Sustainable Water Resource Conservation Practice in a Dairy Processing Factory, Thailand

Shing Tet Leong
Research Lab Supervisor, Urban Environmental Engineering and Management Program, School of Environment, Resources and Development, Asian Institute of Technology, G.P.O. Box 4, Klong Luang, Pathumthani 12120, Thailand.

Preecha Laortanakul
Affiliated Research Associate, Mailing address: 216 Soi Satsana 5, Phya Thai, Bangkok 10400, Thailand, (e-mail: tet@ait.ac.th).

Abstract

This study was conducted in a medium scale dairy processing factory in Thailand. The factory faces serious operational problems in its wastewater treatment plant. In order to solve such problems, an activated sludge plant with anoxic/oxic stage was recommended to treat this type of industrial wastewater. As a package of the improved wastewater treatment system, a rock bed filtration unit was employed for polishing effluent of the treatment plant During the water-wastewater reuse concept, a mass integration is employed for segregation, purification and recycling. In this way, technology modification, good housekeeping and waste segregation, water conservation and reuse can result in up to 63% saving in water resources and 46 % reduction of dairy wastewater input to nearby grassland or stream.

Keywords: Activated sludge plant, dairy processing factory, rock bed filtration unit, waste segregation, water conservation and reuse

1. Introduction

In Thailand, agriculture contributes an important part of its economic development by providing 40% of GDP and employing 60% of the labor force. Raw milk production is one of the important agro-based products. In 2000, there were about 82 dairy processing plants registered in Thailand producing 0.128 million tons of milk (NSO 2000). Likewise, water use in the dairy processing plant has increased at an extremely rapid rate. Excessive use of water from existing streams and poor pollution control will be a potential threat to future expansion plans for the dairy processing industries that depend solely on canal water sources for their water supply. During the dry season (January to April), water from nearby canals is withdrawn faster than it can be replenished by rain. Due to the magnitude of production, dairy processing plants discharge various byproduct effluents containing fluid milk, juice and whey, together with wash water containing detergents and chemicals which have alkaline characteristics coupled with high dissolved organic matter. Discharge of untreated dairy wastewater to the grass field can cause odorous problems and undesirable septic conditions. In addition, there would be a run-off problem during the rainy season creating health risks to the population living downstream (UNEP-UNIDO, 1991). In Thailand, facultative-stabilization ponds were commonly used to treat dairy wastewater. However, obnox-ious odor were the main problem encountered in the pond system. This problem can however be overcome by technological modifications. In a laboratory study, more than 95% COD removal efficiency for diary wastewater was reported in a lab scale anaerobic-oxic activated sludge process (Carta-Escobar et al., 2002). Research conducted by Hosokawa et al. (1992) revealed that suspended and dissolved substances remaining after conventional secondary treatment can be effectively treated by a rock bed filtration unit. This method is considered as low cost water treatment based on biodegradation, sedimentation and filtration in the rock media or void space.

The traditional end-of-pipe waste treatment approach does not totally eliminate pollution, but merely transforms pollution from one form to another which still has impact on the environment. In addition, these approaches have typical technical requirements and cost implementation, which result in higher operation cost. Therefore, waste minimi-zation and cleaner production are often employed to improve the production processes and thereby achieve a sustainable environmental protection. Waste minimi-zation consists of source reduction and recycling and can reduce waste without any major financial burdens (Cheremisinoff et al., 1992). Basically, waste minimization is a systematic planned waste reduction audit to eliminate waste (Rossiter et al., 1995). Typically, waste minimization/ cleaner production refers to heterogeneous group of pollution reduction such as reuse in the production process or process modification including process recovery and reuse options (UNEPA, 1988).

The rapid growth of the milk processing industry in Thailand will continue be a serious threat to the environmental quality. Therefore, a sustainable approach to water management such as recycling some process water several times in certain processing areas and efficient wastewater treatment methods are suggested to offset current shortages and stabilize water resources.

1.1 Description of the Dairy Processing Plant

The selected study site is situated at Saraburi province, Thailand and stretches over 48 km^2 of rolling farmland, with about 300 dairy cows. The area has a tropical climate with annual temperature ranging from 22.4 ^{0}C in the rainy season to 36.6 ^{0}C in the dry season, and the average annual rainfall of over 1,100 mm. The farmland comprises of two commercial and one cooperative farms. The individual location of these farms is indicated in Figure 1. The raw milk collected by commercial and cooperative farms is sent to a central dairy processing plant and processed into ready to drink milk. The dairy processing plant produces three types of principal products namely pasteurized milk, sterilized milk and yogurt. The total land area of the factory is 39,704 m^2 including 21,668 m^2 of available land area for wastewater treatment system. The operational capacity of the factory is 20 tons milk per day. The factory operates three 8 h/d shifts and employs 140 workers. Flow diagram for overview of dairy processing is shown in Figure 2.

Receipt of milk

Raw milk is collected from farms and delivered to the dairy plant for processing. On arrival, the milk is tested for appearance, smell and temperature. A sample is taken to the laboratory to ensure the quality of the milk.

Clarification and separation

A high-speed clarifier is used to centrifuge raw milk ensuring that the milk is free from sediment. A separator is used to remove fat to produce skim milk.

Homogenization process

This process is performed by equipment known as homogenizes which break up the fat globules in the milk and stabilizes the emulsion to an extent that prevents any noticeable rising (cream layer formation) of the fat. During the homogenization process, milk is subjected to violent and whirling-type movements that break up globules of fat into smaller units with a diameter of less than 3 micron. This is achieved by forcing the milk through tiny nozzles under high pressure. Homogenised milk has more pleasant taste and is more easily digested.

Pasteurization process

The purpose of milk pasteurization is to destroy all pathogenic bacteria and the bulk of the non-pathogenic organisms, thereby ensuring that it remains fresh for a longer period. During this process, filtered milk is heated to a predefined temperature of 90 ^{0}C for 15 seconds to destroy all pathogenic bacteria but without affecting the product's nutritional properties. If the heater exchanger temperature falls below mini-mum, the control valve will divert milk to the balance tank for re-processing. The pasteurized milk is then cooled down to 6 ^{0}C, before it proceedes to the final packing process.

Sterilization process

The primary purpose of the heat sterilization of the milk is to ensure that milk is safe for human consumption and has an extended storage life. During the Ultra High Temperature sterilization, milk is heated to 143^0C for 3 seconds. to destroy all microorganisms and their spores. After this the milk is cooled to 18^0C. and packing it in air-tight containers.

2. Materials and Methods

A thorough planning is a prerequisite for developing comprehensive waste minimi-zation options. General information about the factory was gathered and compiled via factory visits. Information in the existing facilities about raw material management was gathered through discussion with the concerned factory personnel and from the production record. Water and wastewater sources for the production process are shown in Figure 2. Water meters were installed to measure daily water usage in the whole production process. Amount of water consumed by the factory was calculated from the weekly average in one month. Some losses of water were also estimated in this area. Water balance was conducted based on actual measurements following an identification of water consumed for each key unit operation and wastewater generated in processes. Composite water samples were collected from general floor washing, equipment cleaning and the processing plant to determine the wastewater characteristics. Hourly grab samples were collected for the wastewater treatment plant. Flow measurement is very important for estimating the quantity of wastewater discharge in each unit. Wastewater flow rate in open channel was measured by using a container and timer or current flow meter. A portable ultrasonic flowmeter equipped with Portaflow sensor is also used for ease of measuring the flow rate from the outside of a processing pipe. Water and wastewater analytical methods are strictly followed in the "Standard Methods" (APHA, 1992). Probable source reduction, reuse and recycling were considered as alternative methods for elimination or reduction of excessive water use and wastewater generation. The focus was on one or more of the following probabilities:

- Technological modifications
- Good housekeeping and process execution
- Reuse and recycling and source segregation
- Purification of process wastewater
- Minimization of wastewater generation

Quantification of benefit from the generated waste minimization options was done depending on the probable waste reduction. Percent reduction in waste volume or weight were calculated and compared with the existing one to study the feasibility of implementation of that option.

3. Results and Discussions

3.1 Water Source and Consumption

The existing water supply for the dairy processing plant is drawn from a nearby stream. The raw water is treated by sedimentation and a sand/anthracite filter and stored in water tower. Water from raw water tank is supplied for the whole factory by two main pipelines, to processing plant and to other areas. From the record, the average daily water consumption of the factory is about 714 m^3/d.

There is no control over the water usage within the factory, the majority of which is released as wastewater. The principal water usage within the factory is process water, floor washing, equipment cleaning and domestic purposes. Utility water consum-ption is made on the basis of processing: 236 m^3/d, deodorizer: 80 m^3/d, equipment washing: 70 m^3/d, cooling water: 50 m^3/d, floor washing: 25 m^3/d, hand washing: 4 m^3/d, office use: 7 m^3/d and domestic: 111 m^3/d, service: 109 m^3/d, and backwash: 22 m^3/d. Overexploitation of water from nearby stream has resulted in deterioration of water quality with depleted water resources. As a result, a sustainable approach to water management is needed to conserve the water resource, in order to avoid a water shortage within the dairy processing plant.

3.2 Conservation, Minimization and Reuse Management

Table 1 and Figure 2 respectively show the typical wastewater characteristics and wastewater generating points in the production process. It is noted that different strengths of wastewater (different concentrations of suspended solid) were generated along the production line. The low strength washing process wastewater was generated from cooling, domestic, back-wash and boiler condensate while wastewater from receiving, processing and packaging areas were the main sources of high strength process wastewater. Low strength hot wastewater from cooling process, instead of being discharged continuously to effluent treatment plant, a separate pipeline would be necessary to collect this type of wastewater, purified and reused for either processing or cleaning and washing. However, reused wastewater lines should be carefully installed to ensure product quality and hygiene. Water used for the deodorizer could also be recirculated to reduce the necessity of discharging it. In this way, the waste volume to be treated could be reduced by water conservation, which results in reduction of wastewater treatment cost. High strength wastewater were generated from rinsing and cleaning of process equipment, which contains milk solids and cleaning agents. If this waste was discharged along with the effluent stream, it could greatly increase the organic load of the effluent. It has been observed that spilled milk wastewater contains a substantial amount of milk products. Fat and cream in the wastewater could be recovered by separator and reprocessed again. In the dairy processing plant, the main problem was pollution through spoilage of milk. In normal cases, the spoiled milk was sold to the farmers for animal feed. Sometimes, the quantity of spoiled milk exceeded the farmers' demand then it was discharged to the sewer. This practice would contribute an extremely high pollution load to the wastewater treatment plant. Thus high strength wastewater has to be segregated to avoid difficulties encountered with end of pipe treatment. All spoiled milk wastewater in the processing area should be minimized or eliminated and routed to a separate part of the wastewater handling system.

High frequency of floor and equipment washing was identified as a cause of high wastewater generation in the factory. Open tap washing, lack of good housekeeping and inefficient use of water were observed very frequently in the factory contributing to high water consumption. In addition, washout of spilled milk was observed very frequently which contributed to higher organic load in the wastewater. Using high-pressurized cleaning technique for floor and equipment washing purpose could mitigate this problem. Open-ended hose equipped with trigger nozzle can reduce a high percentage of wastewater generation in are production line. An effective cleaning technique can also be achieved by pre-soaking floor and equipment to loosen dirt before the final cleaning. Installation of automatically shut off hand washing taps are recommended to reduce the water consumption used for hand and body washing. In the factory, water leakage was observed in many units as in valve, pump seals, pipeline, etc. Proper maintenance of equipment is another option for wastewater minimization in production plant. It can save an estimated 20-30 % of treated water per year and can reduce the organic loading to the wastewater treatment plant. Worker's awareness is important in proper use of water during hand washing by closing the tap when not in use. This can help in preventing the water wastage to a large extent. Figure 3 illustrates overall water balance for proposed water reuse in the factory which is a sustainable approach to recycle water sources from both high and low strength wastewater.

3.3 Effluent Characteristics

Figure 4 shows the composition of dairy wastewater (processing: 54%, dormitory: 16%, cleaning: 18%, office: 1%, and other: 11%). The BOD levels from each production process ranges from 202 mg/L to 4157 mg/L depending on the dilution factor related to water usage. Table 1 presents the wastewater characteristic from milk production processes. Biological treatment appears to be the most promising technique, since the dairy wastewater has low BOD to COD ratio of 0.65. However, due to their lack of nitrogen and phosphorus, (BOD:N:P = 100:2.7:1.9) dairy wastewater are not sufficient as nutrients for mineralizing bacteria. Therefore, the addition of nutrients to the wastewater is required or the wastewater must be mixed with domestic wastewater. The pH value should be regularly checked and corrected in order to keep it within the limits of 6.5 and 9. Total solids in the dairy wastewater are higher than suspended solids indicating that most of the solids are in dissolved form and thus sedimentation of solids will be necessary (Tchobanoglous, et al., 1991).

3.4 Existing Wastewater Treatment System

The wastewater from the process are treated by facultative waste stabilization ponds. The treated effluent is discharged into an earthen retention pond before it can be land applied by irrigation or disposal into nearby river (Figure 5). However, dairy wastewater can not be disposed by land irrigation during the rainy season. The runoff wastewater will pollute the nearby stream. In addition, surveys show that there are operating problems exhibited in the existing treatment plant. Dairy effluents comprise mainly milk and alkaline washing waters and usually contain high content of milk solids and odorous compounds. This normally leads to scum formation and blackish effluent in the pond system which prevents light from penetrating into the algae culture system. The odor of wastewater is more distinctive under anaerobic decomposition and has turned out to be a more objectionable problem at peak production period generating a large volume of odorous wastewater. Failure of the facultative waste stabilization ponds is also compounded by the excessive use of non-biodegradable chemicals to meet stringent quality control requirements.

3.5 Improved Wastewater Treatment System

A concrete settling basin and pre-settling tank are recommended to trap any solids from both process and domestic wastewater and the settled solid is reclaimed as animal feed. The installation of an equalization pond upstream of treatment stages is recom-mended so that variations in quantity, pH and temperature corrections can be balanced. An activated sludge plant of anoxic and oxic system equipped with one 4 kW aerator is recommended to improve effluent quality of the wastewater treatment plant. A mixed liquor suspended solids of 4,000 mg/L, should be maintained in activated sludge. The food-to-micro-organism ratio of 0.2 d^{-1} and retention time of 6.8 h. should also be maintained in the tank. The system works effectively for the removal of organic carbon as well as suspended solids. The BOD in the effluent is brought down to 40 mg/L, which meets the Thai effluent standard (PCD, 1997). Thereafter, the wastewater is sent to a polishing pond The treated effluent from polishing pond has algae concentration of 85 mg/l and suspended solid concentration of 125 mg/l. Some portions of the treated effluent in the polishing pond are disposed of land irrigation (371 m^3d^{-1}). The remaining volume of 165 m^3/d together with backwash: 22 m^3/d and condensate: 87 m^3d^{-1} is recommended to undergo tertiary treatment to remove suspended solids The characteristics for the upgraded treatment plant are presented in Table 2.

A rock bed filtration unit of 6 reinforced concrete channels (2 m x 2 m x 20 m) is proposed for the tertiary treatment system. The average diameter of rocks ranged from 5 cm to 15 cm having 50 % in porosity. The hydraulic retention time of the bed is one day with organic loading rate of 0.01 kg/(m^3.d) BOD. Daily flushing (6 m^3/d of water) is required to overcome mosquito breeding and heavy algae growth within the rock media. Suspended solid and algae can be successfully removed by rock bed filtration unit with removal efficiency of 96 % of chlorophyll-a and 72 % of suspended solid, from 120 mg/l of chlorophyll-a and 125 mg/l of suspended solid to 4.5 mg/l and 25 mg/l respectively. The removal of COD and dissolved solids by the rock bed filter was found to be effective and met the stringent disinfection requirement. The effluent from the rock filter is hygienically safe and can subsequently be reutilized for floor cleaning, toilet flushing, process washing and deodorization unit.

The reuse of 268 m^3/d water will reduce raw water consumption by 63%. This reuse strategy will also save cost on water, as the cost of raw water treatment is 0.2 \$ m^{-3} compared with 0.1 \$ m^{-3} for treating reused water.The improved water-reuse system can reduce wastewater disposal to grassland by 46%. Table 3 shows a comparison between existing water-usage and improved water-reuse systems. The attractive water reuse incentives have given encouragement to the factory owner to implement a long-term economic water conservation and waste-water reuse plan.

4. Conclusion

Water reuse has been shown as one promising method to reduce wastewater sources from dairy processing industry. This has resulted in daily water resource savings and a minimum amount of wastewater discharge. Discharged water from each unit as well as the fresh feed has been considered in the generation and reuse of wastewater from dairy industry. Potential wastewater sources have been segregated, treated and returned back to the process. The finding has also revealed that upgrade of the treatment system using an activated sludge plant offers an improve-ment for effluent quality and yields less odor. Although the initial investment will be high, an activated sludge process has been proven to be an economical possibility. For water-reuse, a rock-bed tertiary treatment system has been recommended to polish WWTP effluent.

From this study, water-wastewater reuse programs have often been found beneficial not only by environmental protection but also by improving competitiveness. Benefits can be viewed with environmental and economic incentives. In an overall view, the comprehensive methodology adopted in this case study can contribute a share experience with other Asian countries, which have similar water resource conservation and zero discharge problems in their dairy processing plants.

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Table 1. Dairy wastewater characteristics at different processing units

Parameter	Receipt Area	Centrifudal Separator	Pasteurizer	Sterilizer	Deodorizer	Yogurt Plant	Packing Area	Combined Wastewater
Temperature (^{0}C)	28	35	78	93	74	29	29	63
pH	8.8	10.6	9.6	9.7	10.7	11.4	9.9	9.3
BOD[1] (mg/L)	469 (4.6)	2501 (26)	1102 (17.3)	2361 (23)	2633 (26)	4157 (49)	202 (1.7)	1430 (19)
COD[2] (mg/L)	721 (6.6)	3847 (36)	1695 (16)	3633 (36)	4050 (34)	6395 (55)	311 (2.8)	2200 (21)
Total solid (mg/L)	480 (3.6)	2915 (25)	3047 (37)	2880 (24)	2290 (21)	3452 (37)	833 (8.8)	960 (9.4)
Suspended Solid (mg/L)	240 (2.7)	1221 (12.1)	1235 (13.4)	1225 (12.9)	1540 (11)	1100 (10)	410 (4.7)	501 (4.8)
Total Nitrogen (mg/L)	13 (1.2)	66 (6.4)	29 (2.3)	63 (6.1)	70 (7.5)	110 (12.5)	5 (0.9)	38 (3.7)
Total Phosphorus (mg/L)	9 (0.8)	46 (4.4)	20 (1.2)	44 (3.4)	49 (4.7)	77 (8.4)	4 (0.2)	27 (2.3)
Oil & Grease (mg/L)	61 (5.5)	69 (4.7)	65 (5.9)	67 (4.0)	72 (5.4)	80 (9.3)	57 (5.1)	66 (5.5)

1) BOD =biological oxygen demand; 2) COD = chemical oxygen demand; All concentrations = mean $\pm$ S.D., n =3.

Values in parenthesis are Standard Deviation.

Table 2. Sizes of the proposed upgrading wastewater treatment units

	Settling Basin	Pre-settling Tank	Equalization Tank	Anoxic Tank	Oxic Tank	Polishing Pond
Area (m^2)	48	28	128	9	84	750
Depth (m)	1	2	2	2	2	3
Flow rate (m^3/d)	147	438	585	85	585	585
Retention time (h)	8	3	10	0.7	6.8	96

Table 3. Comparison of the existing water-usage and improved water-reused Systems

Parameter	No water reuse system	Water reuse system
Raw water consumption (m^3/d)	714	446
Wasteater disposal to grassland (m^3/d)	694	371
Annual water treatment cost (US$)	52,122	42,340

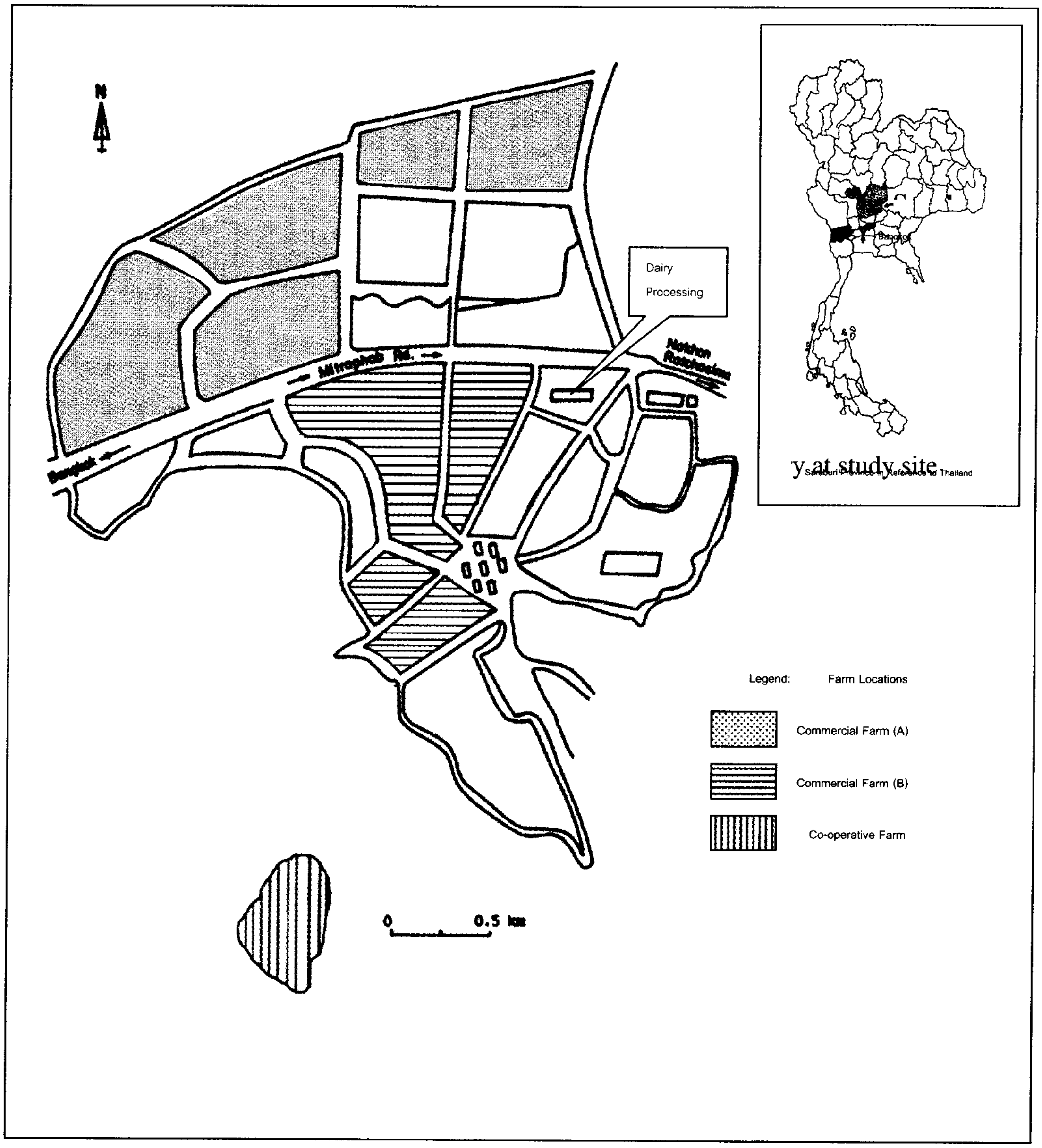

Figure 1. Location of Individual Farms and Daily Processing Factory at Study Site

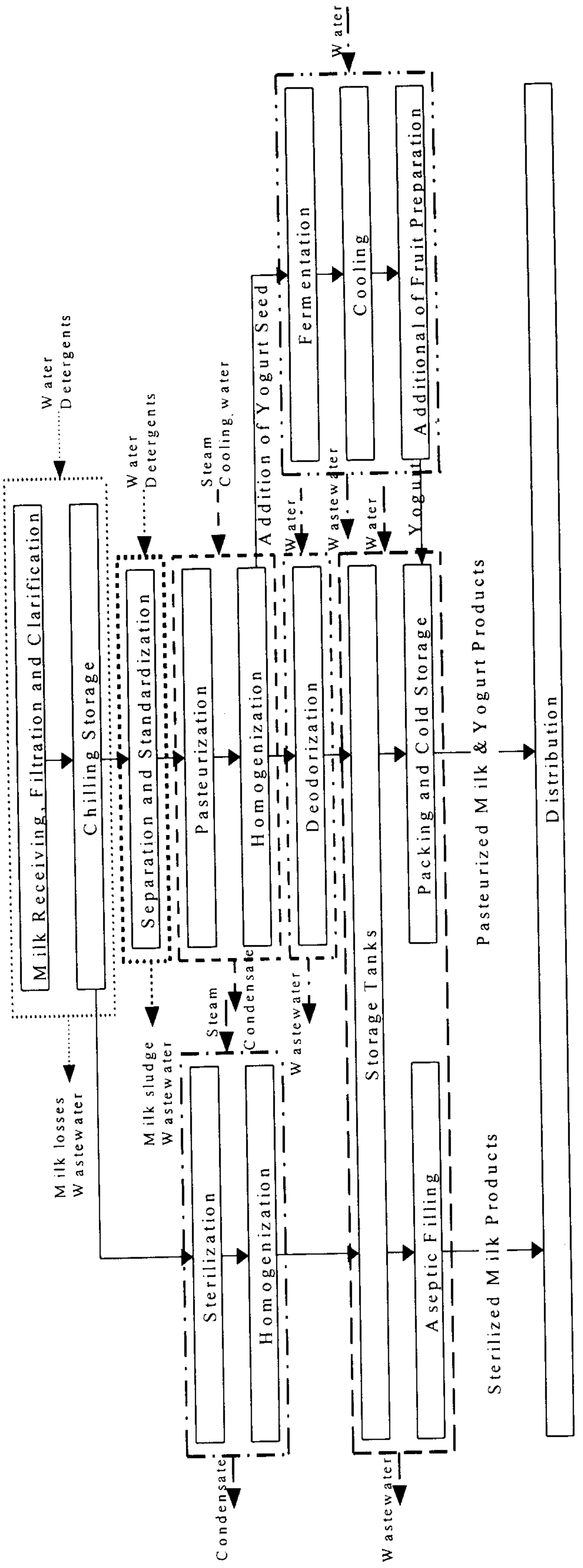

Figure 2. Schematic flow diagram for dairy processing operations and wastewater

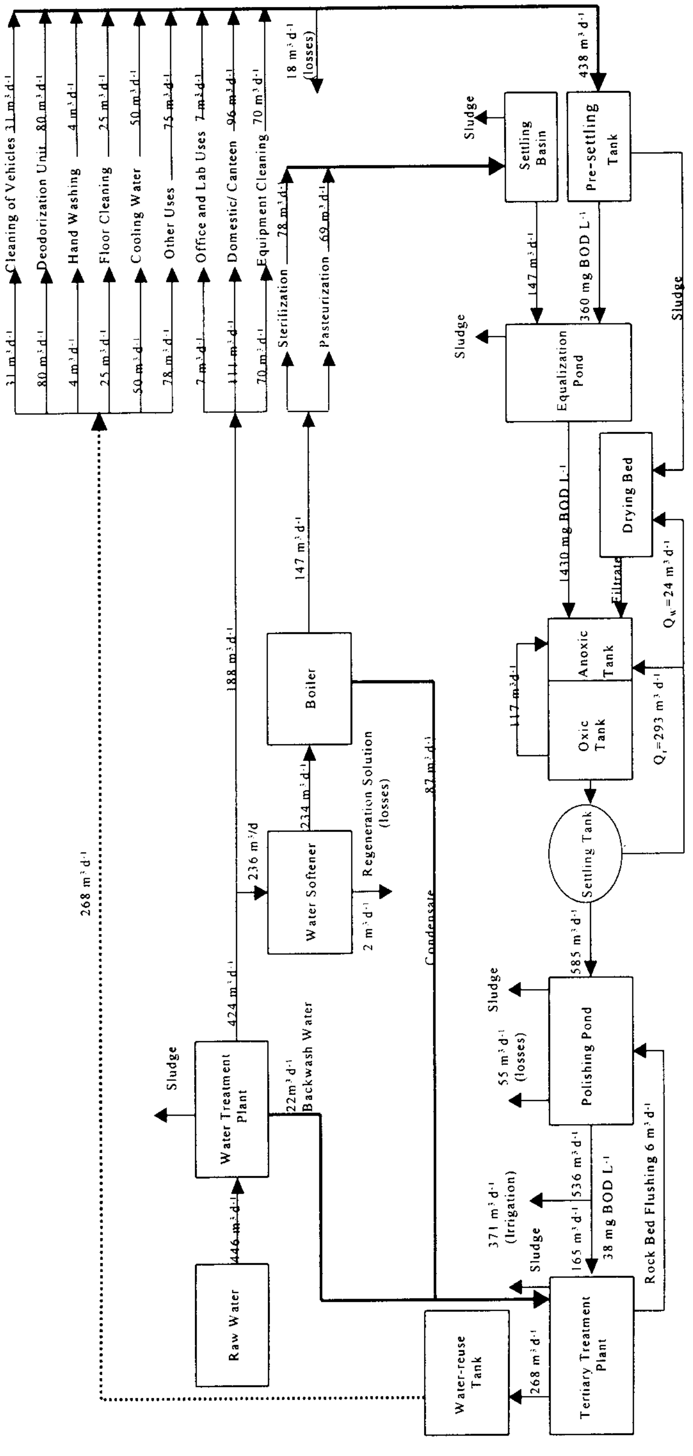

Figure 3. Water balance of the dairy processing plant with proposed water-reuse.

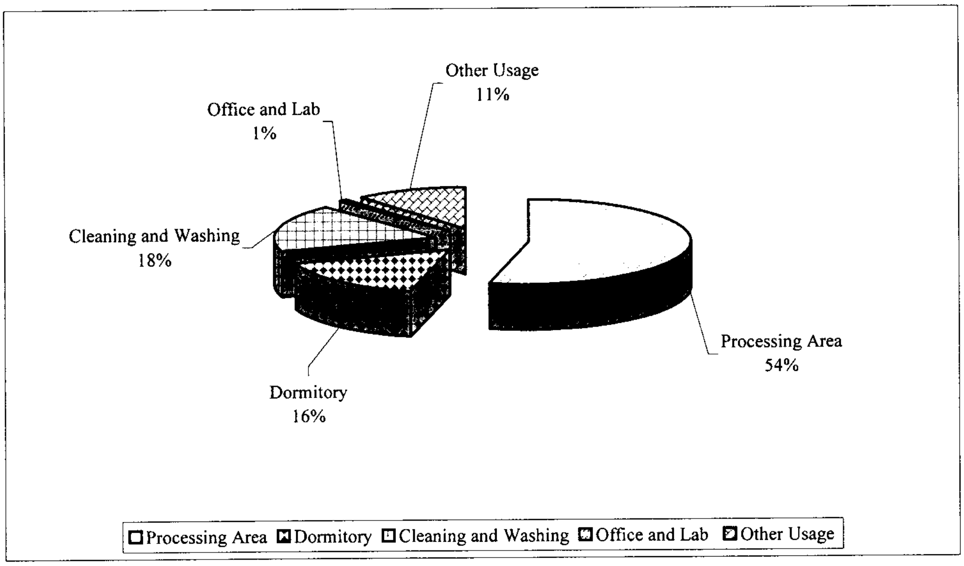

Figure 4. Composition of wastewater in the dairy processing factory.

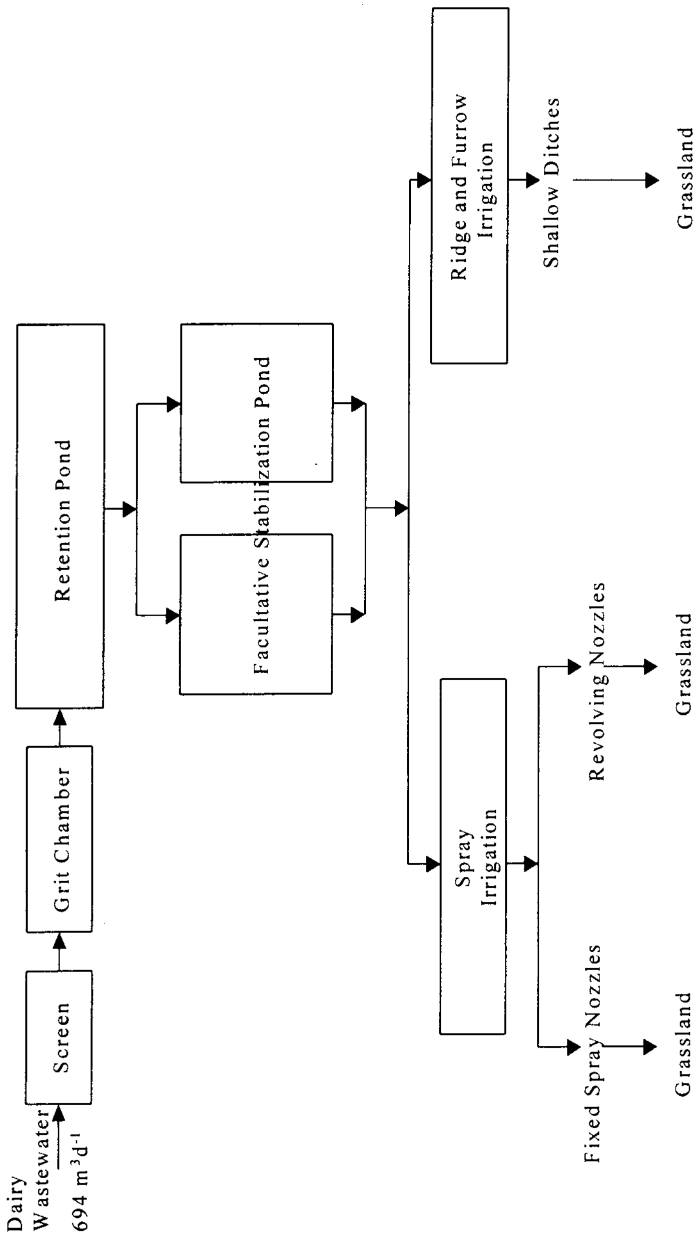

Figure 5. Schematic diagram of dairy wastewater disposal by irrigation.