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DEVELOPMENT OF TECHNO-ECONOMICAL TREATMENT SYSTEM FOR BULK MILK COOLER EFFLUENT IN INDIA

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Abstract

This paper addresses the present status of milk procurement practices in India, advancements in milk chilling technology, cleaning operations of milk chiller units and discusses the issues related to Bulk Milk Cooler (BMC) effluent treatment. Analysis of various physico-chemical parameters revealed that BMC effluent has wide variation in characteristics. BMC effluent discharged after every cleaning process are mainly characterized by the presence of high oil and grease (O&G) (120-2177 mg/L), organic load (COD: 2000-13000 mg/L; BOD_3: 500-7700 mg/L), suspended solids (425-2450 mg/L) and dissolved solids (1075-4610 mg/L). Suitability of employing an anaerobic treatment system consisting of settling cum digestion chamber, baffle reactor and up flow media filtration was studied for its efficacy in treatment of BMC effluent at various loadings. The studies indicated that the stand-alone anaerobic-media treatment with OLR up to ~ 2.0 kg COD/m^3.d and ~36-40 hours HRT was able to achieve substantial removal efficiencies of 82.77, 81.33, 96.92, and 94.2% for parameters COD, BOD, O&G, TSS respectively. Even though the system worked satisfactorily at higher loadings, it is necessary to adopt a holistic approach with an addition of tertiary treatment considering the complexity and wide variation in effluent characteristics in order to ensure its reuse for various non-potable purposes and ensure environmental compliance.

Key words: anaerobic reactor, bulk milk cooler, effluent treatment, hydraulic retention time, organic loading rate

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1. Introduction

India is the world's largest milk producer with over 187.7 million tonnes (MT) of production in the year 2018-2019 against 176.3 MT in 2017-2018 with an increase of about 6.5% and expected to cross 190 MT in the year 2019-2020 (NDDB, 2019). About 50% of produced milk is consumed as raw liquid and remaining are converted into various milk products. The transportation of milk from farms to industry was generally out of question in the past owing to the fact that time needed for all milking operations till it reaches dairy plant roughly takes four to six hours, which cause aroma loss and freshness of milk. Thus, milk procurement without affecting its quality and hygiene was the major drawback prevailed in dairy sector. This problem was fixed by the innovation and installation of bulk milk coolers (BMC) over past few years that aid in milk chilling either at farm or collection centers till the tanker from industry reach for milk collection. Thus, it has generated a new perspective in terms of milk procurement, quality, hygiene and overseas marketing.

1.1. Characteristics of bulk milk coolers

Bulk milk cooler tanks are usually rectangular or cylindrical in shape and made of high-quality stainless-steel shells at inner & outer surface for higher durability. The space in between shells is filled

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with poly urethane foam insulation. Other essential units that equipped with BMC units are separate milk reception unit, refrigeration system, diesel generator set and agitator fixed on lid rotating at 25-32 rpm. The paddle type agitator helps milk to be blended continuously, prevents settlement of milk solids at the bottom of cooler, maintains uniform temperature of milk and avoids its freezing near inside surface. It can be installed easily on uneven ground by adjusting ball feet. The normal capacity of BMC varies from 500 to 5000 liters of milk per day. However, bigger capacities are also available based on demand of customers. It hardly takes less than one hour to chill milk to 4ºC and can easily overcome temperature fluctuations due to intermediate milk pouring. The usage of BMC has become popular in recent past since it not only helps in increasing shelf-life of milk but also enhances ease of operation by ensuring systematic and simple way of milk preservation. In terms of BMC, chilling refers to rapid cooling of milk to very low temperature nearly to 4ºC, so that chances of microbial growth and spoilage is be retarded. This process is considered mandatory soon after reception of milk at collection/chilling centers (Srikari et al., 2014).

1.2. Pre-BMC period

Prior to installation of chilling plants, milk had to reach dairy industry in the morning by 8.30 am or so, before day temperature could rise. The milk collected were then transported in churns to industries by bicycles, bullock carts, barrows, trains and trucks when tankers were not much common in all places in India. Moreover, keeping churns protected from sun rays was a difficult task during the transition period. Frequent power failures in rural areas and inadequate pricing of milk from concerning industries discouraged farmers to install chilling plants in India. This ultimately affects the quality of life of farmers and they could barely meet their livelihood through milk business.

1.3. Post-BMC period

The guaranteed 24-hour power in rural areas including three phase supply enabled installation of chilling technologies in milk collection centers of various parts of India, that gave farmers flexibility to deliver milk even in morning or evening without any difficulty. It even helped them in expansion of herd size and more milk supply. Diesel generation (DG) sets are used as standby source of electricity, in case of any power failure. The chilled milk is usually pumped into tanker using hose connected to the outlet valve of milk chiller. In order to prevent the mixing of air into milk, pumping is stopped as soon as the tank gets emptied. An automatic flow meter is also installed in the tanker for recording milk quantity. The chance of milk spoiling during transportation is eliminated by thermos placed in between walls of tanker container, which keeps the milk in adiabatic condition so that no microbial actions takes place until it reaches the industry.

After each day collection and transportation of milk from chilling centers to industry, the BMC tank is necessarily cleaned and sanitized. This is mandatorily done to avoid any adverse effect on next day collection due to rapid microbial multiplication that lead to deterioration of milk hygiene. Presently, there are approximately more than 10,000 milk coolers of capacities varying between 500 and 5000 L in India; each requires minimum of 60-70 liters of normal water for every cleaning and demand of water varies depending upon the capacity of cooler tanks. Thus, on daily basis, 1.2 million liters per day (1200 m^3/d) effluent in the form of bulk milk cooler effluent is discharged into nearby drainage or sewer line without any treatment that ultimately joins nearby water bodies. This results in violation of environmental compliance caused by depletion of dissolved oxygen, development of anaerobic conditions and release of strong foul odors. The water body thereby becomes a breeding place for flies and mosquitoes carrying malaria and other dangerous diseases like dengue fever, yellow fever and chicken-guniya (Raghunath et al., 2016). It may also contain certain amount of plant nutrients such as nitrogen and phosphorous that results in excessive growth of aquatic plants leading to algal blooms and eventually eutrophication (Subasini et al., 2017). It is also reported that higher concentration of bulk milk cooler effluents is toxic to certain fish and algae. Thus, it has to be treated to remove pollutants prior to the disposal into irrigation lands and water bodies (Demirel et al., 2005).

Most promising and advanced approaches in the application of domestic and industrial wastewater treatment includes sequencing batch reactor (Mahvi, 2008), membrane bioreactor (Naghizadeh et al., 2008; Naghizadeh et al., 2011), submerged fixed film reactor (Gurjar et al., 2019), anaerobic-aerobic baffled reactor (Silva et al., 2018) and combined anaerobic baffled-filter reactor (Renuka et al., 2016). Studies reported that wastewater generated from slaughter house and textile industries contain high organic and inorganic load that can be effectively treated by application of combined physico-chemical process like adsorption, chemical coagulation and electro-coagulation (Bazrafshan et al., 2012; Bazrafshan et al., 2015). Electro-coagulation using aluminum plates is also a better method to removal phosphorous with higher removal efficiency (Gharibi et al., 2010). Studies also reported that from disposal point of view, electro-chemical treatment for dairy wastewater is not sufficient to remove remaining organic matter present in it (Kumari et al., 2019). Nowadays, researches proved the possibility in bio-electricity generation directly from dairy wastewater using some advanced microbial fuel cell in concern with future need for substituting rigorous use of natural energy resources along with better COD and BOD removal efficiency of 90.46% and 81.72%, respectively at 35°C temperature (Mansoorian et al., 2016). Various studies on the effect of operating conditions such as hydraulic retention time and organic loading rate on the performance of anaerobic reactors were reported for treatment of slaughter house wastewater (Musa et al., 2018; Tritt and Kang, 2018; Yousefi et al., 2018), pharmaceutical wastewater (Comoglu et al., 2016) and coffee processing wastewater (Bello-Mendoza and Castillo-Rivera, 1998). Some other research studies were also carried out to evaluate performance of media such as polyethylene granules (Jedrzejewska-Cicinska et al., 2007), lava stones (Gonzalez et al., 2011), coconut shells (Cruz et al., 2013), clay ceramic particles (Han et al., 2013) and blast furnace slag grains (Lee et al., 2015).

The present study deals with a detailed overview of pre & post BMC period as well as management of milk collection centers. It also focuses on developing a techno-economical treatment system which is compact and easy to operate. For this purpose, anaerobic biological effluent treatment system having high specific surface area filter media was studied. Anaerobic treatment technology for such effluents where there is high frequency of change in characteristics, it is more advantageous and mostly preferred because of its low footprint, low maintenance cost, low sludge production and ability to give good performance at high organic loading conditions (Dvorak et al., 2016). The best part is no energy input is required in the form of oxygen and yet biogas recovery is possible.

2. Material and Methods

2.1. Study area

The study areas are located in different parts of Nagpur district in Indian State of Maharashtra, where milk collection centers are undertaken by Mother Dairy, Nagpur. The BMC were located at Ajani and Hingna and a milk chilling plant undertaken by NFB Foods Private Limited under Maharashtra Industrial Development Corporation (MIDC) at Butibori. The location map of study areas in different places of Nagpur is shown in Fig. 1. The collection centers in Ajani and Hingna has only one cooler of capacity 2000 and 1050, respectively; while Butibori has two chilling tanks each of 25000 L capacity such that one of them act as standby. The collected milk is chilled in source at 4ºC in winter and 1-2ºC in summer, so that it remains fresh throughout the transition stage. The capacity of chiller tanks installed in all places varied depending upon the quantity of milk being collected daily in each center. As per the details shared by BMC units, most of the dairy industries have their own milk collection centers at various places where they spend money for purchase and installation of units such as BMC, DG set, Fat-SNF analyzer and weighing machine. The photograph showing milk reception unit and fat-SNF analyzer are shown in Fig. 2.

The quantity of milk brought by farmers is first measured in terms of weight and then quality is analyzed on the basis of fat, solids not fat (SNF), density, protein and added water on milk using fat-SNF analyzer. The sampler used in SNF analyzer is made up of HDPE with a capacity of 10 ml and each farmer enrolls his own identity number which is saved in the analyzer that has to be selected before analysis of samples. If fat-SNF quality is good enough, each farmer is paid ₹ 40/- per liter (~ US$ 530 – 550/ m^3) by the industry through BMC owner person. The income of farmers decreases with drop in milk quality.

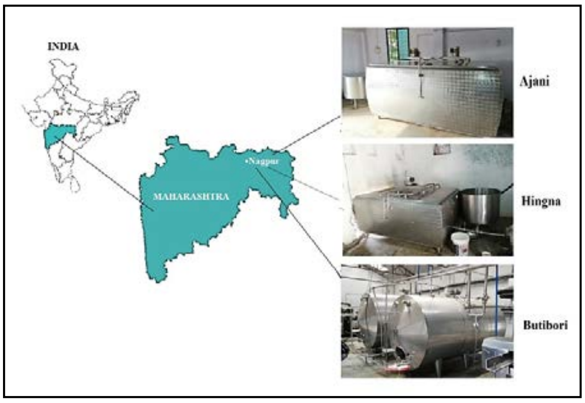

Fig. 1. Location map showing study areas in Nagpur district, Maharashtra, India

a) b)

Fig. 2. Photographs of (a) Fat-SNF analyzer (b) Milk Reception Unit in BMC at collection centre

Milk with more added water and less fat is rejected at the collection center itself. The only expense that farmer has to meet is the land for cattle rearing and its feeds. The milk accepted after analyzing fat-SNF is poured into milk reception unit, without pouring directly in to BMC tank. This help farmers to avoid lifting heavy milk churns to the tank height. The milk reception unit and BMC tanks are connected each other using stainless steel pipeline for the transfer of milk. The commission given by industry to person owner of BMC unit is ₹ 800/ m^3 (~ US$ 10-12/m^3). The only expense they had to meet by themselves is electricity which is about ₹ 300/ m^3 (~ US$ 4-5/m^3). Thus, the income of BMC owner also depends on the amount and quality of milk that can procure daily. For example, if milk procured in any collection center is 2000 L/d, then monthly average earning of BMC owner person considering electricity expense would be ₹30,000/month (~ US$ 400/month). Cleaning process of each units in milk collection centers are done manually first with hot water to remove milk components stuck on tank walls and then using normal water. Apart from this, detergents and sanitizers are also preferred for washing the tank properly such that its quantity varies from one BMC to other. There are no strict rules or guidelines that every cooler tank should be washed with a pre-requisite volume of water, sanitizers or detergents. The most preferred is commercially available detergents washing powder, liquid soap and sanitizers. The quantity of effluent generated from cooler tanks of Ajani and Hingna varies between 50-70 liters per day that is discharged directly into nearby sewer drains without any treatments that finally fall into river Kanhan and Venna, respectively. In Butibori, more than 250 liters of effluent is generated daily from washing of milk reception units, storage tanks, milk churns and floors, where all washing is done manually except churn cleaning. A churn bath is installed as shown in Fig. 3; where vessels are placed longitudinally and cleaning occurs by automatic scrubbing. These effluents are collected in HDPE tanks installed outside the industry from where it is pumped into Common Effluent Treatment Plant (CETP) of Butibori industrial area for treatment. Due to pump failure and high operation-maintenance cost, it was observed that it was discharged into nearby premises without any treatment.

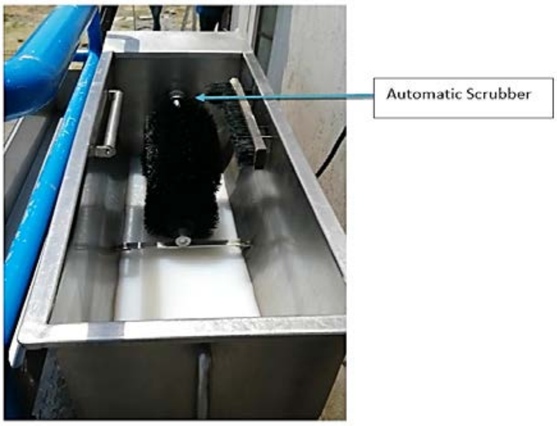

Fig. 3. Churn bath installed in Butibori for cleaning milk churns

2.2. Experiment set-up

The experimental arrangement consists of a multi-chambered anaerobic baffled-filter media reactor, water bath for influent feeding at constant temperature, peristaltic pump, filter media, effluent container and provision for gas collection as presented through the schematic diagram in Fig. 4. The reactor is made up of acrylic sheet, cuboidal in shape with effective size 45 cm x 15 cm x 20 cm and consists of digestion - settling - skimming chamber, baffled chamber and filter media chamber. The raw effluent pumped from water bath into the inlet of reactor, which overflows from one chamber to another through baffles walls provided in between whereas, entry of effluent into media chamber is made from bottom of chamber so that an up-flow is maintained. The baffles provided helps in effective mixing of effluent to prevent short circuiting within the treatment system. A cylindrical shaped synthetic and fluidized media made of recycled HDPE material is used in filter media chamber for biomass support. A total of 37 filter media were placed in reactor randomly that occupied very less volume, but still provided high specific surface area of @ 165 m^2/m^3 with high void volume of 89%. The specifications of filter media is given in Table 1. In order to prevent entry of sunight into reactor and maitaining the reactor temperature constant, it was made opaque using clinical bandage throughout commissioning and operation period. Fig. 5 shows the picture of experimental set-up for treatment of BMC effluent.

Table 1. Specifications of filter media

Specification	***Values***	***Unit***
Type	Fluidized	-
Material	HDPE	-
Height	2.00	cm
Diameter (O/O)	6.50	cm
Specific Surface Area	165	m^2/m^3
Surface Area (1 unit)	216.72	cm^2
Volume Occupied (1 unit)	66.33	cm^3
Weight of media	144.50	kg/m^3
Voidage	89.10	%
Density	0.96	g/cm^3
Weight (1 unit)	13.14	gm
Volume displaced (1 unit)	13.75	mL

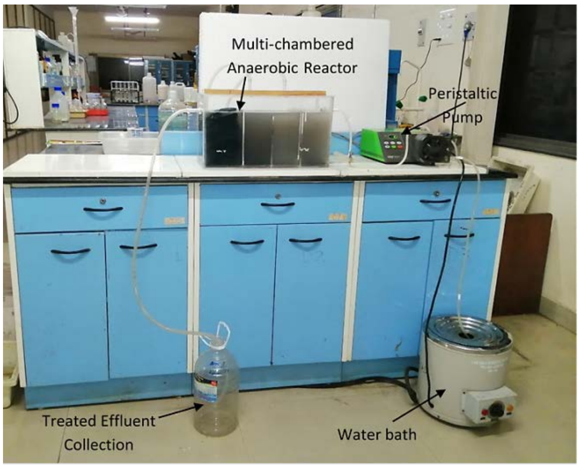

Fig. 5. Picture showing experimental set-up for treatment of BMC effluent

2.3. Sampling and analysis

Grab wash samples were collected from BMC installed in Hingna and Butibori in Nagpur Division. Samples were collected once in a week at the time of washing, which continued for 3 months in coordination with BMC owner. The collected samples were stored in refrigerator below 5ºC in order to prevent degradation of milk constituents. Each raw effluent sample was analyzed in Wastewater Process laboratory of CSIR-NEERI, Nagpur to assess the variation in characteristics.

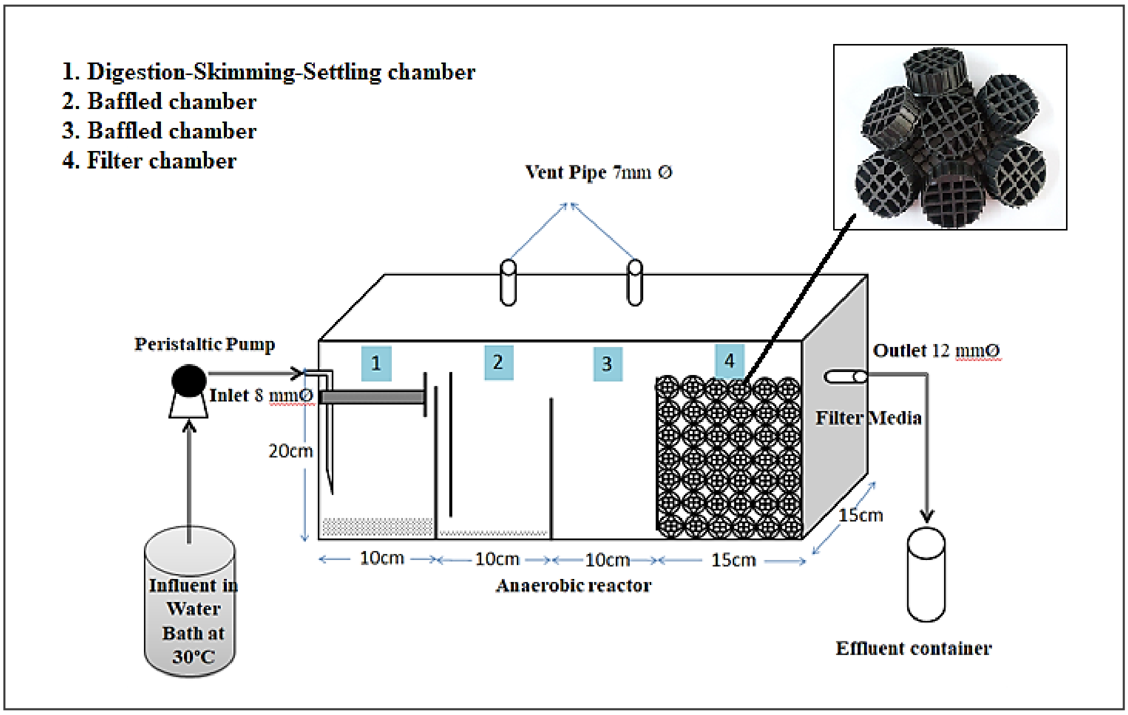

Fig. 4. Experimental arrangement of multi-chambered anaerobic baffled-filter media treatment system

The performance of reactor was monitored continuously with reference to chemical oxygen demand (COD), pH and alkalinity. Other physico-chemical characteristics such as oil & grease (O&G), total suspended solids (TSS), total dissolved solids (TDS), biochemical oxygen demand (BOD) and total phosphate (TP) were also monitored. All these parameters were measured according to Standard Methods for Examination of Water and Wastewater (APHA, 2005).

2.4. Start-up and commissioning of reactor

For the start-up and development of bio-film in the media, the reactor was kept under certain operating conditions. During the entire operational period, influent flow rate into the reactor was kept steady at 8.64L/d with the help of a peristaltic pump set at 2 rpm and connected using 8 mm internal diameter inlet pipe. Thus, overall hydraulic retention time (HRT) for effective volume of 13.5L works out to be 38 hours. HRTs for first three chambers and filter chamber at flow rate of 8.64L/d work out to be 25.5 and 12.5 hours, respectively. All the experiments were carried out at a constant temperature of 30°C throughout the operational period, which was maintained using a water bath in order to maintain uniform working conditions. As seeding inoculums, sewage from NEERI sewer line and microbial cultures from anaerobic reactors of various industries were used. The COD of raw sewage depends upon the climatic conditions and normally varied between 140 mg/L during winter at 6ºC to 980 mg/L during summer at 48ºC. It contains large quantity of suspended as well as dissolved particles and microbes.

The industrial anaerobic cultures also contain large number of methanogens even though COD value is less ranging from 67.2 to 239 mg/L. These inoculums can help in the development of biofilm on the media provided in reactor. About 8L of seeding inoculums were fed into the reactor daily at a temperature of 30°C because commissioning took place during winter season. To provide nutrients for the growth of microbes, some quantity of dextrose anhydrous were also added along with seeding inoculums. The progress of microbial growth in reactor was continuously evaluated by COD analyzes of influent and effluent seeding samples. It was observed that there was a decrease in COD, indicating the initiation of microbial growth in the media inside reactor. The reactor was fed with BMC effluent by varying organic loading rates (OLR) with same operating conditions after the acclimatization. It took over two months for the entire start-up and commissioning of anaerobic reactor.

3. Results and discussion

3.1. Wastewater characterization

The physico-chemical characterization of effluent is essential for appropriate selection and design of suitable treatment method which is effective, economical and sustainable. It helps in appropriate selection amongst different choices of treatment methods to decide the degree of treatment and to assess beneficial use of treated effluent. Raw effluent samples from Hingna and Butibori were collected and its physico-chemical characterization are presented in Table 2.

From the results of physico-chemical characterization of 9 sets of samples, it is clear that concentration of all parameters in BMC effluent shows great variation except for total phosphate. The type and amount of detergents or liquid soap and sanitizers used for washing also contribute to the variation in pH, total phosphate and alkalinity in effluent. The use of detergents or liquid soaps also imparts TDS in effluent. After conducting sampling and performing physico-chemical characterization, it was easy to generalize the non-uniform nature of effluent.

The summary of range in which each parameter vary is presented in Table 3. The value of COD ranges from 2000-13000 mg/L, which indicates high fluctuations in effluent characteristics and complexity for effluent treatment. The concentration of O&G was found to be varying between 120 and 2176 mg/L based on the quantity of fats present in the milk stored in chiller tanks, which depends on breed of cow, cattle feed, temperature. It was noted that BOD to COD ratio ranges from 0.22 to 0.81 indicating the fluctuation in biodegradation rate of effluent.

3.2. Performance of multi-chambered anaerobic media reactor

The long-term performance of multi-chambered anaerobic treatment system was assessed after successful commissioning throughout the operational period. Since there was wide variation in the raw effluent characteristics, it was normalized for uniform pH and organic loading rates with the help of sewage. The reactor was fed at constant flow rate of 8.64 L/d, allowing maximum applicable HRT of 38 hours for the said experimental conditions. The reactor was fed at organic loading rates (OLR) starting from 0.88, 1.1, 1.9 and 2.9 kg COD/m^3.d for three to four weeks each. Treated effluent obtained after treatment had slight whitish color. Table 4 presents the performance of anaerobic media reactor at various organic loading rates. Following section describes the performance of the reactor with respect to all the major parameters.

Table 2. Physico-chemical characteristics of raw BMC samples from Hingna and Butibori

Sampling locations		***Parameters[1]***							
		pH	***COD***	***BOD***	***Oil & Grease***	***TSS***	***TDS***	***Total Alkalinity***	***Total Phosphate***
Hingna	1	4.10	6204	5000	2176	2443	4602	540	0.05
	2	5.50	3489	1500	975	1200	1628	526	0.10
	3	5.43	6829	3000	1619	2000	1895	370	0.96
	4	7.22	3802	1889	682	1195	1075	510	0.42
	5	8.60	2294	500	617	1575	2585	1048	0.52
	6	9.26	2137	735	122	425	2430	1008	0.85
	7	8.99	2937	1000	204	675	2315	1176	1.47
Butibori	8	6.94	4772	1286	563	730	1145	180	1.46
	9	4.86	12932	7636	1728	1979	2460	240	1.52

Table 3. Characteristics of BMC effluent

Parameters	***Range[a]***
Chemical Oxygen Demand	2000-13000
Biochemical Oxygen Demand	500-7700
Oil & Grease	120-2177
Total Suspended Solids	425-2450
Total Dissolved Solids (mg/L)	1075-4610
pH	4.10-9.26
Total Phosphate	0.05-1.52
Alkalinity	180-1200

[a]All parameters are in mg/L, except pH

Table 4. Performance of multi-chambered anaerobic reactor at various organic loading conditions

Parameters[2]	***Organic Loading Rates (kg COD/m³.d)***															***CPCB discharge standards to inland surface waters***
	0.88			***1.053***			***1.071***			***1.926***			***2.972***			
	Concentration[3] (mg/L)															
	I	***E***	***η (%)***	***I***	***E***	***η (%)***	***I***	***E***	***η (%)***	***I***	***E***	***η (%)***	***I***	***E***	***η (%)***	
pH	7.45	7.84	-	7.69	7.82	-	7.82	8.07	-	7.26	7.6	-	7.56	7.84	-	5.5 - 9.0
Alkalinity	1076	880	-	1116	732	-	1200	932	-	528	412	-	544	370	-	-
O&G	304.8	58.4	**80.84**	408.8	74.4	**81.80**	995.6	90.4	**90.92**	780.4	24	**96.92**	2142	62	**97.11**	≤ 10
TSS	850	170	**80.00**	905	125	**86.19**	1965	325	**83.46**	1800	95	**94.72**	2050	65	**96.83**	≤ 100
TDS	2630	1740	**33.84**	2530	1625	**35.77**	2495	1815	**27.25**	1900	1370	**27.89**	2675	2030	**24.11**	-
COD	2294	1196	**47.86**	2745	752	**72.60**	2792	812	**70.92**	5113	881	**82.77**	7747	1840	**76.25**	≤ 250
BOD	500	286	**42.80**	731	345	**52.80**	876	415	**52.63**	1071	200	**81.33**	2604	648	**75.12**	≤ 30
TP	0.51	0.46	**9.80**	1.04	0.85	**18.27**	0.96	0.86	**10.42**	0.96	0.84	**12.50**	0.6	0.54	**10.00**	**-**

I *– Influent concentration;* ***E****- Effluent Concentration;* ***η*** *- Efficiency; [a]All parameters are in mg/L, except pH; [b]Represents average concentration of Influent and Effluent for respective OLR*

3.2.1. pH and total alkalinity

pH of BMC effluent generally depends on the amount of detergents used in washing and the rate of degradation of milk constituents present in it. The pH of raw & treated effluents is ~7.5 and ~7.6 respectively. It is a good evidence to show that the improved system can create a favorable condition for the growth of methane producing bacteria. The alkalinity in BMC influent samples is also an important factor to be considered. It usually varies in each wash outs depending upon the quantity of detergents or liquid soaps used.

It was observed that alkalinity of raw effluent varied between 528 and 1200 mg/L and that of treated effluent varied between from 370 and 932 mg/L in terms of $CaCO_3$, which is an indication of completion of methanogenesis phase after acidogenic stage of anaerobic treatment. The difference in concentration of alkalinity in influent and effluent samples is utilized by the microbes for neutralization of the volatile fatty acids (VFA) produced in the reactor.

3.2.2. Chemical Oxygen Demand

The COD value represents the total amount of organic matter available in the raw effluent, both biodegradable and non-biodegradable. The initial concentration of COD for first three loadings varied from ~ 2300 to 2800 mg/L and their lower treatment efficiency indicates less microbial population in reactor because biomass was not well acclimatized in new environment and hence could not increase their population. COD removals were 47.86 and 72% at OLR of 0.88 and 1.1 kg COD/m^3 d respectively. This indicates that COD removal increases with passage of time even at OLR due to better acclimatization and increase in microbial population. Performance assessment studies were later carried out at increased OLRs of 1.9 & 2.9 kg COD/m^{3}d by feeding raw effluent with average COD concentrations of ~ 5110 and ~7745 mg/L respectively.

COD concentration reduced from ~ 5110 to 881 mg/L at 1.9 kg COD/m^3.d OLR ensuring 82.77 % efficiency. Similarly, COD reduced from ~7745 to 1840 mg/L, when OLR was increased from 1.9 to 2.9 kg COD/m^3.d, thus provided 76.25% treatment efficiency. Hence, the performance of treatment system got affected with increase in OLR up to 2.9 kg COD/m^3.d, which indicated that further increase in OLR was not feasible. Izanloo et al., (2007) also reported decline in COD removal efficiency with increase in OLR for high oily wastewater treated using submerged fixed film reactor. They observed COD removal efficiency ranging from 70.87 to 93.12%, at OLR varying between 1.31 to 15.79 g COD/ m^3.d.

3.2.3. Biochemical Oxygen Demand

The biodegradable fraction of organic matter is measured in the form of Biochemical oxygen demand (BOD). In BMC effluent BOD is mainly contributed by fat, lactose, casein and washing powders, liquid soaps and sanitizers used for washing. BOD varies between ~ 500 to 876 mg/L for initial washings. BOD was reduced from 500 to 286 mg/L giving 42.80% efficiency at 0.88 kg COD/m^3.d OLR, whereas at 1.1 kg COD/m^3.d OLR, the efficiency was increased to nearly 53%. BOD removal efficiency at OLR of 1.9 kg COD/m^3 d was 81.33 % wherein it reduced from ~ 1070 to 200 mg/L and at 2.9 kg COD/m^3.d OLR BOD reduced from ~2600 to 648 mg/L thereby achieving 75.12% efficiency.

The applied BOD:COD ratio for raw effluent varied between 0.21- 0.33 and for treated effluent 0.23 – 0.51, indicating the nature of effluent from low to medium biodegradable.

3.2.4. Oil and grease

It is one of the most important characteristics that need to be evaluated continuously for the efficient functioning of the treatment system since accumulation of higher concentration of oil and grease affects the anaerobic biological processes. The oil and grease that enters in reactor is collected at the top of first chamber in reactor which acts as a skimming tank. These skimmed oil and grease components undergo digestion so that it gets converted into simpler compounds and eventually into fatty acids by further anaerobic reactions. The concentration of oil and grease was determined by gravimetric method and a huge variation of 304.8 to 2141.6 mg/L was observed on several feedings.

Unlike COD and BOD, removal in oil and grease concentration was observed to be consistently improving with increase in OLR and passage of time. This is because substantial oil and grease separation occurs in the first chamber due to adsorption, as the oil and grease layer go on thickening. Oil and grease concentration reduces from 304.8 to 58.40 mg/L (80.84%) and 408.8 to 74.4 mg/L (81.80%) at OLR 0.8 and 1.1 kg COD/m^3.d respectively. It was observed that oil & grease concentration at OLR of 1.9 and 2.9 kg COD/m^3.d reduces from 780 to 24 and 2142 to 62 mg/L giving efficiencies of 96.92 & 97.11% respectively.

3.2.5 Total Suspended Solids

The suspended solids are mainly due to the presence milk solids and its concentration depends on the amount of water used in washing BMC tanks. Majority of the suspended solids present in the effluent are settled at the bottom of first chamber and remaining suspended solids gets degraded in next two chambers, thereby very less suspended solid concentration is obtained in final treated effluent. The suspended solids concentration on several feedings varied between 850 and 2050 mg/L and which were reduced to concentration in the range of 65 to 325 mg/L. TSS removal efficiency varies between 80 to 96.83%.

3.2.6 Total Dissolved Solids

The presence of organic and inorganic dissolved particles in effluent are responsible for concentration of total dissolved solids. In anaerobic treatment, most of the organic particles get utilized by microbes as their food for growth while the inorganic solids remain in the effluent.

The usage of sanitizers and detergents for washing purpose are responsible for persistence of inorganic concentration even after biological treatment. The treatment efficiency regarding total dissolved solids varies between 27.11 to 35.77 % at various organic loading rates, which indicates presence of high fraction of inorganic content in the dissolved solids.

3.2.7. Total Phosphate

The presence of phosphate in BMC effluent is mainly due the application of detergents and sanitizers for cleaning purpose of milk cooler and its concentration ranges from 0.51 to 0.96 mg/L. The treatment result shows that phosphate reduction was very low and varied between 9.79 and 18.27 %. This is mainly due to the utilization of phosphate present in raw effluent by microbial population during their cell synthesis that results in removal of some of phosphate from BMC effluent.

Sometimes, energy conversion from Adenosine Triphosphate (ATP) to Adenosine Diphosphate (ADP) occurs in microbial cell that releases phosphate again into effluent during anaerobic digestion resulting in higher phosphate concentration in effluent samples. However, presence of phosphate is not a matter of concern in case of BMC effluent since the treated effluent concentration is less than the prescribed discharge limit of 1 mg/L.

3.3. Discussion

In the present study, it was noted that the characteristics of BMC effluent discharged after every cleaning process are non-uniform and highly complex in nature. It is normally characterized by the presence of high oil & grease content, organic load, suspended and dissolved solids (Table 3). The complexity of effluent is based on its biodegradability ratio ranging from 0.22 to 0.81 that depends mainly on various site-specific conditions such as amount of milk constituents retained in the walls of BMC tanks after emptied and quantity of water and detergents used for cleaning purpose. Hence, the sudden variation in effluent characteristics, especially oil & grease and organic load imparts difficulties in biological treatment systems. The major organic load present in BMC effluent due to solids and O&G gets separated in first three chambers. All the settleable solids get settled at bottom of the first chamber and O & G remains afloat at the top in baffle reactor in second & third camber and undergo digestion for the conversion of complex to simpler molecules. Baffle chambers also ensure adequate mixing of partially treated effluents.

In the fourth chamber, remaining organic matter is treated through filter media, wherein effluent flows upwards through filter media with acclimatized biomass at longer HRT. Based on the performance of multi-chambered anaerobic-filter media reactor, it is observed that stand-alone anaerobic-media treatment with OLR up to ~ 2.0 kg COD/m^3.d and ~36-40 hours HRT can substantially remove the organic load.

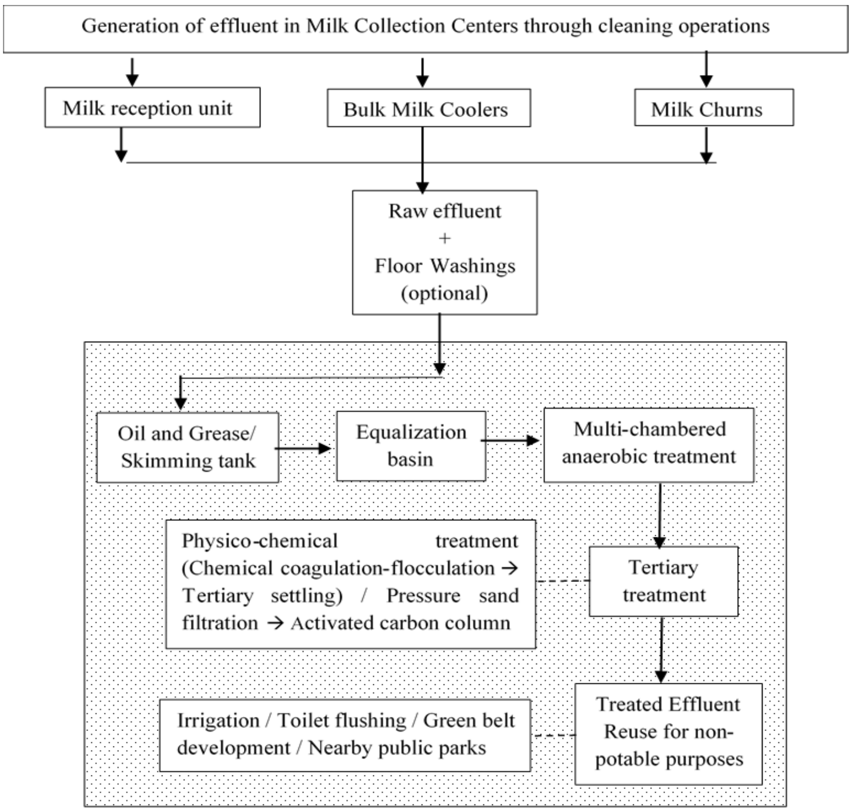

Fig. 6. Schematic diagram representing a holistic approach for BMC effluent management

However, this has to be coupled with pre-treatments systems including oil & grease trap, equalization and chemical aided / plain settling. The final treated effluent from similar system can still create fly nuisance and foul smell to the land or waterbody to which it is being discharged. So, in order to improve treated effluent quality for safe discharge into nearby waterbodies and ensure its reuse in non-potable purposes such as cleaning of floors in milk collection centers, irrigation in nearby lands, gardening, etc., it should be treated to a quality that meets the general industrial effluent discharge standard limits and must not exceed 250, 30, 10 and 100 mg/L for COD, BOD, O&G and TSS respectively (https://cpcb.nic.in/general-standards/).

Thus, it is recommended to adopt a holistic approach consisting of primary, secondary and some tertiary treatment options in order to improve the effluent quality within permissible discharge standard limits. A general schematic diagram which paves a new approach in dealing with complex Bulk Milk Cooler effluent is presented in Fig. 6. This can be practiced as a framework for BMC effluent management.

4. Conclusions

The existing studies have led to an improved understanding about the operation and functioning of bulk milk coolers, their present status in the country including issues of effluent generation, characteristics and status of its treatment. Existing studies revealed that effluent from BMCs varies significantly in terms of its organic strength, SS and O&G concentration and largely depends on the washing patterns including quantity of wash water and cleaning agents. Nevertheless, a multi-chambered anaerobic reactor worked satisfactorily for substantial removal of organic matter, TSS and O&G load from BMC effluent such that most of the pollution load gets reduced. The studies indicated that the stand-alone anaerobic-media treatment with OLR up to ~ 2.0 kg COD/m^3.d and ~ 36-40 hours HRT achieved removal efficiencies of 82.77, 81.33, 96.92, and 94.2% for parameters COD, BOD, O & G and TSS, respectively. The filter media occupied small volume with high specific surface area, thus facilitated the biomass growth and removal of organic matter.

The problem of media clogging due to oil & grease in effluent was avoided throughout the study due to provision of oil & grease trap as pre-treatment. Studies suggest that, a multi-intervention treatment approach is necessary to tackle the BMC effluent considering the complexity and variation in characteristics. Owing to wide variations in organic loading rates of effluent discharged after each washing, it is recommended to use consistent amount of water and detergent for each washing in order to obtain consistent characteristics. The BMC owner should be trained properly to create awareness about the characteristics of effluent generated and importance of safe discharge into environment to prevent water pollution.

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References

APHA, (2005), *Standard Methods for the Examination of Water and Wastewater*, 21st Edition, American Public Health Association/American Water Works Association/Water Environment Federation, Washington DC.

Bello-Mendoza R., Castillo-Rivera M.F., (1998), Start-up of an anaerobic hybrid (UASB⁄Filter) reactor treating wastewater from a coffee processing plant, *Anaerobae Environmental Microbiology*, **4**, 219-225.

Bazrafshan E., Alipour M.A., Mahvi A.H., (2015), Textile wastewater treatment by application of combined chemical coagulation, electrocoagulation, and adsorption processes, *Desalination and Water Treatment*, **57**, 9203-9215.

Bazrafshan E., Mostafapour K.F., Farzadkia M., Ownagh K.A., Mahvi A.H., (2012), Slaughterhouse wastewater treatment by combined chemical coagulation and electrocoagulation process, *PloS One*, **7**, On line at: https://doi.org/10.1371/journal.pone.0040108.

Comoglu B.A., Iscen C.F., Ilhan S., (2016), The anaerobic treatment of pharmaceutical industry wastewater in an anaerobic batch and upflow packed-bed reactor, *Desalination and Water Treatment*, **57**, 6278-6289.

Cruz L.M.O., Stefanutti R., Filho B.C., Tonetti A.L., (2013), Coconut shells as filling material for anaerobic filters, *Springer Plus*, **2**, 1-6.

Demirel B., Yenigun O., Onay T.T., (2005), Anaerobic treatment of dairy wastewaters: A review, *Process Biochemistry*, **40**, 2583-2595.

Dvorak L., Gomez M., Dolina J., Cernin A., (2016), Anaerobic membrane bioreactors-a mini review with emphasis on industrial wastewater treatment: applications, limitations and perspectives, *Desalination and Water Treatment*, **57**, 19062-19076.

Gharibi H., Mahvi A.H., Chehrazi M., Sheikhi R., (2010), Phosphorous removal from wastewater effluent using electro-coagulation by aluminum and iron plates, *Analytical and Bioanalytical Electrochemistry*, **2**, 165-177.

Gonzalez M.S., Gonzalez B.O., Carlos A.F., (2011), Wastewater treatment in an anaerobic filter using small lava stones as filter media without temperature control lava stones as filter media without temperature control, *Water Science and Technology*, **63**, 1188-1195.

Gurjar R., Shende A.D., Pophali G.R., (2019), Treatment of low strength wastewater using compact submerged aerobic fixed film (SAFF) reactor filled with high specific surface area synthetic media, *Water Science and Technology*, **80**, 737-746.

Han W., Yue Q., Wu S., Zhao Y., Gao B., Li Q., Wang Y., (2013), Application and advantages of novel clay ceramic particles (CCPs) in an up-flow anaerobic bio-filter (UAF) for wastewater treatment, *Bioresource Technology*, **137**, 171-178.

Izanloo H., Mesdaghinia A., Nabizadeh R., Naddafi K., Nasseri S., Mahvi A.H., Nazmara S., (2007), The treatment of wastewater containing crude oil with aerated submerged fixed-film reactor, *Pakistan Journal of Biological Sciences*, **10**, 2905-2909.

Jedrzejewska-Cicinska M., Kozak K., Krzemieniewski M., (2007), A comparison of the technological effectiveness of dairy wastewater treatment in anaerobic UASB reactor and anaerobic reactor with an innovative design, *Environmental Technology*, **28**, 1127-1133.

Kumari P., Kushwaha J.P., Sangal V.K., Singh N., (2019), Dairy wastewater treatment in continuous stirred tank electrochemical reactor (CSTER): Parametric optimization and kinetics, *Environmental Engineering and Management Journal*, **18**, 1219-1230.

Lee C., Jo Y., Kim J., Hwang S., (2015), Anaerobic treatment of rice winery wastewater in an upflow filter packed with steel slag under different hydraulic loading conditions, *Bioresource Technology*, **193**, 53-61.

Mahvi A.H., (2008), Sequencing batch reactor: A promising technology in wastewater treatment, *Iranian Journal of Environmental Health Science & Engineering*, **5**, 79-90.

Mansoorian H.J., Mahvi A.H., Jafari A.J., Khanjani N., (2016), Evaluation of dairy industry wastewater treatment and simultaneous bioelectricity generation in a catalyst-less and mediator-less membrane microbial fuel cell, *Journal of Saudi Chemical Society*, **20**, 88-100.

Musa M.A., Idrus S., Hasfalina C.M., Norsyahariati N., Daud N., (2018), Effect of organic loading rate on anaerobic digestion performance of mesophilic (UASB) reactor using cattle slaughterhouse wastewater as substrate, *International Journal for Research and Public Health*, **15**, 1-19.

Naghizadeh A., Mahvi A.H., Mesdaghinia A.R., Alimohammadi M., (2011), Application of MBR technology in municipal wastewater treatment, *Arabian Journal for Science and Engineering*, **36**, 3-10.

Naghizadeh A., Mahvi A.H., Vaezi F., Naadafi K., (2008), Evaluation of hollow fiber membrane bioreactor efficiency for municipal wastewater treatment, *Iranian Journal of Environmental Health Science & Engineering*, **5**, 257-268.

NDDB, (2019), National Dairy Development Board, India, On line at: http://www.nddb.coop/information/stats/milkprodindia

Raghunath B.V., Punnagaiarasi A., Rajarajan G., Irshad A., Elango A., Mahesh Kumar G., (2016), *Impact of dairy effluent on environment-A review*, In: *Integrated Waste Management in India*, Prashanthi M., Sundaram R. (Eds.) Environmental Science and Engineering, Springer, Cham, Switzerland, 239-249.

Renuka R., Mohan S.M., Sowmiya B., Raj S.A., (2016), Performance evaluation of panelled anaerobic baffle-cum-filter reactor in treating municipal wastewater, *Ecological Engineering*, **97**, 1-12.

Srikari S., Hedge V., Bhattacharya A., (2014), Design of mobile raw milk chilling unit for rural areas, *SASTech Journal*, **13**, 31-38.

Silva G.H.R., Nour E.A.A., Fermoso F.G., (2018), Anaerobic-aerobic baffled reactor treating real municipal wastewater in a low income community, *Environmental Engineering and Management Journal*, **17**, 529-535.

Subasini M.L., Asarudin, Ramesh, Pradeep, (2017), Wastewater characterisation of dairy industry, *International Journal of Pure and Applied Mathematics*, **116**, 465-471.

Tritt W.P., Kang H., (2018), Slaughterhouse wastewater treatment in a bamboo ring anaerobic fixed-bed reactor, *Environmental Engineering Research*, **23**, 70-75.

Yousefi Z., Behbodi M., Mohammadpour R.A., (2018), Slaughterhouse wastewater treatment by combined anaerobic baffled reactor and anaerobic filter : study of OLR and HRT optimization in ABR/AF reactors, *Environmental Health Engineering and Management Journal*, **5**, 137-142.

https://cpcb.nic.in/general-standards/