BIOGAS FIRED INDUSTRIAL GAS TURBINES
A TECHNOLOGICAL AND POTENTIAL ASSESSMENT

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ABSTRACT
This paper reviews the advantages, technical considerations and application of biogas fired Industrial Gas Turbines, and suggests strategies for improving the cogeneration of electricity in cane sugar distilleries.

Biogas is produced by the anaerobic treatment of waste by the Indian Distillery and allied alcohol based industries. Treatment of waste has been made mandatory and all distilleries in India are setting up such units. With the generation of biogas, the Indian Distillery has found a novel way of converting waste into energy.

Traditionally, the biogas obtained was fired in boilers to generate steam. Steam could be used for process or to drive a back-pressure steam turbine. A few small units also considered installing dual fuel reciprocating engines.

Recently, a trend setting project of firing biogas directly in a gas turbine to produce electricity and subsequently utilize the hot exhaust gases in a waste heat recovery boiler is being proposed.

There are distinct advantages in selecting the gas turbine route over other competing prime movers.

TREATMENT OF DISTILLERY SPENT WASH WASTE
In the tropical countries, distilleries based on sugar cane molasses, a by-product of the sugar industry, is widely distributed and has gained considerable importance. Alcohol is recovered from molasses by fermentation and distillation. Large quantities of waste liquor called vinasse or spent wash - a major pollutant - is produced by the distilleries. The spent wash or effluent has a high organic loading, making it one of the strongest and most difficult industrial wastes to treat. Its disposal presents a great problem but at the same time it is also a potential source of energy.

The design of the effluent system, hence should not only treat waste, but also allow for recovery of energy. The spent wash can be treated before disposal using:

1. Anaerobic lagooning followed by aerobic treatment
2. Anaerobic treatment with biogas generation
3. Incineration

Until a few years ago the only systems available for treating waste was the aerobic type which had its disadvantages. All these different techniques have been examined and evaluated by the industry. In India and several tropical sugar producing countries, anaerobic treatment has been widely accepted for treating waste. Apart from distilleries other industries which produce such high organic loaded waste are all potential and prospective users of anaerobic treatment to produce biogas. Some of these industries include cane and beet molasses waste, pharmaceutical fermentation wastes, paper mill waste and spent grain liquor, sweet or acid cheese whey, chemical, food packaging and meat packaging waste, corn product wastes etc.

Characterisation of Waste
The actual spent wash quantity or waste obtained from the distillery is about 15 times the quantity of distilled spirit. Table-A provides typical characteristics of the distillery spent wash.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td></td>
<td>4.0 to 4.5</td>
</tr>
<tr>
<td>BOD 1/</td>
<td>mg/lit.</td>
<td>45000 to 50000 mg/lit.</td>
</tr>
<tr>
<td>COD 2/</td>
<td>mg/lit.</td>
<td>90,000 to 110,000 mg/lit.</td>
</tr>
<tr>
<td>Total Solids</td>
<td>mg/lit.</td>
<td>110,000 to 130,000 mg/lit.</td>
</tr>
<tr>
<td>Suspended Solids</td>
<td>mg/lit.</td>
<td>3000 to 4000 mg/lit.</td>
</tr>
<tr>
<td>Total Nitrogen</td>
<td>mg/lit.</td>
<td>1000 to 1200 mg/lit.</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>mg/lit.</td>
<td>200 to 300 mg/lit.</td>
</tr>
<tr>
<td>Potassium</td>
<td>mg/lit.</td>
<td>8000 to 10,000 mg/lit.</td>
</tr>
<tr>
<td>Sulphate</td>
<td>mg/lit.</td>
<td>3000 to 4000 mg/lit.</td>
</tr>
<tr>
<td>Chlorides</td>
<td>mg/lit.</td>
<td>5000 to 6000 mg/lit.</td>
</tr>
</tbody>
</table>

1/ BOD - Biological oxygen demand: Amount of oxygen required for biological decomposition of the organic matter present in the waste; Reference at 20 Deg.C
2/ COD - Chemical oxygen demand for chemical oxidation of the organic matter present in the waste; Reference at 20 Deg.C.
The standards generally set for the receiving water bodies of waste are very stringent, i.e., BOD levels of 20 mg/lit., and suspended solids of 30 mg/lit., has to be met.

**Anaerobic Digestion**

Advanced anaerobic treatment of organic wastes is a biological process in which the organic pollutants present in waste are converted into energy rich biogas by bacteria in an anaerobic environment, i.e., an environment in which no free oxygen is present. The bacteria in the form of micro-organisms present in granular sludge convert the organic pollutants in the waste water into energy rich biogas.

The anaerobic digestion process is able to bring down the BOD concentration in the waste by about 80–90% i.e., from 45000–50000 mg/lit. to 3000–4000 mg/lit. However, to achieve the environmental limits of 20–30 mg/lit., secondary treatment in the form of anaerobic filters or extended aeration needs to be performed.

Figure 1 shows a typical block diagram for the anaerobic treatment of spent wash to generate biogas.

**Technologies for Anaerobic Waste Treatment.** There are a number of established available technologies to treat this waste. See Table-B. Most of these technologies are used in several operating installation plants world wide.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. M/s. C.S.M</td>
<td>Netherlands</td>
</tr>
<tr>
<td>2. M/s. Aqua Technos</td>
<td>Thailand</td>
</tr>
<tr>
<td>3. M/s. Sulzer Brothers</td>
<td>Switzerland</td>
</tr>
<tr>
<td>4. M/s. Bacardi- Puerto Rico</td>
<td>South America</td>
</tr>
<tr>
<td>5. M/s. S.G.N.</td>
<td>France</td>
</tr>
<tr>
<td>6. M/s. Paques</td>
<td>France</td>
</tr>
<tr>
<td>7. M/s. Degremont</td>
<td>France</td>
</tr>
<tr>
<td>9. M/s. Biothane System</td>
<td>Netherlands</td>
</tr>
</tbody>
</table>

**Composition of Biogas**

The biogas produced by the process is rich in methane a gas of high calorific value and an excellent fuel. Typical biogas composition obtained by the treatment is as follows:

- CH₄ – 50 to 60%
- CO₂ – 47 to 36%
- H₂S – 2 to 3%
- H₂O – 1%

Gas calorific value is estimated at 4500–5500 Kcal/NM³

**Factors Affecting Quantity & Composition of Biogas**

The quantity of gas available from the distillery depends on the type of process employed (batch/continuous), the capacity of the distillery and the anaerobic treatment used.

Typically 1 M³ of spent wash spirit produces 30 M³ of biogas. Table-C is an estimate of the quantity of biogas available from different distillery units related to the capacity. The gas is generated in holders at 200 mm to 500 mm H₂O positive pressure. The methane percentage in the gas depends on the treatment technology employed and on how accurately the process parameters are controlled.

The effluent contains sulphates which acts as a source of hydrogen sulfide (H₂S) in the biogas.

**TABLE - C**

<table>
<thead>
<tr>
<th>Typical Capacity of Distillery</th>
<th>Quantity of Biogas</th>
</tr>
</thead>
<tbody>
<tr>
<td>30–35 KI/day ¹/</td>
<td>14000–16000 CMD ²/</td>
</tr>
<tr>
<td>75–80 KI/day</td>
<td>28000–32000 CMD</td>
</tr>
<tr>
<td>100–110 KI/day</td>
<td>39000–40000 CMD</td>
</tr>
<tr>
<td>130–150 KI/day</td>
<td>48000–55000 CMD</td>
</tr>
</tbody>
</table>

¹/ KI/day - Kilo litres of refined spirit/day.
²/ CMD - Cubic Meters per Day

Biogas generation also depends upon temperature. More gas is generated in summer than in winter. A temperature of 37 °C is ideal for optimum gas generation.

**OPTIONS FOR GAS UTILIZATION AND ROLE OF GAS TURBINES**

The biogas in the industr
conventional fuels like coal or oil and meet the energy requirement of power and steam through a back pressure steam turbine.

In the lower end of the industry where the quantity of gas generated is not much, dual fuel reciprocating engines have been popular. However, the role of engines to accept biogas containing H2S has been limited.

A promising alternative is the biogas fired gas turbine system. The gas turbine is a good candidate for achieving higher thermodynamic efficiency and by exploiting the hot exhaust gases allows for better efficiencies than possible with steam cycles.

The hot exhaust flue gas from the gas turbine is passed through a heat recovery boiler to generate steam. This cascading process of producing electricity as well as steam maximises the energy available in the gas. This technically acceptable alternative for utilisation of biogas has not yet been exploited for gas turbine applications.

**Why Gas Turbines should be Preferred**

It is noticed that due to a variety of reasons in almost all process industries, the shift has been towards greater electricity use and lower steam use, i.e., the power to heat ratio of different user industries has been steadily increasing. The distillery industry and alcohol based industries are no exception. The economics of the gas turbine cogeneration system become increasingly attractive particularly as steam conserving measures are installed in factories.

Most industries value electricity more than heat. Whilst heat or steam is generated by a variety of fuels at high efficiencies in conventional boilers, electricity is generated at much lower efficiencies, depending upon the prime mover chosen.

Another important aspect in increasing the distillery electricity load has been the setting up of the waste treatment system. The primary and secondary waste treatment system itself needs a significant amount of electricity, especially the secondary treatment, thereby increasing the power to heat ratio of the plant.

Moreover, electrical energy in most places in the world is 7 to 9 times as valuable as heat energy in monetary terms. Hence, any system which produces more electricity than steam enjoys an advantage.

The gas turbine cogeneration system precisely does the same. For the same quantity of biogas the gas turbine can generate two to three times the quantity of power than a back pressure steam turbine.

Biogas fired boilers and steam turbines operate on steam conditions which are far more modest than those used in large sized plants. This restricts the power output from the steam turbines which is dependent upon the peak temperature and pressure of steam.

The steam output from the gas turbine exhaust waste heat boiler is however lower in comparison with the conventional fuel (biogas) fired boiler. Should extra steam be needed for the process, the gas turbine cogeneration system will allow for additional fuel firing in the exhaust gases. This is due to the high levels of unused O2 available in the gas turbine exhaust. Fig. 2 is a graphical representation of the comparison and differences in power and steam generation of the gas turbine and steam turbine routes. This is for a distillery of 35000 litres/day capacity generating about 17000 cubic meter per day of biogas.

Table-D provides a comparison of the different cogeneration routes a user may choose for utilization of the biogas.

**TABLE - D**

OPTIONS FOR POWER GENERATION USING BIOGAS

<table>
<thead>
<tr>
<th></th>
<th>Gas Turbine 1/ Cogeneration</th>
<th>Back-pressure 2/ Steam Turbine</th>
<th>Gas Turbine 3/ Steam Turbine Cogeneration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>850 kW</td>
<td>400 kW</td>
<td>1227 kW</td>
</tr>
<tr>
<td>Steam</td>
<td>7.37 tph</td>
<td>7.8 tph</td>
<td>7.17 tph 4/</td>
</tr>
</tbody>
</table>

1/ Biogas considered for Gas Turbine: 17000 CMD. Supplementary firing of exhaust gas to use 13000 CMD
2/ Steam generated in a boiler 21 Kg/cm² @280°C. Power generated using a back-pressure turbine exhausting to 2 Kg/cm².
3/ Biogas for Gas Turbine: 17,000 CMD, supplementary firing of 13000 CMD produces steam 21 Kg/cm² @280°C. Additional power generated using a back-pressure steam turbine exhausting to 2 Kg/cm².
4/ tph - tonne
Some gas turbines have operating experience of running on alternative fuels like landfill gas, digester gas or sewage gas (municipal treatment plant). To date it appears that biogas generated from cane molasses distillery effluent plant has not been tried or commercially exploited for gas turbine operation. This is possibly because the anaerobic digestors necessary for the availability of large quantities of biogas have only recently been set up (since 1985) by the alcohol industry.

**SPECIAL FEATURES OF THE GAS TURBINE AND AUXILIARIES**

The biogas fired turbine is a new application and design modifications and adaptation is needed on the gas turbine combustion and control systems to accept low calorific value gas.

**Gas Turbine**

The equipment will have several features traditionally incorporated to use low calorific value gas such as biogas. Volumetric lower heating value (LHV) of a gas is used to classify individual fuels. Each type of fuel requires different handling, combustion and control systems.

As the heating value decreases below standard levels combustion system re-sizing is necessary and may require standard natural gas or liquid fuel for start-up and shut-down and also restrictions on transient load operations.

Typically, firing biogas in a gas turbine will involve the following changes:

- **Combustors**
- **Fuel injectors**
- **Controls**

The turbine should have a dual fuel system with a liquid distillate start and automatic switch over to biogas or similar low calorific value gas. The turbine combustors and injectors will be re-designed and modified to suit the low calorific value gas. The control systems need to be modified.

The H$_2$S present in the gas will have a corrosive effect on fuel wetted parts; thus, steel and/or special coatings are prescribed.

Chemically resistant diffusion coatings are proposed to be applied to the turbine components to prevent sulfide and hot corrosion. 1/ Precious metal aluminides coatings are used on turbine blades and vanes for high temperature oxidation resistance.

To protect the inlet air compressor, blade coatings are proposed where the H$_2$S content in the ambient is high or where there is the possibility of recirculation of exhaust gases in a sulphuric acid dew point corrosion.

**Turbine Auxiliaries**

**Air Inlet Filter.** It is important to note that very high sulphur in the fuel gas can be tolerated if the salts are taken out of the inlet air. Filtration systems are now available to overcome the smallest particles of salt.

A three stage filter system is generally recommended for such applications, the last one being a barrier. Self cleaning filters are being used in non sea coast environment.

**Fuel Gas Booster Compressors.** The fuel gas booster compressor will increase the gas pressure to acceptable inlet requirements. To ensure its safety and reliable operation the compressor may need special liners as well as incorporation of certain features from NACE standards to accept sour (H$_2$S) gas.

For accepting the sour gas several compressor components will be in stainless steel and Ni resist liners are proposed.

**Fuel Gas Conditioning Skid.** The gas conditioning skid will consist of knock-out vessels, separators and filters and include metering and regulating devices. Skid piping is recommended in stainless steel due to the presence of carbon dioxide and hydrogen sulfide.

Heaters may be required to ensure that the gas is above the dew point.

**Waste Heat Recovery Boiler.** A conventional heat recovery boiler is acceptable. The design has to ensure that the stack temperature is maintained sufficiently high to avoid sulphuric acid dew point corrosion.

**PROPOSED DEMONSTRATION PROJECT**

Under the USAID (United States Agency for International Development) sponsored programme of EMCAT (Energy Management Consultation & Training) a demonstration project of using biogas in a gas turbine is proposed to be set up at a distillery in the Northern State of Uttar Pradesh in India. Located near the capital New Delhi, the plant is one of the country’s largest cane molasses distillery.

The effluent treatment plant at the distillery produces about 48000 cubic metres per day of biogas. It is proposed to generate about 1 MW of power utilizing a part of the biogas in a Solar Saturn gas turbine. A waste heat recovery boiler of 3.3 tonnes per hour capacity will capture the hot exhaust gas to produce steam for process.

Kirloskar Oil Engines Limited, Solar’s packagers in India, have the prime responsibility for the contract.

The cogeneration project was evaluated for all different options. The unreliable and poor availability of utility power as well as high utility tariffs make the project extremely attractive.

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1/ No gas sweetening system for H$_2$S removal equipment is proposed in the system.

2/ NACE .... National Association of Corrosion Engineers.
GLOBAL MARKET POTENTIAL

A reasonable global market to use the technology and applications of biogas fired gas turbines will emerge. This would mainly pertain to cane sugar producing countries.

In India, there are presently over 250 alcohol based industries. Of these, around 100 to 120 will generate enough biogas to suit the size of a 1 MW gas turbine. A distillery capacity of 30 to 35 Kl/day produces sufficient gas to install a 1 MW turbine and about 3 tonnes per hour of process steam in a heat recovery steam generator.

The biogas generation system can be applied wherever the waste water contains medium to very high concentrations of dissolved/suspended BOD.

Apart from India, a large potential is believed to exist in Brazil, Thailand and other South American and Far East Countries where similar effluent treatment process for anaerobic digestion is adopted.

Most countries offer incentives as part of their energy conservation efforts to promote use of renewable forms of energy as well as for cogeneration systems.

It is likely that biogas fired gas turbine cogeneration systems qualify for such benefits and incentives like accelerated depreciation, and reduced/concessional levies and duties. All these aspects make the system all the more effective and attractive to the end-user. There are impediments. Gas turbine technologies are unfamiliar. The cane sugar and alcohol industries are not accustomed to embracing major new technologies and the required investments will be large.

However, assuming that sugar cane production continues to grow at the historical rate of three percent per year (since 1960) in the 80 sugar cane producing countries, at the end of the year 2027 some 3140 million tonne of cane will be produced annually. Out of this, according to World Bank projections 1430 million tonnes tonne would be committed to alcohol production, resulting in an annual methane production of 0.5 EJ/year - (methane production via anaerobic digestion at a rate of 0.33 GJ/tonne of cane). This is estimated to be equivalent to 5% respectively of the oil and gas used in all the developing countries in 1987.

Thus a large market for such systems is bound to emerge. Biogas fired gas turbine technologies for cogeneration or stand-alone power applications hold the promise of producing electricity at lower cost in many instances than most alternatives. It will boost the electric power availability from the cogeneration system and widen the cogeneration option to industry.

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