Hexane Reduction in a Thai Rice Bran Oil Factory: A Cleaner Technology Approach

Dominica Dacera
Environmental Technology Program
Sirindhorn International Institute of Technology, Thammasat University
P.O. Box 22 Thammasat -Rangsit Post Office, Pathum Thani ,Thailand 12121

Peesamai Jenvanitpanjakul
Environmental, Ecological and Energy Department
Thailand Institute of Scientific and Technological Research
196 Phahonyothin Rd., Chatuchak, Bangkok 10900, Thailand

Suwanchai Nitisoravut
Environmental Technology Program
Sirindhorn International Institute of Technology, Thammasat University
P.O. Box 22 Thammasat -Rangsit Post Office, Pathum Thani ,Thailand 12121

Sandhya Babel
Environmental Technology Program
Sirindhorn International Institute of Technology, Thammasat University
P.O. Box 22 Thammasat -Rangsit Post Office, Pathum Thani ,Thailand 12121

Abstract

Hexane (C_6H_{14}), is universally employed as a solvent in the extraction of oil from rice bran. It is a colorless volatile liquid which is soluble in water and highly flammable. The EPA has now categorized hexane as a HAP (hazardous air pollutant). Since hexane is very volatile, flammable and explosive, it is also a physical hazard. Numerous plants have exploded and burned over the past 50 years often resulting in the loss of multiple lives.

The inevitable daily loss of hexane into the environment is probably the most severe problem in the industry. Hence, it is a requirement to reduce the release of hexane from the production process. In rice bran oil production, hexane loss in the extraction process is affected by several factors, including the quality and nature of raw rice bran and the operational conditions of the extraction process.

Application of a cleaner technology (CT) concept in Surin Rice Bran Oil Co. Ltd., in Thailand, not only resulted in a decrease in hexane consumption but also improved the quality of crude bran oil produced at one of its extraction plants. Preliminary calculation of the reduction of hexane showed a decrease of about 35% from the average of 6.14 L/ton of rice bran before CT option implementation, to 3.99 L/ton of rice bran after implementation. This amounted to hexane savings of 2.15 L/ton of rice bran [equivalent to about Baht 1.65 Million per year (US$ 39,300/yr)].

Immediate implementation of some CT options, especially in the raw material preparation area, also resulted in a 38% increase in yield of high quality, low acid value (AV) oil.

Key words: rice bran, hexane, extraction, oil yield, cleaner technology

1. Introduction

The production of goods and services results in the generation of various wastes. These wastes frequently have a significant environmental impact, the effects of which can last long after the useful life of the manufactured product. In recent years, awareness of these impacts has raised worldwide attention. Traditionally, the focus of solutions to waste problems have been on the treatment and disposal of the waste rather than on waste reduction and minimization or use of cleaner technologies/cleaner production [1]. Recognizing that many companies have realized improvement in economics through cleaner technologies, which reduce or eliminate generation of waste at the source, a Cleaner Technology (CT) Audit was introduced to Thai industries.

Cleaner Technology Audit is the plant level working method for CT and is a systematic and planned procedure for implementing CT with the objective of identifying ways to eliminate and reduce the generation of waste and emissions [1]. A typical waste minimization assessment (or CT audit) procedure is shown in Figure 1.1 . As CT focuses on the production process that causes a wastestream, the central element of the CT Audit is to examine and re-evaluate the production process [1].

Since the introduction of CT to Thai industries in 1991, various industry sectors have implemented the concept to their plant operations. After implementing the CT concept, a number of seafood processing and fruit and vegetable canning factories obtained as much as 3% product yield improvement, 94% savings in water consumption, 59% reduction in steam consumption, 65% reduction in electricity consumption and 29 % reduction in solid wastes [1]. A dairy processing factory, which is in the process of applying CT techniques such as technology modification and good housekeeping practices, is expected to obtain up to 63% savings in water consumption and 46% reduction in wastewater [3].

A number of textile mills in Thailand which implemented this concept, have obtained similar benefits, such as up to 50% savings in chemical consumption and 70% savings in water consumption [4].

Recent case studies on CT implementation in other countries present tremendous economic and environmental benefits from CT.

By applying reuse of brining wastewater, a "kimchi" (salt-pickled and fermented food) factory in Korea has attained water savings and wastewater reduction [5]. In the fish processing industry in Chile, the application of recirculation of pumping water and other housekeeping practices attained a 7% increase in productivity and a 91.6% reduction in the estimated chemical oxygen demand (COD) value of a ton of processed fish [6]. In Australia, on-site recycling of scrap plates in the lead-acid battery manufacturing industry resulted in a 49% reduction in the quantity of lead waste generated [7].

The various success case studies on CT prompted other companies in Thailand to apply the concept in their own facilities. One of these companies is a rice bran oil factory.

Between September, 2001 to September, 2002, CT Audit and Monitoring was conducted at Surin Bran Oil Co., Ltd., a medium-sized food company located at Amphoe Krasang, Buri Ram, Northeast of Thailand. The factory has three extraction plants and one refinery plant which produces bran extract and rice bran oil.

Rice bran oil (also called rice oil) a by-product of rice milling, has been extensively used in Asian countries such as Japan, Korea, China, Taiwan, Thailand and Pakistan [8]. In Thailand, there are about 7 factories processing rice bran oil.

Rice bran oil is used for both edible and industrial applications. Only high quality rice bran oil is used for food, such as for frying and for making mayonnaise and salad dressing, etc. Recent studies [9] revealed that rice bran oil significantly decreases serum cholesterol levels in the body. Industrial applications of rice oil include glycerine and soap production and as a supplement to animal feeds.

The production of rice bran oil involves three major processes namely: preparation/stabilization; extraction to produce crude bran oil; and refining to further process the oil to refined bran oil. In the extraction process, hexane is universally employed as a solvent to extract oil from rice bran. The solvent is also used to extract oil from soya beans [10] and other grains, such as corn. Hexane (C_6H_{14}) is a colorless volatile liquid

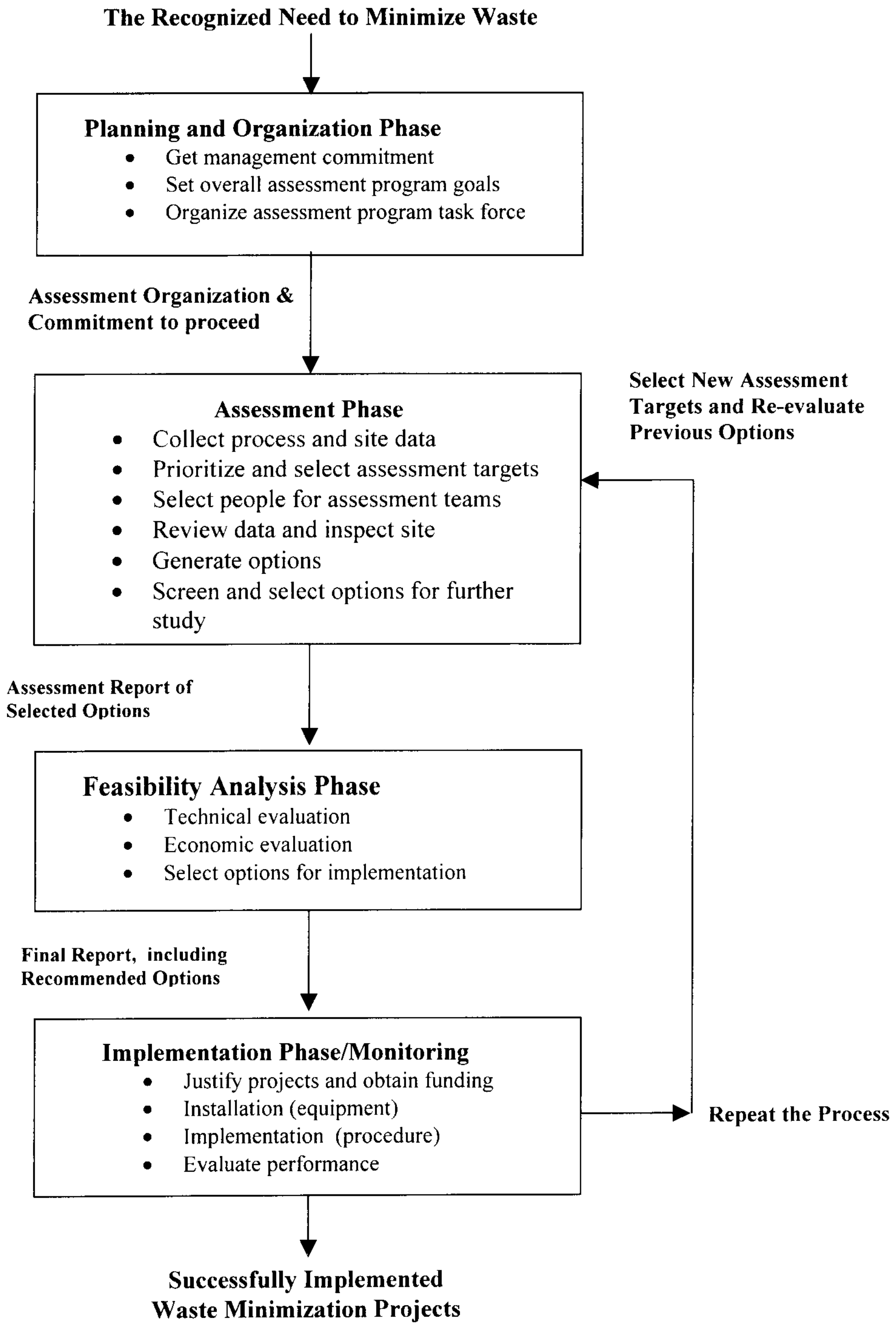


Figure 1.1
The Waste Minimization Assessment Procedure [2]

which is soluble in water and is highly flammable [11].A study of the toxic activity of seventeen industrial solvents and halogenated compounds on human lymphocytes has ranked hexane among the first three solvents that exerted the most toxic effects [12]. The EPA has now categorized hexane as a HAP (hazardous air pollutant). It is now included in the list of 189 toxic chemicals and is controlled under the TRI (toxic release inventory) of the U.S. EPA [13]. Although acute inhalation to high levels of hexane can cause mild central nervous system (CNS) depression and irritation of the skin and mucous membranes, no information is available on the carcinogenic effects of hexane in human or animals. Hexane therefore is not classifiable as a human carcinogen [14].

Since hexane is very volatile, flammable and explosive, it is also a physical hazard. Due to hexane leakage, numerous plants have exploded and burned over the past 50 years often resulting in the loss of multiple lives [11].

The inevitable daily loss of hexane into the environment is probably the most severe problem in the industry [11]. Hence the release of hexane to the environment should be minimized. In rice bran oil production, hexane loss in the extraction process is affected by several factors including the quality and nature of raw rice bran, and the operational conditions of the extraction process [15].

This study focuses on the application of the CT concept by Surin Rice Bran Oil Co., Ltd., to reduce hexane consumption in their production process. It is expected, that after implementation of some CT options, hexane reduction including other economic and environmental benefits will be attained by the company. Moreover, no estimates of pollution prevention in terms of hexane reductions have been done for the bran oil industry [16]. This study also attempts to estimate actual hexane reduction levels in the factory.

2. Methods

The general CT Audit procedure and monitoring as modified by the Industrial Environment Institute of the Federation of Thai Industries (IEI/FTI) from USEPA [2] as shown in Figure 1.1, and UNEP's Cleaner Production Manual [1] was used to conduct the audit for Surin Bran Oil Co., Ltd. This is described briefly as follows:

Phase 1: Pre-assessment

The pre-assessment visit was conducted in September, 2001. The purpose of the pre-assessment was to set up the company CT Audit Team; identify areas of concern in the factory; identify preliminary CT options; and select the audit focus. In this step, the preliminary baseline information was first collected through questionnaires, interviews, visual observation and some measurements related to water consumption.

The audit focus was selected based on the ranking of environmental issues in the factory and by evaluating processes and unit operations which:

- create a high quantity of waste and emissions;
- cause high economic loss;
- have numerous obvious CT potential ; and
- is accepted by all personnel involved [1].

Based on the pre-assessment findings, the audit was focused on Extraction.Plant 3.

Phase 2: Assessment

Once the audit focus has been selected, the assessment visit was conducted in October, 2001. The purpose of the assessment was to collect detailed information on Extraction Plant 3. The following were also done: identification and evaluation of losses and imbalances in the process; evaluation of preliminary CT options; generation of more options especially in the assessment focus; and setting up of the CT goal of the company. Due to time constraints, the assessment evaluation was made using production data for only five days i.e. from October 19 – 24, 2001. CT options generated during the assessment were further evaluated to determine the technical, economic and environmental feasibility.

Based on the CT audit findings, the company set 10% reduction of hexane in one year, as its CT goal.

Phase 3: Implementation

Once feasible options were selected, implementation was done by the company following the stages for implementing any other project, that is, planning, design, procurement and construction. Some CT options which did not require modification or additional equipment were implemented immediately.

Phase 4: Monitoring

The performance was monitored by comparing the "actual benefits" obtained after the implementation of CT Options against the "expected benefits" (Section 3.5) on the following issues: changes in waste and emissions; changes in resource consumption; and profits. A visual comparison was also used to assess the difference in the factory situation.

For determining the loss of hexane, data collection was done by recording the amount of hexane added to the process per time to maintain the required hexane to bran ratio in the extraction process. It is assumed that the amount of hexane which could not be recovered after extraction is lost to the environment.

A monitoring visit was conducted in September, 2002 to collect information on the improvements done by the factory resulting from the CT audit in October, 2001. Data was collected through questionnaires and focused primarily on the CT audit focus, comparing the company situation before and after the CT options were implemented; evaluating the CT goal of the company; and identifying constraints on CT implementation.

3. Discussions

The findings and discussions are focused on Extraction Plant 3 which was selected for the CT audit.

3.1 General Factory Information

Surin Bran Oil Co. Ltd., was established in 1991 and currently employs 70 staff members, including 20 daily workers. The factory is located on 70 rai of plain land surrounded by paddy fields, rice mills, and an ice production plant adjacent to a river. It has three extraction plants and only one oil refinery plant which operates 24 hours per day and 7 days a week. The main raw material is raw rice bran (from Jasmine rice). Parboiled rice (rice that has been soaked, steamed and dried using steam pressure prior to milling) is also used. Table 3.1 gives the information on the raw material consumption and products of the company [17,18]. The data presented are average values of year 2001 data.

Table 3. Production Information [17,18]

Particulars	Amount (Units/year)	Cost (Baht/Unit)
Products		
Bran Extract	48,090 tons	3.62/kg
Crude Bran Oil	11,674 tons	13.13/kg
Refined Bran Oil	324 tons	16.00/kg
Raw Materials		
Rice Bran	63,120 tons	3.78/kg
Hexane	455,280 L	16.19/L
NaOH	33,900 kg	4.20/kg
Sulfuric Acid	51,012 kg	3.00/kg
Bleaching Earth	12,960 kg	13.50/kg
By-products		
Rice Brokens	1,048 tons	4.44/kg
Utilities		
Water	45,960 m^3	0.72/m^3
Oil	32,040 L	9.00/L
Rice husk	9,700 tons	0.13/kg
Electricity	2.5 x10^6 kWh	2.27/kWh

Information on the amount of phosphoric acid used, wax, acid oil, and soap stock produced, was not available.

3.2 Overview of the Production Process in Extraction Plant 3

The company employs three major processes for the production of refined bran oil namely: preparation, extraction and refining. In Extraction Plant 3, only preparation and extraction is done. The resulting oil of the desired acid value (AV) is sent to the refinery plant for refining. The refining process consists of the following steps: degumming, neutralization, bleaching, deodorization and dewaxing.

The following provides a brief description of the major processes in Extraction Plant 3 during the time of the CT Audit [17,18]:

a. Preparation/Stabilization

The bran (at 10.2 % moisture) delivered to the factory from the rice mill was first measured in terms of acid value (AV) of oil, moisture content, and contamination. The AV of oil is regularly analyzed by titrating the bran sample which has been dissolved in a solvent, with potassium hydroxide (KOH) or sodium hydroxide (NaOH) solution against phenolphthalein [6]. Bran with AV value less than 30 was sent for processing. The bran was then sent for sieving to separate rice-brokens, dirt, stones and other impurities. After cleaning, the bran was sent to the cooker for stabilization. The bran was then heated using direct and indirect steam and cooked at a temperature of about 90 – 100° C to destroy or inactivate the enzyme-lipase and prevent the continued production of free fatty acids. The cooked bran was then sent to the extractor.

Wastes produced from the preparation process were dust, rice brokens (sold as animal feed), husks, lumps of bran, spilled bran and other contaminants such as stones and shells. Steam and some spilled bran were the wastes produced from the stabilization process.

b. Extraction

In the extractor, hexane (at the rate of 220–280 L/min) was pumped in and allowed to percolate through the bran to extract the oil. Countercurrent extraction was used. A hexane: bran ratio of about 2.2:1 was used in the process. Extraction took place for one hour at 50° C, after which the hot oil/hexane mixture or so called miscella was passed through cyclones and then to a series of evaporators to separate and hexane from crude bran oil by evaporation. (The boiling point of hexane is 65° C). Hexane was then recovered from the water vapor. The factory has four units of evaporators used for oil separation. Three of these units used indirect steam while the other one used both direct and indirect steam. The evaporators were operated at atmospheric pressure at varying temperatures: unit 1 at 65 –70° C, unit 2 at 80 – 90° C, unit 3 at 90 – 110° C, and unit 4 at 130 – 140° C. The oil rom the evaporators which has a final temperature of 125 – 130° C, was then filtered to remove the bran fines before sending to the centrifuge. The crude bran oil was then measured in terms of AV value. Oil having AV more than 30 was sold as animal feed.

The bran extract (residue) was sent to the toaster where it was heated with both direct and indirect steam at a temperature of 100° C for 45 minutes to evaporate the hexane out of the residue. The bran extract was then sent for sieving and grinding before packaging.

Hexane Recovery

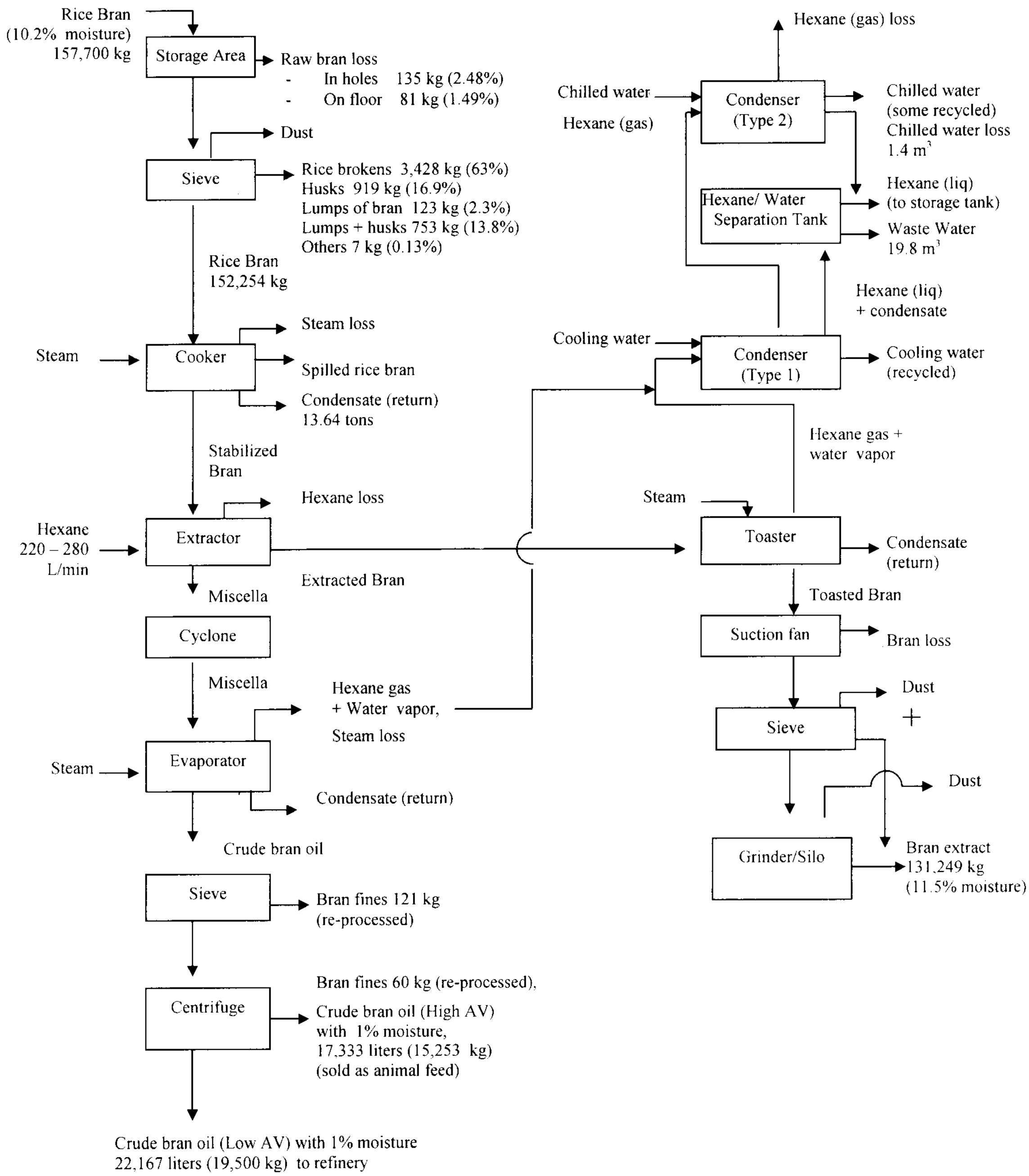
The hexane used in the process was recovered as follows: The mixture of hexane and water vapor from the evaporator and toaster was sent to the condensers, where chilled and cooled water from the cooling tower was used to condense the gas mixture. The condensed mixture was then passed to the water-hexane separation tank where hexane was recovered and used again in the extraction process. This is done in a closed loop continuously everyday. The waste water was then sent to the treatment system.

Wastes produced from these processes included dust, steam, hexane, wastewater and bran fines (which were re-processed).

3.3 Identification of Losses during Production Process

The losses and imbalances were determined using the data collected from Extraction Plant 3 over a week as shown in Figure 3.1. However, not all losses were quantified. For hexane loss, data presented are based on the amount added to the process each time, to maintain the required hexane to bran ratio which was 2.2:1. The hexane loss represents the hexane not recovered at the hexane recovery system.

As shown, most losses in the preparation area were in the form of husks, lumps of bran, spilled bran on floor, dust, etc. which constituted about 37% of the total raw material loss. Rice brokens which constituted about 63% of the losses in this area were sold as animal feed. Hexane loss which was about 4.2-13 L/ton of rice bran processed, constituted a major loss in the process. As shown also in Figure 3.1, hexane losses occurred from the following: extractor, in the form of hexane gas; evaporators, also in the form of hexane gas or liquid which combined with the oil; toaster in the form of hexane gas and liquid which may have combined as moisture in the bran extract; condensers, in the form of both gas and liquid; and the water-hexane separation tank in the form of liquid which might have combined with the wastewater. Other losses included steam, water and bran fines (0.08% of raw rice bran processed), which although being re-processed, used more energy and hexane. Energy losses in the form of electricity were not quantified.



Basis: Average daily values over five day period

Figure 3.1 Process Flowchart Showing Sources of Waste streams [18]
(Extraction Plant 3, Surin, Bran Oil Co., Ltd.)

3.4 Cause Assessment of Losses

- **Raw Material Storage, Preparation and Stabilization**

Most of the raw material losses in this area were due to rice milling operations and improper storage, sizes of mesh screen used for sieving, including the delivery procedure.

It is well known that raw rice bran contains an extremely active enzyme called lipase which hydrolyzes the triglycerides and releases free fatty acids (FFA). High FFA indicates high acid value (AV). In conventionally milled rice bran, FFA levels can rise to up to 10% in a matter of hours. High FFA oils are not suitable for refining since the removal of the acidity leads to considerable losses of neutral oil. It is generally recognized that oils more than 10% FFA can not be refined economically [8].

In Surin Bran Oil, raw rice bran is obtained from different rice mills, some a considerable distance from the factory, and is transported uncovered by a truck. After delivery, the raw rice bran is left in the storage area for several days before being processed. The "old" rice bran, dust and even oil from the truck contaminate the newly delivered rice bran. The long storage causes deterioration in the quality of the raw rice bran.

Analysis of the AV of oil in the bran from the storage area of the factory over a two – day period is shown in Figure 3.2. As shown, there was a continuous increase in acid value of raw rice bran as the bran stayed longer in the storage area. This confirms the study done by Cornelius [19].

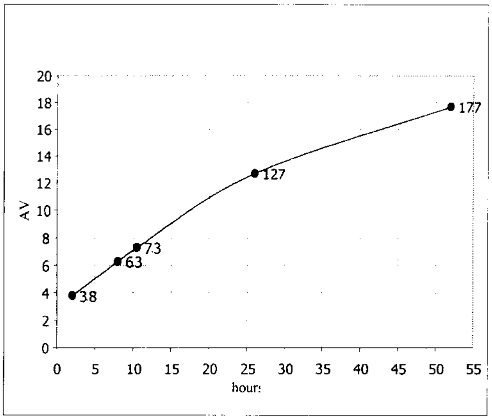


Figure 3.2 Change in Raw Bran Acid Value (AV) with Time [18]

The poor quality of the rice bran also explains the production of about 44 % high acid value crude bran oil which is not suitable for refining, as shown in Table 3.2.

Table 3.2 Crude Bran Oil Production over a 6-day Period [18]

Date	High AV Oil, (Liters)	Low AV Oil (Liters)
19/10/01	2,000(5.3%)	36,000(94.7%)
20/10/01	17,000 (41.5%)	24,000(58.5%)
21/10/01	24,000(63.2%0	14,000 (36.8%)
22/10/01	19,000(48.7%)	20,000(51.3%)
23/10/01	23,000(56.1%)	18,000 (43.9%)
24/10/01	19,000(47.5%)	21,000(52.5%)
Total	104,000	133,000
Average	17,333 (43.7)	22,167 (56.3%)

Losses in the stabilization area were caused by leakages in steam pipes and valves; uncovered areas in the conveyor and leakages in the cooker which caused the spillage of rice bran.

- **Extraction and Oil Recovery**

Losses in the extraction area were caused by several factors as explained below:

Hexane losses due to leakages in the system can be at the extractor, the evaporator, the condensers and at the hexane-water separation tank. The presence of impurities in the raw bran also affected the increased use of hexane in the extraction process. Since the rice bran was not pelletized before extraction, the percolation of hexane through the extraction bed was slower resulting in lower extraction efficiency, thus producing more bran fines for re-processing. The bran fines also clogged the screen in the extractor when hexane was sprayed over the bed, some of which combined with the miscella. Since the company used a high hexane to bran ratio, this caused hexane flooding in the bran and caused difficulty in the evaporation of hexane from the bran extract. This explains the presence of hexane residues in the bran extract and oil. Hexane residues in bran extract can be as high as 0.5% [13]. The use of a cyclone instead of a filter after extraction resulted in lower hexane - oil separation efficiency, with more fines being produced for re-processing. This was because the cyclone did not serve the purpose of separating the bran fines from the miscella resulting in a poor quality and highly colored oil. To obtain a high yield of good grade oil and a trouble free operation of the evaporation unit, miscella filtration is a must [15].

An unsuitable temperature in the evaporators for oil separation also caused hexane loss. Moreover, since the factory employed co-current cooling, the condensation efficiency in the condensers was low causing more hexane to escape into the vent. The temperature at the condenser was observed to be almost 30 °C. From experience, a cooling water temperature of higher than 27 °C was insufficient to condense hexane vapor efficiently, indicating poor cooling.

3.5 Cleaner Technology Options Identified/ Implemented

A total of 50 cleaner technology options were identified for Extraction Plant 3. These were classified mainly as Improved Operating and Housekeeping Practices, Technology Change and Recycling. Improved Operating and Housekeeping Practices include procedural measures, loss prevention, management practices, waste stream segregation, material handling improvements and production scheduling; while Technology Change include process changes, equipment, piping or lay-out changes additional automation and changes in operational settings [1].

Tables 3.3 and 3.4 summarize the CT options, which are directly relevant and recommended for hexane reduction and oil yield improvement.

Table 3.3 Recommended CT Options at Raw Material Storage, Preparation and Stabilization Areas

CT Options	Implementation Status
Improved Operating and Housekeeping Practices:	
Practice FIFO (first in , first out) in raw material processing, to avoid large amounts of high AV raw material	Implemented immediately
Regularly clean the storage area (free of dust, e.g. on the ceiling) to avoid contamination	Implemented immediately
Use a covering for the truck which transports rice bran to protect from rain and bran loss.	Implemented
Install a screen in the storage area to prevent accumulation of dust and other contaminants or construct a new area/silo for storage of raw materials.	Under consideration
Properly weigh the rejects/ other contaminants to identify losses in the process	Implemented immediately
Regularly clean the sieving machine to remove deteriorated rice bran	Implemented immediately
Make a covering for the drain line from sieving to minimize dust .	implemented immediately
Technology Change:	
Use a screen that has automatic cleaning system for better separation of rice brokens	Implemented
Use new direct steam injector for thorough injection and better bran stabilization.	Under consideration
Install temperature controller in the cooker to control the temperature for stabilization to less than 75°C. This is to reduce vapor loss and reduce the wax content in the oil.	Under consideration

Table 3.4 Recommended CT Options at Extraction Area

CT Options	Implementation Status
Improved Operating and Housekeeping Practices:	
Fix the leakages in the system to prevent hexane loss	Implemented
Always check the level of water in hexane–water separation tank to prevent water overflow and enhance hexane-water separation efficiency.	Implemented immediately
Fix the leakage in the condenser to avoid hexane loss and chilled water wastage.	Implemented
Fix/change the gear of the extractor conveyor to avoid bran loss and avoid noise.	Implemented immediately
Technology Change:	
Install a bran pelletizer in the extractor to facilitate solvent flow and avoid clogging.	Under consideration

Change /repair the conveyor used to transfer bran from preparation process to avoid accumulation of deteriorated bran.	Under consideration
Install filtration units instead of cyclones for effective separation of fines and improvement of oil yield.	Implemented
Change the sieve size of miscella filter from 150 mesh to 120 to improve oil quality and reduce maintenance cost.	Implemented
Lower hexane to bran ratio to 1:1 instead of 2.2:1 to avoid flooding of hexane and facilitate its evaporation.	Under consideration
Use appropriate temperature under reduced pressure to increase hexane – oil separation efficiency.	Implemented
Change the feed direction of hexane at the condenser in countercurrent with cooling water for more effective hexane cooling.	Implemented
Practice regular machine maintenance to prevent hexane loss.	Implemented
Install jet pulse bag filter to minimize loss of bran extract	Implemented

Expected Economic Benefits : Minimized bran loss; minimized raw rice bran contamination; improved quality bran for processing; minimized accumulation of deteriorated bran; improved recovery of rice brokens; reduced hexane and steam consumption; improved crude oil extraction; minimized re-processing of bran fines; reduced refining losses; efficient operation of extraction plant; and higher yield of good grade (low AV) oil.

Expected Environmental Benefits: Reduced hexane and boiler air emissions, reduced dust emissions; and reduced solid wastes [18].

3.6 Results of CT Options Implementation

3.6.1 Reduction in Hexane

Figure 3.3 shows the trend in hexane losses in the factory.

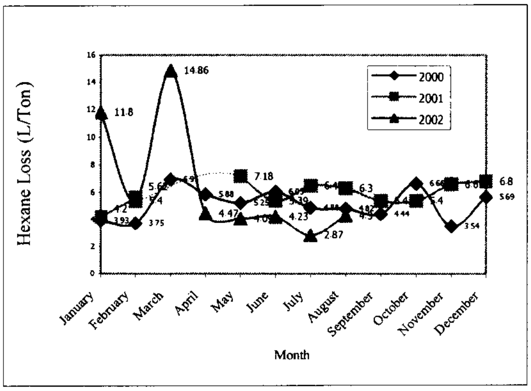


Figure 3.3 Trend in Hexane Losses,Surin Bran Oil Co., Ltd. [20]

As can be seen from the figure, there was a noticeable decrease in hexane loss to the environment after the implementation of major CT options during April-August, 2002. These CT options included the installation of filter unit to replace the cyclone after extraction; and the modification of a condenser such that the flow of hexane becomes countercurrent with the flow of cooling water. However, during the implementation phase from January-March, 2002, a considerable increase in hexane loss to the environment is seen. This was due to an unavoidable loss of hexane during equipment fittings.

Preliminary calculations of the reduction of unrecovered hexane showed a decrease of about 35% from the loss of 6.14 L/ton of rice bran before CT option implementation, to 3.99 L/ton of rice bran after implementation. This amounted to hexane savings of 2.15 L/ton of rice bran which is equivalent to Baht 1,652,200/year (US$39,300 at Baht 42/US$), assuming a rice bran consumption of 4,000 tons per month. The total amount invested so far by the company was only Baht 515,000 (US$12,262) [20].

3.6.2 Improvement in Oil yield

Immediate implementation of some "Improved Operating and Housekeeping" options during October, 2001, especially in the raw material preparation and storage area also resulted in the increased production of low AV oil as shown in Table 3.2 and Figure 3.4.

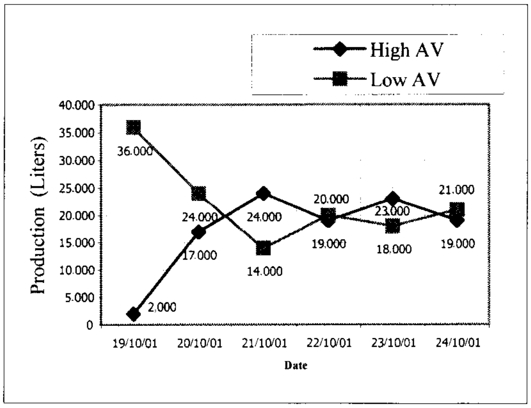


Figure 3.4 Trend in Crude Bran Oil AV [18]

As shown, the average low AV oil produced was about 56.3% of the total oil produced, with 94.7% attained on 19th October, 2001. During this time, the factory had disposed of all "old" bran remaining in the storage area and processed only newly delivered raw bran. The results also showed that the factory is capable of producing about 38% more low AV oil from the average of 56.3%, if the factory continues to use only freshly delivered rice bran. This would eventually save the company about 15,100 liters (equivalent to 13,300 kg of oil at density of 0.88 kg/L) of low AV oil per day which can reach to up to 5,436 m^3 (4,800 tons) per year.

4. Conclusions

The preliminary results of CT monitoring at Surin Bran Oil, indicated the following:

- Implementation of the CT options especially the installation of a filter unit and the modification of the condenser, resulted in a 35% decrease in hexane consumption. The company therefore has surpassed its goal of 10% hexane reduction in one year, by 25%.
- Immediate implementation of improved operation and housekeeping options also improved the high quality, low AV oil yield in the factory. This indicated the capability of the factory to increase the oil yield by about 38% more from the average of 56.3%.
- Other economic and environmental benefits attained by the company included reduction in steam consumption, reduction in boiler air emissions, reduction of dust emissions and reduction of solid waste.

However, CT also has also its limitations as experienced by the company: some CT options could not be implemented immediately because it hindered production; actual hexane lost (such as the determination of the total residual hexane content in waste water, oil and bran extract) was difficult to determine because the company lacked the expertise and equipment for residual hexane analysis; CT suppliers were not known or difficult to find causing delay in implementation; and some CT options although economically feasible, have high initial investment cost.

From the foregoing discussions, however, it can still be concluded that the benefits derived from CT implementation far outweigh its limitations.

5. Acknowledgements

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- Mr. Pongsatorn Artornturasuk
- Mr. Natthawut Sitthitham

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