CHEMICAL ENGINEERING TRANSACTIONS
VOL. 51, 2016

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Tichun Wang, Hongyang Zhang, Lei Tian

ISBN 978-88-95608-43-3; **ISSN** 2283-9216
DOI: 10.3303/CET1651201

Research on the Performance of Fiber-reinforced Energy Pile for Heat Storage

Songying Zhao*[a], Yan Fu[b]
[a] Municipal and environmental engineering School of Jilin Jianzhu University, Changchun, CHINA
[b] The First Construction Engineering Limited Company of China Construction Third Engineering Bureau, Beijing,CHINA
coffeezsy@163.com

The technology of the energy pile for heat storage is to turn the concrete piles buried beneath the ground into a part of Ground Source Heat Pump System, and bury heat-transfer tubes in the foundation piles, which are regarded as heat wells. The structural stability and thermal conductivity of the concrete piles have been taken into full consideration in this report, whose experimental study on the mix of the material of concrete piles is in the process by making use of orthogonal method. By making nine pieces of fiber-reinforced concrete and test their compressive static load and Thermal conductivity, it proves to be that the third and fourth pieces have got the best mixing proportion. The optimized fiber-reinforced concrete has been improved not only in the mechanical properties but also in the thermal conductivity. On the basis of the experimental ratio, setting up experimental stage for fiber-reinforced energy pile for heat storage, and simulating and measuring the single pile have got the conclusion that by means of comparing the real data with the simulated data in the inner temperature of the heat storage devices, the data which is got at 0.65 meter’s deep is less interfered from the outside. This conclusion turns out to be of great value to the study on the process of energy pile for heat storage.

1. Introduction

The technology of the energy pile for heat storage is to turn the concrete piles buried beneath the ground into a part of Ground Source Heat Pump System and bury heat-transfer tubes in the foundation piles, which are regarded as heat wells, (Ahmed, 2009; BRANDL, 2006; Pinel et al., 2011).Thus, digging wells of GSHP and backfill grouting of heat wells have been avoided. The implementation of this technology has reduced the cost, shortened the period of the project under construction, save the earth and hence creates a new form of heating. Because of the heat transfer tubes in the foundation pile, the ultimate compressive bearing capacity and ultimate flexural capacity will be influenced, which will lead to an extremely serious invisible danger to the buildings, even to the capacity of the foundation pile,(Zhao and Chen, 2013; Zhang, 2009).The structural stability and thermal conductivity of the concrete piles have been taken into full consideration in this report, whose experimental study on the mix of the material of concrete piles is in the process by making use of orthogonal method. By making nine pieces of fiber-reinforced concrete and test their Compressive static load and Thermal conductivity, to get the best mixing ratio, (Zhao, 2015).On the basis of the experimental ratio, setting up experimental stage for fiber-reinforced energy pile for heat storage, and simulating and measuring the single pile to analyse the variation of the sand both in and out of the energy pile in the process of storing heat and to ensure a reasonable model of storing heat.

2. The Material Mixing Ratio of the Optimized Energy Pile

2.1 Choosing Raw Material

The main materials referred to the energy piles contain cement binders, aggregate, fiber, admixtures and so on.
The kind of cement: Composite Portland Cement.
The type of coarse aggregate: Basalt gravel and its density are 2.6×10^3Kg/m^3.

Please cite this article as: Zhao S.Y., Fu Y., 2016, Research on the performance of fiber-reinforced energy pile for heat storage, Chemical Engineering Transactions, 51, 1201-1206 DOI:10.3303/CET1651201

The type of fine aggregate: Natural sand, and its modular and density is 2.6 and 2.55×10^3Kg/m^3 respectively, its moisture content, 5%.
The type of fiber: the fiber-reinforced material mentioned here refers to steel fiber, whose length is 30-40mm and whose tensile strength is 4500Mpa.
The type of the material for storing heat: graphite and copper slag have a better thermal conductivity and the density of the graphite and copper slag in this experiment is 1.8×10^3Kg/m^3 and 3.3×10^3Kg/m^3 respectively.

2.2 Concrete Verification Test and Design

The purpose of this experiment is to optimize the material ratio of the energy pile and study the compressive capacity and the thermal conductivity of the optimized energy piles. In this experiment, steel fiber, copper slag, and graphite are chosen as the main factors and each factor includes three levels as Table 1:

Table 1: Factor and level

Factor / level	Carbon fibers (v %)	Graphite (v %)	Copper slag (v %)
1	0.5	0.5	3
2	1	1	4
3	2	2	5

According to the factor and level, make use of the orthogonal method and ensure a corresponding quality of each factor to get a table as Table 2:

Table 2: A Match between Material and Quality

Columns No. / Test No.	Carbon fibers(Kg)	Graphite(Kg)	Copper slag (Kg)
1	186.3	2.1	98.4
2	186.3	4.2	131.2
3	186.3	8.4	196.8
4	372.6	2.1	131.2
5	372.6	4.2	196.8
6	372.6	8.4	98.4
7	745.2	2.1	196.8
8	745.2	4.2	98.4
9	745.2	8.4	131.2

2.3 Analysis of the Test Results of the Mechanical Properties of Fiber-reinforced Concrete

According to Table 2, make nine groups of models with different material ratios, and nine pieces with the same material in one group. Test the compressive capability of the 81 pieces included in this experiment and the result is as Table 3:

Table 3: Test Result of the Compressive Capacity

Columns No. / Test No.	3 days stress(MPa)	7 days stress(MPa)	28 days stress(MPa)
1	21.198	23.492	29.246
2	21.096	23.791	29.493
3	24.502	29.164	36.317
4	22.254	30.655	40.358
5	21.439	25.744	31.044
6	19.982	25.119	29.323
7	19.229	19.627	28.853
8	23.097	26.448	30.73
9	23.948	25.483	32.714

2.4 Measure of Thermal Conductivity

It can be seen from Table 3 that the materials in the 3rd and 4th group have the best compressive capacity, whose thermal conductivity needs to be tested. Make three groups of test pieces whose size is 300*300*300, three pieces in each group and the first group is made to be the standard one, nine pieces included in this experiment, to measure the thermal conductivity. The test result is recorded in Table 4.

Table 4: Thermal Conductivity Test Results

Group	Thermal conductivity(W/m · K)
concrete test block	2.282
Third groups	3.47
Fourth groups	5.44

It can be seen from Table 4 that the thermal conductivity of the pieces in third and fourth group has been improved more than that of the normal concrete. The thermal conductivity of the pieces in the third and the fourth group is 1.52 and 2.38 times that of the standard concrete respectively.

2.5 Comprehensive Analysis

As the data analysis shows, the compressive capacity and thermal conductivity of the test pieces using the mixing ratio in the third and fourth group conform to the characteristics of concrete piles, ranking the first in the orthogonal experiment and the ratio of each group in 50kg concrete is shown as Table 5.

Table 5: Proportion Optimization Table

No.	Composite Portland cement(kg)	Sand(kg)	Gravel(kg)	Carbon fibers (g)	Graphite (g)	Copper slag (g)	water(kg)
Third groups	9.65	11.39	22.55	931.5	42	984	4.45
Fourth groups	9.65	10.82	22.55	1863	10.5	656	4.45

3. Research on the Performance of Heat Storage

3.1 Heat Storage Test of the Energy Piles

Heat Storage Test of the Energy Piles is to transfer the heat to concrete piles through heat exchange tubes inside the piles so as to store the heat in the earth.

The heat storage box is made of wood and the size is 1.3m*1.3m*1.3m, with 200mm the diameter, and 1200mm the length of the pile. There are 13 points for measuring temperature in the heat storage box, including one inside the energy pile and the other 12 points where the temperature sensor lies in the vertical height of 0.15 m, 0.65 m, 1.15 m, and horizontal radius of 150 mm, 300 mm, 450 mm and 600 mm away from the center of the energy pile. Point 1 refers to the center temperature of the energy pile, Point 2 the temperature of the junction between energy pile and the soil; Point 3-5 the soil temperature of every 150mm in the horizontal direction outside the pile. The process of storing heat will last for ten days in this experiment to test the changes of temperature inside the heat storage box.

3.2 Simulative Heat Storage of Energy Piles

Make a 3D modeling for the experiment and a ten-day simulation of heat storage. The related parameter can be seen in Table 6. And the simulative result can be seen in Figure 1 and Figure 2, which show the temperature of the soil in the box in the horizontal and vertical direction.

Table 6: Related Simulation Parameters

	Thermal conductivity($w/m^2.K$)	Specific heat(J/kg)	Density (kg/m^3)	Other
Heat transfer tube	0.2	2000	940	The inlet water
Concrete	3.47	970	2400	temperature 320K
Soil	0.78	1800	1900	Long 12m
Circulating medium	0.6	4200	998	Current Speed 1.5m/s
Initial temperature	290K	Tube inner diameter	25mm	

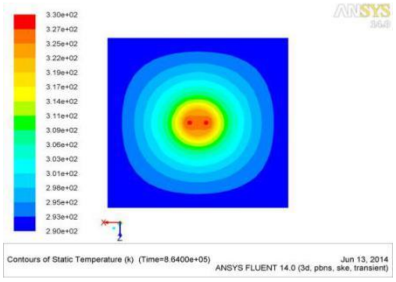

Figure 1: The Cloud Chart of Storing 240 Hours in the Radial Direction

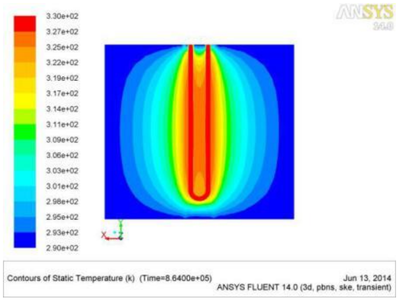

Figure 2: The Cloud Chart of Storing 240 Hours in the Vertical Direction

3.3 Comparative Analysis between the Simulation and Test

3.3.1 The Comparison of Temperature Field 0.15m beneath the Ground

Figure 3 refers to the temperature changes of different points 0.15m beneath the ground under the computer simulation. Figure 4 refers to the thermal history. By comparing the pictures, we can find the thermal histories in both pictures have the same trend, but there are still two differences between the real test and simulation. First, the highest temperature that the pile body reaches is 44.5℃under the simulation, while 40.5℃in the heat storage test, whose quantitative difference is about 10%. Second, the temperature at Point 5 doesn't rise under simulation, while it rises by 2℃when tested. The reason may be that there is no consideration for heat exchange between the box and the air around, and hence the radius of heat influence will get much closer to the situation of the heat storage pile under the ground if the far boundary radius is improved.

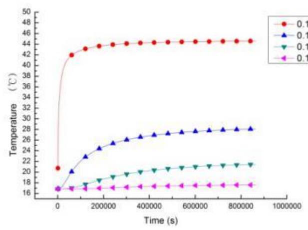

Figure 3: A Chart of Temperature Changes with the Time 0.15m beneath the Ground in Simulation

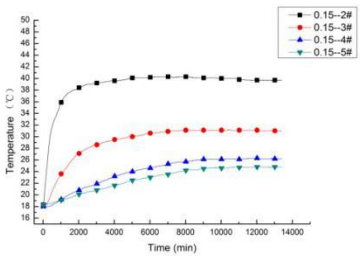

Figure 4: A Chart of Temperature Changes with the Time 0.15m beneath the Ground in Test

3.3.2 The Comparison of the Temperature Field 0.65m beneath the Ground

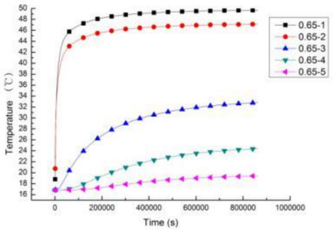

Figure 5: A Chart of Temperature Changes with the Time 0.65m beneath the Ground in Simulation

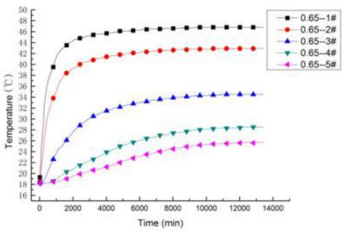

Figure 6: A Chart of Temperature Changes with the Time 0.15m beneath the Ground in Test

It can be seen from Figure 5 and Figure 6 that the temperature trends at different points 0.65m beneath the ground are very close to each other both under the test and simulation, which supplies reliable evidences for simulative research on the heat storage of energy piles.

3.3.3 The Comparison of the Temperature Field 1.15m beneath the Ground

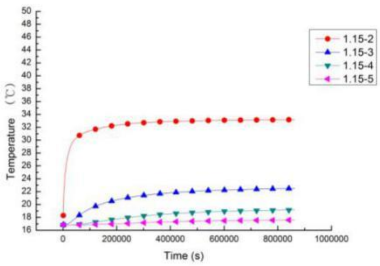

Figure 7: A Chart of Temperature Changes with the Time 1.15m beneath the Ground in Simulation

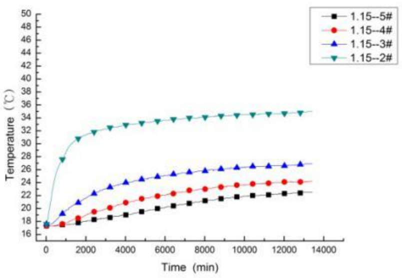

Figure 8: A Chart of Temperature Changes with the Time 1.15m beneath the Ground in Simulation

Comparing Figure 7 with Figure 8, we can see that the main differences between the test and simulation are that the temperatures at all points in the simulation are higher than those in the test, which may be the reason of the small radius of far boundary in the heat storage model. Therefore, the radius of far boundary should be improved in the simulation of heat storage.

4. Conclusion

The structural stability and thermal conductivity of the concrete piles have been taken into full consideration in this report, whose experimental study on the mixing ratio of the material of concrete piles is in the process by making use of orthogonal method. By making nine pieces of fiber-reinforced concrete and test their compressive static load and thermal conductivity, it proves to be that the third and fourth pieces have got the best mixing proportion. The optimized fiber-reinforced concrete has been improved not only in the mechanical properties but also in the thermal conductivity. On the basis of the experimental ratio, setting up experimental stage for fiber-reinforced energy pile for heat storage, and simulating and measuring the single pile have got the conclusion that by means of comparing the real data with the simulated data in the inner temperature of the heat storage devices, the data which is got at 0.65 meter's deep is less interfered from the outside. This conclusion turns out to be of great value to the study on the process of energy piles for heat storage.

Acknowledgment

This work was supported by the National Natural Science Foundation of China (Grant No.51206061) and Ji Lin Sheng Jiao Yu Ting Science and Technology Research [2015] (Grant No. 263).

References

Bensenouci A, Benchatti A, Bounif A, Medjelledi A, 2009, Study of the energy efficiency in building house using the DOE-2E and EE4 softwares simulation, International Journal of Heat and Technology, 27(2): 57-63.

Brandl H., 2006, Energy foundations and other thermo-active ground structures[J]. Géotechnique, 56(2): 81–122, DOI: 10.1680/geot.2006.56.2.81.

Pinel P, Cruickshank C.A., Beausoleil–Morrison I., Wills A, 2011, A review of available methods for seasonal storage of solar thermal energy in residential applications[J], Renew Sustain Energy Rev, 15(7): 3341–3359, DOI: 10.1016/j.rser.2011.04.013.

Sekine KM, Okar, YOKOM, 2007, Development of a ground-source heat pump system with ground heat exchanger utilizing the cast-in-place concrete pile foundations of buildings[J]. ASHRAE Transactions, 113(1): 558–566.

Singh S.N., 2013, Flow and heat transfer studies in a double-pass counter flow solar air heater [J]. International Journal of Heat and Technology, 31(2): 37-42.

Taoufik B., Abdelmajid J, 2012 , Two Dimensional Steady State Roll Heat Pipe Analyses For Heat Exchanger Applications, International Journal of Heat and Technology, 30(2) :115-119.

Zhang W.K, 2009, The heat transfer models for the ground heat exchanger inside foundation piles[D]. Jinan: Shandong Jianzhu University.

Zhao S.Y., Chen C, 2014, The research on a group of energy piles for storing heat temperature field numerical simulation. BioTechnology: An Indian Journal. 10(20): 12672-12676.

Zhao S.Y., Lu J.X., Qin J.Q., Xiao Y, 2015, Numerical Simulation Analysis of Continuous Heat Storage Using Different Number of Inclined Ground Heat Exchangers [J]. Chemical Engineering Transactions, 46, 967-972, DOI: 10.3303/CET1546162.

Zhao S.Y., Chen C, 2013, Simulation and Economic Analysis of the Soil Temperature Field When Concrete Heat Accumulation Piles Buried in Different Modes [J] . Applied Mechanics and Materials Vols. 291-294, 1149-1152. DOI: 10.4028/www.scientific.net/AMM.291-294.1149.

Zhao S.Y., Chen C, 2014, Soil temperature field analysis of radial buried tube continuous heat accumulation [J]. International Journal of Earth Sciences and Engineering, 07(04): 1931-1936.

Zhao S.Y., Chen C., zhan N.Y, 2015, Research on the influences of insulation technology by plastic greenhouses on working temperature in aeration tanks in cold areas in winter. International Journal of Heat and Technology, 32(1), 183-188, DOI: 10.18280/ijht.330125.

Zhao S.Y., 2015, Thermal test and numerical simulation research on energy storage pile[D].ChangChun: JiLin University .