Design and analysis of hybrid domestic gas supply system with biomass energy and hydrocarbons

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Abstract: A new gas supply system for residents was designed, taking puleyuan village as the research object. Aiming at the rural areas with abundant biomass energy and considering the seasonal difference of gas supply to residents, the gas supply system with biomass gasification coupled with hydrocarbons was used. Through the analysis of the system design principle, the calculation of combustible mixture property and the numerical calculation of energy conversion process, the energy efficiency design of the system was analyzed and optimized in this paper. At the same time, the system was evaluated from the economic perspective of energy conservation and emission reduction, compared with those of traditional fossil energy heating. The results showed that the gas supply system could bring considerable economic and environmental benefits, and it was feasible and expansible to implement in the rural areas in the north of China and the southern areas where winter heating was needed.

1. Introduction

There is plenty of biomass energy to be exploited in rural areas of China, which is a kind of economical and applicable clean heating mode as far as possible to replace the bulk coal. Mu Xianzhong summarized the development of rural biomass energy in China from four aspects: potential evaluation, technology update, economic benefit and environmental benefit. The progress of biomass energy utilization technology is conducive to the promotion of energy-oriented projects, and it is also an important way for the efficient utilization of resources, the optimization of energy structure, and the promotion of energy conservation and emission reduction.[1] There are many conversion technologies for biomass energy, and gasification technology is one of them. Biomass gasification is an effective way to realize the distributed development and utilization of biomass and the disposal of combustible solid waste due to its wide use and strong adaptability of raw materials and scale. It can partly replace fossil energy, promote energy conservation and emission reduction, and help realize sustainable development[2-3].

However, the residential gas supply should be designed according to the obvious seasonal difference. Therefore, the gas supply system of rural residents needs to design the gas replenishment system, and the C5 light hydrocarbon fuel is the preferred choice. C5 light hydrocarbon fuel is pentane as the main component of the fuel type. According to GB17930-2016 "automotive gasoline" the latest provisions, gasoline distillation range from the original 30°C-200°C adjusted to 60°C-200°C [4], therefore, the lower boiling point of pentane and other carbon hydrocarbons are no longer used in gasoline products[3]. Therefore, gas supply system has a wide application space, by the biomass energy coupling with C5 light hydrocarbon fuel.
2. The system design

The design of the system is divided into three parts: main system, supplementary system and collaborative coupling system, as Figure 1.

2.1 Main system design

The main system is the important part of the gas supply system. It is introduced from two aspects: preparation of raw materials and biomass gasification.

1). Preparation of raw materials. Biomass raw materials after the initial treatment such as drying into the biomass warehouse for storage. Starting the system, the fluidized bed gasifier preheats the system. Biomass is transported from the warehouse to the dryer for moisture separation. The heat used to dry biomass comes from part of the heat used to supply hot water after the system runs smoothly. After that, it enters into the crusher to prepare the raw materials for the biomass gasifier, and then cuts the raw materials into millimeter-sized particles and stores them in the storage.

2). Biomass gasification. The finished raw materials are fed into the fluidized bed gasifier for biomass gasification chemical reaction, and the readily available air is used as the gasifier. The reaction process includes drying, pyrolysis, reduction and oxidation. Fluidized bed gasifier has higher requirements for raw materials, so it is necessary to dry and break the biomass raw materials in the preparation stage. However, the gasification efficiency of fluidized bed gasifier is high, and the fault handling is easy and the maintenance cost is low, so it brings convenience for the follow-up equipment maintenance. The slag from gasifier is used as fertilizer to return to the field.

2.2 Supplementary system design

The fuel gas replenishment system is mainly composed of carbon storage tank, vaporizer and mixer. The local biomass is insufficient to supply gas to all the residents of the village, especially during the heating season. Therefore, in order to make up for this deficiency, the system designs a supplementary gas system, which uses the remaining C5 light hydrocarbon gas from the refinery petrochemical plant to mix with biomass gasification gas after vaporization for gas supply. The boiling point of C5 light hydrocarbon gas is about 36℃, which is a liquid state under normal conditions. Compared with natural gas, C5 light hydrocarbon fuel transportation is more convenient, and vaporization requires less heat, so the use of C5 light hydrocarbon fuel as fuel in the system of fuel supplement design has obvious advantages. C5 light hydrocarbon gas gets heat in the vaporizer and changes from liquid to gas. External cold water is pumped into the wall of the gasifier for heating. After obtaining heat, the hot water is transferred into the vaporizer, so as to convert the C5 light hydrocarbon into a gaseous state for better fuel gas replenishment. The hot water which has been provided with heat in the vaporizer enters the gasification gas cooler, which is heated by the high temperature gasification gas at 800℃, and converted into "hot water supply" which can be used by residents or for other purposes.

2.3 Collaborative coupling system design

The biomass gasification gas output from the main system is cooled by the air preheater and purified by the purifier, and then mixed with C5 light hydrocarbon gas by the mixer. The C5 light hydrocarbon gas is vaporized by the vaporizer and then enters the mixer through a short distance transmission pipeline. The two combustible gases are mixed according to the results of heat calculation to supply residential gas.
3. System feasibility analysis

In this gas supply system, the biomass gasifier with appropriate capacity can be selected to meet the gasification requirements through the biomass yield of the target village. The evaporative carburetor is adopted for C5 gasification, the pentane steam vaporized is not easy to condense, and the heat source of vaporization comes from the hot water about 70℃ at the outlet of the water wall of the gasifier.

3.1 Physical property analysis of combustible gas mixture

According to gas-related standards, GB 50028-2006 urban gas design code [5] requires that the low calorific value of gas should not be less than 10MJ/m3. Under the conditions of pressure and temperature of gas transmission, the dew point temperature should be 5℃ lower than the lowest ambient temperature. The carbon monoxide content in the gas shall not exceed 20%. Therefore, based on Puleyuan village of the actual situation, the mixing proportion of biomass gasification gas and light hydrocarbon mixture ratio is 39:1 by calculation. It shows the proportion or material gasification gas and light hydrocarbon mixture is safe, no condensation, and can meet the needs of the local actual situation, has feasibility in technology perspective. The physical property parameters under this ratio are shown in Table 1.

| Density (kg/m³) | Net calorific value (MJ/m³) | Wobbe number (MJ/m³) | Dew point (℃) | Lower explosive limit (%) | Upper explosive limit (%) |
|-----------------|----------------------------|----------------------|---------------|--------------------------|--------------------------|
| Mixture         | 1.1181                     | 9.7925               | 10.302        | 41.4                     | 7.73                     | 22.50                   |

3.2 System heat balance balance calculation

The systematic research object is pule yuan village, dongfeng town, longxian county, baoji city, shaanxi province (hereinafter referred to as pule yuan village). There are 450 families in the village, with more than 2000 people. The agricultural area is 4000 mu. Therefore the annual quantity of heat required is 2.21×10¹⁰kJ during the heating season and 2.13×10⁹kJ during other seasons.

The calorific value of gas is ideal when the biomass moisture content of circulating fluidized bed gasifier is controlled at 10-15%. The gasification efficiency can reach over 65% stably, and the gas
rate of this design is 70%\cite{6-7}. If ethane as the main hydrocarbon composition is calculated, according to the principle of material balance and carbon balance to calculate before and after gasification gas supply of the required value, i.e. an equal amount of carbon element before and after gasification principle, biomass gasification and gas is calculated as $2.268 \times 10^6 \text{ m}^3$. It is indicated that the gasification gas is needed $2.07 \times 10^6 \text{ m}^3$ during the heating season, which is $17240 \text{ m}^3 / \text{ d}$.

According to the energy conservation principle, the calculation parameters of the main equipment are shown in the following table:

|                         | Gasification gas cooler | Air preheater |
|-------------------------|-------------------------|---------------|
| Inlet temperature(.hot) ℃ | 800                     | 256           |
| Outlet temperature(.hot) ℃ | 256                     | 150           |
| Flow rate m³/ day        | 17240                   | 17240         |
| Inlet temperature(cool) ℃ | 69 (water)              | 20 (air)      |
| Outlet temperature(cool) ℃ | 90                      | 200           |
| Flow rate (cool) kg/s    | 1.713                   | 0.1215        |

4. Economic analysis

Assuming that all kinds of energy can be selected without considering the actual situation of the village, the comparison of energy types is as follows\cite{8-10}:

| Energy types       | Calorific value | Efficiency | Equivalent heat value | Annual demand | Unit price | Total price (yuan) |
|--------------------|-----------------|------------|-----------------------|---------------|------------|--------------------|
| Natural gas        | 35000 kJ/m³     | 92%        | 32200 kJ/m³           | 751552.8 m³   | 2.5 yuan/m³ | 1878882            |
| Liquefied petroleum gas | 43000 kJ/m³ | 85%        | 36500 kJ/m³           | 663013.7 m³   | 3.5 yuan/m³ | 2320548            |
| Coal               | 29300 kJ/kg     | 60%        | 17580 kJ/kg           | 1376564 kg    | 1480 yuan/t | 2037315            |
| Coal gas           | 12500 kJ/m³     | 85%        | 10625 kJ/m³           | 2277647 m³    | 1 yuan/m³  | 2277647            |
| Electricity        | 3600 kJ/degree  | 92%        | 3312 kJ/degree        | 7306763 degrees | 0.6 yuan/degree | 4384058         |
| Biogas             | 17937 kJ/m³     | 85%        | 15246.5 kJ/m³        | 1587250 m³    | 1.5 yuan/m³ | 2380874            |
| The mixture        | 9792.5 kJ/m³    | 85%        | 8323.6 kJ/m³         | 2907385 m³    | 0.5 yuan/m³ | 1453692            |

In view of the coupling of biomass carbon five pair of liquid gas supply system belong to the government capital injection of public welfare projects, but individuals to participate in the investment operation. Considering the stakeholders on the basis of unification of economic benefit and user benefit, reference cost to market acceptance of the other energy prices and the user of the gas station gas prices below current city natural gas prices, calculated at 0.5 yuan/m³. As can be seen from the above table, the efficiency of natural gas and electricity is the highest, the efficiency of coal is the lowest, and the efficiency of other combustible gases is in the middle. Natural gas is the most efficient energy source for different energy types. The easiest and fastest way to use electricity is expensive. Under the other energy utilization methods, the annual cost of the village is similar, that is, the economic benefits are similar, but the environmental benefits are different. For the gas provided by the gas supply station, the economic burden for users is greatly reduced, and on the premise of no gas and
other efficient fuels, the living standard of residents is improved by new mixture gas supply, which will produce great social benefits.

5. Conclusion
In this paper a new gas supply system for residents was designed, coupling with biomass energy and C5 light hydrocarbon. The design of this system not only solves the problem of waste of biomass, but also reduces environmental pollution and plays a role on energy saving and environmental protection. The properties of the mixed gas are studied and calculated, and the mixing proportion is confirmed based on the safety and economy. The gas supply system is technically and economically feasible, has good economic benefit and environmental benefit, energy conservation, environmental protection, suitable for use in rural areas.

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References
[1] Mu Xianzhong, Yu Shushi, Xu Peng. Research review of rural biomass energy utilization [J]. Modern industrial economy and informatization, 2008,38 (03): 9-13 + 15.
[2] Liu Huacai, Wu Chuangzhi, Xie Jianjun, Huang Yanqin, Lang Lin, Yang Wenshen, Yin xuliu. Analysis on biomass gasification technology and industrial development [J]. Advances in new energy, 209,7 (01): 1-12.
[3] Niu Haitao. Research on application of biomass energy technology [J]. Biochemistry, 2017,3 (04): 84-86 + 106.
[4] GB17930-2016, automotive gasoline [S].
[5] GB 50028-2006, ministry of construction, PRC. Code for urban gas design [S].
[6] Ren xiaojuan. Introduction to petroleum industry[M]. Beijing: China petrochemical press, 2007
[7] Zhang Jiaojing, Song Jun, Gao Yanhua. Introduction to petrochemical products[M]. Beijing petroleum industry press, 2011.09
[8] GB/t12206-2006, technical convergence unit of urban gas standard of the ministry of construction. Determination method of calorific value and relative density of urban gas [S].
[9] CJ/T 341-2010, urban gas standard technical committee, ministry of housing and urban-rural development. Mixed-air light hydrocarbon gas [S].
[10] Fan Yuguang, Wei Jia, Zhang Shuo, Shi Dongyu. Research on density calculation method of mixed air light hydrocarbon gas [J]. Petroleum industry technical supervision, 2008,34 (5) : 23-24.