# Research on Solar Heating and Anti freezing Technology for Water Supply Facilities in Severe Cold Regions

Junkui Niu[1,2*], Liang Cao[1,2], Bingbing Wang[3], Long Chen[3], Yuqing Feng[4]

[1]YinshanbeiluNationalFieldResearchStationofDesertSteppeEco-hydrological System, China Institute of Water Resources and Hydropower Research, Beijing100038, China
[2]Instituteof Water Resources forpastoral Area Ministry of Water Resources, Hohhot 010020, Inner Mongolia China
[3]Inner Mongolia Autonomous Region Institute of Metrology and Testing, Inner Mongolia China
[4]Horqin Right Wing Front Banner Water Conservancy Bureau, Inner Mongolia China

**Abstract:** This study focuses on the serious winter freezing damage, inconvenient management of coal-fired heating, and high energy consumption and cost of electric heating and antifreeze measures in rural pastoral areas in northern China's severely cold regions. Taking into account the abundant resource advantages of northern light resources, a solar heating and antifreeze system for water supply facilities was designed. During the day, the collector absorbs sunlight and converts it into heat energy. The water in the heat storage tank is circulated through the collector to heat and store energy; When the temperature of the well room is low, heat is released to stabilize the temperature of the well at around 8 ℃, achieving solar heating and anti freezing. Through experimental verification, the temperature of solar powered hot water can reach 67.9 ℃, and the temperature of the well room can be maintained between 6.1 ℃ and 10.5 ℃. The heating and anti freezing effect of the system is stable, and the solar heating guarantee rate is nearly 75%. The energy-saving effect is significant, greatly reducing the anti freezing operation cost of water supply facilities. At the same time, the system can operate with full process automation and remote monitoring, effectively improving the antifreeze guarantee rate and management efficiency.

## 1.Introduction

The winter in the north of China is long and cold. The frost period in Northeast China is from November to the end of April of the following year, and the frost period in North China is from December to February of the following year [1] ~ [2]. Due to its unique climate environment, water supply pipelines are often frozen, water treatment facilities are frozen, and water supply power equipment cannot be started due to low temperature [3]. At present, these facilities mainly rely on coal and electric heating for anti-freezing, which is extremely difficult to manage, and has high energy consumption and high cost, resulting in the phenomenon of "construction without use" of water supply projects. It not only affects the normal operation of water supply facilities, but also has a great impact on the agricultural and animal husbandry production and residents' lives in the vast rural pastoral areas. The harsh environment has brought greater challenges to the already weak water supply projects in agricultural and pastoral areas, and the problem of frost prevention in water supply projects has become a difficulty in ensuring drinking water safety [4]. In response to this issue, researchers have proposed corresponding management and protection strategies, such as strengthening the insulation measures of rural water supply facilities, using methods such as releasing water for insulation, to prevent water supply facilities from freezing in low-temperature environments [5]; Some studies also focus on improving design standards, paying attention to comprehensive measures such as insulation of pipeline wells and water pipes [6]; Ma Junwei designed a solution for electric heat tracing insulation of water supply pipelines, which uses electric heat tracing to prevent freezing [7]. Although traditional anti freezing methods such as electric heating and insulation materials are effective, they have problems such as high energy consumption, high cost, and difficult maintenance.

With the enhancement of environmental awareness and the transformation of energy structure, China gradually attaches importance to the application of solar energy, a clean and renewable energy, in the heating field[8]. Especially in cold regions, solar heating systems not only help reduce reliance on traditional energy, but also provide affordable and reliable thermal energy.

At the same time, automatic operation of the whole process of solar heating, and functions such as remote monitoring and abnormal alarm can greatly reduce the workload of water pipe operators and reduce labor costs. Moreover, the abundant solar energy resources in the cold regions of north China provide resource advantages for the application of solar heating antifreeze technology. Therefore, this article proposes using solar collectors as the main heat source for antifreeze in water supply facilities, storing heat in insulated water tanks. When the

*Corresponding author’s email: 1014799348@qq.com

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https://doi.org/10.1051/e3sconf/202457302004

temperature inside the well of the water supply facility is lower than the set value, the heat in the insulated water tank is released through the radiator to maintain the set temperature inside the well. The heating effect was tested by designing and installing a solar heating and anti freezing experimental system. The antifreeze system operates stably and reliably, with good energy-saving effects, greatly improving the antifreeze economy of water supply facilities [9].

## 2. System Structure and Working Principles

### 2.1. System Architecture

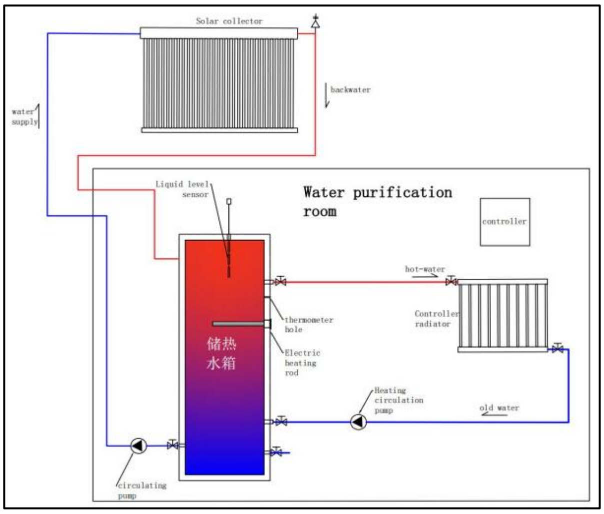


**Fig.1** Structural diagram of solar heating and antifreeze system

The structure of a solar heating and antifreeze system includes: a solar collector, a heat storage water tank, a heat collection circulation pump, an electric auxiliary heat rod, a heating circulation pump, a radiator, etc. [10]. The system structure is shown in Figure 1. The system is designed with a drainage type heat collection structure, which means that the outdoor part of the water supply and return pipes of the solar collector should have a minimum installation slope of 3 °. After the collection circulation pump stops, all the water in the pipes can fall back into the insulation water tank by gravity to prevent freezing and blockage of the circulating pipes[11]. The solar collector has an inclination angle of 60 ° and is installed due south.

### 2.2. System working principle

#### *2.2.1. Working principle of heat collection*

The system's heat collection design is a temperature difference cycle. The collector absorbs sunlight and converts it into thermal energy for heating. When the temperature difference between the collector and the insulation water tank exceeds 6 ℃, the collector circulation pump is started to lift the water in the insulation water tank to the solar collector for heating and then fall back into the water tank. The collector is used to heat and store energy in the insulation water tank; During the process, the temperature of the collector slowly decreases and the temperature of the insulation water tank slowly increases. When the temperature difference between the collector and the insulation water tank is less than 3 ℃, or the temperature of the insulation water tank exceeds the set upper limit of 90 ℃, the collection cycle is stopped, and the water in the circulation pipeline falls back into the water tank by gravity. At this time, there is less water in the collector, and the temperature rises again after absorbing sunlight. When the temperature difference reaches the starting temperature difference, the above collection cycle starts again.

When the sunlight is insufficient and the temperature inside the insulation water tank is below 35 ℃, start the electric auxiliary heating rod to supplement heat to the insulation water tank, so as to maintain the temperature of the water tank above 35 ℃. The workflow is shown in Figure 2.

#### *2.2.2. Working principle of heating*

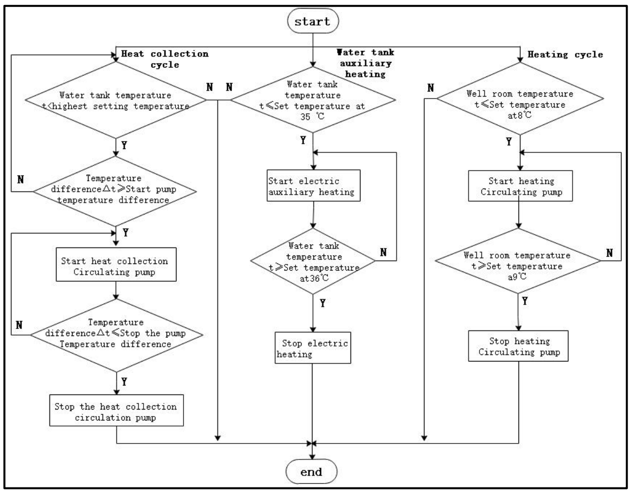


**Fig.2** Working principle diagram of solar heating and antifreeze system

When the temperature inside the water supply well is below the set value of 8 ℃, start the heating circulation pump, and the hot water in the insulation water tank will circulate and dissipate heat through the radiator before returning to the water tank. When the indoor temperature rises to 9 ℃, stop the heating cycle. The hot water in the radiator can continue to dissipate heat and maintain the temperature inside the well until the temperature inside the well drops to the set value again, and the heating cycle starts again. The workflow is shown in Figure 2.

## 3. Experimental System Design

### 3.1. Overview of Water Supply Well House

The well room is located in Sujiyingpan Village, Gongjitang Town, Siziwang Banner, Ulanqab City, Inner Mongolia. The dimensions of length, width, and height are 4m x 3m x 2.5m, with a heating area of 12m$^2$ and a heating space of 30m$^3$. The inside of the well room is 50mm thick metal color steel polystyrene foam insulation board, which is sheathed with a 100mm precast concrete wall, and the inside of the wall is pasted with 50mm thick polystyrene foam insulation. Indoor water supply and purification facilities are installed, and all insulated water tanks and radiators are installed in the well room.

### 3.2. Heating load calculation

Calculation of heating load for solar energy collection systems:

$$Q_H = Q_{HT} + Q_{INF} + Q_{IH} \quad (1)$$

In the formula:

$Q_{HT}$——Heat transfer and consumption through the enclosure structure (W);

$Q_{INF}$——Air permeation heat consumption (W);

$Q_{IH}$——The internal heating of buildings, including the heating of cooking, electrical appliances, and other heating components (W).

Calculation of heat and energy consumption through enclosure structure:

$$Q_{HT} = \varepsilon KF(t_i - t_c)(1 + \emptyset) \quad (2)$$

In the formula:

$t_i$——Indoor design temperature (℃), this design takes 8 ℃;

$t_c$——The average outdoor temperature (℃) is selected based on the analysis of climate data in the experimental area, with an average temperature of -6 ℃;

$\varepsilon$——Correction coefficient for temperature difference of enclosure structure;

$K$——The heat transfer coefficient of the enclosure structure [W/(m$^2$ • ℃)] is calculated to be 0.78 for the roof, 0.47 for the walls, 0.78 for the doors, and 2.05 for the ground;

$F$——The area of the enclosure structure (m$^2$);

$\emptyset$——The proportion of additional energy consumption of the enclosure structure to the basic energy consumption (%).

According to calculations, the heat transfer energy consumption of the water supply well room through the enclosure structure is 709.4W, and the total heat transfer energy consumption is 61.29MJ throughout the day.

Air infiltration energy consumption calculation:

$$Q_{INF} = C_p \rho L(t_i - t_c) \quad (3)$$

In the formula:

$C_p$——Air specific heat capacity, [W • h/(kg • ℃)], taken as 0.28 W • h/(kg • ℃);

$\rho$——Air density (kg/m$^3$), taken as the value under the condition of tc;

$L$——Permeable cold air volume, (m$^3$/h).

After calculation, the heat consumption of air infiltration in the well room is 5.2W, and the energy consumption of heat transfer throughout the day is 0.45MJ/d.

Due to the lack of windows in the well room and minimal internal lighting and electrical heat dissipation, the heat gain inside the building is ignored in the calculation. Therefore, according to the calculation, the heating load of the well room is 714.6W, and the energy consumption of heat transfer throughout the day is 61.74MJ/d.

### 3.3. Calculation of solar energy collection area

Calculation of solar collector area for short-term thermal storage direct system:

$$Ac = \frac{86400 Q_J f}{J_T \eta_{cd} (1 - \eta_L)} \quad (4)$$

In the formula:

$Q_J$——Design load of solar collector (W);

f——Solar energy design assurance rate (%), with a value of 75%;

$J_T$——The daily average solar irradiance in February on the day lighting surface [J/(m$^2$ • d)] was selected as 21MJ based on PVsyst software simulation analysis;

$\eta_{cd}$——The average heat collection rate of the heat collection system (%) is calculated to be 60%;

$\eta_L$——The heat loss rate of pipelines and heat storage systems (%), with a value of 10%.

After calculation, the required solar energy collection area for the well house is 4.08m$^2$. In order to meet the anti freezing problem of collectors in ultra-low temperature environments in northern cold regions, a double vacuum glass tube superconducting collector is designed and selected, using two sets of 20 sets of Ø58 × 1800 type collectors in series. The effective lighting surface size of the collector is 0.058m x 1.72m x 40, with a total lighting area of 3.99m$^2$ [12]. The instantaneous efficiency intercept is 67%, and the total heat loss coefficient is 2.6W/(m$^2$ • ℃). It can withstand low temperatures below -40 ℃ in winter.

### 3.4. Selection and layout of other equipment

According to the short-term heat storage liquid working fluid, the volume of the heat storage water tank per unit of day lighting area of the collector is 40L/m$^2$ to 300L/m$^2$. This design takes a value of 100L/m$^2$, and the volume of the heat storage tank is 400L.

**Table1.** Hard ware equipment list

| Equipment name | Specification and model | number | unit |
|---|---|---|---|
| collector | 20*Φ58*1800 | 2 | group |
| Hot water storage tank | 400L | 1 | individual |
| Electric heating rod | 1.5KW | 1 | individual |
| Heat collection circulating water pump | 250W | 1 | tower |
| Heating circulating water pump | 105W | 1 | tower |
| controller | Solar dedicated controller | 1 | individual |
| radiator | floor type | 1 | group |

Both the collector circulation pump and the heating circulation pump use ultra quiet hot water circulation pump, with a collector circulation pump of 250W and a heating circulation pump of 105W, both rated at 220V.

The radiator adopts a floor standing radiator, with a connection method of bottom in and top out. A floor standing bracket is made and fixed. The main parameters of each device are shown in Table 1.

## 4. Experimental data analysis

(a) (b)

**Fig.3** System on-site installation diagram

The effect of on-site installation of the experimental system is shown in Figure 3. The experiment selected 8h from December 4th, 2023 to 8h from December 5th, 2023 for system data collection. During the experiment, the highest temperature was 1.1 ℃, the lowest temperature was -10.9 ℃, and the average temperature within 48 hours was -5.8 ℃. The number of system runs is shown in Figure 4 [13].

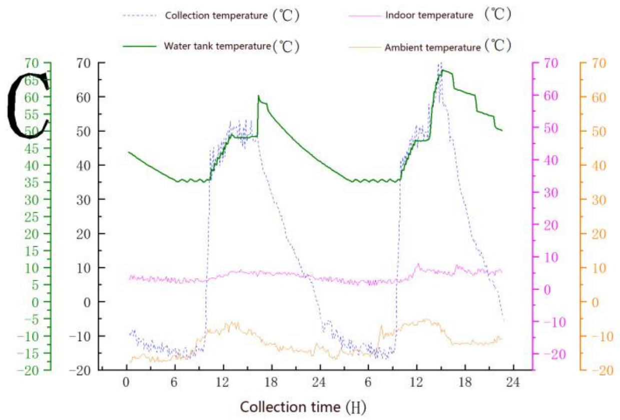


**Fig.4** System operation data curve chart

As shown in Figure 4, during system operation, the indoor temperature remains between 6.7 ℃ and 11.1 ℃, with slight fluctuations with the temperature of the insulated water tank. When the water temperature in the water tank is high in the afternoon, start the heating circulation pump and the temperature in the well room rises rapidly. After the temperature reaches the set 8 ℃ and the pump is stopped, the high-temperature water in the radiator continues to release heat, causing the temperature in the well room to continue to rise. The temperature in the well room reaches the highest temperature multiple times from 14:10 to 18:30; When there is no sunlight or weak light from 3:30 to 9:30 in the morning, the ambient temperature and water tank temperature both reach the lowest of the day, and the heating speed is slow. The temperature inside the well room is maintained in a lower temperature range.

Around 10:30 in the morning, as the sunlight intensifies, the temperature of the heat generated by the collector's absorption of sunlight rapidly increases until the temperature of the collector exceeds the starting temperature difference of the water tank, and the collection cycle begins. The water in the water tank is repeatedly heated and heated by the collector. 16: Around 30, the sunlight is weak and there is no longer a heat collection cycle. The temperature of the water tank reaches the highest value of 67.9 ℃. Subsequently, the temperature of the collector began to decrease and approached the ambient temperature around 6:00 am. During the heating process of the well room, the temperature of the water tank gradually decreases. Around 4:00-10:00 in the morning, the temperature of the water tank drops to the set temperature of the electric auxiliary heating. The electric auxiliary heating starts to supplement heat, maintaining the temperature of the water tank above 35 ℃.

In summary, using solar energy for heat collection, the water in the heat storage tank can be heated to 67.9 ℃ under the average temperature of -5.8 ℃, and the temperature inside the well room can be maintained above 6.7 ℃ through hot water circulation heating, effectively playing a role in antifreeze. According to the statistics of solar heating time, the effective heating time of solar energy accounts for about 75% of the entire day, greatly reducing operating costs. And the system realizes full process automation, remote monitoring, and abnormal alarm, improving the antifreeze guarantee rate and manual management efficiency.

## 5. Conclusion

This article focuses on the size and characteristics of water supply facility well houses, and designs a solar heating and antifreeze system for water supply facilities suitable for severe cold areas in the north. The system structure and working principle, system design, and experimental results are introduced. The equipment has a high degree of automation and does not require manual supervision. At the same time, the energy required for system heating mainly comes from free solar energy, and nearly 75% of the solar energy guarantee rate greatly reduces heating costs. The content of this study is the expansion of the application of solar heating in the water supply industry [14]. The application of this equipment not only effectively solves the problem of antifreeze in winter water supply facilities in the cold regions of northern China, but also provides application cases for the promotion and application of low-carbon water supply technology in rural and pastoral areas.

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