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ANAEROBIC TREATMENT OF DAIRY EFFLUENT- A STEP FOR ENERGY SAVING & GHG MITIGATION

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I. INTRODUCTION

India has emerged as one of the world's largest producer and fastest growing markets for milk and milk products with an annual growth of over 4-5%. As per FAO report (June 2016), India produced 146.3million tonnes of milk in 2014-15 fiscal, which comprised about 18-19% of global production. It is estimated that 148.15 million tonnes of milk will be produced in 2015-16 and a production of 155.2 million tonnes of milk in expected in 2016-17.India has a unique pattern of production, processing and marketing/consumption of milk, which is not comparable with any large milk producing country. Only a small part of milk produced in India is processed. The organized sector (large scale dairy plants) processes about 25-28 million tonnes annually, which is 18-20 per cent of the total production.(140)/ 3,800 LLPD of milk. According to NDDB and Crisil Research estimates, the country produces around **3,800 LLPD** of milk, accounting for a fifth of the global output. About 40 per cent of this is retained by producers (farmers) for household consumption; another 41 per cent share is with the unorganised segment. **Only 19 per cent** is procured, processed and sold through by organised dairies currently. **Organised sector is expected to grow to 25% of total production in** 2018-1050 LLPD of milk from 730 LLPD of milk.

(www.thehindubusinessline.com, 27 oct / 21 Dec 2015)

In the organized sector, there are over 1000 dairy plants in the cooperative, public and private sectors, registered with the Government of India and the State Governments. These plants are projected to process nearly 100 million litres of milk per day. (one single organization with brand AMUL has presently an aggregate national processing capacity of 28.0 million litres per day & expected to be 32 million litres per day by 2017). Most of the plants are in the co-operative or private sector. The processing capacity is expected to grow many fold through external investments in the future to cater to a large market in the Indian cities

The effluent is generated in dairy plant, from washing of cans/tankers, cleaning in place of process equipment(such as pasteurizers, separators, pipelines, chillers, vats, storage tank and silos, sachet filling machines),floor washings, spillages/leakages of milk/milk products, boiler blow down, softener regeneration water & bleed from the condenser etc.[1]

The volume and strength of the effluent generated in a dairy vary from plant to plant. The characteristics depend on the products and production level. Average characteristics as observed during the CPCB survey (1992)[2] are presented in the table 1

Table 1: combined wastewater characteristics of dairies.

Parameter	Milk Processing	Integrated Dairy
BOD_5	657-1,016	1,634-4,953
COD	1,341-2,195	3,800-8,631
SS	538-657	89-4,953
Nitrogen	50.25-126.2	96.32
pH	6.6-6.9	5.6-6.8
Oil and grease	-	280-2,207

- Note: all units are mg/l except pH.

It is estimated that the quantum of milk washed into the drain amounts to almost 2% of milk handled and the volume of wastewater generated is nearly 2 to 5 times of milk processed. Hence, Indian Dairies produce an aggregate 200-500 million litres of wastewater per day.

The dairy plant waste water consists of highly biodegradable organic matter. Aerobic technologies of dairy waste treatment are the most commonly employed methods of treatment in India.[1]
It has been realized recently that anaerobic treatment offers several advantages over aerobic system in terms of energy, chemicals and sludge handling costs. High rate anaerobic systems are capable of removing 60-90% COD and have the advantage of capturing 80-90% of biochemical energy of organic matter in the form of biogas[4].
Energy being a scarce resource in India, therefore the energy analysis of waste water treatment system assumes great importance. In this study, comparisons have been made between aerobic & anaerobic treatment with a view to project the energy saving effected by adopting anaerobic process technology for treatment of dairy waste water in India & the resultant benefits in terms of GWP.
Due to high organic composition, dairy effluents are readily treated by biological process. The treatment process is determined by flow rate, waste strength and stream conditions. Methods used for treatment of dairy effluent include Physico-chemical treatment, Aerobic biological treatment such as Aerated lagoon, Conventional Activated Sludge Process, Extended Aeration, Trickling Filter, Oxidation Pond, Flocculating Algae-Bacterial System etc. ASP is the most common form of biological treatment employed for dairy effluent with COD removal efficiency of 90%. In aerobic systems the provision of oxygen for biochemical oxidation renders the system highly energy intensive.
Rapid advances in bioscience and recent developments in biochemical process engineering are having a substantial impact on the application of anaerobic biotechnology to waste treatment and energy production[5]. Anaerobic treatment units of following configurations have been successfully employed for treatment of dairy waste:

A. Anaerobic contact process

1. Upflow Anaerobic Sludge Blanket Process
2. Anaerobic Activated Sludge Process.
3. Anaerobic digester.

B. Submerged Media Anaerobic Bacteria

1. Anaerobic fixed film Bio-reactors (anaerobic filter)
2. Anaerobic Attached Film Expanded-Bed/ Fluidised-Bed Reactors.
3. Anaerobic Rotating Biological Contactor.

Anaerobic treatment alone does not suffice to reduce the BOD/COD to permissible levels. Therefore, additional Aerobic polishing is required before final disposal.

Table 2: Performance of Anaerobic attached growth bio-reactors on dairy waste

Type of Reactor	OLR Kg.COD/m^3d	Total COD removal, %	Waste strength g COD L^{-1}	Temp	Ref.
Anaerobic Attached Bed Bioreactors	<1.19	80	0.8-3.5	Ambient	6
Anaerobic Packed Bed Upflow Filter	1.348	88	1.203	35	7

Energy Considerations in Dairy wastewater treatment
Aerobic process are inherently energy intensive processes, whereas anaerobic processes are not only requiring lesser energy input but are capable of producing energy by way of biogas. Aerobic process for sewage treatment consume 12-15 kWh/person/year for Activated sludge process, 16-19 kWh/person/year for Oxidation ditch and 7-11 kWh/person/year for Trickling filter. Anaerobic process such as Anaerobic filter and Upflow Anaerobic Sludge Blanket Reactor require only 0.05 kWh/person/year.[8]
*There are however some practical aspect associated with Anaerobic treatment systems: COD removed as sludge- upto 30%, Gas recovery- > 23% COD and Methane remaining in the effluent- .028 M^3/ M^3 waste water.
Mathematical equations to predict the energy consumption in Anaerobic filter and Up-flow sludge blanket reactor are given.[9]
Energy input kWh/year:
Anaerobic Filter =1657.Q.H (i)
UASB = 1657.7Q $(S_s-1)(1-f_e)H_s$ (ii)
Assuming, pump efficiency = 0.8,
Efficiency of motor = 0.75
h = Head lost in Anaerobic filter in m.
H_s = height of sludge blanket in m.
f_e = Porosity of sludge blanket, Dimension less.
S_s = Specific gravity of sludge blanket, Dimension less.
Further the anaerobic waste treatment system have the advantage of capturing the biochemical energy of organic matter in the form of biogas (0.415 m^3 biogas/kg COD removed). The biogas thus produced can be utilized as a fuel for heating or it could be used effectively as a primary fuel source for reciprocating engines and gas turbines. The engine power can be applied to drive electric generator, compressor, pump etc. Gas can be also used to run dual-fuel engines and gas turbine for generating electricity for supplementary implant needs or for sale.

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II. CASE STUDY

In this case study, it is intended to find the energy budgeting of effluent treatment for the whole of the **organized Indian dairy industry**. Comparisons have been made between (i) proposed Anaerobic pre-treatment followed by Aerobic polishing and (ii) currently popular Extended Aeration-Activated Sludge process.

1. Study Basis:

Total Number of Dairies in India = appx 1000
Total capacity of Dairy plants = 100 MLD (in terms of volume of milk processed)
Assuming the volume of wastewater generated from the dairy processing plants is '2.404' times of volume of milk processed.
Wastewater generated from the plants = 240.415 MLD
Chemical Oxygen Demand of a typical dairy = 1500mg/l
Consider 80% of COD being consumed/ utilised for biochemical reactions to be accomplished in an anaerobic process.

Therefore, COD removed = 1200 mg/l
Total COD removed/day
= 240.415 MLD × 1200 × 10^{-6}
= 288.498 × 10^{3} kg COD.

It is reported that one kg of COD is capable of producing 0.415 m^3 of biogas.
Therefore, quantity of biogas generated per day = 288.498 × 10^3 × 0.415 = **119727 m^3**
Calorific value of 1m^3 biogas = 6000 kcal. (The energy equivalent of biogas = 6.978 kWh)

2. Energy saving and cost benefits:

(I) Saving due to recovery of Biogas as a bye product in Anaerobic treatment and its utilisation.

Thus, the total energy available from biogas = 11,9727 × 6.978
= **8.355 lakh kWh/d**

(a) The thermal energy can be transferred by a heat exchanger @ 75% efficiency = 8.355 × 0.75
= 6.266 lac kWh/d

Thermal energy is required for various heating requirements in Dairy plants, so it can act as a light diesel oil (LDO) substitute (calorific value of LDO = 10,700 kcal)
Fuel equivalent in terms of LDO = 67136.64kg
Cost of LDO @ Rs.40/-kg = Rs. 2685465.6/-
Alternatively, if the biogas produced is used for the generation of electricity in a duel- fuel engine:

(b) Electrical energy generated by a duel fuel engine operating @34% efficiency = 8.355 × 0.34
= 2.841 lac kWh/d

(II) Energy demand for treatment of effluent:

It is roughly estimated that energy demand for option :

A. With Anaerobic –Aerobic process = 17hp(EM)/MLD of waste being treated.
B. With Aerobic treatment process = 100 hp(EM)/MLD of waste being treated

Therefore, saving due to implementation of proposed Anaerobic-Aerobic treatment process = 83hp(EM)/ MLD
Therefore, energy saving in treating total waste generated by Indian milk processing industry (B-A) = 240.415 × 83
= 19955 hp(EM)/d
= 359180 kWh/d
= 3.59 lac kWh/d

Therefore, the aggregate energy saving in all 1000 Indian dairies by Anaerobic- Aerobic processs is **3.59 lac kWh/d**
If electricity price @ Rs 6/- per unit
Saving in electricity bill = **Rs.21,54,000/d**
Hence the total conservation of electrical energy by adopting Anaerobic treatment of dairy waste = 3.59+2.841
= **6.431 lac kWh/d**
Considering the price of electricity @ Rs.6/-per unit (kWh) and the contribution of fuel to the total cost of electicity generation taken as 50% of the total generation cost.
Therefore, contribution of bye product biogas for electricity generation
= **Rs.8, 52,300/- per day**
= Rs. 311 million/yr.
Annual O&M cost (assumed) = Annual cost of electricity × 1.2
For (A) 17hp×0.75×240.415×24×365×1.2×6 = Appx. **Rs. 53.77 million**
(B)100hp×0.75×240.415×24×365×1.2×6 = Appx. **Rs. 316.3 million**
Difference in Annual O&M = **Rs. 262.43 million**

3. Annualised cost:

Capital cost
(A) Anaerobic- Aerobic Process = **Rs.8789.2 million**
(B) Aerobic process = **Rs.6358.8 million**

Difference in capital cost = Rs. 2430.4 million
Assuming an interest rate @ 12% & inflation rate @ 6% for design period of 20 yrs & taking 5% salvage on replacement.
Annualised capital cost = Cap. Cost×crf (6%-20yrs) – (0.05) cap.cost×sfdf (6%-20yrs)
(Note : crf = capital-recovery factor, sfdf= sinking-fund deposit factor)
Therefore, annualized capital cost

(A) Rs 755 million
(B) Rs 549 million

Total annual cost (without considering energy recovery from biogas) = Annualised capital cost + Annualised O&M cost

(A) 755**million** + 53 million **= Rs.808.8 million**
(B) 546 **million** + 316.3 million **= Rs.862.3million**

Therefore, annual gain by adopting(A) compared to (B)- **Rs 53.5 million & Option A is a better economic choice.**

Diff. in cost on O&M+ electricity generation/yr(from recovered Biogas) for A = Rs. **262.43 million+ 311 million**= Rs. 573.43 million

Therefore, by an extra capital expenditure of Rs. 2430.4 million on Anaerobic-Aerobic technology, we get an additional saving of Rs.573.43 million annually on recurring cost. Therefore, pay back on investment can be achieved in 4.3 years only.

III. CONCLUSIONS

The following conclusions are drawn from the above case study:

1. Saving on energy demand in comparison with activated sludge process = **3.59 lac kWh/d**
2. Energy gain due to recovery of Biogas as a bye product = 8.355 lac kWh/d equivalent as calorific value. Biogas can be directly used for raising steam/ heating required in the Dairy plant , thus saving fossil fuel.
3. Total conservation of energy in Indian Dairy Processing Industry = (**3.59 + 6.266) lac kWh/d** = 9.856 **lac kWh/d.**

It is found that by adopting combined Anaerobic-Aerobic treatment at additional capital investment of Rs. 2430.4 million yields annual cost benefits of Rs. 573.43 million./yr and pay back on investment can be achieved in a short span of 4.3yrs. Implementation of such treatment process with gas recovery, while controlling pollution can result in energy conservation for the nation.

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