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Biogas generation from distillery spent wash by using an OPUR western biotechnology process: a case study

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ABSTRACT

In India, sugar molasses are used on a large scale to manufacture ethanol. Global ethanol production in 2015 was around 224 crore L. While manufacturing ethanol, distillery wastewater generated is around 2,688 crore L, which affects terrestrial and aquatic ecosystem very badly. In the present paper, an OPUR treatment process is studied to treat the distillery industry wastewater specially implemented for Indian climatic condition. Distillery wastewaters treated by anaerobic digestion produces biogas as a nonconventional energy source and controls the pollution; OPUR process reduces the COD around from 140,000 to 38,500 mg L^{-1} (65%–72%), BOD reduction from 70,000 to 13,000 mg L^{-1} (80%–85%), total dissolved solids reduction from 100,000 to 25,000 (75%), and biogas generation from 0.45 to 0.55 Nm^3 kg^{-1} COD degraded. Calorific value is 4,500 kcal Nm^{-3}, saving bagasse costs with biogas as fuel, €4,891.5 per day, and total revenue generated €911,250 per year.

Keywords: OPUR process; Distillery spent wash; Fermentation; Biogas; Anaerobic digestion; Aerobic

1. Introduction

Sugar molasses based distillery industries expel the tremendous quantity of high-strength wastewater, which is highly hazardous to the environment and ecosystem. Spent wash generated from the distillery industry is one of the most terrific risks that tackle humankind today [1,2]. Industries produce recalcitrant organic compounds, which cause malignant colour and odour complication to terrestrial, aquatic environment and ecosystem [3,4]. Distillery spent wash (DSW) is highly complex wastewater having high chemical oxygen demand (COD, 1,10,000–190,000 mg L^{-1}), very high biochemical oxygen demand (BOD, 35,000–70,000 mg L^{-1}), total solids (82,480 mg L^{-1}), nitrogen (2,200 mg L^{-1}), phenolics (4.20 mg L^{-1}), sulphate (3,410 mg L^{-1}) and several heavy metals (Mn, Fe, Zn, Cd, Ni and Pb) [5–7]. Three types of effluent are generated from distillery industries such as unprocessed wastewater, processed wastewater (biodigested effluent) consisting fermenter sludge, spent less, spent wash and lagoon effluent [8,9]. During ethanol production, spent wash is generated, and its characteristic depends on the feed of raw material [10]. The colour of distillery wastewater is mainly attributed due to alkaline degradation products of hexoses, caramels, polyphenols, and so on. Melanoidin has the empirical formula $C_{17-18}H_{26-27}O_{10}N$ and low molecular weight (5,000–40,000) formed by Maillard reaction [11,12]. Raw spent wash generated during the ethanol, alcohol and rectified spirit manufacturing is highly acidic, complicated, inconvenient, caramel furfural and highly putrid [13,14]. Fig. 1 illustrates the spent wash generation path for the distillery plant during alcohol manufacturing.

BOD to COD ratio suggests biological treatment is the primary treatment to treat the DSW followed by aerobic treatment methods to reduce pollution potential of raw DSW [15,16]. Spent wash is treated by anaerobic digestion to produce biogas. In an anaerobic digestion process, an organic compound present in the spent wash is digested

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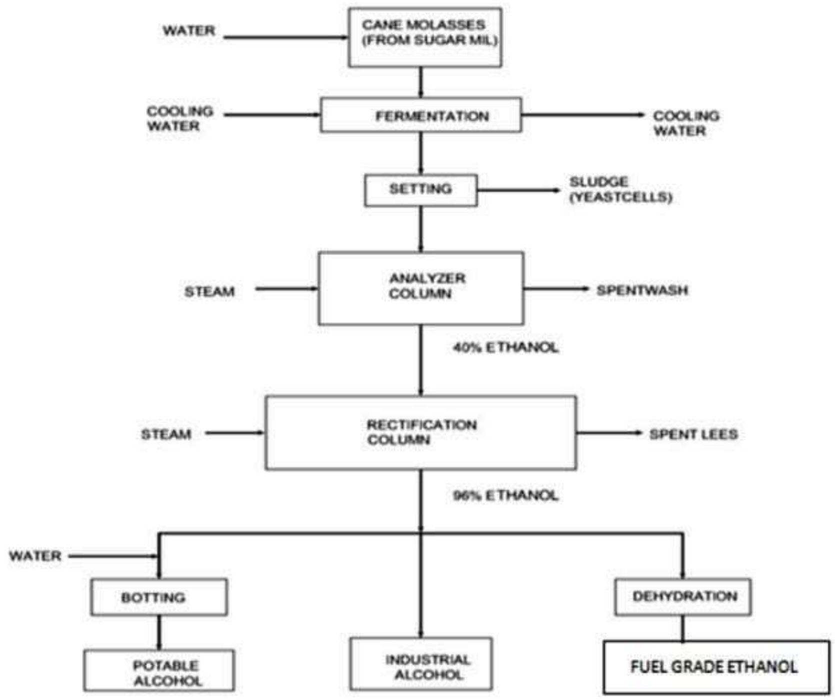

Fig. 1. Spent wash generation path for the distillery plant during alcohol manufacturing.

by the microorganism (methanogens bacteria) to furnish biogas (methane 60% and CO_2 40%). 1 m^3 of spent wash generates 38–40 m^3 of biogas. Fig. 2 indicates that the anaerobic process is more effective than aerobic process, as in anaerobic digestion process, 90% waste is converted into methane gas, and only 10% sludge is formed. In aerobic digestion process, 50% sludge is formed; 50% heat is liberated; and individual secondary treatment is required for the sludge and effluent.

Anaerobic treatment consists single- and bi-phase anaerobic system, anaerobic lagoons, the high-rate anaerobic reactor, anaerobic fixed anaerobic reactor, upflow anaerobic sludge blanket (UASB) reactor and anaerobic fluidized bed reactor [17]. Anaerobic treatment recovers substantial potential energy by biogas production and provides a stable process for medium- and high-strength aqueous organic effluents other than minimizing the effluent load; the methane generated is normally used as a fuel [18]. The aerobic process was quite a bit accepted during the late 1960s to dispose of the distillery effluent. The effluent was neutralized with time and diluted for land irrigation. It creates problems like land pollution, leachate generation and infertility of land. In 1970s, to counterbalance these problems, energy conservation became an important point of concern, and thus, an anaerobic digestion process has been developed, which was realized as an acceptable alternative as it generates biogas [19]. Countries like India have established several large-scale digesters to treat DSW; out of these, the first of its kind was set up in 1979 at Vuyyuru, Krishna, Andhra Pradesh, India. The anaerobic method is developed to retain the biomass in the system as suspended growth or as a fixed filter reactor. As compared with the conventional biological process, anaerobic method is now being universally acknowledged as a better process for the treatment of wastewater. In this paper, the performance of OPUR biotechnology has been initiated to generate the biogas and minimize the pollution of the spent wash by anaerobic treatment. This work also illustrates that how OPUR western biotechnology is more effective than UASB and fixed film reactor. It also insights typical design of the aerobic composting process.

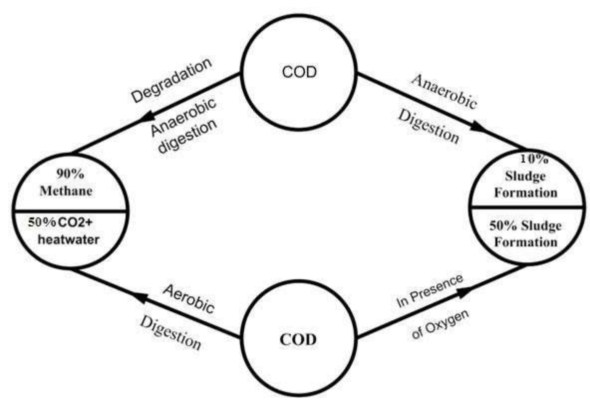

Fig. 2. Comparison of anaerobic and aerobic methods to treat distillery spent wash.

2. Study area

Dr. Vitthalrao Vikhe Patil is the first co-operative sugar mill situated in Ahmednagar, Maharashtra, India (Fig. 3). The first co-operative distillery plant was started in 1970 with capacity of 15 KLPD, by Chemical Consultants and Engineers, Ahmednagar. OPUR biotechnology (Sulzer technology) has been implemented to generate the biogas with capacity of 60 KLPD in 1987. Mill first started biogas plant and composting yard in Ahmednagar.

2.1. Sample analysis

The sample of DSW was collected from a Vikhe Patil distillery industry. Raw spent wash and biomethanted samples were analyzed. Different parameters were determined such as COD, BOD, pH, total dissolved solids (TDS), and so on in triplicate as per the standard methods for the examination of water and wastewater [20] (Table 1).

2.2. Process description (fermentation process)

In the fermentation process, molasses are carried out from molasses storage tank(s) and brought into fermentation tank no. 1. Yeast and nutrient such as diammonium phosphate are added; pH of the tank is kept at 4–4.2; the temperature is maintained at 32°C; and then, fermentation is permitted. At that time, the material is transferred into fermentation tank no. 2 with dilution 1:2 ratio. At this stage, sludge is separated, and the clarified wash is then transferred into fermentation tank no. 3. Clarified wash is further separated, and yeast cream is removed and transferred into fermentation tank nos. 1 and 2. In a clarified wash tank, the supernatant liquid has been taken and delivered to distillation and wash distillation to stripper column (temperature 76°C). At this phase, vapours proceed to condenser and reflux feed to extraction column. In extraction column, impurities are separated; alcohol–water relays to rectifier column; and then, water is drained, and rectified spirit (R.S.) is collected in a receiver tank and then stored in the storage tank. R.S. contains 96% of alcohol; the vapours of R.S. are superheated up to 130°C with the pressure of 0.7 kg cm^{-2}. The effluent initiated during the distillery and brewery operations contains high organic loads.

2.3. Western biosystem (Sulzer), an OPUR process (primary treatment)

Anaerobic digestion offers potential energy recovery through the generation of biogas and is a relatively stable process for medium- and high-strength aqueous organic effluents [21,22]. Apart from reducing a load of wastewater (BOD and COD), the methane produced from the anaerobic system can be used as a fuel for the partial or complete substitute for oil and coal [23]. India is perhaps one of the few countries in the world to establish several commercial-scale digesters for the production of methane gas from the DSW. An OPUR process is an elegant anaerobic contact technique with the fully mixed reactor (anaerobic activation process). The OPUR process consists of spent wash feed pump, heat exchanger (unit to maintain the constant temperature during the process),

Fig. 3. Location of Dr. Vitthalrao Vikhe Patil S.S.K. Ltd., Pravaranagar, Ahmednagar, Maharashtra, India.

Table 1
Characteristics of Pravara distillery effluent before treatment [16]

Parameter	Concentration in ppm except pH
Colour	Dark brown
Odour	Sugar smell
pH	4–4.5
COD	87,000–125,000
BOD	33,000–45,000
TDS	65,000–100,000
TSS	4,300–64,000
Acidity	5,300–8,200
Sulphate	13,300–14,100
Chlorides	4,650–8,450
Total nitrogen	4,300–4,960

biogas digester (to collect the gas), degassing pond (to release the H_2S and CO_2 gas) and lamella clarifier unit work as a sedimentation unit. Table 2 indicates details of OPUR western biotechnology. COD degraded 65%–72% and BOD removal 80%–87% in OPUR treatment technology. Fig. 4 illustrates the working process of OPUR western biotechnology.

The three biogas digesters are being used for treating about 900 m^3 spent wash. Biogas generation depends on the spent wash feed rate. In the month of July, biogas generation rate is maximum 9,43,800 Nm^3, as in the month of July, effluent feed rate is maximum than another month. The industry has also been getting the gas generation of about 45–55

$Nm^3K\ L^{-1}$ spent wash, which is being used as fuel for boiler and surplus to sugar boiler. Salient features of biogas plant are shown in Table 3.

Table 4 illustrates a summary of average weekly observations of feed COD, final COD, feed rate and biogas generation for the period April 2015–October 2015. Fig. 5 shows the profile of concentration of feed COD entering the digester and the concentration of final COD of the effluent. The slightly fluctuating nature of the COD concentration of the distillery wastewater (98–104 g L^{-1}) is evident from feed COD curve. It is important to observe that the digester effluent COD concentration remains reasonably consistent despite the fluctuations in the COD of incoming wastewater. This also reflects the capability of the system to perform in a very stable manner.

The overall performance shows biogas generation rate of 28,127 $m^3\ d^{-1}$, with specific biogas generation 0.45 $Nm^3\ kg^{-1}$ COD removal, based on 300 working days per year. A similar result has been produced by author Abdullah et al. [24] that daily biogas generation was 55,760 $m^3\ d^{-1}$ from 1,394 m^3 spent wash, and total electricity generation was 37.7 million kWh. A similar result has been illustrated by author Aftab et al. [25] that 1-ton biomass anaerobically digested and 10 times diluted sugarcane molasses generate 6.55 m^3 biogas. The anaerobic process of winery effluent produces biogas 400–600 L kg^{-1} COD degraded with 60%–70% methane content [26]. The total volume of biogas production was throughout 1,048,393 m^3/year from a spent wash of quantity 34,627,395 m^3 [27]. Anaerobic digestion is one of the most efficient and effective renewable energy sources than other alternative nonconventional sources of energy, very less capital investment per unit manufacturing cost [28].

Table 2
OPUR western biotechnology details

OPUR western biosystem	
Number of reactor	4
Reactor diameter	30 m
Sludge blanket zone	1.2 m
Height	14 m
Hydraulic retention time, in days	5–6 d
Specific biogas generation, $Nm^3\ kg^{-1}$ COD	0.45
COD reduction (%)	68%–70%
Total biogas generation, $Nm^3\ d^{-1}$	35,000–40,000
Biogas composition	
CH_4	65–70
CO_2	20–25
H_2S	1.8
Calorific value, kcal Nm^{-3}	4,500
Steam generation	
Boiler efficiency (%)	85%
Steam enthalpy at 10 kg cm^{-2}, kcal kg^{-1}	180 MT d^{-1}
Fuel saving	
Steam from 1 MT of bagasse, MT	
Equivalent bagasse saving per day, MT d^{-1}	90.440 MT
Bagasse price Rs MT^{-1}	2,500/MT
Saving in bagasse costs with biogas as fuel, Rs d^{-1}	2,26,100
Number of working days per year	270–300
Saving per year, Rs	60,750,000

3. Secondary treatments (process of composting)

The biomethanated distillery effluent has been treated in the secondary effluent plant by the process of aerobic composting. An aerobic biocomposting is the thermophilic process, adopted by several Indian distilleries as it results in rich humus and can be utilized as a fertilizer [29]. Total effluent is being consumed in the composting plant by using press mud, waste bagasse and boiler ash as a filler material. The composting cycle is of 4–5 weeks. The compaction is carried

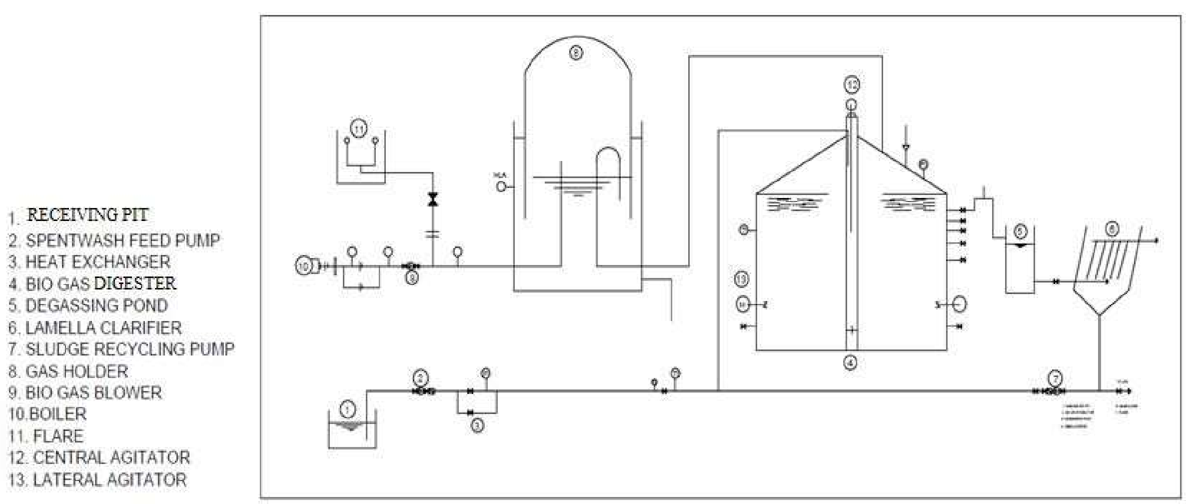

Fig. 4. An OPUR process to treat distillery spent wash.

Table 3
Salient features of biogas plant

Plant supplied	M/s Western Bio-system Ltd., Pune, Sulzer Technology An OPUR Process
Receiving pit	900 m^3 d^{-1}
Digester	4 Nos. (total holding capacity, m^3) 9,200 × 2 Nos. 6,300 × 2 Nos.
Biogas digester in operation	3 Nos. (9,200 m^3 × 2 Nos.) (working) 1 No. (6,300 m^3 × 1 Nos.) (standby)
Loading rate	4.5–5 m^3 kg COD m^{-3}
Biogas generation	0.45–0.55 Nm^3 kg^{-1} COD degraded
COD reduction	65%–72%
BOD reduction	80%–85%

out in such way that no leaching of the effluent from the hips, and the moisture content in the hips is always maintained below 70%. Spent wash mixed with pressmud gives high fertile value pressmud, and bagasse-rich resources of COD are also reduced while using bacteria at temperature 65°C–700°C. The thermophilic bacteria can survive generally in this temperature. The mesophilic bacteria can tolerate up to temperature 450°C and in the range of 15°C–450°C secreting acids, and increasing temperature goes up to 65°C–700°C. The mesophilic bacteria slow down, and the thermophilic bacteria start to grow. Generally, composting is possible at the 40% moisture. Microbial degraded organic matter of spent wash and carbon content of press mud further convert organic matter into complex organic matter to compost. Characteristic of compost consists of N: 1.5%–2.5%, P: 2%–3% and K: 2%–2.5%.

Table 4
Performance of an OPUR system during April–October 2015

Week	Average feed rate (m^3 d^{-1})	Feed COD (g L^{-1})	Final COD (g L^{-1})	COD reduction (%)	Biogas generation (m^3)
1.	720	102	29	71.57	24,457
2.	724	102	30	70.59	24,500
3.	696	103	28	72.8	24,571
4.	682	101	29	71.29	25,157
5.	675	100	30	70.00	21,700
6.	716	98	31	68.37	26,714
7.	720	98	30	69.39	27,486
8.	720	98	29	70.41	28,357
9.	720	99	28	71.72	28,071
10.	744	102	29	71.57	29,157
11.	754	101	30	70.30	29,771
12.	768	101	29	71.29	29,700
13.	768	98	31	68.37	30,129
14.	768	99	29	70.71	30,343
15.	768	102	29	71.57	30,029
16.	768	101	30	70.30	30,571
17.	768	99	30	69.70	30,686
18.	768	104	31	70.19	29,300
19.	768	99	28	71.72	30,129
20.	757	98	29	70.41	30,086
21.	744	101	30	70.30	30,314
22.	744	102	31	69.61	30,057
23.	740	102	31	69.61	30,314
24.	745	100	30	70.00	30,843
25.	727	101	31	70.00	27,100
26.	684	99	29	70.70	27,657
27.	606	98	29	70.41	23,986
28.	635	98	29	70.40	29,914
29.	601	98	28	71.43	28,829
30.	519	98	29	70.41	23,871
Average	717	100	29.50	70.50	28,127

3.1. Design of compost yard

The design of compost yard depends on the quantity of pressmud, bagasse and biodigested spent wash. Space width of each windrow is 1.9 m. 1 ton of 65% moisture pressmud requires about 2 m length (based on field trial). Hence, 100 tons of pressmud requires the length of 200 m. Each windrow is 176 m long, with 7 m on either side for vehicle turning and 5 m either side for canal and piping. 176 m of windrow can hold 0.88 d of production. 25 d of processing requires 29 windrows. Hence, the total width of compost yard is 55 m. Land required to process 100 TPD of pressmud is 2.7 acres. Fig. 6 shows the layout of compost yard.

4. Conclusions

The following conclusions are drawn from the present study:

- OPUR western biosystem was impressive to handle the DSW; daily ethanol production capacity was 110 KLPD. 1 L of ethanol production generates 13 L of spent wash, which means daily 1.43 million L of spent wash is generated.
- COD and BOD value of raw spent wash was very high in the influent, but after the OPUR treatment, it reduces up to 72% and 85%, respectively, with specific biogas generation of 0.45–0.55 $Nm^3\ kg^{-1}$ COD removal.

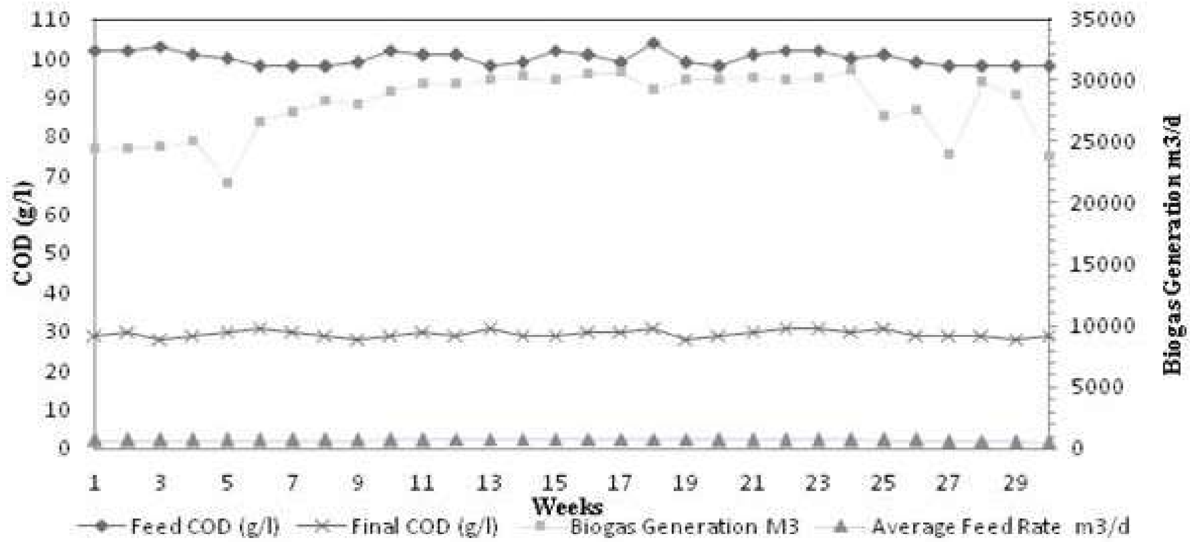

Fig. 5. Profile of weekly average feed and final values and biogas generation rates.

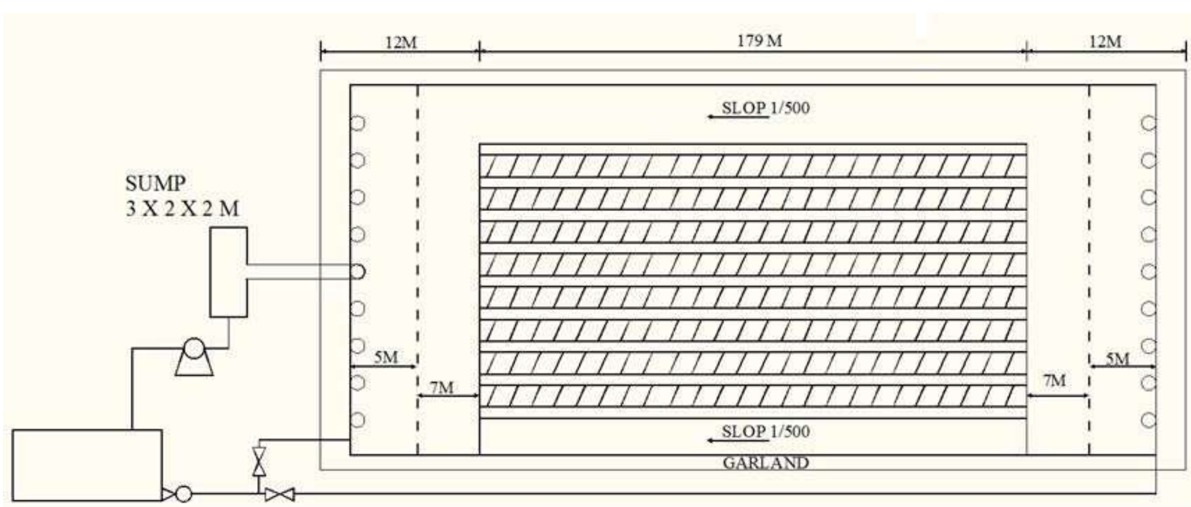

Fig. 6. Compost yard to dispose of the spent wash and pressmud.

- Biogas generation contains 65%–70% methane (CH_4), 20%–25% carbon dioxide (CO_2), 1.8% hydrogen sulphide (H_2S) and a small quantity of moisture.
- COD reduces from 87,000 ppm to 20,000 ppm.
- BOD minimizes up to 4,500 ppm; pH of treated effluent is 7.2–7.8.
- OPUR western biosystem is having benefits throughout other technology processes of biogas generation such as UASB and fixed film reactor that are indicated in Table 5.

During the period of April–September, plant was running at 100% capacity due to the simultaneous supply of molasses. From the month of October, the amount of spent wash was decreased due to deficiency of molasses. The total spent wash feed during these months was 152,855 m^3, and the average spent wash feed was 28,127 m^3. The cost saving through the replacement of bagasse (when available) as fuel for the steam generation has proved to be profitable with payback period less than 2 years. OPUR western biotechnology is in operation for the last 3 decades and gives satisfactory performance with respect to biogas generation and increased COD removal efficiency. This shows that anaerobic digestion technology can remove up to 69% of COD and offer very economical option to solve the effluent treatment problems of the distillery. Cost saving through the replacement of bagasse (when insufficient or not available) by biogas as a fuel for the steam generation has been estimated to be €91,125 per annum. The biogas system has also proved to be profitable with a capital cost of €375,000. Plant saves daily 90.440 MT bagasse; bagasse costs is reduced by using biogas as fuel, €4,891.5 per day; total revenue generated is €911,250 per year.

Energy generation of another plant is very high as compared with other renewable energy sources: capital cost of small hydropower plant is €7,50,000–€9,00,000, and estimated cost of generation of 1 kWh is €0.0225–€0.0375; capital cost of wind power is €6,00,000–€7,50,000, and estimated cost of generation of 1 kWh is €0.03–€0.045; capital cost of biomass power is €6,00,000, and estimated cost of 1 kWh is €0.0375–€0.0525; and capital cost of bagasse cogeneration is €5,25,000, and estimated cost of generation of 1 kWh is €0.0375–€0.045 [30]. Fixed film reactor technology has been implemented to molasses-based distillery by applying organic loading of 22 kg COD m^{-3} d^{-1}, which gives COD reduction 71.8% and biogas generation 0.45 m^3 kg^{-1} COD [31]. Hence, anaerobic digestion is proved to be a primary treatment to distillery effluent with very high energy potential.

The authors also illustrate that the quantity of effluent produced by anaerobic treatment will not be sufficient to fulfill discharge requirement and required additional treatment technologies to dispose of the cumbersome complex effluent. Several distilleries in India follow aerobic treatment as a secondary process to treat the biomethanated effluent

Table 5
Comparison of OPUR western bioprocess with UASB and fixed film reactor

Parameter	UASB	Fixed film	OPUR biosystem (Sulzer's CSTR)
Biomass form	Pellets, granules	Biogas film	Flocky structure
Start-stop capability	Effects formation of pellets	Chances of clogging or channelling of filter bed	Perfect due to adjustable hydraulic system
Tolerance of SS in the influent	Less tolerance	Clogging of filter bed	Wide tolerance
Capability of solid/water separation	No segregation of suspended biomass	No segregation system	Excellent due to lamella clarifier
Tolerance to pH variation in the influent	Poor tolerance as needed plug flow for pellet formation	Vast tolerance due to excessive recycling rate	Extensive tolerance
Process stability	Crucial depending upon changes in influent characteristics	Poor stability due to accumulation of filter bed	Good stability due to biomass segregation system
Required skill for operation	Not required	Required	Not required
Eliminate of sullage	Complicated	Complicated due to clogging filter bed	Easily feasible
Hazardous of biomass washout	Possible	Not possible	Not possible
Retention time	8–10 d	8–10 d	18–20 d
Addition of alkali	Necessary due to less retention time and less tolerance to pH variation	Necessary due to short retention period	No need due to high retention time and sludge recycling
Safety of feed distribution system	Sensitive due to nozzles	Good due to effluent recycling	Better as homogeneous mixing by agitators

(anaerobically digested effluent). Aerobic process is capable of reducing 90% BOD and has rich humus, which is used as a fertilizer. However, the effluent will still contain the high appreciable level of COD and the intense colour, which poses a serious problem in its disposal. Hence, advanced treatment technologies are required for the disposal of effluent.

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