Design and Implementation of a New-energy Self-purification Device for Domestic Sewage

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Abstract: The self-purification MBR system for domestic sewage is commonly used in living areas, scenic spots, and industrial sites, for remote areas and other regions where energy supply is inconvenient. The new energy system provides energy to the sewage treatment system, and achieves remote monitoring, which is of substantial significance for saving energy to reduce pollution. In this paper, three modes of power generation, namely, photovoltaic, wind and temperature difference, are employed for domestic sewage purification systems, and a reasonable energy supply and energy control strategy is proposed according to the conventional water treatment; and then a new-energy self-purification system for domestic sewage is designed and experimented with supplying and consuming quantity, tracking the system-consumed energy and water quality data for one year, so as to present that the equipment has good application prospects.

1. Introduction

At present, as China’s energy constraints continue to intensify and manufacturing industries develop, wastewater from industrial, tourist, medical sectors and the like has been impacting ecology and environment, which is of growing importance for regions and the whole society. After China issues its “30·60” decarbonization goal, a goal to hit peak emissions by 2030 and carbon neutrality by 2060, and along with the development of solar energy, wind energy and other new energy technologies, it is necessary to make comprehensive use of diverse new energy sources to develop a reasonable energy solution to problems in energy operations of small-scale sewage treatment systems, reduce energy consumption, and solve the difficulties of electrical energy access.¹,²

In this paper, the domestic wastewater treatment system is applied in a tourist area in Ulanqab, Inner Mongoli. The design and analysis of the energy self-supply small-scale wastewater treatment system is conducted to explore the application of multi-energy complementary solutions in the small-scale wastewater treatment system, which could be taken as a reference for the promotion of new energy in the sewage treatment systems.

2. Project Overview

In this project, in a tourist attraction where 1,000 people travel and 40 people inhabit every day on average, we design a 12-ton small domestic wastewater treatment system according to the estimated 50L of wastewater generated per person per day and 10L of wastewater generated for touring. The energy to the system is supplied by the wind power generation system and photovoltaic power generation system, with no external power supply. At the same time, the discharge water is used for
self-cleaning the external surface of the system and the photovoltaic modules.

3. System Composition and Principle
The small sewage treatment system with energy self supplied mainly consists of an MBR integrated water purification system, an energy supply system and an energy management (see Figure 1). The energy supply system in it is mainly composed of power generation systems based on photovoltaic, wind and temperature difference.

![System structure diagram](image)

Its operation principle is that photovoltaic modules, wind turbines and thermoelectric modules furnish electrical energy for the water treatment equipment in a highly efficient and complementary manner. Through the energy management system, the energy-supply side of the system is dynamically matched to the energy-consumption side, and the energy storage system provides electrical energy to the water treatment equipment in the MBR system.

4. System Energy Structure and Control Strategy
Due to the significant intermittency problem of wind energy, solar energy and thermoelectric power are used to achieve the complementarity \(^3\). The system in this paper is designed in Ulanqab, Inner Mongolia, which has a mid-temperate continental monsoon climate, and where solar radiation and wind energy could compensate each other in winter and in summer. The main components of the system include wind turbines, solar PV modules, thermoelectric modules, batteries, controllers, inverters, loads and other parts. The control part can control the charging, storing, and discharging of energy according to changes in the three said energy sources, the energy storage mechanism, and the load. In addition, the system can intelligently adjust the energy supply and equipment operation processing mode according to the amount of water in the water treatment system and external temperature changes, so that the system can run continuously, stably, and reliably.

4.1 System Design
The equipment is 2.5m high, with an upper surface area of 13 square meters (2m*6.5m) and a surface PV module power-generation capacity of 2.22KW. The wall area inside the south side is 16.25 square meters (2.5*6.5), ON which 8,000 TEG1-127096b t thermoelectric modules can be installed, with a maximum power-generation capacity of 24KW. The engineering design parameters are shown in Table 1.
4.2 System Power Consumption Estimates

The size of boxes in sewage treatment system is 6.5-m long, 2-m wide and 2-m high, small sewage system would consume 4 kWh/day for treating every ton of sewage, and hence the daily power consumption is about 24 kWh. With six 370W photovoltaic modules, whose power generation capacity is 2.22 kW, installed according to the best tilt angle of 39°, and calculated according to NASA data analysis of the average sunshine duration of 4.55 h [4], then the daily power generation capacity is about 8 kWh. With small wind turbine of 3kw horizontal axis, calculated according to the wind speed which is the start-up speed for power generation, the local climate data regarding winds and fan test data within a year, daily average power generation in the wind power system is about 40 kWh. Therefore, it can satisfy the daily power consumption of 12 kWh within sewage treatment system. Tilt angles in power generation and wind data are shown in Figure 2.

4.3 Control Strategy in Energy System

During the working process of the system, though the battery packs attain a saturation charge, the

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**Table 1 System parameter**

| System parameters                                      | Values                  |
|--------------------------------------------------------|-------------------------|
| Outdoor temperature of the sewage treatment system     | -25~40°C                |
| Average annual sunshine hours                          | 4.55h                   |
| Optimal tilt angle for PV is                           | 39°                     |
| Days with wind class above 2 per year                  | 284 days                |
| Equipment power                                        | 3KW                     |
| Box dimensions for sewage treatment system (L*W*H)     | 6.5m*2m*2.5m            |
| Wind turbine power                                     | 3kw*1                   |
| Size/number of PV modules                              | 1750mm*1038mm/6         |
| Total PV module power                                  | 2.22kw                  |
| Fan height                                             | 6m                      |
| Max. output power/size of thermoelectric modules       | 3.5W/40mm*40mm          |

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**Fig. 2 NASA data statistics of Ulanqab, Inner Mongolia**

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4.3 Control Strategy in Energy System

During the working process of the system, though the battery packs attain a saturation charge, the
priority in use is given to external energy supply, if the energy supply is insufficient, the electrical energy from the battery components would be then utilized\(^5\)\(^6\).

The default setting in the system control center allows the energy system (wind, light, temperature difference) to supply power directly to the load. To ensure normal operations of the system, the average power of the energy system is configured to be much greater than the average power consumed by the load. The system control can switch the different working modes responsible according to the state of the battery. The control strategy of the energy system is shown in Table 2.

### Table 2 Control strategy of energy system

| No. | Does the power generation system generate electricity | Battery capacity | Control centre signal to charge the load cell | Control centre signal from energy system to charge battery | Load state |
|-----|-----------------------------------------------------|------------------|------------------------------------------|-------------------------------------------------|------------|
| 1   | Yes                                                 | 100%             | Off                                      | Off                                             | The load works normally, which is charged directly by the power generation system |
| 2   | No                                                  | >40%             | On                                       | Off                                             | The load works normally, which is charged directly by the battery bank |
| 3   | No                                                  | >40%             | On                                       | Off                                             | The load operation mode is adjusted, with the fan started in low-frequency operation mode |
| 4   | No                                                  | >20%             | On                                       | Off                                             | The load operation mode is adjusted, with the fan started in low-frequency operation mode as well as the conditioning tank and the hydrolysis acidification pump shut off |
| 5   | No                                                  | <20%             | On                                       | Off                                             | Only low-frequency operation of the turbine is ensured until the energy system is restored to 100% power |
| 6   | Yes                                                 | <50%             | On                                       | On                                              | The power generation system functions gradually; one should first check the battery level, then below 60%, he or she should only ensure low-frequency operation of the turbine until the energy system is back to 100% power |

5. Analysis of System Operation

This paper selected October 5, 2020 featuring meteorological conditions in the Ulanqab, and tracked the power generation data of each power generation unit for 8 hours. It obtains the following results: the best power-generation efficiency of solar energy is 3 kWh during 11:00-12:00; the best power generation efficiency of wind power generation system is during 12:00-13:00; the power generation per unit hour is 4.1 kWh; the lowest efficiency of energy system is during 8:00-9:00, with a total generation sum in the system of 4.1 kWh. Tracking the water treatment volume, this paper unveils that the peak of water treatment occurs during this time duration, when the system based on the energy control strategy fulfills the MBR water treatment and tracks COD, ammonia nitrogen, total phosphorus and other water treatment parameters which need to meet the standard\(^7\). The system is powered by the battery once within an eight-hour operation, and the power supply system could meet the external load and operate stably during the dynamic changes in load.

![Fig.3 Statistics of power generation by the energy system on October 5th](image)
According to indicators regarding the energy generation and water treatment in the system in April, two phases during the dates from 1st to 2nd and from 16th to 18th are continuous cloudy days, so wind energy input is insufficient and the system power generation is lower than the system power consumption. However, the energy storage configuration makes it possible to support energy consumption within five days with no wind resources or no sunshine, and then energy would be compensated in an appropriate amount according to the system control strategy, followed by a test of water treatment indicators, which demonstrates that water discharge indicators in the system meet the discharge requirements.
Through the actual operations and data collection analyses of this case, the annual average daily power generation of the system is 47 kWh, and the annual daily power consumption is 24 kWh on average, with a load-to-supply ratio of 47:24, which can fully ensure the stable operation of the system under special circumstances. The application of thermoelectric generation and other new energy technologies to the system is not only a powerful supplement to wind or solar power generation systems, but also a remedy for the influence of the unstable wind or solar energy on the stability of the system operations\(^8\).

6. Conclusion
China’s wind resources rank third in the world, while western China and Inner Mongolia are among the top ten regions in the world with the most profound sunlight, which are very suitable for the promotion and application of multi-power generation technology with wind-solar complementary energies. Along with the rapid technological development of wind turbines and photovoltaic modules in China, the construction cost of wind-solar systems has been decreasing, and the cost-recovery cycle of the systems shortened\(^9\). The multi-energy self-supplied small-scale wastewater treatment system not only enables “zero cost, zero carbon emission”, but also has outstanding economic and promotional values.

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