

UNDERGROUND HEAT STORE AND PROCESS FOR ITS CONSTRUCTION

The present invention relates to an underground heat store, and to a process for its construction.

The heat store according to the present invention is intended, for example, to store heat originating from any source whatever, such as a solar collector, a heat pump, a source of hot water, a generator of electrical energy or the like, with the possibility of the stored heat subsequently being used for various applications, for example to heat dwellings or other buildings. A store of this type can be operated in cycles of varying length, for example, in daily cycles, seasonal cycles, etc.

According to the present invention there is provided an underground heat store, comprising a buried mass of one or more heat-storing materials in which mass a part of at least one energy-transfer circuit is embedded, said store being characterised in that the heat-storing material comprises a binder, clay and water, and that the heat-storing material has a compression strength of at least 0.1 bar and a specific heat per unit volume of at least 0.6 calories/°C/cm³.

The rigid mass which mainly constitutes the heat store according to the present invention offers the combination of the following two important advantages; since it is rigid, it requires neither a supporting structure nor a tank, in contrast to a liquid heat store; since its proportion of water can be relatively high, it can have a thermal capacity per unit volume which is very close to unity (in calories/°C/cm³), that is to say much higher than those of conventional solid materials, including rocks, dry sand and even sand saturated with water.

The process according to the present invention enables an underground heat store of the type mentioned above to be constructed, particularly in water-bearing

land where the water table is near the surface of the land, but also, a fortiori, in dry land where the water table may be at a very great depth.

One process for constructing an underground heat store according to the present invention involves digging in the ground a hole having a volume at least equal to that of the store to be constructed and filling this hole, at least partially, with one or more materials of a suitable specific heat, whilst inserting therein a part of at least one energy-transfer circuit. During the digging of the hole the latter is constantly filled, at least partially, with a suitable liquid, such as water or a drilling mud, the corresponding part of the energy-transfer circuit is submerged and immobilised in the liquid filling the hole and there are added to the said liquid definite quantities of a binder, such as cement, and, if appropriate, other additives which are suitable for ensuring the setting of the binder and, in this way, causing the liquid to solidify into a mass of suitable heat-storage capacity which fills, at least partially, the completed hole.

One embodiment of the invention is described below, by way of example, and illustrated diagrammatically in the attached drawing.

Figure 1 shows a view, in section along an essentially vertical plane, of an underground heat store according to

the present invention.

Figure 2 shows a view, on a larger scale, of the detail A of Figure 1.

Figure 3 shows an alternative to Figure 1, in which the underground store serves as a foundation for a building.

The construction of the underground heat store _____ will be described below, said store being illustrated diagrammatically in Figure 1, in a case where the said store is to be buried in loose or very loose ground or even, as the case may be, in a ground of extremely low compactness, constituted, for example, mainly by sand, mud, peat or silt, the water level in this ground being assumed, moreover, to be at a slight depth. These conditions are, of course, the most unfavourable which can be encountered for the installation of an underground construction of this type. In particular, it is especially difficult and complicated to dig a hole, since the walls of the hole tend to collapse as the hole is being dug. Nevertheless, the present invention makes it possible to construct, in such unfavourable land, a heat store, the volume of which can attain and even exceed several hundred cubic metres. Another object _____ is to impart to the heat store the largest possible thermal capacity for a given volume, at the lowest possible cost. To achieve this object, it would be possible to envisage using water in the liquid state as heat-storing material, since the following table shows clearly that its thermal capacity per unit volume (equal to

the product of its density and its specific heat) is substantially higher than the respective thermal capacities per unit volume of the majority of solid materials, including conventional rocks, dry sand and even sand saturated with water.

Materials	Density g/cm ³	Specific heat Calories/g	Thermal capacity per unit volume Calories/°C cm ³
Iron	7.8	0.1	0.78
Chalk	2.3	0.2	0.46
Granite	2.7	0.2	0.54
Sandstone	2.4	0.2	0.48
Petroleum	0.8	0.5	0.40
Lead	11.3	0.03	0.34
Quartz	2.6	0.2	0.52
Dry sand	1.7	0.2	0.34
Sand saturated with water	2.0	0.3	0.60
Water	1.0	1.0	1.0

Added to the advantage that water has a high thermal capacity per unit volume, is that of a very low cost. However, the use of a mass of underground water as heat store presents certain disadvantages: the layer of earth above such a mass of water does not have sufficient strength to allow constructions to be built thereon, this being possible, in some cases, only by substituting for said layer of earth a "roof" which has sufficient mechanical strength and is, consequently, costly to produce. On the other hand, it is not possible to bury a liquid mass directly in loose ground; to prevent the walls of the hole collapsing, it is indispensable, in that case, to erect walls which are sufficiently robust and which are equally

costly to construct.

One embodiment of the process according to the present invention will now be described, by way of example, for constructing the heat store illustrated diagrammatically in Figures 1 and 2: from the surface of the ground 1 a hole of predetermined shape, for example parallelepipedic, is dug by the use of known public works equipment, for example mechanical buckets or "dragline" buckets. As the hole 2 is being dug, a drilling mud is introduced therein, which is composed mainly of a binder, such as cement, clay, such as bentonite, water and various additives, one of which is selected to retard the setting of the binder in a suitable way; preferably, water is present in by far the greatest proportion by weight. One example of the composition of a drilling mud for carrying out the process according to the present invention is as follows:

Water	:	1000 litres
Slag cement	:	100 - 200 kg
Bentonite	:	35 kg
Setting retarder, for example lignosulphite	:	1 - 5 litres

The drilling mud composed in this way is introduced into the hole, as the hole is being dug, either by means of a pump ensuring a continuous flowrate of mud, adapted to the digging rate, or discontinuously by pouring into the hole successive batches, preferably of the same appropriate volume. The proportion of the setting retarder in the drilling mud must, of course, be selected to prevent the mud from setting into a solid mass, not only until

completion of the hole, but also until completion of subsequent operations which will be described below; in determining the proportion of the setting retarder, it is also necessary, if appropriate, to take into account periods of interruption in the digging of the hole, for example during the night. During this phase of digging of the hole, the main function of the drilling mud which fills the hole at least partially is, in a way known per se, to prevent the walls of the hole from collapsing during digging; this function is a fundamental one, particularly in the case where the ground which is dug possesses a very low cohesion and considerable quantities of water near its surface, as has already been mentioned above.

To provide the heat store _____, which is illustrated in Figures 1 and 2, panels _____ which are heat-insulating and/or impermeable to water are subsequently submerged in the not yet solidified drilling mud which fills, at least partially, the completed hole. In a case of a parallelepipedic hole which is intended for the construction of a store of the same shape, it is a question, in the first place, of submerging and immobilising, by suitable means, panels such as 3 a, 3 b..., near the lateral, essentially vertical walls of the hole 2, the said panels being provided to constitute the lateral walls of an enclosure which is intended to enclose the heat store completely. For a store of large dimensions, each lateral wall is, in that case, formed preferably by abutting the sides of several panels, such as 3 a, and the edges of these panels can be smooth or designed so that they can be

fitted into one another. After these lateral walls have been put in place, one or more panels 3d which are intended to constitute the floor of said enclosure are submerged and immobilised near the substantially horizontal bottom of the hole 2. The panels 3d of the floor could, of course, be submerged before those of the lateral walls. In the embodiment illustrated in Figures 1 and 2, each of the panels 3a to 3d can have the following constitution which is illustrated, on a larger scale, in Figure 2: each panel, for example 3b, is constituted essentially by an insulating plate 4 made of a material of low heat conductivity, for example of polystyrene or of phenolic foam, which is arranged between two ballasting and mechanical-protection plates 5a and 5b which are connected to one another by stiffeners such as 6 passing through the insulating plate 4. Each stiffener 6 can be designed to prevent the possible crushing of the insulating plate 4 by the weight of the store or the thrust of the earth; for this purpose, in the case, for example, of a stiffener held in place by nuts 6a, lock nuts 6b can be provided. On the other hand, the face of each panel such as 3b which is turned to the outside of the store, that is to say towards the nearest lateral wall of the hole 2, as well as its other face, if appropriate, are covered by sealing elements such as films or sheets 7 impermeable to water, for example single sheets of synthetic material which are fixed to the concrete plate 5a by any suitable means, for example by adhesion. Each panel constituted in

this way reduces to a very large extent the heat exchanges between the store and the ground in which it is buried, due particularly to its insulating plate 4; its sheet 7 prevents virtually all circulation of water between the interior of the enclosure of the store, on the one hand, and the ground, on the other hand, so as also to avoid the heat losses which would result from these circulations of water; finally, the concrete plates 5a and 5b impart to each panel such as 3b a sufficient rigidity and mechanical strength. By substantially increasing the weight of the corresponding panel, the concrete plates 5a and 5b also serve as ballast, once the said panels are submerged in the not yet solidified mud.

Before the hardening of the drilling mud which fills the enclosure formed by the panels 3a to 3d, the lower parts of two energy-transfer circuits are subsequently submerged therein and fixed therein, appropriately by any suitable means, said energy-transfer circuits consisting of a primary circuit which is intended to transfer into the underground energy store the heat originating from an energy source and of a secondary circuit which is intended to transfer at least part of the heat stored in the store to consumers located on the surface of the ground 1 or above. In the embodiment illustrated in Figure 1, the primary circuit is constituted essentially by electrically resistant wires such as 8, each of which is surrounded by an electrically insulating sheath and, if appropriate,

by a protective tube 9. The tubes 9 are submerged in the drilling mud so as to assume definite positions therein.

The secondary circuit is also constituted by tubes such as 11, preferably metallic, some of which are arranged, for example, vertically and others horizontally like the tubes 9, but in the gaps between the latter; the ends of these various tubes 11 are connected two by two, so as to constitute a heat exchanger distributed in the interior of the abovementioned enclosure; the input and output of the heat exchanger constituted in this way are connected respectively by two pipes 12a and 12b, which are, for example, vertical, and by other pipes (not shown) to the consumers of the heat energy, particularly to a heat exchanger which enables the transferred heat to be extracted. This secondary circuit is, of course, intended to be filled with a heat-transfer fluid which can be of a suitable known type such as water, air, or the like.

If the drilling mud does not totally fill the enclosure formed by the panels 3a to 3d, an additional quantity of drilling mud is then poured, so as to ensure the complete filling of the said enclosure. When the drilling mud has entirely solidified, in the hole 2 and in the enclosure formed by the panels 3a - 3d, into a mass 13 in which the tubes 9 and 11 of the primary and secondary circuits are completely embedded, the said enclosure is closed by means of a roof or ceiling which can be constituted, in particular, by a panel 3e

similar to the floor 3d. Of course, sealed passages are provided in this upper panel 3e to permit the passage of electrical cables 10a - 10b which serve to connect the primary circuit to an external source of electrical energy, and for the input and output conduits 12a to 12b of the secondary circuit. A layer T of humus, concrete or another material can, finally, be deposited over the upper panel 3e of the enclosure formed, in order to restore the continuity of the surface of the ground 1.

In the case of a store which is constructed by using a drilling mud having the composition given above by way of example and containing, in particular, 150 kg of slag cement per 1,000 litres of water, it was possible to determine that the solid mass of heat-storing material had a thermal capacity per unit volume of approximately $0.98 \text{ calories/}^{\circ}\text{C.cm}^3$, which is very near that of water ($1 \text{ calorie/}^{\circ}\text{C.cm}^3$). It was also possible to determine that its compression strength, after a hardening time of one month, is approximately 5 bars, which is amply sufficient to allow, if appropriate, buildings to be erected on the surface of the ground, particularly above the layer T, straight above the heat store according to the present invention. This store can, in particular, be used advantageously to provide, by means of its secondary energy-transfer circuit, heating for buildings. Figure 3 shows one embodiment of this type in which the heating radiators R of a building 14 are supplied by means of the

secondary circuit 11-12a-12b of a heat store 13 according to the present invention. This store possesses lateral walls such as 3a, 3b which extend to the vicinity of the surface of the ground 1 and which serve as foundations for the building 14. The whole constituted by the mass 13 of heat-storing material and by a heat-insulating horizontal wall 3e which lies above the mass 13 has, above the bottom or floor 3d, a height h which is substantially less than the height H of its lateral walls such as 3a, 3b; thus, the horizontal wall 3e delimits, together with the upper parts of the lateral walls such as 3a, 3b, a substantial volume 15 which can serve as basement for the building 14.

If, on the other hand, it is not envisaged to build straight above the heat store according to the present invention, the rigid mass which constitutes the store can have a lower compression strength, requiring the use of a lower proportion of cement in the drilling mud, for example only 100 kg of slag cement, or even less, per 1,000 litres of water. The compression strength of the rigid mass of heat-storing material can thus be reduced, according to the present invention, to approximately 0.1 bar, which is just sufficient to maintain therein the circuits 9 and 11 of the heat exchangers and the walls 3a, 3b, ..., 3d, 3e in the planned positions. Such a material which a layman would consider to be pasty rather than solid is, however, distinguished from a liquid in that it has a certain cohesion, that is to say it can withstand

shearing stresses without substantial deformation, which is not the case with simply viscous materials, whether they be pasty or liquid.

The above-described embodiment of the heat store according to the present invention, as well as the above-mentioned method of carrying out the process for its construction, can undergo many variations, all coming within the scope of the invention. The constitution of each of the panels 3a - 3e forming the closed enclosure is optional; each panel could be constituted simply by a plate of heat-insulating material, for example synthetic material, or else by a plate of material impermeable to water but relatively thin. Instead of being ballasted on its two faces by concrete plates, as illustrated in Figure 2, the plate of insulating material could be ballasted by a concrete plate on a single face. The concrete plates can themselves be strengthened by reinforcements or replaced by suitable steel plates. In addition, instead of being vertical, the lateral walls of the closed enclosure can be arranged obliquely for certain applications. In one alternative, the lateral walls of the closed enclosure, instead of being constituted by panels submerged in the drilling mud before it solidifies, are walls cast in the ground by a known process, before the digging of the hole; in this case, of course, the hole is then dug between the walls previously cast in the ground, ensuring that they are not damaged and using a drilling mud which has, for

example, the composition mentioned above; the subsequent operations remain unchanged: the floor 3d and the tubes 9 and 11 of the heat-transfer circuits are put in place before the drilling mud solidifies; the closed enclosure is finally completed, after the drilling mud has solidified, by the installation of the upper panel 3e.

The provision of a closed enclosure around the heat store _____ is optional; such an enclosure can be waived, particularly whenever the ground in which the hole can be dug is such as to limit the exchanges of heat between the walls of the hole, on the one hand, and the heat-storing mass, on the other hand, whether they be losses by conduction or by circulation of water; in particular, it is not indispensable to provide a closed enclosure when the store _____ is to be buried in dry sand or in virtually impermeable clay. The composition of the drilling mud is a matter of choice, the abovementioned proportions being only examples. The cement used as binder can also be Portland cement; although slag cement is particularly suitable because of the relatively high mechanical strength which can thereby be obtained for a low proportion of cement and also because of its good resistance to the action of natural waters containing calcium sulphate, it can be replaced by any other cement; however, to obtain an equivalent mechanical strength with, for example, Portland cement, much more of this is needed

than slag cement. The cement can also be replaced, in whole or in part, by another suitable binder, such as flying ash, puzzolane powders, lime, or the like. The bentonite can also be replaced by a local clay, but in a larger proportion. Instead of containing electrical resistors, the primary circuit can contain a heat-transfer fluid exchanger analogous to that of the secondary circuit. The various tubes of the primary and secondary circuits can be distributed irregularly in the mass of the store, for example concentrated in its central region. In an alternative version, each tube of the secondary circuit is closely associated with a tube of the primary circuit, to which it is, for example, brought nearer over at least a part of its length. For certain applications, it is sufficient to provide a single energy-transfer circuit which, during different periods of time, can be used at one time as primary circuit and at another time as secondary circuit, by incorporating therein, for example, a known system of multiple-way valves.

In an alternative _____ process for constructing a heat store according to the present invention, the binder and, if appropriate, the other additives are added to the drilling mud, not before the latter is used to fill the hole being dug, but only after completion of the hole. This obviously dispenses with the need to use a setting retarder.

The cement and the other possible additives can be discharged directly into the drilling mud which fills the

completed hole. It is also possible to use a closed circuit comprising at least one pump and a mixer which are located outside the hole, so as to extract the drilling mud from the latter, mix said drilling mud with the cement and the other additives and then pour the resulting mixture into the hole. Enrichment of the mud with cement in the mixer is continued until the mixture filling the hole contains the necessary proportion of cement. In addition to enabling the setting retarder to be saved, this alternative version of the process _____ allows a saving of cement; in fact, in the case of the process described above in which the cement was already contained in the drilling mud used during the digging of the hole, a part of the mixture and, consequently, of the cement which it contained was inevitably carried away with the excavated material and lost as a result.

Depending on its volume, the hole which is intended for the construction of a heat store according to the present invention can be dug either as a whole in a single operation, without stages or joints between the various parts, or in separate parts, each of which is provided, in particular, with energy-transfer circuits and, if appropriate, with walls of the closed enclosure, and is then solidified before the adjacent part is made. In the case of a heat store of very large volume, requiring the successive provision of, for example, N juxtaposed parts, numbered from 1 to N, the parts of the store bearing even numbers, for example,

will preferably be made first of all, and then, after their completion, the parts bearing uneven numbers.

It has already been mentioned that the arrangement of the tubes of the energy-transfer circuits on the inside of the heat store according to the present invention is a matter of choice. Instead of forming a sort of network of parallelepipedic meshes, as in Figure 1, the tubes of the primary exchanger and/or of the secondary exchanger can be distributed in any way whatever in the heat-storing mass or else arranged in circles, spirals, coils and the like.

Of course, the underground heat store according to the present invention can also be constructed in a highly cohesive ground in which the walls of the hole, during digging, present little risk of collapsing. In this case, there is no need to use a drilling mud during the digging of the hole. It is sufficient to fill the completed hole with a liquid mixture composed mainly of a binder, such as cement, clay and water. If the corresponding parts of the energy-transfer circuit or circuits, as well as, if appropriate, the lateral walls and the floor of the enclosure of the store have been installed in the completed hole before it has been filled with the said liquid mixture, it is not necessary to add a setting retarder to this mixture. If, however, a sheet of water is present at a slight depth in such ground which is relatively cohesive, but not impermeable, the hole can be filled with water as it is being dug. In this case, as soon as the corres-

ponding parts of the energy-transfer circuit or circuits, as well as, if appropriate, the lateral walls and the floor of the enclosure have been submerged in the water filling the completed hole and have then been immobilised near the walls of the said hole, the completion of the store requires only the addition of a binder, such as cement, and clay to the water contained in the said hole.



CLAIMS :

1. Underground heat store, comprising a buried mass of one or more heat-storing materials in which mass a part of at least one energy-transfer circuit is embedded, said store being characterised in that the heat-storing material
5 comprises a binder, clay and water, and that the heat-storing material has a compression strength of at least 0.1 bar and a specific heat per unit volume of at least 0.6 calories/°C/cm³.
2. Store according to Claim 1, characterised in that the
10 binder comprises a cement, that the clay comprises bentonite and that of the three components binder, clay and water, water is present in the largest percentage *by weight*.
3. Store according to any one of Claims 1 or 2, characterised in that the heat-storing material has a spec-
15 ific heat per unit volume equal to or greater than 0.9 calories/°C/cm³.
4. Store according to any one of Claims 1 to 3, characterised in that the mass of heat-storing material is insulated, from the earth in which it is buried, by
20 heat-insulating walls.
5. Store according to Claim 4, characterised in that the mass of storing material is insulated, from the earth in which it is buried, by walls which are impermeable to water and constitute a closed enclosure around the said
25 mass.



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6. Store according to Claim 5 or 6, characterised in that at least some of the walls are cast in the ground.
7. Store according to Claim 5 or 6, characterised in that at least some of the walls are each constituted
5 by at least one panel obtained by assembling a plate made of a material of low heat-conductivity and at least one ballasting and/or mechanical protection plate.
8. Store according to Claim 7 wherein the ballasting and/or mechanical protection plate is made of steel, of
10 concrete or of reinforced concrete.
9. Store according to Claim 7 or 8, characterised in that the plate of low heat conductivity is arranged between two ballasting and/or mechanical protection plates.
10. Store according to either one of Claims 8 and 9
15 characterised in that each panel is covered, on at least one of its two lateral faces, by a sealing element impermeable to water.
11. Store according to any one of Claims 1 to 10, which is installed beneath at least one superstructure
20 and is characterised in that it serves as a foundation or bed for the superstructure.
12. Store according to Claim 11, characterised in that it possesses lateral walls which extend up to the vicinity of the surface of the ground and which serve as foundations
25 for a building, and in that the whole formed by the mass of heat-storing material and by a substantially horizontal,



heat-insulating wall which lies above the sand mass has, above the bottom of the store, a height substantially less than that of its lateral walls, so that the said horizontal wall delimits, together with the upper parts of the lateral walls, the basement of the building.

13. Process for constructing a heat store according to any one of Claims 1 to 12, particularly in water-bearing ground, which process involves digging in the ground a hole of a volume at least equal to that of the store to be constructed and filling this hole, at least partially, with one or more heat-storing materials comprising binder, clay and water which when set have a compression strength of at least 0.1 bar and a specific heat per unit volume of water of at least 0.6 calories / °C/cm³, whilst inserting therein a part of at least one energy-transfer circuit, and is characterised in that, during the digging of the hole the latter is constantly filled, at least partially, with a suitable liquid such as water or a drilling mud, in that the corresponding part of the energy-transfer circuit is submerged and immobilised in the liquid filling the hole, and in that there are added to the said liquid quantities of a binder and optionally other additives suitable for ensuring the setting of the binder and, in this way, causing the liquid to rigidify into a mass of suitable heat-storage capacity which fills, at least partially, the completed hole.



14. Process according to Claim 13, characterised in that the binder and an additive which retards the setting of the binder, at least until completion of the hole and installation of the energy-transfer circuit, are added to the drilling mud before the latter, is used to fill the hole.

15. Process according to Claim 13, characterised in that the binder and any other additives are added to the liquid which fills the completed hole.

16. Process according to any one of Claims 13 to 15, for constructing an underground heat store which is enclosed in a heat-insulating and/or sealed envelope, characterised in that substantially vertical walls of concrete which are intended to constitute the lateral walls of the insulating envelope are cast in the ground by a method known per se, in that the hole is then dug between the said cast walls, in that, before the liquid filling the hole solidifies, a heat-insulating and/or sealed panel is submerged in the said liquid, said panel being immobilised near the bottom of the hole to constitute the floor of the closed envelope, and in that, after the liquid has rigidified and the energy-transfer circuit has been installed, the envelope is completed by an upper heat-insulating and/or sealed panel.

17. Process according to any one of Claims 13 to 15, for constructing an underground heat store which is enclosed in a heat-insulating and/or sealed envelope characterised in that panels which are heat-insulating and/or impermeable

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to water are submerged in the liquid filling the completed hole, before the said liquid solidifies, and are immobilised near the bottom and the lateral walls of the hole, to constitute, together with an analogous upper panel the closed
5 enclosure.

18. Underground heat store according to Claim 1 wherein the store has a specific heat per unit volume greater than 0.8 calories/°C/cm³.

19. Underground heat store substantially as hereinbefore
10 described with reference to the embodiment of Figures 1 and 2 or the embodiment of Figure 3.

20. Process of constructing an underground heat store substantially as hereinbefore described with reference to the embodiment of Figures 1 and 2 or the embodiment
15 of Figure 3.

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