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Cost Evaluation of Compact Dairy Wastewater Treatment System in Kuwait

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Abstract: In Kuwait, wastewater management has gained extra attention in recent years and becomes crucial for sustainable industrial development sector. Among the food industry sector, dairy processing plants generate huge amount of wastewater, which is heavily loaded with organic and other toxic compounds. Disposal of dairy wastewater effluent without sufficient treatment can contaminate aquatic ecosystems. Cost efficient treatment processes that are effective in removing organic load and other contaminants are essential to meet stringent environmental regulations applied in Kuwait. A research study was carried out at the KISR (Kuwait Institute for Scientific Research) to assess the technical viability and economic feasibility of combined microfiltration and biological treatment system. This work presents the economic evaluation of the adopted treatment system. The results show that the cost of the integrated system for large scale is estimated to be US$ 1.575/m^3, which is 25% less than the cost of wastewater transportation and treatment in conventional sewage plants.

Key words: Wastewater, treatment, dairy, cost.

1. Introduction

Dairy industry is very important to state of Kuwait and its products are wildly consumed by Kuwaiti people. Similar to most of food industries, the dairy industry characteristically requires very large quantities of freshwater and generates large quantites of wastewater [1]. Most of the wastewater volume generated in the dairy industry results from cleaning of transport lines and equipment between production cycles, cleaning of tank trucks, washing of milk silos and equipment malfunctions or operational errors [2, 3]. Disposing untreated dairy wastewater can lead to adverse public health and environmental impacts. Examples of environmental concerns include objectionable odors and fly infestations that have resulted from the disposal of the untreated effluent in open land [4]. Recently, the enforcement of environmental legislations is becoming a high priority for the state of Kuwait. Dairy industrial sectors have to comply with the KEPA (Kuwait Environment Public Authority) regulations for wastewater discharge and reuse [5]. To satisfy these regulations the effluent must be collected and treated to meet the quality standards set by KEPA. A research project was conducted to assess the technical viability and economic feasibility of implementing MBR (Membrane Bioreactor System) to treat dairy wastewater effluent generated by one of the largest dairy companies in Kuwait [6]. This work describes the experimental set-up and economic assessment of treating dairy processing wastewater by integrated MBR system.

2. Process Description

The complete system for dairy processing wastewater treatment involves the integration of membrane separation and conventional biological treatment processes. The membrane separation process includes the submerged membrane microfiltration system,

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which is a polypropylene membrane filter to remove particles greater than 0.2 μm in size from a feed stream. The main treatment steps in the integrated system are shown in Fig. 1, in which feed water passes through an aeration tank for biological treatment. An air compressor injects adequate air into the aeration tank. The aerobic system includes the process air blowers, which are installed adjacent to the system. The required process airflow is 227 m^3/h introduced at the bottom of the aerobic tank through air scour distribution header pipes. After passing through the upstream flow, the mixed liquor is transferred by overflow to a suitable buffer flow tank and then pressurized to an operating pressure in accordance with the membrane's design.

3. Cost Analysis

In KD-Cow (Kuwait Dairy Company) factory the dairy production process requires huge quantities of freshwater which is used mainly for cleaning purposes and, as a result, large amounts of wastewater are generated. Due to lack of treatment system in the factory, this wastewater is transported and distributed to remote sites through sewage tankers. The company uses 17 sewage tankers per day with a capacity of 30 m^3. The purpose of this study is to evaluate the economic feasibility for the treatment of dairy processing wastewater effluent for reuse. Specifically, the objectives of this task are to:

- To estimate the operating cost and total cost of the dairy wastewater treatment;
- To calculate the unit costs of the treatment of dairy wastewater;
- Use economies of scale to figure out the feasibility of the project.

3.1 Cost Estimation

Table 1 shows experimental plant operating data for the integrated system as obtained during the project. Table 2 provides the estimated cost details for operation expenses.

3.1.1 Capital Costs

Costs incurred on the purchase of land, buildings, construction and equipment to be used in the production of goods or the rendering of services are categorized under capital cost. In other words, it is the total cost needed to bring a project to a commercially operable status. Capital costs do not include labor costs except for the labor used for construction. Unlike operating costs, capital costs are one-time expenses, although payment may be spread out over many years. Capital costs are fixed and are therefore independent of the level of output.

3.1.2 Operation Costs

Total cost needed in daily operations is categorized under operation costs. Operation costs are variable costs, and are dependent on the level of output.

Table 3 shows the total cost calculations for the dairy processing wastewater treatment and expenses details for the operation costs. The total cost is US$ 171,975.

4. Results and Discussion

The estimates of unit costs of the experimental plant for wastewater treatment are provided in Table 4. The estimated unit costs are US$ 2.695/m^3.

In Table 5, the unit costs are represented as percentages of the total unit cost, where capital costs account for approximately 65% of the total cost and operating cost is estimated to be around 35%.

Table 5 shows the estimated unit costs using a small experimental plant operating data. A scale-up approach will be used to determine the cost of a large capacity plant. Due to economies of scale, the unit cost for a larger plant is likely to be lower than in a smaller one. The Eq. (1) will be used to scale-up the unit cost of the pilot plant:

$$C_x = C_y\,(Q_x/Q_y)^{\eta} \qquad (1)$$

where:

C_x = The capital cost for a large plant with a specific capacity;

C_y = The capital cost for a small pilot plant with its actual capacity;

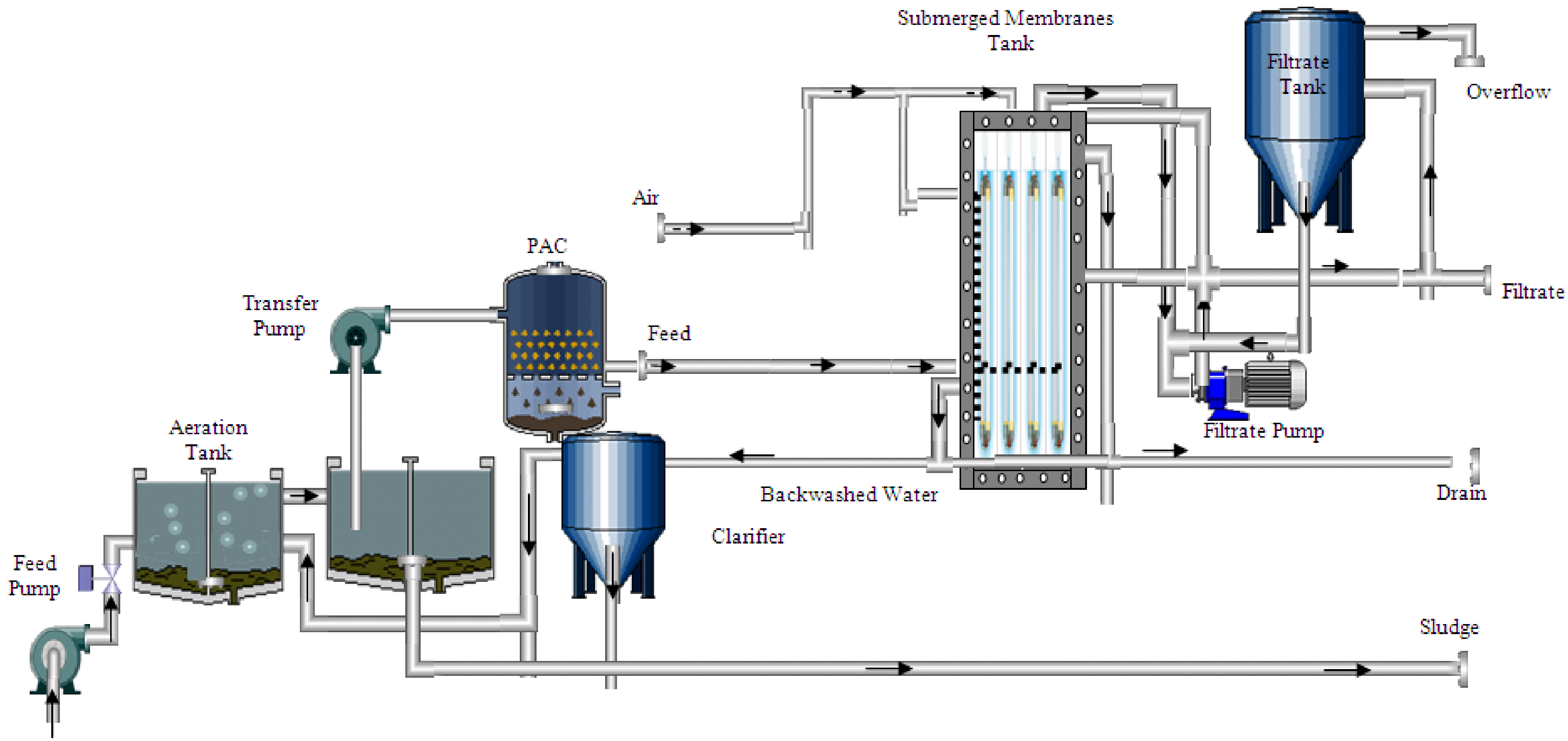

Fig. 1 Integrated submerged membrane microfiltration treatment system.

Table 1 Operating data for the integration system and the experimental plant.

Parameter	Dairy operations
Plant capacity (m^3/day)	24
Plant life (years)	20
Running days	137
Running hours (h)	2,972
Feed inflow (l/h)	1,000
Filtrate outflow (l/h)	1,000
Feed pressure (bar)	1.05
Total feed (m^3)	2,972
Total filtrate (m^3)	2,972
Total electricity consumed (kWh)	27.8

Table 2 Estimated costs of capital and operating expenses.

Parameters	Cost (US $)
Total unit capital cost	95,000
Machinery—compressor	3,000
Machinery—feed pump	1,000
Machinery—transfer pump	900
Machinery—backwash pump	1,000
Tanks	2,830
PVC pipes and valves	540
Membranes	9,260
Civil work	3,330
Concrete base	3,330
Kirby shade	2,660
Operating cost	0.335
Manpower for monitoring (2 technicians)	2,330
Chemicals agent (100 lts)	400
Maintenance and spare parts	1,066

Table 3 Total costs of dairy processing wastewater effluent for reuse.

Capital cost		Cost (US $)
	Machinery—unit cost	95,000
2	Machinery—compressor	12,000
3.	Machinery—feed pump	4,000
4	Machinery—transfer pump	3,600
5	Machinery—backwash pump	4,000
6	Membranes	37,335
7	Tanks (3 tanks)	2,830
8	Manpower	4,665
6	Total civil work	6,000
	Total capital cost	169,165
B.	Operating cost	
1	Electricity = (E/Q)*R	1.65
2	Chemicals	1,200
3	Pipes and valves	545
4	Maintenance and Maintenance parts	1,065
	Total operating cost	2,810
Total cost		171,975

Table 4 Estimates of unit costs for the treatment of wastewater produced from dairy production in a small experimental pilot plant.

Wastewater treatment		Cost (US $)
A	Total unit capital cost (depreciation)	
1	Unit Cost	0.543
2	Machinery—compressor	0.068
3	Machinery—feed pump	0.023
4	Machinery—transfer pump	0.020
5	Machinery—backwash pump	0.023
6	Membranes	0.212
7	Tanks	0.016
8	Manpower	0.811
9	Total civil work	0.034
B	Operation cost	
1	Electricity	0.0006
2	Chemicals	0.403
3	Pipes and valves	0.182
4	Maintenance and maintenance parts	0.359
Total cost (A+ B)		2.695

Table 5 Distribution of unit costs for the treatment of wastewater produced from dairy production in a small experimental pilot plant.

Wastewater treatment		Cost (%)
A	Total unit capital cost (depreciation)	64.90%
1	Unit cost	20.12%
2	Machinery—compressor	2.54%
3	Machinery—feed pump	0.85%
4	Machinery—transfer pump	0.76%
5	Machinery—backwash pump	0.85%
6	Membranes	7.85%
7	Tanks	0.60%
8	Manpower	30.06%
9	Total civil work	1.27%
B	Operation cost	35.10%
1	Electricity	0.02%
2	Chemicals	14.98%
3	Pipes and valves	6.78%
4	Maintenance and maintenance parts	13.32%
Total cost (A+ B)		100%

Table 6 Unit cost estimates for treatment of wastewater produced from dairy production in a large commercial size plant.

Unit cost (US $)	Economies of scale		
	$\eta = 0.95$	$\eta = 0.90$	$\eta = 0.85$
Capital	0.63	0.413	0.270
Operation	0.945	0.945	0.945
Total	1.575	1.355	1.575

Q_x = The capacity of a large plant (120,000 m^3/d);
Q_y = The capacity of a small pilot;
η = A parameter representing economies of scale.

The value of η is unknown due to lack of relevant information. Therefore, different assigned values will be used in this study ($\eta = 0.95$, $\eta = 0.90$ and $\eta = 0.85$)

which imply a modest to reasonable level of economies of scale. Not all cost components are affected to the same degree by plant capacity. The most affected component is the capital cost, so for simplicity, an assumption will be made that no economies of scale exist in other components.

Table 6 shows the variation of the unit cost with different value of η .Whereas the economies of scale increase, the estimated unit cost decreases.

For a modest economies of scale ($\eta = 0.95$), the unit cost of the system is estimated to be US\$ 1.5/m^3 and for a greater economies of scale ($\eta = 0.85$), the unit cost is estimated to be US\$ 1.575/m^3.

Currently, 17 tankers with an 30 m^3 capacity are hired to carry the wastewater. The cost of each tanker is US\$ 45 per day. So the annual cost for wastewater discharge is a total of US\$ 280,000. The total amount of wastewater to be carried for one year is 175,200 m^3 and therefore, the annual cost of transporting generated wastewater is US\$ 1.55/m^3. Extra cost needs to be added if the tankers dispose the wastewater into nearby conventional treatment plant. The cost of conventional treatment of municipal wastewater in Kuwait was reported by previous study to be US\$ 0.55/m^3 [7]. Therefore, the total cost of this process will be US\$ 2.1/m^3.

5. Conclusion

The unit costs of dairy-processing wastewater treatment for a small experimental plant using the integrated system technique have been estimated based on the operational data and cost elements. The result is US\$ 2.695/m^3 which, in capital costs account for 65% of the total cost, whereas the operating cost accounts for 35% of the total. Using economies of scale to calculate the unit cost for a large commercial plant, the analysis shows that the unit cost is US\$ 1.575/m^3, whereas the unit cost for wastewater transportation and treatment in a conventional plant is US\$ 2.1/m^3. This reveals that the proposed treatment system is cost effective and can be used to treat industrial waste effluent.

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