COMPUTATIONAL RESEARCH PROGRESS IN APPLIED SCIENCE & ENGINEERING (CRPASE)

CRPASE: TRANSACTIONS OF ELECTRICAL, ELECTRONIC AND COMPUTER ENGINEERING

Journal homepage: http://www.crpase.com

CRPASE: Transactions of Electrical, Electronic and Computer Engineering, Vol. 06(04), 232-237, December 2020 ISSN 2423-4591

Research Article

Analysis of Air Storage Model of Compressed Air Energy Storage

Ning Bai[1], Chang Lu[2], Shuangshuang Cui[2], Xiaoyu Guo[1], Yuchen Han[1], Han Wang[1], Qing He[2*]

[1] *State Power Investment Corporation Research Institute, Beijing 102209, China*
[2] *School of Energy Power and Mechanical Engineering, North China Electric Power University, Beijing 102206, China*

Keywords

CAES,
Air storage,
Model,
Thermodynamic,
Analysis.

Abstract

The traditional compressed air energy storage (CAES) technology requires the use of fossil fuels, which will cause environmental pollution and other problems. The development of advanced adiabatic CAES (AA-CAES) system is of great significance for promoting the development of energy storage technology. First, the development of CAES technology is studied and analyzed. Then, according to the thermodynamic characteristics of the air storage components of energy storage system, we build two general purpose air storage models. Finally, based on the thermodynamic characteristics of the two air storage models, the AA-CAES system model is established, and the thermodynamic characteristics of the system are compared and analyzed with different air storage models. There are great differences in the stability, efficiency, thermal utilization and thermodynamic properties of AA-CAES system when the different air storage models are used.

1. Introduction

Intermittentness, volatility and aperiodicity are important characteristics of new energy sources such as wind and solar energy, which are also important reasons for the instability of wind power and photovoltaic power generation systems. With the rapid development of wind power and photovoltaic industries, the phenomenon of abandonment of wind power and solar power is becoming more and more serious. So far, the only energy storage technologies that can be applied to the scale of 100MW are pumped water energy storage and compressed air energy storage (CAES) in the world. Although pumped energy storage has higher energy storage and conversion efficiency, the application of this technology has greater limitations due to higher requirements for terrain and water sources. Therefore, CAES technology is considered to be one of the important technical ways to solve the problems of abandonment of wind and abandonment of solar [1-3]. However, traditional CAES technology requires the use of fossil fuels, which will cause environmental pollution and other problems. At the same time, there is still a big gap in the research on the integrated application of wind power, photovoltaic and CAES technology. Therefore, it is very significance to design and develop a new type of green, efficient, and pollution-free CAES system and to carry out integrated application research on wind power, photovoltaic and CAES systems, which can improve the safety and stability of grid operation and the utilization rate of wind turbines, reduce abandonment of wind and abandonment of solar and promote the development of energy storage [4-7].

This paper combines theoretical analysis and simulation methods to carry out related research. First, through the research and analysis of the development status of CAES technology, the Advanced Adiabatic CAES (AA-CAES) system is the main research object. According to the thermodynamic characteristics of air storage (AS) components of energy storage system, two universal air storage models (constant volume adiabatic model and constant volume isothermal model) are constructed [8-11]. On the basis of obtaining the thermodynamic characteristics of the two air storage models, this paper firstly establishes the AA-CAES system model, then compares and analyzes the thermodynamic characteristics of the system using different air storage models, lastly, the correlation analysis

* Corresponding Author: Qing He
E-mail address: Hqng@163.com

Received: 12 August 2020; Revised: 15 October 2020; Accepted: 22 October 2020

Please cite this article as: N. Bai, Ch. Lu , Sh. Cui, X. Guo, Y. Han, H. Wang, Q. He, Analysis of Air Storage Model of Compressed Air Energy Storage, Computational Research Progress in Applied Science & Engineering, CRPASE: Transactions of Electrical, Electronic and Computer Engineering 6 (2020) 232–237.

between the system and the core components and parameters is completed.

Based on the basic theory of thermodynamics, the modeling and comparative analysis of AA-CAES systems using different air storage models is completed by starting from the air storage model and considering a variety of different types of air storage models; in addition, the correlation analysis between the system and the core components and parameters is carried out and the grasp of the operating characteristics of the AA-CAES system is completed.

2. AA-CAES System

The schematic diagram of the AA-CAES system is shown in Figure 1. The system generally mainly includes the following components: compressor, turbine, heat exchanger, heat storage, AS, heat carrier medium supply source, motor and generator. The working process of the AA-CAES system can be divided into two stages: energy storage and energy release [12-15].

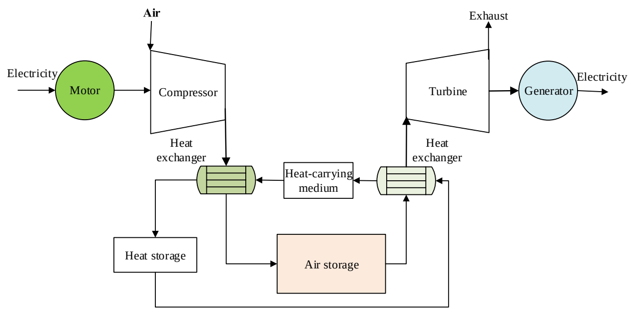

Figure 1. Schematic diagram of AA-CAES system

In the energy storage stage, the air compressed by the compressor enters the heat exchanger after being boosted and heated, and fully exchanges heat with the lower temperature heat carrier medium from the heat carrier medium supply source. After the air cools down, it enters the AS for storage; at the same time, the heat carrier medium after absorbing heat and increasing temperature enters the heat storage to store the absorbed heat.

In the energy release stage, the high-pressure and low-temperature air stored in the AS first enters the heat exchanger; then fully exchanges heat with the higher temperature heat carrier medium released by the heat storage, and enters the turbine to perform work after the temperature rises, finally, which be discharged to the atmosphere; meanwhile, the heat-carrying medium after heat exchange and cooling is recovered and stored by the heat-carrying medium supply source.

The AS is one of the core components of the AA-CAES system, and the study of its theoretical model is one of the current hot issues. Although some scholars have established air storage models with different characteristics, most of the air storage models are based on actual topography or for energy storage systems of a specific scale, so the generality of the models is poor. Considering the versatility and typicality of the air storage model, the two most basic air storage thermodynamic characteristic models are established, which are shown in Table1.

Table 1 Air storage mode

Mode	Abbreviation	Characteristic
Constant volume isothermal model	VT	The volume of the ASR is constant and the temperature is constant
Constant volume adiabatic model	VA	The volume of the ASR is constant and it is insulated from the outside

These two models are constructed based on the characteristics of the ASR in terms of pressure, volume, temperature and insulation. For the enclosed space formed by the AS, according to the energy conservation equation, we can get

$$\delta Q = \mathrm{d}U_{\mathrm{CV}} + h_{\mathrm{out}}\delta m_{\mathrm{out}} - h_{\mathrm{in}}\delta m_{\mathrm{in}} + \delta W \tag{1}$$

where, δQ is the heat transfer between the AS and the external environment, taking heat absorption as positive, J; δW is the amount of work done by the AS to the external environment, taking the external work as positive, J; δm is the air quality in the air storage room, kg ; h is the specific enthalpy of air, J/kg; $\mathrm{d}U_{CV}$ is the amount of change in the internal energy of the AS, J; subscripts in and out represent entering and leaving the AS respectively.

Based on the environmental state, when the temperature of the air is T, the specific enthalpy is defined as

$$h = c_{\mathrm{p}}(T - T_0) \tag{2}$$

According to the relationship between specific enthalpy h and specific internal energy u, the expression of specific internal energy u can be obtained as

$$u = h - pv = c_{\mathrm{v}}T - c_{\mathrm{p}}T_0 \tag{3}$$

where, T_0 is the ambient temperature, K; c_{p} is the specific heat capacity of air at a constant pressure, J/(kg·K); is the specific heat capacity of air at constant volume, J/(kg·K).

3. VT model

The basic characteristics of the constant-volume isothermal model of the AS are that the volume is constant and the temperature is constant (which is assumed to be equal to the ambient temperature T_0). The air storage process and air release process are analyzed separately below.

3.1. Air Storage Process of VT Mode

The temperature of the air entering the ASR is assumed to be T_{in} and the pressure is p. Taking the ASR as the control volume, the VT model has a constant volume and a constant temperature, which is no power exchange with the external environment. If the leakage problem of the ASR is not considered, that is, no air leaves the AS during the storage process, so the energy conservation Eq. can be simplified as

$$\mathrm{d}(mu) = h_{\mathrm{in}}\mathrm{d}m + \delta Q \tag{4}$$

Substituting the expressions of specific enthalpy and specific internal energy into the above formula respectively, we can get

$$(c_{\mathrm{v}}T_0 - c_{\mathrm{p}}T_{\mathrm{in}})\mathrm{d}m = \delta Q \tag{5}$$

It can be seen that in order to ensure a constant temperature in the AS, the VT model needs to exchange heat with the environment. If the inlet air temperature $T_{in}=T_0$, according to the ideal gas state equation, the above equation is simplified as

$$\delta Q = -R_g T_0 \mathrm{d}m = -V\mathrm{d}p \qquad (6)$$

where, R_g=287.1J/(kg·K), which is the air constant.

Assuming that p_1 and p_2 are respectively the lower pressure limit and upper pressure limit of the ASR, after integrating the above formula, we can get

$$Q = V(p_1 - p_2) \qquad (7)$$

Therefore, for the VT model, the amount of heat exchange between the external environment and the AS during air storage process is related to the volume of the AS and the difference between the upper and lower pressure limits of the ASR. Since $p_1<p_2$, $Q<0$, that is, the AS releases heat to the external environment during the air storage process.

According to the ideal air state equation, the relationship between the air quality in the AS and other parameters can be obtained as

$$\mathrm{d}m = \frac{V}{R_g T_0}\mathrm{d}p \qquad (8)$$

3.2. Air Release Process of the VT Mode

During the air release process, the AS is still used as the control volume. According to the deflation characteristics of the AS, the energy conservation equation is simplified

$$\mathrm{d}(mu) = \delta Q - h_{out}\delta m = \delta Q + h_{out}\mathrm{d}m \qquad (9)$$

Since the outlet air temperature is T_0, $h_{out}= c_p(T_0-T_0) =0$. So the above formula is simplified to

$$\delta Q = -R_g T_0 \mathrm{d}m \qquad (10)$$

Similarly, after integrated, we can get

$$\delta Q = V(p_2 - p_1) \qquad (11)$$

It can be known from Eq.(11) that for the VT model, there is also a heat exchange phenomenon with the external environment during the air release process. And compared with the heat exchange between the AS and the external environment during the air storage process, the amount of heat transfer is equal, but the transfer direction is opposite. Therefore, during the air release process, the AS absorbs heat from the external environment, and the amount of heat absorbed is equal to the amount of heat released during the air storage process.

4. VA Mode

The main features of the constant volume adiabatic model are that the volume is constant and there is no heat exchange with the external environment. The air storage process and air release process of the VA model are analyzed respectively.

4.1. Air Storage Process of VA Mode

Referring to the analysis ideas of VT model's air storage process, the VA model has a constant volume and is in adiabatic state, so there is no heat and power exchange between the VA model and the environment. Therefore, the energy conservation Eq. can be simplified to

$$\mathrm{d}(mu) - h_{in}\mathrm{d}m = 0 \qquad (11)$$

Substituting the expressions of specific enthalpy and specific internal energy into the Eq. (12), we can get

$$\mathrm{d}(mu) = \frac{V}{T_{in}R_g\gamma}\mathrm{d}p \qquad (12)$$

4.2. Air release Process of the VA Mode

The VA model has no heat and power exchange with the environment during the air release process. Taking the VA model as the control volume, the energy conservation equation for the air release process of the VA model can be obtained as

$$\mathrm{d}(mu) + h_{out}\delta m = 0 \qquad (13)$$

Considering that δm=-dm and $h_{out}=h$, the Eq.(14) can be simplified as

$$m\mathrm{d}u + u\mathrm{d}m = h\mathrm{d}m$$
$$m\mathrm{d}u = (h-u)\mathrm{d}m = R_g T\mathrm{d}m \qquad (14)$$
$$\frac{\mathrm{d}m}{m} = \frac{c_v}{R_g}\frac{\mathrm{d}T}{T}$$

According to the ideal gas equation of state

$$\frac{\mathrm{d}p}{p} + \frac{\mathrm{d}V}{V} - \frac{\mathrm{d}T}{T} - \frac{\mathrm{d}m}{m} = 0 \qquad (15)$$

Eliminate the temperature parameter, we can get

$$\frac{\mathrm{d}m}{m} = \frac{c_v}{c_p}\frac{\mathrm{d}p}{p} = \frac{1}{\gamma}\frac{\mathrm{d}p}{p} \qquad (16)$$

Finally, we can get

$$\mathrm{d}m = \frac{V}{TR_g\gamma}\mathrm{d}p \qquad (17)$$

According to the above formula, it can be deduced that the air in the AS in the VA model will undergo a reversible adiabatic process during the air release process.

5. Influence of Air Storage Model

In order to compare and analyze the thermos- dynamic characteristics of the AA-CAES system using different air storage models conveniently, firstly, the parameters of several air storage models are set to ensure the comparability of these models.

For the VT model and the VA model, it is assumed that the initial air temperature of the AS is $T_{s1}=T_0$, the lower and upper pressure limits of the air storage chamber with volume

V are $p_1$and p_2 respectively. Therefore, the initial volume V_1 of the AS can be obtained based on equal air quality, namely

$$V_1 = \frac{p_1 V}{p_s} \tag{19}$$

In summary, the parameter settings of several models are shown in Table 2.

Table 2. Parameters setting of air model

Parameter	VT mode	VA mode
Initial temperature	T_0	T_0
Initial pressure	p_1	p_1
Initial volume	V	V
Maximum pressure	p_2	p_2
Maximum volume	V	V

On the basis of the above parameters, a air storage process and a air release process are regarded as a cycle, and the state changes in the AS when several air storage models undergo multiple cycles are analyzed, and the cycle times is recorded as n. Assuming that the initial state of the first cycle is $T_{s1}=T_0(T_{s1}/T_0=1)$, the initial pressure is 5 times the ambient pressure ($p_1/p_2=5$), and the maximum pressure is 10 times the ambient pressure at the end of the air storage process ($p_2/p_0=10$)。 If the upper and lower pressure limits of each cycle are the same, and the state changes of the parameters in the AS during the process transition are not considered, then after multiple cycles, for the VT model, the temperature in the AS always satisfies $T_{s1}=T_0(T_s/T_0=1)$, which is shown in Figure 2.

For the VA model, the variation of temperature parameters with cycle times is shown in Figure 3. In this figure, T_{sl} is the initial temperature in the ASR at the beginning of each cycle, T_{s2} is the final temperature in the AS at the end of each cycle's air storage process, and T_{s3} is the final temperature in the AS at the end of each cycle's air release process. Meanwhile, this is also the initial temperature at the beginning of the next cycle. It can be seen from Fig.3 that the temperature T_{s1}, T_{s2} and T_{s3} in the VA model changes with the increase of cycle times. On the whole, as cycle times n increases, the temperature in the AS gradually decreases and eventually stabilizes. When the cycle times tends to infinity, we can get $T_{s2}/ T_0=1.093$ and $T_{s1}/ T_0=T_{s3}/ T_0=0.897$.

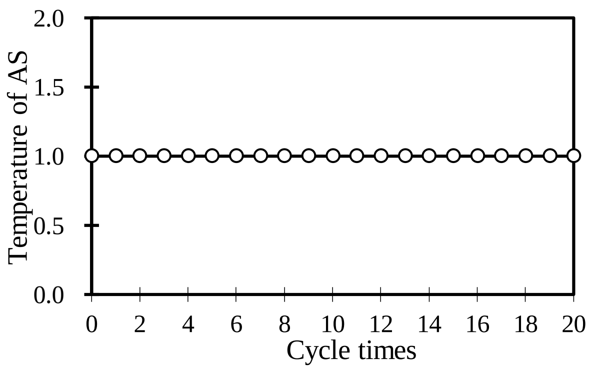

Figure 2. Temperature of air storage vs cycle times

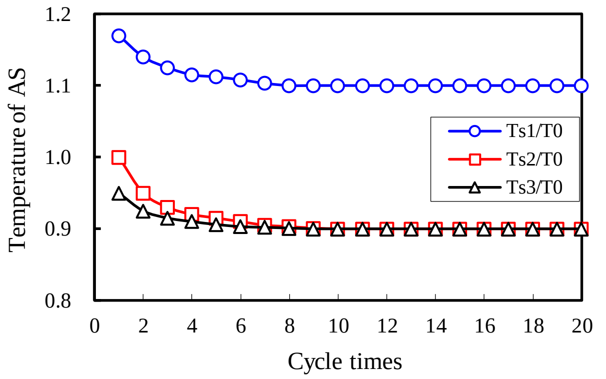

Figure 3. Air storage temperature of VA model vs. cycle times

In addition, according to the basic equation of the VA model in the process of air storage and release, the stable value of the temperature of the VA model can also be obtained by

$$T_{s2} = \frac{\beta_2 T_{s1}}{\frac{T_{s1}}{T_0}\frac{\beta_2 - \beta_1}{\gamma} + \beta_1} \tag{20}$$

$$T_{s3} = T_{s2}\left(\frac{\beta_1}{\beta_2}\right)^k \tag{21}$$

Therefore, for the AA-CAES system using different air storage models, when the AA-CAES system is in continuous energy storage and energy release working state (without considering the change of the system state parameters during the conversion of the process), it is affected by the different air storage and release characteristics of several air storage models, so the operating characteristics of the AA-CAES system are different:: First of all, when the AA-CAES system adopts the VT model, since the temperature changes in the two air storage models are independent of the cycle times, the operation of the AA-CAES system is also in a stable state and does not change with the increase of cycle times. Secondly, when the AA-CAES system adopts the VA model, because the parameter status in the ASR changes with the increase of cycle times, the operating status of the AA-CAES system fluctuates. However, as the cycle progresses, the AA-CAES system will also reach a stable working state with the parameters in the AS will eventually stabilize. In addition, since the final state of the VA model parameters is related to the upper and lower pressure limits, and the initial temperature of the AS will also have a certain effect on the final equilibrium state of the ASR, the final stable working state of the AA-CAES system will be directly related to the above parameters.

Taking N=1 as an example, based on the parameter settings in Table 2, when the AA-CAES system adopts different air storage models, the expressions of dimensionless work and heat in the energy storage stage and the energy release stage are as shown in Table 3. It can be seen from this table that when the air storage model adopted by the system is different, the amount of work and heat of the system in the energy storage and energy release stages are different.

Table 3. The work and heat of AA-CAES with air storage model

Mode	Parameter	Result
VT	Input work	$\frac{W_c}{p_0V}=\frac{1}{k}[\frac{1}{k+1}(\beta_2^{k+1}-\beta_1^{k+1})-(\beta_2-\beta_1)]$
	Heat storage	$\frac{Q_c}{p_0V}=\frac{\varepsilon}{k}[\frac{1}{k+1}(\beta_2^{k+1}-\beta_1^{k+1})-(\beta_2-\beta_1)]$
	Output work	$\frac{W_t}{p_0V}=\frac{1}{k}\frac{T_h}{T_0}[(\beta_2-\beta_1)-\frac{1}{1-k}(\beta_2^{1-k}-\beta_1^{1-k})]$
	Input heat	$\frac{Q_t}{p_0V}=\frac{\varepsilon}{k}(\frac{T_w}{T_0}-1)(\beta_2-\beta_1)$
VA	Input work	$\frac{W_c}{p_0V}=\frac{1}{k\gamma}[\frac{1}{k+1}(\beta_2^{k+1}-\beta_1^{k+1})-(\beta_2-\beta_1)]$
	Heat storage	$\frac{Q_c}{p_0V}=\frac{\varepsilon}{k\gamma}[\frac{1}{k+1}(\beta_2^{k+1}-\beta_1^{k+1})-(\beta_2-\beta_1)]$
	Output work	$\frac{W_t}{p_0V}=\frac{1}{k\gamma}\{[\varepsilon\frac{T_w}{T_2}\beta_2^k-(1-\varepsilon)]\frac{1}{1-k}(\beta_2^{1-k}-\beta_1^{1-k})$ $+(1-\varepsilon)(\beta_2-\beta_1)-\varepsilon\frac{T_w}{T_2}\beta_2^k\frac{1}{1-2k}(\beta_2^{1-2k}-\beta_1^{1-2k})\}$

The electrical efficiency $\eta_W=W_t/W_c$ (The ratio of the output electric energy in the energy release stage to the input electric energy in the energy storage stage) and the heat utilization rate $\eta_Q=Q_t/Q_c$(The ratio of the heat used in the energy release stage to the stored heat in the energy storage stage) are defined by selecting the parameters in Table 4, and the results of parameters such as work, heat and efficiency of the AA-CAES system when using different air storage models under the condition of N=1 are shown in Table 5.

According to the previous analysis, the parameter results of the AA-CAES system using the VT model are independent of cycle times and the parameters such as work, heat and efficiency are constant values due to the stable model characteristics of the VT model during multiple cycles. As the parameters of the VA model change with increasing cycle times, the work, heat, and efficiency parameters of the AA-CAES system using the VA model also change. The specific changes are shown in Figure 4, Figure 5 and Figure 6. It can be seen from these figures that when the system adopts the VA model, the work, heat and efficiency parameters of the AA-CAES system achieve the minimum value at the first cycle; as the cycle times increases, the results of the work, heat and efficiency parameters of the system achieve the maximum value and stabilize.

Table 4. The parameters of AA-CAES

Item	Symbol	Unit	Value
Ambient temperature	T_0	K	293
Ambient pressure	p_0	MPa	0.1
Minimum pressure of AS	p_1	MPa	0.5
Maximum pressure of AS	p_2	MPa	1.0
AS volume	V	m^3	1
Specific heat ratio	γ	-	1.4
Heat exchanger efficiency	ε	-	0.7
Gas constant of air	R_g	J/(kg·K)	287
Specific heat capacity of air at constant pressure	c_p	J/(kg·K)	1000
Specific heat capacity of heating medium (water)	c_w	J/(kg·K)	4200

Table 5. Parameters of AA-CAES with air storage models

Item	VT	VA(n=1)	VA($n\to\infty$)
W_c/p_0V	13.50	9.64	9.64
Q_c/p_0V	9.45	6.75	6.75
W_t/p_0V	10.47	7.09	7.45
Q_t/p_0V	6.64	3.90	4.75
$Q_{s,in}/p_0V$	5.00	0.00	0.00
$Q_{s,out}/p_0V$	5.00	0.00	0.00
η_W(%)	77.6	73.5	77.3
η_Q(%)	70.3	57.8	70.3
T_W(K)	451.90	451.90	451.90

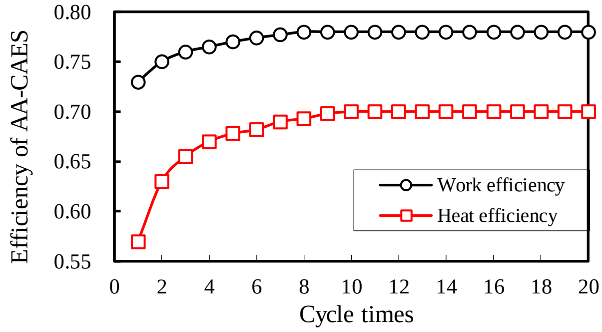

Figure 4. Efficiency of AA-CAES with VA vs. cycle times

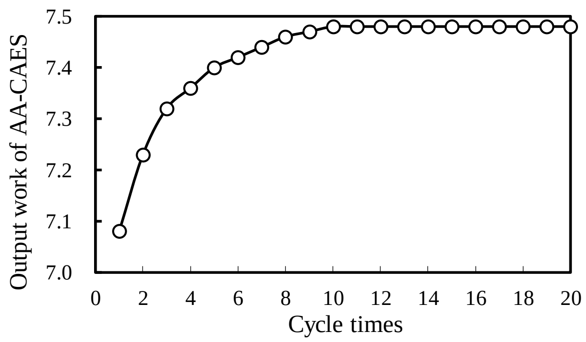

Figure 5. Output work of AA-CAES with VA vs cycle times

According to the results in Table 5, under the same pressure conditions, when the AA-CAES system adopts the VT model, the dimensionless value of the work and heat of the system is greater than that of the VA model; when the system uses the VT model, the work and heat are about 1.4 times the result (stable value) of the system using the VA model. Although the dimensionless value of the work and heat of the AA-CAES system corresponding to the VA model changes with increasing cycle times, the maximum value (stable value) is still smaller than the result of the VT model.

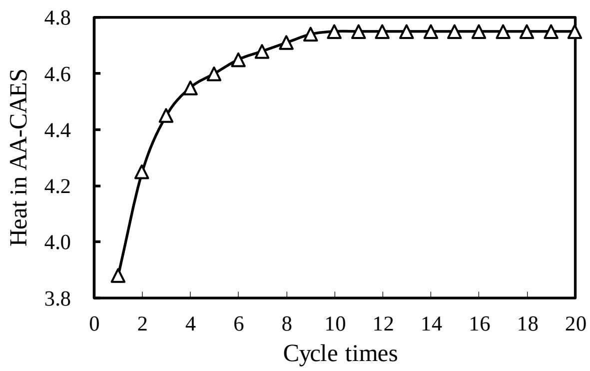

Figure 6. Heat of AA-CAES with VA vs. cycle times

From the perspective of efficiency, although when the cycle times is low, the η_W and η_Q of the AA-CAES system using the VA model are lower than the results of other VT models, as the cycle times increases, the AA-CAES system using the VA model increases monotonically and reaches its maximum value. For the VA model itself, the η_W and η_Q of the system using the VA model when the number of cycles n=1 are lower by 3.8% and 12.5% than the corresponding results when $n \to \infty$ respectively; under stable conditions, the η_Q of the AA-CAES system using the VA model is the same as the result of the VT model air storage model, and the η_W is 0.3% lower than that of the VT model.

It should be pointed out that the VT model exchanges heat with the environment during air storage and release process, and this part of the heat does not take into account the η_Q.

In summary, compared to the VA model, the AA-CAES system using the VT model runs more stably, moreover, the work and heat values are independent of the cycle times. For the AA-CAES system using the VA model, the working state of the system will gradually stabilize with increasing cycle times. In addition, the AA-CAES system using the VT model has the highest η_W under the same conditions of the η_Q from the perspective of system efficiency.

6. Conclusions

(a) According to the characteristics of the ASR in terms of pressure, volume, temperature and insulation, two general air storage models (VA model, VT model) are constructed, and the air storage and release characteristics of the two models are analyzed. The results show that the VT model has strong stability during the process of air storage and release process; the parameters of the VA model change with increasing cycle times and eventually tend to a stable value, which is related to the upper and lower pressure limits of the air storage model.

(b) The AA-CAES system has differences in stability and thermodynamic characteristics when using different air storage models. Since the VT model has stable characteristics during air storage and release process, the parameters of the AA-CAES system using the VT model have nothing to do with the cycle times, and the system operating characteristics and thermodynamic parameters remain stable. With increasing cycle times, the thermodynamic parameters of the AA-CAES system using the VA model will change, and the parameters such as work, heat and efficiency will increase with the increase of cycle times and eventually stabilize.

(c) Comparing the η_W, η_Q and other parameters of the AA-CAES system using different air storage models, it can be found that the η_W of the system using the VA model increases by about 3.8% with increasing cycle times by comparing the initial and stable values of the η_W of the system using the VA model under the same working conditions.

Conflict of Interest Statement

The authors declare no conflict of interest.

References

[1] J. Bai, W. Wei, L. Chen, S. Mei, Modeling and dispatch of advanced adiabatic compressed air energy storage under wide operating range in distribution systems with renewable generation, Energy, 2020, 206:1-43.

[2] Y. Zhang, Y. Xu, X. Zhou, H. Guo, X. Zhang, H. Chen, Compressed air energy storage system with variable configuration for accommodating large-amplitude wind power fluctuation, Applied Energy, 2019, 239: 957-968.

[3] B. Ghorbani, M. Mehrpooya, A. Ardehali, Energy and exergy analysis of wind farm integrated with compressed air energy storage using multi-stage phase change material, Journal of Cleaner Production 259 (2020)1–15.

[4] X. Xu, W. Hu, D. Cao, Q. Huang, W. Liu, Z. Liu, Z. Chen, H. Lund, Designing a standalone wind-diesel-CAES hybrid energy system by using a scenario-based bi-level programming method, Energy Conversion and Management 211 (2020)1–19.

[5] Z. Han, Y. Sun, P. Li, Research on energy storage operation modes in a cooling, heating and power system based on advanced adiabatic compressed air energy storage. Energy Conversion and Management 208 (2020) 1–14.

[6] S. Koohi-Fayegh, M.A. Rosen, A review of energy storage types, applications and recent developments, Journal of Energy Storage 27 (2020) 1–23.

[7] A. S. Alsagri, A. Arabkoohsar, A. A. Alrobaian, Combination of subcooled compressed air energy storage system with an organic Rankine cycle for better electricity efficiency, a thermodynamic analysis. Journal of Cleaner Production 239 (2019) 1–15.

[8] H. Meng, M. Wang, O. Olumayegun, X. Luo, X. Liu, Process design, operation and economic evaluation of compressed air energy storage (CAES) for wind power through modelling and simulation, Renewable Energy 136 (2019) 923–936.

[9] J. Zhan, O. A. Ansari, W. Liu, C.Y. Chung, An accurate bilinear cavern model for compressed air energy storage, Applied Energy 242 (2019) 752–768.

[10] H. Qing, W. Lijian, Z. Qian, L. Chang, D. Dongmei, L. Wenyi, Thermodynamic analysis and optimization of liquefied air energy storage system, Energy 173 (2019) 162–173.

[11] Y. Zhou, C. Xia, H. Zhao, S. Mei, S. Zhou, An iterative method for evaluating air leakage from unlined compressed air energy storage (CAES) caverns, Renewable Energy 120 (2018) 434–445.

[12] S. Zhou, J. Zhang, W. Song, Z. Feng, Comparison analysis of different compressed air energy storage systems, Energy Procedia 152 (2018) 162–167.

[13] Z. Han, S. Guo, S. Wang, W. Li, Thermodynamic analyses and multi-objective optimization of operation mode of advanced adiabatic compressed air energy storage system, Energy Conversion and Management 174 (2018) 45–53.

[14] P. Li, C. Yang, L. Sun, J. Xiang, X. Wen, J. Zhong, T. Deng, Dynamic characteristics and operation strategy of the discharge process in compressed air energy storage systems for applications in power systems. International Journal of Energy Research 44 (2020) 6363–6382.

[15] Q. He, G. Li, C. Lu, D. Du, W. Liu, A compressed air energy storage system with variable pressure ratio and its operation control. Energy 169 (2019) 881–894.