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Study on multi-cavern optimization allocation for injection and production of salt cavern gas storage

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Abstract. The salt cave gas underground gas storage is composed of a plurality of independent cavity, which are uniformly monitored and deployed by the system on the ground. The morphological structure, thermal state and supporting wellbore parameters of each cavity are different. Based on the thermal characteristics of the injection and operation of the salt cavern gas storage, the multi-cavity injection and production operation of the gas storage reservoir is regarded as the overall system. Under the constraints of urban peaking demand, reservoir gas injection plan, wellbore erosion flow, and operating limit pressure, the minimum compressor power consumption during the gas injection, the minimum multi-cavity total temperature rise, the power consumption temperature rise double target, and the minimum multi-cavity total pressure drop during gas production are optimized. The model of multi-cavity injection gas production in salt cavern gas storage was established. The model was solved by complex genetic algorithm. The optimal daily injection volume of each cavity was determined, and the results of the production were compared and analyzed. The results show that reasonable optimization of production can effectively improve the economics of gas storage, improve the total storage capacity of the gas storage, avoid excessive pressure drop of individual chambers, and help to maintain the stability of the chamber. Based on the results of gas production and distribution, the control scheme of multi-cavity operation of salt cavern gas storage is proposed. The research results can provide reference for the formulation and production scheduling of salt cavern gas storage.

1. Instruction

The salt cavern gas storage system consists of a number of independent underground salt cavern. The shape, size, internal thermal state, injection-production and operation conditions, and matching injection-production wellbore parameters of each cavity are different. Salt cavern gas storage has large reserves, large instantaneous throughput, flexible and convenient gas injection, high working gas volume, and the working gas volume can reach 65% of the total storage capacity, while the proportion of other gas storage is about 30%[1,2]. It has the advantages of complete structure, less inter-layer,



large thickness, good non-permeability, high gas injection capacity and strong peak-sharing ability, which is very suitable for urban natural gas peak shaving [3,4].

When there is demand for peaking in the city, it is necessary to combine with many salt cavern to injecting and producing gas[5]. If the distribution of each single chamber injection quantity is unreasonable, it may lead to the excessive compressor power, as well as the capacity of individual single chamber storage is obviously reduced and the injection pressure temperature changes too much, which is directly affects the reliability and stability of the operation of the gas reservoir cavity group[6,7].

When the salt cavern gas storage reservoir is operated in multiple cavities, the structure size, thermal state, operating constraints and injection-production wellbore parameters of each cavity are different, and the operation of the gas storage is restricted by many factors. A variety of factors are constrained[8]. Therefore, while meeting the demand for natural gas in the city, rational distribution of the gas in the gas storage tanks can maximize the working gas volume and peak injection intensity of the gas storage, save compressor power consumption, and ensure reliable gas storage. It can ensure the gas storage warehouse is reliable[9]. Based on the thermodynamic characteristics of natural gas injection and production in salt cavern gas storage, this paper considers the multi-cavity injection and production operation of gas storage as the whole system. Under the constraints of urban peaking demand, reservoir gas injection plan, wellbore erosion flow rate and maximum and minimum operating pressure of the solution chamber, the minimum power consumption of the compressor and the minimum pressure drop of the multi-cavity are optimized. The model of multi-cavity injection gas production in salt cavern gas storage is established, and the model is solved based on genetic algorithm to determine the optimal daily injection volume of each cavity. Based on the results of gas storage production, a multi-cavity combined injection operation scheduling scheme for salt cavern gas storage is proposed. The research results can provide reference for the formulation and production scheduling of salt cave gas storage.

2. The establishment and solution of mathematical models

2.1. Injection and operation model of salt cavern gas storage

The salt cavern gas storage is composed of injection-production wellbore and underground cavern. The natural gas is injected and discharged in the gas storage tank along with the heat exchange with the surrounding salt rock, and the Joule Thomson effect caused by the compression expansion of natural gas in the cavity. The underground salt cavern of the gas storage tank is assumed to be cylindrical, and the salt rock layer is infinite rock formation, which is considered as the lumped parameter; the natural gas flow in the injection wellbore is one-dimensional flow along the wellbore direction.

2.2. Wellbore model.

In the injection wellbore, the natural gas flow is unsteady flow. Based on the flow mass conservation equation, momentum equation and energy equation of the natural gas in the wellbore, the wellbore model of the salt cavern gas storage reservoir is obtained:

$$\begin{cases} \frac{\partial \rho_{git}}{\partial t} + \frac{\partial (\rho_{git} v_{jt})}{\partial y} = 0 \\ \frac{\partial (\rho_{git} v_{jt})}{\partial t} + \frac{\partial (\rho_{git} v_{jt}^2)}{\partial y} = -\frac{\partial P_{jt}}{\partial y} - \rho_{git} g - \text{sgn}(q_{sc}) \frac{\rho_{git} f_{jt} v_{jt}^2}{2d_{jt}} \\ \rho_{git} c_{vijt} \left(\frac{\partial T_{jt}}{\partial t} + v \frac{\partial T_{jt}}{\partial y} \right) = T_{jt} \left(\frac{\partial P_{jt}}{\partial T_{jt}} \right) \rho_{git} \frac{v_{jt}}{\rho_{git}} \frac{\partial \rho_{git}}{\partial y} + \frac{\pi d_{jt}}{A_{jt}} q_{wjt} - \text{sgn}(v_{jt}) \frac{f_{jt} \rho_{git} v_{jt}^3}{2d_{jt}} \end{cases} \quad (1)$$

Among them: ρ_{git} is the natural gas density in the wellbore, v_{jt} is the natural gas flow velocity in the wellbore, y is the vertical direction of the wellbore; P_{jt} is the natural gas pressure in the wellbore, g is the gravity acceleration, f_{jt} is the natural gas friction factor in the wellbore, d_{jt} is the wellbore hydraulic

diameter; A_{jt} is the heat exchange area between the natural gas and the surrounding salt layer in the wellbore, q_{wt} is the heat flux in the wellbore.

2.2.1. Cavity model. Combined with the actual gas state equation, based on the energy conservation equation of the continuity equation, the underground cavity model of the injection and operation of the salt cavern gas storage is obtained.

$$\begin{cases} \frac{P_{rq}(t)VM_g}{z_{rq}(t)RT_{rq}(t)} = m_{rqS} + \int_{t_0}^{t_e} (\text{sgn}(q_{sc})m_{pi} + m_{wf})dt \\ \frac{dT_{rq}}{dt} = \frac{1}{V\rho_{grq}c_{vrq}} \left[\frac{VT_{rq}}{\rho_{grq}} \frac{d\rho_{grq}}{dt} \left(\frac{\partial P_{rq}}{\partial T_{rq}} \right) + m_{pi}c_p(T_j - T_{rq}) + A_{rq}q_{wrq} \right] \end{cases} \quad (2)$$

Among them: P_{rq} and T_{rq} are the pressure and temperature of the cavity, M_g is the molecular weight of the natural gas in the cavity, m_{rqS} , m_{pi} and m_{wf} are the moles of natural gas at the initial time, injection, and leakage, respectively, and $t_e - t_0$ is the running time. Among them, the gas production process is $\text{sgn}(q_{sc}) = -1$; the gas injection process is $\text{sgn}(q_{sc}) = 1$.

2.2.2. Heat exchange model between cavity and surrounding rock. Set the boundary conditions and initial conditions to establish a radial transient thermal differential equation:

$$\begin{cases} \frac{\partial T_{srq}}{\partial \tau} = a_{srq} \left[\frac{\partial^2 T_{srq}}{\partial z^2} + \frac{\partial^2 T_{srq}}{\partial r^2} + \frac{1}{r} \frac{\partial T_{srq}}{\partial r} \right] & 0 \leq r \leq \infty \\ T_{srq}|_{t=0} = \text{const} \\ T_{srq}|_{r \rightarrow \infty} = \text{const} \\ -\lambda \frac{\partial T_{srq}}{\partial r} \Big|_{r=R_{rq}} = \alpha_{rq}(T_{wrq} - T_{rq}) \end{cases} \quad (3)$$

Among them: T_{srq} is the temperature of the salt rock layer, τ is the time, a is the temperature coefficient of the salt rock layer, r is the radial direction; λ is the thermal conductivity of the salt rock layer, α_{srq} is the convective heat transfer coefficient of the natural gas, T_{wrq} is the wall temperature of the cavity, and T_{rq0} is the cavity initial temperature.

2.3. Gas injection operation production model

2.3.1. Gas injection production objective function. When the city uses low gas, the natural gas has a large margin. At this time, excess natural gas needs to be injected into the gas storage for storage. When injecting gas, the natural gas is pressurized by the compressor and injected into the underground cavity of the gas storage tank through the injection wellbore, and the compressor consumes power. Under the conditions of urban gas injection demand and operation constraints, the objective function of the reciprocating compressor with minimum power consumption for gas injection operation is as follows[10]:

$$\begin{cases} N = \min \left(N_{ys} = \frac{16.883}{\eta_c \eta_g} \frac{k}{k-1} P_{ysi} Q_{ysi} \left[\left(\frac{P_{yso}}{P_{ysi}} \right)^{\frac{k-1}{k}} - 1 \right] \right) \\ \Delta t = \min \sum_{i=1}^n \Delta t_i \end{cases} \quad (4)$$

Among them: N_{ys} is the compressor power consumption, k is the gas adiabatic index, P_{ysi} and P_{yso} are respectively the reciprocating compressor inlet pressure and outlet pressure, Q_{ysi} is the volume flow rate of the gas in the suction state, η_c is the transmission loss of reciprocating compressor, belt transmission $\eta_c=0.96-0.99$, gear transmission $\eta_c=0.97-0.99$, direct connection $\eta_c=1.0$, η_g is the mechanical efficiency of reciprocating compressor, $\eta_g=0.9-0.95$ for large and medium compressor For small compressors $\eta_g=0.85-0.9$.

Under the premise of ensuring the multi-cavity combined gas injection volume, the gas injection volume of each cavity can be reasonably distributed, which can effectively reduce the power consumption of the compressor, increase the total storage capacity of the gas storage, and ensure the economic operation of the gas storage.

2.3.2. Gas injection production constraints. The multi-cavity gas injection operation of the salt cavern gas storage reservoir should also consider various operational constraints while meeting the urban gas storage requirements, thereby limiting the maximum injection volume of the wellbore; The maximum operating pressure of the gas storage chamber determined by the actual fracture pressure and the cavity pressure data at the site of the reservoir salt layer; and the excessively high natural gas flow rate will cause erosion of the injection and production wellbore. Therefore, in the gas injection operation of the gas storage, the gas injection rate is restricted by the gas injection volume planned by the gas storage, the natural gas erosion flow rate, the maximum gas injection capacity of the wellbore, and the highest operating pressure of the gas storage chamber:

$$\begin{cases} Q_{jh} = \sum_{i=0}^N q_i \\ q_i < q_e \\ 0 \leq q_i \leq q_{rq\max} \\ P_{rq} \leq P_{rq\max} \end{cases} \quad (5)$$

In the formula, Q_{jh} is the daily gas injection volume of the gas storage plan, q_i is the daily gas injection volume of a single cavity, q_e is the wellbore passing capacity constrained by the erosion flow rate, $q_{rq\max}$ is a single note The maximum injection volume of the production wellbore, P_{rq} is the pressure of the gas storage chamber, $P_{rq\max}$ is the highest operating pressure of the gas storage chamber.

2.4. Gas production and operation model

2.4.1. Gas production paternity objective function. During the gas production operation of the salt cavern gas storage, the temperature and pressure inside the cavity gradually decrease, and the salt cave volume convergence caused by the creep property of salt rock becomes more and more obvious. In the gas production operation, if the pressure drop of the solution chamber exceeds the allowable range, the volume of the solution cavity is strongly converged, which directly affects the gas storage capacity and stability of the gas storage. Under the conditions of urban gas demand and operational constraints, the objective function of multi-cavity minimum total pressure drop for gas production is as follows[11]:

$$\Delta P = \min \sum_{i=1}^n \Delta P_i \quad (6)$$

In the formula, ΔP_i is the temperature rise of each cavity, MPa.

Under the premise of ensuring the demand for gas in the city, the gas volume of each cavity is reasonably distributed, and the pressure drop of each cavity is controlled, which can effectively reduce the creep of salt rock and the volume convergence speed of the cavity, and ensure the stability of gas storage operation.

2.4.2. Gas production and production constraints. The multi-cavity gas production operation of the salt cavern gas storage reservoir should meet various operational constraints while meeting the peak demand of the city, including the pressure requirements of the gas gathering ground gathering pipeline, and the erosion of the natural gas flow to the injection and production wellbore and the minimum operating pressure of the gas storage chamber.

$$\begin{cases} Q_{cjh} = \sum_{i=1}^n q_{ci} \\ q_{ci} < q_e \\ 0 \leq q_{ci} \leq q_{rqmaxc} \\ P_{rq} \geq P_{rqmin} \end{cases} \quad (7)$$

In the formula, Q_{cjh} is the daily gas injection volume of the gas storage plan, Nm^3/d ; q_{ci} is the daily gas injection volume of single cavity, Nm^3/d ; q_{rqmaxc} is the maximum production volume of single injection wellbore, Nm^3/d ; P_{rq} is gas storage Reservoir cavity pressure, MPa; P_{rqmin} is the lowest operating pressure of the gas storage chamber, MPa; n is the number of cavities sharing a compressor in the gas storage.

2.5. Model solution

Under the constraints of the injection and gas production, firstly, the initial gas injection volume of each cavity of the gas storage is given, and the gas storage and gas production operation model is solved. The injection wellbore is divided into several micro-element segments, and the model (1) is solved by the finite difference method. The gas flow direction is calculated step by step according to the gas flow direction. In each wellbore, the gas physical property parameters are calculated by using the average value of the inlet and outlet temperature pressures. Based on the wellbore calculation results, the Newton-Raphson iterative method is used to solve the cavity model (2). The control error is $\Delta P \leq 0.1MPa$, $\Delta T \leq 0.1^\circ C$, and the finite element method is used to solve the heat exchange model(3) between the cavity and the surrounding rock, and then the temperature of the wall surface of the cavity and the temperature field distribution of the surrounding salt rock layer are obtained.

Based on the results of the injection-production operation, the complex optimization genetic algorithm[12,13] is used to optimize the objective function under the constraint conditions. Every time the objective function is calculated, the solution of the gas injection operation model is solved until the minimum value of the objective function is found. At this time, the independent variable in the function corresponds to the optimum value of the gas injection volume of each cavity.

3. Result analysis

3.1. Basic data and parameter conditions

Four representative salt caves in Maoping area of Jintan salt cavern gas storage in China were selected as research objects. In the simulation calculation, the feasibility report of the Jintan gas storage is referenced in the parameters of the cavity and wellbore, the parameters of natural gas, the geological and thermal properties of the salt rock[14,15,16]. The parameters of the gas storage chamber wellbore mechanism are shown in Table 1.

Table 1. Basic data for optimizing the dissolution of a solution.

Wellbore number	Depth of rock salt(m)	Center pipe sinking depth(m)	Mining time	Cavity volume ($10^4 m^3$)	Maximum diameter (m)	Cavity height (m)	Wellbore pipe diameter (m)	Well wall roughness (mm)
1 [#]	858-1030	1019.60	11	18.69	109	91.57	0.1651	0.3
2 [#]	866-1042	1036.45	10	20.51	103	81.42	0.1778	0.3
3 [#]	867-1039	1035.50	8	23.26	83.8	92.64	0.2032	0.3
4 [#]	860-1029	1019.75	8	20.13	80.8	90.19	0.1778	0.3

3.2. Analysis of gas injection production results

In the calculation of gas injection production, the planned total injection volume of four chambers is set to $180 \times 10^4 Nm^3/d$, the inlet pressure of gas storage compressor is 4.37MPa, the adiabatic index of natural gas is 1.285, and the gas injection temperature of wellhead is $40^\circ C$. The minimum flow rate

of the solution chamber is limited to $0.05 \times 10^6 \text{Nm}^3/\text{d}$, and the gas injection operation parameter conditions and the production constraints are shown in Table 2.

Based on the parameters of the cavity and the constraints, the average gas injection operation and the gas injection optimization production simulation calculations were carried out for the four gas injection chambers. The operating parameters of the average gas injection operation and the operation with different production targets are shown in Table 3.

Table 2. Operating parameters and constraints of gas injection production chamber.

Wellbore number	Initial gas injection pressure of the cavity(MPa)	Injecting initial temperature of the cavity($^{\circ}\text{C}$)	Highest pressure (MPa)	Maximum temperature ($^{\circ}\text{C}$)	Maximum gas injection capacity ($10^4 \text{Nm}^3/\text{d}$)	Gas injection erosion flow ($10^4 \text{Nm}^3/\text{d}$)	Gas injection temperature ($^{\circ}\text{C}$)
1 [#]	6	25	15.5	51	224.0	160.54	40
2 [#]	6.5	28	16.5	53	284.6	203.76	40
3 [#]	7	30	17	53.7	362.4	283.21	40
4 [#]	6.5	28	16.5	53	275.6	177.32	40

Table 3. Gas injection operation, gas injection volume under different production targets, compressor power consumption and temperature rise of the cavity.

Average gas injection operation				Dual target production		
Wellbore number	Gas injection volume($10^4\text{Nm}^3/\text{d}$)	compressor Power consumption (10^5kW)	Total temperature rise of the cavity($^{\circ}\text{C}/\text{d}$)	Gas injection volume($10^4\text{Nm}^3/\text{d}$)	Compressor power consumption (10^5kW)	Total temperature rise of the cavity($^{\circ}\text{C}/\text{d}$)
1 [#]	45			82.7		
2 [#]	45	6.5945	6.9103	48.6	6.0162	6.9748
3 [#]	45			5		
4 [#]	45			43.7		
Targeting minimum compressor power consumption				Targeting the minimum total temperature rise		
Wellbore number	Gas injection volume($10^4\text{Nm}^3/\text{d}$)	Compressor power consumption (10^5kW)	Total temperature rise of the cavity($^{\circ}\text{C}/\text{d}$)	Gas injection volume($10^4\text{Nm}^3/\text{d}$)	Compressor power consumption (10^5kW)	Total temperature rise of the cavity($^{\circ}\text{C}/\text{d}$)
1 [#]	82.7			5		
2 [#]	48.6	6.0162	7.7723	43.3	7.0947	6.5969
3 [#]	5			86.8		
4 [#]	43.7			40.4		

It can be seen from Table 3 that when the minimum compressor power consumption is the target, the volume with the largest volume and the highest initial temperature and pressure is the smallest. After the production, the power consumption of the compressor is reduced by 8.77% compared with the average power consumption of the compressor. When the minimum temperature of the minimum cavity is used as the target, the smallest volume and the lowest initial pressure will minimize the injection volume, the total temperature rise of the four chambers after the production was reduced by 4.54% compared with the total temperature rise of the average gas injection operation.

Considering the dual-target production of compressor power consumption and temperature rise, the compressor's good work and the total temperature rise of the dissolved chamber are increased compared with the single target production. The result of the dual-target optimized production is to sacrifice a certain compressor power consumption, thereby reducing the total temperature rise of the four chambers, thereby increasing the total reservoir capacity of the four chambers of the gas storage.

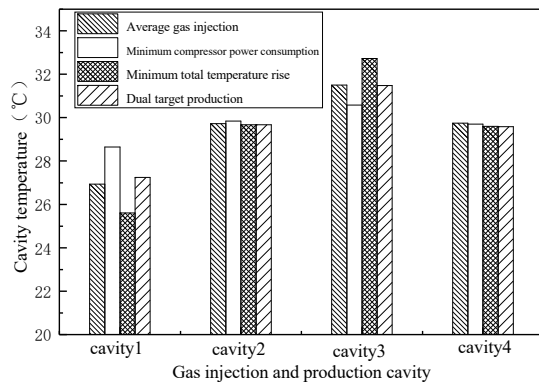


Figure 1. Cavity pressure after gas injection operation under different production targets.

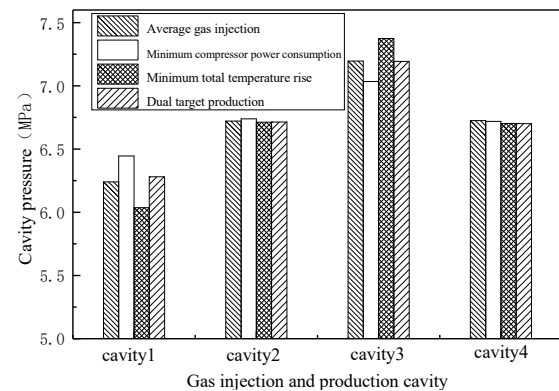


Figure 2. Cavity temperature after gas injection operation under different production targets.

Figure 1 and Figure 2 show the temperature and pressure of each cavity of the salt cavern gas storage when the total injection volume of the four chambers of the gas storage is planned to be $180 \times 10^4 \text{ Nm}^3/\text{d}$, the average gas injection, two single-objective optimization production and dual-objective optimization production gas injection operation. It can be seen from the figure that the operating parameters of each cavity are within the limited conditions of the production and meet the requirements. Under the gas injection operation under different production targets, the pressure and temperature of the No. 1 and No. 3 chambers changed significantly, and the pressures of the No. 2 and No. 4 chambers did not change significantly. It can be seen that when the multi-cavity is simultaneously in the production operation, the volume of the solution chamber and the initial parameters of the solution chamber have a direct influence on the distribution of the gas injection volume and the thermal parameters of the cavity after the production of the different targets. When the gas storage multi-cavity is running at the same time, the solution chamber group with similar cavity volume and initial parameters should be selected, and the solution chamber group with large difference between the volume of the solution chamber and the initial parameters should not be selected.

3.3. Gas production and production results and analysis

When optimizing the production, the starting point pressure of the gas pipeline is set to 6.07 MPa, the total planned production volume is $280 \times 10^4 \text{ Nm}^3/\text{d}$, and the maximum pressure drop of the limited chamber is 0.53 MPa/d, the minimum flow rate of each cavity is limited to $0.05 \times 10^6 \text{ Nm}^3/\text{d}$. Table 4 shows the optimization of the production chamber parameters and constraints for gas production.

Table 4. Gas production and distribution cavity parameters and constraints.

Wellbore number	Cavity gas initial pressure (MPa)	Cavity temperature at initial gas recovery (°C)	Minimum pressure (MPa)	lowest temperature (°C)	Maximum gas production capacity ($10^4 \text{ Nm}^3/\text{d}$)	Gas erosion flow ($10^4 \text{ Nm}^3/\text{d}$)
1 [#]	15	50	6	25	827	308.29
2 [#]	16.5	53	6.5	28	970	380.09
3 [#]	17	53.7	7	30	1114	517.12
4 [#]	16	52	6.5	28	860	352.82

Based on the parameters of the cavity and the constraints, the average gas production operation of the four chambers and the simulation of the total pressure drop of the minimum solution chamber were carried out, Table 5 shows the operating parameters for the average gas production operation and the production operation with the minimum total pressure drop.

Table 5. Average gas production and minimum total chamber pressure drop are the total pressure drop of the chamber during the target gas production operation.

Wellbore number	Optimize gas production ($10^4 \text{Nm}^3/\text{d}$)	Average gas production ($10^4 \text{Nm}^3/\text{d}$)	Planned total production ($10^4 \text{Nm}^3/\text{d}$)	Optimize the total pressure drop of the solution(MPa/d)	Total gas pressure drop in total gas recovery(MPa/d)
1 [#]	5	70	280	1.0574	1.1387
2 [#]	125.5	70			
3 [#]	142	70			
4 [#]	7.5	70			

It can be seen from Table 5 that when the planned total gas production is constant, the gas storage operation of the gas storage is carried out with the minimum total pressure drop of the solution chamber as the target, and the gas volume with the smallest volume and the lowest initial temperature pressure is the smallest. On the contrary, the largest volume, the highest initial temperature and pressure of the cavity, the maximum amount of gas produced by the production. After the production of the minimum total pressure drop of the solution, the total pressure drop of the four chambers was reduced by 7.13% compared with the total pressure drop of the average gas production.

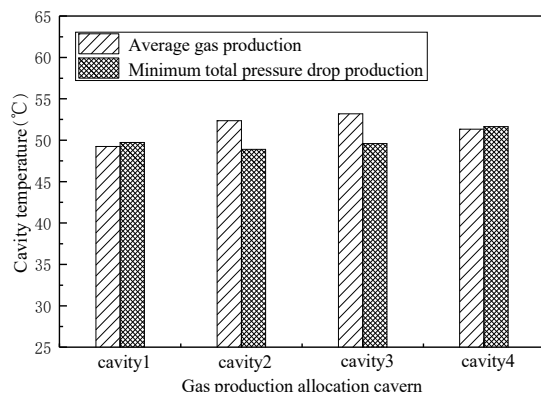


Figure 3. The chamber pressure after the production of the average gas production and the minimum total pressure drop.

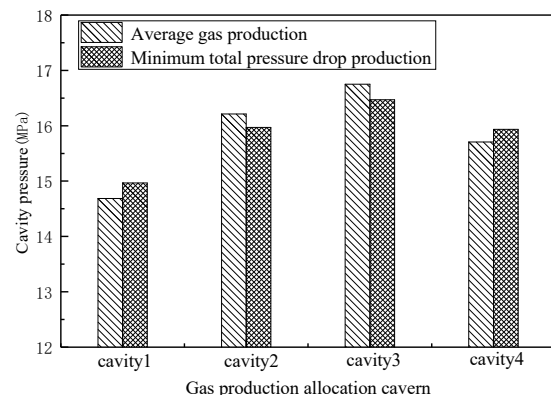


Figure 4. The temperature of the cavity after the production of the average gas production and the minimum total pressure drop.

It can be seen from Figure 3 and Figure 4 that the temperature and pressure of the solution chamber at the end of the two different gas production operations decrease with the increase of the production amount, and the operating parameters of each solution chamber are within the limited conditions of the production, which meets the requirements. The calculation result is the same as that of the gas injection production. When the gas storage multi-cavity is combined with the gas production, the volume of the cavity and the initial parameters of the cavity have a direct influence on the production results. When the gas storage operation of the gas storage is carried out, the combination of the cavity volume and the initial parameter conditions should be avoided.

It can be seen from Table 6 that when the market demand is different, the operating strategies of the four chambers are diverse. This phenomenon will be more pronounced when the number of cavities increases. The optimal allocation of salt cavern gas storage should firstly be based on the principle of safe, stable and efficient operation of gas storage. Secondly, it should consider the feasibility of optimizing the production results and avoid the abnormal operation of gas storage.

It can be seen from Table 6 that under different market demands, the operating strategies of the four chambers of the gas storage are diverse. This phenomenon will be more pronounced in the case of an increase in the number of reservoirs in the gas storage. The optimal allocation of salt cavern gas storage should be based on the principle of safe, stable and efficient operation of gas storage. At

thesame time, the feasibility of optimizing the production results should be considered to avoid the abnormal operation of the gas storage.

Table 6.Multi-chamber combined gas production operation plan.

Market demand($10^4\text{Nm}^3/\text{d}$)	1	2	3	4	Remarks
5-125	C	O	C	C	2 [#] meets the demand
125-127	O	O	C	C	1 [#] , 2 [#] two Cavities running simultaneously
128-133	C	O	C	O	2 [#] , 4 [#] two Cavities running simultaneously
134-142	C	C	O	C	3 [#] meets the demand
143-147	O	C	O	C	1 [#] , 3 [#] two Cavities running simultaneously
147-150	C	C	O	O	3 [#] , 4 [#] two Cavities running simultaneously
151-272	C	O	O	C	2 [#] , 3 [#] two Cavities running simultaneously
273-275	C	O	O	O	1 [#] , 2 [#] , 3 [#] three Cavities running simultaneously
275-280	O	O	O	O	FourCavities running simultaneously

4. Conclusions

(1)Based on the thermodynamic characteristics of the gas injection and gas injection in the salt cavern gas storage, under the premise of meeting the requirements of the city's residual gas injection. If the multiple chambers in the combined gas injection operation are properly distributed, the compressor power consumption and the total temperature rise of the solution chamber can be effectively reduced, the economy of the gas injection operation of the gas storage tank can be improved, and the total storage capacity of the gas storage tank can be improved.Under the premise of satisfying the user's peaking demand, if the coordinated operation of multiple chambers is carried out, the total pressure drop of the gas storage operation can be significantly reduced, so as to avoid excessive pressure drop of individual chambers, and it can ensure the stability of each salt cavity in the gas storage operation of the gas storage.

(2) The volume of the underground cavity and the initial parameters of the cavity have a direct impact on the distribution of the gas injection volume and the thermal parameters of the cavity. When the gas storage multi-cavity is operated in combination, the solution chamber group with similar cavity volume and initial parameters should be selected to avoid the joint operation of multiple cavities with large capacity and thermal state.

(3) In the actual operation process of the salt cavern gas storage, in order to ensure the safety and stability of the operation process of the gas storage, the operators tend to maintain a stable operating state, that is, keep the injection rate of the cavity unchanged during a certain running time. However, the production planning and scheduling of the gas storage warehouse should be continuously adjusted according to the changes in the market gas supply demand, and the operation strategy of the multi-cavity of the gas storage tank has diverse characteristics. The production of salt cavern gas storage should be based on the principle of safe, stable and efficient operation of gas storage. At the same time, the feasibility of optimizing the production results should be considered to avoid the abnormal operation of the gas storage.

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