acceptable $CaCO_3$ content. However, the content of Fe_2O_3 in this condition still does not meet the standard requirements of the industry.
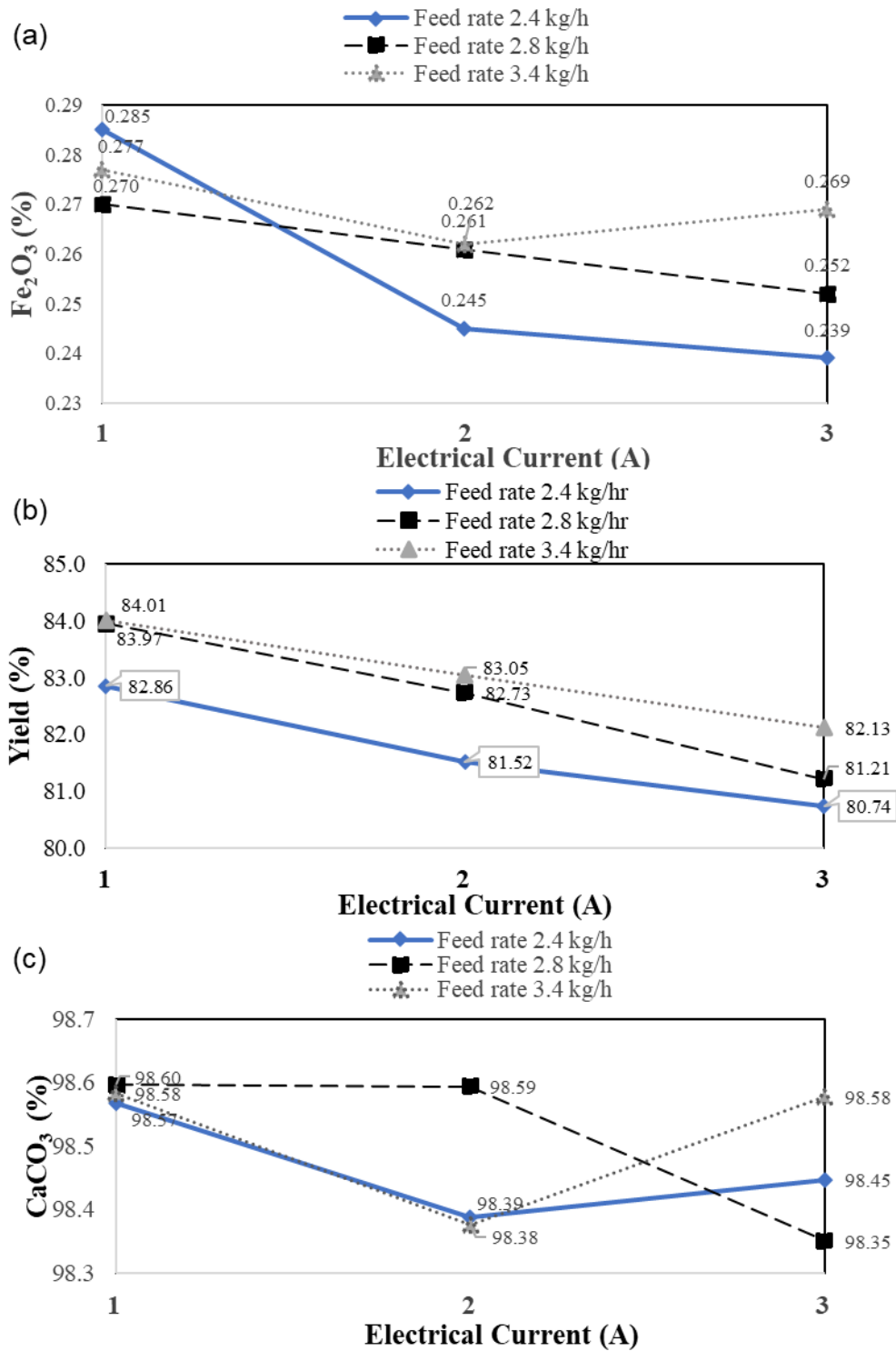
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Fig. 4.2 (a) yield percentage, (b) Fe$_2$O$_3$ in non-magnetic product, and (c) CaCO$_3$ in non-magnetic product after dry magnetic separation experiments with different magnetic field intensity (at electrical current of 1, 2, and 3 A) and feed rate (2.4, 2.8, and 3.4 kg/h)

4.3.2   Effect of cleaning process by repetition

In the previous experiment, due to the high electrical current and low feed rate required to achieve low iron content, the D7 condition (i.e., electrical current of 3 A and feed rate of 2.4 kg/h) was the best condition. However, the iron content is still higher than the requirements of the industry. To improve the quality of products, the non-magnetic products were repeatedly fed into IRMS to remove more iron content. D7, D4, D8, and D5 were used as a sample to investigate the effects of repetition on the quality of products. The samples were repeatedly separated two more times (a total of three times) using IRMS with the same conditions as in the previous experiment. After this step, non-magnetic was analyzed for calcium carbonate and iron content using XRF.

For yield percentage, the results showed that most of the samples were recovered into non-magnetic products. The yield percentage of non-magnetic products was decreased when the samples were more repeatedly separated. So, the lowest yield percentage was achieved when high magnetic field intensity (high electrical current of i.e., 3 A), low feed rate (i.e., 2.4 kg/h) with 3 repetitions is used. In contrast, the highest yield percentage was achieved at low magnetic field intensity (low electrical current of i.e., 2 A), high feed rate (i.e., 2.8 kg/h) with only one step used (Fig. 4.3 (a)).

For Fe_2O_3 content, non-magnetic products were between 0.136 and 0.261%, which was lower than the original feed at 0.672%. The percentage of iron content decreased when the samples were more repeatedly separated. The lowest Fe_2O_3 content was obtained when high magnetic intensity (high electrical current, i.e., 3 A) and a low feed rate (i.e., 2.4 kg/h) with 3 repetitions were used (Fig. 4.3 (b)).

In the case of $CaCO_3$ content, the range in non-magnetic product were 98.35−98.60% that were higher than that of original feed with 98.19% (Fig. 4.3 (c)). These results showed the optimum condition (D7) with 3 rounds of IRMS showed the lowest Fe_2O_3 content with lowest yield and acceptable $CaCO_3$ content however, the content of Fe_2O_3 in this condition still not meet the standard requirement of industry. However, the content of Fe_2O_3 in this condition still not meet the standard requirement of industry.
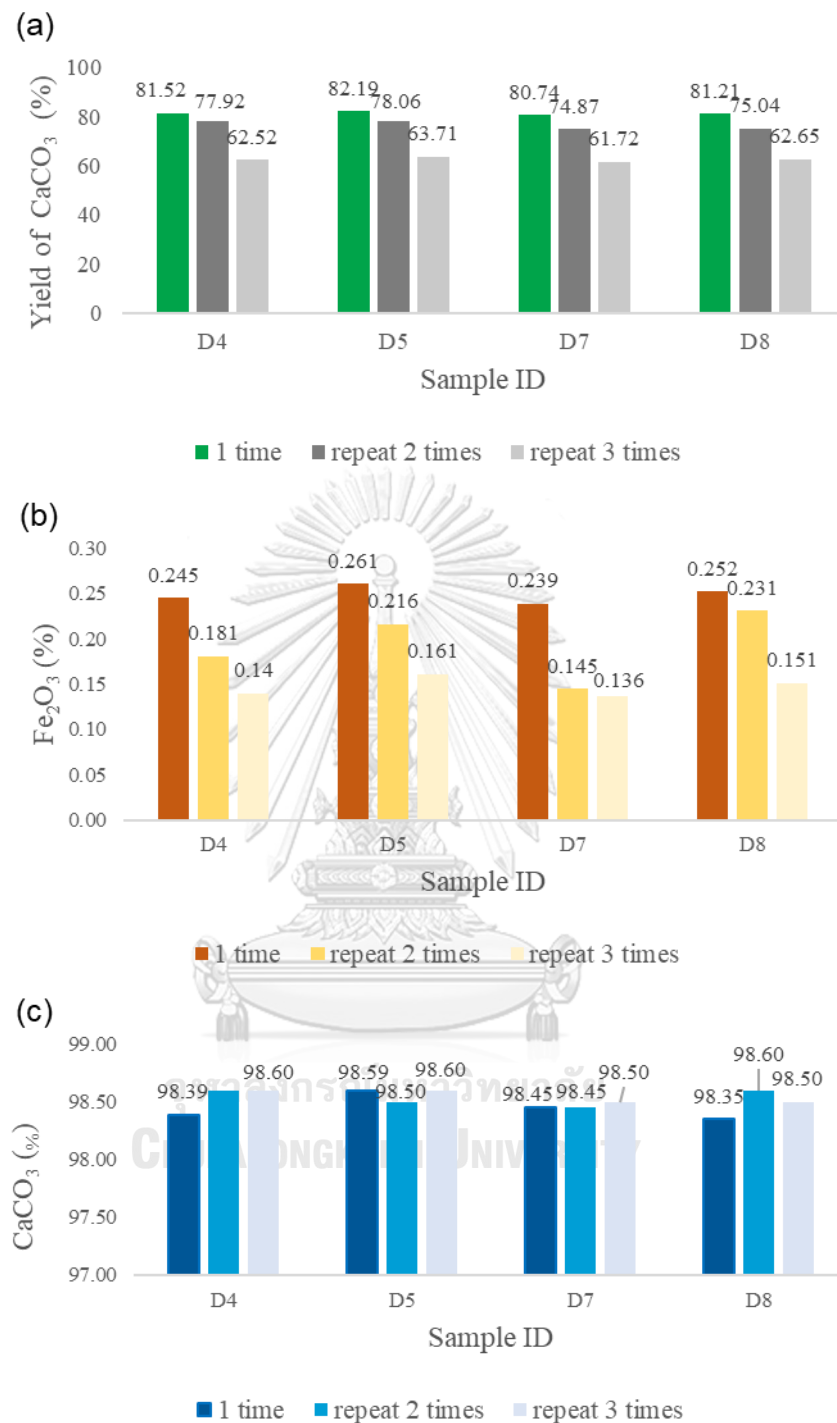
Fig. 4.3 (a) yield percentage, (b) Fe_2O_3 content, and (c) $CaCO_3$ in non-magnetic product after dry magnetic separation experiments with different magnetic field intensity (at electrical current of 2 and 3 A) and feed rate (2.4 and 2.8 kg/h)

Note: D4 (electrical current of 2 A and feed rate of 2.4 kg/h), D5 (electrical current of 2 A and feed rate of 2.8 kg/h), D7 (electrical current of 3 A and feed rate of 2.4 kg/h), and D8 (electrical current of 3 A and feed rate of 2.8 kg/h).

4.3.3 Optimization

From previous experiments, it is indicated that high magnetic field intensity (high electrical current) and low feed rate are required to achieve the low Fe_2O_3 content. Since Fe_2O_3 content in non-magnetic is still higher than the requirement of industry. To improve the quality of products, the optimum condition with 3 rounds of the IRM separation experiments can occur with the highest electrical current of 3 A and was carried out with a low feed rate of 2.4 kg/h. In this section, the optimization experiments were carried out using low feed rates (i.e., feed rates of 1.7, 2.0, and 2.4 kg/h with more repetition (four repetitions) and electrical current of 3 A (maximum electrical current of IRMS). The first condition is electrical current of 3 A and a feed rate of 1.7 kg/h. The second, electrical current of 3 A and a feed rate of 2.0 kg/h, and the last condition, electrical current of 3 A and a feed rate of 2.4 kg/h. These conditions were used as the sample to investigate the effects of repetition and feed rate on the quality of products. The samples were repeatedly separated four times using IRMS. After this step, non-magnetic was analyzed for calcium carbonate and iron content using XRF. The minimum of % Fe_2O_3 is showed at electrical current 3A and feed rate 1.7 kg/h. At the higher magnetic field intensity of 3A, the iron content has increase down to a minimum of 0.08% Fe_2O_3 from 0.67% Fe_2O_3. At this quality is meet the properties standard of food animal grade in Sand and Soil Industry Co., Ltd., and from the experiment before, that shown at low feed rate has efficiency to remove the iron content.

The results showed that most of samples were recovered into non-magnetic products. The yield percentage of non-magnetic products were decreased when the feed rate was increased while electrical current of 3 A (maximum electrical current of IRMS). So, the condition of electrical current and feed rate equal to 3 A and 2.4 kg/h (maximum feed rate) showed the highest yield percentage at 73.51% while the condition of 3 A and 1.47 kg/h. (minimum feed rate) showed the lowest yield percentage at 70.81% (Fig. 4.4 (a)). Thus, it is quite clear that the effect of the feed rate is very significant to optimum yield. In other words, at lower feed rate, the selectivity of iron oxide particle is very well but the yield is low and results of iron oxide content in calcium carbonate (non-magnetic product) is low.

For Fe_2O_3 content, non-magnetic product were between 0.08−0.12% that were lower than original feed with 0.67%. The percentage of the iron content were decreased

when the samples were more repeatedly separated. The lowest Fe_2O_3 content was obtained when high magnetic intensity (high electrical current of i.e., 3 A), low feed rate (i.e., 1.7 kg/h) with 4 repetition is used (Fig. 4.4 (b)). When a decrease feed rate; there is marginal change in the iron content of calcium carbonate (non-magnetic product). At the higher electrical current 3 A there is a decrease in the iron content in non-magnetic product with decrease in the feed rate. It may be due to the passage of single layer particle flow over the rotor that improved the selectivity compared to the multilayer passage at higher feed rate.

The case of $CaCO_3$ content, the range in non-magnetic product were 98.60−98.73% that were higher than that of original feed with 98.19% (Fig. 4.4 (c)). calcium carbonate content in the non-magnetic product increases with the decrease a feed rate. It clear that that with a decrease the feed rate there is a significant change in the percentage of calcium carbonate. These results showed the optimum condition showed the lowest Fe_2O_3 content with lowest yield and acceptable $CaCO_3$ content and the content of Fe_2O_3 in this condition meet the standard requirement of industry.

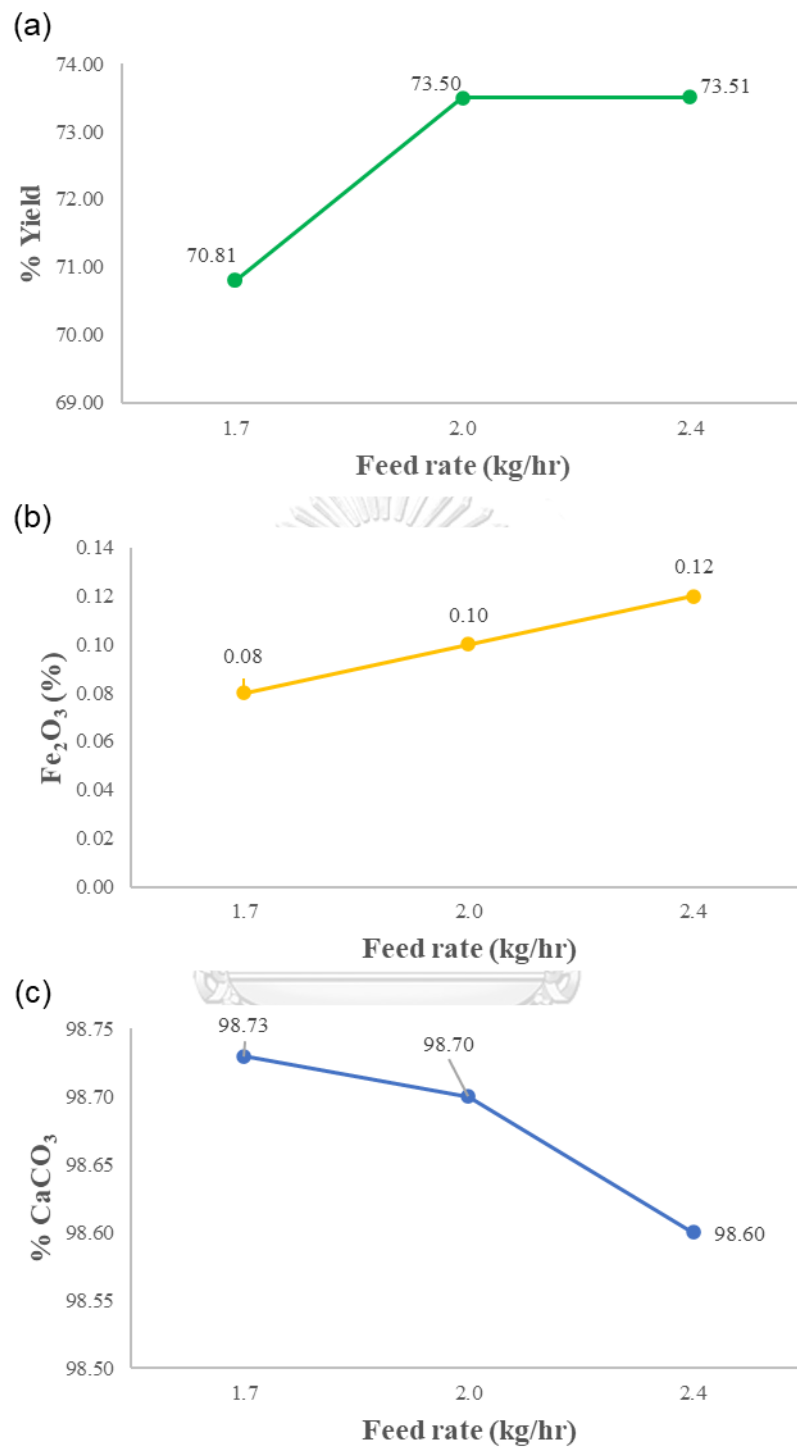จุฬาลงกรณ์มหาวิทยาลัย

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Fig. 4.4 (a) yield percentage, (b) Fe_2O_3 in non-magnetic product, and (c) $CaCO_3$ in non-magnetic product after dry magnetic separation experiments with maximum magnetic field intensity (at electrical current of 3 A), feed rate (1.7, 2.0, and 2.4 kg/h) and four times repetition.

CHAPTER 5
PROJECT FINANCIAL EVALUATION

5.1   Processing plant design

5.1.1   Processing plant design of this study

From the results of chapter 3 showed that iron content come from both of source rock (raw material) and the process, especially the ball mill due to the abrasion of the grinding media and/or the wall of the ball mill. The S11 sample (underflow of air classifier), has the iron content exceed standard requirement and the iron is in the form of magnetite, pyrrhotite, and synthesis iron. From these results, magnetic separators are suggested to be installed at the point of ball milling discharge (M1) and underflow of air classifier (M2) as shown in Fig. 5.1 to reduce the iron content.

Dry high-intensity magnetic separators are proposed. The first one should be placed at M1 to remove magnetic fraction from both of source rock (i.e., magnetite and pyrrhotite) and abrasion of the ball mill (i.e., synthesis iron) prior the classification of using air classifier. One more unit is suggested to be installed at M2 to secondary remove the magnetic fraction that still remains in the underflow product of air classifier prior to recharge to the ball mill.

This installation might improve the quality of calcium carbonate from low grade to higher grade that meets the requirement of animal food. The condition of magnetic separation from laboratory-scale experiments can be considered. However, the pilot tests and commercial scales should be investigated to optimize the separation efficiency.

Fig. 5.2 shows dry power electromagnetic separator (GDF250, Weifang GUOTE Mining Equipment Co., Ltd., China) that recommend being used in this processing plant and specification are shown in Table 5.1
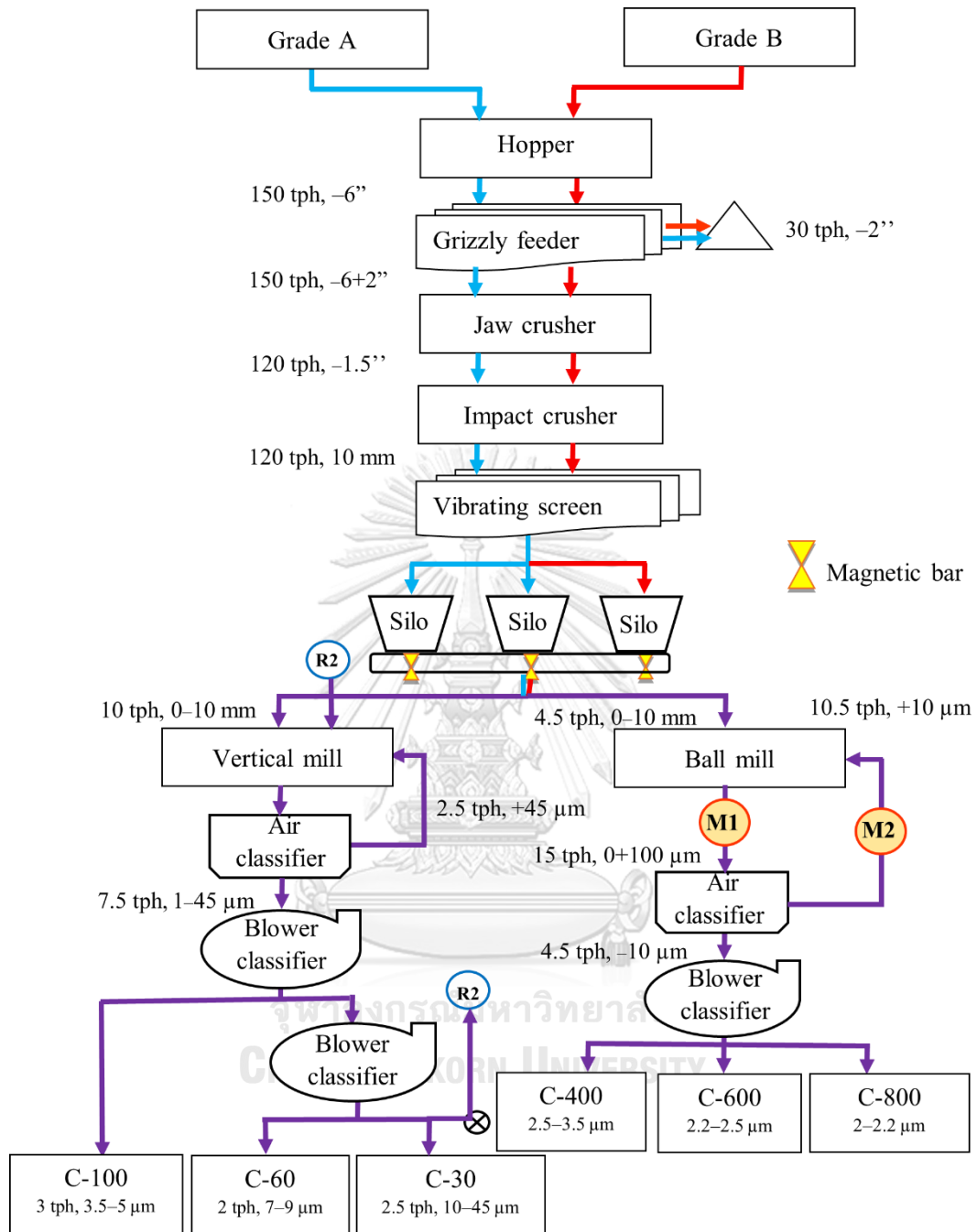
Fig. 5.1 Calcium carbonate processing plant arrangement

Table 5.1 Dry power electromagnetic separator

Name	Model	Unit	QTY	Price/Unit USD	Total price USD
Dry power electromagnetic separator	GDF250	Unit	2	72600	145200
		USD total			145200

Note 1 dollar = 32.88 baht (1 july, 2021)

Fig. 5.2 Dry power electromagnetic separator (GDF250, GUOTE, China)
(Weifang GUOTE Mining Equipment Co., Ltd., 2022)

5.2   Financial evaluation

The economic evaluation for long-term investment involves a discount cash flow (DCF) analysis. It provided the critical value for net present value (NPV) at the discount rate of 13 % and the internal rate of return (IRR). For all investment projects, there are some essential parameters for considering them to be feasibility: DCF, IRR, modified initial rate of return (MIRR) and NPV. In DCF calculation, cash inflow and cash outflow are considered. IRR is used to compare with MIRR.

5.2.1 Discounted cash flow (DCF) calculation

Cash flow (CF) model is a model that shows the flow of cash of an investment over a defined period of time. DCF model is used as a tool to assess the feasibility of investment projects in the industry for all types of capital investment evaluations. DCF method concerns the time value of money. Cash flow shows cash receipts at the end of each year generated by the investment and cash disbursements of all costs (initial and subsequent costs) per year required for the operation and total time span of the investment in years (Mian, 2011).

The cash flow is referred to net inflows or outflow of money that occurs during a specific time period. The Formula for calculate cash flow is

Gross profit =   Gross revenue – operating expense   (5.1)

Net profit   =   Gross profit (taxable income) – tax   (5.2)

Cash flow   =   Net profit + DD&A – Capital cost   (5.3)

where DD&A is Depreciation and Depletion.

The discounted cash flow method is widely accepted and used in the industry for all types of capital investment evaluations. In order that determine the discounted cash flow, there are many stages, the parameters input to calculate in this stage are capital cost or capital expenditure (CAPEX), operation cost or operation expenditure (OPEX), depreciation, tax rate, and royalty rate. This project operated one product that contained $\geq$ 95% of $CaCO_3$ and $\leq$ 0.1% of Fe_2O_3 contents. Table 5.2 illustrates the product design to produce 36,288 tons per year for 10 years, a profitable tax rate 20%, and a discount rate 15%.

Table 5.2 Capital Expenditure of project (THB)

Investment	THB
Machine and Equipment (10 years)	4,779,437
Installing of Machinery (25%)	1,194,859
Reserve (15% of Machine)	1,911775
Total CAPEX	**6,691,212**

This project will be invested in an initial investment cost or capital cost (CAPEX) of approximately 6,691,212 baht and the cost of operation (OPEX) will be 38,528,643 baht in year 1 to 3, 38,435,211 bath and increase 5% from year 4 to 6, 54,933,038 baht from year 7 until year 10, the inflation rate was increased of 5% from year 1 to year 10, total OPEX will be 132,896,892 bath of project period as shown in Table 5.3. and Table 5.4 indicates the total operation cost (bath unit), labor cost, and 5% increase per year for 5 years. In addition, this project considers welfare, and management assumed 20% of the investment.

Table 5.3 Operation cost (THB)

Description	THB	Unit
Raw Material	10,886,400	
Electric	1,088,640	THB/Year
Maintenance (5% of investment)	238,972	
Consumable (1% of investment)	47,794	
Total cost	**12,261,860**	

Table 5.4 Total operation cost (THB)

Year	1-3	4-6	7-10
Processing cost	36,785,419	36,785,419	49,047,225
Labor cost and inflation (5%)	1,162,149	1,766,528	3,923,876
Welfare and management (50%)	581,075	883,264	1,961,938
Total Operation Expense	38,528,643	38,435,211	54,933,038

5.2.2 The weighted average cost of capital (WACC)

The weighted average cost of capital (WACC) is a calculation of a firm's cost of capital in which each category of capital is proportionately weighted. All sources of capital, including common stock, preferred stock, bonds, and any other long-term debt, are included in a WACC calculation (Hargrave, 2019). A firm's WACC increases as the beta and rate of return on equity increase because an increase in WACC denotes a decrease in valuation and an increase in risk. Eq. 5.4 shows the formula of WACC.

$$WACC = E/V * Re + D/V * Rd * (1 - Tc) \qquad (5.4)$$

where   Re = cost of equity,

Rd = cost of debt,

E = market value of the firm's equity,

D = market value of the firm's debt,

V = E + D = total market value of the firm's financing (equity and debt),

E/V = percentage of financing that is equity,

D/V = percentage of financing that is debt,

and   Tc = corporate tax rate.

This project assumed that 40 % fund was from the bank and 60 % from the owner. The cost of equity and the cost of debt is 20%, and 10%, respectively. The discount rate estimates to be 13%, so the WACC value is 15% as shown in Fig. 5.5.

Table 5.5 Weighted average cost of capital (WACC)

WACC parameter	Parameter value
Market value of equity (THB)	4,014,727
Cost of equity (%)	20
Market value of debt (THB)	2,676,485
Cost of debt (%)	10
Tax rate (%)	20
WACC (%)	**15**

5.2.3 Net present value (NPV)

The Net Present Value (NPV) is the present value of cash surplus or present worth, which is obtained by subtracting the present value of periodic cash outflows from the present value of periodic cash inflow (Main, 2002). The present value is calculated using the weighted average cost of capital of the investor, also referred to the discount rate or minimum acceptable rate of return. Remer and Nieto (1995) claim that maximizing or minimizing the NPV of a project, depending upon 9 the situation, will provide the most efficiency, and as a result, the most profitability.

The formula for NPV is:

$$NPV = \sum_{t=0}^{n} \frac{Rt}{(1+t)^t} \tag{5.5}$$

where Rt = net cash inflow-outflows during a single period t

i = discount rate or return that could be earned in alternative investments

t = number of time periods.

According to (Park, 2002) the decision rule for NPV is:

If > 0, accept the investment;

If = 0, remain indifferent to the investment;

If < 0, reject the investment.

The NPV decision criterion follows directly from the assumption that the analyst is required to maximize the value of the project. This criterion results in the optimal choice of project. NPV should be accepted since the objective is to minimize cost (not maximize profits).

To determine NPV from summation of discount cash flow and present value. In this thesis, NPV value is positive, it would be considering of further feasibility study. According to the excel calculations NPV is 17,992,947 baht which is considers financially feasibility to investment of using the dry high intensity to reduce the iron oxide content from the processing of Sand and Soil Industry Co., Ltd., as shown in Table 5.5.

The total capital is 6,691,212 baht invested in the year zero, it can be seen that the gross revenue is rising in the first-year operating, which means this project can be recovered in the short period of time of investment as shown in Fig. 5.6. Therefore, the

budget of investment in this project was borrowed from a bank and the owner of the project.

Table 5.6 The NPV calculation

Year	1-3	4-6	7-10
Product (Ton)	77,087	77,087	102,782
Sale Product (THB)	61,669,279	61,669,279	82,225,705
Gross revenue (THB)	61,669,279	61,669,279	82,225,705
Royalties 7% (THB)	4,316,850	4,316,850	5,755,799
Net revenue (THB)	57,352,429	57,352,429	76,469,906
Depreciation (THB)	2,007,363	2,007,363	2,676,485
Operation Expense (THB)	38,528,643	38,435,211	54,933,038
Income before Tax (THB)	16,816,423	15,909,855	18,860,383
Tax 20% (THB)	3,363,285	3,181,971	3,772,077
Income after Tax (THB)	13,453,139	12,727,884	15,088,306
Cash flow (6,691,212)	15,460,502	14,735,247	17,764,791
NPV@15%	THB		17,992,947

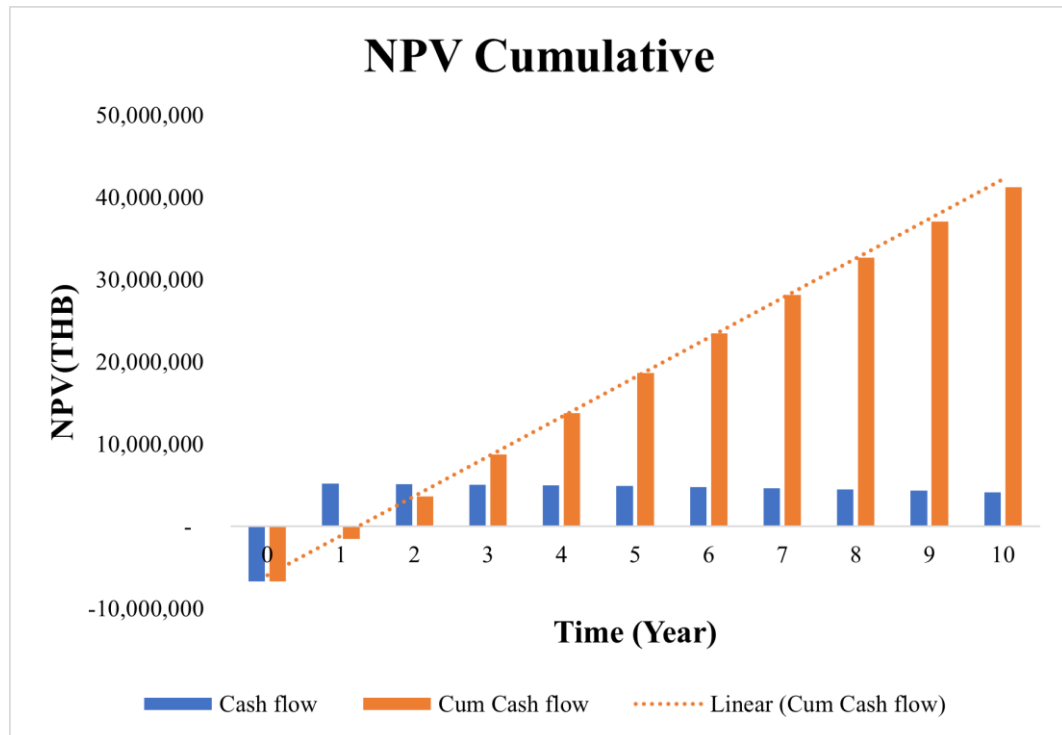จุฬาลงกรณ์มหาวิทยาลัย

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Fig. 5.3 Cumulative cash flow

5.2.4 Internal rate of return (IRR) and modified internal rate of return (MIRR)

Internal rate of return (IRR) is a concept based on the return on invested capital in terms of project investment, or as Park (2002) defines it: "IRR is the interest rate charged on the unrecovered project balance of the investment such that, when the project terminates, the unrecovered project balance will be zero". Another definition of IRR is the inter rate received for an investment consisting of payment (negative value) and income (positive value) that occur at regular period. The Formula for IRR is

$$\text{IRR} = \text{NPV} = \sum_{t=1}^{T} \frac{C_t}{(1+IRR)^t} - C_0 = 0 \qquad (5.6)$$

where C_t = net cash inflow during the period t,

   C_0 = total initial investment costs,

   IRR = the discount rate,

and   t = the number of time periods.

The investment decision when using IRR is Equation whether to accept the investment if the calculated IRR is greater than the return on the alternative use of funds

or cost of capital, and to reject the investment if its calculated IRR is less than the return on the alternative use of funds or cost of capital.

The modified rate of return (MIRR) is a financial measurement of an investment's attractiveness. It is used in capital budgeting to rank alternative investments of equal size with the aim of resolving some problems with IRR. The MIRR is a function of both the reinvestment rate and the pattern of cash flow, with higher reinvestment rate leading to greater MIRR. Following by equation below.

$$\text{MIRR} = \sqrt[n]{\frac{\text{FV (Positive cash flows x Cost of capital}}{\text{(PV (Initial outlays x Financing cost)}}} - 1 \qquad (5.7)$$

where   FVCF (c) = the future value of positive cash flows at the cost of capital,

PVCF (fc) = the present value of negative cash flows at the financing cost of the company,

and   n = number of periods.

The decision rule for the MIRR is to invest in a project if it provides a return greater than the cost of capital, which means the investment is expected to return more than a requirement. If MIRR less than capital cost rejected, which mean the investment is expected to return less than a requirement. If MIRR equal to zero are indifference between accepting or rejecting the project, which means the investment is expect5ed to return what is required.

The discount payback period (DPP) is the number of years for the projects to break even. The number of years for which a discounted annual net cash flow must be summed before the sum becomes positive. The payback period is the time during which the initial cash outflow of investment is expected to recover from the cash inflows generated by the investment.

DPP = Cut off Period + Initial /Cash inflow per period   (5.8)

Internal rate of return (IRR) is the rate at which the return by an assuming the rate of cash flows reinvestment. IRR is the rate to made NPV = 0, as an essential for investment, also identify the discount payback period of project. The project will not obtain profit when IRR equaled to WACC or discount rate, or NPV equaled to zero. In this project, NPV was 17,992,947 baht, IRR was 53% and MIRR was 24% respectively. Therefore, IRR was concerned in this project by change the assumption rate of reinvestment growth in the project, MIRR is designed to solve the IRR. Consequently,

the payback period was investigated determine the project life in order to recover initial investment by given a number of years. In this project, discounted payback period was 1.5 years of recover initial investment. However, NPV and IRR methods may provide conflicting results in case of mutually exclusive projects. Fig. 5.4 shown the IRR value gives an over number of potentials of project, whereas the MIRR value gives more realistic of project evaluation.
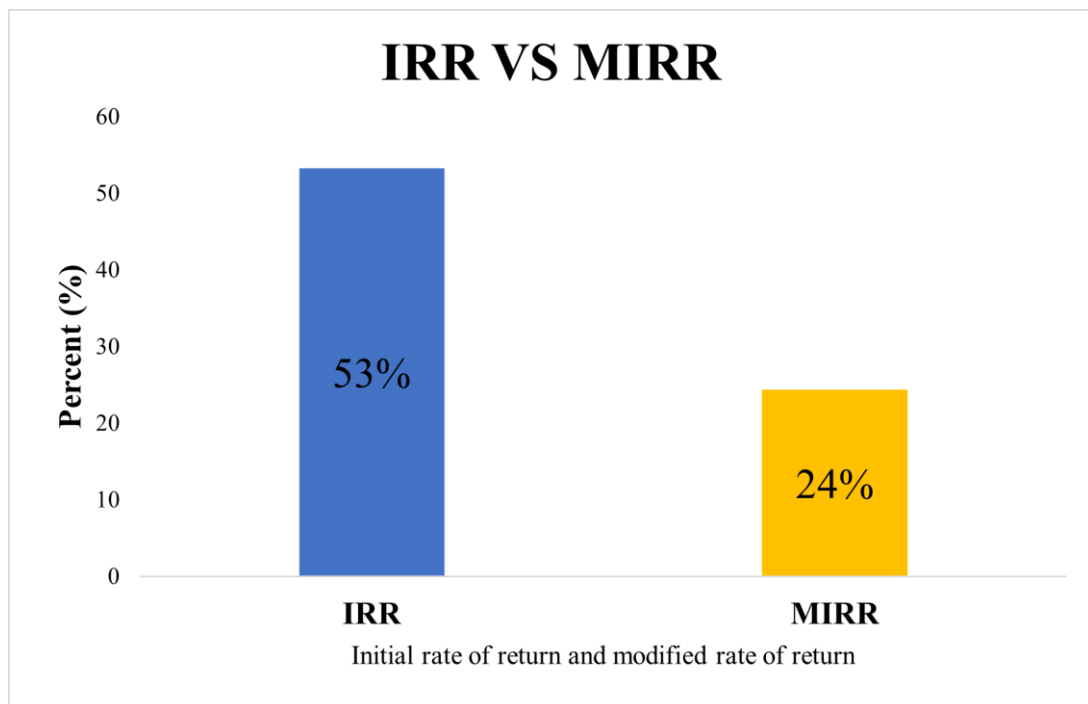
Fig. 5.4 Initial rate of return and modified rate of return

CHAPTER 6
CONCLUSIONS AND RECOMMENDATION

6.1 Conclusions

This study aims to find a source that caused the increase of Fe_2O_3 content in the processing plant, remove the iron oxide from the process at Sand and Soil Industry Co., Ltd., and determine the project financial evaluation in terms of economics.

The XRF results revealed that iron content comes from both source rock (raw material) and the process, especially the ball mill, due to the abrasion of the grinding media and/or the wall of the ball mill. As a result of these factors, the product has an iron content that exceeds the standard requirement. The XRD results showed that the iron content in the sample is in the form of magnetite and pyrrhotite, which come from the source rock of grade B. However, in the case of S11 (underflow of air classifier from ball mill), sometimes magnetite and pyrrhotite were found similar to the S4 sample and similar to the grinding ball from the ball mill, indicating that both iron from the source rock and ball mill are contained in this sample.

The laboratory-scale induced roll magnetic separator was used to reduce the iron content in the samples. The optimum condition with 4 rounds showed the lowest Fe_2O_3 content with the lowest yield and acceptable $CaCO_3$ content, and the content of Fe_2O_3 in this condition meets the standard requirements of the industry.

Magnetic separators are suggested to be installed at the point of ball mill discharge (M1) and underflow of air classifier (M2). Dry high-intensity magnetic separators are proposed. The first one should be placed at M1 to remove magnetic fraction from both of source rock (i.e., magnetite and pyrrhotite) and the abrasion of the ball mill (i.e., synthesis iron) prior to the classification using an air classifier. One more unit is suggested to be installed at M2 to secondary remove the magnetic fraction that still remains in the underflow product of the air classifier prior to recharge to the ball mill. This installation should improve the quality of calcium carbonate from low grade to higher grade that meets the requirements of animal food (Fe_2O_3). The condition of magnetic separation from laboratory-scale experiments can be considered. However, the tests in the pilot and commercial scales should be investigated to optimize the separation efficiency.

Based on the result of reducing the iron content from the process of calcium carbonate plant was undertaken to determine the financial analysis indicated that the project required CAPEX of 6,691,212 baht to setup. The raw material price is 300 baht per ton, including the price of transport to processing plant, whereas the OPEX was 132,896,892 baht. The net revenue was 191,174,764 baht, the depreciation cost was 6,691,212 baht/year all time of 10 year. the income before tax 20% was 51,586,660 baht and income after tax was 41,269,328 baht within 10 years of the operation. Therefore, the Net present value (NPV) was 17,992,947 baht. The interest rate defined at 15%. IRR was estimated at 53% MIRR was 24%, and WACC rate was 15% which can be recovered back from initial investment within 1.6 years. Taking these economics factors into account, using the dry high intensity magnetic separator for reducing the iron content from ball mill at Sand and Soil Industry Co., Ltd. It was concluding that this project is proven feasible.

6.2   Recommendation

There are some recommendations for further study: according to previous experiments revealed that the removal of iron content from calcium carbonate ore can be used with a high electrical current, and low feed rate is required to achieve low iron content. It should use a lower feed rate and higher electrical current than this study and should use vary the parameter of the magnetic separator such as rotor speed, particle size, and splitter for found the optimum condition to reduce the iron content.

Therefore, using other magnetic separators such as wet high intensity magnetic, or others to remove the iron content which is a higher capacity for increasing % yield in order to figure out the optimization between grade and yield.

In addition, the financial analysis of this project indicated that this project could be considered continuing estimation in more detail as feasibility and reasonable to investment.

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APPENDICES

Table A1. Revenue

Description	Values	Unit
Calcium carbonate price (animal food grade)	800	Bath/ton
Price of raw material	300	Bath/ton
Operation	108	ton/day
	3,024	ton/month
	36,288	ton/year
Tailing	29.19	%
Yield	70.81	%
Product for sale (concentrate)	25,696	ton/year
Tailing	10,592	ton/year
Revenue	20,556,426	Bath/year

Table 2. Employment expends

Labor cost	Unit	THB per unit	Total
Plant manager	1	90000	90000
Engineer	6	30000	180000
Accountant	2	20000	40000
Sales manager	2	19000	38000
Overseas purchasing officer	2	22000	44000
Marketing Manager	2	19000	38000
Foreman	3	18000	54000
worker	30	10000	300000
Security	2	15000	30000
Housekeeper	2	9000	18000
Driver truck operator	3	16000	48000
Driver	1	12000	12000
Warehouse worker	2	13000	26000
Total			**918000**

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