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POLLUTION CONTROL THROUGH WATER CONSERVATION AND WASTEWATER REUSE IN THE FISH PROCESSING INDUSTRY

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ABSTRACT

The seafood processing industry is the major food processing industry in Thailand. It consumes large quantities of water and thereby generates huge volumes of wastewater of a polluting nature. A major tuna processing factory is presented as a case study to highlight the inter-related issues of excessive use of groundwater, the resultant deterioration in water quality and the economic consequences of this impact. To address these issues, the need to conserve water and reuse it is also examined in relation to the design and operation of a wastewater treatment plant using high loading rates in anaerobic ponds followed by a conventional activated sludge system.

KEYWORDS

Seafood processing; groundwater quality; conservation; reuse; pollution control; anaerobic ponds; activated sludge.

INTRODUCTION

In Thailand the agro-industrial sector invariably makes the biggest withdrawal of water for its production needs. A large portion of these industries is located in the Bangkok Metropolitan Region (BMR) and its surrounding provinces of Samutprakarn, Samutsakorn and Pathumthani. Water resources in these areas are being depleted and contaminated at alarming rates due to over use and poor pollution control. This is potentially a major threat to further industrial development in this sector. For instance excessive groundwater abstraction has led to depletion of aquifers, saltwater encroachment, and land subsidence on a large scale. There is thus a real need to curb overuse and implement water conservation and industrial wastewater reuse as tools for pollution control and abatement together with appropriate systems for end-of-pipe wastewater treatment.

A case study of a seafood processing factory specialising in tuna canning and which is served by the consultants is presented herewith to highlight the inter-related issues and provide details of the wastewater treatment approach which incorporates waste segregation, water conservation and reuse, and eventual waste treatment using high loading rates in a design employing anaerobic ponds and an activated sludge system.

THE FISH AND SEAFOOD PROCESSING INDUSTRY

Thailand is one of the major fishing nations of the world and has a large seafood processing industry which is undergoing considerable modernization while retaining its labour intensive features. The seafood industry in Thailand is an integral part of the food processing industry and is the major industry in this category. It has grown tremendously in the last 5 years especially in relation to the export market with current sales exceeding 1.5 billion US dollars per annum. It imports large quantities of fish, especially tuna for further processing prior to export. There are in total approximately 60 registered factories processing fish and other seafoods for export. Of these, 8 represent the largest and most modern sea food canneries in Thailand. These 8 companies represent about 50% of the entire sector's capital investment and account for almost 2,000 tons/day.

Fresh fish exports in 1986 were 120,000 tons while canned fish exceeded 180,000 tons in the same year. Canned fish alone accounts for about 30% of all processed food exports. Thai exports of tuna make up 80% of US imports and in 1988, Thailand exported close to 145,000 tons of tuna amounting to 8,150 million baht (315 million US dollars). The total export value of fish rose from 26.8 billion baht in 1986 to 33 billion in 1987 of which 80% was canned and the rest frozen. Total production is greater than 200,000 tons per annum and tuna accounts for 60-65% of the total value of canned seafood exports.

POLLUTION FROM THE SEAFOOD PROCESSING INDUSTRY

Due to the magnitude of production, tuna is given special attention in this paper, though reference is made to other types of seafood. The processing of tuna is divided into several unit processes, specifically: receiving, thawing, butchering, precook, cleaning, canning, retorting, and finally, labelling and casing. Product flow, wastewater flow, pet food production, and waste utilization is shown schematically in Figure 1. Processing requires significant water inputs and generates large quantities of wastewater. Total water use ranges from 10 m^3 to 20 m^3 per ton of tuna processed depending on the measures taken to curb overuse and conserve water. Most water (up to 30-40%) is used in thawing, depending on whether quality control procedures permit reuse and the degree of water conservation adopted.

BOD levels for all types of fish waste generally vary in the range of 500 to 1,000 mg./l Fish processed for canning operations, particularly tuna and sardines, produce significantly more wastes due to the cooking operation that precedes canning, usually in a pressure vessel or cooking retort. The waste load, due to the removal of oil and fats which account for almost 25 percent of the total fish weight, is traditionally discharged with the wastewaters from the cooking retorts. The BOD levels from factories canning tuna and sardines range from 3,000 to 5,000 mg/l depending on the dilution factor related to water usage. In addition the combined waste contain suspended solids up to 1,500 mg/l, highly variable oil/grease levels, and are nutrient rich with concentrations of total nitrogen ranging from 400 to 1,000 mg/l and total phosphorous from 40 to 80 mg/l . With increasing quality control demands to meet export market requirements these factories are using large quantities of water for factory washdown, can cleaning and can cooling operations.

Assuming an average water use of 15 m^3 per ton of tuna processed and an average wastewater BOD value of 3,000 mg/l, the environmental impact of untreated wastewater is potentially considerable. For the 8 largest plants with a total production of 2,000 tons/day the water demand is almost 30,000 m^3/day, the majority of which is released as wastewater. With an average BOD of 3,000 mg/l this translates to almost 90,000 kg BOD/day. Of the 8 largest factories, 6 are situated in the provinces surrounding Bangkok, namely Samutprakarn and Samutsakorn, with more under construction. The waterways of these surrounding provinces are already heavily polluted by sewage and industrial discharges due to the rapidly expanding population of Bangkok which has no comprehensive sewage treatment facilities and the current industrial boom. Any additional loads will worsen the already unacceptable levels of pollution especially if these are as high as those generated by the seafood processing industry. Needless to say, water conservation strategies and proper working wastewater treatment systems are vital to halt and reverse the pollution trend.

The waste waters from seafood processing plants are, in general, considered to be amenable to treatment using standard physical chemical and biological systems. Wastewater management in the form of increasing by-product recovery, in-plant control and recycling is not practised uniformly throughout the industry. There is a relatively wide range in the amount of water used per unit of raw material. The concepts of water conservation and by-product recovery are at early stages in most parts of the industry. Therefore, in addition to applying treatment to the total effluent, there is much room for the improvement of water and waste management practices. These will reduce the size of the required treatment systems or improve effluent quality, and in many cases, conserve or yield a product that will help offset or often exceed the costs of the changes. It can be shown that for some cases a relatively moderate

investment can result in a significant reduction in water used. The BOD reduction represents the amount of BOD input avoided by reducing the product-water contact time through decreased water use.
The Ministry of Industry Effluent Standards in Thailand require that the effluent BOD level should be equal to or less than 20 mg/l, suspended solids equal to or less than 30 mg/l and oil/grease less than 5 mg/l.

MANUFACTURING PROCESS AND WATER USAGE

The factory which is cited as a case study in this paper is situated in Mahachai in Samutsakorn province, approximately 70 km from central Bangkok. It processes three main categories of seafood, namely petfood using sardines, human food which consists of canned tuna and shrimp and crabs. The plants average daily production figures are 90 tons of tuna, 50 tons of petfood, 3 tons each of crabs, shrimp and clams. The factory works on a three shift day and employs a total of 1,500 people.

The production flow process is similar to that shown in Figure 1. All water in the factory is supplied by 3 deep wells abstracting from groundwater aquifers. Water consumption figures shown in Table 1 indicate that the average daily use is about 2,500 m^3/day. This is equivalent to about 18 m^3/ton of raw material processed and is higher than the typically encountered figures of 10-15 m^3/ton. The reason for this is poor control of water at user stations and the lack of any conservation plans.

Frozen fish (tuna and sardines) are weighed, sorted and then sent for thawing in thawing tanks. Considerable amount of water is used in this stage and although there is the potential for using recirculated water, this is not a recommended procedure as laid down by customers. This process uses as much as 500 m^3/day and is discharged as a low-strength waste which could be reused. Since it is not permitted, it has been proposed to segregate it from other plant waste and discharge it to the sewers to reduce the hydraulic load. In the tuna production line, the tuna heads are cut off and the fish eviscerated. The bones, heads and other recovered solids are at this point collected for sale to fish-meal vendors. After this the fish is precooked. Following precooking the tuna are cooled with water and then after manual deboning and cutting they are canned with oil and/or brine. The canned tuna is then seamed and the can washed after which retorting takes place for pasteurization.

Water is used for four different functions with different water quality requirements in the industry. These are:

Process water	: contacts products and raw material in the manufacturing process
Cooling water	: for process operation
Steam production	: for process use
Cleaning	: for cleaning floors, equipment and drains due to stringent QC requirements.

TABLE 1 - Water Consumption Data

Date	Production Data (Tons/day)				Total Production Tons/day	Water Consumption m^3d^{-1}	m^3/ton of Product
	Human Food		Pet Food				
	Tuna	Crab	Tuna	Sardines			
15/5/89	90.7	2.2	8.9	37.8	139.6	2330.0	16.7
16/5/89	90.8	2.0	12.8	30.3	135.9	2466.0	18.1
25/5/89	90.8	1.3	11.3	37.9	141.3	2563.0	18.1
26/5/89	91.7	1.8	12.1	41.2	146.8	2428.0	16.5
27/5/89	90.6	1.2	7.9	36.2	135.9	2092.0	15.4
31/5/89	95.7	1.8	13.5	33.9	144.9	2488.0	17.2
1/6/89	92.3	1.2	12.4	41.4	147.3	2764.0	18.8
2/6/89	95.2	1.1	12.6	33.1	142.0	2769.0	19.5
3/6/89	90.7	1.2	11.6	41.7	145.2	2256.0	15.5
6/6/89	90.1	1.3	10.5	36.3	138.2	2729.0	19.7
7/6/89	92.3	0.6	10.8	42.1	145.8	2836.0	19.5
8/6/89	93.4	2.7	11.3	39.4	146.8	2673.0	18.2
10/6/89	90.3	1.8	9.0	35.8	136.9	2519.0	18.4

Wastewater is generated mainly from the following sources:

1. Raw material thawing and washing
2. Conveying of fish slices on moving belts
3. Tuna cooling after precooking
4. Can cooling after cooking (retort usage) and can washing (after filling)
5. Workers washing and cleaning
6. Clean up of spills, floors and machine wash down

Water consumption data for May and June 1989 are shown in Table 1. Water usage over a range of mixed production levels for tuna and sardines is 16.5 - 19.7 m^3/day. Apart from water used for retort cooling and can washing where some recirculation is carried out, all water usage results in waste flows to the treatment plant. Recirculation was only implemented recently after fears of contaminating cans with bacteria-laden cooling waters were overcome by including a system of chlorination with a contact time of 20 minutes.

WASTEWATER FLOWS AND WASTE LOADS

Tables 2 and 3 respectively show the typical wastewater characteristics and the waste loads per ton of raw material processed from the various waste generating points in the plant. The solids and effluents from all fish and shellfish operations consists of:

1. Hot and cold water solutions containing dissolved materials (proteins and breakdown products), suspended solids consisting of bone, shell or flesh, and foreign material carried into the plant with the raw material.
2. Solid portions consisting of flesh, shell, bone, cartilage, and viscera. From the biological standpoint, all of these materials are either inert or have sufficient nutritive value to make them valuable as a food or food additive.

Monitoring of the process operations shows that the in-plant changes that can be made to solve the waste and pollution problems do not involve extensive study and development of each type of processing procedure, but conversely, the development of a few basic techniques that will be applicable to any process. These include:

- a. minimizing the use of water (thus minimizing loss of solubles);
- b. recovery of dissolved proteins in effluent solutions; and
- c. recovery of solid portions for use as edible products.

Effective use of these three procedures would reduce pollutant levels in the effluent from the plant. Total waste water flows are as much as 90% of total water usage because waters used for cooling and thawing are still discharged to the wastewater plant. Fish storage and thawing and tuna cutting generate the major volumes.

ENVIRONMENTAL AND ECONOMIC LINKAGES

The object of this paper is to examine within the context of the case study presented, the inter-related issues of excessive groundwater use, the resultant environmental impacts, and the need for water reuse, conservation and appropriate design of waste treatment facilities to combat these impacts as well as to control pollution.

The factory consumes excessive quantities of water exceeding 2,000 m^3/day with an average consumption of 2,500 m^3/day. At 140 tons of seafood processed per day this constitutes an average consumption rate of 18 m^3 per ton of raw material processed. This is more than double the average figures attainable in a factory with a well implemented strategy for water conservation and reuse.

Water is supplied by 3 deep wells which are about 130 metres deep. Over abstraction by all users in the district has resulted in increased salinity and hardness with the result that one well had to be abandoned in 1989 and two new wells drilled to tap water from a deeper uncontaminated aquifer at 250 metres. In addition to the cost of using excess water the deteriortion in water quality has meant greater capital investment in the deeper new well and a higher operating cost. The other two wells have also shown increasing salinity and hardness which is forcing the factory to increase its water softening capacity which in turn has a direct impact on the capital expenditure and operating costs. The deterioration in water quality is clearly a result of excessive water abstraction and has to be managed if it is not to be repeated in the new wells with the associated economic cost.

Raw water is also softened and supplied to the boilers, the cooling towers serving the retorts (120 m^3/hr) where make up of 15-20 m^3/hr is needed and for the cooling towers serving the compressors for the freezing room, the blanching system etc. In order to conserve water the factory reuses the retort and can washing water by first cooling it. However, residual oil/ grease in this water limits the reuse potential and there is the need to treat it to remove the contaminants prior to its reuse. Furthermore the lack of a proper water treatment system to control the build up of total dissolved solids and hardness has contributed to deteriorating quality.

Quality control requirements also stipulate that the retort water must be chlorinated to 3-5 ppm and held for 20 minutes. To attain the effective residual chlorine in the reuse water system the reuse water must have minimum turbidities which have to be eliminated by some form of filtration or reduced by process improvements upstream. The result has been the need for careful chlorine dosing to control residual chlorine levels to 1-2 ppm after retorting to avoid excess residuals causing corrosion. The resultant economic cost of can damage is significant now as reuse water is not treated to enhance chlorination efficiencies.

Another source of can damage, related to rising hardness due to deteriorating groundwater, is that of poor scale control in the boiler system and the increasing hardness in the recirculating water. Currently recirculated water from the retorts is not softened. It is delivered from the retorts to a storage tank and then pumped to a cooling tower from which it flows to another storage tank. Losses in retorting are made up for by the addition of softened water. The build up of hardness in the recirculating water needs to be controlled by incorporating chemical treatment for the cooling tower, appropriate blow down and water treatment of the recirculating water using softeners.

Against this background it is evident that strategies for conservation and reuse should be employed as tools for pollution control and abatement, a dual strategy of water conservation and water resource recovery. The question was one of how to motivate a traditionally profligate consumer to change habits. It was necessary to show how the long-term advantage of encouraging increased wastewater reuse and groundwater conservation can be achieved. The factory is being compelled to understand that limited water supplies for increased processing and the need for large quantities of processing water are major issues, and that water conservatation and reuse are vital parts of the water use system and thereby also of the wastewater system.

Poor housekeeping practices are also widespread and in many parts of the plant the first line of defence against waste, the metering of all water use was not employed. Conservation and reuse are almost synomyous when applied to water use in such an industry where large volumes are used. The use of unneeded water (i.e no conservation) thus becomes not only a double cost, first of the input water, and then in the wastewater system (i.e no reuse) but also a cost which has to be borne in addressing the other issues arising from water quality deterioration due to over abstraction. These include the increasing cost of softening water, treating water for the cooling towers and the increased cost of all water and wastewater treatment equipment due to the larger scale of consumption.

The excessive use of water has overburdened the waste treatment plant, not allowing it to perform according to the original design. Specifically it has caused failure of the aeration basin by affecting the kinetics of the system. Failure of the aeration pond is also compounded by the excessive use of non-biodegradable detergents to meet the increasingly stringent QC requirements.

TABLE 2 - Wastewater Characteristics of Combined Tuna and Sardine Processing

PARAMETER	MEAN	RANGE
Flow rate m^3/day	2,500	2000 - 2800
Flow ratio m^3/ton	18	14 - 20
pH.	6.7	6.5 - 6.8
Settleable Solids mg/l	25	20 - 30
Total Solids mg/l	5,200	4500 - 6100
Suspended Solids mg/l	1,100	750 - 1400
BOD (5 days) mg/l	3,500	3000 - 4200
COD mg/l	5,330	4800 - 6400
BOD:COD	0.65	0.54 - 0.73
Grease and Oil mg/l	1,000	400 - 1800
Total nitrogen mg/l	250	150 - 300
Phosphorous mg/l	60	50 - 80

TABLE 3 - Tuna Process Wastewater Characteristics

Pollution point Source	Waste Water Flow m^3/day	Wastewater m^3/ton	Waste Characteristics				BOD load kg/ton	% BOD load
			SS mg/l	BOD mg/l	COD mg/l	O/G mg/l		
Storage/Thawing	800	8	400	975	1320	<100	7.2	22
Butchering	800	8	400	975	1320	<100	7.2	22
Precook	150	1.5	2100	7350	9800	2500	11	35
Spray Cooling	150	1.5	1100	860	1200	350	1.3	4
Filling/Closing	100	1					-	-
Can Wash	200	2	120	185	260	100	1.3	4
Retorting (make-up water)	400	4					-	-
Washdown	200	2	1500	1950	2500	250	3.9	13
Combined	2000 m^3/day	20 m^3/ton	520	1300	1950	300	31.9	100

Note: 1. Wastewater flows per ton based on average tuna (human food and pet food) production of 100 tons/day, sardine (pet food) 40 tons/day, and 3 tons of shrimp, crabs.
2. Sardine water use is 20% i.e 500 m^3, tuna use 2,000 m^3/day.

EXISTING WASTEWATER TREATMENT PLANT

The existing wastewater plant designed by the consultants uses a series of high-loading anaerobic ponds followed by an activated sludge plant. This system was designed 2 years ago for a flow rate of 1,500 cubic metres. The amenability of tuna waste to biological treatment is however affected by the low BOD:COD ratio. However, it is supplemented by the pet food waste (sardine) and domestic waste which enhances the BOD:COD ratio. The BOD:N:P ratio typically encountered is 100:7:1 which exceeds the minimum BOD:N:P ratio of 60:3:1 needed for biological treatment.

The design basis and performance of the existing plant is indicated in Table 4 and the schematic of the proposed upgraded facility is shown in Figure 2. The three anaerobic ponds operating at high loading rates showed very high efficiencies beyond normally accepted values. The initial design basis was formulated from measurements and monitoring of an existing anaerobic pond system which had to be replaced with the newer system. The analysis showed that BOD reduction efficiencies of up to 60% could be obtained in the series of anaerobic ponds with a retention time of only 5-6 days. Due to area limitations, when the new system was designed these higher loading rates were employed based on the data collected. After 2 years of operation the performance of the existing ponds has shown that the higher loading rates were justified. Results from May 1989 as shown in Table 4 bear this out.

The existing treatment plant does not provide for solids and oil/grease removal, which was a result of cost saving measures at the implementation stage. The result has been solids build up in the first anaerobic pond and the associated increase in BOD loading which could have been reduced by solid separation. However, the effect of the first anaerobic pond has been to act as a basin for solids separation (60% removal) which together with oil/grease has resulted in a thick surface scum layer. The thickness of the scum layer after 2 years has stabilised at about 10 cm. Anaerobic activity in the form of gas bubbles is very evident when breaks in the surface scum layer are made and is responsible for maintaining a stable scum layer. The factory prefers not to have the scum layer for aesthetic reasons and the consultants have proposed a solids removal device for the upgrading (Fig. 2). The device is a self-cleaning rotostrainer with 0.5 mm openings capable of 30-40% solids and 40-60% oil/grease removal.
It has also been proposed by the consultants in upgrading the plant to remove the existing scum layer so that efficiencies can be increased especially in relation to degradation of detergents used in cleaning. Fat/oil/grease are obviously only broken down very slowly in this pond (15-20 days) and appears to occur at the scum interface after natural physical separation. A saturation point appears to be reached but more monitoring is needed. It seems that this condition is reached when the biodegradation rate and accumulation rate are equal, which has yet to be verified. The results show that oil/grease removal efficiencies are as high as 95%. Oil and grease should be reduced to 100 mg/l prior to aeration. The oxidation of oil/grease generally is a function of temperature, acclimatization of bacteria and the nature of oil.

The ponds are followed by a conventional activated sludge plant with a retention time of about 10 hours. The mixed liquor suspended solids are maintained at 3,000-3,500 ppm with the influent BOD in the range of 150-100 ppm. The low BOD concentration and high hydraulic load results in operating problems needing nutrient and pH adjustment. Settled sludge from the secondary clarifier is returned to the aeration pond and excess sludge discharged to the second and third anaerobic pond for digestion, thus eliminating the need for sand drying beds.

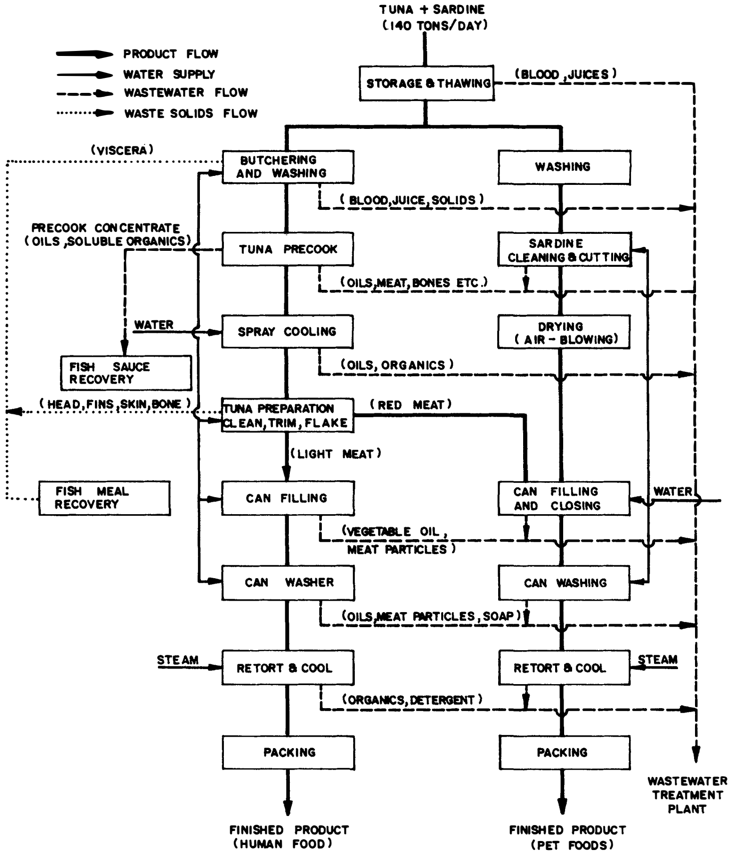

FIG. 1: TUNA, SARDINE PROCESS FLOW

RECOMMENDATIONS TO UPGRADE THE WASTEWATER TREATMENT PLANT

The main emphasis of the latest upgrading effort has been to reduce the hydraulic and BOD load to the wastewater plant so that efficiencies can be further improved. The plant is very often hydraulically overloaded due to excessive water comsumption and thus there is the danger of washout of biomass in the aeration pond and reduced clarifier efficiency resulting in high suspended solids in the effluent.

The approach to dealing with reducing the hydraulic and BOD load has been to begin by addressing it in the process area. The measures for reducing the hydraulic load that have been taken or are being recommended are:

- Elmination of the use of all flumes for in-plant transport of product.
- Evalution of steam and water piping systems (valves especially) to repair old components which are prone to leaks.
- Adoption of air cooling of tuna following the precook.
- Reduction of water use in the butchering area and in the frequency of cleaning by using more efficient systems such as high pressure spring loaded hoze nozzles, automatic cleaning brushes and biodegradable detergents.

- Waste segregation, especially of the thawing waste flows.
- A scheme to provide simple treatment for recirculation of thawing water to meet Q/C requirements.
- Pressure controls in water distribution lines to reduce use especially during clean-up operations.
- Educating plant personnel on water conservation.

Measures being employed to reduce the organic load are:

- Installation of high efficiency solid separators to remove suspended solids and entrapped globules of oil/grease. The solids can be recovered for organic recycling.
- An additional clarifier to provide sufficient settling time for MLSS when peak flow conditions prevail.
- Separation of the tuna pre-cook waste which has a very high BOD of 20,000 mg/l (25% of total BOD load) and contains significant quantities of oil and grease. This is proposed to be sold to traditional fish sauce manufacturers.
- Screens in drains especially in cut up and receiving area.

Other problems of the system which are being addressed in the latest upgrading of the wastewater treatment plant are:

- Appropriate nutrient addition to maintain bacterial growth when needed.
- pH adjustment using chemical dosing systems.
- Complete revision of site drainage plans to segregate all storm wastes from wastewaters.
- Conversion of one anaerobic pond to an equalization pond to ensure continuous and equal flows to the aeration pond so as to maintain the F/M ratio.

TABLE 4 - Wastewater Treatment Plant Data (Past and Existing)

Phase	Effluent Source	pH	SS mg/l	BOD mg/l	COD mg/l	O/G mg/l	BOD loading rate kg BOD/m^3/day
I Water Consumption (1,500 m^3/day)	Combined Waste	6.7	820	2010	2610	135	-
	Pond I	6.8	250	1230	1650	88	2.3
	Pond II	7.1	150	650	1000	58	0.8
II Water Consumption (2,500 m^3/day)	Combined Waste	6.9	520	1300	1950	250	-
	Pond I	6.8	400	450	720	72	2.0
	Pond II	7.0	235	150	225	11	0.6
	Pond III	7.2	108	72	115	2	0.3
	Aeration Pond	8.0	3500	33	56	-	-
	Clarifier	7.5	54	19	32	1	-

Note: Combined wastewater characteristics changed with increase in water consumption and changes in production levels and type.

CONCLUSION

As evident from the wastewater characteristics the concentration of BOD etc dropped with the corresponding increase in waste flows. Thus, although the plant was originally designed for 1,500 m^3/hr with the intention of implementing measures for curbing overuse, this was not sustained after the initial six months. The plant then reverted to consuming large quantities of water (partially due to increase in production capacity) as shown in Table 4. This resulted in hydraulic overloading of the wastewater treatment plant and failure of the aeration pond (wash-out of MLSS) and the secondary clarifier.

Realizing the implications of continued overuse, the factory, under the recommendations of the consultants, is now implementing the necessary measures to curb overuse, and to conserve water by reusing wastewater. It is still too early to say if these will be successful in reducing water use to less then 2,000 m^3 per day (15 m^3/ton) but the consultants have been engaged to achieve this objective through the various strategies discussed in the paper.

Together with rising water rates and treatment requirements the stringent enforcement of water quality standards will encourage efforts in the industry as a whole to reduce water pollution discharges. These will compel users to recognise the wisdom of using water for several different applications in descending order of cleanliness before calling it waste. The incentives for greater conservation of water and re-use in the future are considerable, and will stem from increasing pressures on limited supplies, integration of reclamation schemes into comprehensive water resource planning, and the changes which will occur in the economic value placed upon alternative sources of water.

Utilization of some or all the concepts outlined in the paper, together with conservation, can lead to water consumption savings of 30 percent, with concomitant BOD reduction of 10 percent. This, together with appropriately designed waste treatment plants which minimise operating costs and need minimal operation and maintenance, as described, can play a significant role in reducing the pollution of water resources.

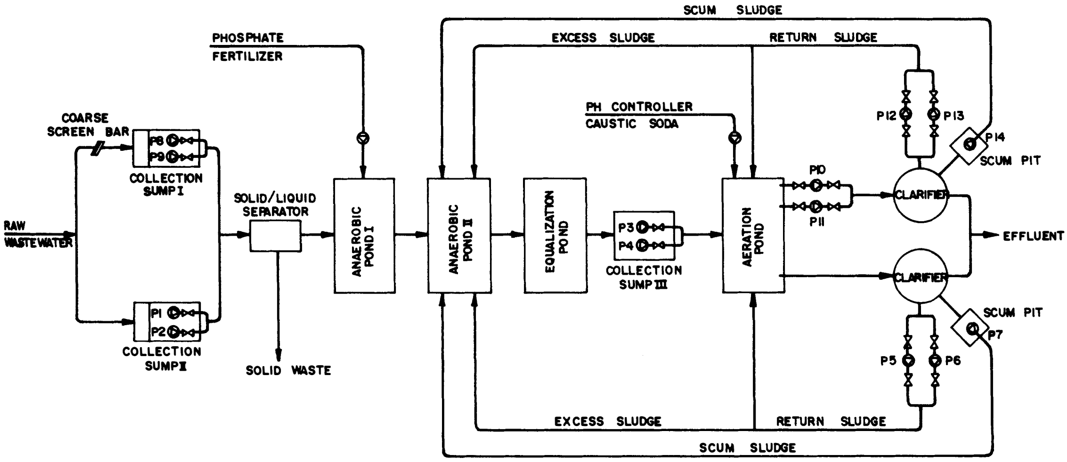

FIG. 2: SCHEMATIC FLOW DIAGRAM FOR UPGRADING WASTEWATER TREATMENT PLANT

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