Energy use project and conversion efficiency analysis on biogas produced in breweries

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Abstract: Electric power, steam and chilled water were consumed in beer brewing process. The process is intensive in energy conversion and utilization. The brewery wastewater can generate biogas of high methane content through anaerobic sludge fermentation. This high concentrated biogas could be an excellent choice employed in energy conversion and utilization. The reclaimed water, after proper treatment, could be employed to scrub CO_2 and H_2S in biogas. Through compression, the purified biogas could be stored as fuel for mechanical operation and further incorporated into the municipal LNG pipe network. According to biogas yield and energy requirements in breweries, energy usage efficiency and configuration of device for biogas Integrated Energy System (IES) were investigated. This paper introduced an Otto cycle internal combustion engine using biogas for power generation. With the biogas yield of 34.84m^3/h (standard state), the power efficiency of 28.45% could be generated with electricity of 70.0kW. Efficiency of combined heating and power (CHP) can reach 61.80% employing the excess heat of the engine exhaust. There are successful examples of combined cooling and power (CCP), combined cooling and heating (CCH) that has efficiency of over 60%.

Keywords: *Biogas produce, Purification process, IES conversion Using efficiency*

1. Introduction

In China, Biogas is not only new energy source, but also an important aspect of sustainable development for the renewable energy. The biogas is generated by industrial wastewater or municipal solid waste through degradation process of anaerobic digestion. Consequently, heat and electricity is generated through the biogas [1]. Adopting the technology of combined cooling, heating, and power (CCHP), this is also known as trigeneration, or integrated energy system (IES). CCHP is the simultaneous production of mechanical power (often converted to electricity), heating and/or cooling from one primary fuel, and is an extension of CHP (combined heat and power, also defined as cogeneration) by coupling with thermally activated cooling technologies that take the waste heat from CHP for producing cooling [2].

Moving parts of internal combustion engines and gas turbine contacts directly with burning gas, there need cleaner fuels, biogas as a biomass energy source by the removal of CO_2 and H_2S and combined with high conversion efficiency, low emission rates, suitable for CHP, CCH and CCP technology. Medium and small-scale units high exhaust temperature, heat recovery of flue gas is conducive to heat (cold) output, and improve unit efficiency.

Because the biogas contains a large share of the inert gas, emissions of oxides of nitrogen (NOx) were reduced relative to natural gas, while unburned hydrocarbons (CH) were increased, and exhibit penalties of performance compared with spark ignition engine of natural gas or gasoline [3].

Kautz et al. [4] studied a 100kW gas turbine recuperative cycle of exhaust to heat air and the influence of low calorific biogas on the combustion air ratio. Kim et al. [5] studied regenerative Brayton cycle using gas turbine recycling exhaust heat. Nwafor [6] examined the impact of advanced injection timing on the emission characteristics of dual-fuel engine.

Ahead of injection timing was intended to compensate for longer ignition delay and slower burning rate of fuelled natural gas engine, and there was a s lightly increase in the oil consumption accompanied with reduced emission of CO and CO_2.

Smith et al. [7] introduced an innovative domestic scale combined heat and power (CHP) plant incorporating a heat pump (HP). HP incorporating enhanced economy efficiency of domestic use of CHP equipment and satisfied flexibility of the family energy requirements.

Biogas was compressed to gather energy density and reduce storage capacity, the best method is biogas purified, then to compress [8]. For example, in New Zealand, both gas compressor and gas scrubber used in conjunction with, in Belgium, biogas produced from the livestock manure is being dried, scrubbed, compressed and stored in a steel tank with pressure of 4 bar in 0.2 m^3, so that is alternative fuels for CNG(compressed natural gas), gasoline, diesel and LPG (liquefied petroleum gas) [9].

2. Biogas process and energy demand in breweries

2.1. Biogas process

Brewery wastewater comes from various procedures, such as the cleaning process of the malt production, brewing, bottling, and the wastewater from cleaning the recycled beer bottle and the packaging sterilization, as well as the overflow, disqualified product, and filter back wash water. This wastewater is rich in carbohydrates, pectin, mineral salts, cellulose etc. Therefore, it is an organic wastewater with high BOD_5 and COD.

Aeration pond m ethod is the application of biological treatment earlier; because of aerobic bacteria have an allergic reaction to load fluctuations, not to deal with high carbohydrate and volatile components of beer wastewater. Use of the up-flow anaerobic sludge blanket (UASB) has a feature that of high organic loading, short hydraulic retention time, no filler in reactor, no sludge return and stirring device, low operation cost, can be inoculated directly with the sludge particles to produce biogas etc., and that is a wastewater treatment technology for sustainable development. It can not meet emission standards used alone. In most cases, the first need to treat beer wastewater by anaerobic digestion, the most of high concentration organic wastewater in UASB was degraded, and then, under the aerobic environment oxidize and decompose low concentration of pollutants in wastewater.

Fig.1 shows the brewery wastewater processing units and biogas generation set. The brewery wastewater discharged from workshop flows to the sump. Most of suspensions in waste water filter through the sieve grid. The pretreatment pool is necessary for wastewater with unqualified temperature and other physical/chemical conditions. Subsequently, the wastewater flows through the balance pool with the pH values adjusted by acid, alkali or $FeCl_3$. The adjusted water is pumped to UASB reactor in the reaction pool to decompose the organic first into acids, then to methane and CO_2. The three phase separator on top of the reactor could separate the biogas, mud and wastewater efficiently. Meanwhile, the methane bacteria could be effectively retained. The biogas is collected in gas tank after adsorption of H_2S through activated carbon. After anaerobic treatment, COD of beer wastewater dropped from about 2500 t o 500 mg / L. The use of air blower aerate for further processing in the aeration tank. Wastewater COD reduced to about 50 mg / L and then flow into the sediment pool. After suspended solid of aerobic fermentation were filtered, the reclaimed water qualified discharged to the sewer.

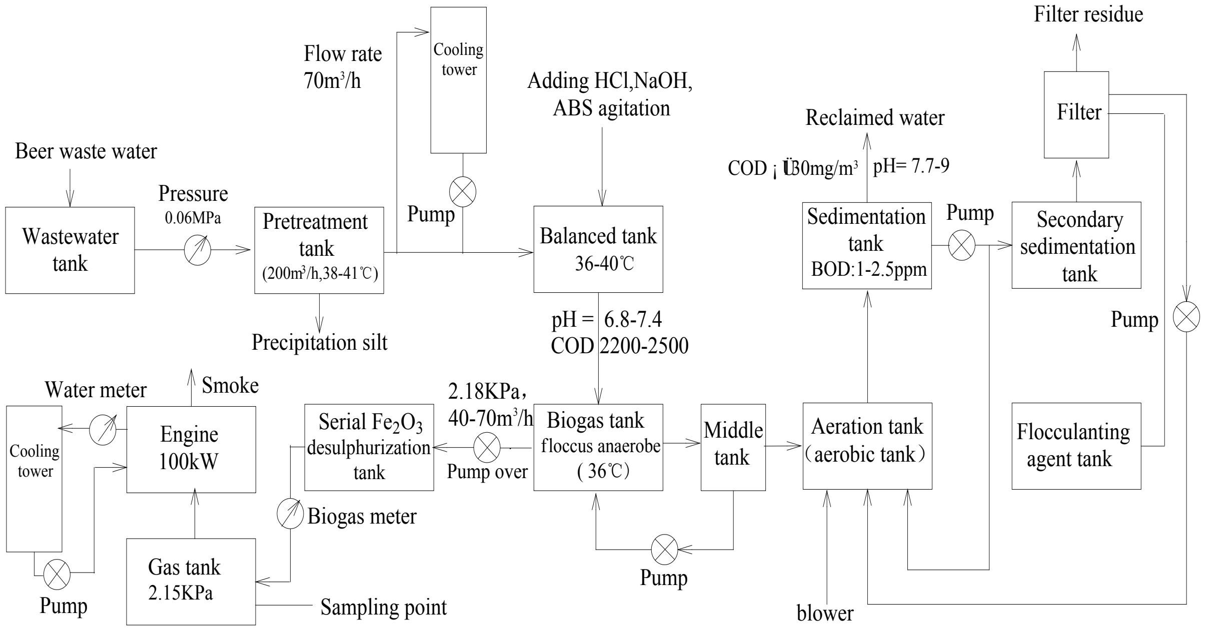


Fig.1. Schematic diagram of processing organic wastewater and generate electricity sets.

2.2. *Energy requirement*

The brewing process consumes a lot of electricity, steam and chilled water. This process is an intensive process of energy conversion and utilization. Therefore, energy consumption cost accounts for a large proportion of the production cost. Power workshop has 2 sets of 25t steam saturated boiler (burning oil and/or natural gas), steam pressure 7.0-8.0bar. 3 sets of ammonia compression refrigerator, cooling capacity of 496 RT, evaporator pressure of 3.7bar, chilled water supply 4°C, return 9°C. Fig.2 is energy flow diagram of steam and chilled water.

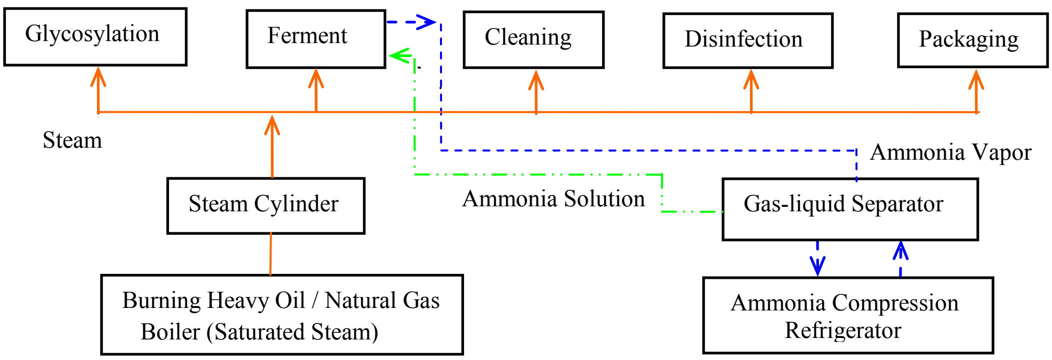


Fig.2. Energy flow diagram of steam and chilled water in breweries.

3. Status of biogas utilization

Shenzhen Kingway brewery (2 plants) and Shenzhen Tsingtao-Asahi brewery could treat beer brewery wastewater of 80-120m^3. The amount of biogas produced is 35-60 m^3 (maximum volume of 80m^3) per hour with the measured methane content of 71.2%. Table 1 shows the biogas composition with low heat value of about 25 426 kJ/Nm^3 and thermal capacity produced as 282.51-423.77kW per hour. Biogas power generation has been running for 1 year period, in order to prevent greenhouse gas emissions before it is used by the torch burning. The heat demand of beer production process provides a choice for biogas CHP and CCHP.

3.1. Engine power generation

Ignition engine was used for power generation in Shenzhen Kingway brewery, Table 2 was the spark ignition engine specifications. Biogas after the removal of H_2S could be generating 70kW (field test) per hour, efficiency of power generation was 28.45%. Table 3 was Composition of engine exhaust for the actual measurement.

Table1. Composition of the biogas

Component	Content (%)	Component	Content (%)
CH_4	71.2	H_2S	＞2500ppm
CO_2	17.1	H_2O,H_2	2.0
O_2	2.39	N_2*	7.31

* Air has leaked into biogas collection cavity over the silt anaerobic digestion pond.

Table2. Specification of 4 strokes and spark ignition engine.

Engine model	Q6135DA$_1$	Generator model	90GFTA$_1$
Rated power (kW)	83	Rated power (kW)	80
Rated speed (rpm)	1500	Rated speed (rpm)	1500
Arrangement/cylinder bore(mm)	6L /135	Rated voltage (V)	400
Displacement (L)	12.9	Nominal current (A)	162
Compression ratio	10.5	Nominal frequency (Hz)	50
Poston travel (mm)	150	Power factor	0.8
Exhaust temperature (°C)	≤630	Fuel gas consumes (m^3/kW h)	≤0.33

Table3. Composition of the exhaust gas (volume percent).

Item	Test value	Reference value*	
		Gasoline	Diesel
O_2 (%)	6.24	0.3-0.8	2.0-18.0
CO_2 (%)	8.36	5.0-12.0	1.0-10.0
NO (ppm)	1793		
NOx (ppm)	1883	10^5-0.5×10^5	10^3-0.4×10^5
SO_2 (ppm)	32-0		
H_2O (%)	~8.8	3.0-5.5	0.5-4.0
N_2 (%)	~76.6	74-77	76-78

* Reference value from Table 4 of reference [10]

3.2. Heating boiler

There is a biogas fired boiler (model: FBA-080 F) in Shenzhen Tsingtao-Asahi Brewery with the parameters as follows: rated pressure: P = 1.04MPa (saturated steam), the amount of steam produced 1.25 t / h, e xhaust temperature 300°, biogas/ steam ratio = 2:1, boiler efficiency η = 80%. The actual operation pressure was 0. 6MPa.

4. Biogas processing

Because high temperature of biogas fire, slower burning speed, serious ignition delay and higher exhaust temperature, all that resulting in lower efficiency of biogas power generation. biogas purification (removal of CO_2 and H_2S), then compressed and stored as alternative products of CNG, gasoline, diesel and LPG, showing the goods value of biogas through the transport.

4.1. Gas purification, compression and storage

Removal of H_2S in the biogas can be divided into ① dry and oxidation,② ferric oxide adsorption, ③ activated carbon adsorption, and④ liquid-phase oxidation process. A simple adsorption method using activated carbon was used in 3 breweries.

The amine solution of 10% mono-ethanolamine (MEA) and diethanolamine (DEA) are usually used to absorb CO_2. It takes 5min for the solution regeneration to be completed by boiling. The newer approach is the sulfolane method or the Sulfinol method composed by alcohol amine and sulfolane adding water. Method of reclaimed water which was beer wastewater treated when water pressure increased as the absorbent to remove CO_2 is the most simple and less expensive. Efficiency of the scrubber depends on that scrubber specifications, packing and gas pressure in scrubber, composition of raw biogas, the flow rate and purity of water used and so on.

The critical temperature and pressure required to liquefied biogas were: -82.58 °C and 47.5 bar respectively. Purification biogas compressed by the compressor, according to different pressure stored in cylinders, which could be transported with long-distance, may be also build a small scale station on side.

4.2. Power fuel

After CO_2, H_2S and water vapor in biogas were removed, the methane (>90%, heat value equivalent to LNG), could be compressed and stored as fuel for car and other power machines.Table 4 is data of LNG imported to Guangdong province of China from Australia, kindly provided by the Shenzhen Gas Group.

Table 4. Data of physical and chemical for LNG.

Composition	(%)	Data (0℃,1 atm)	Value
CH_4	87.59	HHV (MJ/Nm^3)	45.08
C_2H_6	8.13	LHV (MJ/Nm^3)	40.71
C_3H_8	3.2	Density (kg/Nm^3)	0.8318
C_4H_{10}	0.99	Specific volume (Nm^3/t)	1202
C_5H_{12}	0.05	LHV (MJ/kg)	48.92

Use of CNG instead of gasoline as a motor fuel, the emissions of CO, CH compounds and NO compounds can be decreased by 97%, 72%, and 39% respectively. Performance of resistance to blast for CNG equivalent to gasoline is about octane number of 130, and CNG does not release lead, benzene and other toxic substances all which can cause cancer. Forklift which using LPG as fuel made by Japan Fuji Co. in Shenzhen Tsingtao-Asahi brewery, may also use purified biogas as a substitute.

4.3. Incorporate into LNG pipe network

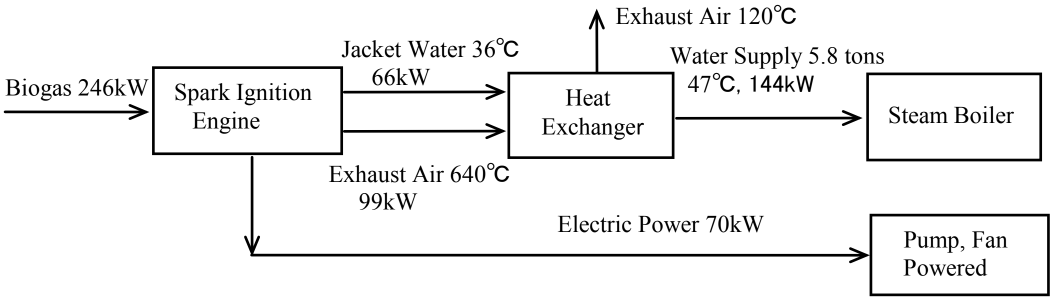
Due to lower productive rate of biogas, gas source instability, lower energy carrier demand load, difficult to manufacture equipment and operation and a long payback time as investment etc., biogas can no effectively use in the IES, so that, it could be considered incorporate into the municipal LNG Network pipe after the quality checked up.

5. Integrated energy system (IES) of biogas

Electricity is the high grade energy. According to the second law of thermodynamics, the electricity generated by biogas is of the highest efficiency, meanwhile, the exhaust gas could be employed for heating or cooling. IES of biogas would adopt the following technologies such as Otto cycle of ignition engine, Brayton cycle of gas turbine, power generation of fuel cells, absorption and adsorption refrigeration, high efficient combustion, high efficiency removal of H_2S and CO_2, as well as recovery and storage for thermal energy.

5.1. CHP project

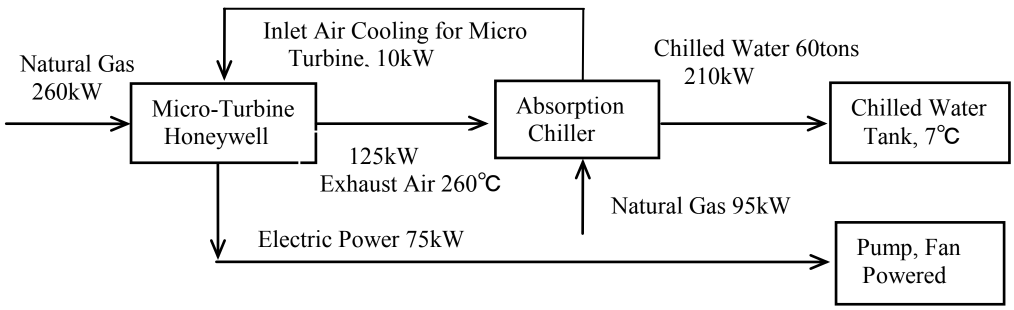
Project 1: Engine + Heat tube exchanger of condensation type
(Shenzhen Kingway brewery)



• Spark Ignition Engine of biogas fueled without removal of CO_2, generate electricity efficiency of 28.45%, discharged heat of 99kW by engine exhaust and of 66kW by jacket cooling water, dispersed heat of 2.8kW by convection and of 4.6kW by radiation.
• If heat of engine exhaust was utilized through heat tube heat exchanger to heat water supply and temperature was reduced to about 120℃, then, overall CHP efficiency may be reached 61.8%, and engine exhaust even could be discharged at the condensation temperature of 57℃.

5.2. CCP project [11]

Project 2: Micro Turbine (Honeywell) + Direct fired double effect chiller



• Turbine efficiency 28.75%. Inlet air cooled to 16℃ to keep constant capacity of turbine.
• Broad absorption chiller using lithium bromide-water, direct fired double effect chiller with COP of 1. Chilled water temperature: supply 7.8-9.4℃, return 12.8-14.4℃.
Performance of MT Honeywell and absorption chiller were shown in Table 5 and Table 6.

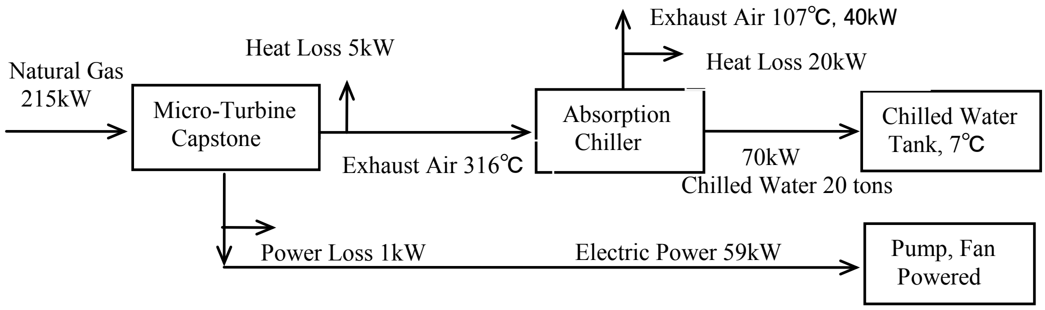
Table 5. Performance parameters of MT (Honeywell).

Item	Parameter	
Rating power (kW)	75	15℃,1atm
NG wastage (m^3/h)	27	≥0.62MPa(absolute)
Thermoelectricity efficiency (%)	28.5	15℃,1atm
Exhaust temperature (℃)	280	
Exhaust flux (kg/s)	0.67/0.76	
Emission of NO_X (ppm)	<13	15℃,1atm, full load

Table 6. Broad LiBr absorption chillers (Mode: BD7N280-15).

Item	Parameter	Item	Parameter
Capacity of refrigeration (USRT)	23	Produce heat (kW)	114
Chilled water outlet/inlet temp. (℃)	6.7/12.2	Warm water outlet temp.(℃)	50
Chilled water flux (m^3/h)	12.8	Warm water flux (m^3/h)	19.6
Cooling water outlet/inlet temp.(℃)	36/29.4	Inlet temp. of exhaust (℃)	280
Cooling water flux (m^3/h)	24.3	Match electricity (kW)	1.2

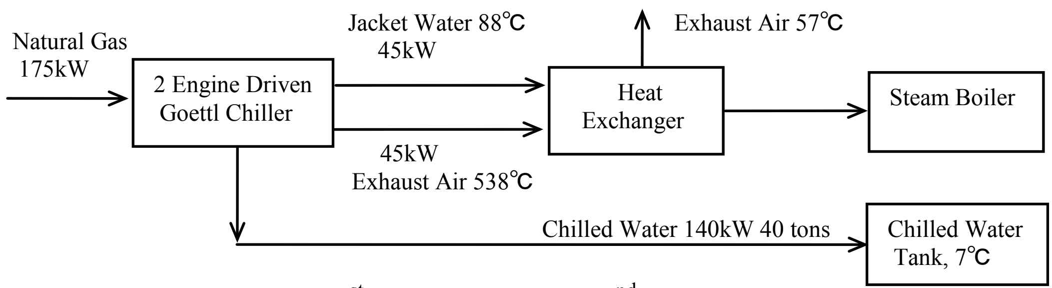
Project 3: Micro Turbines (Capstone) + Single effect chiller



• MT Capstone efficiency 27.9%, with chiller 63.5%. Average exhaust inlet temp.271℃, outlet temp.113℃.
• Broad absorption chiller driven only by MT exhaust. Single effect chiller with COP of 0.7, nominal capacity of chilled water is 20 tons. Parasitic power is 6.4kW.

5.3. CCH project

Project 4: Engine driven Goettl Units + Heat tube exchanger of condensation type



• Engine Driven Goettl Units. 1st stage COPG=1.4, 2nd stage COPG=0.8, Engine output 52kW, engine efficiency 30%.

6. Conclusion

This paper introduced and analyzed biogas utilization for the three large modern breweries, which is not perfect and irrational for use of biogas energy. Based on the current biogas technology and equipments, accordingly to the biogas yield and energy demand in breweries, analyzed and studied the energy utilization technology, equipment configuration, and conversion efficiency on the integrated energy system (IES) . The biogas purification process employs qualified reclaimed water from wastewater treated of the brewery to scrub CO_2 and H_2S in biogas. This process is simple with low operation cost. The resultant biogas is rich in methane content and efficient to improve the efficiency of IES. Both electricity generation and heating efficiency, as well as the cooling efficiency can reach as high as 60%.

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