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Simulation and experimental studies to enhance water reuse and reclamation in India's largest dairy industry

Sarojini Tiwari, Chitta Ranjan Behera, Babji Srinivasan*

Department of Chemical Engineering, Indian Institute of Technology, Gandhinagar, VGEC Campus, Chandkheda, Ahmedabad 382424, India

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ABSTRACT

The stringent norms laid down by Pollution Control Boards in India are forcing dairy industries to have efficient waste water treatment processes and zero discharge treatment units. However, there are no standard protocols available to reduce waste water and encourage water reclamation and sustainability. To address this issue, a framework for water reclamation and reuse is developed for India's largest dairy industry called Amul Dairy. In this work, the sources of waste water are identified and a unique scheme is suggested to improve water reclamation and reuse. Results show that on an average, more than 5% water used per day can be reclaimed. Simulation of the effluent treatment plant at Amul Diary is performed to provide suggestions to enhance water quality that could aid reclamation. Modifications based on these simulations could result in 10% increase of biogas production. Further, 85% of the energy consumed by aerobic bioreactors in the Effluent Treatment Plant (ETP) could be reduced resulting in energy savings. The proposed methodology can be extended to all cooperative dairy industries in India that are developed based on recommendation from Amul.

1. Introduction

India is the largest producer of milk [1] owing to "Operation Flood" [2], a project launched by National Dairy Development Board (NDDB) in 1970 and lead by Verghese Kurien. The common dairy products such as butter, cheese, ghee, and curd, are the major sources of animal protein for the vegetarians. The enormous vegetarian population makes India the largest consumer of its own dairy products. Dairying is a persistent source of income for the ruler area in India. As per NDDB, the Indian dairy industry is all set to experience high growth rates in the next eight years with demand likely to reach 200 million tonnes by 2022 [3].

Dairy industries, similar to other food processing industries, consume substantial amount of water predominantly for cleaning in place (CIP) processes, tankers, crate, silos and floor wash. The present annual consumption of water in dairy sector is roughly 62 billion m^3 and is all set to rise well above 400 billion m^3 by 2025 [4]. The major sources of water in India for industrial and agricultural consumptions are river and ground water [5]. However, the Central Pollution Control Board (CPCB) report on the status of water quality indicate alarming decrease in the quality of surface water in India [6]. The proliferating water demand by the booming dairy industry would create a considerable impact on the water sustainability in India [7]. The depleting water resources and quality necessitates initiation and application of sound water and waste water management systems. This management system should not only be able to address water scarcity but also be able to minimize waste water production by endorsing reclamation and reuse.

In a typical Indian dairy industry, the volume of waste water effluent is 10 L per 1 L of milk processed, at-least twice greater than advanced countries [8]. Further, a report by Columbia Water Centre states that over exploitation of ground water in northern Gujarat is unsustainable and may exhaust this valuable water resource if left unchecked [9]. Perverse energy subsidies (used for pumping groundwater) to support agrarian economy have lead to unorganised and mishandled practices of water usage in dairy and other agro based industries [10]. Feasible water and waste water management practices are the need of the hour [11,12]. Although many water and waste water management protocols in dairy industries have been advised in literature, there are few case studies to observe the outcomes of their application [13]. Alongside better water management practices, new technologies

Abbreviations: ASM, activated sludge model; CIP, cleaning in process; COD, chemical oxygen demand; CPCB, Central Pollution Control Board; ETP, effluent treatment plant; NDDB, National Dairy Development Board; RMRD, raw milk relieving and processing department; TDS, total dissolved solid; TKN, total Kjeldalh nitrogen; TSS, total suspended solid; UASB, uplift anaerobic sludge blanket.

* Corresponding author.
E-mail addresses: babji.srinivasan@iitgn.ac.in, babggg1@gmail.com (B. Srinivasan).

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on treatment of dairy waste effluent are coming up with the sole purpose of reclamation and reuse [14,15]. There are still many uncertainties on the application of such technologies due to the lack in their cost effectiveness. Hence, a proficient water and waste water management is the best practice to minimise water usage and maximise water reclamation. A detailed review of the state of art water reclamation and energy saving practices in dairy industries is provided by Rad and Lewis [16]. Though several water reclamation techniques like pinch analysis is widely applied in dairy industries of developed countries [16], there is hardly any followed in India. This is mainly due to lack of proper monitoring of wastewater treatment plants to identify the source, nature and dynamic information about the effluent; vital for implementation of any water reclamation process. Limited reward for water conservation and perverse energy subsidies are major reasons for improper maintenance (with minimum/no sensors installed) of wastewater treatment plants in India.

Mathematical modelling and simulation of waste water treatment processes plays an important role to describe and predict the complex behaviour of various biological process units [17]. Plant wide modelling based on fundamental principles is a great tool in designing and optimising waste water treatment systems. Benchmark simulation models (BSM) of waste water treatment plants and their many improvements have come up in the last few years to monitor and develop control strategies for the better performance of the same [18]. Also, these simulation tools do not rely totally on measurements and hence well suited to analyse wastewater treatment plants in India.

This article aims to develop a framework for water sustainability in Indian dairy industries through experimental and simulation studies. Experimental studies are conducted to identify the source and nature of wastewater in India's largest dairy industry unique scheme is suggested to improve water reclamation and reuse. Further, a model of the Effluent Treatment Plant (ETP) in the dairy industry is developed and validated using experiments. Simulation studies using this model aided to provide a few suggestions that could result in improvement of biogas production and energy savings in treatment plant along with improved effluent quality. The reclamation techniques suggested in this work are best applicable to dairy effluents and can be further generalised in various industries to promote water savings by reclamation and reuse.

2. Methodology

The subject of this case study, Kaira District Co-operative milk producers union Limited, widely known as Amul Dairy, is located in Anand, Gujarat. Amul is the largest food brand in India majoring in production of milk and milk products. Back in 1946, this dairy was the significant centre of "white revolution". It is run by collection of milk from around 700,000 villagers. With a daily milk handling capacity of 4.5 million litres, Amul dairy manufactures ghee, butter, processed milk, milk powder and flavoured milk.

The first objective this work is to assess Amul Dairy in terms of its water usage and waste water effluent sources. Based on the above assessments, a unique scheme of segregation and treatment is developed to reclaim water and thus minimize water usage and wastage. Further, in order to assess and improve its performance, the dairy's ETP is modelled at steady state. The behaviour of the real plant is compared with the virtual simulated plant using experimental techniques. These simulation and experimental studies on the ETP promotes the techniques required to make a treatment plant perform better with energy efficiency. Based on these simulations, minimal modifications are suggested to the ETP that could result in improvement of biogas production and energy savings in treatment plant along with improved effluent quality. Further, the better quality of the treated water generated as the result of suggested improvements can be then reclaimed by use of advanced treatment processes.

The following sub-sections details the approach taken to achieve the objectives of this work. The first subsection suggests the procedures required to assess the water usage at Amul dairy. This is followed by a brief description on modelling and simulation of its ETP along with details on mathematical models used in modelling the various reactors at ETP. The final subsection describes the techniques used for characterising the waste water effluents at Amul dairy.

2.1. Water usage assessment at Amul Dairy

Amul Dairy, apart from processing the collected raw milk, manufactures various milk products such as butter, ghee, milk powder, skimmed milk and powder, and flavoured milk. It has a separate milk packaging unit where the processed milk is packed in pouches before being sold in markets. The dairy requires an average of 1600 m^3 of water per day. The chart in Fig. 1 gives a complete description on distribution of water usage in various process units within the dairy.

Operational processes involve a daily usage of 41.6 m^3 of hot and chilled water mostly in heat exchanger units used in ghee and butter manufacture and milk pasteurisation. Crate wash and railway tanker wash together takes up 38.4 m^3 of water per day. The make-up water requirement for the cooling tower and boiler feed adds to 295.2 m^3/day. Cleaning in place (CIP) and floor wash account for maximum consumption of water which is 1200 m^3/day. The 24.8 m^3 of water used per day in research and development labs and other similar areas are clubbed in the "Other" section of the chart.

CIP, demanding large water consumption, is a three stage process. The first stage is rinsing of equipments with soft water. The second stage is to wash the equipments with hot Lye (sodium hydroxide soln.) to wash out the microorganisms. The third stage involves washing out leftover lye in the equipments with soft water. Automatic CIP systems usually re-utilises the washed out water used in its third stage for rinsing. A fourth and a final cycle of washing out the equipments with nitric acid followed by soft water is also carried out once in a week. On an average, 1200 m^3 of water is being used by the dairy for cleaning in process and floor wash. Fig. 2 shows the distribution of the same in various process units of Amul Dairy. Raw milk receiving and processing department (RMRD) of Amul dairy utilises 89% of the total water used for CIP and floor cleaning, possibly because of the large amount of milk handled every day. The milk packaging section packs the

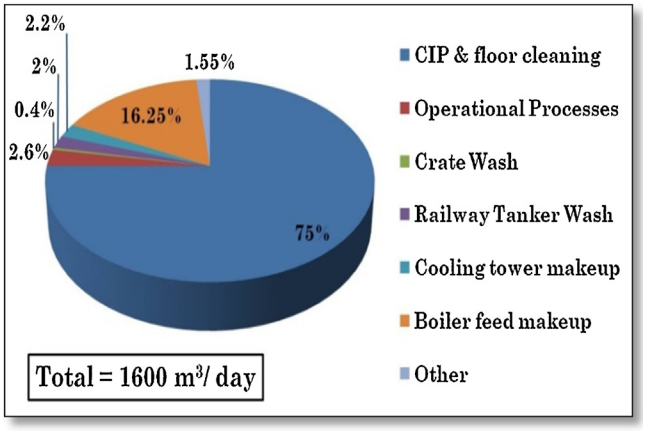

Fig. 1. Breakdown of water usage at Amul Dairy.