Performance Study of Salt Cavern Air Storage Based Non-Supplementary Fired Compressed Air Energy Storage System

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Abstract. Large-scale energy storage system (ESS) plays an important role in the planning and operation of smart grid and energy internet. Compressed air energy storage (CAES) is one of promising large-scale energy storage techniques. However, the high cost of the storage of compressed air and the low capacity remain to be solved. This paper proposes a novel non-supplementary fired compressed air energy storage system (NSF-CAES) based on salt cavern air storage to address the issues of air storage and the efficiency of CAES. Operating mechanisms of the proposed NSF-CAES are analysed based on thermodynamics principle. Key factors which has impact on the system storage efficiency are thoroughly explored. The energy storage efficiency of the proposed NSF-CAES system can be improved by reducing the maximum working pressure of the salt cavern and improving inlet air pressure of the turbine. Simulation results show that the electric-to-electric conversion efficiency of the proposed NSF-CAES can reach 63.29% with a maximum salt cavern working pressure of 9.5 MPa and 9 MPa inlet air pressure of the turbine, which is higher than the current commercial CAES plants.

1. Introduction

With the pressure of environment and energy issues, renewable energy such as wind and solar have been developed rapidly [1, 2]. However, due to the intermittent and stochastic characteristic, large-scale integration of such renewable energies into power system is challengeable. Energy storage techniques provide a new insight for this phenomenon by capturing the features of load shifting, smoothing renewable energy output, and improving the safety operation of power grid [3, 4].

Compressed air energy storage (CAES) is one of the most prominent large-scale energy storage techniques [5, 6]. The CAES technique has no strict requirements on geographical condition and many researchers have been focused on the design [7, 8], control [9], and optimization [10]. The conventional CAES system is composed of compressor, air storage chamber, gas combustion, turbine, generator, etc.[11, 12]. Air storage chamber is the energy storage equipment while the compressor and the turbine are the energy conversion devices as well as the interface with power grid. The world-wide two commercial CAES power stations including the Huntorf plant and McIntosh plant are respectively built in 1978 and 1991[13, 14]. The electric-to-electric conversion efficiency of these two plants can reach 33%-46% and 54% on average, respectively. Both of them are still in operation until now [13].

The above two plants both adopted a supplementary fired CAES (SF-CAES) architecture [15]. However, it consumes fossil fuels, which brings about emission problems. Therefore, the non-supplementary fired CAES (NSF-CAES) technology is developed from the conventional SF-CAES [16]. In contrast, heat regeneration is the one that collected and stored thermal energy during
compression, and then used to preheat inlet air of the turbine, which eliminates the dependence on fossil fuels, and enables the zero-carbon-emission during system operation in NSF-CAES.

Advanced adiabatic compressed air energy storage (AA-CAES) and TICC-500 [8] are representatives of NSF-CAES systems. By the cascade utilization of the collected heat to preheat inlet air of the turbine, its electric-to-electric conversion efficiency is expected to reach 41%. However, the high-pressured air in TICC-500 is stored in a high-pressure container, which both reduces the system capacity and results in high cost. Advanced high-pressure air storage techniques are needed for the further development of NSF-CAES technique [17].

This paper presents a novel NSF-CAES system scheme with salt cavern air storage based on our previous system TICC-500. The rest of this paper is organized as follows. Available salt cavern distribution and non-supplementary CAES system diagram based on salt cavern air storage is proposed in Section 2. Systematic thermodynamic is analysed in Section 3. Systematic performance analysis is elaborated in Section 4. Conclusions are drawn in Section 5.

2. Salt cavern air storage based NSF-CAES
As indicated previously, air storage is a key factor for the implement of such compression heat feedback based NSF-CAES. As a mature technology, salt cavern has been used widely in the natural gas storage. It has merits such as large capacity, higher storage pressure, and lower construction cost, which meets the requirements of NSF-CAES. In this respect, we carried out researches on NSF-CAES based on the salt cavern air storage in this section.

2.1. System configuration
At present, the major underground gas storage methods includes depleted oil and gas reservoir, water aquifer air storages, discharge gas pit and salt cavern gas storage [19]. Salt cavern gas storage technology uses the artificial cavity in salt bed or salt dome to store high pressure gas. Compared with other existed gas storage methods, salt cavern gas storage captures the advantages of large capacity, stable reliability, low cost, good seal, and long service life. Salt cavern gas storage has become an important part of the natural gas gathering and transportation system in China.

The use of salt cavern for gas storage can date back to 1960s. In 1961, the world's first salt cavern natural gas storage station was built in Michigan. Subsequently, France, Germany, Britain and Denmark built many salt cavern gas storage stations. China also carried out the studies on salt cavern gas storage. The available salt caverns distribution in East China by 2015 illustrate in Figure 1 and corresponding available volume is shown in

Table 1.

![Figure 1. Available salt cavern distribution in East China by 2015.](image)
Table 1. Available salt cavern volume in East China by 2015.

| No. | Salt cavern name | Province | Available Volume (×10^6 m^3) |
|-----|------------------|----------|-------------------------------|
| 1   | Jintan           | Jiangsu  | 14.3                          |
| 2   | Huan’an          | Jiangsu  | 10                            |
| 3   | Pingdingshan     | Henan    | 4                             |
| 4   | Yingcheng       | Hubei    | 8                             |
| 5   | Zhangshu         | Jiangxi  | 10                            |
| 6   | Qianjiang        | Hubei    | 4                             |

Specially, a huge salt cavern storage system with the storage volume of (10-15)×10^6 m^3 was built in Jintan City, Jiangsu Province. This salt cavern is selected as a potential site for building a 10 MW/100 MWh NSF-CAES plant. Therefore, it is practical to develop salt cavern based NSF-CAES system in China [20].

The flow chart of NSF-CAES with 2-stage compression and 2-stage expansion architecture based on salt cavern air storage depicted in Figure 2. In this system, thermal energy storage is applied to recycle the compression heat. The compression heat stored in TES system is used to heat the inlet air of the turbine, which improves the energy storage efficiency of the system.

![Figure 2](image_url)

**Figure 2.** Diagram of salt cavern air storage based non-supplementary CAES system.

The proposed salt cavern air storage based NSF-CAES has the following advantages: First, salt cavern based air storage technique is widely used in natural gas storage fields supported by mature techniques. Second, salt cavern based air storage technique can guarantee a narrow pressure range, which is of great value for the stable and efficient operation of compressor and turbine, to yield a high-efficiency CAES. Third, salt cavern based air storage technique can save system cost, which is vital to the engineering application of this technique in smart grid and energy internet.

2.2. Operation mechanism

Operation of the proposed NSF-CAES system involves two basic processes: charging and discharging. In charging, ambient air is compressed to the high pressure by a 2-stage compressor. Then the high pressure air is stored in salt cavern. Meantime, the TES system recycles the compression heat generated with compression process. The electrical energy is converted into heat energy and potential energy of molecular [8]. While in discharging, the high pressure air is released from the salt cavern and heated by the heat energy stored in TES. The hot air expands in the first stage of the turbine and...
generate electricity. After first stage expansion, both the pressure and temperature of the air decrease. The air is then heated again by the stored heat energy and expands in the second stage of the turbine to produce electricity.

The two-stage compression structure guarantees the compressor-discharged temperature less than 380°C, thus conventional industrial centrifugal compressors can satisfy the demand, which get rid of the limit of high temperature compressor. The TES system consists of cold tank, hot tank, working fluid, circulating pump, and heat exchanger. VP1, with high temperature characteristic, utilize as the heat storage medium. Maximum temperature of VP1 can reach to 398°C. To prevent the solidification of oil, the lowest temperature of heat conduction oil should higher than 30°C, and it driven by the oil-circulating pump. In heat exchanger 1 and 2, the compression heat is recycled and stored in the hot tank. In heat exchanger 3 and 4, the air is heated by high temperature oil, thus the reuse of compression heat is realized. Using the recycled heat stored in the TES to increase inlet air of the turbine temperature to 350°C, which greatly improves the system output power and the energy conversion efficiency. The pressure fluctuation of gas storage chamber is relatively small due to the huge volume of the salt cavern, so the system can operate more stable.

3. Systematic thermodynamic analysis

Thermodynamic analysis of the NSF-CAES based on salt cavern air storage is carried out in this section, following assumptions are made for the simplify of the analysis:

- The air is the ideal air, i.e., meets the ideal gas state equations;
- The mass flow rate of the compressor in charging and the mass flow rate of turbine in discharging are constant;
- The air storage chamber adopts the isothermal model, i.e., the air in air storage chamber can exchange heat sufficiently with the external environment, and the temperature of the air is equal to the ambient temperature during the whole charging and discharging process [7];
- The rated compression ratio is same in each stage, and the expansion ratio is also equal in each stage;
- The mechanical loss of the compressor, turbine and generator are considered with efficiency factor.

3.1. Compressor

The off-peak electricity, curtailed wind, solar and hydro power are used to compress the air to high pressure. In this process, with the increase of pressure in the salt cavern, the discharging pressure also increases, leading to the non-stationary operation of compressor [18]. The power consumed by compressor grows with the increase of the discharging pressure. Therefore, the first-stage compressor is working in rated operation conditions, while the second-stage is not.

During compression, the electric power consumed by i-stage compressor satisfies:

\[
W_{c,i} = \frac{1}{\eta_{ci}} \frac{k}{k-1} R_g T_{ca,i}^m \left( \frac{p_{cai}}{p_{cai}} \right)^{\frac{k-1}{k}} - 1
\]

where \( \eta_{ci} \) is the adiabatic compression efficiency, \( k \) is the specific heat ratio, \( R_g \) is the gas constant, \( T_{ca,i}^m \) is the inlet air temperature, \( q_{m,c} \) is the mass flow rate of compressor, \( p_{cai}^m \) and \( p_{cai}^o \) are the inlet and outlet air pressure respectively. For simplicity, a two-stage compressor is utilized in the proposed salt cavern based NSF-CAES system. Thus, the total electricity consumption in charging can be determined by:

\[
W_c = \eta_c \sum_{i=1}^{2} W_{c,i} t_c
\]

where \( \eta_c \) is the efficiency of motor, \( t_c \) the compression time. The outlet air temperature of i-stage compressor is:
3.2. Salt cavern

Usually, the air in the salt cavern can exchange heat with the ambient through salt cavern surface, so the salt cavern adopts the isothermal model. The air temperature of salt cavern and the temperature of salt cavern surface keep constant during the whole charging and discharging process.

3.2.1. Air charging. The inner air pressure of salt cavern $P_{\text{cav}}$ is equal to the high pressure air from the last stage exchanger, i.e., heat exchanger 2 in Figure 2 while the temperature is equal to the ambient $T_{\text{cav}} = T_0$. In charging, the air energy conservation equation in salt cavern is [12]

$$d(mu) = h_{\text{in}}dm + Q$$

(4)

In equation (4), $h_{\text{in}} = C_pT_{\text{cav}}^{\text{in}}$, $u = C_vT_{\text{cav}}$. Thus:

$$Q = (C_vT_0 - C_pT_{\text{cav}}^{\text{in}})dm$$

(5)

Under the condition of $T_{\text{cav}}^{\text{in}} = T_0$, we have

$$Q = -VdP_{\text{cav}}$$

(6)

The state equation for ideal air in salt cavern is

$$dP_{\text{cav}} = \frac{R_gT_0}{V}dm$$

(7)

Assuming that, the initial air pressure in storage room is $P_{\text{cav},1}$. Air pressure in salt cavern increases gradually during charging. By integrating equation (7), we have the state of charge (SOC) of the salt cavern:

$$P_{\text{cav}} = P_{\text{cav},1} + \frac{q_{\text{m}}R_gT_0}{V}t$$

(8)

3.2.2. Air discharging. Similar with equation (4), the energy conservation process in salt cavern during discharging can be illustrated as:

$$d(mu) = -h_{\text{out}}dm + Q$$

(9)

In equation (9), $h_{\text{out}} = C_pT_{\text{cav}}^{\text{out}}$, $u = C_vT_{\text{cav}}$. Thus:

$$Q = -R_gT_0dm = -VdP_{\text{cav}}$$

(10)

From above analysis, heat exchange between the high pressure air in the salt cavern and the ambient is existed in charging and discharging.

3.3. Turbine and generator

To ensure a stable power output of the turbine, throttle valve is used to adjust the inlet air pressure of the turbine. Usually, the inlet air pressure of turbine is inlet air pressure of the first stage turbine, and equals to the minimum working pressure of salt cavern.

For each stage $i$ of the turbine, the actual output shaft power is

$$W_{\text{e},i} = C_pq_{\text{m},i}T_{\text{e},i}n_{\text{e},i}\left[1 - \left(\frac{p_{\text{cav},i}}{p_{\text{cav},\text{out},i}}\right)^{\frac{k-1}{k}}\right]$$

(11)

The illustrated turbine in figure 2 adopts a two-stage architecture, thus, the actual electricity output of the whole turbine is
\[ W_e = \eta_e \sum_{i=1}^{2} W_{e,i} t_e \]  

where \( \eta_{e,i} \) is the adiabatic efficiency of \( i \)-stage of turbine, \( \eta_e \) is the generator efficiency, \( q_{me} \) is the air mass flow rate of the turbine, \( p_{ea,i}^{in} \) and \( p_{ea,i}^{out} \) are the inlet and outlet air pressure of the turbine, respectively, \( T_{ea,i}^{in} \) is the inlet air temperature and \( t_e \) is the turbine generation time.

3.4. Heat exchange

3.4.1. Recycling compression heat. The TES captures the function of recycling and reusing the compression heat, thus improves the system efficiency.

In charging, heat storage medium in heat exchanger 1 and 2 is heated by high pressure air from compressor, so the recycling of compression heat is fulfilled. The efficiency of heat exchanger is defined by [21].

\[ \varepsilon = \frac{(c_p q_m)_{1} (T_{1}^{in} - T_{1}^{out})}{(c_p q_m)_{in} (T_{1}^{in} - T_{2}^{out})} = \frac{(c_p q_m)_{2} (T_{2}^{out} - T_{2}^{in})}{(c_p q_m)_{in} (T_{1}^{in} - T_{2}^{in})} \]  

where subscript '1' stands for hot fluid, i.e., air, '2' cold fluid, i.e., heat conduction oil. Superscript 'in' is the inlet of heat exchanger, 'out' the outlet of heat exchanger.

For the \( i \)-stage cooler of adiabatic CAES system, the hot fluid inlet temperature is \( T_{ca,i}^{out} \), outlet temperature is \( T_{ca,i+1}^{in} \), the cold fluid inlet temperature is \( T_{cw,i}^{in} \). The relationship between \( T_{ca,i}^{out} \), \( T_{ca,i+1}^{in} \) and \( T_{cw,i}^{in} \) can be denoted as

\[ T_{ca,i+1}^{in} = (1 - \varepsilon) T_{ca,i}^{out} + \varepsilon T_{cw,i}^{in} \]  

Through heat exchanger, the temperature of heat-storage medium is changed to

\[ T_{cw,i}^{out} = (1 - \varepsilon) T_{cw,i}^{in} + \varepsilon T_{ca,i}^{out} \]  

The total heat absorbed by the heat-storage medium during charging is

\[ Q_c = \sum_{i=1}^{2} \int_{0}^{t} C_{p} q_{m,c} (T_{ca,i}^{out} - T_{cw,i}^{in}) \]  

3.4.2. Reusing Compression Heat. In discharging, the air in the heat exchanger 3 and 4 is heated by the heat storage medium, thus, the reuse of compression heat is achieved. After \( i \)-stage heat exchanger, the air temperature is

\[ T_{ea,i}^{in} = (1 - \varepsilon) T_{ea,i-1}^{out} + \varepsilon T_{tes} \]  

The total heat released by the heat-storage medium during discharging is

\[ Q_e = \sum_{i=1}^{m} \int_{0}^{t} C_{p} q_{m,c} (T_{tes} - T_{ea,i-1}^{out}) \]  

3.5. Energy Storage Efficiency

The ratio between output electricity in discharging and the consumed electricity in charging is system energy storage efficiency, as shown in

\[ \eta = \frac{W_e}{W_c} \]  

Noting that, the efficiency in equation (19) is the electric-to-electric efficiency, which will be utilized to analyze the overall performance of the proposed salt cavern based NSF-CAES.

4. Systematic Performance Analysis

Under the condition of thermodynamic analysis, the performance of salt cavern based NSF-CAES including power consumption of compressor, temperature of TES, mass of heat-storage medium, volume of salt cavern, energy storage density and system efficiency are studied with different
inlet air pressure of turbine $p_{ea}^{in}$ and maximum working pressure of salt cavern $p_{cav}^{max}$ . Key parameters of the proposed NSF-CAES system are shown in Table 2.

Table 2. Main parameters of the proposed NSF-CAES system.

| Parameter | Capacity | Charging time | Discharge time |
|-----------|----------|---------------|---------------|
| Value     | 50(MW)   | 8(h)          | 4(h)          |
| Parameter | Compressor stage | Turbine stage | Heat medium |
| Value     | 2        | 2             | VP1 conduction oil |

4.1. Power Consumption of Compressor

The relationship between consumed electricity by the compressor $W_c$ and inlet air pressure of the turbine $p_{ea}^{in}$ and maximum working pressure of salt cavern $p_{cav}^{max}$ is illustrated in Figure 3.

Figure 3. Influences on power consumption by the compressor.

With the growing of maximum working pressure of salt cavern $p_{cav}^{max}$, the compressor power consumption $W_c$ increases under a certain inlet air pressure of turbine $p_{ea}^{in}$. The reason is that with the increase of $p_{cav}^{max}$, the discharge pressure of the compressor enhances, thus $W_c$ gradually increases. On the other hand, the electricity consumption of compressor decreases as the turbine inlet air pressure increases under a constant working pressure of salt cavern. As the turbine inlet air pressure enhances, the work ability for per unit air improves. The total mass of air in need drops, thus the compression work goes down.

In this regard, the compressor can reach a 315.9 MWh minimum consumption under the condition of $p_{ea}^{in}$ is 9 MPa and $p_{cav}^{max}$ is 9.5 MPa. When $p_{ea}^{in}$ is 7MPa and $p_{cav}^{max}$ is 12 MPa, the compressor can reach a 331.2 MWh maximum consumption.

4.2. Temperature of TES

Temperature is an important index for TES system. The higher the temperature is, the higher the efficiency is. The relationship between temperature of TES and inlet air pressure of the turbine $p_{ea}^{in}$ and the maximum working pressure of salt cavern $p_{cav}^{max}$ is depicted in Figure 4.

Figure 4. Influence on TES temperature.

At a certain inlet air pressure of the turbine $p_{ea}^{in}$, the temperature of TES system increase with the increase of $p_{cav}^{max}$. When $p_{cav}^{max}$ increases, the discharge pressure of compressor increases and the discharge temperature of the also increases. Furthermore, the heat-storage medium can be heated to a higher temperature in the heat exchanger. Similarly, when the pressure of storage room is fixed, the increase of $P_{in}$ will also enhance pressure and the compressor discharge temperature.

In this regard, under the condition of $p_{ea}^{in}$ is 7 MPa and $p_{cav}^{max}$ is 9.5 MPa. The TES system can obtain a 344°C lowest temperature while a 364°C highest temperature can be reached when$P_{in}$ is 9 MPa and $p_{cav}^{max}$ is 12 MPa.
4.3. Mass of heat-storage medium

The proposed salt cavern based NSF-CAES system takes the heat conduction oil as the heat-storage medium. Mass of heat-storage medium is a key parameter for this kind of NSF-CAES system. The relationship between the mass of heat-storage medium and the inlet air pressure of the turbine $p_{in}$ and maximum working pressure of salt cavern $p_{cav}^{max}$ is shown in Figure 5.

As shown in Figure 5, at a certain $p_{in}$, with the raise of $p_{cav}^{max}$, the mass of heat storage medium needed by the TES system drops. The reason is that with the increment of $p_{cav}^{max}$, the temperature of heat-storage medium also increases. The specific heat capacity of oil enhances. Therefore, under a certain power generation, the quantity of heat in need drops, so does the mass of heat-storage medium. Similarly, with the increase of $p_{in}$, the mass of the heat-storage needed by the system drops under a fixed operation pressure of salt cavern.

To be specific, when the inlet air pressure of turbine $p_{in}$ is 7 MPa and maximum working pressure of salt cavern $p_{cav}^{max}$ is 9.5MPa, the TES system needs a 1644 t heat storage medium. While the TES system needs a 1485t minimum heat-storage medium with a 9 MPa $p_{in}$ and 12 MPa $p_{cav}^{max}$.

![Figure 5. Influence on mass of heat storage medium.](image)

![Figure 6. Influence on salt cavern volume.](image)

4.4. Volume of salt cavern

CAES employs air as electric energy storage medium. A huge air storage space is needed to realize a high capacity ESS. As for the proposed salt cavern based NSF-CAES, the volume of salt cavern is vital to the system capacity and functionality. The relationship between volume of salt cavern and the inlet air pressure of the turbine $p_{in}$ and maximum working pressure of the salt cavern $p_{cav}^{max}$ illustrates in Figure 6 shows that the volume of salt cavern decreases with the increment of $p_{cav}^{max}$ under certain $p_{in}$. Since the higher the storage room pressure is, the greater the air mass stored in per volume is. Under the same power generation, the mass of air required is the same, so the storage room that needed will drops.

When the maximum working pressure of the salt cavern is given, the volume of the salt cavern increases together with $p_{in}$. This is due to the higher the turbine inlet pressure is, the smaller the available pressure interval of salt cavern is. For per unit air storage space, the mass of available air for power generation decreases. Therefore, for a given amount of power generation, the required storage space increases.

Definitely, for the proposed salt cavern based NSF-CAES with parameters in

Table 1, the volume of salt cavern can reach the minimum value i.e. 26,500m$^3$, with a 7 MPa inlet air pressure of turbine and 12 MPa maximum working pressure of salt cavern. Alternatively, the volume of salt cavern can reach the maximum value, i.e. 253,000m$^3$, with a 9 MPa inlet air pressure of turbine and 9.5 MPa maximum working pressure of salt cavern. With different system parameters, the storage space differs greatly. The cost of storage room takes a great percentage on the whole cost. It is a key problem on how to choose adequate parameters to determine the storage space.

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4.5. Energy Storage Density
Energy storage density is an important evaluation index for ESS. Take air storage chamber as an example, the quantity of electric energy that can be stored in per cubic meter of air storage space is analysed under different system parameters. The connection between the energy storage density with inlet air pressure of the turbine $P_{ea}^{in}$ and maximum working pressure of salt cavern $P_{cav}^{max}$ is given in Figure 7. We can learn from Figure 7 that energy storage density decreases with the increases of $P_{ea}^{in}$ and $P_{cav}^{max}$. If the maximum working pressure of salt cavern $P_{cav}^{max}$ is fixed, the available pressure interval of salt cavern goes down with the increase of inlet air pressure of turbine $P_{ea}^{in}$. The available air mass in unit storage space decreases, so does the power generation and energy storage density.

As for the NSF-CAES system shown in table 2. By fixing the inlet air pressure of the turbine, with increasing air pressure in storage room, the available air mass in unit storage room goes up, so does the power generation. The turbine inlet air pressure is 9 MPa, and air pressure in storage room is 9.5 MPa. The energy storage density can reach its least, i.e. 0.79kWhm$^{-3}$. When the turbine inlet air pressure is 7 MPa, and the air pressure in storage room is 12MPa, the energy storage density is at its most, which is 7.52kWhm$^{-3}$.

![Figure 7. Influence on storage density.](image1)

![Figure 8. Influence on system efficiency.](image2)

4.6. System efficiency
Energy storage efficiency is the most important index for ESS. The influence of inlet air pressure of the turbine $P_{ea}^{in}$ and maximum working pressure of salt cavern $P_{cav}^{max}$ on the efficiency illustrates in Figure 8. We can draw the conclusion that the energy storage efficiency goes down as the maximum working pressure of salt cavern goes up under a fixed inlet air pressure of the turbine. When $P_{cav}^{max}$ keeps constant, the energy storage efficiency goes up along with $P_{ea}^{in}$. At a given power generation, improving the turbine inlet pressure helps to reduce power demand of compressor, thus, improves the energy storage efficiency. However, if the working pressure of salt cavern goes up, the compressor power consumption will also become greater, thus, the efficiency will decrease. To achieve a higher energy storage efficiency, the inlet air pressure of turbine should be improved as much as possible, and the working pressure of salt cavern should be limited down as much as possible.

Specifically, for the proposed NSF-CAES system with parameters in table 2, the energy storage efficiency reach 63.29% with a 9 MPa inlet air pressure of turbine and 9.5 MPa maximum working pressure of salt cavern. In this system, the highest energy storage efficiency corresponds to the storage room volume of 253,000 m$^3$. It has been one of the key problems in system design about how to balance the energy storage efficiency and volume of salt cavern.

5. Conclusion
This paper proposes a novel CAES system based on salt cavern air storage technique and thermal energy techniques. It adopts mature technologies, with an easily applicable system architecture. Particularly, TES enables no gas combustion and zero-carbon emission in the whole energy storage process. Thermodynamic design and thermodynamic characteristics of the energy storage system are carried out.
Generally, with the increase of pressure and temperature of inlet air of turbine, power consumption of compressor decreases, and also the power loss of molten salt, so do the mass of heat conduction oil in the heat storage system. The volume of salt cavern decreases with the increase of inlet air temperature of the turbine. The energy storage density increases with the increasing turbine inlet temperature and decreasing turbine inlet pressure. The energy storage efficiency increases as the pressure and temperature of turbine inlet air. The electric-to-electric efficiency of the system can reach 63.29%, which is higher than the currently commercial CAES plants, under the condition of a 9.5 MPa salt cavern pressure, and 9 MPa inlet air pressure of turbine.

The findings in this paper are applicable to the design and construction of large-scale CAES power plants. To obtain more reasonable parameters configuration in the future, optimization and simulation are needed to realize a NSF-CAES with high energy efficiency, low construction cost, and high reliable technique.

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