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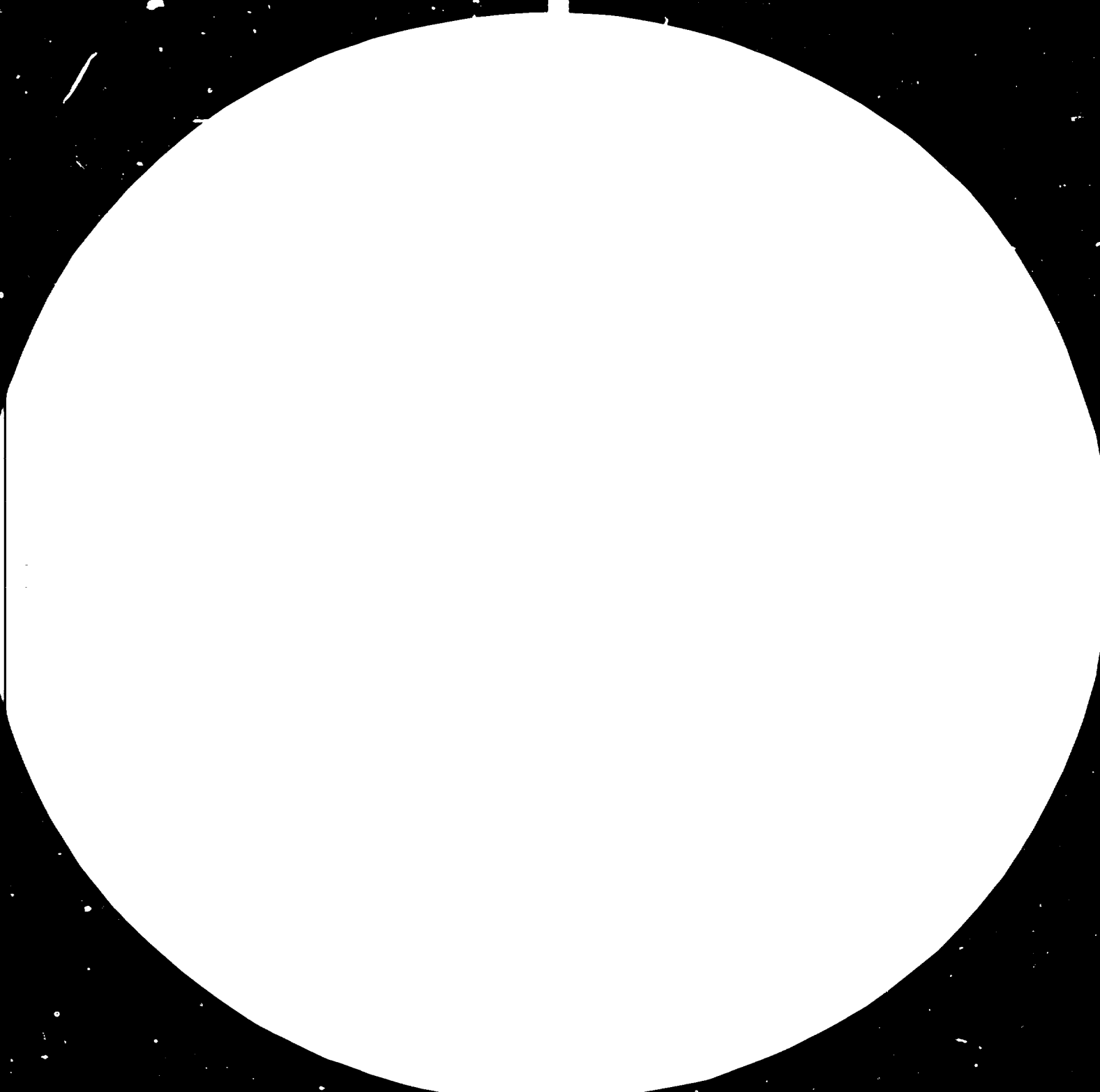

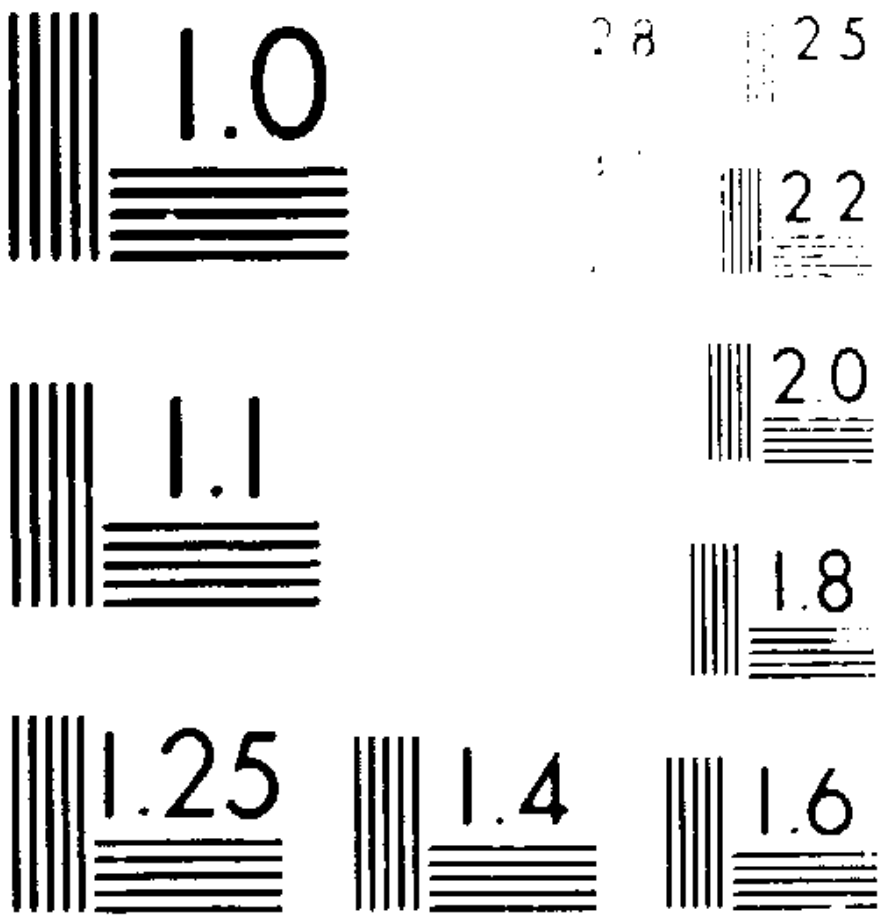
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BIOGAS UTILIZATION *

prepared by

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Biogas is a mixture of gases with methane as its main content. According to the analysis and measurements made by Chengdu Institute of Chemistry, Academia Sinica, of 64 biogas digesters in six counties in Sichuan Province, biogas contains 61.9% of methane and 35.77% of carbon dioxide with very small percentages of nitrogen, sulfurated hydrogen etc.

Methane is transparent, smell-less and tasteless, but biogas smells of garlic or rotten eggs. Complete combustion of 1 cubic meter of biogas generates 5,500 to 6,500 kilo-calories of heat, which is enough to run a one horse-power internal combustion engine for two hours, or generate 1.25 kilowatt hours of electricity, or produce 5.2 kilograms of carbon tetrachloride. One cubic meter of biogas is equivalent to 0.4 kilograms of diesel oil. 0.6 kilogram of petrol or 0.8 kilograms of standard coal.

Both the physical properties and chemical composition of biogas indicate that it is not only a good fuel, but also an important chemical raw material.

Biogas is an inexhaustible energy source. Solar energy stored in plants by light synthesis process is converted into biogas energy through the action of bacteria; and, therefore, this bio-energy - biogas will always exist so long as the sun exists.

The raw materials for artificial production of biogas are organic matters such as human and animal excrements, stalks, weeds, leaves, garbage, sewage etc. As these materials are to be found almost everywhere, they can be collected and fermented locally. Recently, peasants in Sichuan Province have been growing more and more water hyacinths(pistia stratiotes L.). This fast-growing, high-yield plant is not only a good forage, but also a good raw material for biogas fermentation.

When used as a fuel, biogas produces no ash, no smell, no poison and no hazards or pollution.

Therefore, biogas is an inexhaustible, cheap and clean energy source.

Biogas is artificially made by allowing anaerobic methane-producing bacteria to decompose the fermenting raw materials under a tightly-sealed environment. Raw materials for fermentation should meet certain specifications with regard to their carbon-nitrogen ratio, concentration, temperature, acidity and alkalinity.

1. Carbon-nitrogen ratio

Carbon and nitrogen are the major nutrients for anaerobes, which feed on carbon 25 to 30 times more quickly than on nitrogen. Generally, fresh cow dung, sheep manure and human excrements have good carbon-nitrogen ratios (See Tables 1 and 2).

2. Concentration

The most suitable dry matter concentration of a raw material is 7-9% (See Table 3).

Table 1 Carbon-Nitrogen Ratios of Most-Used Raw Materials for Bio-Gas Fermentation (Approximate Values).

materials	carbon weight percentage (%)	nitrogen weight percentage (%)	carbon-nitrogen ratio
dry wheat straw	46	0.53	87:1
dry rice straw	42	0.63	67:1
maize stalks	40	0.75	53:1
fallen leaves	41	1.00	41:1
soya bean stalks	41	1.30	32:1
weeds	14	0.54	27:1
pea-nut stems & leaves	11	0.59	19:1
fresh sheep manure	16	0.55	29:1
fresh cow dung	7.3	0.29	25:1
fresh horse manure	10	0.42	24:1
fresh pig manure	7.8	0.65	13:1
fresh human wastes	2.5	0.85	29:1

Table 2 Bio-Gas Yield of Several Raw Materials for Fermentation

materials	amount of bio-gas generated by 1 t of DRY matters (m^3)	methane content (%)
barnyard manure	260—280	50—60
pig manure	561	
horse manure	200—300	
green grass	630	70
flax stem	359	
WHEAT STRAW	432	59
tree leaves	210—294	58
garbage & mud	640	50
distillery sewage	300—600	58
CARBOHYDRATES	750	49
quasi-fat compounds	1400	72
protein	980	50

Table 3 Water Contents of Several Bio-Gas Raw Materials

materials	water content (%)
human excrements & urine	80 , approximately
pig manure	82
pig urine	96
horse manure	76
ordinary weather-dried manure	30—40
dry rice straw	10—20
cow dung	83

3.Temperature

Fermentation may take place at high temperature (thermophilic fermentation, 47--55 deg C), medium temperature (mesophilic temperature fermentation, 35 - 38 deg C) and ambient temperature(15 - 35 deg C). Gas production rate may reach approximately 250% at high temperature, and 150% at medium temperature and only 15% or so at ambient temperature. The high temperature fermentation cycle is the shortest of all.

4. Acidity and alkalinity (PH value)

The optimum PH value ranges between 7 and 8. Usually the PH value needs no adjustment because bacteria in the fermenting materials undergo a process of self dynamic balance with respect to the PH value. Adjustment is necessary only when a great quantity of volatile acids have been accumulated due to improper material mix and management.

The combustion of bio-gas demands a sufficient supply of oxygen.

$$CH_4 + 2O_2 \text{ ---- } CO_2 + 2H_2O + \text{heat}$$

From this chemical reaction equation we can see that the methane-oxygen ratio is 1:2. Oxygen content in air is only 1/5 and, therefore, in terms of volume, complete combustion of one part of methane needs 10 parts of air. Since bio-gas contains60 - 70% of methane, complete combustion of one part of bio-gas needs only 6 - 7 parts of air.

According to current data, biogas can be used for the following purposes.

1. Cooking and lighting

In China, ambient temperature fermentation is at present

the most popular way to make biogas. There are altogether more than seven million home biogas digesters in China's rural areas. The average gas production rate is 15%. Generally, the capacity of a digester is determined in design by the size of a family. There are four size ratings for home biogas digesters in China, namely, 6, 8, 10 and 12 cubic meters. A family of five people consumes about 1 cubic meter of biogas for cooking the three meals of a day. To produce this amount of biogas, a digester of 8 cubic meters should be established and 100 - 150 kg of pigs should be kept in stable to provide raw materials for fermentation. When raw materials for fermentation are abundant, a bigger digester or separate digesters may be built so as to increase gas yield and meet the various demands of a peasant family. Two digesters of 5 cubic meters each are more efficient than one digester of 10 cubic meters because gas production rate increases in proportion with the fermentation area. In addition, it is easier to stir the materials in the two separate digesters and consumption of biogas will not be hindered during change of materials, maintenance and repair.

The role which the biogas can play for cooking depends on the heat efficiency of the stove. At present the heat efficiency of the best stove in China exceeds 60%. When we use good stoves such as the Nanting County's Type double and single-fire stoves, it takes 15 - 20 minutes and 61 litres of gas to boil 2.5 kg of water from 18 - 19 deg C to 98 deg C at a room temperature of 19 deg C.

The bio-gas lamp is composed of a bio-gas intake, an air intake, an air governor, a mixing channel, a fire-proof earth block and a mantle. When the difference between bio-gas pressure and water column is above 80 cm, the gas jet is strong and illumination is good. When the pressure difference is under 4^0 cm, poor illumination results. One cubic meter of bio-gas can light a bio-gas lamp for 6 hours, with the brightness of a 60 - 100 watt electric lamp.

2. Dual-fuel internal combustion engines for farm uses

Techniques to convert diesel engines into bio-gas-diesel dual-fuel engines are as follows. Keep the fuel system of the original engine. Install a flammable gas (bio-gas)-air mixer between the air-filter and the intake of the diesel engine. Both direct intake mixer and cross pipe mixer are widely used now in Sichuan Province. 70 - 90 % or diesel oil can be saved after conversion. According to the report made by the Sichuan Institute of Agricultural Machinery in October, 1979, tests on Type 1105 engines (separate chamber) show a result of 15 g/hp-hr of liquid fuel. The test results of Type S195 (narrow path swirl combustion chamber) and Type 175 (pre-combustion chamber) also show a substantial saving of liquid fuel.

Table 4

Data indicate that sulfurated hydrogen content is 300 - 700 mg/m^3 in natural gas and 50 - 300 mg/m^3 in bio-gas in Sichuan Province. The Sichuan Institute of Agricultural Machinery conducted a test on a dual-fuel engine (with an installed power of 20 hp) in Luzhou, Sichuan, between September 4th and December 4th, 1975, using a natural gas with a high sulfurated hydrogen content of 740 mg/m^3. After running for 1500 hours, the engine was dismantled. The engine parts were quite intact on the whole except ø for one or two pieces such as the 40 Cr air valve and the copper cylinder liner, which were corroded substantially. As a matter of fact, some bio-gas-diesel engines have already been in operation for more than 3000 hours without any obvious early wear or serious corrosion. These facts have indicated that sulfurated hydrogen contained in bio-gas does not have a substantial impact during the long period of engine operation.

The above-mentioned conversion technique using a flammable gas-air mixer has the following advantages: no destruction of the original engine structure, no degradation of the original engine performances, simple and easy conversion, very low cost (RMB 20 yuan or so), and the capability of burning either gas-oil mixture or diesel alone.

The bio-gas diesel-dual oil engine can be used for pumping, power generating, rice husking, wheat milling and breaking of by-products etc. with a big saving of farming cost. For every horse-power of a dual-fuel engine, gas consumption is 0.45 m^3/hr. By the end of 1979, there were already 514 dual-fuel engine stations in the whole of Sichuan Province, with a total capacity of 5,542 hp. In the droughty year of 1976, the second prodution team of the Yongle brigade of the Jing bian Commune in Quxian County in Sichuan used a Type 1105 dual-fuel engine for irrigation of up to 11 hectares of land. Their engine was in operation for 200 hours, pumping more than 45,000 cubic meters of water. They had a total rice yeild of more than 50 tons, an increase of 23 % as against that of the previous year. Between July and December, 1978, the 8th production

Table 4 Test Performances of S195 Diesel Engine

And S195 Bio-Gas Diesel Engine

	engine speed (RPM)	readings from hydraulic dynamometer (kg)	effective power (hp)	fuel consumption (kg)	time of fuel consumption (s)	specific fuel consumption (g/hp-hr)	fuel consumed (%)	fuel saved (%)	time of gas consumption (sec/0.05m³)	gas consumption (m³/hr)	specific gas consumption (m³/hp-hr)	water temperature (deg C.)
original engine	2000	3	6	50	133.6	214.7						92
	2000	4.5	9	50	104.7	191						90
	2000	5.5	11	50	88.4	135						90
	2000	6	12	50	79.1	189.9						90
with direct mixer	2000	3	6	10	110	54.5	24.8	75.2	85	2.12	0.352	90
	2000	4.5	9	10	115.4	54.6	18.1	81.9	68.4	2.63	0.293	90
	2000	5.5	11	10	153.7	20.63	11.2	88.8	56.2	3.21	0.291	90
	2000	6	12	10	109	27.5	14.5	85.5	51.4	3.49	0.291	90
with cross mixer	2000	3	6	10	201.6	29.8	13.6	86.4	63	2.86	0.411	90
	2000	4.5	9	10	194.1	20.55	10.16	89.24	63.7	2.83	0.315	90
	2000	5.5	11	10	186.8	17.54	9.48	90.52	56	3.22	0.292	90
	2000	6	12	10	163.6	18.35	9.68	90.32	52.6	3.43	0.286	90

Table 5 Operation Details of Type 175 Bio-Gas Diesel Engine

items	running hours	working load	combustion of diesel alone (kg)	diesel consumed in combustion of gas-diesel mixture (kg)	diesel saved (kg)
power generation	390	1170 (kw-hr)	390.00	126.10	263.90
irrigation	120	120	120.00	35.00	85.00
threshing	103	49.724 (jin)	103.00	30.40	72.60
total	613		613.00	191.50	421.00

Table 6 Operation Details of Type 1105 Bio-Gas Diesel Engine

items	running hours	working load (kg)	combustion of diesel alone (kg)	diesel consumed in combustion of gas-diesel mixture (kg)	diesel saved (kg)
processing unhusked rice	406	99023	974.40	224.15	7504.25
breaking fodder	174	12316.5	435.00	232.40	202.60
processing maize	64	7610	153.60	38.40	115.20
total	644	118949.5	1563.00	844.95	1068.05

team of the 8th brigade of the Xiangyang Commune in Nanchong, Sichuan, used an S195 dual-fuel engine for husking rice, milling wheat and breaking fodder. They consumed 115 kg of oil but earned 998.78 yuan and out of every 100 yuan of their income they took 8 yuan to pay for the oil they had consumed. In contrast, for the three neighbouring brigades who used the same type of engines but only with diesel, they had to take 40 - 45 yuan out of every 100 yuan of their income to pay for the oil.

Tables 5 and 6 show from an economic point of view the various operational aspects of the two types of engines used by the 11th production team of the Tongle Brigade of the Dragon Pond Commune in the outskirts of Chengdu, Sichuan.

Recently, the Rongxian County Distillery has succeeded in driving their trucks by pure combustion of bio-gas compressed into oxygen cylinders. These trucks have been used to carry the more than 100 tons of wastes from a 2000 m^3 digester to the countryside as fertilizer. One cubic meter of bio-gas is enough to drive a conventional truck 3 kilometers. The distillery has four trucks to do the job. Daily bio-gas consumption is 60 m^3 for each truck and 240 m^3 for the four trucks, which cover a total distance of 720 kilometers everyday. 48.6 tons of petrol or 36455 yuan can be saved in a year.

3. Generating Electricity

By the end of 1979, there were 301 small biogas power stations with a total capacity of 1494 kilowatts in Sichuan Province. Using the electricity generated with bio-gas for lighting is easier and more economical than directly using bio-gas for the purpose(in terms of gas consumption). The electricity generated with 0.75 m^3 of bio-gas can light 25 40-watt lamps for one hour while the same amount of bio-gas can only light 7 bio-gas lamps for one hour by direct burning.

The research personnel of the Sichuan Institute of Agricultural Machinery has converted a Type J02 asynchronous motor into a small-capacity asynchronous generator as a stop-gap equipment to meet the rural demands for bio-gas power generation for lighting. This particular kind of asynchronous generator is known as Type CYF generator (with four power ratings: 3, 4, 5.5 and 7.5 kw) and can be configured with Type 175 (5hp), 180 (7hp), 1105 (10 hp) and S195 (12hp) dual-fuel engines respectively. After 500 hours' production test and performances measurement, this asynchronous generator has been found having the following advantages.

(1) Simple structure. The generator has no field commutator or brushes such as found on a synchronous generator and therefore there will be fewer faults.

(2) No need for short circuit protection. Voltage drops as soon as shorting occurs. The shorting current is also less than in a synchronous generator.

(3) Low cost. Its cost is only half or even a third of that of a synchronous generator.

(4) It is best suited for a production team with 50 to 100 households.

The Chengxiang Brigade of the Benniu Commune in Wujin County, Jiangsu Province, has built a 1200 m^3 bio-gas digester. They

Table 7 Oil Savings of the Bio-Gas Power Station of the Deyang Horticultural Farm in Sichuan

No.	engine type	kw/hp	oil saving rate (%)	operational period	operational hours	power generated (kw-hr)
I	1105	6/10	95--98	May '75 — Dec. '79	3377	18538
II	2105	12/20	70—75	Jan. '78 — Jul. '79	982	6671
III	4125	50/75	70-75	Oct. '76 — Dec. '79	1183	24825

use bio-gas to drive a 75 hp diesel engine geared to a 40 kw generating set, which has greatly enhanced the development of their industry and sideline production. The brigade is currently running a distillery and a brick kiln. Income from running industry and sidelines constitutes more than 50 % of the brigade's total income.

The horticultural farm in Deyang County, Sichuan, has built a bio-gas power station using cow dung as raw materials, which generates half of the electricity needed for production and lighting on the farm (having more than 200 workers and 50.7 hectares of land). The farm has benefited much through economics from bio-gas.

The Hongxian County distillery in Sichuan uses distiller's grains to produce bio-gas in a 2000 m^3 digester employing high temperature fermentation technology with a gas production rate of 100 % (without any stirring facilities). Their bio-gas power station now has an installed capacity of 120 kw, which, according to their plan, will reach 415 kw by the end of this year. This power station has already been combined into the state-owned power network. It is estimated that in two or three years' time all the investment can be recouped.

Small bio-gas power stations can be run in the countryside with little investment and quick results. They will not be influenced by shortage of water or droughts. When there are 100,000 small bio-gas power stations of 7.5 kw (12 hp) across the country, the total electricity generated will be elevenhundred million kw-hr, which is the equivalent of the power generated by two Sanmen Gorge-sized hydropower stations.

4. Drying farm produce and kiln-drying tiles

In places where fuel is both lacking and expensive and in

wet seasons, bio-gas can be used to dry farm produce so that it they will not go mouldy or rotten, and at the same time, fuel, manpower and money can be saved.

The Quxian County in Sichuan grows an abundance of day lilies. The harvest time happens to be in the rainy season. When dried by burning wood in the past, day lilies were smoked and polluted by carbon ions. After such treatment, day lilies lost their lustre and oily smoothness and some even looked burnt, hence the quality deteriorated. The 5th production team of the 6th brigade of the Pingxi Commune in Quxian County has a 56 m^2 baking house with a ceiling height of 2.7 m, using bio-gas from a 160 m^3 digester. Inside the house the temperature is kept at 50 deg C or so.There are 7 parallel baking shelves, on which 150 - 250 kg of day lilies can be dried everyday. With such a baking facility the team can earn 755 yuan extra every year.

In 1976, Fengyang County in Anhui Province and Ziyang County in Sichuan Province etc. succeeded in using bio-gas to flue-cure tobacco. Bio-gas has the following advantages in this application: (1) Coal and charcoal can be saved and cost reduced. On the average, every kang (heatable bed) yields 125 kg of dry tobacco. As it takes 2.5 kg of coal to cure 1 kg of tobacco each kang saves 312.5 kg of coal. (2) Generally, tobacco can be cured to one grade higher in quality due to the uniform distribution, rapid rise and flexible regulation of the kang temperature. (3) Manpower can be saved. When bio-gas is used to cure tobacco, there will be no need for anyone to look after the fire. By using biogas to cure 5 tons of tobacco, more than 200 man-days can be saved that would otherwise be spent in transporting coal and in building and heating the kang. (4) The technology of controlling fire and air temperature with switches is easy to master and fairly safe. (5) The structure of the kang house can be simplified. Chimneys, ridges and furnace chambers can be dispensed with. Burning of bio-gas is

Table 8 Comparison of Day Lily Treatment Results

item / group no.	fuel used	baking hours	dry day lily rate (%)	grade specified in acceptance
1	bio-gas	24	26.9	A
2	wood	18—48	25	C
3	sunning	48	21	A
4	day-time sunning, night bio-gas baking	24	21.2	A
5	day-time sunning, night wood baking	24	26.8	B

Table 9 Economy Involved in Obtaining Every 100 Jin of Dry Day Lily

item / group no.	manpower used	wood burnt (kg)	bio-gas consumed (m^3)	cost of wood (yuan)	sale price (yuan)
1	0.3		40---60		75
2	10	60 -125		7 -10	65
3	0.6				15
4	0.5		20 —30	2	15
5	5	30 -35		5 -1	10

smokeless and very clean.

Based on the same technology, bio-gas may be used for drying rice grains and potatoes, raising silk-worms, and for growing rice seedlings and vegetables in green-houses.

Biogas is alsc being used more and more widely as fuel for far infra-red emitter ovens. These are used as room heaters and for water heating for raising fish.

Since June 1975, the 2nd production team of the 4th brigade and the hospital of the Taiping Commune in Muchuan County, Sichuan, have conducted 14 experiments on kiln-drying tiles with bio-gas. Each kiln houses 500 tiles. The perfection rate of "bio-gas tiles" is 80 - 88.8 %. Kiln-drying tiles with bio-gas has the following advantages. (1) It takes less time than when wood or coal is used, hence increasing the availability of a kiln by a factor of one to two. (2) Cost is reduced. When coal and wood is used, the cost is 1.5 times greater than when bio-gas is used. (3) Manpower for looking after the fire is reduced. (4) Temperature inside the kiln is stable and tiles are uniformly heated, thus assuring good quality of products. Small bio-gas heaters for tile kilns such as these are suitable for separate uses in the countryside where only small quantities are needed.

5. Bio-gas is an important industrial raw material. Bio-gas contains roughly 60 % of methane and 35 % of carbon dioxide, both of which can serve as raw materials for the manufacture of chemical industry products. When methane reacts with chlorine at high temperature, the hydrogen atoms in methane are replaced by chlorine atoms. According to the different numbers of atoms being replaced, various chloromethanes with their byproduct hydrogen chloride are formed. After condensation and separation of chloromethane, the following products

are obtained, namely, monochloromethane (major raw material for making organic silicon, or serving as solvent, coolent and insecticide), dichloromethane (degreasing agent, permeating agent, coolent and raw material for making cine-films), trichloromethane (raw material for making polytetrafluoroethylene plastic and antibiotic, extracting agent, solvent and anaesthetic) and carbon tetrachloride (fire-extinguishing agent and raw material for making fluorine-containing plastics).

// Methane is also a raw material for making acetylene, methanol, formaldehyde, carbon black, ammonia fertilizer and other chemical industry products. Vitamin B12 can be extracted from digested slurry.

In 1966, the Nanyang Alcohol Distillery in Henan Province built two digesters of 2000 cubic meters each. They used distillers' grains as raw materials for fermentation and obtained a daily gas yield of 6000 - 8000 cubic meters. Bio-gas was produced with high temperature fermentation technology. Every cubic meter of digester volume could dispose of 0.1 m^3 of distillers' grains in 24 hours. In 1970, a chemical plant was built using bio-gas as raw material, which started production in 1972 with an annual output of 700 tons of dichloromethane and 230 tons of trichloromethane. At the same time, the digested liquid after bio-gas fermentation was used as raw material for the extraction of vitamin B12. Daily output is about one gram of crystaline product. All these chemical products meet the specifications defined by the State.

Carbondioxide contained in bio-gas can be used to make dry ice or as fertilizer. One cubic meter of carbon dioxide is enough to make one kilogram of dry ice. Dry ice can be used for artificial rainfall and 0.3 tons of dry ice can cause a rainfall of 3 mm to cover an area of 60 squeare kilometers. Dry ice can be used also as important raw material for manufcaturing safe explosives. It is also

a good coolent, which transforms from solid directly into gas, giving a cooling capability three times greater than ordinary ice. Furthermore, it is small in size, clean, sanitary and non-toxic.

In the last few years, scientists of China and abroad have been envisaging a way to increase crops yield by using carbon dioxide as a gas fertilizer, namely, growing leguminous plants in a greenhouse complex, extracting edible protein from these plants, using the plant remains as fodder or raw materials for bio-gas fermentation, and filling the greenhouse with carbon dioxide separated from biogas produced as fertilizer. Methane and carbon dioxide in biogas can now be separated from each other by employing the technique of high polymer film separation.

It may be added that exploiting the utilization of biogas also encourages the use of digesters to provide good quality organic fertilizer, improve environment and sanitation, permit better use of excrements and prevent diseases. However, these topics are outside the scope of the present paper.

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