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SHUAI ZOU[1,3]
KANGCHUN LI[2,3]
MINGYUAN DOU[1,3]
JING YANG[1,3]
QING FENG[1,3]
FUCHUAN HUANG[1,3]
LIN CHEN[1]

[1]School of Mechanical Engineering, Guangxi University, Nanning, Guangxi, China

[2]School of Chemistry & Chemical Engineering of Guangxi University, Nanning, Guangxi, China

[3]Guangxi Key Laboratory of Petrochemical Resource Processing and Process Intensification Technology, Guangxi University

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EXERGY ANALYSIS OF THE BIOGAS MULTISTAGE COMPRESSION PROCESS BASED ON ASPEN PLUS SIMULATION

Article Highlights

- It simulated and analyzed the exergy changes of the biogas multistage compression process by Aspen Plus
- The interstage cooling temperature affects the energy consumption of the whole compression process
- The exergy efficiency increased with the increase in the number of compression stages

Abstract

In this study, by taking the compression separation process of a biogas project as a research subject, a multistage compression process was simulated using Aspen Plus software. The exergy analysis of the biogas project under multistage compression and adiabatic or isothermal conditions was performed employing the thermodynamic principle. The results showed that the biogas exergy increased with pressure during the compression process and correspondently decreased in the interstage cooling process. Further, the compression series increased with the increase in efficiency, but the increase was gradual. The results of the example study of the four-stage compression process are as follows: the process exergy increased by ~83.07 kW, the process exergy efficiency was ~75.56%, and the recovery exergy potential was ~12.6 kW. In this study, the allocation of compression ratios and the selection of compression stages within the multistage compression process were analyzed by Aspen Plus was used to analyze., This analysis can ultimately help others design efficient multistage compression systems that reduce energy losses.

Keywords: Aspen Plus, biogas, exergy analysis, multistage compression.

As a part of clean energy, biogas is inexhaustible renewable energy. Biogas projects can solve the daily energy problems in rural areas, effectively deal with all kinds of organic waste, and produce efficient and harmless organic fertilizers [1]. Moreover, they play an active role in environmental protection, ecological improvements, energy security, etc. Thus, the Chinese government has significantly supported the biogas industry [2]. By the end of 2018, 108,059 biogas projects had been completed, more than 7,900 being large-scale biogas projects [3]. Moreover, under carbon neutrality, the supply of biomass gas energy has significantly increased [4]. As a form of high-quality renewable biomass energy, biogas is mainly composed of CH_4 (60%-70%) and CO_2 (28%-40%), and the remaining components are H_2S, N_2, NH_3, etc. [5,6]. Despite the efficiency of using biogas, the considerable amount of CO_2 in biogas decreases its calorific value and energy density and leads to the corrosion of its transportation pipelines. Therefore, biogas must be purified to remove CO_2 and other impurities and improve its use value [7]. Generally speaking, the sepa-

Correspondence: F. Huang, L. Chen, School of Mechanical Engineering, Guangxi University, Nanning, 533004, Guangxi, China.
E-mail: huangfuchuan@gxu.edu.cn; gxdxcl@163.com
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ration methods of CO_2 are the absorption method [8], membrane separation method [9,10], pressure swing adsorption method [11], and cryogenic separation method [12]. Cryogenic separation is a common method for CO_2 capture and separation. The principle is to use the liquefaction characteristics of CO_2 at 31 °C and 7.39 MPa or -59–30 °C and 0.47–7.22 MPa. The multistage compression and cooling of biogas make CO_2 liquefied, thus realizing the separation of CO_2 and CH_4. The technological process is as follows: dedusting, desulphurization, drying, multistage compression, CO_2 liquefaction separation, and storage. Biogas is treated by dedusting, desulphurization, and dehydration to prevent the impurities in the gas from corroding and damaging the compression equipment, pipes, and accessories [13]. The purified biogas enters multistage compression equipment when the temperature is lower than 31 °C. Then, the compressed biogas is cooled and liquefied by a condenser, and the CO_2 in the biogas is separated. The cryogenic separation method produces high-purity biological methane, and the separated high-purity liquid CO_2 can be used in other fields [14].

Xu *et al.* [15] proposed a new integrated method for CO_2 compression separation. Their research showed that the higher the initial pressure and initial CO_2 concentration in the mixture, the better the refrigeration cycle performance and the lower the energy consumption of the new integrated method. Using Aspen Hysys, Zhou *et al.* [16] simulated the low-temperature liquefaction process separating CO_2 gas from biogas. By changing the volume fractions of CH_4 and CO_2, the dew point and separation pressure ranges of biogas were obtained. At the same time, through experimental verification and simulation, a method for the industrial separation of CO_2 and purification of biogas was obtained. Li *et al.* [12] simulated a low-temperature biogas purification process using the Aspen Plus software. They analyzed the influences of pressure and temperature on the effect of the low-temperature purification process. Ahmed *et al.* [17] proposed an improved cryogenic separation for CO_2/CH_4 gas mixtures, and it could significantly reduce methane losses, energy consumption, and investment costs while ensuring the purity of methane and CO_2. These researches studied the whole process, but there is still no research on the compression step in the biogas purification process. Since the energy consumption in the compression process accounts for a large proportion of the total energy consumption, effectively improving the efficiency of the compression process is of great significance for reducing the energy consumption of the compression device. The efficiency of the isothermal and adiabatic compression process can be estimated using thermodynamic principles. The efficiency of the actual compression process is usually between isothermal and adiabatic compression. Aspen Plus [18] is a process simulation software integrating chemical engineering designs, dynamic simulations, and other calculations. It comprises a physical property database, a unit operation module, and a system implementation strategy. Generally, it can simulate various operation processes and single operation units. This study is based on an Aspen Plus simulation. The energy-saving potential of biogas' multistage compression separation process was analyzed using the exergy analysis method. A *p-V* diagram visually demonstrated the difference between the ideal isothermal and adiabatic compression. In addition, the effect of the number of compression stages on energy consumption was quantitatively revealed. Moreover, based on simulation data, the exergy change of biogas was analyzed, and its exergy recovery potential was discussed.

Exergy analysis of the biogas compression process

Simulation model of the polytropic compression process

Regarding the polytropic centrifugal compression process of biogas, Aspen Plus provides two thermodynamic calculation methods: the GPSA and ASME methods [19]. The ASME algorithm is aimed at real gas, so the condition of the ASME algorithm is more stringent than that of the GPSA algorithm. For a real gas, the polytropic coefficient (*n*) value of the polytropic compression process is uncertain, so a correction factor is introduced into the isentropic compression equation.

The calculation formula of the enthalpy change is as follows:

$$\Delta H = \frac{HEAD}{\eta_p} \tag{1}$$

$$HEAD = f\frac{np_1V_1}{n-1}\left[\left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}} - 1\right] \tag{2}$$

$$\eta_p\left(\frac{n-1}{n}\right) = \frac{k-1}{k} \tag{3}$$

$$f = \frac{n-1}{n}\frac{H_2 - H_1}{p_2V_2 - p_1V_1} \tag{4}$$

$$n = \ln\left(\frac{p_2}{p_1}\right) / \ln\left(\frac{V_1}{V_2}\right) \tag{5}$$

where ΔH is the molar enthalpy change, *HEAD* is the polytropic energy head, η_p is the polytropic efficiency, n is the polytropic coefficient, k is the specific heat capacity ratio of gas, f is the correction factor of the polytropic energy head, H_1 and H_2 are enthalpies of the initial and final states of the compression process, respectively, P_1 and P_2 are the gas pressures in the initial and final states respectively, and V_1 and V_2 are the molar volume flow rates of the initial and final states, respectively.

Exergy analysis of the compression process

According to the first and second laws of thermodynamics [20], energy is conserved during energy conversion and transmission, and the energy level decreases. Exergy (E_x) is the energy that can theoretically be converted into work to the maximum extent under certain conditions. When the system changes from any state (P, T) to the benchmark state (P_0, T_0) :

$$E_x = H - H_0 - T_0(S - S_0) \tag{6}$$

where H and S are the enthalpy and entropy of the fluid in a specific state, respectively, H_0 and S_0 are the enthalpy and entropy of the fluid in the reference state, and T_0 is the benchmark state temperature.

The enthalpy of the gas compression process is changed into:

$$dH = C_p dT + \left[V - T\left(\frac{\partial V}{\partial T}\right)_p \right] dp \tag{7}$$

The process entropy is changed into:

$$dS = C_p \frac{dT}{T} - \left(\frac{\partial V}{\partial T}\right)_p dp \tag{8}$$

It should be noted that:

$$S = C_p \ln T - R_g \ln p + C \tag{9}$$

When the initial state is isothermal in the final state, the gas entropy is changed into:

$$\Delta S = S_2 - S_1 = \Delta C_p \ln T + R_g \ln\left(\frac{p_1}{p_2}\right) \tag{10}$$

where C is the integral constant, and ΔC_p is the difference between the specific heat capacities of the final and initial states at constant pressure. When the gas is compressed and cooled, the initial and final states are isothermal, where ΔS<0 is the entropy reduction, the compressed gas works to the environment, and R_g is the gas constant.

According to the second law of thermodynamics, the exergy difference between the compressed gas in the initial and final states is taken as a target, and the exergy efficiency (η_x) is used to evaluate the effectiveness of the energy process. That is,

$$\eta_x = \frac{\Delta E_x}{W} = \frac{H_2 - H_1 - T_0(S_2 - S_1)}{W} \tag{11}$$

where W is the compression power of the multistage compressor.

Analysis of the biogas multistage compression process

Multistage compression process simulation

Taking the biogas project that the raw biogas is passed already through the pre-conditioning step with some non-major elements (traces) of nitrogen (N_2), water (H_2O), hydrogen sulfide (H_2S), and volatile organic gases (VOCs) have been removed. Therefore, a typical composition of 60% (mol) CH_4 and 40% (mol) CO_2 for the raw biogas fed to the proposed process is adopted in this work.

The four-stage compression separation process of purified biogas was chosen as a research subject, and the process diagram is shown in Fig. 1. First, the biogas is compressed to 525 kPa by the first-stage compressor and cooled to 25 °C by the first-stage intercooler. Then, it enters the second-stage compressor to be compressed to 1105 kPa, and the compressed biogas enters the second-stage intercooler to cool down to 25 °C. Then, the biogas is compressed in the third-stage compressor to 2320 kPa, and the compressed biogas is cooled to 25 °C by the third-stage intercooler. Finally, the biogas is compressed and pressurized to 4908 kPa by the fourth-stage compressor. After the compression, the biogas enters the fourth-stage intercooler and is cooled to 25 °C. The main characteristics of the principal streams numbered in the process (from S1 to S12, as shown in Fig. 1) are listed in Table 1 in terms of flow rate, pressure, temperature, vapor fraction, and composition.

The compression process was simulated and analyzed using the Pressure Changers/Compr module and the Heat Exchangers/Heater module in Aspen Plus. The analysis of the simulation results of the actual centrifugal multistage compression process shows that the ASME polytropic model is more rigorous than the GPSA polytropic model and can be closer to the actual working conditions [18]. Therefore, the compressor model should choose the ASME polytropic model in the actual engineering simulation. After purification, biogas mainly contains CH_4 and CO_2, both of which are composed of nonpolar molecules. For this case, the PR-BM physical property method is usually selected, suitable for nonpolar or weak polarity systems under all temperatures and pressures, and its simulation results are more accurate [21]. Table 2 shows the Aspen Plus simulation parameters of the biogas compression process.

RESULTS AND DISCUSSION

Table 3 shows the Aspen Plus simulation results of the four-stage compression process. Also, Table 4

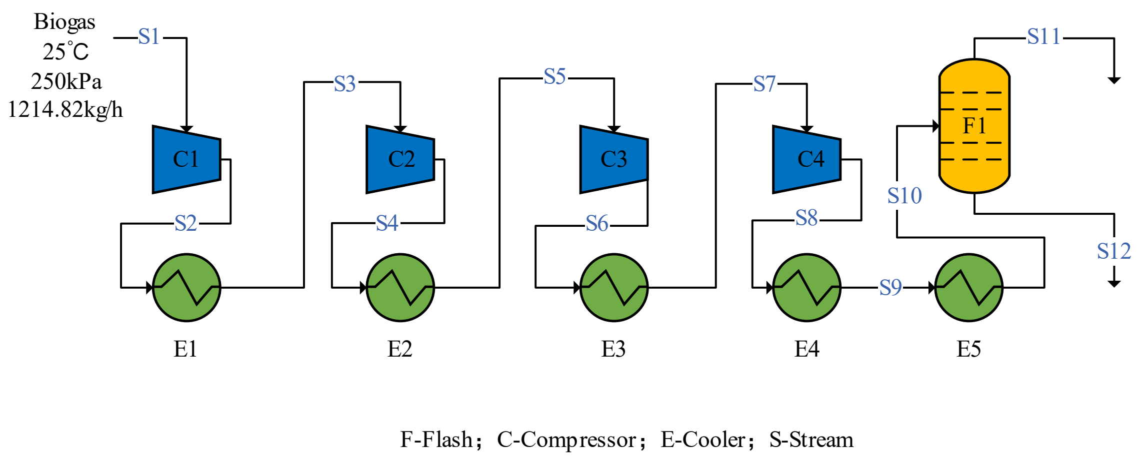

Figure 1. Four-stage compression process diagram.

Table 1. Streams characteristics of the compression process

Stream no.	Composition (% mole base)		Vapor fraction	Temperature (K)	Pressure (MPa)	Molar flow (kmol/h)
	CH_4	CO_2				
S1	60.00	40.00	1	298.15	0.25	44.615
S2	60.00	40.00	1	361.87	0.525	44.615
S3	60.00	40.00	1	298.15	0.525	44.615
S4	60.00	40.00	1	362.51	1.105	44.615
S5	60.00	40.00	1	298.15	1.105	44.615
S6	60.00	40.00	1	363.13	2.32	44.615
S7	60.00	40.00	1	298.15	2.32	44.615
S8	60.00	40.00	1	365.29	4.908	44.615
S9	60.00	40.00	1	298.15	4.908	44.615
S10	60.00	40.00	0.776	233.15	4.908	44.615
S11	5.51	94.49	0	190.86	3.750	26.795
S12	91.86	8.14	1	265.01	4.906	17.820

Table 2. Simulation parameters of the biogas compression

Items	Data
Polytropic Compression efficiency	0.85
Quantity of flow/ kg·h^{-1}	1214.82
Temperature / C	25
Pressure / kPa	250

compares the volume flow rates of the ideal isothermal and polytropic compression of biogas under different pressures. Fig. 2 shows the *p*-*V* relationship when biogas is compressed to 4.908 MPa under different compression conditions.

As shown in Fig. 2, the actual compression process of biogas after the four-stage compression process is close to ideal isothermal compression, and its efficiency is higher than that of the one-stage compression. According to the work calculation formula $W = pV$, the area enclosed by the multistage compression curve and first-stage compression curve in Fig. 2 is the work saved by the multistage compression of the compressor compared with the first-stage adiabatic compression. Under the premise of choosing a reasonable compression ratio, the more the stages of the compressor, the larger the enclosed area. That is, energy-saving increases with the increase in saved work. However, in actual projects, investment accordingly increases. Therefore, we need to make comprehensive considerations need to be made before making choices.

Table 3. Simulation results of the four-stage compression

Compression Stage	Quantity of Flow / $kg \cdot h^{-1}$	Outlet Pressure / kPa	Inlet Temperature / ℃	Outlet Temperature / ℃	Interstage Compression Power / kW	Interstage Cooling Load / kW
1	1214.85	525	25	88.72	29.38	-30.25
2	1214.85	1105	25	89.36	29.23	-31.09
3	1214.85	2320	25	89.98	28.63	-32.62
4	1214.85	4908	25	92.14	27.93	-36.88

Table 4. Comparison of volume flow rates between ideal isothermal compression and polytropic compression of biogas under different pressures

Pressure / kPa	Ideal isothermal compressed volume flow rate (25 ℃) / (m^3/h)	Polytropic compression	
		Temperature / ℃	Volume flow rate / (m^3/h)
250	438.93	25	438.93
525	209.01	88.72	253.59
1105	99.31	159.81	144.26
2320	47.30	237.25	81.25
4908	22.36	321.84	45.15

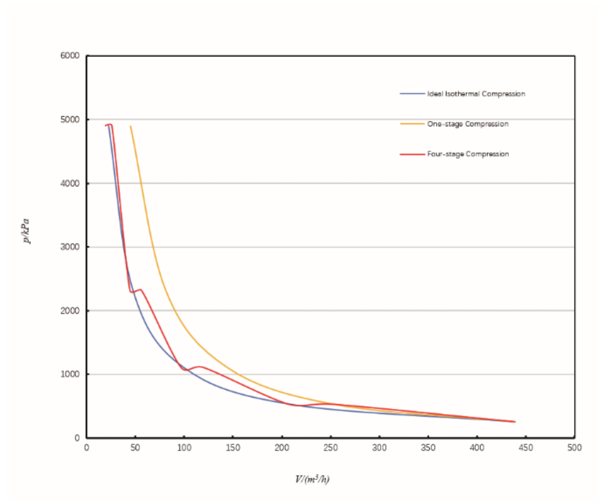

Figure 2. Analysis of energy-saving potential in biogas four-stage compression process.

Analysis of the main factors influencing the energy consumption of the compressors

The compression ratio is one of the most important parameters affecting energy consumption in multistage compression processes [22]. Therefore, four operating conditions were set up to discuss the compression ratio influence. Operating condition 1: the average distribution of the compression ratio in the multistage compression process, i.e., ε_1 = 2.105. Operating condition 2: the compression ratio of the multistage compression process gradually decreases, i.e., $\varepsilon_{2\text{-}1}$ = 2.5, $\varepsilon_{2\text{-}2}$ = 2.112, $\varepsilon_{2\text{-}3}$ = 2, $\varepsilon_{2\text{-}4}$ = 1.859. Operating condition 3: the compression ratio gradually increases in the multistage compression process, i.e., $\varepsilon_{3\text{-}1}$ = 1.859, $\varepsilon_{3\text{-}2}$ = 2, $\varepsilon_{3\text{-}3}$ = 2.112, $\varepsilon_{3\text{-}4}$ = 2.5. Working condition 4: the compression ratios of the first and fourth stages in the multistage compression process are slightly lower than those of the middle stages, i.e., $\varepsilon_{4\text{-}1}$ = 2, $\varepsilon_{4\text{-}2}$ = 2.216, $\varepsilon_{4\text{-}3}$ = 2.215, $\varepsilon_{4\text{-}4}$ = 2. The Pressure Changers/Compr and Heat Exchangers/Heater modules in Aspen Plus were used to simulate the compression process of biogas under four operating conditions, respectively, and the simulation results are shown in Table 5 and Fig. 3.

It can be seen from Table 5 and Fig. 3 that under operating condition 1, the compressor power and heat exchanger load in the multistage compression process are the lowest: 115.170 kW and 130.842 kW, respectively. The simulation results are also consistent with the theoretical optimal compression ratio of multistage compression [23].

The number of compression stages is also one of the important parameters that affect the energy consumption of the multistage compression process. When gas is compressed to a certain pressure, the more the compression stages, the smaller the corresponding compression ratio, reducing the multistage compressor energy consumption.

Based on the above simulation results, the average distribution method of the multistage compression ratio was considered, so the number of compression stages (m) can be expressed as follows:

$$m = \ln \frac{p_2}{p_1} / \ln \varepsilon \tag{12}$$

Table 5. Simulation results of biogas compression under four operating conditions

	Interstage Compression Power / kW				Interstage Compression Power / kW			
	1	2	3	4	1	2	3	4
Condition 1	29.377	29.233	28.627	27.934	30.248	31.091	32.619	36.884
Condition 2	37.120	29.293	26.406	22.479	38.309	31.530	30.776	30.355
Condition 3	24.180	27.093	29.025	35.317	24.861	28.578	32.397	45.451
Condition 4	27.269	31.494	30.910	25.534	28.060	33.442	35.341	34.035

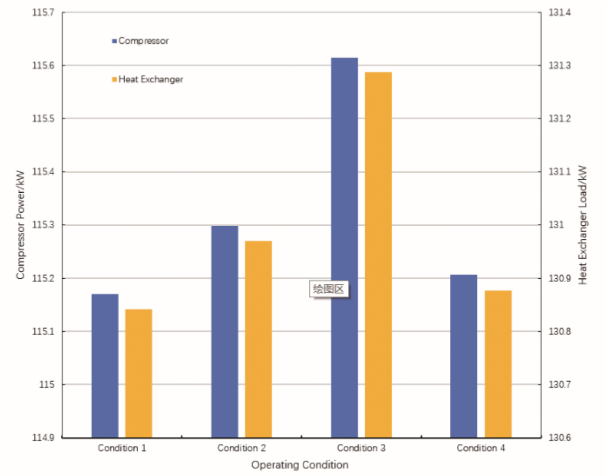

Figure 3. Compressor power and heat exchanger load under four operating conditions.

where p_1 and p_2 are imported pressure and outlet pressure MPa, respectively.

Based on the above conditions, the biogas compression process with the mass flow rate of 1214.85 kg/h and final pressure of 4.908 MPa was simulated. The one-stage to five-stage compression conditions were set for analysis, respectively. The Pressure Changers/Compr and Heat Exchangers/Heater modules in Aspen Plus were used to simulate the biogas compression process, and the simulation results are shown in Table 6.

As shown in Table 6, the power of the one-stage compressor is ~156.302 kW, and the power of the five-stage compressor is ~112.560 kW, which was reduced by ~44 kW. As a result, the outlet temperature of the compressor stage decreased from 321.84 °C to 76.47 °C, and the heat exchanger load decreased from 171.974 kW to 128.232 kW. Therefore, in practical engineering, the multistage compression method is often used to reduce the outlet temperature of compressors. In addition, the compressor power, interstage cooling outlet temperature, and heat exchanger load all decrease with the increase in the number of compression stages, and the decreasing trend gradually slows down, as shown in Fig. 4.

Table 6. Simulation results of biogas compression under different compression stages

Number of stages	Interstage compression ratio	Compressor power / kW	Average outlet temperature between compressor stages / ℃	Interstage cooling outlet temperature / ℃	Heat exchanger load / kW
1	19.632	156.302	321.84	25	-171.974
2	4.431	128.475	161.70	25	-144.147
3	2.698	119.550	113.25	25	-135.222
4	2.105	115.170	90.05	25	-130.842
5	1.814	112.560	76.47	25	-128.232

Besides the number of compression stages, the outlet temperature of the interstage cooler is one of the main factors affecting energy consumption in the multistage compression process. In the simulation, the outlet temperatures of the interstage coolers with three stages, four stages, and five stages of compression were set to 15°C, 20°C, 25°C, 30°C, and 35°C, respectively.

The simulation results show that the power of the three-stage compressor is 116.648, 118.102, 119.550, 120.990, and 122.419 kW, respectively. Under the same working conditions, the power of the four-stage compressor is 111.948, 113.563, 115.170, 116.768, and 118.354 kW, respectively. The power of the five-stage compressor is 109.161, 110.865, 112.560, 114.245, and 115.920 kW, respectively. The power of the compressors with different compression stages varies with the outlet temperature of the interstage cooler, as shown in Fig. 5. As seen in Fig. 5, the compressor power increases with the increase in the

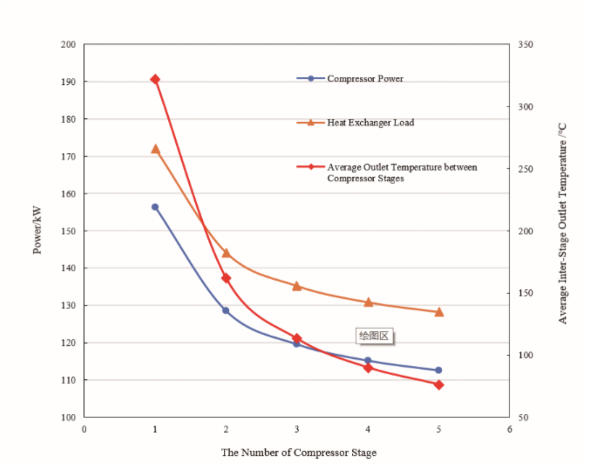

Figure 4. Variation of heat exchanger load, compressor power, and average interstage outlet temperature with a compression stage.

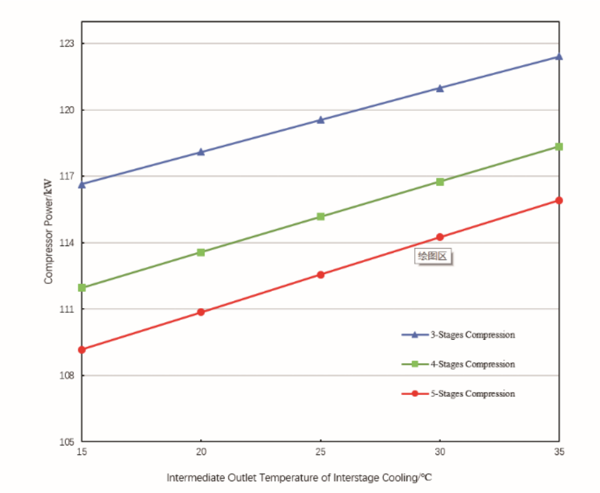

Figure 5. Variation of compression power with the outlet temperature of the interstage cooler.

outlet temperature of the interstage cooler. The simulation results show that in the biogas four-stage compression process, when the interstage cooling temperature decreases by 5 °C on average, the energy consumption in the whole compression process is reduced by ~1.5 kW.

Since equipment cost increases with increasing the number of compression stages, and the outlet temperature of the interstage cooler of compressed gas is usually higher than that of the circulating cooling water, it is necessary to comprehensively evaluate the factors, such as the equipment and energy consumption costs, in practical engineering applications.

Exergy analysis of multistage compression process

When the benchmark state is fixed, meaning that the pressure and temperature of the compressed gas are determined, the energy and exergy of the gas are determined [24]. The benchmark pressure was set to 101.3 kPa. The benchmark temperature was set to 298.15 K. The relevant thermodynamic parameters of the beginning and end states of biogas were simulated by Aspen Plus, as shown in Table 7.

Table 7. Thermodynamic parameters of the initial and final states of the biogas

Items	Unit	Initial state	Final state
Pressure	kPa	250	4908
Temperature	K	298.15	298.15
Enthalpy	kJ/mol	-202.179	-203.444
Entropy	kJ/mol·K	-0.0482	-0.0771
Flow Rate	kmol/hr	44.615	44.615

As seen in Table 7, under the isothermal condition, when the gas is compressed, the enthalpy when the final pressure of the gas is high is lower than that when the initial pressure is low. It results from the decrease of the gas enthalpy due to the exothermic isothermal compression. In addition, the final gas entropy is lower than the initial gas entropy because with the increase in gas pressure, the molecular arrangement tends to be ordered, and the entropy decreases.

The Aspen Plus software was used to simulate the thermodynamic parameters related to the four-stage compression process of biogas, and the exergy changes in the four-stage compression process were calculated through the exergy definition formula. The results are shown in Table 8.

Table 8. Exergy changes in four-stage compression process

Compression stage	Interstage exergy /kW	Exergy after interstage cooling /kW	Exergy loss after interstage cooling /kW	Interstage exergy efficiency /%
1	53.007	50.141	2.865	76.68
2	75.415	72.448	2.967	76.50
3	97.201	94.072	3.128	76.18
4	118.239	114.637	3.602	75.56

According to the exergy analysis of the compression process in Table 8, the interstage cooling loss of the four-stage compression process is 12.6 kW, accounting for 10.9% of the total compression power. If this thermal energy part can be recovered, the exergy efficiency of the whole compression process can be significantly improved. The exergy value of biogas increased with the increase in pressure. Also, the exergy value increased by ~87.03 kW after the fourth-stage compression process was completed, and the exergy of the biogas decreased after interstage cooling. The cooling water took away the exergy of the compressed biogas due to the increase in the gas temperature after the interstage cooling process. The relationship between the compression exergy efficiency and the number of compression stages is shown in Fig. 6.

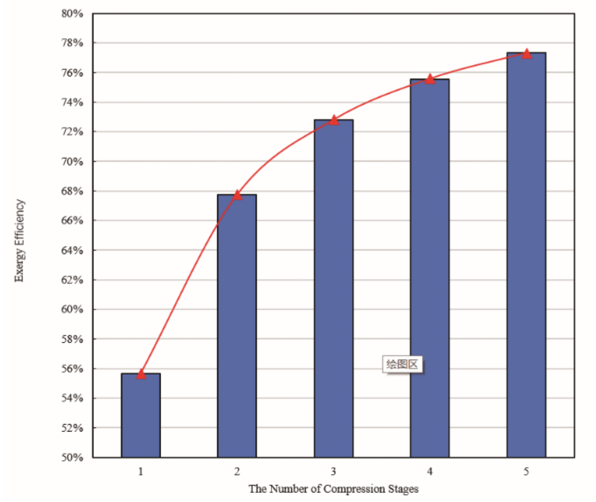

Figure 6. Exergy efficiency changes under different compression stages.

As shown in Fig. 6, the exergy efficiency values of the one-stage compression, two-stage compression, three-stage compression, four-stage compression, and five-stage compression processes are 55.68%, 67.74%, 72.79%, 75.56%, and 77.31%, respectively. Also, the growth rates are 21.66%, 7.47%, 3.80%, and 2.32%, respectively. In the biogas compression process, the exergy efficiency in the compression process increased with the increase in the number of compression stages, but this increase tended to be gradual. Therefore, it is very important to choose appropriate compression stages for application in practical engineering. Based on determining factors, such as the gas flow rate and final pressure conditions, a comprehensive analysis of the exergy efficiency increase, water-saving rate, and equipment costs of different compression stages, a more reasonable compression stage of biogas under the above-mentioned working conditions can be determined.

In the biogas project of an agricultural livestock and poultry breeding farm, it was measured that the exergy increase of final biogas was about 80.60 kW, exergy efficiency was 72.12%, and exergy recovery potential was about 10.88 kW. These simulated results are close to those measured in practical engineering.

CONCLUSION

In this study, a biogas multistage compression process was simulated by the Aspen Plus software. The simulation calculations found that the selection of the number of stages and the compression ratio distribution significantly influenced the simulation results. Overall, the four-stage compression process simulation results and average distribution compression ratio were the best without considering equipment investments.

According to the simulation calculations, in the four-stage biogas compression process, the exergy increase of the final biogas was about 83.07 kW. Its exergy efficiency was 75.56%, and the recovery exergy potential was ~12.6 kW. These results are close to those measured in practical engineering.

The simulation results showed that in the multistage biogas compression process, the total energy consumption decreased by 1.5 kW for every 5 °C decrease in the interstage cooling temperature, where the biogas exergy increases with the increase in pressure. In addition, the exergy efficiency increased with the increase in the number of compression stages, but the increase tended to be slow.

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EKSERGIJSKA ANALIZA PROCESA VIŠESTEPENE KOMPRESIJE BIOGASA SIMULACIJOM KORIŠĆENJEM SOFTVERA ASPEN PLUS

SHUAI ZOU[1,3]
KANGCHUN LI[2,3]
MINGYUAN DOU[1,3]
JING YANG[1,3]
QING FENG[1,3]
FUCHUAN HUANG[1,3]
LIN CHEN[1]

[1]School of Mechanical Engineering, Guangxi University, Nanning, Guangxi, China

[2]School of Chemistry & Chemical Engineering of Guangxi University, Nanning, Guangxi, China

[3]Guangxi Key Laboratory of Petrochemical Resource Processing and Process Intensification Technology, Guangxi University

NAUČNI RAD

U ovoj studiji, uzimajući proces odvajanja kompresije u projektu biogasa kao predmet istraživanja, simuliran je proces višestepene kompresije korišćenjem softvera Aspen Plus. Eksergijska analiza projekta biogasa u višestepenoj kompresiji i adijabatskim ili izotermnim uslovima izvršena je primenom termodinamičkog principa. Rezultati su pokazali da se eksergija biogasa povećava sa pritiskom tokom procesa kompresije i shodno tome smanjuje u međustepenom procesu hlađenja. Dalje, serija kompresija se povećava sa povećanjem efikasnosti, ali je povećanje postepeno. Rezultati studije procesa četvorostepene kompresije su sledeći: eksergija procesa je porasla za ~83,07 kV, efikasnost eksergije procesa je ~75,56%, a eksergijski potencijal oporavka ~12,6 kV. U ovoj studiji, softverom Aspen Plus je analizirana raspodela odnosa kompresije i izbor stepena kompresije u okviru procesa višestepene kompresije. Ova analiza na kraju može pomoći drugima da dizajniraju efikasne višestepene sisteme kompresije koji smanjuju gubitke energije.

Ključne reči: Aspen Plus, biogas, eksergijska analiza, višestepena kompresija.