Saline Soil of Urban and Rural Areas in the West of China

Fukang Deng[1, 2]

*Research Centre of Northern Anhui Urban-rural Integration, Suzhou University,
Suzhou 234000, Anhui, China
School of management and engineering, Suzhou University, Suzhou 234000, Anhui, China*

Xiaofang Chen[1, 2]

*Research Centre of Northern Anhui Urban-rural Integration, Suzhou University,
Suzhou 234000, Anhui, China
School of management and engineering, Suzhou University, Suzhou 234000, Anhui, China*

Shuxia Wang[1, 2]

*Research Centre of Northern Anhui Urban-rural Integration, Suzhou University,
Suzhou 234000, Anhui, China
School of management and engineering, Suzhou University, Suzhou 234000, Anhui, China*

Chengwei Wang

*School of civil engineering, Anhui University of Science and Technology,
Huainan 232000, Anhui, China*

Abstract

In this paper, the transient experiment method of transient hotline method is adopted, by applying the method of TC3000 hotline coefficient of thermal conductivity tester, the study is be carried about the subgrade engineering

of frozen Lanzhou saline soil thermal properties and the relative relationship between basic physical parameters of soil. By experiment a great influence on the coefficient of thermal conductivity of saline soil by the freeze on saline soil dry density, moisture content and the salt content of the soil type, soil salt content and temperature change can be found. The research mentioned a significative train of thought, and provide important reference significance for the future indoor saline soil coefficient of thermal conductivity research.

Key words: FROZEN SALINE SOIL, COEFFICIENT OF THERMAL CONDUCTIVITY, HEAT-POLE METHOD, INFLUENCE FACTOR

1. Introduction

With the vigorous development of society and economy, the number of railways, highways, houses and other buildings has been increasing on the permafrost and areas and the seasonal frozen soil areas. However, the existing buildings have significantly changed the heat exchange conductions between the land and the air. Coupled with the moisture and heat transmission process, the roadbed accumulates heat year by year and the rising temperature of the soil body causes the thaw collapse of the frozen soil. [1] At the same time, during the freezing process, water migration and in-situ freezing leads to the inflation and frost heaving of soil mass. Either thaw collapse or frost heaving damage cannot be separated from the analysis and calculation of the frozen soil temperature field. Thermal property is one of the important factors to be taken into consideration for the calculation of the frozen soil temperature. [2] Thus, it is imperative to study the heat conductivity of frozen soil heat conduction and its influencing factors.

Over the past years, measurement of the heat conductivity coefficient and factors influencing heat conductivity coefficient have been studied on and off. Scholars at home and abroad have developed a relatively systematic heat conductivity coefficient theory and feasible experiment techniques. In the mid-18th century, Benjamin Franklin et al. conducted an experimental research and analysis of the heat conductivity of solids, developing multiple ways to measure the heat conductivity coefficient of materials and the heat conductivity coefficient instrument to measure various materials. Deng Yousheng et al. [3] proved that there is a close bearing between the heat conductivity coefficient of the saline soil and the salinity of the soil. Wen Zhi et al. [4] studied the heat conductivity coefficient of permafrost of the Tibet Plateau, finding out that the heat conductivity coefficient of the soil is decided by components, density and water content of the remolded soil. Based on the thermodynamic parameter test of the artificial secondary freeze thawing, Liu Ruifeng et al. [5] found out that the freezing temperature, conductivity coefficient, frost heaving force and frost heaving rate of the soil mass under the

effect of the secondary cycle of freezing and thawing decrease considerably compared with those under the effect of one cycle of freezing and thawing. Thus, it can be seen that the research into the heat conductivity coefficient of the frozen saline soil is insufficient. Therefore, this paper adopts the saline soil on the highway roadbed in Lanzhou as the surface soil, and the transient hot-wire method [6,7] and TC3000 heat conductivity coefficient tester to conduct an indoor experiment of the saline soil in Lanzhou. The heat conductivity coefficient of saline soil in Lanzhou under the condition of different water content, dry density, salinity and salt types is tested and the relationship between the saline soil and the other influencing factors is discussed at an attempt of serving as a reference to the construction of the engineering construction in the cold areas and the research of the temperature field.

2. Heat conductivity coefficient test of the saline salt

2.1. Heat conductivity coefficient test system and preparation of the experimental soil samples

The experimental instruments adopted in this experiment were provided by Xi'an Xiaxi Electronic Technology Co., Ltd. The instrument type is TC3000. The test main engine, the sensor, the test software Hotwire3.0 and the cryogenic box constitute the test system and the experiment environment system for the whole test process. (please see Figure 1.)

Processed the soil samples into a φ 61.8×21mm cylinder. Wrapped the soil mass with the ultra-thin preservative film so as to prevent the influence of moisture evaporation from influencing the test accuracy. Three of every sample group were processed. See Table 1 for the experiment arrangement. The preparation of the soil samples proceeded strictly in accordance with the soil test, and the soil samples were put into the preservative film 24 hours in advance.[8] The air dried soil mass and the increased water mass for every group should be calculated according to the following equation:

$$m = (1+0.01w_0)\rho_d V \tag{1}$$

$$\Delta m_w = 0.01(w-w_0)\rho_d V \tag{2}$$

Where, m (g) stands for the required soil mass to make a soil sample; Δm_w (g) stands for the required water mass to prepare a remoulded soil sample; w $(\%)$ stands for the water content required by the soil sample; w_0 $(\%)$ stands for the water content of the air dried soil sample; ρ_d (g/cm^3) stands for the dry density of the soil sample; V (g/cm^3) stands for the volume of the cutting ring for the sample preparation.
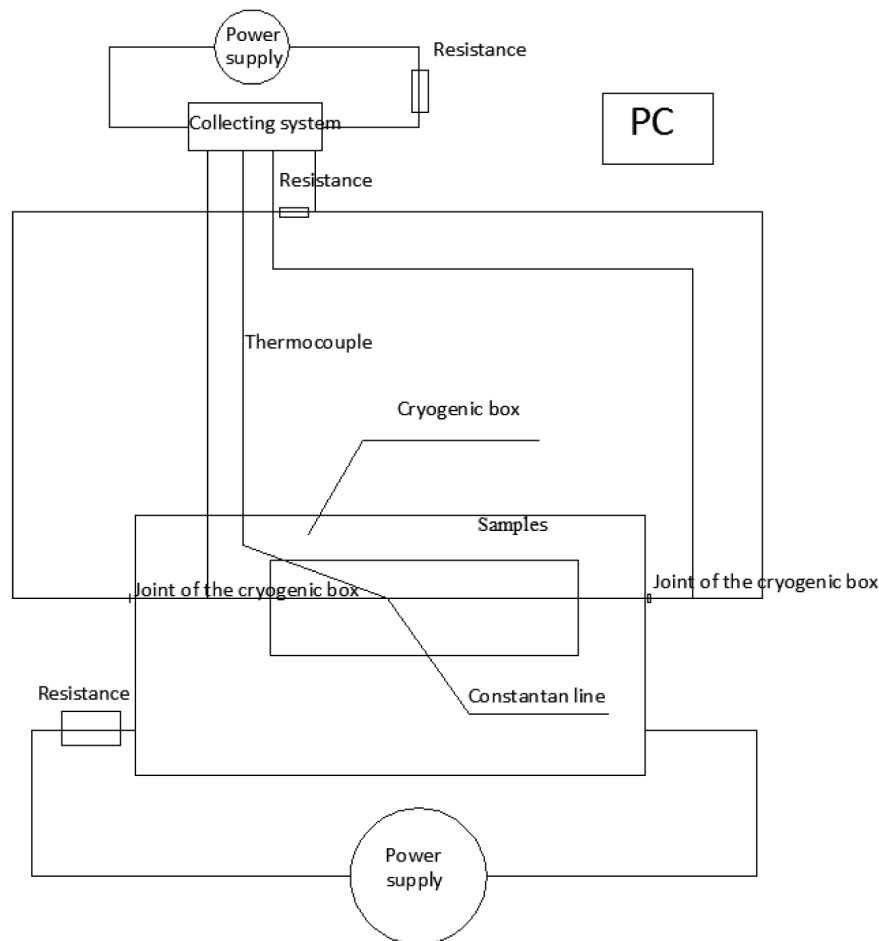

Figure 1. Schematic diagram of TC3000

Table 1. Experimental arrangemetn

Item	Moisture content (%)	Dry density (g/cm³)	Test temperature	Item	Salinity (%)	Salt type	Test temperature
A1	10	1.5		E1	—		
A2		1.6		E2	1	MgSO	
A3		1.7		E3	1.5	MgSO	
B1	12	1.6		F1	—		
B2		1.7		F2	1	CaCl	
B3		1.8	0°C, -3°C, -5°C -8°C, -10°C	F3	1.5	CaCl	10°C, 3°C, 0°C, -3°C, -5°C, -8°C, -10°C and sine wave(temperature of the peak was -10°C)
C1	15	1.7					
C2		1.8					
C3		1.9					
D1	18	1.8					
D2		1.9					
D3		2.0					

Note: The water content and the dry density sof Group E and F is 12% and 1.6g/cm³. In Group A, Group B, Group C, Group D, Group E1 and Group F1, the experimental soil mass is not added with any salt type.

2.2. Measurement and experimental steps to test the heat conductivity coefficient of the artificial frozen saline soil

(1) Prepared soil samples according to the dry density, water content, salinity and salt types in the experiment arrangement table. Put it into the freshness protection package for 12~24 hours.

(2) Got the prepared soil samples into three cylinders of φ61.8×21mm. Opened the cryogenic box and put the hot wire between two soil samples to make the soil samples and the hot wire fully contacted with each other. Put the permeable stone and weight on the upper soil sample to ensure the soil sample and the soil samples to be voidless. Close the case cover of the cryogenic box [9-11].

(3) Connected and start the tester, the computer power and the cryogenic box in turn, and set the cryogenic box to the required temperature. Used Hotwire3.0 to conduct temperature test [12,13]. When the temperature error was $\Delta \le 0.1$, closed the temperature test and conducted the heat conductivity coefficient test. Ensured the test interval of heat conductivity to be around 5min, and the voltage to be around 1.3V. Every temperature spot was tested for five times, and three samples in every group were tested. The temperature tested included 10ºC, 0ºC, -3ºC, -5ºC, -8ºC

and -10ºC, and sine wave (temperature of the peak was -10ºC), etc. [14]

(4) Took out samples and replaced them with two new samples with the same composition when the measured came to an end. Opened the temperature control software, set the changing period of the sine wave to be 720min, the initial temperature to be 0ºC and the peak temperature to be -10ºC. Clicked start, opened Hotwire3.0 and set the test times to be 240[15].

(5) Repeated the above steps and measured the heat conductivity coefficient.

3. Experimental results and conclusions

(1) Relation curve chart between heat conductivity coefficient and dry density

When water content, salt type and salinity remain the same, the curve relation chart between the heat conductivity coefficient and the dry density is shown in Fig. 2. Based on the changes of data points measured by the experiment, it can be seen that the heat conductivity coefficient of the saline soil increases along with the increase of the water content when the other factors remain the same. Besides, the heat conductivity coefficient shows a linear growth along with the increase of the dry density. This is because, when the dry density increases, the density of the
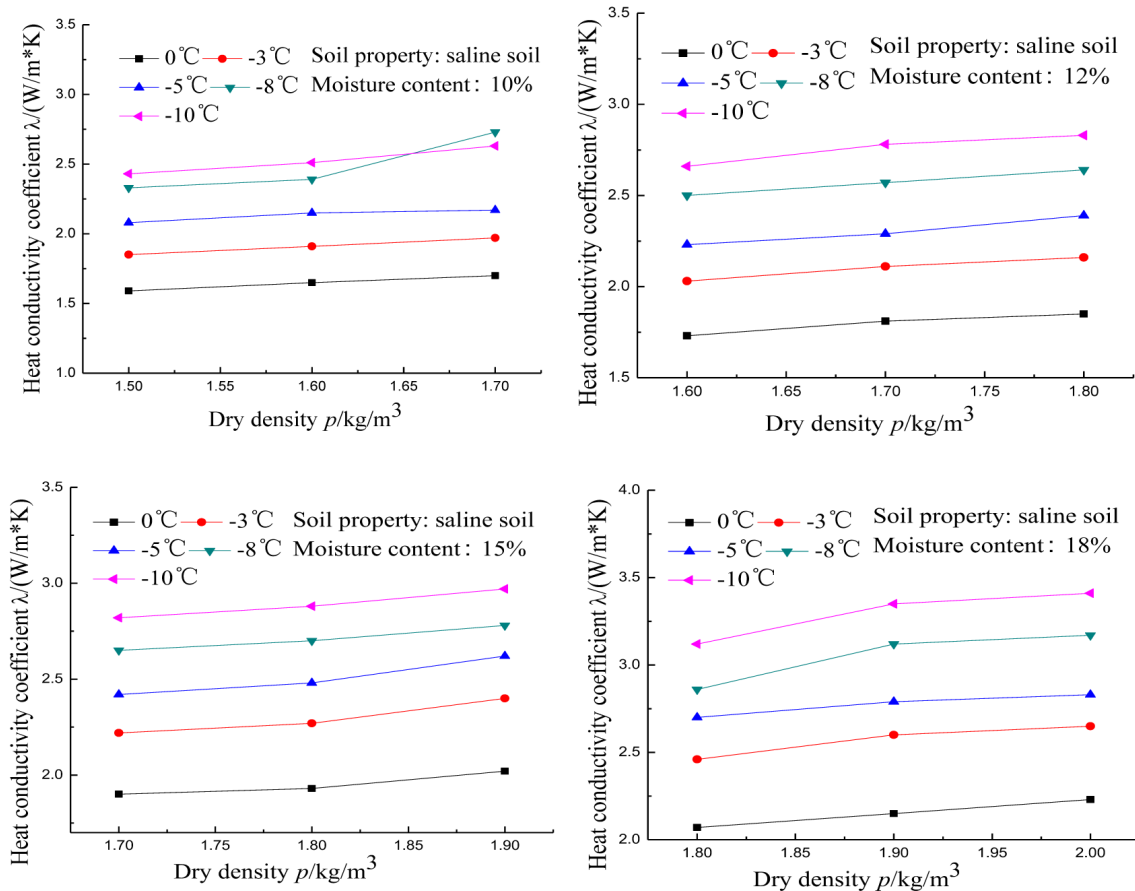

Figure 2. Heat conductivity coefficient under the condition of different water content and temperature

soil mass also increases. The heat conduction of soil mass through solids is obviously faster than the other media. Therefore, the heat conductivity coefficient will increase linearly along with the increase of the dry density. The relation between the two can be expressed below: $0.04{\sim}0.08\,W/(m\cdot K)\,/0.1\text{Kg/m}^3$.

(2) Relation curve chart between the heat conductivity coefficient and the water content

When dry density, temperature and varying factors of the saline soil are fixed, the changing relation between the heat conductivity coefficient and the water content is shown in Fig. 3. From the figure, it can be seen that the heat conductivity coefficient increases along with the increase of the water content. The phenomenon is caused because, when the temperature is relatively low and has not yet reached the freezing

zero point, the moisture in the soil mass turns into ice and little water is migrated within the soil mass. The heat conductivity coefficient of the soil mass increases slowly before the zero point, which is approximate to no growth. When the temperature reaches the zero point, the moisture in the soil starts glaciation. The heat conductivity coefficient of the ice is four times higher than that of the water. Therefore, when water gradually glaciates into the ice, the heat conductivity coefficient of the soil mass increases rapidly, whose growth is approximate to a linear relation. When the water content of the soil mass is largely or almost totally turned into the ice, the heat conductivity coefficient of the saline soil will reach the peak value. Only at the moment, some bound water in the soil mass will be frozen.
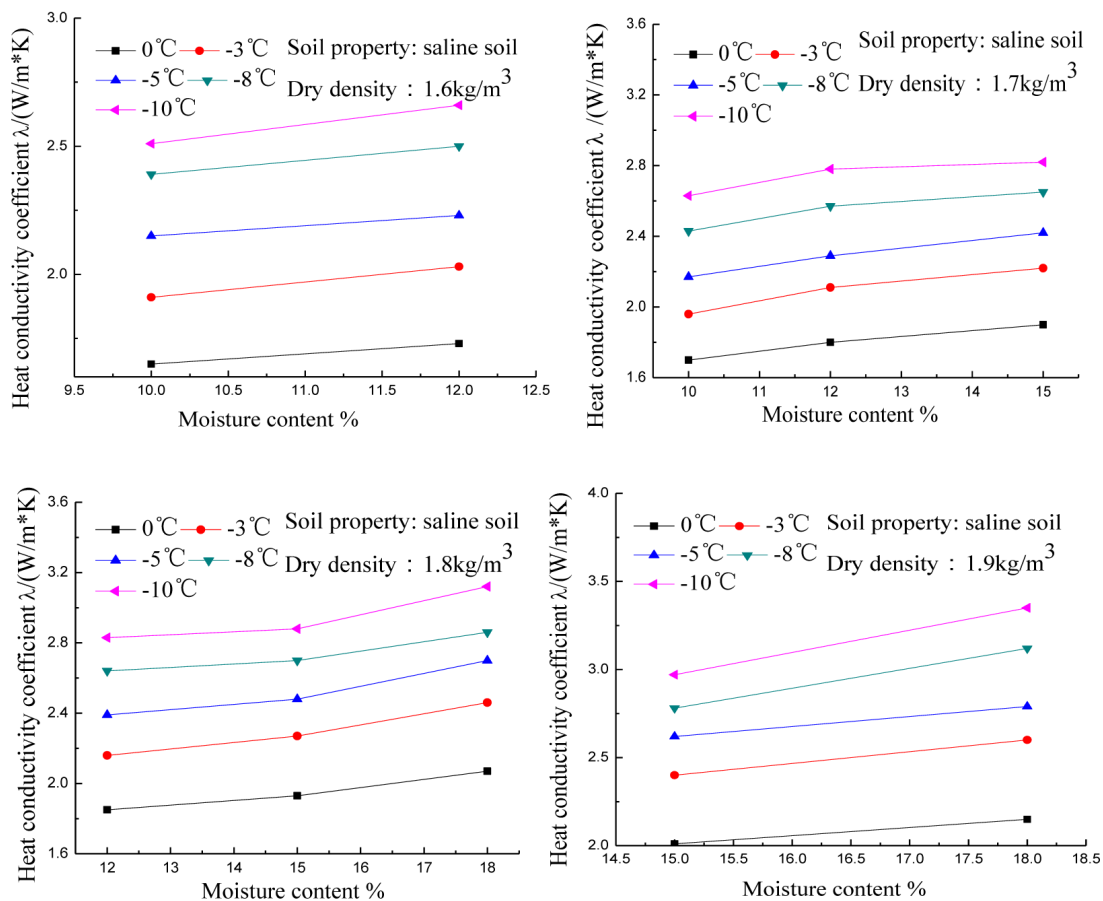

Figure 3. Heat conductivity coefficient under the condition of different dry density and temperature

(3) Relation curve chart between the heat conductivity coefficient, salt type and salinity

The Figure 4 shows the relation between heat conductivity coefficient, salinity and salt type when the dry density is 1.6g/cm^3 and the water content is 12%. Generally speaking, the heat conductivity coefficient increases along with the increase of the content. The solubility of MgSo is relatively low. Therefore, when MgSo increases, there will be crystal separation. A

large amount of moisture will be separated out. With the decrease of the water content in the soil mass, the heat conductivity coefficient decreases. In the soil mass added with chlorine salt, the heat conductivity coefficient test results are completely different. The reason is that the solubility of CaCl is higher than that of MgSO. Therefore, before freezing, with the increase of the CaCl content, the solution content in the soil increases relatively, leading to the increase of
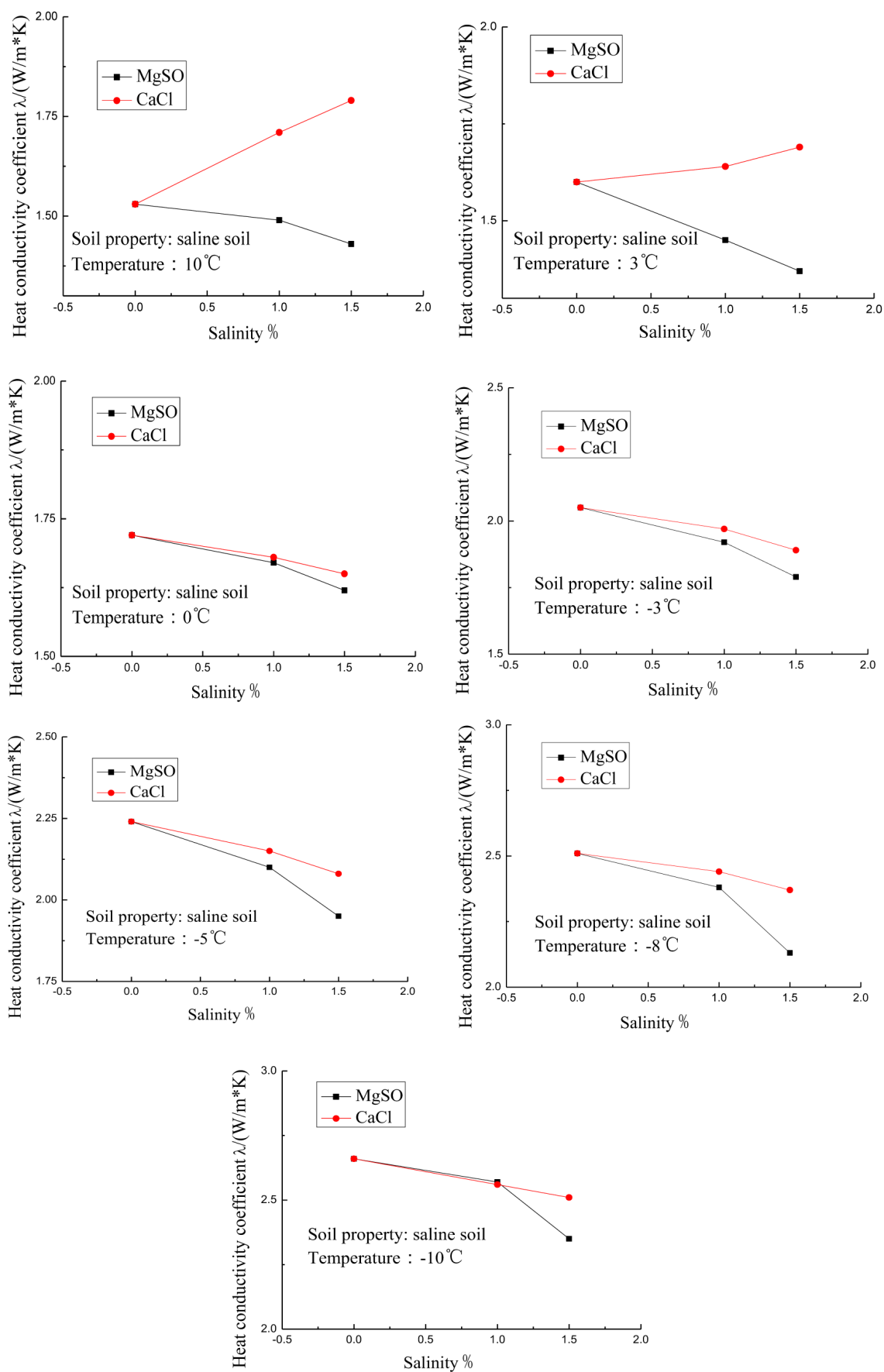
Figure 4. Relation between heat conductivity coefficient, salinity and salt type

the heat conductivity coefficient of the soil mass. On the other hand, after freezing, the heat conductivity coefficent of the soil mass either added with MgSO or CaCl is lower than that of the soil mass without adding any salt. However, before freezing, with the increase of temperature, the heat conductivity coefficient of the soil mass added with either MgSO or CaCL is higher than that of soil mass without adding any salt. This is because, after freezing, the soil mass added with salt has some solution within it, thus enabling it to freeze the water content, and resulting in the decrease of the heat conductivity coefficient of the soil mass. Before freezing, with the increase of the temperature, the solubility of temperature will also

increases, thus leading to a high content of solution in the soil mass. The increase of the water content in the soil mass leads to the increase of the heat conductivity coefficient of the soil mass.

(4) Relation curve chart between heat conductivity coefficient and temperature points

The Figure 5 shows that the heat conductivity coefficient of the frozen soil is higher than that of the melted soil either added with the salt or not. The cause is that the internal structure of the soil mass after the cycle of freezing and thawing is loose. The increase of the interspace of the soil mass leads to partial water leakage, thus resulting in the reduction of the heat conductivity coefficient. On the other
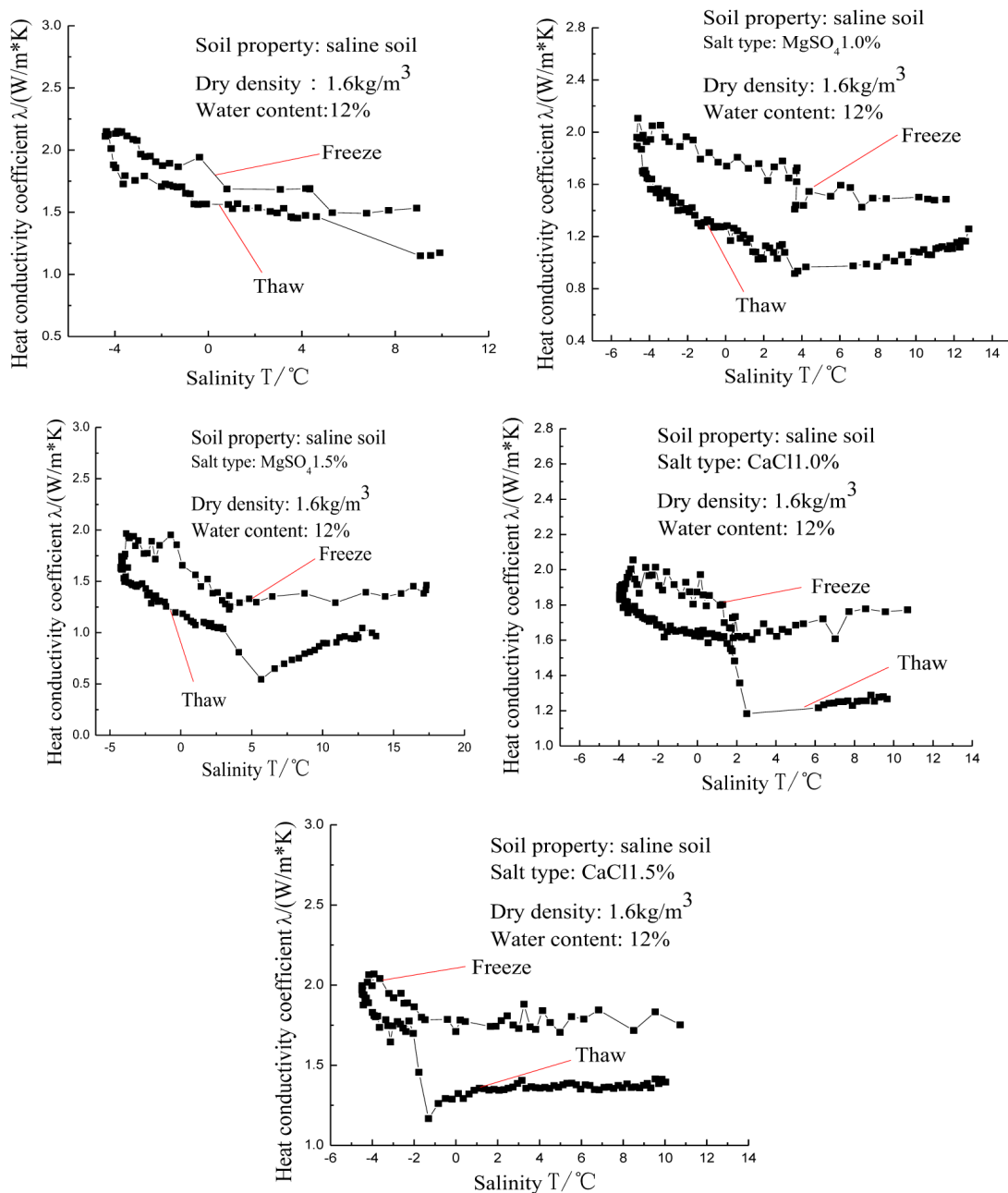
Figure 5. Heat conductivity coefficient of the saline soil under the condition of different salinity and salt type along with the sine wave changes of temperature.

hand, the changes of the heat conductivity coefficient are not obvious before freezing; while the heat conductivity coefficient of the soil mass shows a linear relation with the temperature changes after freezing.

4. Conclusions

Through the test of the heat conductivity coefficient of the saline soil, it is found that the relation between heat conductivity coefficient, temperature, dry density, salt type, ingredient and water content is shown below:

(1) Water content has the greatest influence on the heat conductivity coefficient of the saline soil. When the dry density is the same, the heat conductivity coefficient of the saline soil increases along with the increase of the water content. The relationship between the two resembles a linear one. When the water content is the same, the heat conductivity coefficient of the saline soil with the same freezing temperature increases slightly along with the increase of the dry density. With the decrease of the temperature, the larger the dry density is, the smaller the increase rate of the heat conductivity coefficient in the soil mass.

(2) Different salt type in the saline soil have a different influence on the heat conductivity coefficient of the saline salt. The function of salt on the heat conductivity coefficient is achieved through the mechanism of different solubility of the salt content leading to different solution content in the soil mass and the different water content of the glaciation. Before freezing, the heat conductivity coefficient of the saline salt with the $MgSO$ decreases slightly along with the increase of the salinity. During the freezing process, with the increase of the salinity, the heat conductivity coefficient decreases significantly. Before freezing, the heat conductivity coefficient of the saline soil with $CaCl$ increases slowly along with the increase of the salinity.

(3) Influence of temperature changes on different saline soil types: Since the salinity of the saline soil adopted by the experiment is relatively low, the heat conductivity coefficient of the saline soil without adding any salt increases slowly or even remains the same before freezing. During and after the freezing process, the heat conductivity coefficient of the soil mass linearly increases along with the decrease of temperature. When $MgSO$ is added into it, the heat conductivity coefficient decreases slowly along with the decrease of temperature before freezing. During the freezing process, along with the decrease of the temperature, the heat conductivity coefficient linearly increases. The heat conductivity coefficient of the saline soil added with $CaCl$ increases linearly along

with the decrease of the freezing temperature during the freezing process, and is higher than that added without any salt under the same temperature.

(4) When the temperature shows sine wave changes, the heat conductivity coefficient during the freezing process is obviously higher than that of the heat conductivity coefficient of the melted soil. When temperature changes in the form of sine wave (the temperature of the peak is -10°C), the freezing temperature of the soil mass cannot reach -10°C, but just around -5°C.

References

1. Yi Feng (2008) Development and steady state simulation study of frozen soil heat conductivity coefficient instruments. [dissertation]Jilin University.
2. Wu Gang (2009) Study for thermal conductivity measure of geotechnical materials and simulation and experiment of water source heat pump in the lab. [dissertation]Jilin University.
3. Deng Yousheng, He Ping, Zhou Chenglin, et al.(2004) Experimental study into the heat conductivity coefficient of saline soil. *Journal of Glaciology and Geocryology*, 26(3), 319-323.
4. Wen Zhi, Ma Wei, et al. (2005) Experimental studies of thermal conductivity of undisturbed permafrost on the Tibetan Plateau. *Journal of Glaciology and Geocryology*, 27(2), 182-187.
5. Liu Ruifeng, Hu Xiangdong & Pi Airu (2008) Experiment on thermodynamic parameters of soils under secondary freeze-thaw action. *Journal of China Coal Society*, 33(5), 518-521.

6. Yan Qiuhui, Liu Zhigang & Yin Jianmin (1997) On the thermal conductivity coefficient of fluid by the transient hot-wire technique. *Journal of Xi'an University of Architecture & Technology*, 29(3), p.p.322-325.

7. Gustafsson Silas. E., et al. (1979) Transient hot-strip method for simultaneously measuring thermal conductivity and thermal diffusivity of solids and fluids. *Journal of Physics D Applied Physics*, 12(9), p.p.1411-1421.

8. Standard for soil test method (GB/J50123-1999), Beijing: China Planning Press. 1999.

9. Qiao Shuang (1992) Hot-wire method to test heat conductivity and measures to improve the precision. *Physical Experiment*, 14(2), p.p.56-57.

10. Wang Buxuan, Yu Weiping (1986) Experimental technique of simultaneously testing the heat conductivity coefficient and the thermal diffusivity of moisture porous media. *Engineering Thermophysics*, 7(4), p.p.381-386.

11. Wang Buxuan, Jiang Yi (1985) The "heating-cooling method" for measuring thermal diffusivity and conductivity of dispersed medium in the scene with a probe. *Engineering Thermophysics*, 6(3), p.p.249-254.

12. Zhang Meifeng et al. (2004) Research into the measurement of the heat conductivity coefficient of biological materials through the micro-probe method. *Chinese Journal of Scientific Instrument*, 25(l), p.p.53-60.

13. Chang Shuyun, Chen Rongguang, LV Huiling (1994) Measurement of heat conductivity coefficient of solid materials under the low temperature. *Cryogenics*, No.4, p.p.31-35.

14. Lu Sen, Ren Tusheng (2009) Model for predicting soil thermal conductivity at various temperatures. *Transactions of CSAE*, 25(7), 13-18.

15. Zhang Yanjun, Yu Ziwang, Huang Rui, et al. (2009) Measurement of thermal conductivity and temperature effect of geotechnical materials. *Journal of Geotechnical Science*, 31(2), p.p.213-217.