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Effluent Treatment System for RRIM Rubber Glove Manufacturing Plant[†]

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A prototype effluent treatment system for the Rubber Research Institute of Malaysia (RRIM) rubber glove manufacturing plant was designed and constructed at a cost of about RM 360 000. The system comprising a rubber trap, a chemical flocculation unit, a primary sedimentation tank, anaerobic and aerobic fluidised beds and a secondary sedimentation tank was designed to treat 120 m³/d effluent. The design of the prototype system was partly based on pilot-plant studies. The construction of the prototype system was completed in September 1996. It was commissioned in January 1997. This paper discusses the development of the prototype system and the comparative evaluation with the conventional activated sludge system.

The rubber glove manufacturing industry in Malaysia has expanded rapidly in recent years due to the increase in the world demand for the product. Exports earning for the product in 1995 valued at RM 2.27 billion, an increase of about 23% over the previous year[1,2]. It contributed to about 73.3% of the total earnings from exports of latex products and 58.8% of total exports of rubber goods.

The RRIM has been actively involved in the research and development to support the rubber industry in Malaysia including the rubber glove manufacturing industry. The RRIM has recently set up a rubber glove manufacturing plant with the aim of assisting rubber glove manufacturers in solving their industrial-scale problems.

Effluent from the glove manufacturing facility is treated using a treatment system comprising a rubber trap, a chemical flocculation and a biological fluidised bed system. The design, construction and commissioning of the full-scale effluent treatment plant were carried out in-house.

This paper discusses some major aspects of the development of the prototype effluent treatment plant, including the starting-up experience and the comparative evaluation with the conventional activated sludge system.

PROCESS DESIGN

The results of the laboratory and pilot plant studies[3] were used to develop the process design of the prototype effluent treatment system. Theoretical calculations[3] were applied where experimental data were unavailable. The

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process flow diagram of the effluent treatment system developed is shown in *Figure 1*.

In rubber glove manufacturing, there are two main sources of effluent, namely, latex compounding waste and leaching tank discharge. Latex compounding waste contains uncoagulated latex and chemical sludge. It is usually discharged in batches, that is, during the cleaning of latex compounding and storage tanks. Leaching tank discharge contains pollutants leached out from rubber gloves during washing.

Latex compounding effluent is treated using a flocculant to separate out latex particles from the effluent. A rubber trap is used for recovery of latex coagula (*Figure 1*). Leaching tank effluent, which does not usually contain latex particles, can be discharged directly into the holding tank, bypassing the rubber trap.

Effluent in the holding tank is pumped into several mixing tanks where it is mixed with chemical flocculants. The flocculants combine colloidal particles into larger agglomerates which can be removed by settling. Colloidal particles in rubber glove manufacturing plant effluent comprise mainly organic and heavy metals such as zinc. At present, chemical flocculation is considered indispensable for the removal of these toxic and hazardous chemicals from the effluent prior to biological treatment.

Biological treatment of the partially treated effluent involves a fluidised bed system comprising an anaerobic and aerobic fluidised bed reactors. These fluidised bed reactors contain fine sand which is fluidised by recycling effluent. The sand has an effective size of 0.1 mm and a uniformity coefficient of 2.4. Each bed contained 0.2 m of gravel (1.5 mm to 25 mm in diameter) placed at the bottom and supported by a perforated plate. The gravel bed supports the sand particles and uniformly distributes the effluent. The design of the fluidised bed system was based on work carried out by Jeris *et al.*[4,5].

The effluent from the aerobic fluidised bed is passed through a tube settler and a sand filter to remove suspended solids from the effluent.

For the process design, estimated effluent flow rate and chemical oxygen demand (COD) concentrations were based on assumptions given in *Table 1*. Thus, the estimated average effluent flow rate was 80 m^3/d and the average COD concentration in the rubber glove manufacturing plant effluent was 500 mg/L.

EFFLUENT TREATMENT AREA AND COST

Total land area occupied by the various units of the effluent treatment plant is approximately 110 m^2. Construction cost of the effluent treatment plant is listed in *Table 2*.

Construction of the effluent treatment plant started in October 1995 and completed in September 1996. The plant was commissioned in January 1997.

REGULATORY STANDARDS

The effluent treatment plant has to comply with *Standard B* of the effluent regulatory standards[6], as specified in the Third Schedule of the Environmental Quality Regulations (Sewage and Industrial Effluents) 1978. Parameters required for analysis are given in *Table 3*.

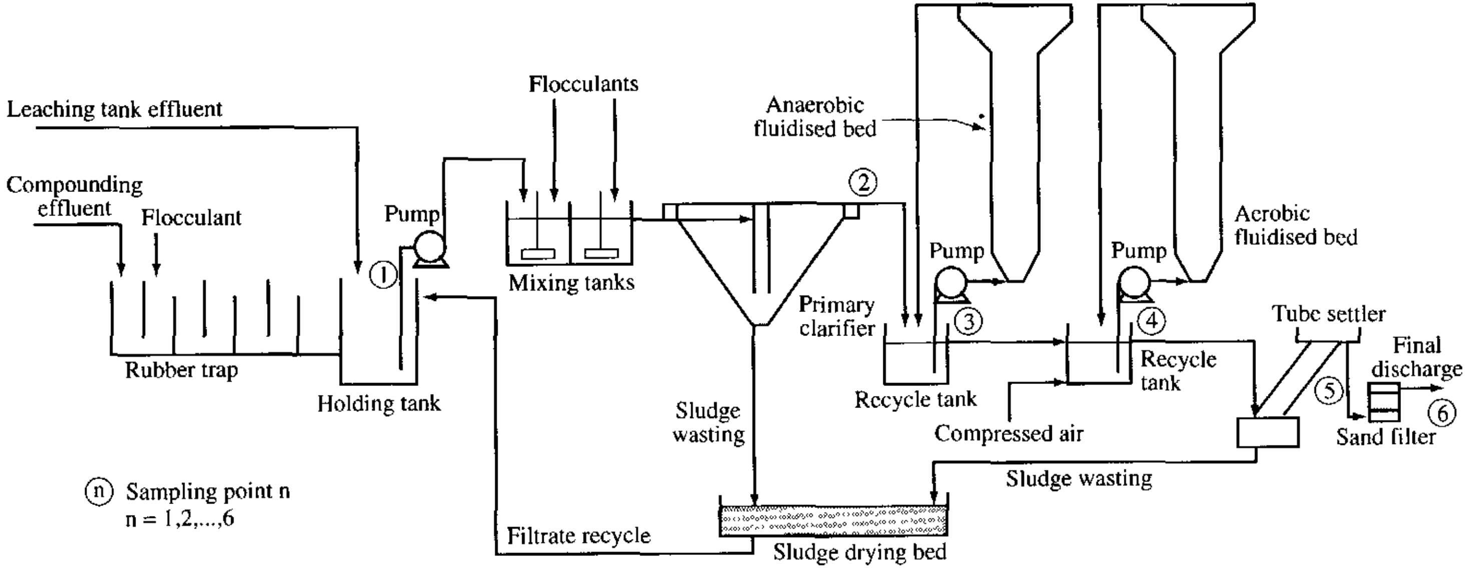

Figure 1. Schematic flow diagram of RRIM effluent treatment plant.

TABLE 1. ASSUMPTIONS[3] FOR ESTIMATING EFFLUENT FLOW RATE AND COD

Production of gloves	7 000 pieces/h/line
Production duration	24 h daily
Number of lines	2
Average COD generated per thousand pieces of glove	0.108 kg COD/10^3 pieces/d
Ratio of maximum flow to average flow	1.5
Ratio of maximum COD to average COD	1.5

TABLE 2. EFFLUENT TREATMENT PLANT COST

Item	Cost (RM)
Preliminaries, delivery, installation and miscellaneous	13 600
Civil and structural work (building, fence, gate, compound and rubber trap)	81 320
Chemical flocculation system	19 825
Neutralisation tank	4 800
Primary clarifier	14 600
Anaerobic fluidised bed reactor	32 500
Aerobic fluidised bed reactor	31 000
Air supply system	11 490
Secondary settling tank	11 500
pH controller and metering pumps	15 194
Transfer pumps	55 945
Additional structural and piping work	17 350
Professional fee for mechanical design	12 250
Electrical work	40 530
Total	361 904

EXPERIMENTAL EVALUATION

During the monitoring period (April 1997 to June 1997), the average glove production was 142 kg per week (about 18 000 pieces of glove per week). The production was less than 1% of the design production capacity. Raw materials for the glove production were prevulcanised latex, calcium nitrate (coagulant), calcium carbonate and cornstarch (slurry). Latex compounding was not carried out.

TABLE 3. REGULATORY STANDARDS

Parameter	*Standard B*
pH	5.5 – 9
BOD at 20°C (mg/L)	50
COD (mg/L)	100
Suspended solids (mg/L)	100
Lead (mg/L)	0.50
Copper (mg/L)	1.00
Zinc (mg/L)	1.00
Iron (mg/L)	5.00
Oil and grease (mg/L)	10.00

The flocculants for removing COD and heavy metals from the effluent were polyaluminum chloride (PAC) and *Magnafloc 1597*. The dosages of PAC and *Magnafloc 1597* were 50 p.p.m. and 20 p.p.m., respectively.

The average effluent flow rate was 13.8 m^3 per week (about 2.5 % of the design flow rate). The effluent discharged was let to fill the holding tank before pumping into the first mixing tank at 3 m^3/h for about 5 h weekly.

Effluent samples were taken hourly over the duration of the effluent pumping, from sampling points shown in *Figure 1*. Analyses carried out on the samples are as given in *Table 3*.

Effluent flow rates were measured using a water meter. This meter measures flow in the pipe transporting effluent from the aerobic effluent recycle tank to the tube settler.

Seeding of the fluidised beds with biological sludge was necessary for the starting-up of the fluidised beds. Each bed was seeded with about 1.25 m^3 of activated sludge. The sludge was obtained from nearby rubber factories.

Skim latex serum, with COD concentration of about 19 800 mg/L, was added periodically at a rate of about 20 L per addition into each fluidised bed to sustain growth of bacteria in the biological system. Without the addition of the serum and with insufficient effluent flowing into the system, the bacteria in the system, which require nutrients and a source of carbon for growth, will not survive. With a low population of bacteria, the fluidised beds will not be effective in treating the effluent.

In evaluating the performance of the fluidised bed system, the fluidised bed was operated as a batch reactor, that is, with no effluent flow. Effluent samples from the effluent recycle tank and the fluidised bed were taken at two-hourly intervals and analysed for COD, total and volatile suspended solids. The results of this study were compared with those obtained earlier from pilot-plant studies[3].

RESULTS AND DISCUSSION

Efficacy of Treatment System

Data collected show that the treatment plant was functioning satisfactorily although its performance at the design loading rate could not be assessed, as the effluent flow rate was below the design capacity. *Figures 2 – 4* give the results of the monitoring study.

Removals of COD, BOD and zinc from the treatment plant were 48.4%, 75% and 85.9%, respectively. Removals of the same parameters from the chemical flocculation system were 46.6%, 78.7% and 65.4%, respectively. These

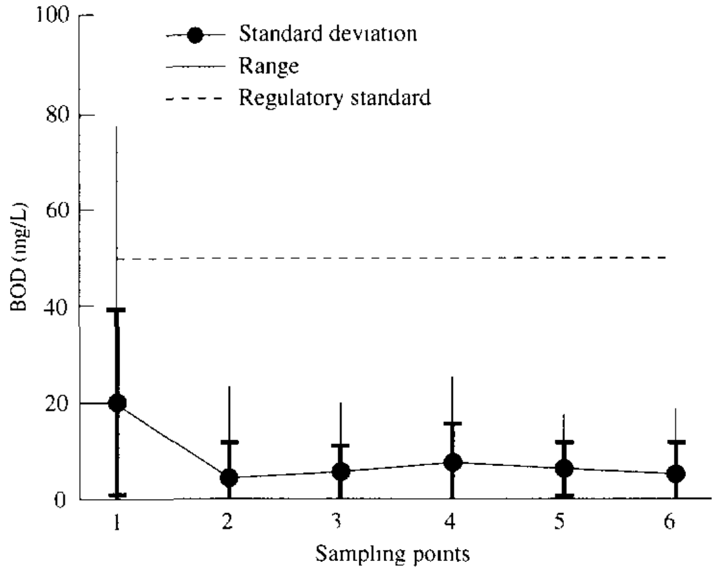

Figure 2 Effluent BOD concentrations at sampling points 1 to 6 indicated in Figure 1 *(20 samples per sampling point)*

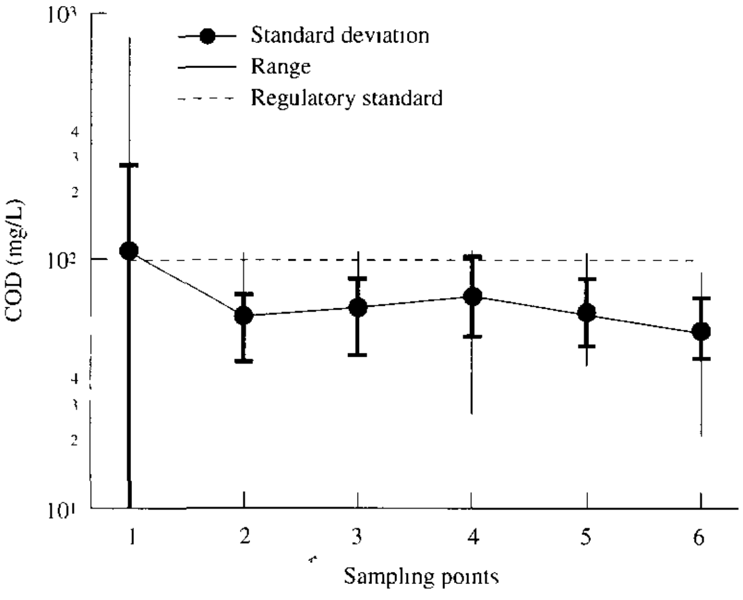

Figure 3 Effluent COD concentrations at sampling points 1 to 6 indicated in Figure 1 *(19 samples per sampling point)*

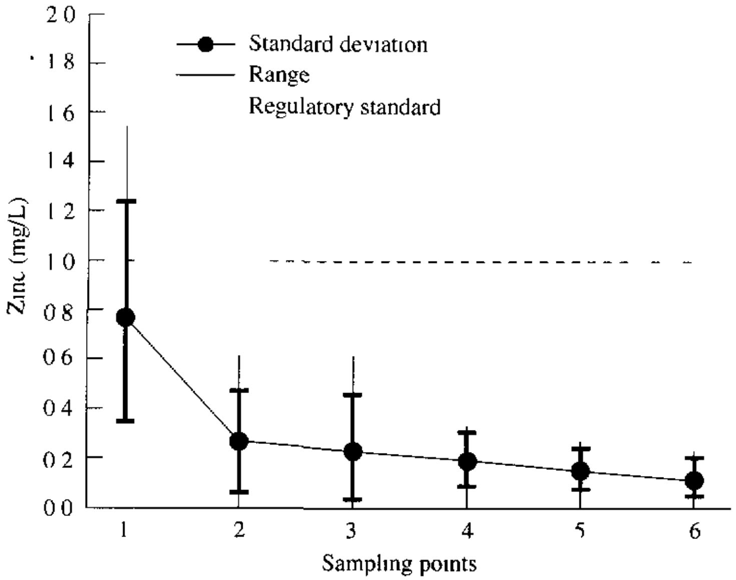

Figure 4 Effluent zinc concentrations at sampling points 1 to 6 indicated in Figure 1 *(9 samples per sampling point)*

results indicate the effluent treatment was mainly by chemical flocculation. Because the chemical flocculation system was evaluated at the effluent flow rate of 3 m^3/h (60% of the design effluent flow rate), the results are thus considered representative of its performance.

From the survey[7] of existing effluent treatment plants carried out by the RRIM, removals of COD, BOD and zinc by chemical flocculation varied from 33.1% to 48.7%, 26.7% to 43.1%, and 40.0% to 75.9%, respectively. The results obtained from the present study were comparable to those obtained from the survey.

The concentrations of COD, BOD and zinc in the untreated effluent were lower than the corresponding values obtained from the survey[7]. The average concentrations of COD, BOD and zinc in untreated rubber glove manufacturing effluent, based on the survey involving four rubber glove manufacturing factories, were 857 mg/L, 420 mg/L and 10 mg/L, respectively. The lower concentrations of COD, BOD and zinc in the untreated effluent of the RRIM rubber glove manufacturing plant were attributed to the use of prevulcanised latex for rubber glove production

The pH of the treated effluent varied from 7.1 to 8.8, which was within the limits of the regulatory standard for the parameter. Suspended solids in the treated effluent, which varied from 8 mg/L to 35 mg/L, complied with the standard for the parameter. Oil and grease in the treated effluent, which varied from

1 mg/L to 10 mg/L, also complied with the standard for the parameter. Lead, copper and iron in the treated effluent were undetectable.

The true performance of the fluidised bed system in removing BOD could not be inferred from the data shown in *Figure 2.* Because of the already low BOD concentration (< 5 mg/L) in the effluent fed to the fluidised bed system, further BOD reduction in the fluidised bed system was not possible.

Evaluation of Fluidised Bed System

As mentioned earlier, because of the low BOD concentration in the effluent, the fluidised bed system could not be evaluated under the continuous flow conditions. As an alternative, the system was operated as a batch reactor. Skim serum was added in batches to provide the system with organic carbon and nutrients.

The reduction of COD and the biomass concentration in the anaerobic and aerobic fluidised beds were monitored at two-hourly intervals after the addition of the skim serum. From these data, substrate utilisation rates were determined (*Table 4*). The substrate utilisation rates for the full-scale units were comparable to that obtained for the pilot plant[3] operated under continuous flow conditions.

Biomass concentrations in the full-scale units were lower than that in the pilot plant (*Table 4*). These lower biomass concentrations in the full-scale system were attributed to the lower density of fine sand in the full-scale columns. The density of fine sand in the full-scale fluidised bed system was about 118 kg/m^3 and that in the pilot-scale system was about 327 kg/m^3. For the full-scale system containing sand with an effective size of 0.1 mm, the specific surface area of sand particles in the full-scale system was 1336 m^2/m^3, which was only about 45% of that in the pilot-scale reactor. The specific surface area of sand particles in the fluidised bed system used by Jeris *et al.*[5] was 3300 m^2/m^3.

The biomass concentration in the aerobic full-scale fluidised bed system was about 33% of that in the anaerobic system. This could be attributed to lower substrate concentrations in the aerobic system.

Sludge Production

Chemical sludge was produced from the chemical flocculation stage and accumulated in the primary sedimentation tank. Based on the concentration of suspended solids in the effluent from the chemical mixing tanks, the quantity of chemical sludge produced weekly was about 3.5 kg dry weight.

Biological sludge is expected from fluidised bed reactors. However, because of insufficient discharge of effluent from the glove plant, the fluidised beds were not operating at the optimum conditions and sludge accumulated in the tube settler that received effluent from the reactors was insufficient to be withdrawn.

Energy and Chemical Usage

The total power of equipment installed for the effluent treatment plant is about 21 kW. The actual energy usage was only about 2 000 kWh per month as the equipment was not operated continuously.

Chemical flocculation was carried out using 50 p.p.m. PAC and 20 p.p.m. *Magnafloc 1597.* At these dosage rates, the cost of the flocculants was RM 0.25/m^3 effluent.

TABLE 4 SUBSTRATE UTILISATION RATES IN THE FLUIDISED BED REACTORS

Fluidised bed system	SUR (kg COD/kg VSS-d)	Biomass (kg VSS/m^3)	n
Anaerobic (full-scale)	0.55 ± 0.15[a]	5.03 ± 0.35	3
Aerobic (full-scale)	1.32 ± 0.58	1.65 ± 0.19	3
Anaerobic (pilot plant)	0.49 ± 0.17	10.20 ± 2.33	4

[a]Values expressed as mean ± standard deviation
SUR: substrate utilisation rate
VSS: volatile suspended solids
n: number of runs

Biological Treatment Alternatives

Most rubber glove manufacturing factories use an activated sludge system for the biological effluent treatment. The activated sludge system is a conventional system compared to the fluidised bed system adopted by the RRIM rubber glove manufacturing plant.

Activated sludge systems use suspended growth of microorganisms and the retention time of these microorganisms in the aeration tanks is controlled by solids recycle. The performance of the system is dependent on the separation of solids in the settling tank. On the other hand, fluidised beds use biomass support particles such as sand for microbial growth and attachment. Biomass concentrations in fluidised beds are usually higher than those in activated sludge systems depending on the size of support particles. Due to the higher biomass concentrations, the overall volumetric rates of carbon conversion in fluidised beds are higher than those in the activated sludge systems. *Table 5* gives the comparison between these two systems, based on the experience of the writers.

The cost of the fluidised bed system is lower than that of the activated sludge system despite using fibre-reinforced plastic for its construction (*Table 5*). The cost of fibre-reinforced plastic is higher than that of concrete. *Table 5* also indicates that the fluidised bed system requires smaller land area.

CONCLUSION

The effluent treatment system for the RRIM rubber glove manufacturing plant was functioning satisfactorily although its performance at the design loading rate could not be assessed, as the effluent flow rate was below the design capacity.

Removals of COD, BOD and zinc from the treatment plant were 48.4%, 75% and 85.9%, respectively. The effluent treatment was mainly by chemical flocculation.

Although the BOD removal in the fluidised bed system was negligible because of low BOD concentrations in the influent, the substrate utilisation rates for the full-scale units were comparable to that obtained for the pilot-scale reactor.

TABLE 5 COMPARISON BETWEEN ACTIVATED SLUDGE AND FLUIDISED BED SYSTEM

Treatment system	HRT (h)	Volume[a] (m^3)	Surface area[b] (m^2)	Cost[c] (RM)
Activated sludge	24	120	80	90 000
Fluidised bed	1	5	20	63 500

HRT = hydraulic retention time

[a] Volume of liquid inside the tank calculated based on the HRT and the design flow rate of 120 m^3/d

[b] Surface area required by the system calculated based on the given volume, depth of 1.5 m for the activated sludge system and 5 m for the fluidised bed

[c] Construction cost of the system excluding cost of equipment and settling tank, and based on the unit cost of concrete tank of RM 750/m^3 tank volume for the activated sludge system and the unit cost of fibre-reinforced plastic of RM 12 400/m^3 tank volume for the fluidised bed

For the treatment of 120 m^3/d effluent, the fluidised bed system, compared with the conventional activated sludge system, requires lower cost and smaller land area for construction.

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