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Multimedia environmental audit in a rice cracker factory in Thailand: a model case study

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Abstract

This case study was conducted in a medium scale food-processing factory in Thailand. The factory, which manufactures rice crackers, faced serious problems in the operation of its effluent treatment plant (ETP). In order to solve this problem by reducing the waste generation at source, rather than retrofitting the ETP, this study was initiated using the waste audit approach advocated by the manual published by UNEP-UNIDO. The study also considered more comprehensive issues such as noise pollution, occupational safety (heat stress on workers) and multimedia aspects of waste generation (airborne emissions, solid waste). Thus, after conducting a thorough multimedia environmental audit, a number of avenues for improved integrated environmental management could be identified, leading to cleaner production. The study showed that by water reuse, waste segregation and solids recovery, water consumption could be reduced by 25%. BOD, COD, and SS loading of overall wastewater discharged to ETP could likewise be reduced, by around 20%, 25%, and 50% of the existing situation, respectively. This would in turn result in the more efficient operation of ETP, as well as economic benefits. Moreover, the comprehensive methodology adopted in this study could be proposed as a model methodology to conduct a multimedia environmental audit leading to cleaner production.

Keywords: Waste audit; Source reduction; Food processing; Multimedia environmental audit

1. Introduction

In Thailand, industrial waste management still generally adopts a traditional end-of-pipe waste treatment approach. In most cases, industries address the issues of waste management by designing waste treatment plants and installing pollution control equipment. This approach enjoys several advantages. It is a straightforward and simple operation, low risk, and offers the ability to meet the required effluent standards in a relatively short span of time. However, effluent treatment costs increase steeply with increased production, or with increased treatment efficiency. Furthermore, waste treatment does not result in the total elimination of pollution, but merely results in the transformation of pollution from one form to another and it still has an impact on the environment. Especially in recent years, by-products from waste treatment such as sludges have become an important problem regulated by strict legislation. In many situations, therefore, end-of-pipe treatment provides only a short-term, inadequate and costly solution.

A sustainable environmental protection method should therefore focus on preventing and reducing wastes *at source only* by improving the production processes. An audit is the first step towards achieving this goal and consequent cleaner production. An environmental audit is a basic management tool which might be considered to comprise a systematic, documented, periodic and objective evaluation of how adequately environmental organization, management systems and equipment are performing. The aim of such an audit is to facilitate management control of environmental practices, and to enable the company to assess compliance with company policies, including regulatory requirements [1]. In the present context, the scope of environmental audit was restricted only to the various aspects of production processes, resource consumption, waste generation and occupational health and safety issues. This process also

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enables the industry to take a comprehensive look at its operations and understand material flows; it thus helps to focus attention on areas for waste reduction. This may also result in economic benefits in addition to the environmental benefits.

2. The present study

The present study was conducted in Factory A, a medium scale manufacturing enterprise in Thailand producing rice crackers. A typical small and medium scale enterprise in Thailand is defined as one which employs less than 50 workers, with a total investment of less than US$40,000 [2]. Although the study was initiated to solve the ETP problem, it was not restricted to this objective. The volume of wastewater produced and its characteristics prima facie suggested higher water intake and higher wastewater discharges than the prescribed comparable norms. Hence, these issues were addressed in the study. Further, multimedia issues such as air emissions, occupational safety (noise and heat stress and its effect on workers) and solid waste generation were studied. Avenues for valuable resource recovery and recycling in an economically attractive manner were also explored. Thus, the outcomes of the entire study were expected to serve as pointers leading to integrated environmental management and cleaner production.

The philosophy and methodology adopted in this study basically followed, but was not restricted to, that recommended in the Audit and Reduction Manual of Industrial Emissions and Wastes prepared by UNEP-UNIDO [3]. Accordingly, an audit team comprised of the factory personnel and the external auditors was formed for this exercise. Further, this study was seen as an opportunity to field test a model methodology for multimedia environmental audit to supplement this manual. This field tested methodology could then be proposed as a 'Model Multimedia Environmental Audit Methodology'.

3. Background information about the candidate industry

Rice crackers, a Japanese baked snack food made from rice, is now becoming increasingly popular in Thailand. During the preparation of the rice, large volumes of wastewater are produced in the soaking, cooking, and washing stages. As per the available literature, the average BOD of the wastewater is around 1000 mg/L [4,5].

Fig. 1 gives a schematic flow chart of rice cracker processing in Factory A. The rice cracker production process typically involves the following main steps: rice washing, rice soaking, grinding, steaming, kneading, cutting, baking or frying, seasoning, coating (if any) and packing [5]. The following major environmental problems could be summarized in the production process of rice crackers: wastewater, solid waste, noise, dust and high temperature/heat stress.

Raw material used in the rice cracker production in Factory A is primarily non-glutinous rice (91% refined), soy sauce and other materials to improve the taste and flavour. This factory consumes around 150 m^3/day of raw water, with an average production of 2000 tons of rice crackers per year.

There are two wastewater streams from various production units of the plant. First, the rice cracker processing wastewater, which is treated at the wastewater treatment plant, and the treated effluent are discharged to public drainage; second, storm water, domestic waste (partly) and wastewater from cleansing soy-sauce-coating tanks in the factory area are discharged directly to public drainage, which is close to the public canal. The typical characteristics of raw wastewater of Factory A are: wastewater volume: 40 m^3/d; pH: 4.5, BOD_5: 1900 mg/L, with a suspended solids concentration of 300 mg/L.

All the process stream wastewater is discharged into the wastewater treatment plant through the open channels. Originally, the effluent treatment plant had been operated as an activated sludge system, which consisted of a sump, a primary clarifier, an aerated lagoon, an aerated tank, a final clarifier, an oxidation pond and a sludge drying bed. Due to unsatisfactory results, the management decided to change this system to a sequencing batch activated sludge system in 1980. The existing ETP combines the aerated tank and the aerated lagoon, and obviates the need to use the final clarifier.

4. Methodology

As mentioned earlier, the basic philosophy adopted in the study was as recommended by the UNEP-UNIDO Audit Manual. Broadly, this methodology consists of the following phases:

1. Collection of background information (process inputs and outputs);
2. Preparation of the process flow diagram;
3. Establishment of material balance; and
4. Identification and evaluation of waste reduction options.

4.1. Step 1: collection of background information (process inputs and outputs)

4.1.1. Preassessment: conducting plant walk-through

In order to gain a first-hand understanding of the production process, a thorough walk-through of the entire factory area was conducted. Initial visits to the factory

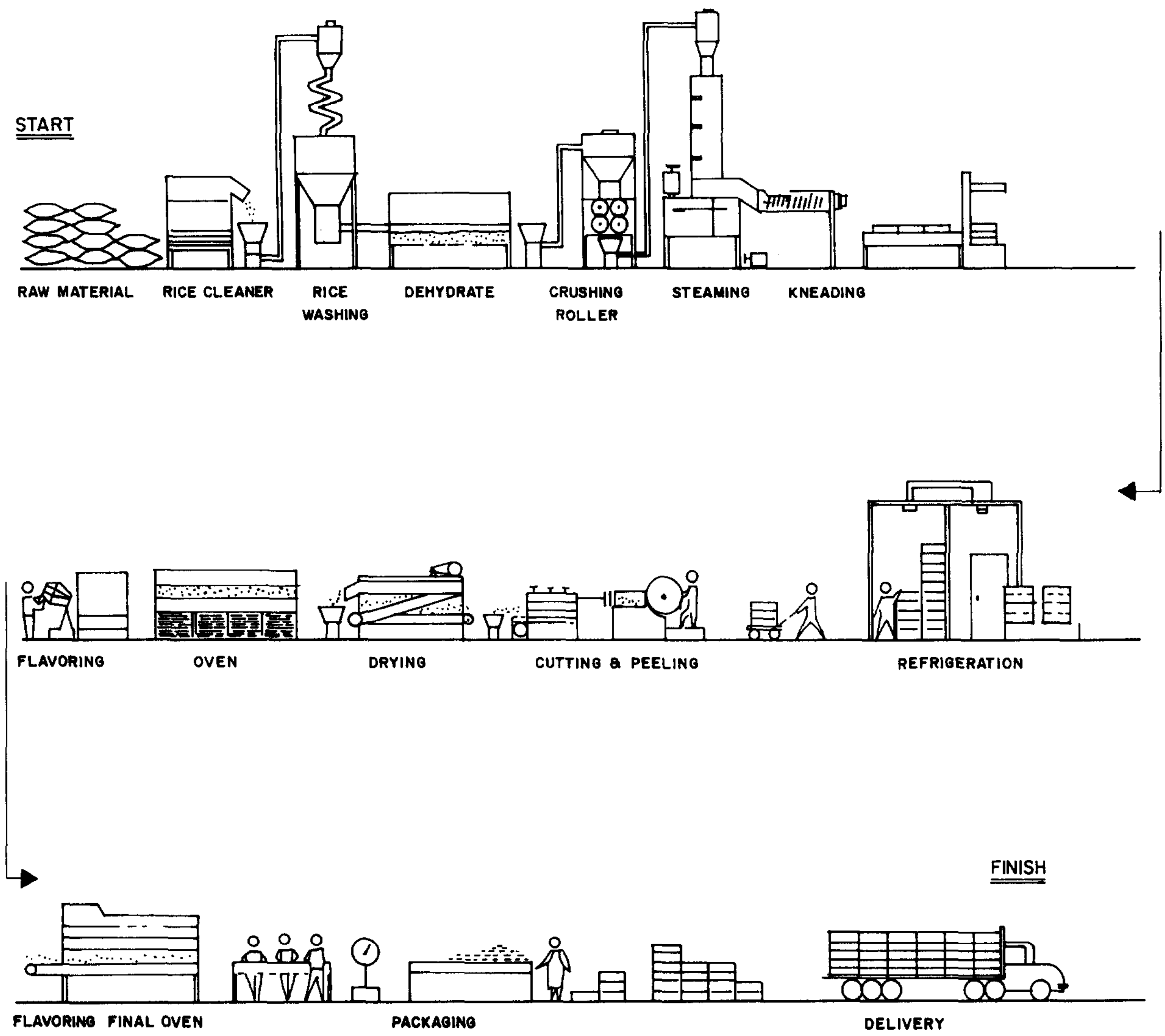

Fig. 1. Flow diagram of rice cracker processing in Factory A.

were devoted to understanding the production process, production practices, material flows and sources of wastewater generation. Raw material storage and handling practices were reviewed and data pertaining to raw material consumption were also collected.

The information was collected and recorded not only through visual observation, but also through discussion at every stage with the production managers and machine operators. This background information was very useful in assessing the present performance of Factory A with respect to resource consumption and wastewater generation.

In the audit activity, it is important to minimize the data collection work by identifying the appropriate sampling locations and parameters [6]. From this point, the initial walk-through also helped in identifying major priority problem areas in the factory that needed attention and improvement, and hence there was a need to conduct a detailed and exhaustive data collection at these points. Thus, the sampling locations emerged after this initial preassessment phase, and hence more attention could be given only to these priority areas. An appropriate detailed sampling programme was then chalked out which was approved by the factory management. In the second phase, this data collection programme was implemented.

4.1.2. Water and wastewater

In the case of water and wastewater, both volume and water/wastewater characteristics data were collected. The sampling locations are shown in Fig. 2. Flows were measured using flow measuring devices such as a flow meter and a V-notch. In addition, crude methods, such as bucket and stopwatch, were also adopted at times, where practical problems were faced in installing a flow meter or a V-notch.

4.1.3. Physical agents in the work environment

In the work environment study, the evaluations focused on three hazards, namely noise, heat stress and airborne particulate matter that affect the workers.

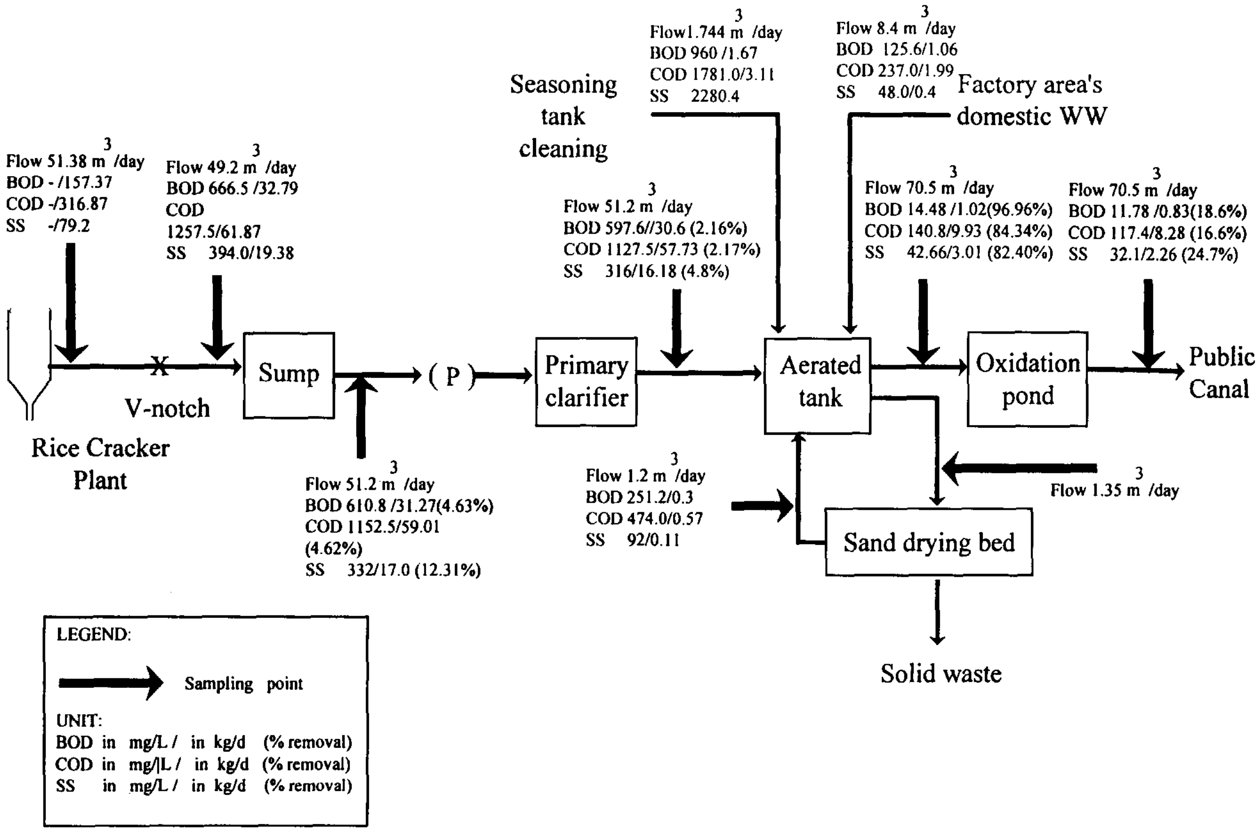

Fig. 2. Location of sampling points and existing BOD, COD, and SS loads on the effluent treatment plant.

4.1.4. Noise

The noise sources in the factory, such as the crushing roller, kneader and pump, generate continuous noise. During this study, mainly two types of noise level measurements were done. These were:

1. Noise level measurement based on area; and
2. Noise level measurements based on activity.

The unit used in both these cases was dB(A). By using sound pressure level (SPL) meters, spot sampling was done for noise evaluation. Noise dosimeters were used to evaluate the impacts on workers, while working in a particular type of environment and exposed to this noise. A sound pressure level meter and noise dosimeters were used to evaluate the noise exposure value in terms of sound pressure level (SPL) and equivalent sound pressure level (Leq), respectively.

4.1.5. Heat stress

Heat produced by the body and the environmental heat together determine the total heat load. Therefore, if work is to be performed under hot environmental conditions, the workload category of each job should be established and the heat exposure limit pertinent to the workload be evaluated against the applicable standard, in order to protect the worker exposure beyond the permissible limit.

Since the measurement of deep body temperature was impracticable for monitoring workers' heat load, the measurement of atmospheric factors was required. This could be nearly correlated with deep body temperature and other physiological responses to heat. The Wet Bulb Glove Temperature Index was thought to be the simplest and most suitable technique to measure the environmental factors. In this method, three types of temperature measurements were carried out, namely: Natural Wet Bulb Temperature, Dry Bulb Temperature and Glove Temperature.

4.1.6. Airborne particulate matter

In this study, airborne particulate matter measurements were done in three locations, which were most likely to have the maximum particulate concentration. These were:

1. Rice cleaning;
2. Rice powder machine (*kum-bi-ko*); and
3. Frying.

In the frying section, airborne particulate matters are due to natural or vegetable oil aerosols. Thai standards do not specify a limit for this oil type. Therefore, existing standards for dust were used as the standards for natural oil aerosols.

4.2. Step 2: preparation of the process flow diagram and other data representation

Exhaustive raw data collection is useful only if it is properly represented and appropriately interpreted. The key to a successful environmental audit lies in this step and was thus recognized as an important step in the entire exercise. Further, preparing detailed process flow diagrams sharpens the understanding of the entire production process and material flows, and thus pinpoints priority issues.

A very detailed process flow diagram was developed based on visual observations and exhaustive data collection made at earlier steps. All the raw material inputs, waste and by-product generation from each step, material movements, recycle streams, and air emissions were represented in this diagram. In this way an attempt was made to make the diagram as comprehensive and as illustrative as possible.

The data pertaining to physical agents like noise and heat stress were tabulated. However, a novel method for representing this data was adopted in this study. Both noise level and heat stress data were presented in the form of heat stress and noise contours. By comparing with prevailing Thai standards for noise and heat stress values in the work area, the locations in the factory exceeding these limits could be identified and those were then marked in red as priority locations where some corrective or prohibitive measures needed to be undertaken. This system of representing the collected data was found to be much more self-explanatory and thus appealing to the factory management.

4.2.1. Noise

According to Noise Level Standards for the workplace announced by the Ministry of Industry of Thailand, occupational exposure of not more than 90 dB(A) for 8 h/day is considered acceptable. Of the 62 sampling locations, 14 locations (between 20 and 25% of total sampling points) exceed maximum noise levels specified by the standards. Areas exposed to a noise level of more than 90 dB(A) are: the steaming area, the rice powder machine, packaging room of the roasted products and the roasting section. These noise values are the maximum values measured at sampling points. They also represent the noise levels generated by surrounding unit processes.

Fig. 3 shows the noise level contours in terms of dB(A), and thus rapidly classifies the hazardous areas by using shading. The areas marked in shade are exposed to excessive noise levels.

4.2.2. Heat stress

Permissible Heat Exposure Threshold Limit (PHETL) values of various sections of the factory were in the range of 28–30°C. In the study, it was revealed that 10 of 11 locations are exposed to excess heat stresses.

4.2.3. Airborne particulate matter

Airborne particulate matter was evaluated in the rice cleaning area, the frying section, and the rice powder machine, which generates airborne particulate matter such as 'nuisance dust'. According to the specified standards, the average amount of inert or nuisance dust generated throughout the normal working time is 15 mg/m^3. It was observed that the concentration of airborne particles in the factory is below the standard levels.

4.3. Step 3: establishment of material balance

In order to account for the excessive water consumption in the factory, a material balance across the entire production process, as well as across important unit operations, was established. Since excessive water consumption was an important issue of concern, water was adopted as the 'tie parameter'—in other words, a water balance was established during this exercise.

In this study, water consumption by each unit operation was measured and recorded. An intensive water usage monitoring programme for each key unit operation was completed taking into consideration all water-consuming equipment individually and subsequently accounting for all the washing activities for each process. The major process output of concern was the liquid waste from the washing and soaking processes, and a detailed account of wastewater discharge was prepared based on field measurements.

4.4. Step 4: identification and evaluation of waste reduction measures

After establishing the material balance and understanding the important factors resulting in any imbalance, a number of avenues for improvement could be identified by the audit team. These modifications are discussed in detail below.

4.5. Proposed modifications in the production process

In this study, it was found that 30 m^3/day (i.e. 75% of the total) of wastewater generated by the rice washing and dehydration unit had high pollution potential in terms of SS. These SS could not be avoided from the process in any case. It was recommended that these settleable SS be removed by some pretreatment given only to this stream. Coagulation sedimentation and centrifugation are the two shortlisted technical options the factory management wanted to consider for detailed technoeconomical evaluation. These methods would not only reduce the water used for cleaning the drain, or reduce the wastewater load, but would also eliminate settling in the drain. The recovered solids could possibly be used as animal feed.

Table 1 summarizes the quantity of water available

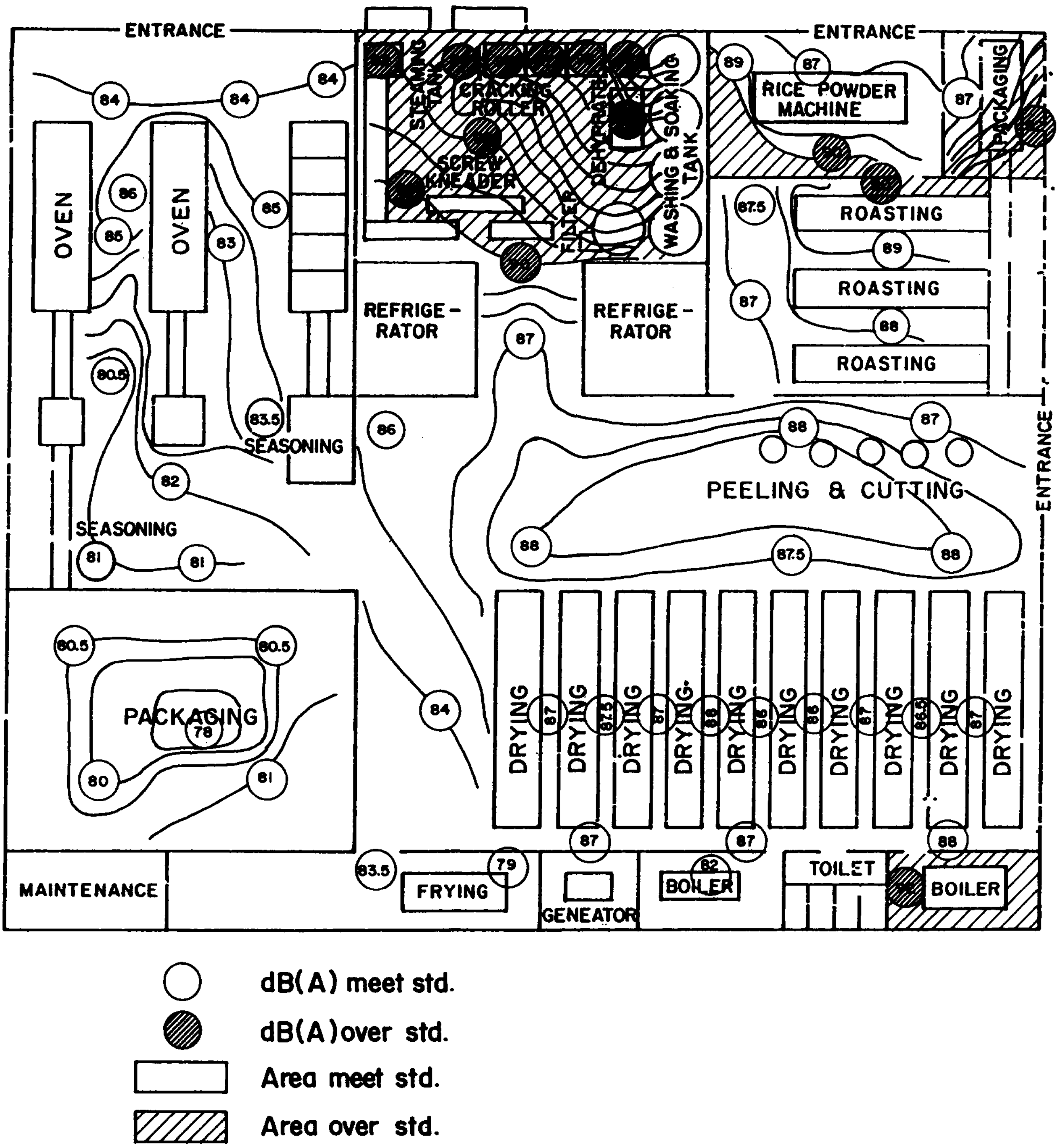

Fig. 3. Location of sampling points and noise levels.

for reuse and the reduction in water consumption. From the table, it is apparent that the total water consumption could be reduced by 21 m^3/day. Because of the high quality of overflow water from activities under category A and cooling kneader water, it can be reused for activities such as cutting or container cleaning. Details of group B are schematized in Fig. 4. The direct savings in terms of water and wastewater treatment cost and the possible waste recovery are estimated at US$900/month.

4.6. Water and wastewater aspects

In this factory, water is obtained by manual operation of valves and washing machines, equipment, containers, cooling gear wheel and floors use 20% of total water. By applying simple in-plant modification, the amount of water required could be reduced drastically. Some such modifications are:

1. Replacing manually operated tap valves with auto-

Table 1
Quantity of water available of reuse and the reduced consumption of water

Activity A	Wastewater volume (m^3/day)	Activity B	Possible reuse (m^3/day)	Wastewater for treatment (m^3/day)
Rice washing	7.5	Floor cleaning	4.5	
Dehydration	22.0	Drain cleaning	12.0	13.0
Lubricating conveyor	4.0	Cooling gear wheel	1.0	3.0
Overflow water	4.5	Kneader cleaning	1.0	
		Cutting	1.0	2.5
Cooling kneader	3.5	Container cleaning	2.0	1.5
Total	41.5		21.5	20.0

matic shutoff valves and using spray guns for washing;
2. At the steam and cutting section, dry cleaning of floors or equipment should be done before using water in order to reduce cleaning water consumption and to avoid waste rice or products entering the wastewater stream; and
3. A screening unit can be installed at the discharge point and open drainage system to prevent residue material (waste cake, wood stick, papers, etc.) from entering the waste stream. However, disposing of screening will have to be done daily.

The study revealed that substantial settling of SS was taking place in the drainage line (Fig. 2). Around 12 m^3 of water is used daily for cleaning and flushing sediment in this drainage system. Increasing the slope of the drainage canal can increase the wastewater flow rate to reduce sedimentation in this canal.

Collection of strong wastes and isolating them from the relatively diluted effluent would substantially reduce the quantity and, accordingly, the strength of the wastewater for easy and economical treatment. Figs 2 and 4 show the effects on wastewater flow, BOD, COD, and SS concentrations after segregation of wastes.

4.7. Occupational health and safety aspects

The effects of physical agents such as noise, heat stress and particulate matter in the various unit operations were assessed by summarizing them as shown in Table 2. The weighted sum method was done in order to determine the most critical areas in order to assist the factory management in preparing an environmental action plan. This weighting process was based on the number of workers exposed to each hazard, i.e. noise, heat stress and airborne particulate matter. Based on this weighted sum analysis, the following conclusions were drawn:

1. Airborne particulate matter is not found to be harmful;
2. The drying oven, frying, roasting and rice powder sections in the factory were exposed to excessive heat;
3. The boiler and steam sections are exposed to high levels of noise and appropriate action must be taken; and
4. To reduce the effect of heat and noise hazards, the following measures should be taken:
   4.1. Noise
      4.1.1. Provide education and training for the workers;
      4.1.2. Provide regular maintenance for all noise producing equipment;
      4.1.3. Cover the noise generating part of equipment in order to reduce noise levels;
      4.1.4. Workers should be provided with noise protective equipment, such as ear plugs, as per the recommendations of ACGIH; and
      4.1.5. Reduce the exposure time of the workers.

   4.2. Heat
      4.2.1. Provide good ventilation; and
      4.2.2. Reduce the exposure time of the workers.

Based on this detailed weighted sum method, the audit team concluded that the two most important priority areas in terms of occupational health and safety are the roasting and oven sections.

5. Conclusions and recommendations

Conclusions and recommendations for waste minimization strategies and waste reduction measures to achieve cleaner production at Factory A can be summarized as follows.

5.1. Factory A

It can be said that the rice cracker plant has been operating with a significant degree of water wastage leading to a considerable amount of effluent generation. For this reason, the effluent of this factory is potentially a pollutant to the environment. Simple in-plant modifi-

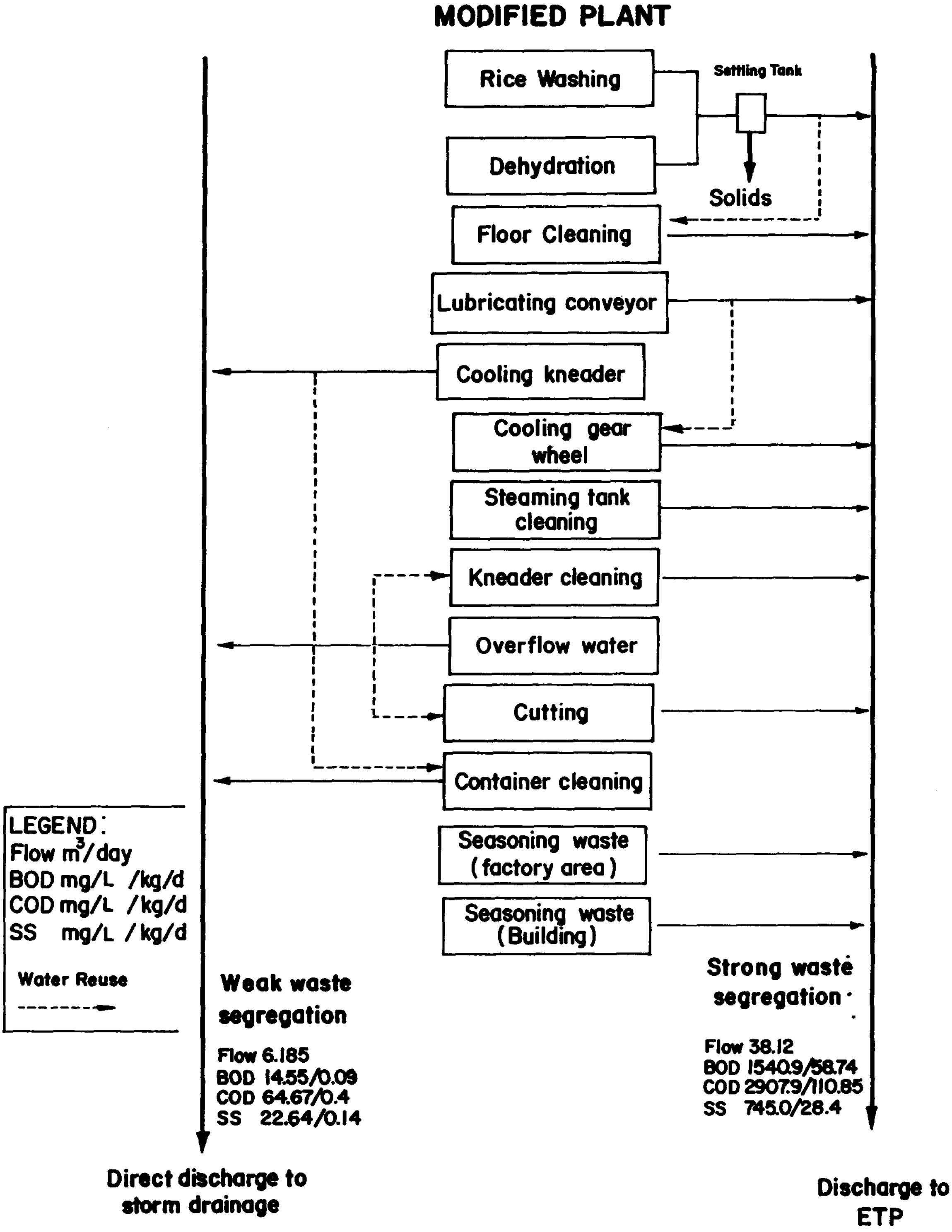

Fig. 4. Waste segregation for the modified effluent treatment plant.

cations, such as the following, can reduce water consumption significantly.

Wastewater segregation, which refers to the collection of strong wastes for separate treatment, is highly recommended. Isolation of high pollution process outputs, such as steaming tank cleaning, rice washing, dehydration, lubrication conveyance, and cutting, is proposed for the purpose of effecting a reduction in wastewater volume and concentration levels of BOD, COD and SS in the effluent. Based on the measurements of 62 sampling points, the noise level produced in the steam section, rice powder machine and boiler room are higher than Thai standards, and about 44 sampling points higher than the recommended levels of the ACGIH.

Table 2
Weighted sum method for identifying priority areas (occupational health and safety)

Activity/ section	No. of workers	Risk weighting[d]	Max. noise value (dBA)[a]	Risk weighting	Exposure of heat stress[b]	Risk weighting	Airborne particulate matter (mg/m^3)[c]	Risk weighting	Total	*Priority*
Steam	5	1	98	2	NP	0	NP	0	3	6
Peeling and cutting	12	3	88	1	NP	0	NP	0	4	5
Drying	20	4	88	1	OS	2	NP	0	7	3
Oven	21	5	86	1	OS	2	NP	0	8	2
Frying	7	2	83.5	0	OS	2	2.92	1	5	4
Roasting	27	6	90	2	OS	2	NP	0	10	1
Q.C.	6	2	86	1	NP	0	NP	0	3	6
Rice powder (*kum-bi-ko*)	7	2	90	2	OS	2	0.91	1	7	3
Boiler	—	1	92	2	NP	0	NP	0	3	6
Godown	5	1	89	1	NP	0	3.75	1	3	6

[a]Noise–risk relationship: < = 85 dB(A) = 0; 85.5–90 = 1; > 90 = 2.
[b]Heat stress: NP = not significant (risk = 0); OS = over standard.
[c]Airborne particulate (mg/m^3)–risk relationship: NP = not significant 0; < 15 (mg/m^3) = 1; > 15 (mg/m^3) = 2.
[d]No. of workers vs risk: 1–5 = 1; 6–10 = 2; 11–15 = 3; 16–20 = 4; 21–25 = 5; 26–30 = 6.

From the heat stress determination results of the rice cracker plant, it was found that in almost all the areas which involve heat, workers are exposed to a higher degree of heat stress than the recommended levels of ACGIH. Rice cleaning, frying, and rice powder machine operations are not significantly affected by airborne particulate matter. Concentrations of particulate matter in the ambient air from these activities are lower than the maximum permissible value assigned as per Thai standards.

Based on the weighted sum method used in this study, it was found that the roasting section should be considered the priority for control of appropriate working conditions.

5.2. About the methodology

The multimedia waste audit methodology as an extension to the UNEP-UNIDO waste audit and reduction methodology based on the material balance was implemented and tested in a typical medium scale food-processing factory. It was found to be extremely useful in clearly identifying problem areas, and thus arriving at integrated waste management solutions without relying on expensive waste treatment. Moreover, this methodology is more effective, as it is not restricted to traditional aspects of waste management such as wastewater and solid waste, but embraces other aspects such as noise and occupational safety, and thus addresses waste management problems in their totality.

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