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Solution for Smart Hybrid System of Electricity and Heat Generation for the Farms in Mongolia

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Abstract: In Mongolia, the numbers of herders who own more than 1,000 herds have been increasing year by year. Some of the herder families are operating small agricultural factories as well. The appropriate power supply systems are not being developed yet in their farms. At the farms, mostly 4-10 herder families work together and the monthly power consumption of one farm reaches to 11.8-14.9 kWh. Currently, the gasoline, diesel, solar and wind power are being used as a source of energy production. In addition, the small-scale CHP (Combined Heat and Power) system is not introduced to the farms for their sustainable operation. There are abundant biomass resources in the rural area of Mongolia. In this paper, we conduct experimental studies on biomass gasification system and suggest small-scale CHP system for rural farms in Mongolia.

Key words: Herders, wind, solar, biomass, biogas, smart hybrid system, CHP.

1. Introduction

Traditional Mongolian herder families move around with their livestock at least 5 times a year. The lifestyle of herder families has changed a little under the influence by modern lifestyles. In the last decade, the living condition and its level have been changed at the country side of Mongolia.

The number of farmers who own more than 1,000 livestock has been increasing year by year [1]. Some of these farmers run their own farms on their own land. So, they could install a necessary stand-alone power source on their farms. There are several options that could be mentioned as the stand-alone power sources, such as petrol, diesel, solar and wind.

However the prices for crude oil were unstable internationally, the wind and solar irradiation have shown large energy fluctuations.

A stable output could be obtained by combining several renewable energies in Mongolia. In Mongolia, there are abundant biomass resources that are renewable and it could control energy output.

In order to decrease the emission of GHG, it is necessary to use this biomass resource as much as possible. There are two biomass technologies, which are biomass gasification and biogas, for power generation that could be introduced to Mongolian herder families.

In Mongolia, research and development activities on biogas were started in 1980's. At a farm, mostly 4 to 10 herder families work together and their power demand reaches to 10-20 kW in total. The power demand of one farm is shown in Table 1 [2].

In Japan, the renewable triple hybrid generation system which consists of 40 kW wind, 20 kW solar and 20 kW biomass was installed by the Ashikaga University [3].

The produced gas from the gasifier is being used to operate the rotary engine for power generation. During the experiment, contents of the produced gas, such as carbon oxide (CO_2), carbon monoxide (CO), methane gas CH_4, oxygen (O_2) and hydrogen (H_2) were monitored with the gas chromatography and temperature inside of gasifier was monitored at the oxidation and reduction layers [4].

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Table 1 Power consumption of the farm.

	Quantity	Mean power (kW)	Operation time (h)	Total power consumption (kWh/day)
Herder family	10			5.83-8.91
Outside lighting		0.4	10	4.00
Well	1	1.00	2	2.00
Total				11.83-14.91

2. Experiment of Biomass Electricity Generation System with the Biomass Briquette

The biomass gasification electricity generation system of AU is shown in the Fig. 1.

The first step is to ignite the charcoal and afterwards to put it in the gasifier. The air will be sent by a blower to raise the temperature inside the gasifier and reaches around 500 °C at the oxidation layer. Then put biomass (briquette or cow dung) into the gasifier from the opened top lid. After that, put biomass (briquette or cow dung) through the top of the gasifier [5]. The total duration of this experiment will be around 6 h. The test result is shown in the Fig. 2, 3 and 4. According to the test results, the maximum value of CO content was over 30% as shown in Fig. 2. Fluctuation of CO contents was caused by reduction of temperature by adding the biomass fuel, by opening the top lid for supplying fuel and so on.

It is important to control the temperature in gasifier to obtain the produced gas in steady condition (Fig. 3).

The temperature difference between the outlet and cooling gas after the process is over 100 °C. It is sufficient to heat water for both household use and heating (Fig. 4).

Another purpose of this research is to design the electricity and heat supply system for Mongolian farmers. Therefore, some additional parts, such as gas analyzer, thermostats, exhaust tower, cooling water drainage system and some valves will not be needed to install at the small-scale CHP (Combined Heat and Power) system.

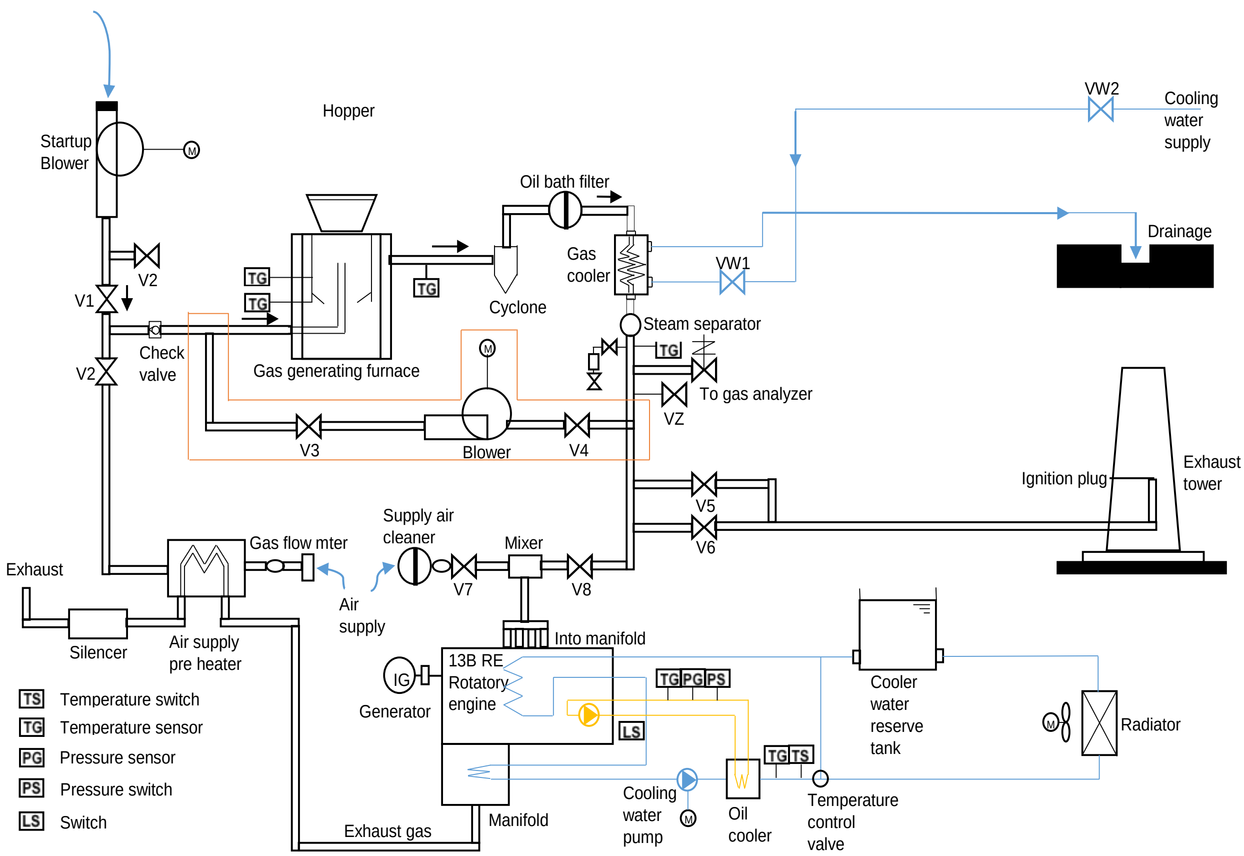

Fig. 1 Existing 20 kW gasification system.

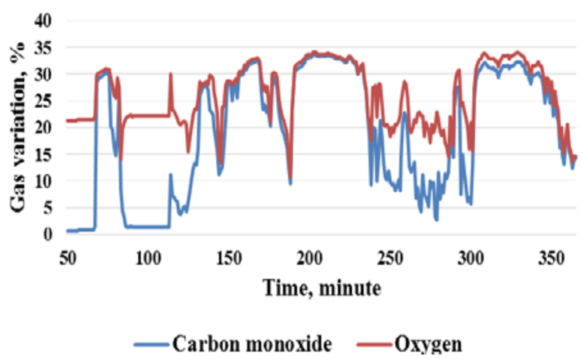

Fig. 2 Carbon monoxide CO and oxygen O_2.

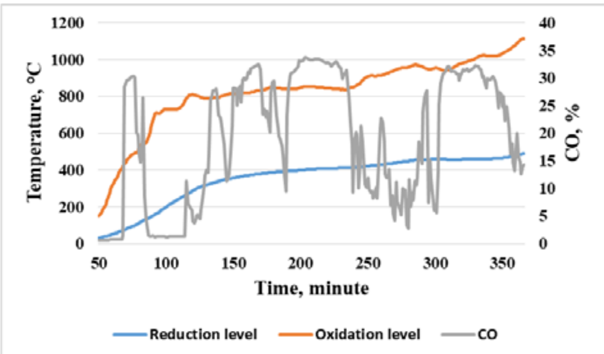

Fig. 3 Temperature at oxidation and reduction level and carbon monoxide production.

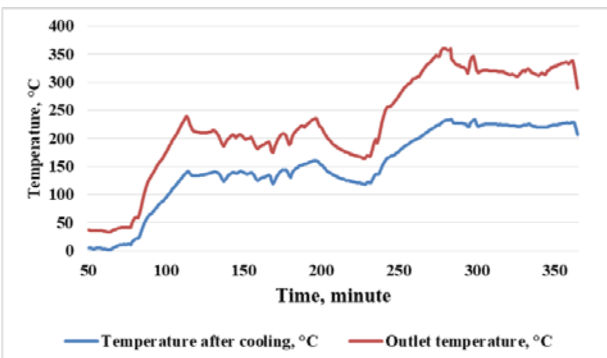

Fig. 4 Temperature of the exhaust gas.

3. The Biogas Digestion Research in Mongolia

The global biogas digestion practical experiments and researches were started in almost 4 centuries ago from the present era. But in Mongolia, it is started very recently, in 1983.

At the first stage, the small scale or 20 liters biogas digester which was heated by the electricity heater was used for the biogas digestion experiment in laboratory. After that, the biogas digester with the volume around 1.7-2.0 m^3 for nomadic families, 40 m^3 of heat insulation for the farms and 100 m^3 of heating system with heat insulation at the outer surface and the mixer system inside the digester were developed at the different sites of the country.

At the Gobi region which covers 10.8% of national territory, the ground temperature over 15 °C is recorded for over 120 days. As for the steppe which covers 37.5% of national territory, it was recorded for over 90 days.

Therefore, it is possible to produce biogas for 4-5 months from May to September in Mongolia by using psychrophilic type biogas generation system without any additional heating.

According to the research result, 2.5 m^3 of biogas was produced from 1 m^3 slurry in case of thermophile. And 1.5-2 m^3 of biogas was produced from mesophyll, 1 m^3 of biogas was produced from psychrophilic anaerobic digestion respectively. By the digester with volume of 30 m^3, 80-100 m^3/day of biogas could be produced from mesophyll (Figs. 5 and 6) [6].

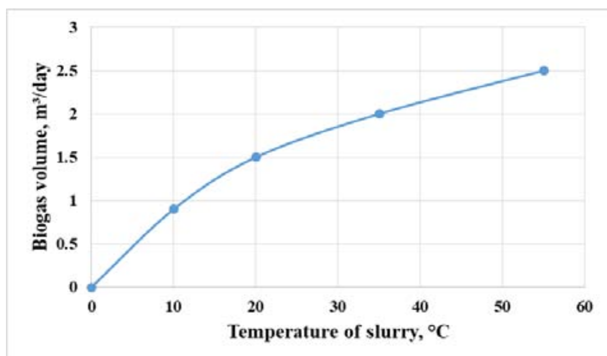

Fig. 5 Biogas production from slurry.

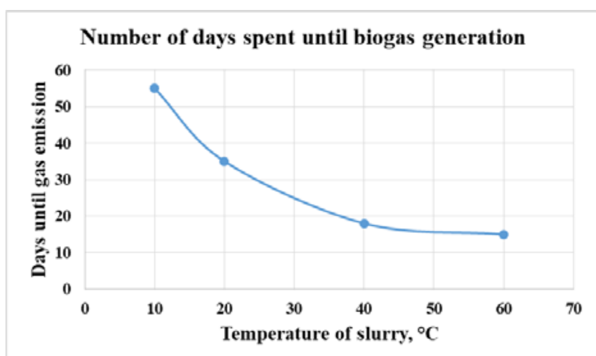

Fig. 6 Number of fermentation days.

4. The Research of Renewable Energy Resources in Mongolia

4.1 Wind Energy

According to the report of National Renewable Energy Laboratory (NREL), the potential area for utility-scale wind power development is estimated to be more than 160,000 km^2 in Mongolia. The windy area which is suitable for wind power development is around 10% of national territory. The possible installation capacity in national area is estimated to be over 1,100,000 MW which could generate 2.5 trillion kilowatt-hours (kWh) per year, in the case of installation of 7 MW/km^2 at wind potential area [7]. The potential reserve of wind energy in Mongolia is 836.8 billion kW/h, and it is usable for a period of 3.5-4.6 thousand hours per year. The average velocity of wind in the southeast part of the country is 4-5 m/s, which has wind energy reserve for over 100 W/m^2 [8].

The average and maximum wind speed curve were calculated based on the recorded data at CHINGIS KHAAN international airport. The monitoring height is 6 meters above the ground level (Fig. 7).

4.2 Solar Energy

In Mongolia, approximately 71% of the total land area receives solar intensity at a rate of 5.5-6.0 kWh/m^2 per day, and 2,900-3,000 sunshine hours per year. An additional 18% of land of the country receives intensity at the rate of 4.5-5.5 kWh/m^2 per day, and 2,600-2,900 sunshine hours per year [9]. In the research report introduced by the Ministry of Energy of Mongolia, the annual average amount of solar energy is 1,400 $kWh/m^2/y$. The total annual radiation intensity equals to 2.2×10^6 TW [10].

The radiation incident on a tilted surface (S_{module}) could be calculated by the equation:

$$S_{horiz} = S_{incid} * \sin(\alpha),\ S_{module} = S_{incid} * \sin(\alpha + \beta)$$

Elevation angle: $\alpha = 90 - \emptyset + \delta$

Declination angle:

$$\delta = -23.45 * \cos\left(\frac{360}{365}\right) * (d + 10)$$

where, $\emptyset$ = latitude, β = tilt angle, d = day of year.

The solar radiation near Ulaanbaatar city was calculated by using the abovementioned equations and summarized in the table below (Table 2).

Table 2 Solar radiation near Ulaanbaatar city.

Tilted angles of the module at the latitude 45 degree of north hemisphere	0	30	45	60	75	90
Solar radiation near Ulaanbaatar per square meter year, kWh/m2/year	1502.9	2434.4	2665.0	2714.2	2578.6	2267.5

According to the calculation, the annual power generation of the fixed PV module at 60 degrees was the largest one for Ulaanbaatar city or near to the north 45th parallel (Fig. 8). Generally, the most PV modules were fixed at 60 degrees in Mongolia.

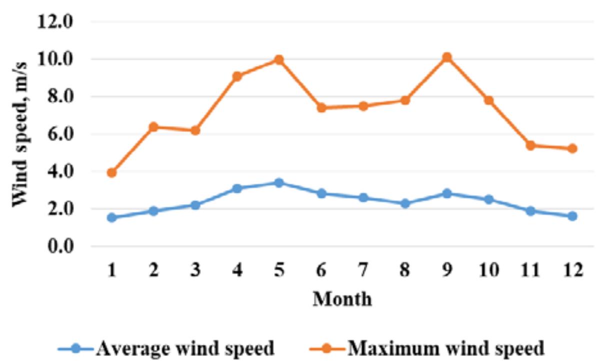

Fig. 7 Monthly average and maximum wind speed near Ulaanbaatar city.

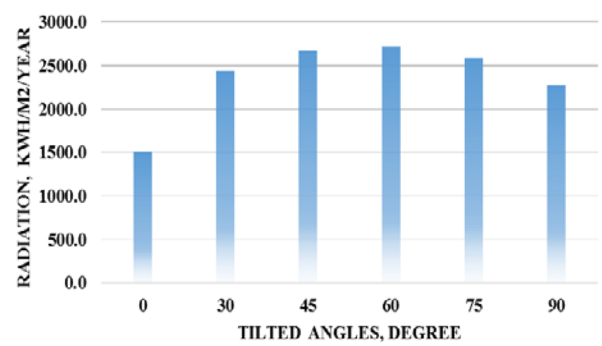

Fig. 8 Solar radiation on tilted surface.

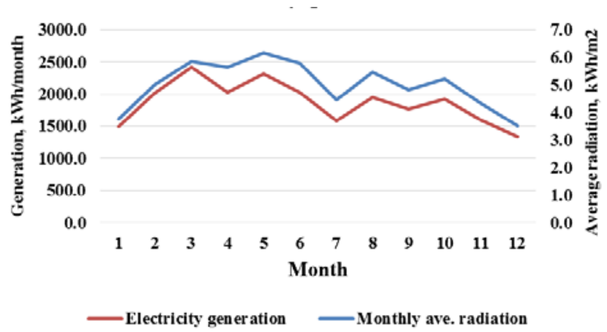

Fig. 9 Energy output of 450 kW solar PV plant.

The energy output of July was lower than that of June. At the 45 degrees inclined radiation (4.47 kWh/m^2) of July was lower than that of horizontal line (5.08 kWh/m^2) in the Fig. 9.

4.3. The Research of Biomass Energy Resource

According to the research result and statistic number of livestock, the biomass production is estimated to be 114.4 billion tons per year. Therefore, it will be able to produce 3,500.0-4,000.0 billion m^3 biogas per year in Mongolia (Tables 3 and 4).

Feedlot cattle could generate manure about 5-6% of their body weight each day, and roughly a dry mass of 5.5 kg per animal per day. Full-grown milking cows could produce 7-8% of their body weight as manure per day, roughly a dry mass of 7.3 kg per animal per day [11].

Table 3 Number of livestock in Mongolia.

No.	Livestock	Number (2019)
1	Horse	4,214,820.00
2	Cattle	4,753,190.00
3	Camel	472,380.00
4	Sheep	32,267,270.00
5	Goat	29,261,660.00
Total		70,969,320.00

Table 4 Volume of waste of cattle in Mongolia.

Cattle		Waste per day, kg		
		Urine	Manure	Total
Calf	1-3 months	2.5	5	7.5
	4-6 months	4	10	14
	7-12 months	12	14	26
	Over 12 months	12	23	35
Cow		20	35	55
Bull		10	30	40

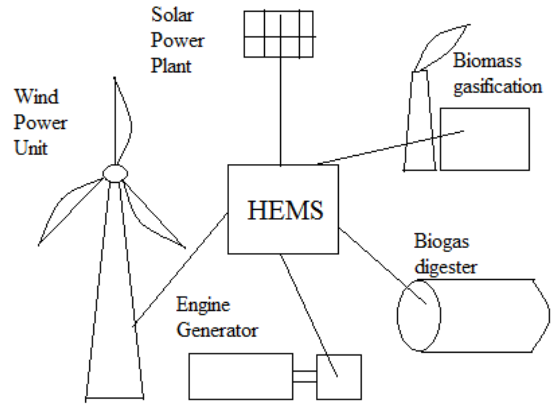

Fig. 10 Smart hybrid system (5-20 kW).

The manure extraction from a goat that weights 20-40 kg is approximately 0.32-0.625 kg per a day, equivalent to about 0.1 - 0.2 tons per year [12].

The engine would consume 2.39 m^3 biogas to produce 1 kWh, while if in small scale situations with an efficiency of 25% this is 0.66 m^3. [13]. It means that 1.5-1.6 TWh electricity could be produced per year by using the biogas at the farms in Mongolia.

5. The Electricity and Heat Generation Smart Hybrid System for Farmers

The capacity of smart hybrid system for electricity and heat generation will be depended on the demand of the farms. The practical power demand of the farmer is around 5-20 kW depending on the number of herder family. The smart hybrid system consists of: (1) biomass gasification, (2) biogas digester, (3) solar PV, (4) wind generator. The biomass gasification unit, biogas digester, and engine-generator unit are needed to be installed in the building and ambient temperature in this building should be kept over 5 °C even in winter.

The biomass gasification could be used from November to May while the biogas digester could be used from June to October. The biomass gasification could be used for heat supply of the farm during winter. The engine generator could be operated by syngas and petrol. The biogas and petrol could be stored in the tank separately.

The smart control unit or home energy management system (HEMS) will control the operation of this system.

The general diagram of smart hybrid system is shown in Fig. 10.

6. Conclusions

In Mongolia, the PV and wind power sources could be used mainly for the power supply while biomass and biogas sources could be used for both power and heat supply of the farms. The biomass gasification could be used as like as main heat generator during winter for the farms.

The tilt angle of the fixed PV module should be adjusted between 45 to 60 degrees in Mongolia.

The HEMS could automatically control and drive the operation of the power generators in this smart hybrid system.

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