Experimental research on GHP with U-Tube loop system

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Abstract

In June 1998, Qingdao Institute of Architecture and Engineering built an experimental installation using a closed U-shaped loop system made of plastic pipe that was buried in the earth vertically. In summer indoor heat is extracted from room and transferred into the earth through liquid by the heat pump unit. In winter, the earth will be the heat resource of the heat pump to provide heat for the room.

Purposes of this experiment are to get knowledge concerning heat released into the earth or extracted from it annually, as well as experience of design and management. A U-shaped loop of plastic pipe inserted in a borehole with a depth of 53m is used to extract energy from the earth. Three secondary boreholes of a depth of 13m were drilled near the main borehole, which are spaced out by 0.8m apart. A large number of thermocouples were buried in the four holes to measure the earth temperature.

This paper will illustrate the experimental installation in detail and present the results of long term measurement. Finally, the primary conclusions will be introduced.

Preface

As far as environment protection, energy conservation and heat stability are concerned, it is well known that Geothermal Heat Pump is one of the best models to heating and cooling. Hitherto developed countries have used the earth as GHP’s energy sources supplying heat or cool to rooms for several ten years, such as North America, middle and north Europe. In particular, a lot of useful information and data of design, construction and management concerning heating knowledge have been accumulated so far.

Since China is a developing country, the research and development of GHP started ten years ago only. China is located in the north temperate zone and majority of its territory need to be heating and cooling, thus it is not enough to introduce simply advanced GHP 's technique from the countries mentioned above. A set of GHP's technical data, which are suitable to China climate conditions, should be developed out. The first GHP in China with an underground loop system laid horizontally was built successfully in 1989 by the Q.I.A.E. Long term observations and measurement were conducted and a large amount of precious data for design and operation were obtained. Because there are some vulnerabilities to loop system laid horizontally, such as huge field occupied, bad heat storage character and so on, a vertical buried closed loop system was built in 1998 by the institute. Two years observation and measurement have been conducted so far. The paper will present the results of the experiment.

The purposes of this research subject are to obtain data for designing, to construct and measure GHP system, to research quantitative relationship between pipe length or borehole depth and heat released or absorbed by the earth and to get the optimal characteristic parameters for designing heat pump unit itself. If a vertical bored loop system is deep enough so that the influence of air must be very small. Therefore, it is possible to store the heat that was transferred into the earth during summer time, and then when winter is coming, the heat stored perhaps can be used for heating and vice versa. Finally, what is the effect that the warm vertical bored loop system exerted on surrounding earth temperature field? How big is the effect radius? A primary answer will be presented in this paper.

Experimental installations and measurement system

The sketch of circuit is illustrated in Fig.1. 1). Heat pump unit, Model OM 300, piston compressor made in the Copland, power 2.2Kw, F-22. 2). Piping pump, MX

L25-25, three gears in speed, the highest 2600 revolutions per minute, power

65-95W. 3). Vertical fan-coil unit FP-5 50w. 4). Fan coil S324 0.12KW. 5). Water tank 0.96m^3 with copper coil. 6). Air heat exchanger made of plastic pipe d45×4mm Located on roof closed by this time. 7). Heat exchanger made of plastic pipe of d45×4mm buried under the ground horizontally, depth of 1m. Closed by this time. 8). Vertical U-shaped loop of polystyrene pipe of d40×4 was inserted in a borehole; depth and diameter are 53m and 110mm separately. The hole was backfilled with thin sand. The total length of the loop is 110m including horizontal section of 4m long, the area of which are 13.82m^2. The loop system is filled with antifreeze solution, whose volume ratio between alcohol and water is 1:3. In order to measure the earth temperature field around the main loop, three boreholes were bored by a space of 0.8m each, into which thermocouples were buried (See Fig.2). 9). Closed expansion water tank ZIMET 00201 made in Italy. 10). Cumulative flow meter MCE 08-787, d24mm made in Sweden. 11). Float flow meter LZB-25 D25mm, made in China. 12). Float flow meter LZB-15. 13). Mercury-In-Glass thermometer with metal sleeve. 14). 15). 16). 17). Tube header. 18). Charge tank on roof. 19). Charge tank on the top of the room.

Fig.3 shows the heat pump unit and indoor tube system. Fig.4 shows that workers were installing the plastic tube and thermocouples into the borehole. The geological structure of the earth is as following: 0-3m is ordinary earth and 3-53m is granite. There are three terminals in parallel on each side of the heat pump unit (See Fig.1). A control valve is mounted on each terminal. There are many combinations to operate the terminals, which can be operated separately or simultaneously. The continuous-line-circuit represents heating mode in winter and the dashed-line-circuit represents cooling mode in summer. The direction of refrigerant flow in the compressor does not change any time.

The electrical energy consumed by the heat pump unit is measured by a power meter D33-W and a cumulative energy meter TYP-C 14 GIY simultaneously. Float flow meters and cumulative flow meters measure the flow rates of the liquid solutions simultaneously, which are calibrated under conditions of operating temperature by using gravitational method. Temperatures of the underground earth and circulated solution within the heat pump system are measured by copper-constantan thermocouples and a highly precise digital volt meter 1061A made in U.K. Majority of 69 couples are buried in the four boreholes. The principle sketch is illustrated in Fig.5. The measurement system consists of thermocouples 1, Pt resistance 2, Reference 3, circular switch 4, Numeral converter 5, Digital voltmeter 6, computer 7, screen 8, printer 9 and general lines IEEE-488 10. Fig.6 shows the measurement system.

Experimental method and Procedure

In order to get the test targets mentioned before, long term experiment and observation have been conducted on the unit all day and all night. The following data have been measured: instantaneous input power, cumulative energy consumption by the unit, flow rates and cumulative volumes of solutions through both the evaporator and condenser separately. And temperatures have been measured on different points, which are indoor and outdoor air, both sides for each of evaporator, condenser and buried loop and different depths in the four boreholes. The temperatures measured were recorded and printed automatically once an hour during the experiment. In general the measurement work was divided into four stages: summer, winter, spring and autumn. To know the earth temperature field throughout one year, the measurement works continued in autumn and spring, although the unit had stopped at that time.

The cooling test started on Aug. 26, 1998 and stopped on Oct. 25, 1998. Because of trouble in computer the unit did not operate continuously until 7th of Oct. Oct.7th to Oct. 25th, however, it worked well. The total running time lasted 984 hours during entire cooling test. Temperature distributions in the earth were recorded before switching on the unit to get natural temperature field without interruption. After stopping operation, the measurement went on during the autumn.

The heating test started on the 2nd of Dec.1998 and switched off on 3rd of Apr.1999. It operated for 2568 hours continuously during the heating season excluding 20 days holidays. After switching off the unit, the measurement went on for same reason during the spring.

The next cooling test started on July 1, 1999 and switched off on the 26th of Sep. 1999. However the operation lasted for 1368 hours only because of some troubles during the cooling period. It is pointed out that during the period between the 1st of July and the middle of Aug., the unit worked pretty well. There are totally 5 season's data to be included in this report.

Results of the measurement

More than ten thousand sets of data have been gotten from the experiment. This paper presents only three days' data. They are cooling process on Oct. 19, 1998, cooling process on Aug. 6 1999, and heating process on March 16, 1999. Completed data are listed in Table-1.

An experimental curve of heat discharged into the earth by the heat pump system is shown in Fig.7, which includes entire data from Oct. 7, 1998 to Oct. 19, 1998. The vertical coordinates represent the discharged heat and the horizontal represents date. The temperature distribution in the main borehole earth on Aug. 21, 1998 is shown in Fig.8, which is the natural temperature field without interruption before the unit's running. The outdoor mean temperature was 24.9^{o}C. Temperatures in main borehole earth on Dec. 1, 1998 shown in Fig.9 were measured after 35 days passing, when the unit stopped operation on Oct. 25,1998. Then, the outdoor temperature was 0.34 ^{o}C.

The result measured on Nov. 25, 1999 shown in Fig.10 was obtained after 60 days, when the unit stopped operation on Sep. 26, 1999. The curve B drawn in Fig.11 shows temperatures in the main borehole earth on Apr. 6, 1999, three days only after the unit stopped heating process on Apr. 3, 1999. The outdoor temperature was 9.39

^{o}C then. The carve A shows temperatures in the same place on the 24th of June 1999 after stopping operation for 81 days, when the outdoor temperature was 22.74 ^{o}C. The horizontal coordinates (see Fig.8~Fig.11) represent daily mean temperatures and the vertical coordinates are different depths of the main borehole earth, among them O represents surface level. Mean daily temperatures drawn for different depths of the four boreholes shown in Fig.12 were measured on Aug. 26, 1998 just before starting operation.

Fig.13 shows temperature increments for different depths of the four bores, comparing the temperatures gotten after long term cooling operation with the temperatures before the unit's running during 1998's summer. The horizontal coordinates in Fig.12 and Fig.13 represent horizontal distance from central axis of the main bore and the vertical represent mean temperature for 24 hours.

Analyse of Results

As mentioned before, the geological structure mainly consists of granite, physical natures of which are as following: specific density of 8.4 T/M^3, specific heat of 0.92 KJ/kg k, heat conductivity of 3.49W/MK. There is a very large heat capacity around the buried loop. Annual periodic interruptions coming from air, solar radiation and heat pump system cause temperature of the earth to change continuously. Thus, a stable state of heat transfer in the earth theoretically couldn't be got forever. The data listed in Table 1 give three seasons' information, which was acquired in the end of each season. It can be considered as sub-stable state because of long time running. The national temperature curve for the main borehole before summer running is drawn in Fig. 8. It is easy to see that the temperature decreases with earth depth increasing specially the temperatures above 5m deep. The temperatures below 20m are less than 15 ^{o}C that are far less than outdoor mean temperature of 24.9 ^{o}C. Finally, the temperature below 40m keeps constant, equaling to 12.5 ^{o}C, which is about the same as the annual average temperature of 12.2 ^{o}C of Qingdao region. The curve 2 represents mean temperature throughout the 53m deep borehole equaling to 14.7^{o}C, which is so low that it is very advantageous to the liquid solution coming from condenser. Hence daily heat released into the earth at the beginning of run was the largest (170KWH). However with heat accumulation day by day, the earth temperature near the loop became higher and higher, the condensation temperature increased, and then, the heat released got less and less. After running for 528 hours, the daily heat gained by the earth is 145.5KWH on the 7th of Oct. The heat-date curve shown in Fig.7 was measured during the 7th of Qct. to the 19th of Oct. In this case the unit was running without break. It is easy to see that the heat is getting decrement slow until date of the 19th, when the curve becomes horizontal nearly, being considered as stable state. The daily averages for each datum are listed in Table-1 dated on the 19th of Oct. The condensation temperature is the maximum and the heat released into the earth was 134KWH or 5.58KW. It is reasonable to consider these data as a design references. In order to calculate conveniently, the parameters are converted into length of pipe or depth of borehole per unit kilowatt (see Table-1, column 23,24,25). It should be pointed out that some information present length of buried pipe or depth of borehole per unit cooling load as a calculation criterion. It is not recommended by the author, for the COP value varies with heat-pump unit model and difference between high and low heat sources. It will be more precise ,if real heat released is taken as design basic information. Based on same reason, so does heat abstracted from the earth in winter.

When it had already undergone a long fall stop, winter operation and spring stop, next cooling process and measurement started on July 1, 1999. The continual measurements were lasted for 840 hours until Aug. 6, 1999. The situation of the operation is the same as last summer. Table-1 lists data on Aug. 6, 1999. Released heat is 131.74KWH or 5.49KW, which has a little difference with the data of last summer.

Total heat abstracted from the earth is 8103KWH during winter season corresponding 107 days. Because so much heat had been abstracted from the earth in winter, it would have been advantageous for summer operation. However, the answer is not ideal. The underground temperature curve B shown in Fig. 11 was measured by stopping winter's operation immediately, when outdoor temperature was 9.39^{o}C. The curve A was measured after stopping the unit for 81 days, when outdoor temperature was 22.74 ^{o}C and mean temperature of the earth is 13.92 ^{o}C. Obviously the temperature of the earth was recovered through 81 day's stopping operation. Mean temperature A is 3.88 ^{o}C higher than the temperature B, and is slightly less 0.8 ^{o}C than mean temperature in summer (see Fig.8). This important fact proves that the cool (8103 KWH) stored in the earth has disappeared. There are two reasons to explain this fact: 1. The single borehole earth cooled abstracts heat from surrounding earth ; 2. Heat exchange between the warmer outdoor air and the underground earth occurs, and the shallower the borehole is, the larger the air influence is. The earth surface climate affects underground temperature for more than 20 M deep. (See Fig.8~Fig.11). Therefore, the deeper the depth of borehole is, the better the efficiency of heat stored will be. To run the heat pump for heating began on Dec. 2, 1998 and stopped on Apr. 3, 1999. The results listed in Table-1 were measured on March 16, 1999, after operating for 2136 hours. For higher temperature of earth at beginning, both evaporation temperature and an amount of heat abstrcted by the buried pipe were much larger. However the abstracted heat was getting less and less with increase of accumulative abstracted heat from the earth all day and all night, and at the same time the earth temperature and evaporation temperature got lower.Finally, the heat and evaporation temperature approached constant nearly. The daily mean data on the 16th of March are listed in Table-1 being regarded as a stable state. The abstracted heat is 76.27KWH or 3.18KW. If so much heat discharged (7498KWH) had been stored into the earth throughout 1999's summer, it would have been advantageous for heating in winter. A real situation, however, is as following: the temperature field of the earth shown in Fig.9 was measured on Dec. 1, 1998 before running the heat-pump unit in heating mode, just stopping it for 35 days later. The curve 1 is a real temperature distribution and the outdoor temperature is 0.34 ^{o}C. The curve 2 is mean temperature of the earth, which is 16.36 ^{o}C. It is more 1.62 ^{o}C than the national mean temperature measured on Aug. 21, 1998 only (see Fig.8). The temperature distributions of the earth shown in Fig.10 were measured on Nov. 25, 1999, stopping summer process for two months later when the outdoor temperature was 5.48 ^{o}C and the underground mean temperature was16.46 ^{o}C. It will be found by comparing between Fig.9 and Fig.10 that the shape of the curves is same and the two mean temperature of the earth are equal nearly. The fact tells us that majorities of heat stored throughout entire summer have disappeared, passing such a long fall period. Benefits from the two summer seasons are less useful to heating in winter. It is easy to imagine that results measured on next winter will be as same as the one obtained on March 16, 1999. Thus the experiments of next heating season were not carried out. The relationship between heat abstracted from the earth and area of pipe can be expressed with pipe lengths or borehole depths per each kilowatt. (See Table-1 and column 23,24,25).

It should be pointed out that when the heat pump system operates in heating mode, heat abstracted makes evaporation temperature so low that the liquid circulated in the ground loop system will be frozen. According long-term observations and experiments, it is suitable to take –7^{o}C as freezing point of the liquid. In summer the indoor air passing through fan-coil units has a higher temperature. As a result, temperatures of liquid circulated in indoor pipe system are always far higher than zero degree, so do the evaporation temperatures, see Table-1 column 5,6. Thus pure water can be filled in the fan-coil system instead of antifreeze solution. The conclusion is that in summer if the system is designed and operated carefully, it is unnecessary to fill antifreeze solution in the indoor system.

The heat abstracted from the earth in heating mode, which is 76.3KWH, is far less than heat released into the earth, which is 131-133KWH, in cooling mode by the same unit (See Table-1 and column 3). Because an extra heat produced by input drive power is added into the underground loop system. Frozen earth maybe constitutes another second reason to decrease heat transfer. The area of heat exchange needed by heating mode should be larger than cooling mode. Hence the area of heat exchange calculated by using heating mode would be enough for cooling mode. However, calibration for summer process is recommended.

When processing mode of the unit is reversed from winter to summer or from summer to winter, the circulation of liquid medium will be exchanged, instead of changing internal refrigeration circulation. In practice, however, a special valve with four passages is taken to reverse internal circulation direction of the unit. The best advantageous temperatures of both evaporation and condensation in summer differ from winter, and in winter the situation is opposite, so it should be careful to calculate and choose evaporator and condenser. Data listed in the Table-1 are recommended.

The daily mean temperature distributions for different depths and boreholes were measured prior to running the unit in cooling mode (See Fig.12). The depths are 1m, 5m, 10m and 13m separately. It is obvious that the temperatures near surface are higher, the temperatures in level of 13m are lower and the temperatures on same level for the four holes are nearly same. The temperature increments on different boreholes and depths were measured after passing through 984 hours. For the earth temperature near the main loop system is getting higher gradually, and then, followed by surrounding earth. The earth temperature is raised about 2-3 ^oC at the place, which is 2.4m away from the main loop horizontally. The deeper the depth is, the more the increment is. The increment near surface is less; e.g. increment on the depth of 1m is 0.6 ^oC only. It follows that outdoor air effects changes in temperature of nearby earth greatly, heat transferring into air immediately. But in deeper level the effect by air is a little and one way of heat transfer exists only, therefore the increment on deeper depth must be higher than surface earth. In other words, distance effected on surrounding earth by shallow buried loop known as effect radius, is smaller, and, larger for deeper. Radius of 3m is recommended for designing a similar project.

Conclusions

The experimental research is conducted in the Qingdao region, using a closed U-shaped loop of polystyrene pipe of Φ40mm inserted in a borehole of 53m depth as a terminal of heat pump. The following conclusions can be got from the experiment:

1. The heat-pump unit with vertical buried loop system has the ability to be heating and cooling system in one. When compared with horizontal installations it occupies a little field only.
2. If a single borehole is taken as heat source or cool source, then function of heat storage can be neglected.
3. Radius of effected on surrounding earth by this kind of loop is 3m.
4. Heat exchange ability between the plastic pipe and the earth is as following:
   a. Heat released into the earth (cooling mode) pipe length: 20m/Kw, borehole depth: 10m/Kw, pipe area: 2.5m^2/Kw.
   b. Heat extracted from the earth (heating mode) pipe length: 35m/Kw, borehole depth: 17-18m/Kw, pipe area: 4.5m^2/Kw.

The loop system can be calculated according to heating mode. Calibration according to cooling mode is recommended. 5. Following parameters are recommended to calculate and choose evaporator and condenser containing F-22 medium:

Condensation temperature equal to or less than 60^{o}C, evaporation temperature: minus 2-minus 7 ^{o}C, the lower is taken for heating mode. An antifreeze solution filled in the buried loop system should enable itself to have at least freezing point of minus 7 ^{o}C. A temperature increment of liquid circulated in buried loop system ranges 6 to 8 ^{o}C. Mean temperature difference for evaporator ranges 6-12 ^{o}C, the lower for heating mode. Mean temperature difference for condenser ranges 8-14 ^{o}C. It is

not necessary to fill antifreeze solution is indoor loop system.

6.Improving construction method, e.g. boring and tube inserting; developing special tube fittings; joining fittings and inventing special materials backfilled to borehole to increase heat transfer efficiency.

Table-1

	Term	1998.10.19 Cooling process	1999.8.6 Cooling process	1999.3.16 Heating process
1	Chill output KWH (KW)	87.08 (3.63)	87.37 (3.64)	96.17 (4.01)
2	Heat output KWH (KW)	141.96 (5.92)	144.28 (6.01)	136.89 (5.70)
3	Heat released to loop KWH (KW)	133.96 (5.58)	131.74 (5.49)	-76.27 (-3.18)
4	Energy consumption by the unit KWH (KW)	55.60 (2.32)	59.02 (2.46)	51.38 (2.14)
5	Liquid temp. into evap. ^oC	9.74	11.92	2.58
6	Liquid temp. out evap. ^oC	3.15	4.33	-4.30
7	Mean temp. diff. through evap. ^oC	6.59	8.13	6.88
8	Evaporation temp. ^oC	-5.41	-2.1	-6.5
9	Temp. diff. of evap. ^oC	11.86	10.23	5.64
10	Cond. temp. ^oC	56.64	62.0	58.0
11	Mean temp. through cond. ^oC	44.65	47.67	46.29
12	Mean temp. diff. through cond. ^oC	8.70	7.06	8.26
13	Temp. diff. of cond. ^oC	12.0	14.30	11.71
14	Liquid temp. into loop ^oC	47.46	49.28	-2.36
15	Liquid temp. out loop ^oC	39.25	42.72	3.12
16	Mean temp. through loop ^oC	43.36	46.0	+0.38
17	Temp. diff. through loop ^oC	8.21	6.56	5.48
18	COP of heat KW/KW	2.55	2.44	2.66
19	COP of chill KW/KW	1.57	1.48	1.87
20	COP of heat released into loop	2.41	2.23	-1.48
21	Outdoor temp. ^oC	15.50	27.31	11.17
22	Indoor temp. ^oC	———	25.5	21.24
23	Pipe length per unit heat to loop M/KW	19.71	20.04	-34.60
24	Pipe area per unit heat to loop M^2/KW	2.48	2.52	-4.35
25	Hole depth per unit heat to loop M/KW	9.50	9.66	-16.68

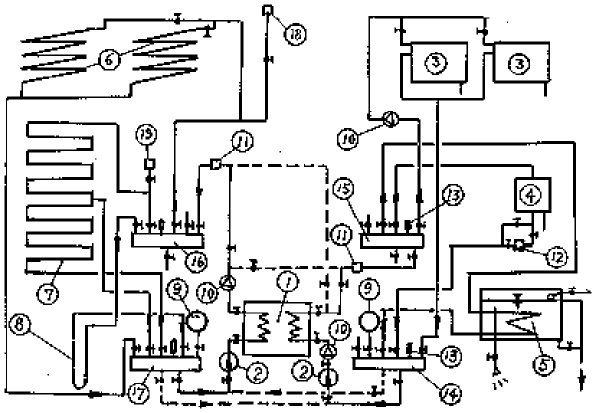


Fig 1

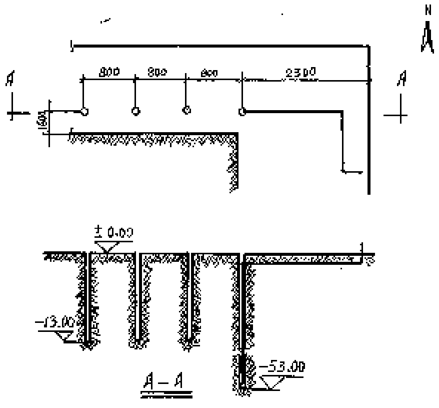


Fig.2

Fig.4 Inserting pipe

Fig.3 Unit & loop system

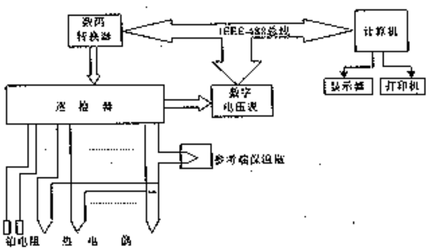


Fig.5 Measurement system

Fig.6 Measurement instrument

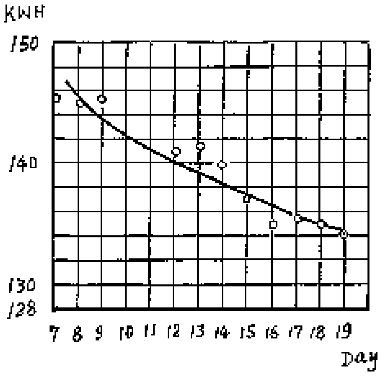


Fig.7

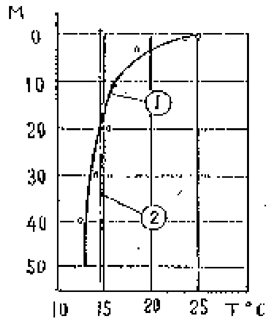


Fig.8 (98 08)

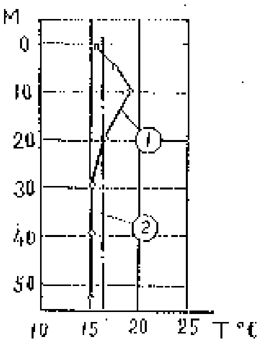
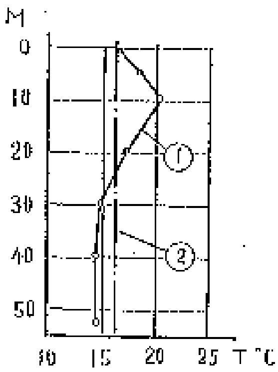


Fig.9 (98 12)



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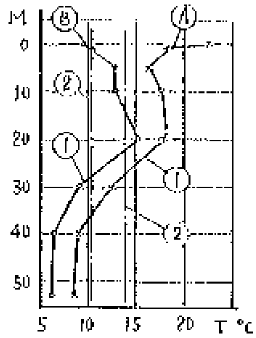

Fig 11 (99 04&06)

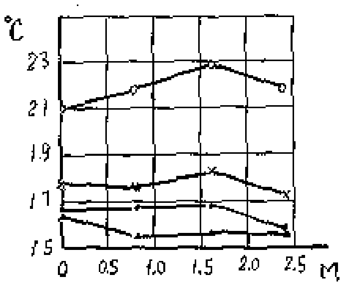

Fig.12 (98 08)

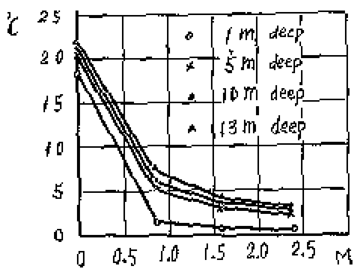

Fig.13 (98 10)