Chapter

Green Gold from Dairy Industry: A Self-Sustained Eco-Friendly Effluent Treatment Plant

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Abstract

The major bottleneck of dairy effluent treatment plant operation is the generation of 10 m^3 of nutrient rich wastewater per m^3 of milk processed resulting in an annual production of 7.93 tons of carbon dioxide equivalent (CO_2 e) gas during treatment in a 7–8 step process. It is an expensive, non-ecofriendly, laborious process which is often not adoptable by the small segment installations. A carefully selected tailor-made bacterial consortium in biofilm reactor within 4 h of incubation in a single step operation under ambient condition could transform the total volume of wastewater into ammonia rich liquid biofertilizer generating 0.79 tons/year CO_2 e gas. This biofertilizer replaces the use of fresh water and chemical fertilizer for agriculture, producing economic crops at par with chemical fertilizer. In certain cases, the production of crops is increased substantially over chemical fertilizer based growth. It reduced carbohydrate content of tuber crops. The generated liquid biofertilizer can overcome the shortage in fodder production without using chemical fertilizer and fresh water, hence solving one of the major concerns for sustaining the expansion of dairy industry, hence making dairy effluent treatment plant (ETP) operation an eco-friendly, self-sustainable operation.

Keywords: dairy wastewater, liquid biofertilized, CO_2 equivalent gas emission, fodder production, self-sustainable effluent treatment plant operation

1. Introduction

The dairy industry is a growing sector globally with ever increasing need for constant development to meet the needs of the population. It is one such food industry which serves the life from day 1 till life ends. The industry has its own issues that need to be addressed. Different countries have used different models to sustain its dairy industry. One of the common problem faced across the globe is the constant supply of adequate quantity of healthy fodder for the cattle [1]. The high price of the fodder often takes away any profit that would come out of the sale of the milk or milk product [2]. Quality of livestock and availability of land for fodder production are two major concerns that holds back the desired progress in the dairy sector in regions like India, Bangladesh, China, Mangolia, Philippines and Vietnam [3].

There are regions like Sri Lanka which have good livestock as well as land, yet have insufficient fodder due to lack of proper scientific management strategies [4].

The demand of milk in the domestic market is much more than the production, leading to import of dairy products in Sri Lanka. This harms the economy of the country due to spending of the limited foreign exchange. Adequate scientific input for agricultural produce increase can lead to addressing the need for nutritious food supply for its citizens, strengthening the agricultural activity without addition of excessive chemical fertilizer and strengthening the dairy sector through adequate fodder production. Dairy has been identified as a dynamic, integrated and integral part of rural economy of Sri Lanka by its government. The tropic environment results in experiencing different diseases, calling for adequate measures for improving the livestock as well as fodder producing pastures [5]. Adequate fodder plots are required for making the smallholder dairy operation profit yielding. Lack of ownership of adequate land creates hurdle in producing quality fodder by the farmers. Lack of quality feed round the year at reasonable prices prevents the farmers from realizing the genetic potential of high milk yielding animals. Adequate management of common grasslands can address this problem to a major extent.

The 10-Year Development Framework estimated 44% of agricultural land to be inadequately used, indicating towards a greater opportunity for further improvement of this fodder production practices. Unutilized state authority lands could also be put to use for fodder production. The Livestock Development Policy states that these lands will not be privatized but would be made available to private sector for production of superior quality fodder material. Providing access to the fodder cultivating land alone would not be sufficient for sustaining the economy [4]. In addition, access to modern technology would be needed.

Countries like India have developed to be the largest milk producer from a country with shortage of milk, due to operation flood (initiated in January 1970), with intense focus on development of dairy sector under the leadership of Verghese Kurien. One of the steps towards enhanced productivity of dairy industry was ensuring availability of cattle feed. National Dairy Development Board (NDDB) predicted the milk demand to be around 180 million tons in 2022. Increasing demand was expected to influence the milk prices globally. This called for a careful review of the requirements for the local dairy development.

The marginal dairy farmers with 2–3 animals form a major portion of dairy units in India. Their major investment is in the purchase of fodder. Hence a sustained fodder supply at affordable cost is a must to promote the dairy industry and the rural economy of a country. Such changes would have significant implications on the smallholder farmers who constitute about 75% of rural population, leading to alleviation of poverty. Moreover, it is these farmers who own major fraction of female cattle (60%) as well as land (33%). Feed is mainly the residue of crop, coarse grains, cereal remains/byproducts (brans, meal and cakes). Cooperatives have picked up the responsibility of production and supply of feed at subsidized rates to farmers. Inspite of all these, the average milk production per animal per lactation (987 kg) is considerably lower than the global figure (2038 kg). This also depends to certain extent on the feeding practice, quality, availability and affordability in addition to the breed of the cattle. The land use for green fodder production varies between 15 and 20%. Insufficient fodder resources and absence of regulations to check the fodder quality is one of the major constraints in sustaining the milk production [2].

In Bangladesh too the cooperatives supply fodder to the farmers at subsidized rates from the agricultural by product growing in the locality. This ensures healthy livestock. The farmers in turn, use the cow dung for running the biogas digesters which provides the cooking gas and the source of illumination. The spent slurry from the digester is used in fish ponds to enhance fish production. The fish pond is dried and dredged ever 2–3 years and the mud scooped out of the pond bed is used as fertile soil on adjacent farm lands. Through this approach, the small scale dairy practice becomes an eco-friendly integral part of the sustainable development of the rural community [6].

Rapid urbanization in China lead to expanding of the commercial activities outside the cities, resulting in rising prices of land, hence less available farmlands at affordable rates for dairy farming. This in turn lead to feed scarcity for the dairy. The model adopted in China to address this issue was to group the small scale dairy farmers in a designated region with all necessary infrastructure build up from the contributions of individuals, farmers and the local government. Each designated area with common facility for all (including milking and disease control), houses the cows which are managed by the households themselves (fodder production: from cultivation to processing) [7]. In order to solve the land problem in Mangolia, the state law has kept all grazing lands under its ownership, ensuring equal access to all [8].

In Pakistan the milk production faces a seasonal variation due to the variation in availability of green fodder. Though production of milk is highest between January to April, consumption is higher in summer months (May to August) due to dairy product consumption preferences. In order to solve this variation, there is a need for sustained production of green fodder round the year [9]. Philippines emphasizes on training of dairy farmers on different aspects including indigenous feed sources [10]. Thailand had its first dairy as early as 1962 which was handed over to the government on 1971. The government body has been operating since then with four objectives of which the first objective is farmer training in techniques of dairy farming, fodder production and disease management. The milk production expanded producing surplus milk. Cooperatives were formed to channel the produce to processing units. Some cooperatives have started feed mills to provide low price fodder. Superior quality of feed, concentrates and roughage has played an important role in improving milk yield of dairy farms in Thailand [11].

Provincial governments in Vietnam under its dairy development policies provides financial support for fodder production, among other things. Some provinces exempt agricultural land taxes while giving priority to making fodder production land available for the dairy farmers. Their decline in dairy industry was partly due to lack of fodder supply. Directed efforts are needed to designate priority fodder growing area in zones with ongoing dairy activities with special emphasis on the fodder type to be grown considering the seasonal variations, land type and irrigation facilities [12]. Unavailability of ownership land is the prime concern for lack of quality fodder production. Government intervention can improve the situation by leasing communal land and encouraging innovative methods for pasture development and fodder production [13]. One of the major component which could sustain expansion of dairy industry in different countries is a sustained production and supply of green fodder to the cattle at subsidized rates in order to cut down on the major investment of the small and middle segment farmers.

2. Rural dairy wastewater management

After petrochemical, dairy industry is a major sources of large volume of highly polluting wastewater generation. The volume of wastewater generated per unit of milk processed can go upto 10 times [14]. This is mainly from the cleaning activity at the processing plant with 2% of the total milk processed going into the wastewater. The quantity of milk to be processed is expected to rise to meet the demand of the rapidly expanding population [15]. Dairy industry wastewater is eco toxic unless adequately treated because of the biodegradable pollutants preset in it. This industry consumes a substantial volume of water and produces enormous wastewater which seeps into the environment polluting fresh water reserves. The conventional dairy operation, to get the wastewater to discharge level, involves about 8 unit operations namely collection of wastewater in receiving tank, passing the wastewater through skimming tank to remove fats, subjecting the skimmed wastewater to anaerobic treatment, biological oxygen demand removal in aeration tanks, passing the water to settling tank, removing the settled sludge to sludge tank while passing a part of the sludge back to the aeration tank while the rest to the sludge drying bed. In addition, it might have separate arrangements for dewatering the sludge before sending to the sludge drying bed. This involves a large space and energy for transporting the wastewater between the units as well as in the aeration chamber. The treated water is mostly discharged into the environment while part of it might be used for non-potable application within the effluent treatment plant (ETP) premises.

Dairy wastewater is rich in plant growth nutrients like nitrogen, carbon and phosphorous. These pollutants are lost during conventional process of treatment due to biological action. A clear understanding of the pollutant to be treated [16], the microbial metabolic pathway that breaks down/converts the pollutant into plant acceptable form [17–19] and the kind of microbes known to harbor these pathways [17–20] can lead to development of processes which would convert the pollutant into a value added product [21]. The dairy wastewater with enhanced phosphate and nitrate along with a high carbon:nitrogen ratio [22] could be used directly for sustaining bacterial growth. This property causes nuisance when the wastewater is left unattended. However, the same raw material (entire volume of dairy wastewater) can be selectively converted into ammonia rich liquid using selected microbial consortium under ambient condition with no additional requirement of aeration [16, 20].

Ammonia is a preferred nitrogen source for plants than any other form. The microbes selected for the bioconversion should be able to degrade protein and lipid; remove phosphate while convert nitrate and nitrite into ammonia (ammonification) and not into nitrogen (denitrification) within the reactor. Therefore, the nutrient rich dairy wastewater gets converted to ammonia rich liquid by the enzymatic activities of microbes. This liquid demonstrates the properties of a liquid biofertilizer that can replace the use of fresh water and chemical fertilizer during agricultural [16, 20] operations. Lack of additional aeration and ambient operation ensures savings in energy expenditure.

Six well characterized bacteria (Firmicutes and Proteobacteria) from environmental origin were combined in definite proportion [16] and put as a biofilm in a single unit (well designed) biotreatment plant [21] that replaces the storage tank, skimming tank, anaerobic digester, aerobic digester, settling tank, sludge tank and sludge drying bed of a conventional dairy effluent treatment plant, hence reducing the space requirement for setting up an effluent treatment plant by about 80%.

The conventional treatment takes about 120 h [23] for treatment of the wastewater which is mostly discarded into the environment. Some part of it after further treatment is reused in plant operations. In the developed technology [16, 21], the organisms were placed as biofilm in the biotreatment plant. The biofilm formation ensures one-time bacterial inoculation with continuous operation for couple of years. Biofilm development with tailor-made consortium with synergistic interaction among the members ensures rapid stabilization of the biofilm (unlike industrial approach of using activated sludge for immobilization which take longer time for stabilization). This faster stabilization of the bacterial consortium is due to reduction in doubling time of the bacteria in the consortium [24]. In the case of the dairy wastewater treating consortium the doubling time in immobilized condition becomes 17 min and 10 s while the same under suspended condition was 78 min and 56 s. This ensures rapid stabilization of the system with more biomass for active metabolism in biofilm based systems, hence improved performance.

In addition, bacteria in biofilm are more resistant to external perturbation, a property essential for treatment of wastewater whose nature might occasionally vary due to difference in the upstream operations. The current system takes only 4 h of incubation to convert the dairy wastewater into an ammonia rich liquid biofertilizer. This makes the current operation 30 times faster in dairy wastewater treatment than the conventional system. An added advantage of this system is no sludge formation unlike the conventional systems. Hence, if operated as per standard operating procedure, the system demonstrates stable perform over extended period of time.

Unlike the conventional dairy effluent treatment system which requires about 60 kW (kilo watt) of energy for treatment of 600 m^3 of wastewater, the current system consumes only about 6 kW of energy for pumping the wastewater into the biotreatment plant. Since no aeration or temperature control is needed, hence the system utilizes only 10% of the energy of a conventional system resulting in a savings of approximately 90% on the carbon dioxide equivalent gas emission due to the effluent treatment plant operation [21].

The major drawback of this system is that it is only suitable for dairy installations in rural area which have large farm lands in their vicinity. The transportation of the large volume of liquid fertilizer would not be economically viable and hence direct use in adjoining farm lands is a must to ensure complete use of the by product (liquid biofertilizer) without damage to the environment. Through this approach, the major misuse (89%) of fresh water (for agriculture) can be stopped in agro-ecological zones of the globe. The fresh water can be set aside for portable applications while the plant growth essential nutrients along with the huge volume of the water (generated as wastewater) with suitable treatment could be used for such non-potable applications like agriculture. This would slow down the rapid depletion of fresh water reserves worldwide which is predicted to affect 40% of the world population by 2025 [25] unless checked immediately.

The treated water is suitable for irrigation purpose. In order to get the water to a nutrient free condition, it could be used for cultivation of yet another well-defined mixed consortium of bacteria and microalgae enriched from wastewater fed fish pond. This consortium with minimal aeration using bubbling and light could completely remove nitrate and phosphate with 93% removal of chemical oxygen demand and 87% removal of ammonia while growing in treated dairy wastewater for 48 h [26]. The consortium shows 67% enhancement in biomass with 42% enhancement of lipid and 55% enhancement of carbohydrate content when compared to biomass grown on wastewater fed aquaculture fish pond water (from where the biomass was originally enriched) as control [26].

3. Sustainable production of quality feed

About 80–89% of fresh water that is drawn every day is used for non-potable agricultural purposes in agro-economic regions [27]. This needs to be checked urgently to protect 40% of the world population from facing scarcity of fresh water by 2025 [25]. However, the agricultural practices cannot be avoided to sustain the lives of the ever increasing population of human. Similarly, fodder production is also a must, desirably green fodder for sustaining dairy industry directly, and the human population indirectly.

The agricultural practice consumes chemical fertilizer in addition to fresh water. However, only 12–30% of it is utilized while the rest pollutes the ground water and the surface water bodies due to leaching [28]. Adequate scientific intervention leads to development of bacterial formulations which ensures entrapment of plant growth nutrients in the root zones by the microbes ensuring minimal leaching into the surrounding environment [29] and hence continuous access to nutrients during the growing season resulting in faster maturation of the crops [21, 28–30].

To address this requirement of sustaining agriculture without fresh water consumption and chemical fertilizer leaching, the liquid biofertilizer developed from bioconversion of dairy wastewater using well characterized bacterial biofilms was used for pot trial experiments followed by field trial experiments. A significant increase in production of mung bean (2.12 folds compared to chemical fertilizer) with enhanced chlorophyll content (1.4 folds compared to chemical fertilizer) of the leaves indicated health growth of the plants.

While the seeds serve as food for human consumption, its husk and the green plant serves as fodder. The maturation of plants was faster with liquid biofertilizer application showing shorter roots with fewer nodules than chemical fertilizer treated plants. The shorter roots with fewer nodules indicate easy access of nutrients in the root zone which neither needs to penetrate deep into the soil, nor establish association with rhizosphere bacteria for nitrogen fixation [16, 21].

In case of pot trial of sorghum sudan grass, there was 3.5-fold increase in biomass production compared to control (without fertilizer), hence ensuring enhanced supply of fodder per unit land without use of fresh water and chemical fertilizer. In case of field trial, sorghum sudan grass showed an increase of 2.53 folds within 2 months of growth.

In case of mung bean, the peak production was obtained within 18 days of podding and was significantly higher than chemical fertilizer grown plants. The production was increased by 2.09 folds if considered for the standard growing time of 65 days while was 1.56 folds higher when compared to chemical fertilizer grown production after 75 days. Faster maturation ensured higher fodder within shorter time with availability of land for the next crop.

In case of black gram a similar production (1.04-folds) was seen compared to chemical fertilizer during field trial. This biofertilizer enhanced the cob yield in maize (*Zea mays* var. Vijay) by 1.19-fold with associated biomass increase which serves as a fodder. The liquid biofertilizer caused 2.1–2.64-folds increase in biomass of lemongrass (*Cymbopogon citratus* var. Dhanitri and var. Krishna) with significant enhancement in oil content. Lemon grass addition to animal feed in definite proportion is reported to enhance nitrogen uptake, leading to healthier growth of animal [31–33]. When compared to chemical fertilizer, the liquid biofertilizer enhanced yield of ramie fiber (1.39-folds), sweet potato tubers (1.44-folds), cassava tuber (1.86-folds), yam tuber (2.55-folds) and elephant foot yam tuber (3.8-folds).

The yield was similar to chemical fertilizer in case of field pea seeds (1.16-folds), colocasia tubers (1.01-folds) and sugar cane (1.01-folds) indicating the biofertilizer to be as effective as chemical fertilizer. This biomass in case of colocasia showed significant increase (2.05-folds increase). Similarly, higher production was seen in case of sugar cane, cassava and sweet potato biomass, indication towards enhancement of fodder crops.

Through this approach, the fodder production around the rural dairies could be sustained round the year with no additional cost as a zero discharge technology considering the effluent treatment plant and the surrounding field [21]. The environment is protected as well as the fresh water reserves will be preserved. The access liquid biofertilizer could also be sold to the neighboring farm owners by the dairy effluent treatment plant owners at a very subsidized rate, which would be beneficial for both the seller and the buyer making the dairy effluent treatment plant operation self-sustainable.

4. Urban dairy wastewater treatment

The above approach can work only in case of rural dairies [21] with vast farm lands in its vicinity. However, microbial approach with tailor-made consortium can also work in case of urban dairies with space limitation. Appropriately designed consortium using well characterized microbes from activated sludge of dairy effluent treatment plant and other environmental origin can be combined in definite proportion to give a sludge free biofilm based dairy wastewater treatment system which within 20 h of incubation under ambient condition in a single unit operation can reduce the nitrate and phosphate substantially [20]. The treated water after further treatment with bacteria microalgae mixed consortium for 48 h was free of nutrients and suitable for discharge or reuse [26].

The biomass can be used as the raw material for biofuel production due to its high lipid and carbohydrate content. Another advantage of this technique is the growth of the consortium as attached biomass. That makes the harvesting of the biomass less energy intense (as centrifugation is not required) with no requirement for external supply of nutrients and fresh water for growing the microalgae. The dairy wastewater substitutes for the fresh water and the nutrient and hence makes algal growth for biofuel production an economically viable process. The requirement of 48 h compared to 5–7 days during conventional algae based wastewater treatment makes the process rapid and hence requiring less space for treatment. The total time required for the combined treatment of 68 h (bacterial plus the microalgae bacterial) is still less than the conventional system of 120 h [23]. In addition, each process is a single unit operation, hence saving in terms of land involvement.

The dairy wastewater could also be treated using pure bacterial isolates in biofilm reactors capable of removing ammonia, nitrate and nitrate within a much shorter time (depending on the initial pollutant concentration) [34] for reuse in aquaculture, again saving wastage of fresh water from being used for dilution of the wastewater before it could be used for aquaculture.

5. Conclusion

It can be concluded that microbial technology application for dairy wastewater treatment can lead to solving two of the major concerns of the dairy industry namely, (i) ensuring round the year green fodder for the cattle without wasting fresh water and using little chemical fertilizer, as well as (ii) making its effluent treatment plant operation ecofriendly and self-sustainable. The crux of the problem is in developing the right combination of microbes which would convert the pollutants into a plant usable form, resulting in little dead mass generation. This liquid biofertilizer, unlike the conventional organic fertilizers available, release nutrients at sustained, sufficient rate from the beginning of the cultivation resulting in higher yield. Hence health crop in high quantity can be produced from the byproduct (green gold) generated from the dairy effluent treatment process.

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Conflict of interest

There is no conflict of interest.

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