Introduction and literature review
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There are 290 distilleries in India producing 2.75 billion liters of alcohol and generating 45 billion liters of wastewater annually. The quantum of BOD generated from this volume of distillery wastewater corresponds to BOD generated by a population of 6.2 billion, which is approximately 6 times the entire Indian population (Nemade, 2002).

Alcohol production bears immense significance, as it is a basic chemical for the rapidly advancing chemical industry and is also a readily available source of energy. Therefore, in the present scenario as well as for future, demand for alcohol will increase in the country and so also the number of distilleries producing alcohol. This is clearly evident from the twofold increase in number of alcohol industries in India during the last decade. Most of these distilleries are located in the rural countryside. These are concentrated in the states of Maharashtra, Uttar Pradesh, Andhra Pradesh, Madhya Pradesh, Tamil Nadu and Karnataka. The proportion of wastewater, generally known as spentwash, is nearly 15 times the total alcohol production. This massive quantity, approximately 40 billion litres of effluent, if disposed untreated can cause considerable stress on the watercourses leading to widespread damage to aquatic life. (Joshi, 1999 and Mall and Kumar, 1997)

Therefore, It will be useful to know more about a number of aspects of spentwash production.
1.1. Alcohol processing and spentwash generation:
A cane molasses based distillery, which manufactures rectified spirit for industrial use, as also for human consumption is one of the most polluting industry. The spentwash is generated as a byproduct of alcohol. In India distilleries are of two types: Old (typical) and New Distilleries.

1) Old (Typical): These distilleries employ the method of batch production. They produce 15 to 20 Litres of spentwash / litre of alcohol. These are seasonal in operation.

2) New Distilleries: These are continuous type in which modern technology is used to reduce spentwash from 15-20 L to 8-12 L per litre of alcohol produced. The yield of alcohol is also increased. (Hapse et al., 1992).

Figure 1.1. Schematic of alcohol processing and spentwash generation:
1.2 Characteristics of distillery spentwash:

Spentwash is the dark brown coloured liquid left over from the broth of the alcohol fermentation after distillation process. It has a jaggery odour. The physico-chemical characteristics of spentwash are as follows (Table 1.1.):

**Table 1.1. Physico-chemical characteristics of raw spentwash**

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Parameter</th>
<th>Magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Colour, Pt-Co units</td>
<td>$2.38 \times 10^3$-$2.52 \times 10^3$</td>
</tr>
<tr>
<td>2.</td>
<td>Temperature, °C</td>
<td>71-80</td>
</tr>
<tr>
<td>3.</td>
<td>pH</td>
<td>4.2-4.3</td>
</tr>
<tr>
<td>4.</td>
<td>Conductivity, mS/m</td>
<td>5100-5380</td>
</tr>
<tr>
<td>5.</td>
<td>Acidity (total)</td>
<td>7.4-8.1</td>
</tr>
<tr>
<td>6.</td>
<td>Volatile fatty acids</td>
<td>2.3-2.4</td>
</tr>
<tr>
<td>7.</td>
<td>Suspended solids</td>
<td>2.0-2.2</td>
</tr>
<tr>
<td>8.</td>
<td>Total dissolved solids</td>
<td>89-91</td>
</tr>
<tr>
<td>9.</td>
<td>COD</td>
<td>92-100</td>
</tr>
<tr>
<td>10.</td>
<td>BOD</td>
<td>52-58</td>
</tr>
<tr>
<td>11.</td>
<td>Chlorides</td>
<td>5.8-7.6</td>
</tr>
<tr>
<td>12.</td>
<td>Sulphides</td>
<td>0.6-0.7</td>
</tr>
<tr>
<td>13.</td>
<td>Sulphates</td>
<td>2.1-2.3</td>
</tr>
<tr>
<td>14.</td>
<td>Phosphates</td>
<td>0.3-0.4</td>
</tr>
<tr>
<td>15.</td>
<td>Ammoniacal nitrogen</td>
<td>0.2-0.3</td>
</tr>
<tr>
<td>16.</td>
<td>Nitrates</td>
<td>0.004-0.005</td>
</tr>
<tr>
<td>17.</td>
<td>Total Kjeldahl nitrogen</td>
<td>1.6-1.8</td>
</tr>
<tr>
<td>18.</td>
<td>Sodium</td>
<td>0.4-0.5</td>
</tr>
<tr>
<td>19.</td>
<td>Potassium</td>
<td>8.7-9.7</td>
</tr>
<tr>
<td>20.</td>
<td>Calcium</td>
<td>750-820</td>
</tr>
<tr>
<td>21.</td>
<td>Iron</td>
<td>15.5-18.0</td>
</tr>
</tbody>
</table>

All concentrations are reported in Kg/m$^3$. (Nandy *et al.*, 2002)
1.3. **Pollution and its significance:**

Distillery spentwash is highly acidic in nature. The magnitude of the various parameters like very high BOD and COD indicate that the distillery spentwash is high strength organic matter loaded waste. High conductivity means high salt concentration. Nitrates, Phosphates and nitrogen levels are also alarmingly high. Colour of the spentwash is also very deep indicating very high pollution threat to the soil, surface water, ground water and surrounding ecosystem after disposal.

*a) Disposal into surface water bodies:*

If the spent wash is disposed of in the water body, the normal flora and fauna get disturbed and are unable to sustain due to its acidic nature. Even acid tolerant fungi grow very slowly. Presence of high biodegradable organic matter makes the water bodies devoid of oxygen and putrefying conditions are established. Toxic chemicals and offensive odours are produced due to putrefaction.

Dark brown colour is imparted to the stream due to the recalcitrant melanoidin pigments present in spentwash. This hampers the light penetration in water bodies and thus photoautotrophic flora that helps in maintaining the oxygen levels and the fauna of water bodies are damaged. Massive fish kill may be another outcome of it (Pande, 1995). Hatching rate and larval survival of frog *Rana hexadactyla* were reduced at 1.2% distillery effluent concentration due to toxicity. Above this concentration it was found to be toxic to eggs. However, sub-lethal concentrations are found to promote tadpole growth (Andrews et al., 1990)

Faecal coliforms that are damaged by sunlight at wavelengths >425 nm are protected by some of the humic subsatances (Curtis et al., 1992). In near-shore coastal waters *C. albicans* and *E. coli* survival times in diffusion chambers were enhanced by effluent from a rum distillery. The rum distillery effluent had a greater effect on *E. coli* than on *C. albicans* survival in the diffusion chambers (Valdes-Collazo et al., 1987). Anaerobic bacteria from the human large bowel get affected due to the melanoidin *in vitro* (Ames et al., 1999). This indicates that pollution due to distillery spentwash gives rise to the unaesthetic and unhygienic conditions for humans by creating conditions favourable for the enteric pathogens. Nearby wells and other fresh water bodies get contaminated depending on the terrain and soil due to colour. As a result it becomes unfit for the human consumption on aesthetic grounds.
b) *Disposal of spent wash into Lagoons or soil irrigation:*

Disposal of spentwash in lagoons means wastage of huge fertile land near the distillery which otherwise can be used for the production of sugarcane or other crops. In addition to this, its openness causes air pollution due to obnoxious putrefying odour. It also contaminates the aquifers and wells near its vicinity and imparts colour to the water making it unfit for human consumption. Irrigation of soil with the untreated spent wash or storage in the lagoons without proper precautions also alters the physicochemical properties and soil structure due to the high salt content, in turn changing the micro-flora of the fertile soil. Seedling growth, catalase activity, chlorophyll levels and 8 ALA contents were found to be decreased due to distillery spentwash in case of *Arachis hypogaea* L. and *Madhuca longifolia* seeds respectively (Madhusree and Raman, 1995 and Singh, 1997). This results in the reduction in crop yield. Over a long period of spentwash application fertile land may be converted into a barren land (Joshi, 1999).

1.4. **Environmental Law:**

In India, the following Indian Standards are in vogue for guiding the public with regard to the disposal of an Industrial effluent.

   
   Tolerance limits for industrial effluent discharged on land for irrigation purposes.

   
   Tolerance limits for industrial effluent discharged into public sewers.

   
   Tolerance limits for industrial effluent discharged into marine coastal areas.

   
   Tolerance limits for industrial effluent discharged into inland waters.
Table 1.2. IS Norms for Disposal of effluent:

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>PH</td>
<td>5.5-9</td>
<td>5.5-9</td>
<td>5.5-9</td>
<td>5.5-9</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>-</td>
<td>45*</td>
<td>45*</td>
<td>40*</td>
</tr>
<tr>
<td>TSS (mg/l) Max.</td>
<td>-</td>
<td>100</td>
<td>500</td>
<td>30</td>
</tr>
<tr>
<td>TDS (mg/l) Max.</td>
<td>2100</td>
<td>-</td>
<td>2100</td>
<td>-</td>
</tr>
<tr>
<td>BOD (mg/l) Max.</td>
<td>500</td>
<td>100</td>
<td>600</td>
<td>100</td>
</tr>
<tr>
<td>Particle size of SS</td>
<td>-</td>
<td>3 mm</td>
<td>-</td>
<td>850 μm</td>
</tr>
<tr>
<td>Oil and Grease (mg/l) Max.</td>
<td>10</td>
<td>10</td>
<td>100</td>
<td>10</td>
</tr>
<tr>
<td>COD (mg/l) Max.</td>
<td>-</td>
<td>250</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Phenolics (mg/l) Max.</td>
<td>-</td>
<td>5</td>
<td>5</td>
<td>1</td>
</tr>
</tbody>
</table>

* : At the point of discharge

TSS: Total suspended solids; TDS: Total dissolved solids; SS: Suspended solids;

Following options are available as per gazette, Part II, Sec. 3, subsec. (ii), (Jan. 8, 1990) from Environmental and Forest Ministry, Govt. of India.

1) Full treatment to bring BOD$^{20}$ to 30 mg/l and disposal in streams provided minimum 12 times dilutions is perennially assured.

2) Full treatment to bring BOD$^{20}$ to 100 mg/l and disposal on land by irrigation.

3) Full treatment to bring BOD$^{20}$ to 500 mg/l and disposal on land using it as secondary treatment system.

The limit of 500 mg/l is entitled only in case land application is envisaged as secondary treatment system for further removal of BOD. It is to be noted that controlled and properly designed land treatment system has to be adopted for this purpose taking into account soil and crop characteristics. Approval of concerned state pollution control board is necessary prior to adopting this system. In Schedule I of Environment Protection (Amendment) Rules, 1996, substitution was made against Sl. No. 15 relating to fermentation industry (distillery, maltry and brewery) in columns 3 and 4 (parameters & standards).
Table 1.3. Environment (Protection) (Amendment) Rules, 1996, Schedule-I:

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Industry</th>
<th>Parameters</th>
<th>Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>Distillery</td>
<td>BOD (3 days at 27°C)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>---- Disposal into inland surface water/river/streams</td>
<td>30 mg/l</td>
</tr>
<tr>
<td></td>
<td></td>
<td>---- Disposal on land or for irrigation</td>
<td>100 mg/l</td>
</tr>
</tbody>
</table>

Published in the Gazette of India, Extraordinary, Part. II, sec. 3 (i), (Apr.3, 1996) w.e.f. Apr. 3, 1996.

All efforts should be made to remove colour and odour as far as possible.

Out of 177 audited distillery units 134 had adequate facilities for pollution control, 11 were closed and 32 are defaulters. Distillery units have been advised to follow the protocol developed by Indian Agricultural Research Institute and take necessary measures to comply with the prescribed standards as stated in the chapter 5, Moeff report 2000-2001. (www.envfor.nic.in/report/0001/chap05.html)

In 2001, the Karnataka State Pollution Control Board (KSPCB) ordered the immediate closure of M/s Gemini Distilleries Pvt. Ltd. at Nanjangud in Mysore District, till further orders, for failing to prevent pollution of air and water in the surrounding areas. The order was pursuant to an inspection of the locality by the Karnataka Lok Ayukta and a hearing of the grievances of people affected by the distillery, the KSPCB said. (KSPCB orders closure of Gemini Distilleries, The Hindu, November 20, 2001).

The Central Pollution Control Board (CPCB) has directed State Pollution Control Board to ensure that M/s Associated Distillers and Breweries stop its production in Barwaha, Khargaon as it failed to take steps in compliance with the standards notified by the Central Government and was polluting the Narmada river. CPCB has also directed the Madhya Pradesh Pollution Control Board (MPPCB) to cut water supply and electricity of other polluting industries on the bank of river Narmada. (CPCB directs closure of Barwaha located distillery, Central chronicle, Bhopal, July 13, 2002). These reports and news suggest that law is becoming more stringent and standards are made stricter by the Central Government and CPCB, as more and more people are becoming aware of their environment. In order to meet the standards of law enforcement body, distillery spent wash treatment technologies should be more efficient and effective.
1.5. Pollution abatement measures:

Most of the distilleries in India use molasses as a raw material for alcohol fermentation. Distillery spentwash from these distilleries is more difficult to treat as compared to the spentwash from distilleries using grain or beet as a raw material.

There are variations in the organic load and salt concentration in the spentwash from distilleries employing different processes. Availability of land also varies from distillery to distillery. Therefore, it is difficult to have identical wastewater treatment designs for all the distilleries. However, pollution abatement measures for the distillery spentwash can be broadly classified as follows after considering its characteristics i.e. high organic content, high salt content and dark brown colour due to melanoidin pigment.

a) Reuse on land.

b) Physico-chemical processes

c) Incineration and potash recovery

d) Biological processes

a) Reuse on land:

Recycle: CSR constructed a new distillery at Sarina, using a two-tank, semi-continuous Biostil fermentation system, coupled with the latest technology in heat reuse distillation system. The result of recycling was a reduction of 30% in steam and 70% in water usage. Biodunder, a by-product of conversion of dunder, was sufficiently concentrated to be used as a cane-field potassium fertilizer.

Use of membrane filters was suggested for the zero discharge system in alcohol fermentation by recycles of distillery waste through membrane process (Kim and Chung, 1998; Kim et al., 1999). However, humic acid reduces the efficiency of nano-filtration membrane by scale formation in water treatment (Lee and Lee, 1998).

Direct land application: Direct land application of spentwash was reported for sugar cane field by Sheehan and Greenfield (1980). Studies on application of distillery wastewater irrigation and its impact on soil micro flora by Juwarkar and Datta, (1989) and Juwarkar et al. (1990) revealed that soil microbiological properties and plant growth were affected. Application of raw distillery wastewater, diluted distillery wastewater and anaerobically treated distillery wastewater hampered the growth of Rhizobium population and nodulation of groundnut.
Several researchers reported beneficial effect of distillery effluent on the yield of wheat, rice and maize (Joshi et al., 1996), sorghum (Zalawaida and Raman, 1994), and onion (Zalawadia et al., 1996). Soil application of distillery effluent for wheat and rice cultivation resulted in increased grain yield at the BOD level of 1000 mg/L for wheat and 1500 mg/L for rice. Highest biomass yield was obtained from plots irrigated with 1500 mg/l and 2000 mg/L BOD for wheat and rice respectively (Pathak et al., 1998). Groundnut plant growth, nitrogen fixation and yield were increased after application of raw spentwash. (Ramana et al., 2002) However, long-term use of raw effluent may cause increase in salinity, soil sickness and groundwater contamination (Pathak, 1995). Therefore, the irrigation of land with effluent should be done strictly as per the direction of CPCB.

**Biomass production:** Biomass from distillery spentwash was used for heavy metal biosorption (Bustard and McHale, 1998) and alginate cross-linked waste biomass for uranium extraction by Bustard and McHale (1997 and 1998). Distillery stillage can be effectively used to increase biomass production (Suresh and Vivekanadan, 1997).

**b) Physico-chemical treatment:**

In general, physico-chemical treatment of spentwash as a primary treatment has met with little success. Sedimentation was found to be unsatisfactory with addition of coagulants (alum, ferric chloride and lime) and other additives like iron, bentonite and activated charcoal. Use of reverse osmosis and electro flocculation (Hallvard and Suporn, 1982). Treatment processes such as chemical precipitation, chemical adsorption or carbon adsorption are used for the removal of the colored substances. However, color removal by the above processes still has disadvantages due to the high operation cost, high consumption of chemicals, variations in the color removal efficiency and the high volume of solid waste produced (Suntud et al., 1998). The chemical structure, decolourisation and properties of glucose-glycine melanoidin were reported by Seon et al., (1985) and Fumitaka et al., (1984) with the help of ozone and hydrogen peroxide degradation products of melanoidin respectively. Fe-Cr impregnated coir pith was used for the removal of turbidity and colour of distillery wastewater. The optimum values for flash mixing time, flocculation time, settling time and flocculant's dosage for maximum turbidity removal were found to be 2 min, 15 min, 30 min and 2 g, respectively (Namasivayam et al., 1994).
Decolourisation of spentwash melanoidin pigment was studied by chemical and biological methods. Spentwash from an anaerobic digester was treated with hydrogen peroxide, calcium oxide and soil bacteria to achieve maximum decolourisation and COD reduction to the tune of 98% and 88%, respectively (Patil and Kapadnis 1995). Chemical precipitation was used to remove coloured substances from biologically treated molasses wastewater. FeCl₃, Al₂SO₄ and NaOH at pH7 yielded 93% decolourisation (Suntud, et al.,1998). Decolourisation (94.6%) of anaerobically treated spentwash was achieved with aluminium sulphate (3.0 gm/L) and bleaching powder (5.0 gm/L) treatment at pH 7.2. The optimum decolourisation was observed (96.4%) after addition of 3.0gm/L aluminium sulphate and 5.0gm/L bleaching powder in the dark coloured anaerobically treated distillery effluent. The maximum reduction of BOD and COD was noted at 92% and 95% respectively at neutral pH, that is 7.2 ±1 by Chandra and Singh (1999).

Non biodegradable COD and colour from anaerobically treated distillery spent wash was successfully removed with loading rate of 10.8-14.5 kg solids/m³/hr by chemical treatment with Fe(III) and cationic polymers. Pregenerated Bubble Flotation (PBF) technique was used to remove the chemical sludge from each chemical reaction process. The quality of final effluent can be below 40 mg/L-CODₘₙ but Il San Distillery has maintained effluent quality of 73 mg/L-CODₘₙ and 10-80 mg/L-SS. The chemical cost was saved by more than 30% as compared with that of prior process. Sludge generated during this process was however high (Chung, 1999).

Biological degradation of vinasses, generated during alcohol production from wines and pressed grapes, has been studied in four digesters operating in fill and draw mode. Digesters 1 and 2 were fed with nonozonated and ozonated mixtures of vinasses and domestic sewage (1:10 by volume), respectively. Digesters 3 and 4 operated with pure vinasses at acid and neutral pH values, respectively. The effects of pH, temperature, and ozone dose conditions were studied. Preozonation removed inhibitory compounds and improved the growth of nitrifiers. Ozone dose is the key variable to treat a vinasse-domestic sewage effluent effectively with a combined chemical-biological system. Contois’ kinetic model has been applied to experimental results, and kinetic parameters related to the maximum specific growth rate of microorganisms (μₘₐₓ), and inhibitory effects (α), were calculated and compared for nonozonated and ozonated wastewaters (Beltran et al., 1999).
Postmethanated spentwash decolorisation was carried out using chitosan. Chitosan is a modified (deacetylated), natural, carbohydrate polymer derived from the chitin of crustacean (shrimp, crab, crawfish, etc.) exoskeletons. It is widely used as a non-toxic cationic flocculent in treatment of organic polluted wastewaters and as chelator of toxic (heavy and radioactive) metals. Decolorisation of the distillery effluent was done with an ion-exchange process using chitosan as anion exchanger. Model experiments with different amounts of chitosan and different time of contact with the wastewater showed that chitosan concentration of 5 mg/l and contact time of 30 minutes were most suitable for the decolorisation of the distillery effluent (Yamini and Lalithakumari, 2001).

c) Incineration and Potash Recovery:

From literature survey it was found that concentration and incineration methods offer the possibility of maximum energy recovery. Thermal solidification and liquefaction are also potentially attractive as compared to biological treatments and wet air oxidation. Bagasse mixed with original waste also showed better properties than bagasse alone or 65% concentrated waste alone. The economic viability of the concentration by incineration system depends on its efficiency of heat recovery from the furnace and recovery of valuable chemicals from ash (Thampi, 1999-2000). Patel (2000) used single droplet combustion process for combustion and gasification of distillery spentwash (up to 70%) without supporting fuel.

In a typical incineration, spentwash is neutralized and then concentrated to 60-65% solids in multi-step evaporation system. The concentrated spentwash is subsequently burnt in a fluidized bed combustion unit above 700°C. Ash, K₂SO₄ or KCl are recovered. The process can be operated on a continuous mode. Although this is claimed to be the total and final solution to the water pollution problem, it overlooks the severe gaseous pollution. Other major drawbacks as reported by Hapse et al. (1992) and Pagavi (1992) are as follows:

1. High capital and operating cost.

2. Technologically sophisticated and warrants specialized operational skills.

3. No net energy return to compensate cost of operation.
4. Economics of process rely heavily on the fertilizer value of potash; whereas in Indian conditions it is of little significance as Indian soils are generally not deficient in potash (Hapse et al., 1992; Pagvi, 1992).

d) Biological Treatment:

**Aerobic treatment:** Treatment of high-strength organic effluent of distillery by the conventional aerobic process is very costly. For every kilogram of BOD destroyed, about 1.8 kg of oxygen is required. This amounts to approx. Rs. 2.50 per kg of BOD destroyed. This amount is required mainly to satisfy power requirements for high aeration. Electric power in the recent times is very costly, and it becomes a deterrent factor for the industry to install a proper treatment plant. Due to high concentration of organic matter it needs large dilution water and the low loading rates compels to design large sized treatment plant. Therefore, it is not feasible and economically viable treatment for the distillery spent wash at the primary level.

**Composting:** Reuse of agro-based industrial waste like distillery spentwash to obtain different byproducts can be an economically viable treatment to reduce the pollution load. The spentwash is in essence a dilute form of liquid organic fertilizer due to its high K content. However, it is poor in N content and rich in C content. If the N content of the spent wash is increased, so as to obtain an optimum C: N ratio, it can serve as a good biological fertilizer. This can be achieved by the composting, an ancient method for production of high fertilizer value bio-manure. Various researchers have used aerobic and anaerobic composting methods for the distillery spentwash treatment and emphasized its usefulness of bringing the C: N ratio close to that of a good fertilizer.

Kapadnis and Joshi (1990) carried out experiments on anaerobic composting of the raw spentwash and biomethanated spentwash decolorized by *Aspergillus* sp. Spentwash and pressmud were used in combination with bagasse and trash as a primary treatment. The C: N ratio was brought down to 28.73 after 30 days of anaerobic composting. *Azotobacter chroococcum* inoculation improved the nitrogen content of biomanure. The final compost was rich in P and K with 2.4 ppm humic acid and 2.2 ppm fulvic acid. Further increase in the N content of the distillery spentwash by inoculating with *Azotobacter* sp. was reported by Joshi and Kapadnis (1992).
Untreated distillery spentwash can be easily converted to good quality organic fertilizer by using pressmud as filter in 25-30 days by aerobic composting process. It comprises of three stages, initial mesophilic stage of 1 day, followed by a second accelerated rate thermophilic stage of 6 days and finally mineralization stage of 15-20 days. Inocula, temperature, moisture content and aeration period was optimized by studying microbial consortia at different stages (Khambe et al., 1990). A reaction period of 45 days with additional 15 days for curing was required for composting. The temperature of composting was initially 35°C, which gradually rose to 70°C during the period of 30 days and declined to 35°C during the process of stabilization (Gaur, 1985; Patil, 1995). The biomanure thus obtained was rich in humus, which provides slow release of all the nutrients essential for crops. Increased crop yields have been reported through utilization of the biomanure (Samuel, 1986; Ramadurai and Gerard, 1994).

Nandy et al., (2002) took more holistic approach while using composting as secondary treatment for distillery spentwash. Biomethanated spentwash was evaporated in Multiple Effect Evaporator (MEE). Concentrated spentwash was used for composting along with the press mud in windrows. The windrows were inoculated with microbial consortia of bacteria viz. Azotobacter, Pseudomonas, Aerobacter and cellulolytic organisms, viz Trichurus spiralis, Chaetomium sp., Aspergillus sp., Penicillium sp. A total of 84000 m³/annum concentrated postmethanted spentwash was handled in three cycles of 70 to 80 days each. Land required for composting process was 3.5 hectares with an yield of 1900 tonnes of biomanure per annum. The biomanure had 35% moisture and C: N ratio of 10-15:1. The revenue earned from the sale of biomanure averaged Rs. 28.5 lakhs per annum. However, use of composting is practicable only for the distilleries having large areas available for windrows and large storage tanks. Another constraint is the prohibitive investment cost of the evaporator.

Anaerobic Digestion: From the end of the last century onwards, anaerobic digestion has been also applied in man-made environments for both energy production and as a cost-effective method for waste stabilization (Lettinga 1996; Van Lier et al., 1997). The latter refers to the dual energy benefit of anaerobic digestion viz. no energy requirement for waste stabilization and production of an energy-rich end product. The positive energy balance on one hand and the increasing energy demand on the other
have generated a growing interest in anaerobic digestion. During anaerobic digestion, the chemical energy present in organic compounds is largely conserved as methane (Claassen et al., 1999).

Speece (1996) has listed advantages and disadvantages of the anaerobic wastewater treatment technology in comparison with conventional aerobic methods. Although anaerobic wastewater treatment was developed for environmental engineering purposes, it may significantly contribute to meeting the energy demands of industry and replace energy from fossil resources. For instance, alcohol production from waste can satisfy up to 50% of the industrial energy demand while reducing organic pollution by 80%. Important disadvantages are that anaerobic treatment is associated with sulphide and odor formation and that nitrification is not possible. Thus, aerobic post treatment is essential. Efficient methods to deal with sulphide and odor have been developed (Buisman et al., 1990). Sulphide can be converted in a micro-aerobic process to elementary sulphur, and the recently observed anaerobic ammonium oxidation can be implemented in existing anaerobic treatment technologies (Jetten et al., 1998). Recently, Gaikwad and Naik (2000) showed that wet-air oxidation of distillery spentwash along with bagasse was useful to remove sulphates from the effluent.

From a technological point of view it is important to note that complete methanogenic conversion occurs by mixed microbial communities yielding methane as the sole reduced organic product. In India the high rate anaerobic reactors in operation have the fully stirred or UASB design. Most of the treatment plants installed in distilleries are provided by Western Paques India Ltd. of Pune (Dutch Technology) and Sulzer Technology installed by Western Biosystems. However, researchers have constructed and studied different designs of digesters for distillery wastewater treatment and methane recovery.

1) Anaerobic Contact Recycle: As shown in Fig. 1.2, settling tank is used in addition to CSTR to separate biomass from digested effluent and concentrate it to recycle to the digester. Gas bubbles interfere in sludge separation hence de-gasifier is used and thermal shock is given prior to flocculated setting process. CSTR was used for the winery and grain distillery wastewater treatment (Solera et al., 2001; Laubscher et al., 2001). Two CSTR were used to study the evolution of biomass during start-up of two-
phase anaerobic treatment system (Solera et al., 2002). However, UASB, anaerobic filter and fluidized packed bed reactors are preferred over CSTR for the treatment of high strength molasses based distillery wastewater because in comparison to a CSTR system, fixed film and other attached biomass reactors have better stability. Moreover, high degree of COD reduction is achieved even at high loading rates at a short hydraulic retention time (Rajeswari et al., 2000; Dunn and Etheridge, 2001).

![Schematic diagrams of Anaerobic Contact Recycle and Anaerobic Filter Reactors](Morgan, et al., 1991).

2) Anaerobic Filter: Since the introduction of the anaerobic filter (AF) by Young and McCary (1969), anaerobic technology has gradually become accepted for the treatment of high strength wastewater from various industries, such as food/beverage, distillery and agriculture (Lettinga and Hulshoff, 1991).

As shown in Figure 1.4, modified AF reactor packed with plastic rings and featured with built-in internal GLS separator was used in cornstarch wastewater treatment which reduced the adverse effect resulting from the high SS contents in wastewater (Kwong, et al., 1996).
3) Anaerobic Expanded/Fluidized bed Reactor: This reactor is similar to suspended growth reactors in that the active biomass is present in the form of bed of readily settelable aggregates. Aggregates consist of biomass grown on small inert particles such as sand, coal or alumina (Fig 1.3.). The high rate of liquid flow necessitated re-circulation of effluent in high rate reactors. Capital cost of flow distribution systems and the pumps is high and also the net energy yield is lower than for other reactors.

Lab scale experiments were carried out for the treatment of concentrated wine distillery and vinases at thermophilic conditions. The purposes were to operate and characterize AFB under high organic loading conditions and to report on their steady-state performance. It was confirmed that AFB systems can achieve >82.5% COD reduction at a COD loading of 32.3 Kg of COD m$^{-3}$ day$^{-1}$, whereas, max.97% substrate removal for organic loading rate of 5.9kg COD m$^{-3}$ day$^{-1}$ and HRT 2.5 days (Perez et al., 2001a). Further experimentation on distillery wastewater, using fixed bed reactors and immobilized active biomass in thermophilic reactor at batch condition demonstrated that high microorganisms:substrate ratios favour the degradation activity of different anaerobic cultures, allowing stable operation without lag-phases and giving better quality effluent (Perez et al., 2001b).

4) Up-flow Anaerobic Sludge Blanket Reactor (UASB): Since the development of the UASB process in the 1970s this has been widely applied for the treatment of industrial effluents. Effluents from alcohol producing industries are mostly highly
polluted and therefore in principle very suitable for anaerobic treatment (Rajeshwari et al., 2000).

Distilleries use different kinds of raw materials such as malt, sugar cane juice, sugar cane molasses, sugar beet molasses, wine, grape press or corn for the production of alcohol (Goodwin et al., 2001; Borja et al., 1996; Fdz-Polanco et al., 2001 and Beltran et al., 1999). The use of different materials and the different processes applied, result in a wide variety of effluents produced (Zeeman and Sanders, 2001). The process conditions under which good results of the anaerobic process are obtained depend heavily on the type of distillery effluent being treated. The choice of right set of process parameters for every type of distillery effluent has shown to be of crucial importance for the anaerobic process. Despite expected toxicity problems arising from the high concentrations of COD, sulfide and salts, anaerobic treatment with the UASB process proved to be successful in treating distillery effluent (Driessen et al., 1994). However, biological systems do not perform well on champagne industries wastewater and long start-up periods, of the order of one to two months, are being reported (Austermann et al., 1994). When commissioning a reactor for the first time on a particular effluent stream, it is advantageous to utilize sludge from a reactor treating a similar waste. If this is not possible, the sludge will have to be acclimatized to the specific effluent (Hickey et al., 1991).

5) Two-phase anaerobic reactor: A perusal of discussion on microbiology of anaerobic digestion reveals that methanogenic bacteria differ significantly from acid forming bacteria in terms of physiology and nutritional requirements and sensitivity to environmental factors. It is suggested that acid and methane formers should be physically separated and preacidification of waste be done prior to biomethanation (Pohland and Ghosh, 1971; Jans and de Man, 1988; Shin et al., 1992). Kowng et al. (1996) used it for cornstarch wastewater treatment (Fig. 1.4).

Consequently, conditions that are favourable to acidogenic bacteria may be unfavourable to methanogenic bacteria (Ince et al., 1997). It is possible to provide optimum environmental conditions for these bacterial groups, thereby enhancing overall efficiency. First reactor must be made sufficiently unfavourable to methane formers to force them to grow only in second reactor, which can be achieved by application of chemical, kinetic controls and physical separation. Use of first reactor
removes stress for the methanogenic bacteria, which leads to better performance and improved quality of gas at lesser cost (Becaari, et al., 1998).

Fig. 1.4. Flow diagram of Diphasic anaerobic reactor (Kwong et al., 1996).

Distillery wastewater was treated using two-phase anaerobic system (Shin et al., 1992). Simultaneous removal of nitrogen and sulphur in two-phase digester treating vinasse was newly reported (Fdz-Ploanco et al., 2001). Solero et al. (2002), studied evolution of biomass and tried to achieve phase separation by varying hydraulic retention rates in two-phase anaerobic digester using distillery wastewater. However, complete phase separation could not be achieved at 1.7 and 4 days HRT.

They also stated the advantages of two-stage anaerobic treatment process over conventional process as follows:

1. It permits selection and enrichment of acidogens and methanogens in each digester. Complex pollutants are degraded to volatile fatty acids in first phase and converted to methane and CO₂ in second phase.
2. Increases stability of process by controlling acidogenic phase in order to prevent overloading and a built-up of toxic material.

3. The first stage may act as a metabolic buffer, preventing pH shock to the methanogenic population.

4. Low pH, a high organic loading rate and a short hydraulic retention time favour the establishment of the acidogenic phase, and preclude the establishment of methanogens.

1.6. Major concerns of distillery spent wash treatment and its disposal:

1. Longer start-up periods and starter cultures.
2. Efficient microorganisms for the decolourisation of post-methanated spent wash.
4. Effect of melanoidin on plants and plant growth promoting microorganisms.

1.7. Objectives:

The major objectives of the present work can be stated as follows:

1. Development of microbial consortia to reduce longer start-up period of biomethanation plant.
2. Screening of compatible and efficient decolorizing microorganisms for the treatment of post-methanated spent wash.
3. Development of effective and safe treatment method for distillery spent wash.
4. To study effect of distillery spent wash irrigation and melanoidin on economically important plants.
5. To study effect of melanoidin (colour) on the nitrogen fixing microorganisms.
1.8. References:


(http://www.cleantechindia.com/eicimage/210301_24/itm.htm )


