CITY UNIVERSITY OF HONG KONG

High-Performance Solar Interfacial Evaporation Technology

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By

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ORIGINALITY STATEMENT

“I hereby declare that this submission is my own work and to the best of my knowledge contains no materials previously published or written by another person,except where due acknowledgement is made in the thesis.”

Signed…… Zhihao Hou ……

Date ……2024/.4./20 ………….……..

Abstract

Solar interfacial evaporation technology is an environmentally friendly and efficient evaporation technology. In this paper, the evaporation effect of a new spherical shell solar evaporator is designed and simulated. The material composition of each part of the evaporator fully considers the characteristics of environmentally friendly, cheap, and durable materials. The evaporation time is divided into one hour, and the evaporation capacity and evaporation efficiency are obtained by calculating the temperature field and velocity field of the whole solar evaporation interface, and the water transport capacity of the water transport layer material and the salt precipitation on the surface of the light and heat absorption layer are simulated and analyzed. In this paper, Comsol 6.1 software is used to simulate and analyze the efficiency of a new evaporator, which greatly saves manpower and material resources and can further optimize the problems existing in the experiment.

Contents

1. Literature Review

Since the 20th century, the freshwater resources on the earth have been unable to meet the needs of population growth and industrial development. 71% of the earth's surface is ocean, which has huge seawater reserves. Therefore, people focus on the field of seawater desalination. If the corresponding technology is used to desalinate seawater, the dilemma of the lack of freshwater resources in the world can be solved(Kummu et al.,2016;Wondimu et al.,2023).People have made a cost analysis on the feasibility of seawater desalination in a certain area(Liu et al.,2019;Angelis et al.,2021).Comprehensively weighing various factors, people tend to use solar energy to desalinate seawater, because the application of solar energy can not only break the limitation of regional geographical conditions but also solve the problem of uneven energy distribution. The utilization of solar energy is mainly photothermal conversion, photoelectric conversion, and photochemical utilization.Therefore, it is particularly important to develop a solar interface evaporation technology with high efficiency, low cost, and environmental friendliness(Ling et al.,2021).

High-performance interfacial evaporation technology refers to gathering fully absorbed solar heat at the gas-liquid interface to reduce energy dissipation(Ghasemi et al.,2014).The interfacial evaporation structure is mainly composed of three parts: the light absorption layer, the water transmission layer, and the heat insulation layer(Huang et al.,2021).Solar-driven interfacial evaporation technology (SDIE) is dedicated to strengthening the performance of photothermal materials (Li et al.,2023), which includes the following three points: 1) excellent light trapping performance, which can absorb solar radiation in all bands and convert it into heat; 2) Good pore performance, which can transport moisture quickly; 3) Small heat conduction can reduce the energy loss caused by heat diffusion to water (Wang et al.,2016; Zhao et al.,2019).According to these three criteria, scientists have conducted in-depth research on the preparation and improvement of photothermal materials, and their fields mainly involve biomass materials (Fang et al.,2019; Hao et al.,2018; Li et al.,2020; Li et al.,2018; Li et al.,2021), carbon-based materials (Wang et al.,2016; Liu et al.,2017; Ito et al.,2015; Li et al.,2016), polymer materials (He et al.2020; Mu et al.,2018; Zhou et al.,2019; Wang et al.,2021), semiconductor materials (Zhu et al.2016; Wang et al.,2017; Yang et al.,2017; Shi et al.,2018) and natural mineral materials (Chen et al.2020; Jia et al.,2019; Xia et al.,2020).

The structural design of solar interface evaporation system(Mao et al.,2023) has experienced the evolution of direct interface contact (2011), adding thermal insulation contact (2015), two-dimensional transportation path (2016), one-dimensional transportation path (2017), mushroom-type one-dimensional transportation (2018) and inverted cone-type one-dimensional transportation (2019).At present, the research of carbon materials is still a hot spot in this field, but the interfacial evaporation performance of two-dimensional carbon materials seems to have been stagnant. At the same time, three-dimensional porous photothermal conversion materials, such as carbon foam (Qiu et al.,2019), aerogel (Li et al.,2022), hydrogel (Zhou et al.,2018), and so on, are favored because of their good solar evaporation performance such as low bulk density, high porosity, and low thermal conductivity.Besides the adjustment of structure, the improvement of evaporation performance (such as salt resistance and high evaporation rate) is also an important focus of research (Wu et al., 2023).The research of scientists is generally to prepare the required membrane materials through experiments and conduct simulation experiments in the laboratory. The application scenarios involve seawater desalination, wastewater treatment, and other fields (Li et al.,2022; Wang et al.,2023; Xu et al.,2023; Ma et al.,2023; Su et al.,2022).Scientists' evaluation of the evaporation performance of a composite material is based on experimental data, and this judgment process requires a lot of time and resources to conduct repeated experiments. Such an experiment-verification-application process cannot solve the increasingly serious energy and environmental problems quickly.In recent years, most of the research work only focuses on the stage of laboratory testing, and people will choose to use Comsol software to verify the experimental results of evaporation performance (Yu et al.,2023). However, in the face of the multi-physical field application scenario of solar interface evaporation, there is no simulation study on the influence ratio of each part of a certain evaporation result to the evaporation result. For solving the actual seawater desalination problem, the limitations of application scenarios, lighting, seawater salinity, size, and other conditions will increase the diversity of interfacial evaporation structure construction. We can't expect to prepare an evaporation structure with an efficiency close to 100% or even more than 100% under any circumstances, which is too harsh and does not meet the practical application requirements.

In this study,we designed a new spherical shell-shaped solar interface three-dimensional evaporation structure, which consists of a graphene heat absorption layer, peanut shell water absorption layer, and Silica Aerogel heat insulation layer from outside to inside. The materials used in the whole structure are environmentally friendly, the price is relatively close to the people and the manufacturing process is simple.To analyze and optimize the performance and efficiency of this evaporation structure, we use comsol 6.1 software to model the early stage, set the physical field conditions, simulate the evaporation process, calculate the relevant evaporation efficiency, and analyze the salt transfer process. If more and more detailed simulation optimization is carried out, this technology can be applied to practical production on a large scale.

2. Methodology

2.1 Materials

Graphene (Tab.1)is used as the light-absorbing material, and the product data are from Changzhou Fuxi Technology Co., Ltd(Zhou et al.,2014;Jie et al.,2019;Mu et al.,2019;Qing et al.,2022).We use peanut shell as water conveyance layer(Zhao et al.,2017;Zhang et al.,2020;Shi et al.,2017;Lu et al.,2020;Suman et al.,2022;Fu et al.,2018;Zheng et al.,2006).Silica Aerogel is used as the insulation layer material.(Fig.1.a)

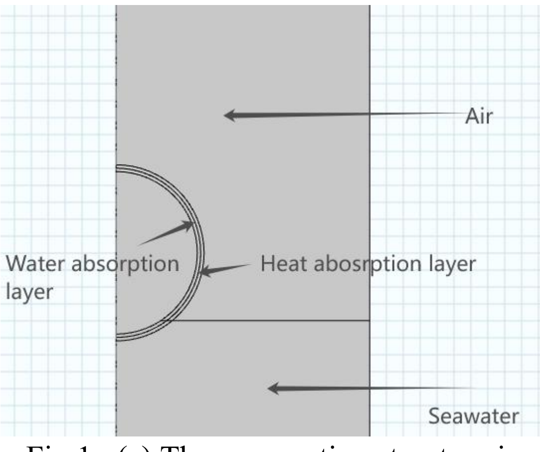
	epsilon	kappa_iso	k_iso	rho	Cp	w_c	D_iso
Graphene	0.9	0.56	1000	2150	850	wc_int(phi)	1E-3
Unit	1	m^2	W/(m·K)	kg/m^3	J/(kg·K)	kg/m^3	m^2/s

	rho	mu
Air	1	1.76E-5
Unit	kg/m^3	Pa·s

Tab.1 Material properties of the light-absorbing layer and air domain

2.2 Setting

The radiation source is the solar radiation in Comsol, and the radiation intensity is $1kW/m^2$. The water comes into contact with seawater from the lower entrance of the water conveyance layer, and the water rises along the direction of the spherical shell through capillary action. This part is simulated by Darcy's law in Comsol. The evaporation of water(Fig.1.b) mainly occurs at the interface between the lower surface of the porous medium graphene and the upper surface of the water conveyance layer of the peanut shell. In this part, the coupled function of heat and moisture in comsol is used to analyze simultaneous equations(Li et al.,2023;O.A. Bazarkina et al.,2021;Li et al.,2022;Liu et al.,2021;Lv et al.,2023).



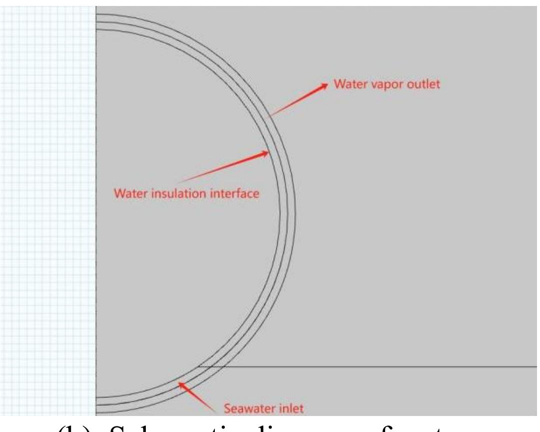


Fig.1 . (a) The evaporation structure is composed of various parts. (b) Schematic diagram of water transport

When using Comsol 6.1 software to build the model, the author simplified the conditions of the model. First of all, to analyze the evaporation characteristics and evaporation efficiency of spherical shell-like solar interface evaporation, this paper simplifies the water transport process in porous media, regards the interface between the water transport layer and photothermal absorption layer as the water evaporation surface, and ignores the change of evaporation wet surface with time. Secondly, to reduce the calculation of simulation, according to the symmetry of the spherical structure, the author uses a two-dimensional axisymmetric model for analysis, and the conclusion is reasonable and brief. Then, to ensure that the water saturation is always positive in the whole process of seawater evaporation, the relative permeability of wet air (Fig.2.a) and liquid phase (Fig.2.b) are defined respectively, and the function (Fig.2.c) of water content in porous media changing with time is given.

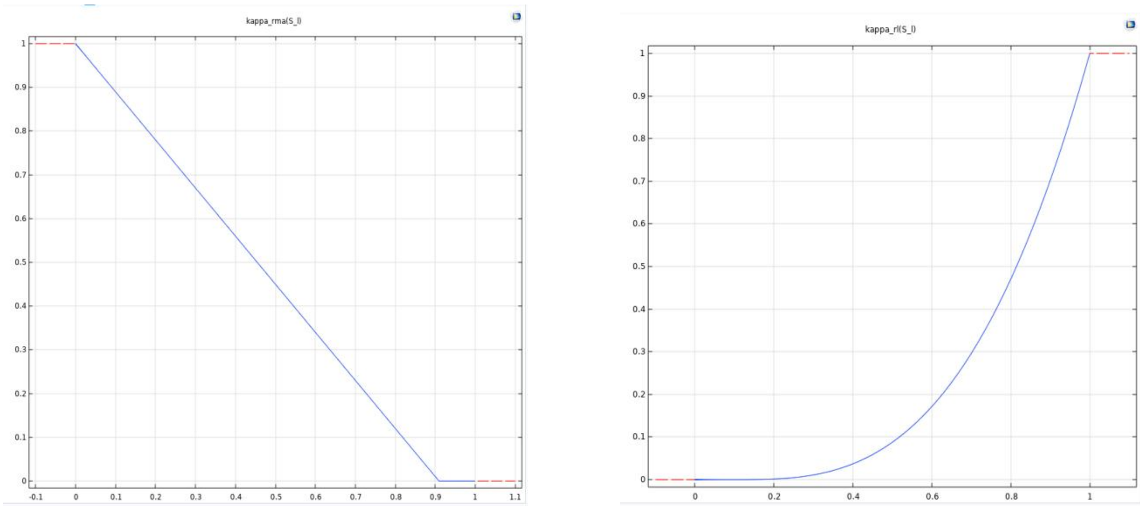
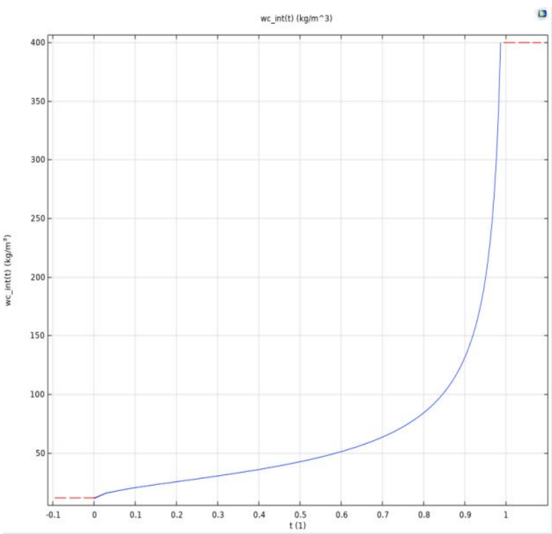
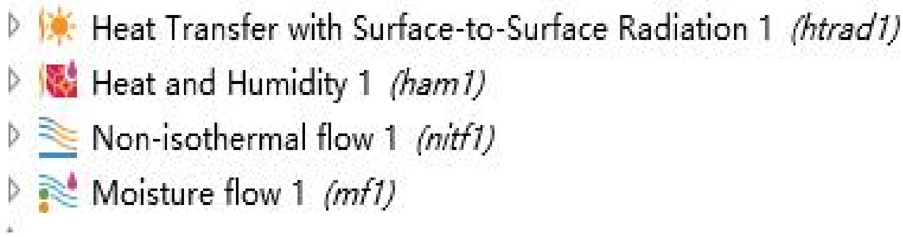


Fig.2 . (a) Kappa_rma (b) Kappa_rl



(c) Wc_int



(d) Multiple physical fields

In the whole simulation process, the author used four physical fields, namely, surface-to-surface radiation heat transfer, heat and humidity, non-isothermal flow, and moisture flow, to analyze the whole evaporation process of the high-performance solar interface.The related physical equations are as follows:

Solid heat transfer:

$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p \mathbf{u} \cdot \nabla T + \nabla \cdot \mathbf{q} = Q + Q_{\mathrm{ted}} \quad (1)$$

$$\mathbf{q} = -k \nabla T \quad (2)$$

Surface-to-surface radiation:

$$J_i = \varepsilon_i e_b(T) FEP_i(T) + \rho_{d,i} G_i \quad (3)$$

$$G_i = G_{m,j} + G_{amb,i} + G_{ext,i} \quad (4)$$

$$G_{amb,j} = F_{amb,j} \varepsilon_{amb} e_b \left(T_{amb}\right) FEP_i \left(T_{amb}\right) \quad (5)$$

$$e_b(T) = n^2 \sigma T^4 \quad (6)$$

$$\mathrm{FEP_i}(T) = \frac{15}{\pi^4} \int_{C_2/(\lambda_i - 1T)}^{C_2/(\lambda_i T)} \frac{x^3}{1 - e^x} dx \quad (7)$$

Wet air heat transfer:

$$\rho C_p \frac{\partial T2}{\partial t} + \rho C_p u \cdot \nabla T2 + \nabla \cdot q = Q + Q_p + Q_{vd} \quad (8)$$

$$q = -k \nabla T2 \quad (9)$$

Moisture transport in the air:

$$\rho_g \frac{\partial \omega_v}{\partial t} + \rho_g u \cdot \nabla \omega_v + \nabla \cdot g_w = G \quad (10)$$

$$g_w = -\rho_g D \nabla \omega_v \quad (11)$$

$$\omega_v = \frac{M_v c_v}{\rho_g} \quad (12)$$

$$c_v = \phi_w c_{sat} \tag{13}$$

$$g_{lc} = 0 \tag{14}$$

Laminar flow:

$$\rho \frac{\partial u}{\partial t} + \rho(u \cdot \nabla)u = \nabla \cdot [-pI + K] + F + \rho g \tag{15}$$

$$\frac{\partial \epsilon_p \rho}{\partial t} + \nabla \cdot (\rho u) = 0 \tag{16}$$

Among them, the physical field of surface-to-surface radiation heat transfer is set as follows: the external radiation source is solar radiation, the radiation intensity is 1 kW/m^2, and the outer surface of the light-absorbing layer in contact with air is set as a diffuse reflection surface, and the setting of surface emissivity is related to the wavelength band (Tab.2).The light-absorbing layer has a high absorption rate of solar radiation and can transfer the absorbed heat to the wet surface where the liquid evaporates through heat conduction.

Spectral band	Emissivity(1)
Sun:[0, 2.5[um][	0.94
Environment:[2.5[um], +∞[	0.76

Tab.2 Surface Emissivity

In the physical field of heat and humidity, the evaporation water flow in the air domain and the temperature field change caused by the fluid flow with heat itself are mainly coupled(Fig.2.d).Here, the temperature of the evaporation surface (i.e. wet surface) is set as the temperature T for solving the physical field of surface radiation heat transfer. It should be noted that this temperature T is a changing function, and this setting can couple the temperature change of wet surfaces caused by solar radiation with the influence on evaporation of wet surfaces.

In the physical field of non-isothermal flow, the change of temperature field on a solid surface and airfield belongs to the heat transfer process between solid and fluid, and its main influencing factor is the convection heat transfer process. In order to simplify the analysis process, the convective heat transfer coefficient of the air environment is set to a fixed value, 20 W/(m^2·K).

In the physical field of Moisture flow, the change of moisture is mainly caused by the evaporation of the wet surface. The direction of moisture flow is that it evaporates from the wet surface by heating, and the water vapor diffuses into the air along the gap of the porous medium, the photo-endothermic layer.

2.3 Evaporation test

In the simulation experiment, the initial temperature of each part is set at 293.15K, and the time of solar radiation after entering the store is set at 1 h. Analyze the changes in physical quantities such as temperature and flow rate in the air domain and porous media domain after one hour.The physical parameters of seawater are set as the corresponding parameters at the temperature of 293.15K.

2.4 Thermal conversion efficiency calculation

The evaporation rate ($\dot{m}$)can be obtained from the fluid velocity field of Comsol 5.6, and the velocity field distribution of the entire evaporation surface can be obtained. The corresponding heat conversion efficiency (η)can be converted by evaporation rate.

$$\eta = \frac{\dot{m} H_{LV}}{C_{opt} P_i} \tag{17}$$

where $\dot{m}$ is the evaporation rate under the simulating sun ($\dot{m} = m_{light} - m_{dark}$), and H_{LV} comprises sensible heat (Q) and enthalpy of vaporization (h_{vap}).

$$H_{LV} = Q + h_{vap} = C \times (T - T_0) + h_{vap} \tag{18}$$

where C is the specific heat of water, which is 4.18 J g^{-1} K^{-1} ; T and T_0 represent the evaporation temperature (K) and water temperature (K), respectively;and hvap is determined by the temperature .Pi refers to the irradiance intensity (1 kW m^{-2}), and C_{opt} is the optical concentration.

2.5 Mesh division

According to the response characteristics of the model, the boundary layer is set for the grids with light and heat absorption layer, open boundary, and wall surface, and the grid is locally encrypted(Fig.3).The grid independence is verified, and it is concluded that the density of the grid does not affect the solution result, but only affects the solution time. The denser the grid, the longer the solution time.

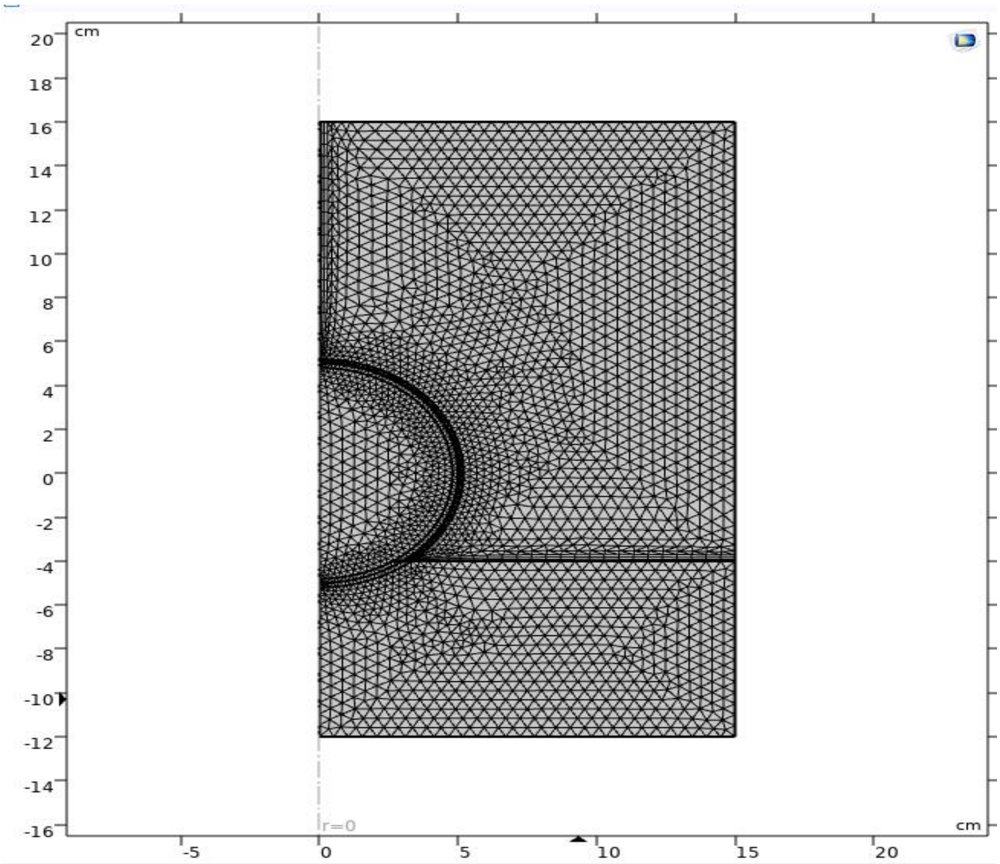


Fig.3 Mesh division diagram

3. Data analsyis and interpretation

The evaporation rate is the most important part of the efficiency analysis of the whole evaporation process. In this experiment, the evaporation rate of water is changed by the fluid velocity field simulated by Comsol 6.1. The actual fluid flow should be that the fluid rises slowly from the lowest entrance of the water conveyance layer due to capillary action, and the fluid flow conforms to Darcy's law during its rising along the spherical shell. Because the time interval of analyzing the fluid flow process is in hours, the fluid has already filled the whole fluid water conveyance layer. Therefore, in the simulation process, the process of fluid rising is reasonably simplified, and the boundary condition of the water output interface of the fluid water transfer layer is set as a stable interface. This setting makes the simulation results more reasonable.

3.1 Evaporation

The simulation time of solar interface evaporation is 1h, and the simulation results of 0s, 1800s, and 3600s are selected as the control. Since 0s, the evaporation efficiency of water increases with the increase of evaporation time (Fig.4.a,4.b,4.c,4.d,4.e,4.f), and the maximum evaporation rate increases from 0.382 m/s to 1.04 m/s.

We use the surface integral function of comsol to get the total evaporation rate of 0.374 kg m^{-2} h^{-1} , and calculate the efficiency of the whole evaporation process according to the total evaporation rate, and we can see that the efficiency is 90 % when time is 3600s.

The fluid field in the airfield is mainly composed of evaporated gas on the wet surface. Starting from 0s, the fluid field around the interface of the light-absorbing layer is enhanced, while the fluid field at the wall is low. With the increase of time, the fluid field gradually increases from the wet surface to the open boundary.

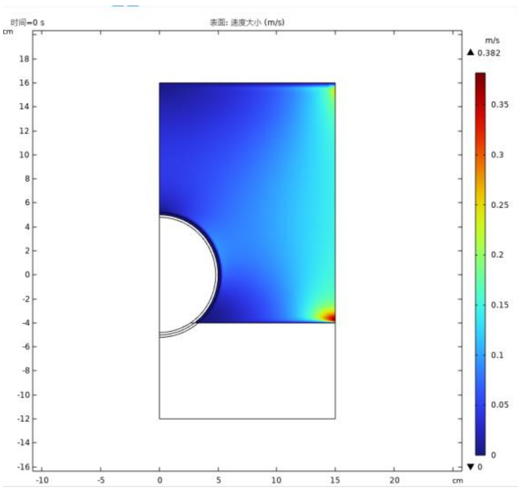


Fig.4. a 0s

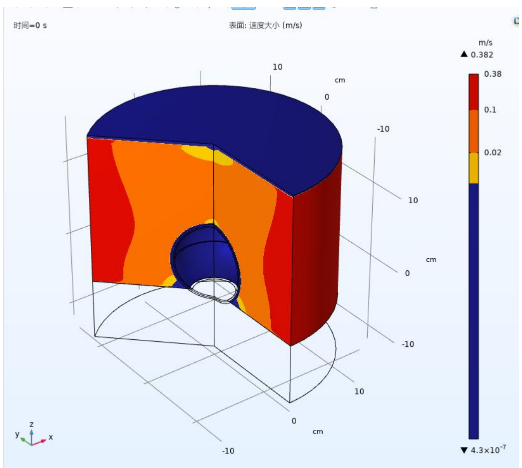


Fig.4.b 0s

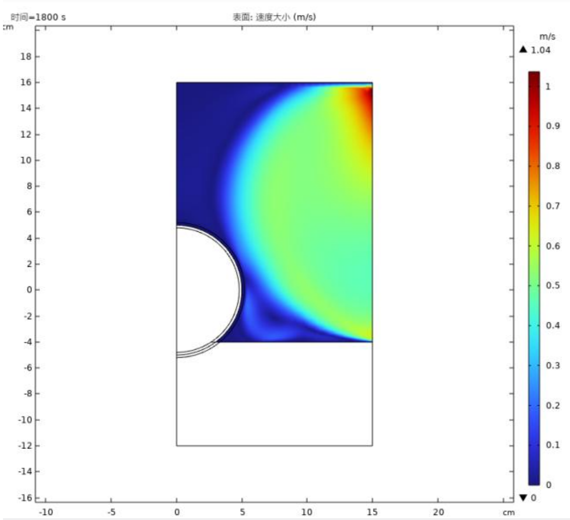


Fig.4. c 1800s

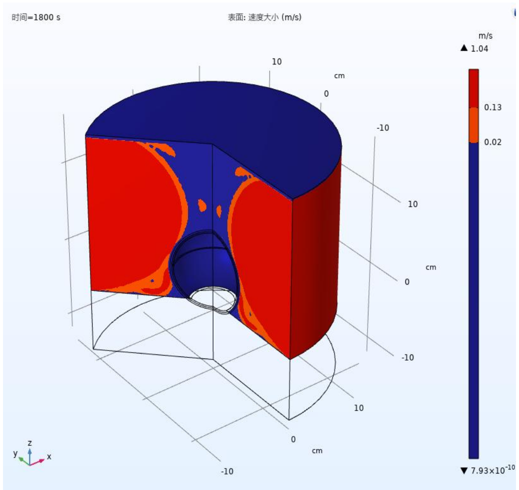


Fig.4.d 1800s

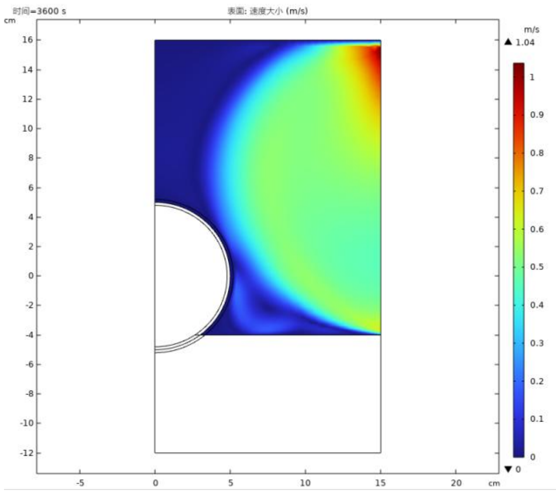


Fig.4. e 3600s

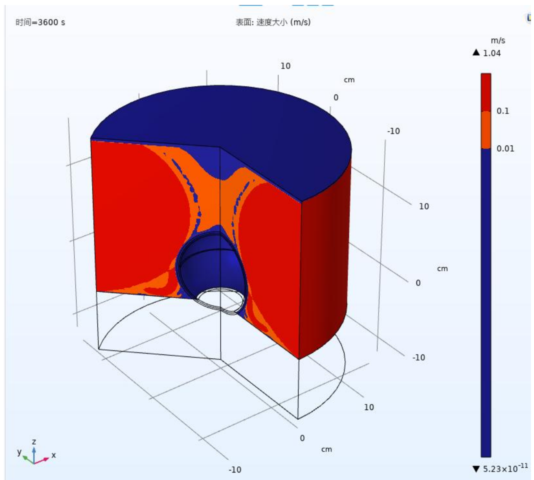


Fig.4.f 3600s

3.2 Heat transmission

3.2.1 Heat transmission in photo-endothermic layer

The surface temperature of the light-absorbing layer is mainly affected by solar radiation. In the process of 1-hour simulation, the temperature distribution of 0 s, 1800 s, and 3600 s was analyzed respectively(Fig.5.a,5.b,5.c,5.d,5.e,5.f).

For the heat transfer problem of the light-absorbing layer, solar radiation is mainly absorbed by the outer surface of the light-absorbing layer which is in contact with the air. In the process of simulation setting, to simplify the operation, the influence of solar radiation as an external radiation source is equivalent to a boundary heat source, which causes the same temperature change as the result of directly setting solar radiation as an external radiation source. The temperature of the light-absorbing layer decreases from outside to inside, and at the same time, the temperature of the outer surface of the light-absorbing layer increases with the increase of solar radiation time. However, the temperature of the lower part of the spherical shell-like light-absorbing layer is lower than that of the upper part of the spherical shell. This is because the lower part is on the backlight surface and receives less short-wave radiation. From the overall temperature change trend, after 1 hour of evaporation, the maximum temperature of the whole photo-endothermic layer increased from 293.15K at the beginning to 312K .

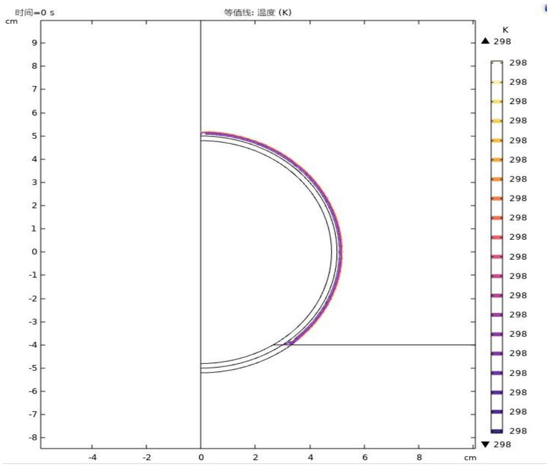


Fig.5.a 0s

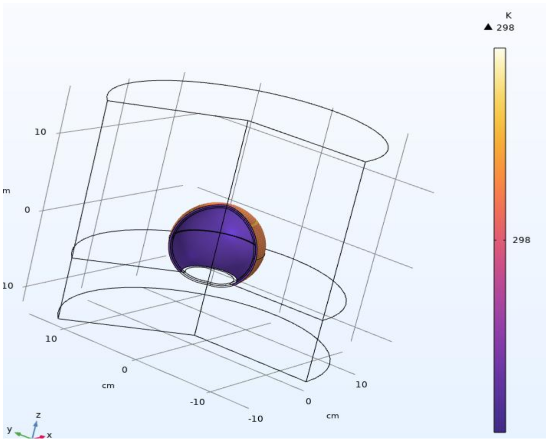


Fig.5.b 0s

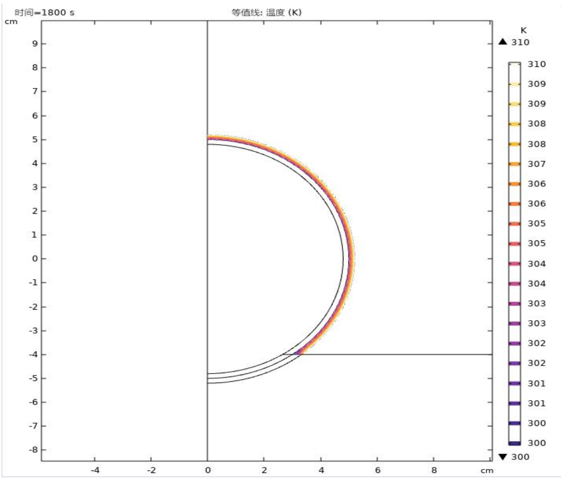


Fig.5.c 1800s

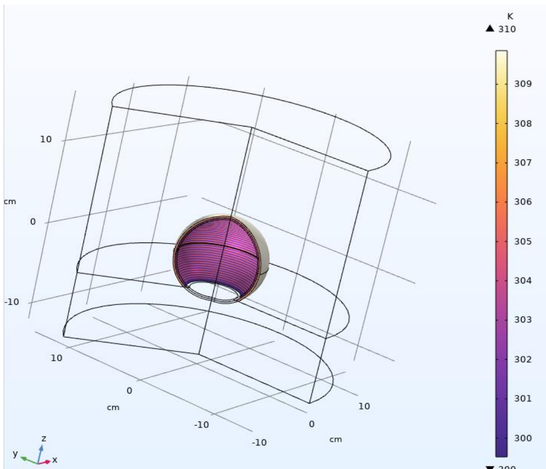


Fig.5.d 1800s

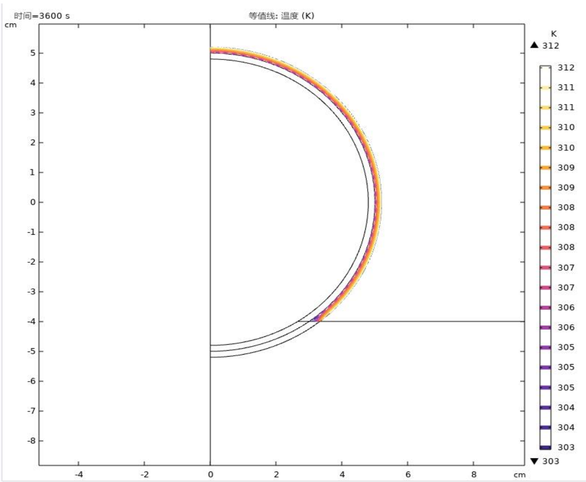


Fig.5.e 3600s

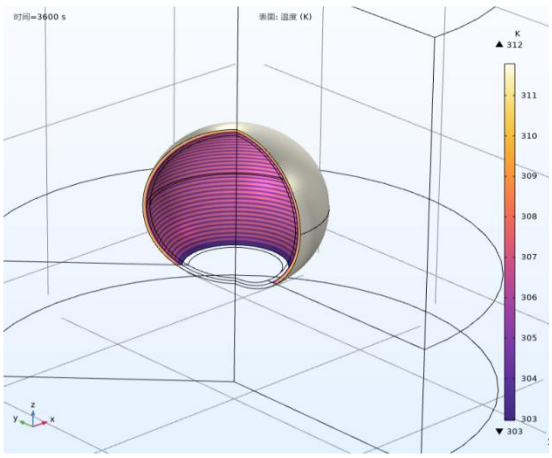


Fig.5.f 3600s

3.2.2 Heat transmission in air domain

The surface temperature of the air domain is mainly affected by Convective heat transfer between evaporated moisture and humid air. In the process of 1-hour simulation, the temperature distribution of 0 s, 1800 s, and 3600 s was analyzed respectively(Fig.6.a,6.b,6.c,6.d,6.e,6.f).

The change of temperature field in the air is caused by the fact that the evaporated water vapor itself has a certain temperature. Due to the natural convection heat transfer and the combined action of the fluid field, the temperature of water vapor with different temperatures in the air domain will increase with the increase of evaporation time. However, after evaporation for 1 hour, the increase in air temperature is not more obvious than that of the photo-endothermic layer. This is because the natural convection heat transfer coefficient is small, and its influence on temperature is far less than that of radiation heat transfer on the light-absorbing layer. The analysis of the temperature field in the air is mainly solved by the physical field of heat and humidity in Comsol 6.1. We can find that the temperature is the highest in the part of the outer surface of the light-absorbing layer that is in contact with the air because the evaporation heat transfer process is the most intense there.

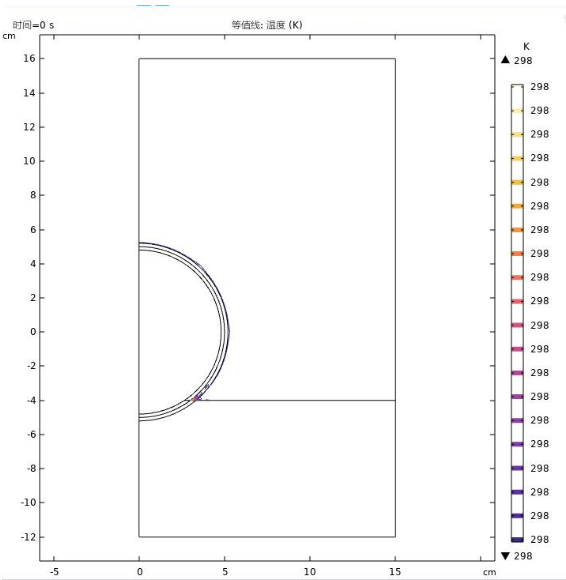


Fig.6.a 0s

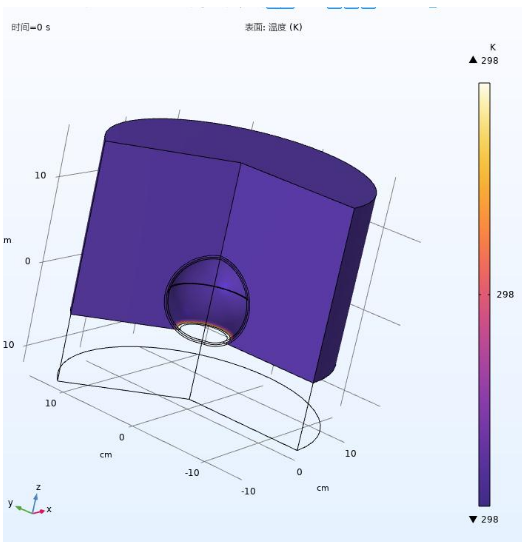


Fig.6.b 0s

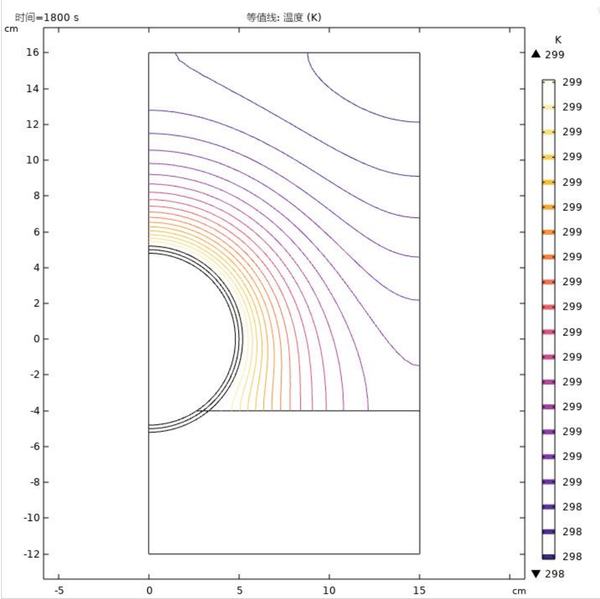


Fig.6.c 1800s

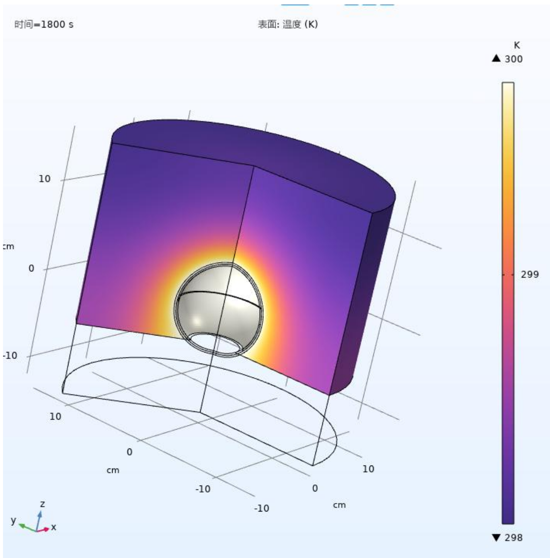


Fig.6.d 1800s

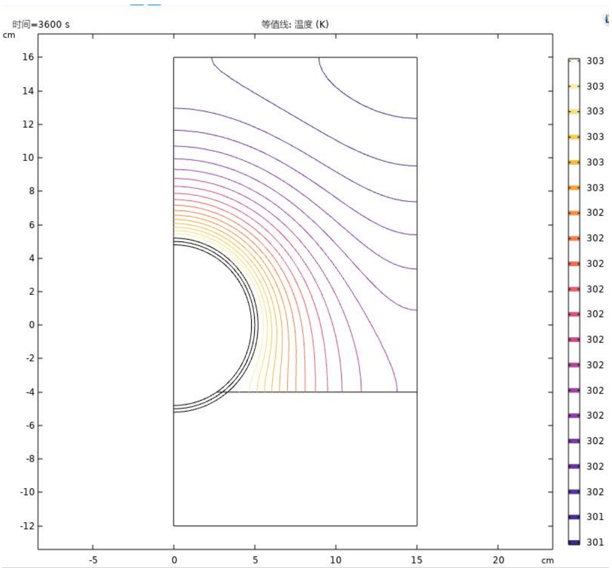


Fig.6.e 3600s

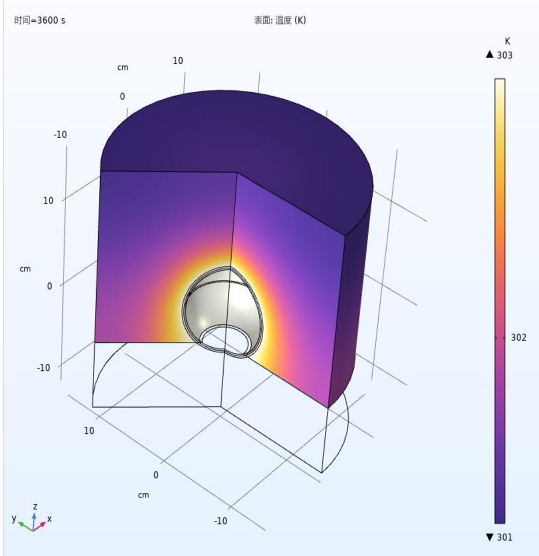


Fig.6.f 3600s

3.3 Salt precipitation

Regarding the salt precipitation of seawater during evaporation, the author uses the reacting flow, diluted categories physical field in Comsol 6.1, which couples the fluid flow in the internal gaps of porous media caused by evaporation of wet surface and the mass transfer caused by salt during the fluid flow(Fig.7).

Fig.7 The Reacting Flow, Diluted Species

To better discuss the law of salt precipitation, the author chose four kinds of seawater materials with different concentrations(Tab.3).

Seawater 1	liquid	S=10g/kg	C=171mol/m3
Seawater 2	liquid	S=30g/kg	C=514mol/m3

Seawater 3	liquid	S=35g/kg	C=600mol/m3
Seawater 4	liquid	S=38g/kg	C=651mol/m3

Tab.3 Seawater with different concentrations

Setting the evaporation time to 3600s, the simulated convergence of multi-physical fields under different seawater concentrations(Fig.8.a,8.b,8.c,8.d) and the corresponding two-dimensional (Fig.9.a,10.a,11.a,12.a) and three-dimensional(Fig.9.b,10.b,11.b,12.b) concentration distribution maps under each concentration are obtained.

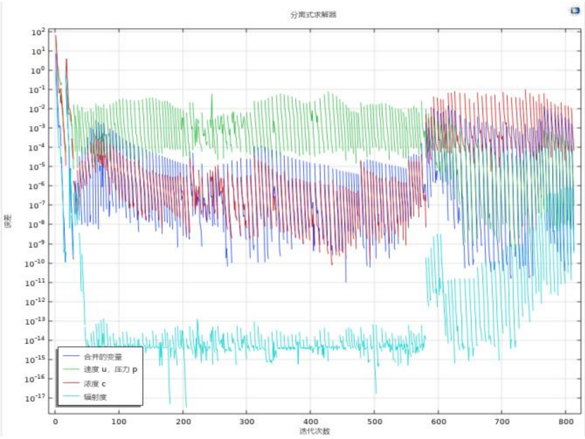


Fig.8.a S=10g/kg

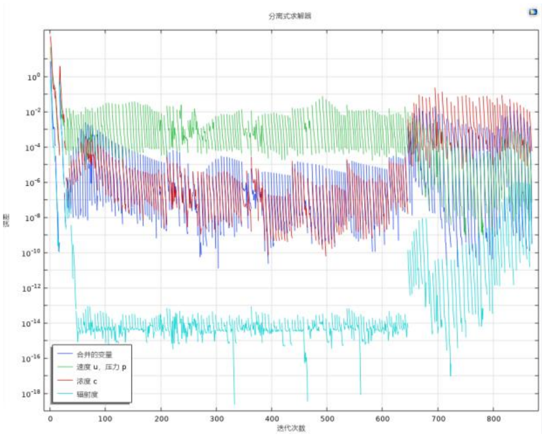


Fig.8.b S=30g/kg

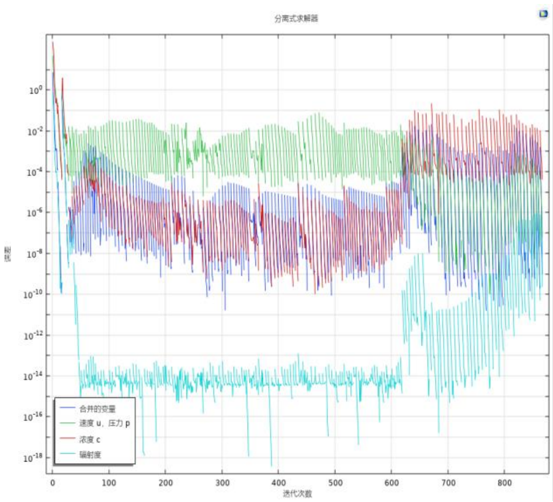


Fig.8.c S=35g/kg

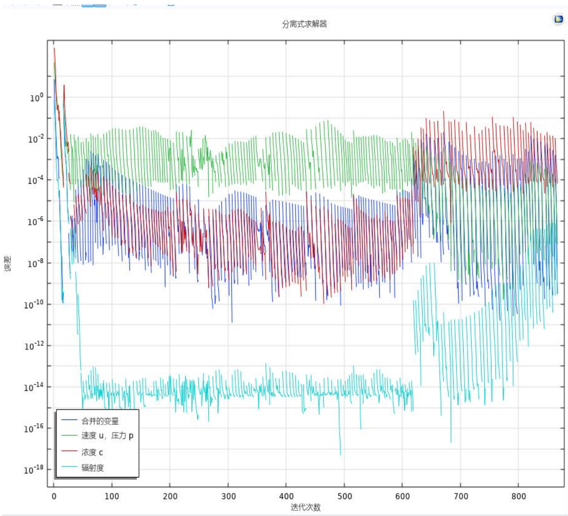


Fig.8.d S=38g/kg

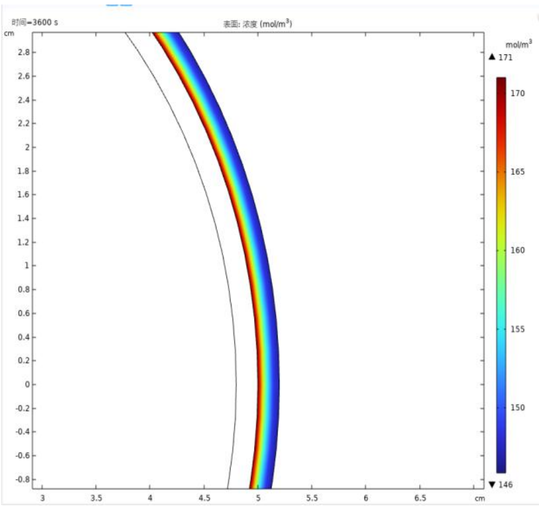


Fig.9.a S=10g/kg (2-D)

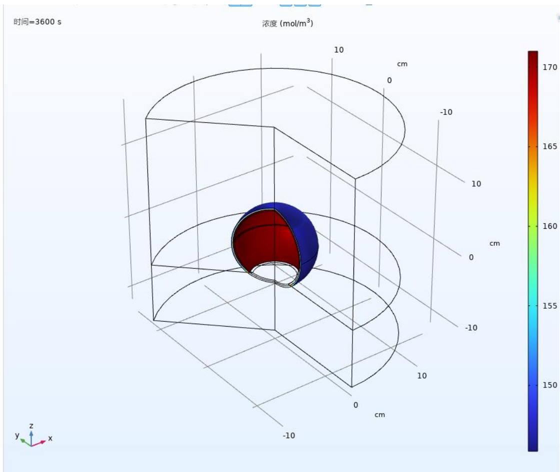


Fig.9.b S=10g/kg (3-D)

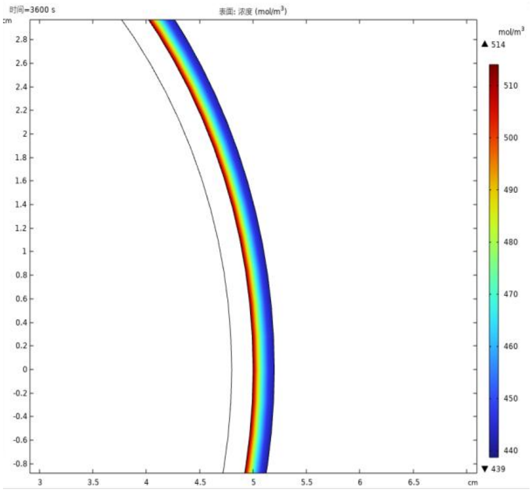


Fig.10.a S=30g/kg (2-D)

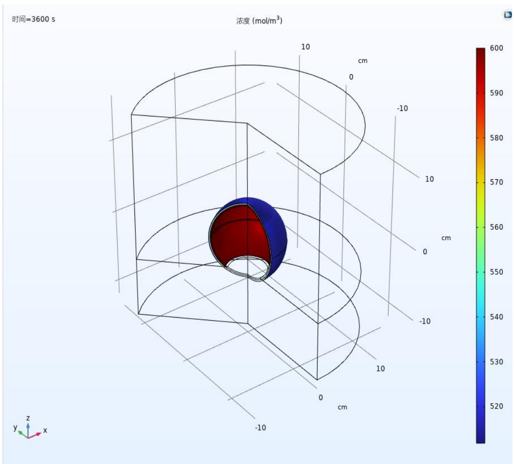


Fig.10.b S=30g/kg (3-D)

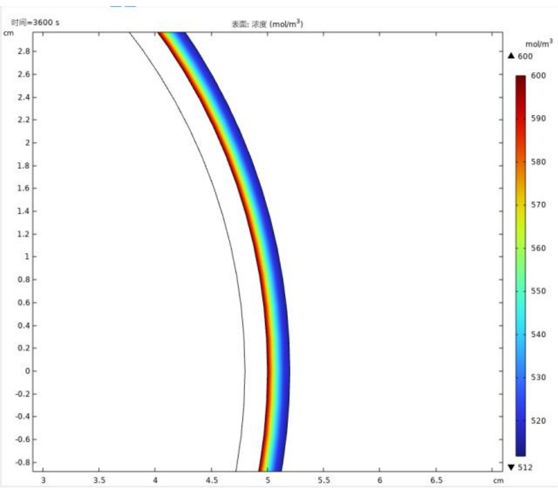


Fig.11.a S=35g/kg (2-D)

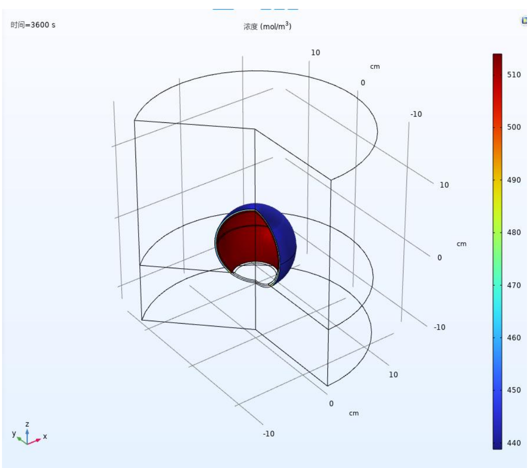


Fig.11.b S=35g/kg (3-D)

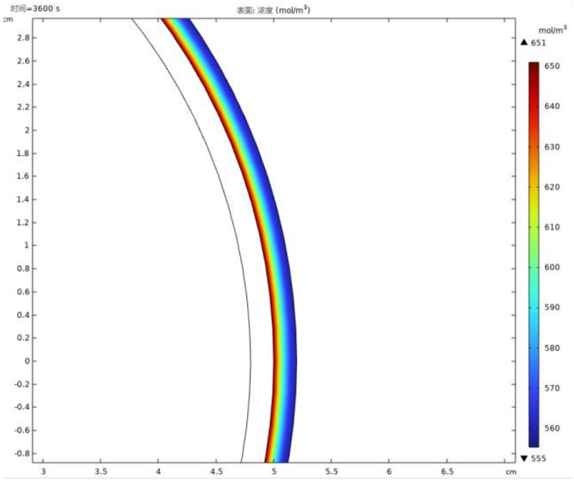


Fig.12.a S=38g/kg (2-D)

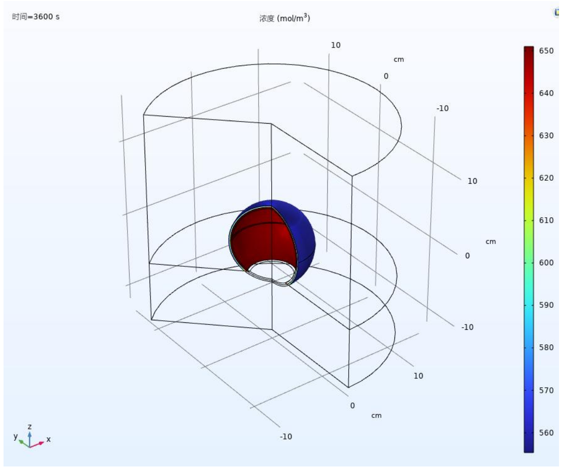


Fig.12.b S=38g/kg (3-D)

We use the concentration difference between the wet surface and the light-absorbing layer surface to analyze the change in salt precipitation. According to the salting-out simulation results of seawater evaporation with four different salinities, we can conclude that in the same evaporation porous medium, with the increase of salinity, the amount of salt precipitation in the inflow and outflow increases obviously. After calculation, it can be found that the ratio of concentration difference to the initial inlet concentration value is approximately equal. This shows that the ability of salt precipitation is almost unchanged for the same porous media.Of course, the influence of salt precipitation in porous media on pore fluid flow is not discussed in detail here.

3.4 Water absorption capacity of water conveyance layer materials under capillary action

The water conveyance layer is made of a peanut shell(Tab.4), and this part mainly analyzes the water conveyance ability of a peanut shell under capillary action.

	por	K
Peanut shell	0.8	6.286E-14
Unit	1	m^2

Tab.4 Peanut shell

In Comsol 6.1, we use Multiphase Flow in Porous Media to analyze the water transport caused by capillary action in porous media peanut shells. To simplify the analysis, we choose vertical water transport and draw a general conclusion(Fig.13.a,b,c,d).

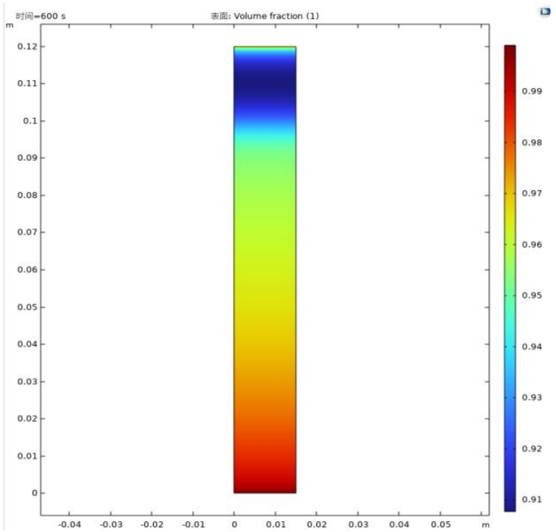


Fig.13.a Volume Fraction (phtr)

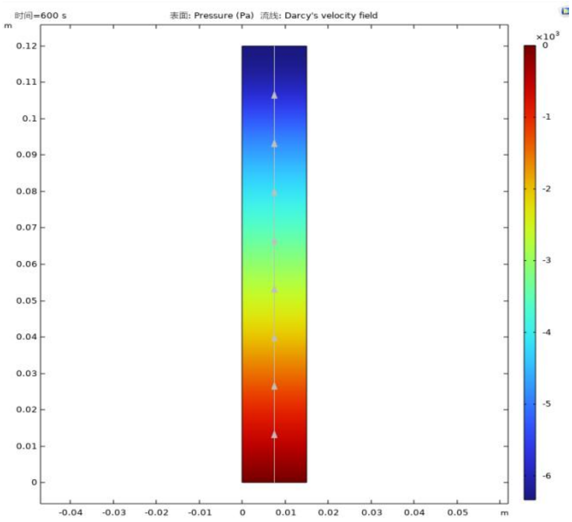


Fig.13.b Pressure (dl)

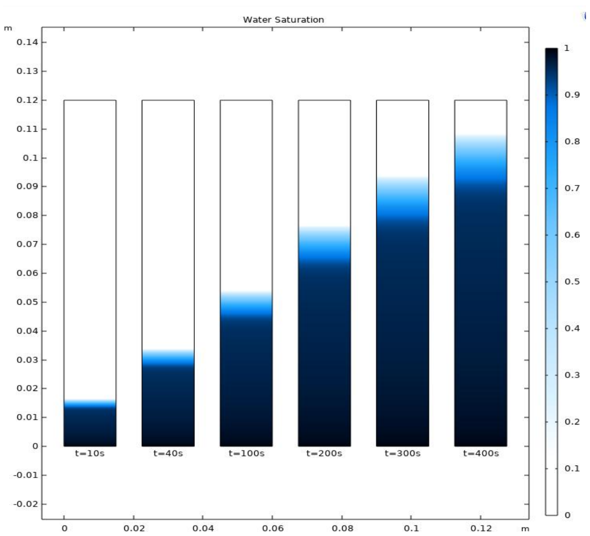


Fig.13.c Water Saturation (grouped)

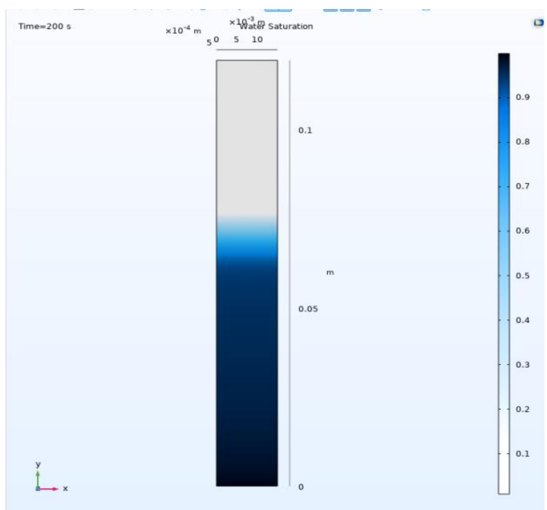


Fig.13.d Water Saturation 3D

According to the simulation results, we can find that the selected peanut shell material is a very good water conveyance layer material, and its capillary action is enough to absorb the seawater in the experiment and fill the water conveyance layer, to ensure the lasting and efficient evaporation process of seawater.

4. Conclusion
4.1 Summary of innovation in this paper

1. For the design of the evaporation structure, I refer to and preliminarily analyze the mainstream structure in the current field. High-performance interfacial evaporation technology has evolved from a two-dimensional at the beginning to a three-dimensional structure today. The characteristic of this technology is to concentrate the energy of solar radiation on the light-absorbing layer as much as possible, so the ability to absorb solar radiation on the surface of the light-absorbing layer, the structure, and the radiation area of solar radiation is very important.

On the one hand, it is considered that the actual average solar radiation area is much larger than that of the traditional two-dimensional plane, and in the process of seawater evaporation and desalination, there will always be salt precipitation on the surface of the light-absorbing layer. After the salt accumulates to a certain extent on the surface of the spherical material, the salt will naturally decline with the curved surface under the action of gravity, thus solving the problem of salt accumulation.

As for the solar radiation absorption capacity of the light-absorbing layer, the author makes a theoretical simulation here, so the selected material is the mainstream material of graphene with high performance.

2. For the selection of materials for the water conveyance layer, the main considerations are the strength of water conveyance capacity under the capillary action of materials and the preparation cost of materials.

According to the relevant predecessors' literature, the author chose peanut shells as raw materials to be prepared by special treatment, and the correlation analysis of its capillary water transport capacity has been simulated and demonstrated in this paper. As for the production cost, there are abundant and low-cost raw materials of peanut shells in China.

3. The main feature of this paper is to use Comsol 6.1 software to model and analyze the seawater desalination process in high-performance interface evaporation technology in detail.

The analysis contents include the temperature and fluid field in the photo-endothermic layer, the temperature and fluid field in the airfield evaporated by seawater, the water transport capacity of the water transport layer material, and the salt analysis of the photo-endothermic layer.

In this paper, the evaporation process of the high-performance interface is analyzed and simulated from many angles, and the theoretical trial operation is realized. Finally, it is in good agreement with the experimental results in related literature, which shows that the simulation software can better guide the experiment and reduce manpower, material resources, and financial resources.

4.2 The paper's shortcomings and further thinking.

1. The author has done a lot of simplification to solve this problem by reasoning equations, and the simulation results are similar to those in the laboratory. Simplification reduces the process of solving multi-physical field equations, but this simplification will miss the influence of these physical factors on the whole solution.

2. In the research of performance optimization, at present, the author can only analyze the change in evaporation efficiency performance by controlling variables. I try to get a formula through research, which includes every factor in the evaporation process, defines the influence degree of each factor on the evaporation process as a weight, and obtains the specific value of the weight through the equation. Trying to get $y = A^{X_1} * B^{X_2} * C^{X_3} \bullet\bullet\bullet$ similar equation. But at present, there is no breakthrough in this research. In other words, some empirical formulas can simplify the evaporation process.

3. Data processing, on the premise that the first two points are perfected, we can use Matlab, python, and other software to solve the linear regression equation of experimental results.

4. In practical application, the current mainstream research direction in this field is to change the structural characteristics of porous media. However, the research on the characteristics of results is not thorough. Even the software simulation effect is not good, because the void structure simulation of software simulation follows the random number function, and there is no general conclusion. The simulation generally approximates the

properties of porous media by assuming permeability and porosity. However, the multi-factor coupling in the actual situation is not considered in the process of solving.

5. The ability of quantitative production is weak, the reason is that the laboratory experimental conditions are too idealized.

6. If it is direct evaporation on the sea surface, the influence of wave fluctuation on the stability of the whole fluid field may be needed. If it is still water evaporation, then the simulation in this paper has certain reference significance.

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