Investigating the effect of different salts on the thermal efficiency of a solar pond device

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Abstract. This article describes an experimental method for determining the physicochemical properties of NaCl, $MgCl_2$, and KCl salts to establish a salinity gradient in an experimental solar pond located at Karshi engineering-economics institute. During the experiments, separate brine solutions of each salt were prepared in the solar pond device in order to establish the density profile, concentration, and heat capacity of these salts. Based on the study of samples taken from different points of the pond, the density profile of each salt was studied and graphs were constructed. Using an adiabatic colorimeter made for the experiment, the heat capacities of each salt brine were studied in the temperature range of 20ºC-70ºC and at values of brine concentration of 5%-28%, and the change graphs at different temperatures were presented.

1 Introduction

In the last decade, salinity gradient solar ponds have been increasingly used in practical projects of science and technology. Today, in energy saving projects in a number of countries, along with salt gradient solar ponds of up to several hundred square meters in size, mini solar ponds are being built [1-4]. On the basis of the research carried out in them, different constructions of the solar pond, prospects for improving performance, factors affecting productivity, parameters of different salts in the formation of salinity gradient, heat recovery mode, parameter measurement, economic analysis and its application are considered.

Salts are widely used in solar ponds due to their high heat capacity. Sodium chloride, magnesium chloride and fertilizer salts are usually used. The physical parameters of the various salts used in improving the energy efficiency of solar ponds should be considered.

The solubility property of the salt, which corresponds to the variation of the temperature of the solar pond with time and the depth of the pond, is important in increasing the efficiency of the pond. Different salts exhibit different solubility characteristics as the temperature of the solar pond water changes. It can be summarized as follows (Figure 1). It can be seen that sodium chloride (NaCl), magnesium chloride ($MgCl_2$) and sodium sulfate (Na_2SO_4) salts have stable solubility comparatively with the temperature [5].

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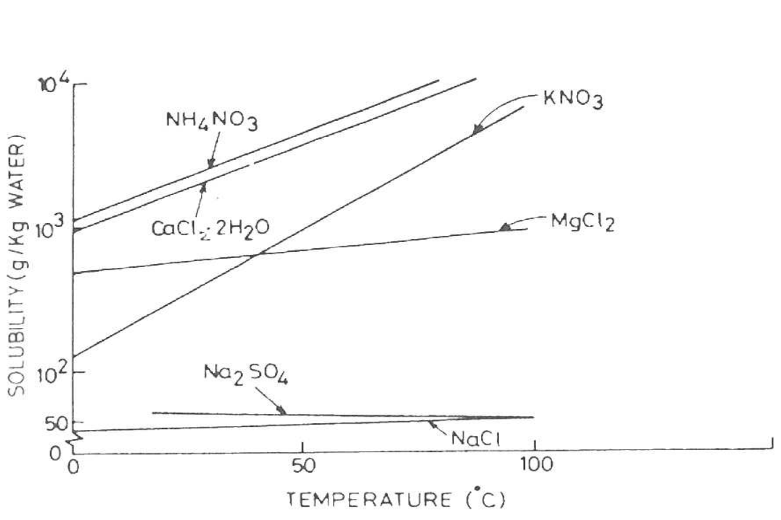

Fig. 1. A graph of the temperature dependence of the solubility of salts.

The spreading value of salt is another important factor in improving the efficiency of solar ponds. Solvent viscosity decreases with the increasing of the temperature because the molecular diffusion of salt depends on salinity and temperature. For example, the solubility of sodium chloride (NaCl) at a temperature of 90 ºC is 5 times higher than its solubility at a temperature of 10 ºC [4-5]. At a given temperature, the molecular diffusivity of salts K_s changes by less than 10%, while the salinity changes by up to 20%. Molecular diffusion of different types of salts at room temperature is given in Figure 2. The diffusion coefficient generally increases at higher temperatures, which causes the salt flux to rise upward in the solar pond.

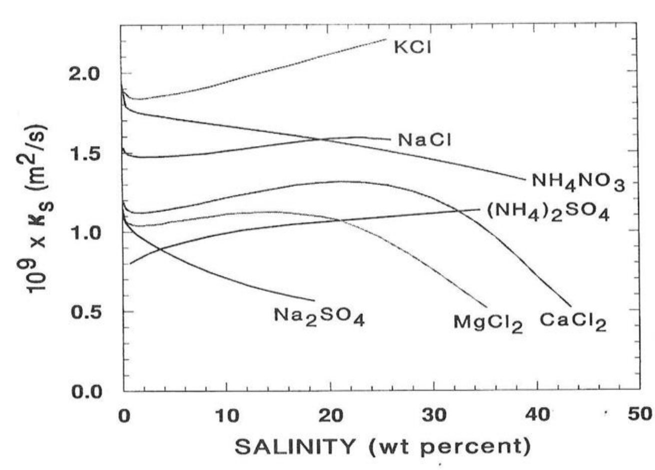

Fig. 2. Graph of the dependence of molecular diffusion of salts on changes in salinity at a temperature of 25 ºC.

According to the research, sodium chloride (NaCl) is one of the most effective salts used in solar ponds around the world. Sodium chloride (NaCl) salt is one of the most stable salts with temperature changes, and its brine has a significantly higher transparency. In addition, sodium chloride (NaCl) salt occurs naturally as rock salt (halite) in sea and salt lake waters, and seawater is 77% salt. It is cheaper than other salts. This salt dissolves in water up to 27-30% until it reaches saturation as shown in Figure 2 [6-7].

Another salt used in solar ponds is magnesium chloride ($MgCl_2$), which creates a higher salinity gradient in the water compared to sodium chloride (NaCl). This salt is very stable during operation and has high solubility to form high density brine. Magnesium chloride ($MgCl_2$) salt has a solubility of 35% and 40% depending on the solution temperature. Magnesium chloride ($MgCl_2$) solution brine is the densest brine. But magnesium chloride ($MgCl_2$) salt is more expensive than sodium chloride (NaCl) salt [8-9].

Potassium chloride (KCl) salt, which is considered a fertilizer salt, can also be used to create a salinity gradient in solar ponds. Potassium chloride (KCl) is a white, odorless crystalline substance. It dissolves well in water. In nature, it occurs in the form of sylvine and carnallite minerals, and is also part of sylvinite. At low temperatures, the solubility of potassium (KCl) and sodium (NaCl) chlorides is almost the same. With increasing temperature, the solubility of sodium chloride (NaCl) almost does not change, while the solubility of potassium chloride (KCl) increases sharply [10-11].

Thermophysical properties of various salts, such as thermal conductivity, heat diffusion, heat capacity, density, kinematic viscosity have been studied by scientists in the field and certain results have been achieved [12-14].

The values of the specific heat capacity of the mixture of high temperature and different concentrations of saline brine help to accurately estimate the heat energy extracted from the hot brine layer in the solar pond device. A number of foreign literatures have been published that summarize the thermophysical properties of various salt solutions. However, the physico-chemical effect of different salts on the efficiency of obtaining heat energy from the solar pond, the evaluation of the relative heat capacity of the salt water solution at different concentrations and temperatures have not been sufficiently studied by experts. Therefore, the effects of sodium chloride, magnesium chloride, and potassium chloride salts on solar pond thermal efficiency were experimentally investigated in the conditions of Karshi city, and research results were obtained for each salt.

2 Materials and methods

The Republic of Uzbekistan is one of the countries rich in salt reserves. During the research process, the potential of the country to produce 3 salts of sodium chloride (NaCl), magnesium chloride ($MgCl_2$) and potassium chloride (KCl), which are considered fertilizer salts, and the thermal-technical, physico-chemical characteristics of using these salts in the solar pond were studied (Table 1).

Table 1. Heat-technical, physico-chemical properties of NaCl, $MgCl_2$ and KCl salts.

No	Type of salt	Density kg/m^3	Melting temperature (°C)	Boiling temperature (°C)	Solubility at a given temperature (g/l)					
					0 °C	20 °C	40 °C	60 °C	80 °C	100 °C
1	Sodium chloride (NaCl)	2165	801	1465	356	359	364	370	380	391
2	Magnesium chloride ($MgCl_2$)	2316	714	1412	528	546	575	607	658	734
3	Potassium chloride (KCl)	1984	776	1407	281	347	403	456	510	567

Accordingly, based on the information received from the State Statistics Committee of the Republic of Uzbekistan, the production potential of the regions of our Republic for salt (table salt, NaCl) and potassium chloride (KCl) and solid salt ($MgCl_2$) for the last 3 years is presented in the following tables.

Table 2. Volume of solid salt production in regions of the Republic of Uzbekistan.

Name	Year 2020	Year 2021	January-October in 2022 (in terms of large enterprises)
	Volume (tons)	Volume (tons)	Volume (tons)
Solid salt	292720.7	409765.5	129419
Regions			
Andijan	118.7	667.2	-
Jizzakh	8.6	53.9	-
Kashkadarya	39644.4	47611.3	19209
Navoi	115805.4	63637.2	-
Namangan	64.4	828.5	-
Samarkand	60.1	65	-
Surkhandarya	35491	30323.2	18095
Tashkent city	1666	1740.6	-
Tashkent	1063.1	366	-
Fergana	490	106	-
Republic of Karakalpakstan	97635.1	262975.6	92115
Bukhara	674	1391	-

Table 3. Production volume of potassium chloride salt in the regions of the Republic of Uzbekistan.

Name	Year 2020	Year 2021	Year 2022
	Volume (tons)	Volume (tons)	Volume (tons)
Potassium chloride	210001	197602	160900
Regions			
Kashkadarya	210000	197400	159200
Tashkent	1	2	-
Jizzakh	-	200	1700

3 Results and Discussion

The research work was carried out in February 2023 in a trapezoidal solar pond with a height of 1.5 m and the dimensions of the bases of 0.7 m and 1.5 m square in the climatic conditions of Karshi city. The experiment used 3 salts of sodium chloride (NaCl), magnesium chloride ($MgCl_2$) and potassium chloride (KCl) in the solar pond. Research processes were carried out for 7 days for each salt, for a total of 21 days. During the experiment, samples were taken from different depths of the pond in order to determine the density level of each salt in the salt water and the salt water gradient. Density profiles of each layer of the solar pond were studied at the beginning and end of the experiment for each salt. At the beginning of the experiment, the density of salt water in the lower heat storage zone was 1200 kg/m^3 in sodium chloride (NaCl) salt water, 1210 kg/m^3 in magnesium chloride ($MgCl_2$) salt water, and 1195 kg/m^3 in potassium chloride (KCl) salt water. It was found that the density of each salt brine in the upper zone is close to the density of fresh water and varies around 1002-1004 kg/m^3 and increases to 1007 kg/m^3 at the end of the experiment. A comparison of the initial and research results for each salinity in the experimental solar pond shows that the density of salt water in the lower zone of the solar pond at these two times is significantly different from each other. Graphs of changes in the density profile at the beginning and end of the experiment for each salt are shown in Figures 3. In these graphs, it can be seen that the slope of the density profile at the beginning of the experiment in the middle zone is higher than at the end of the experiment. The opposite situation was observed in the lower energy storage zone of the solar pond.

This process depends on the decrease in the rate of diffusion of salt molecules in the pond over time.

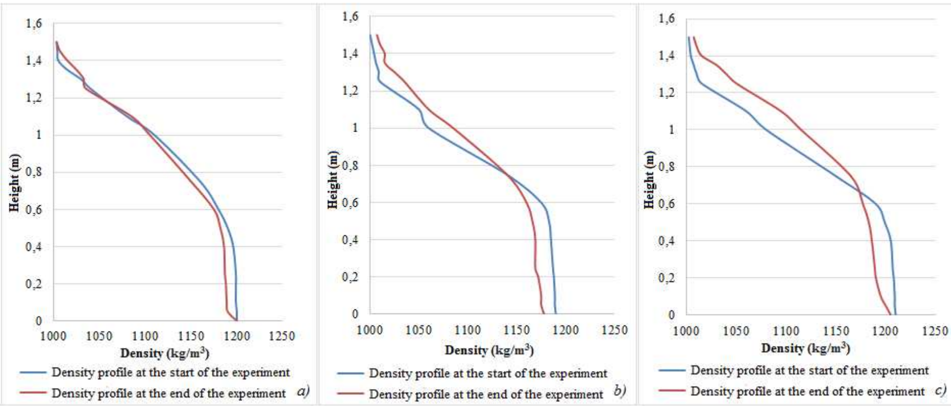

Fig. 3. Distribution graph of salt water density by depth of the solar pond (*a*-NaCl brine, *b*- KCl brine, *c*- $MgCl_2$ brine).

At high temperatures and concentrations, the specific heat capacities of NaCl, $MgCl_2$, and KCl brine are important in calculating the thermal energy obtained from the solar pond. Using an adiabatic calorimeter, specific heat capacity of these salts was determined experimentally. During the research process, specific heat capacities of these salts at different temperatures and concentrations were determined using the adiabatic calorimetric method. There is an adiabatic calorimeter for determining the specific heat capacity of a brine solution based on these salts, which consists of a test chamber placed in a box, a thermometer placed in the chamber, and a heating coil with a spiral wire (Figure 4).

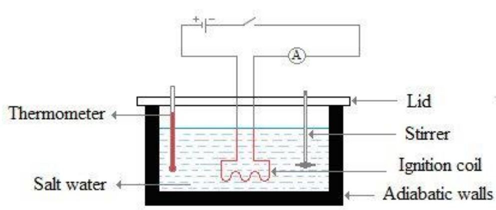

Fig. 4. Experimental adiabatic calorimeter equipment.

Saline solutions of NaCl, $MgCl_2$ and KCl salts were prepared in the solar pond. During the study, the temperature and concentration of each salt brine sample from the upper convective zone (UCZ), middle nonconvective zone (NCZ), and lower convective zone (LCZ) of the solar pond facility were determined.

The conducted research work was carried out in the temperature range of 20°C-70°C and at values of salt water concentration of 5%-28%. The results of the research conducted on the saline solution of each salt showed that the heat capacity of the solution decreases with increasing temperature and concentration of salt water.

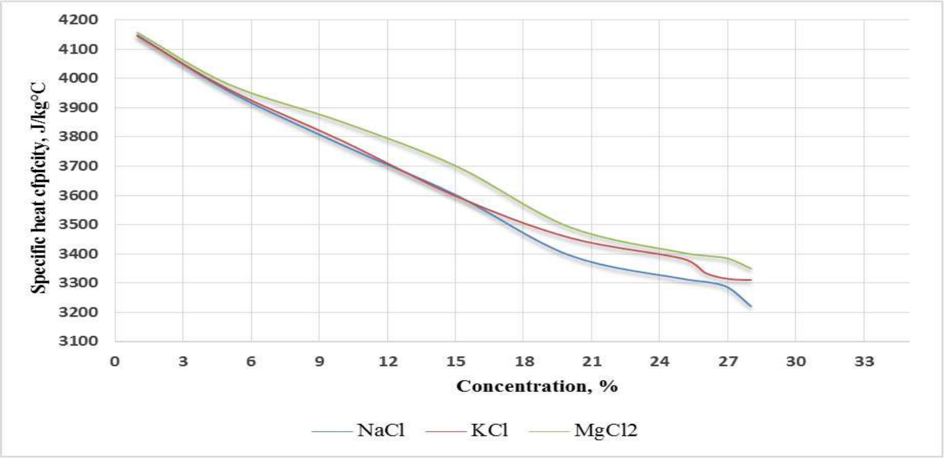

Fig. 5. The graph of changes in specific heat capacities of NaCl, KCl and $MgCl_2$ salt solutions at different concentrations.

4 Conclusion

The following conclusions were drawn based on the research of physical-chemical, thermal-technical properties of various salts in the solar pond.

The $MgCl_2$ salt brine in the solar pond had a higher density profile than the other two salt brines and was 1210 kg/m^3.

The density profile of each salt in the lower energy storage zone of the pond was found to be higher at the beginning of the experiment than at the end of the experiment.

The results of the study showed that the heat capacity of the solution decreases with increasing temperature and salt water concentration in the saline solution of each salt.

It was observed that the heat capacity of NaCl salt solution is lower than the heat capacity of KCl, $MgCl_2$ solutions at concentrations higher than 17%, and the lower energy storage zone of the solar pond has reached the maximum heat storage.

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