

## Simulation of High Pressure Water Washing and Purification of Biogas

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**Abstract.** Purification of biogas by water washing method is widely used in large and medium scale biogas projects because of its non-pollution and low cost. In this paper, the purification effect of Plus Aspen chemical process simulation software was used to simulate the purification effect of biogas washing tower with 120m<sup>3</sup> per hour. This paper studied the effects of different pressure, temperature and absorption liquid flow rate (water gas ratio) on the purification of biogas. The simulation results show that the optimum operating parameters of the absorber are: pressure 0.8Mpa, temperature 10°C, absorption liquid flow (water vapor ratio) 1.1m<sup>3</sup>/h and the material composition of the inlet and outlet of the absorber under the optimum operating parameters are given. This paper not only laid the foundation for the later experiment, but also provided a reference for the design and optimization of the equipment for the purification of the biogas washing equipment.

### Introduction

With the increasing depletion of fossil fuels, more and more attention is paid to the research and development of renewable energy in various countries[1]. Biogas is a kind of high quality renewable energy. It can come from the anaerobic fermentation of straw, domestic waste and agricultural waste[2,3]. The main components of biogas are CO<sub>2</sub> (about 44%), CH<sub>4</sub> (about 55%) and a small amount of H<sub>2</sub>O, H<sub>2</sub>S[1]. Biogas has long been the used in the northern region of China. However, due to the high content of carbon dioxide in the biogas, the low efficiency of the direct use of heat value is poor. It is a waste of biogas resource and also restricts the development of the project of biogas. Large and medium sized biogas projects in many countries will purify the output biogas, and when the concentration of CH<sub>4</sub> reached 95% or more, it can be quite a natural gas, which is an ideal substitute for natural gas[4]. Purified biogas can be incorporated into a gas pipeline, as a vehicle fuel or used for electricity generation.

Developed countries in Europe and America have become mature in technology and equipment of biogas after nearly twenty years of development. Biogas purification contains water washing, membrane separation and pressure swing adsorption method, organic solvent absorption. Because water purification method has the advantage of non-pollution and low cost, it becomes a commonly used method in large and medium-sized biogas projects [5,6]. The development of biogas engineering in China is slow, and there is a big gap between European and American countries. In spite of the increasing investment in this area in recent years, it has not made significant achievements.

Biogas purification is a key step in the whole biogas project, this paper will rely on a powerful chemical simulation software Aspen Plus to simulate the process of high pressure water washing purification. There are many factors affecting the water purification effect of biogas. To get the optimal operating conditions, effects of temperature, pressure and liquid flow rate (water vapor ratio) three variables on the purification efficiency of biogas are investigated in this paper. It supplies the foundation for the later washing biogas purification experiment.

## Purification Technology of Biogas by Water

The main components in biogas are  $\text{CH}_4$  and  $\text{CO}_2$ , these two gases are different in water solubility, the solubility of  $\text{CO}_2$  is far greater than the solubility of  $\text{CH}_4$  in water. Water washing method is carried out by using the difference of two kinds of gas solubility in water. There are many factors that affect the purification efficiency of biogas water washing method. Pressure, temperature and the flow rate of the absorption liquid (water / gas ratio) will result in the outcome. With the increase of water washing pressure,  $\text{CH}_4$  and  $\text{CO}_2$  solubility differences in water will be expanded,  $\text{CO}_2$  can be more dissolved in water. The temperature has great influence on the solubility of  $\text{CO}_2$  in water. The lower the temperature, the greater the solubility of  $\text{CO}_2$  in water is. Water vapor ratio is also an important part of the washing process, good washing ratio not only can improve the efficiency of purification of methane gas, but also save energy[7]. If the design of gas washing purification equipment is reasonable, the operation parameters is proper, the concentration of  $\text{CH}_4$  in the biogas can reach more than 95%.

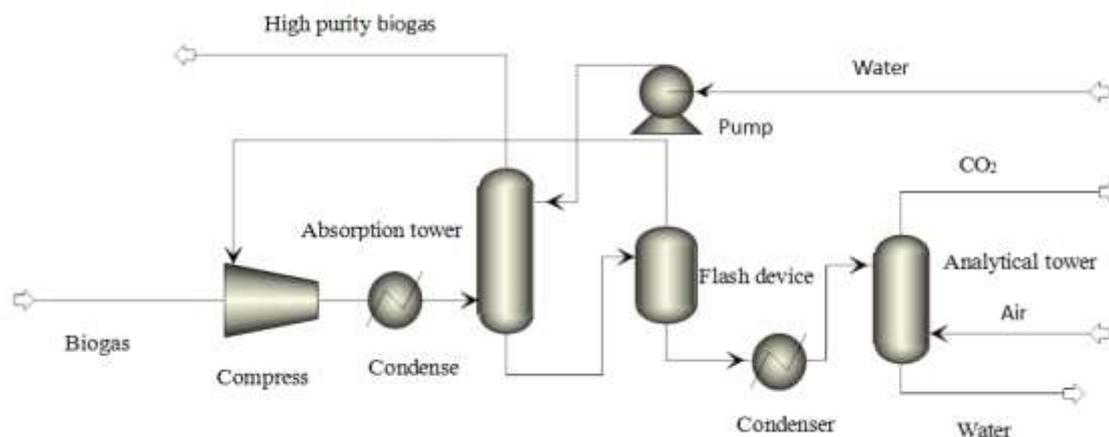


Figure 1. Flow chart of biogas purification process.

Gas washing purification process concludes absorption, flash, analysis of three parts (Figure 1)[8]. Anaerobic digestion biogas go through the compressor, and then enter the absorption towers from the bottom. Water flows enter the absorption towers from the top after it goes through the high-pressure water pump. Two flows countercurrent contact in Water absorption tower later, purified biogas outflows from the top of the tower. The rich liquid flows which dissolved  $\text{CO}_2$  enter the flash tower from the bottom of the tower, small amount of  $\text{CH}_4$  will be released when it goes through the flash tower. The outflow from the bottom of the flash tower will release  $\text{CO}_2$  when it goes through the desorption tower. The high purity biogas outflowing from the top of the absorption tower can be compressed and stored after the separation of gas and water.

## Simulation of Purification Process of Biogas

### Simulation Conditions

The purification and absorption tower of biogas is used in the process of chemical production, which has the advantages of high production capacity, high separation efficiency, low pressure loss, small liquid holdup and flexible operation flexibility. The simulation of the absorption tower height is 4m, the tower diameter is 0.35m, the maximum working pressure is 2Mpa, the filler is ceramic step ring packing and the stacking mode is the bulk. Simulated biogas composition is (volume fraction) 55% of  $\text{CH}_4$  and 45% of  $\text{CO}_2$ . It compressed from the compressor, and then enters the absorption tower from the bottom of absorption tower, the power is 7.5KW. Water flows enter the absorption towers from the top of the absorption tower, the pump power 3KW.  $\text{CH}_4$  concentration after treatment requires is not less than 95% which is meet natural gas  $\text{CH}_4$  concentration standards. Table 1 shows the water purification biogas simulation parameter settings.

Table 1. Simulation parameters set.

Name	Numerical
Pressure	0.2~2Mpa
Temperature	0~25 °C
Treatment quantity	120m <sup>3</sup> /h
Clear water flow	0.6~1.5m <sup>3</sup> /h
Packing	Ceramic step ring packing(25mm)

## Simulation Method

Use the Plus Aspen to simulate, Plus Aspen is a large-scale general chemical process simulation software. Because it has a complete physical system, the majority of the world's chemical companies and researchers prefer to use it. Physical method and model selection are very important to the accuracy of the simulation results. The physical property of this model is NRTL, and the selection of the unit operation module is RadFrac. RadFrac module can be used in ordinary distillation, absorption, extraction and distillation, distillation, reactive distillation, three-phase distillation and other strict calculation. The RadFrac module is selected to calculate the non-equilibrium stage model, the condenser and the re-boiling device are selected and the gas liquid phase state is selected. The convergence method is the standard method. The diameter of the column is set to 350mm, the packing height is set to 2m, the choice of packing device is set to 25mm cascade ring. The water inputs from the top of the tower, gas inputs from the bottom of the tower, the two set contact countercurrent absorption, temperature, pressure and flow of two streams can be set. The effect of the purification of biogas can be obtained under different conditions. In this way, the optimum operating parameters of the equipment will be selected.

## Simulation Results and Analysis

### The Effect of Pressure on the Purification Efficiency of Biogas

The solubility and dissolution rate of CO<sub>2</sub> in water are affected by many factors, and the pressure is one of the most important factors. According to the theory of mass transfer, the higher the pressure, the greater the distance from the equilibrium line, the greater the driving force of CO<sub>2</sub> dissolved in water, the greater the solubility and dissolution rate. Besides, the CO<sub>2</sub> dissolution rate in water is also influenced by the ground area, on the basis of packing tower theory, when the tower pressure is increased, the contact area of gas-liquid two will be increased. The greater the contact area of the mass is, the higher the transfer rate is, CO<sub>2</sub> can also be quickly dissolved into water, so as to improve the concentration of the tower top product CH<sub>4</sub>. The simulation results are shown in figure 2.

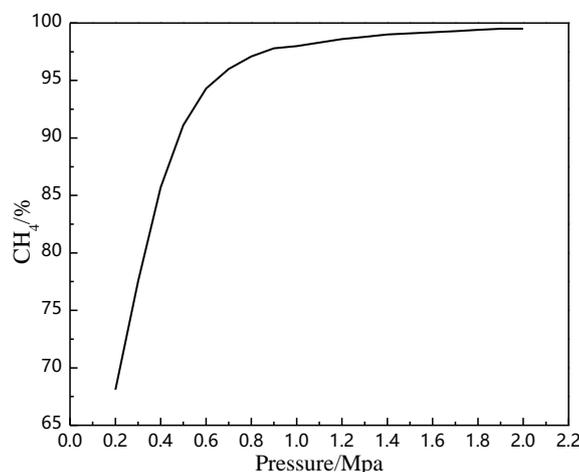


Figure 2. Simulation of the effect of biogas purification under different pressure.

The effect of the pressure on the purification of biogas is very significant, the higher the pressure is, the better the effect of washing will be. However, the high pressure brings more energy consumption, which is the problem of water washing has to be considered. It can be seen from the figure, with the increasing of pressure, the concentration of CH<sub>4</sub> was faster, and then leveled off. When the pressure reaches 0.8Mpa, the increase of the pressure effect on the concentration of CH<sub>4</sub> is very limited, so in the current size of the tower, the pressure of 0.8Mpa is a suitable operating pressure.

### Effect of Temperature on the Purification Efficiency of Biogas

Temperature affects the solubility of CO<sub>2</sub> in water, the Henry coefficient of mass transfer in water at different temperatures is also different, the lower the temperature, the more conducive to the absorption of water to CO<sub>2</sub>. The decreasing of temperature needs to consume more energy, and temperature can't be infinitely reduced. When the temperature is below 0 Centigrade, the absorption tower water is frozen. It leads to the equipment unable to work. Figure 3 shows the 0.8Mpa pressure situation, the simulation of the effect of water washing and biogas purification at different temperatures.

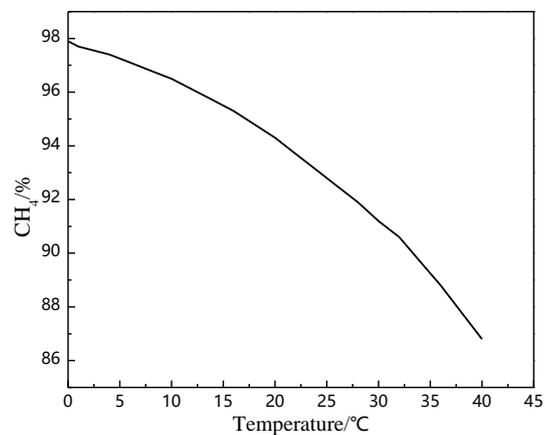


Figure 3. Simulation of the effect of biogas purification at different temperatures.

As can be seen from the figure, when the temperature is not higher than 10 °C degrees Celsius, the treatment effect can reach more than 95%. It meets the requirements of biogas purification.

### The Effect of Absorption Liquid Flow Rate (Water Vapor Ratio) on the Purification Efficiency of Biogas

The water washing process of biogas uses water as absorption liquid, gas and water counter current contact, in the process of contact with water to absorb the CO<sub>2</sub> in order to achieve the purpose of improving the concentration of CH<sub>4</sub> in biogas. The rate of CO<sub>2</sub> dissolved in water was related to the concentration of dissolved CO<sub>2</sub> in the water. When CO<sub>2</sub> concentration dissolved in water is lower, the operation line is further away from the equilibrium line, the rate of CO<sub>2</sub> transfer to water is faster, or the rate of CO<sub>2</sub> dissolution slower. When the gas flow rate is constant, increasing the flow of water (that is to change the water gas ratio) can accelerate the renewal rate of the absorption liquid, so as to reduce the average concentration of CO<sub>2</sub> in the water, increase the driving force of CO<sub>2</sub> to dissolve in water and improve the absorption rate of CO<sub>2</sub>[11]. Figure 4: simulation of the effect of water washing and biogas purification under different influent flow rate of pressure 0.8Mpa, temperature 10°C.

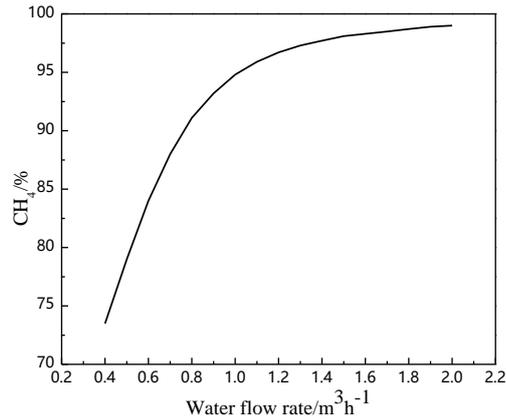


Figure 4. Simulation of the effect of biogas purification under different water flow rate.

As can be seen from the figure, in a certain condition, the effect of the flow rate of the absorption liquid on the purification efficiency of biogas is great. When the water flow rate is at 1.1m<sup>3</sup>/h, the CH<sub>4</sub> concentration of biogas can reach more than 95%. As the increasing of the flow of water, then CH<sub>4</sub> concentration change tends to be gentle and water resource will be wasted. Therefore, the most suitable operating parameters for this tower is: temperature 10 degrees Celsius, pressure 0.8Mpa, liquid flow rate of 1.1m<sup>3</sup>/h. Table 2 shows the composition of the inlet and outlet of the packed absorption tower under the operating conditions. Table 2 shows the composition of the inlet and outlet of the packed absorption tower when the operating conditions is given, and the loss of CH<sub>4</sub> in the water washing process no more than 1%.

Table 2. Packing absorption tower import and export logistics.

Project	Logistics composition (molar ratio)
Gas inlet	CO <sub>2</sub> 0.45 CH <sub>4</sub> 0.55
Gas outlet	CO <sub>2</sub> 0.039 CH <sub>4</sub> 0.959 H <sub>2</sub> O 0.002
Absorption liquid inlet	H <sub>2</sub> O 1
Absorption liquid outlet	H <sub>2</sub> O 0.96 CO <sub>2</sub> 0.034 CH <sub>4</sub> 0.006

## Summary

In this paper, the absorption tower of the water washing method and biogas purification are simulated in different force, temperature and liquid flow rate based on the Plus Aspen chemical process simulation software. The absorption tower diameter is 0.35m, height is 4m, packing device is 25mm cascade ring. According to the simulation results, the effect of pressure and liquid flow rate on the water washing effect is obvious. When the absorber pressure is 0.8Mpa, the gas flow rate is 120m<sup>3</sup>/h, the water flow rate 1.1m<sup>3</sup>/h and the temperature is 10°C degrees centigrade, the concentration of CH<sub>4</sub> in biogas can reach more than 95% and the loss of CH<sub>4</sub> is low. The process and results of simulation can not only provide the optimum operating conditions for the biogas washing test, but also provide the method and basis for the design and optimization to the same type of biogas washing absorption tower.

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## References

- [1] Ge Zheng, Quanguo Zhang, The research progress of biogas purification biological natural gas, Journal of Agricultural Engineering. 17(2013)1-8.

- [2] Wenwen Cui, Junfeng Liang, Current situation and problems of China's large-scale straw biogas project, Chinese Agricultural Bulletin. 11(2013)121-125.
- [3] Yi Li, Yuqiu Liu, Zhen Zhang, Corn straw and pig manure mixed anaerobic fermentation biogas production process optimization, Journal of Agricultural Engineering. 05(2014)185-192.
- [4] Liangwei Deng, Ziai Chen, Development status of Biogas Engineering in Europe, China Biogas. 05(2007)23-31.
- [5] Feng Dang, Yun Bi, Analysis of the current situation of large and medium sized biogas projects in Europe and Its Inspiration to China, China Biogas. 01(2014)79-83+89.
- [6] Hongchao Geng. Research on the equipment and technology for the purification of the biogas pressure water washing, Soochow University(2015).
- [7] Zhikui Wang. Principle of Chemical Engineering, Chemical Industry Press(2010).
- [8] Zhiyong Ma, Li Huang, Experimental study on the purification of methane by zeolite packing washing method, Journal of Solar Energy. 04(2013)718-722.
- [9] Chang Liu, Chunyan Ma, Simulation of high pressure water washing and purification process for large and medium scale biogas project, Renewable Energy. 07(2014)1028-1032.
- [10] Lanyi Sun. Chemical process simulation, Chemical Industry Press(2012).