March 20, 1973 A. BRACHET ETAL 3,721,116

METHOD FOR DETECTING STEAM LEAKAGE IN A HEAT EXCHANGER HAVING CIRCULATION TUBES SURROUNDED BY LIQUID SODIUM AND DEVICES FOR THE APPLICATION OF SAID METHOD

Filed Dec. 1, 1970 2 Sheets-Sheet 1

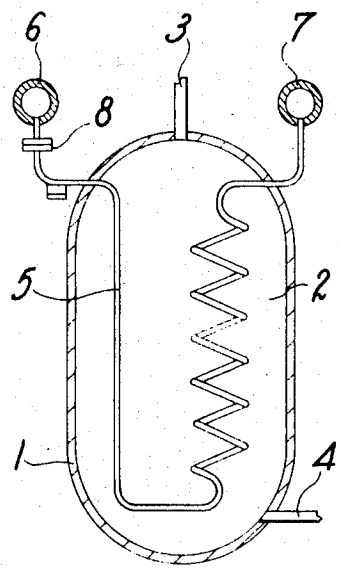


FIG. 1

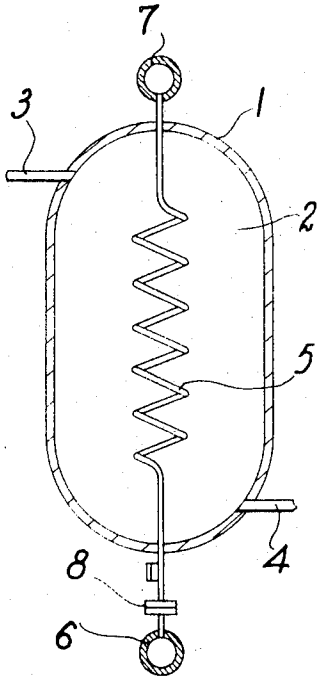


FIG. 2

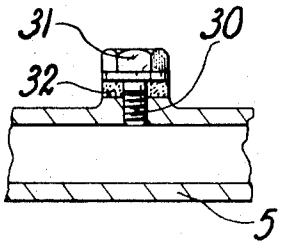


FIG. 4

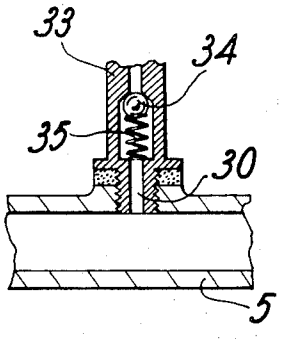


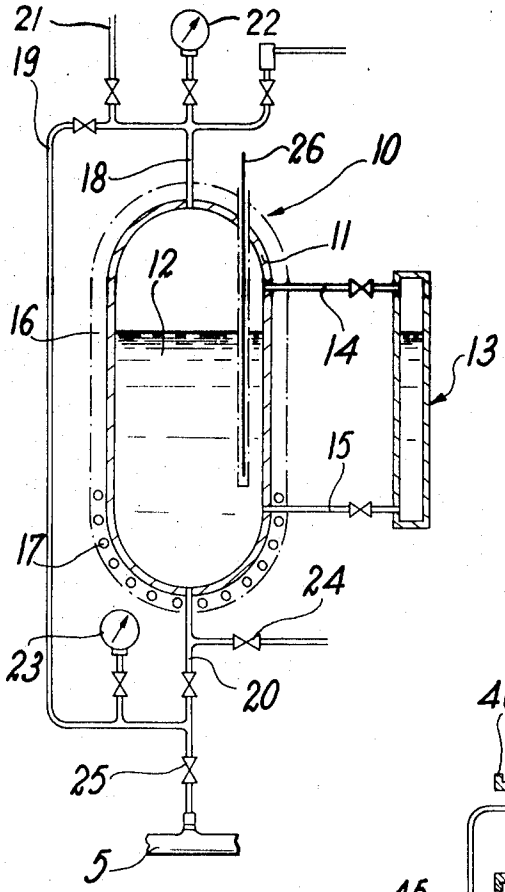
FIG. 5

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FIG. 3



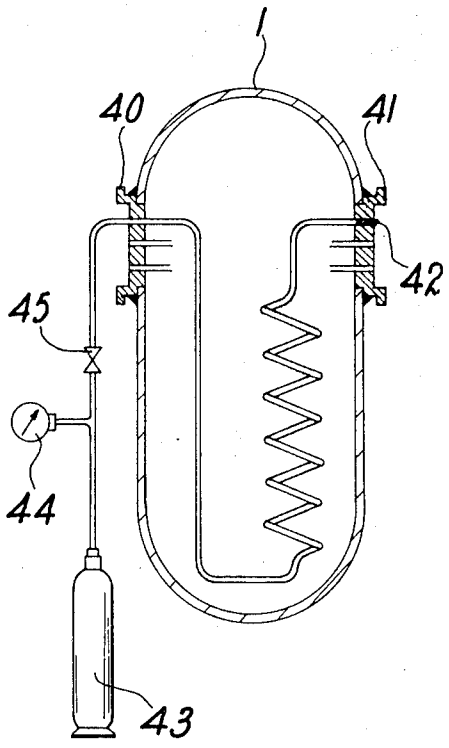


FIG. 6

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METHOD FOR DETECTING STEAM LEAKAGE IN A HEAT EXCHANGER HAVING CIRCULATION TUBES SURROUNDED BY LIQUID SODIUM AND DEVICES FOR THE APPLICATION OF SAID METHOD

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Int. Cl. G01m 3/04
U.S. Cl. 73—40 15 Claims

ABSTRACT OF THE DISCLOSURE

The leak flow rate, in particular for the determination of a micro-leak, in heat exchangers employed in conjunction with fast nuclear reactors which are cooled by liquid sodium is determined employing known means by locating a given group of tubes including the tube which exhibits leakage among all the tubes of a heat exchanger without modifying the operating conditions of the installation. The tube in the group in which a leak has developed is located. The defective tube is then plugged outside the tank without draining the sodium contained therein and without connecting the steam circulation tubes to the atmosphere.

This invention relates to a method for locating a tube in which a leak has developed among all the tubes of a heat exchanger, especially in which liquid sodium is employed as primary fluid and circulated in contact with the external walls of said tubes in order to transfer heat while the secondary fluid which absorbs said heat is circulated within the interior of the tubes is water in the state of steam or of liquid mixed with steam.

In a heat exchanger of this type consisting of a very large number of tubes which pass in leak-tight manner through a tank containing the liquid sodium and are connected externally of said tank to the manifolds which effect the distribution and circulation of the water or steam within said tubes, the aim of this invention is to minimize outage of the installation in the event of detection of a leak in any tube, detection being carried out by determining the quantity of hydrogen produced by the reaction of the water with the sodium, and to select the leaking tube with accuracy but without any need to drain the sodium from the tank and preferably even without discharging the steam circuit to the atmosphere if this is permitted by the constructional design of the heat exchanger. A further object of the invention is to make it possible in a simple manner, when the defective tube has been located, to plug said tube at both ends, locating and plugging operations being carried out in a simple and rapid manner, thereby permitting start-up of the installation in a very short time.

It is known that heat exchangers and especially those employed in conjunction with nuclear reactors which are cooled with liquid sodium give rise to awkward problems in regard to safety of installations. In fact, as a result of any leakage which occurs in one of the heat-exchanger tubes, the water in the form of either liquid or steam which is circulated within said tube at high pressure is permitted to penetrate into the sodium which is in contact with the external wall of said tube. The resultant reaction between the sodium and the water gives rise to many disadvantages which lead ultimately to outage of the installation over a more or less extended period of time.

If leakage of the tube considered is substantial and

higher, for example, than a few grams of water per second and in particular when said leakage results from fracture of said tube, shut-down of the installation is necessary and reconditioning is always a complex and costly operation. If the leakage is relatively minor and ranges, for example, from a few hundred grams per second to a few grams per second resulting in particular from a crack or hole of small size, the reaction is less violent; but experience shows that a leak of this type nevertheless behaves as a vertiable high-temperature jet in a liquid medium, said jet being liable to cause serious and rapid damage to the adjacent structures and in particular to the other tubes. In this case also, total shut-down of the installation is necessary in practice in order to carry out esesntial inspections and repairs.

Finally, if the leakage of any one of the tubes of the bundle which constitutes the heat exchanger is extremely small and less than a few hundredths of a gram per second, for example, and can consequently be assimilated to what is commonly referred-to as a "micro-leak" arising in particular from a manufacturing defect which has escaped preliminary inspection of the tubes prior to assembly within the heat exchanger, from a crack resulting from fatigue stress or any other cause, it is found that the consequences in the immediate vicinity are relatively non-existent or at least sufficiently minor to produce appreciable damage only after a substantial time of action; in the case last mentioned, it is therefore possible to contemplate very limited outage of the installation. In fact, if the tube which has a micro-leak can be identified and put out of service so as to introduce minimum disturbance in the operation of the installation, complete disassembly of the apparatus for inspection of all the tubes of this later is not necessary but is on the contrary essential in the case of leaks having a higher flow rate by reason of their action on the immediate vicinity.

To this end, the present invention relates to a method for carrying out the repair of a minimum leak or micro-leak within the meaning defined above without calling for extended outage of the installation, the defective tube being readily plugged after location, that is to say plugged at both ends outside the tank which contains the sodium. Said plugging results only in slight reduction in thermal efficiency of the heat exchanger, this reduction being usually negligible when taking into account the very large number of tubes constituting the installation.

To this end, the method according to the invention which consists as an initial step without modifying the pressure and temperature regime under normal operating conditions of the heat exchanger in locating and classifying the leakage in the category of micro-leaks by detection of hydrogen in the sodium by means of a known method and in selecting from all the heat-exchanger tubes a group of tubes containing the particular tube in which a micro-leak has developed. Said method essentially consists in bringing the heat exchanger to an isothermal temperature in which the thermal power exchanged between the sodium and the water is substantially zero, in simultaneously depressurizing the steam within all the tubes of the heat exchanger to a pressure which is slightly higher than the pressure of the sodium, in connecting each tube of the group successively to a reservoir containing hydrogenated fluid which is introduced into said tubes at a pressure equal at a maximum to the pressure of the steam under normal operating conditions and to the isothermal temperature of the sodium, in detecting the presence of hydrogen in the sodium by means of the known method for selecting the tube in which a leak has developed and in plugging said tube externally of the tank.

In a general manner, the known method of detection of hydrogen consists in determining the quantity of hydro-

gen contained in the sodium after diffusion through a metallic membrane associated with an analytical device such as a mass spectrometer (the method just referred-to and the corresponding equipment being described in particular in report ANL.7520 entitled "Proceedings of the International Conference on Sodium Technology and Large Fast Reactor Design" Nov. 7–9, 1968 and especially in the article entitled "Detection of Small Leaks by Hydrogen Measurements in Sodium-heated Steam Generator" pp. 345 to 373).

It has already been found uneconomical to make use of conventional monitoring and measurement systems such as those described in the above-mentioned document and employed for total detection of the presence of hydrogen in order to carry out individual identification of tubes in which leakage has developed during normal operation of the heat exchanger by adapting these systems in particular to a complex mechanism for tube-by-tube inspection of the entire tube bank. A heat exchanger for a high-power nuclear reactor in fact comprises several hundreds or even thousands of tubes and any method of direct location of individual tubes can rapidly lead to prohibitive capital expenditure.

On the other hand and in accordance with the invention, it becomes possible at relatively low cost to provide a device wherein a group of tubes which may include a tube having a micro-leak has been selected in a first stage by means of any suitable method and as a function both of the basic concept and structural design of the heat exchanger, wherein said preliminary selection and detection operations are carried out simultaneously during normal operation of the installation and wherein said device carries out accurate identification of the tube which exhibits leakage among those of the selected group in a second stage of limited duration during which particular conditions of temperatures and pressures within the heat exchanger are satisfied, said operation being carried out with a minimum disturbance of the operation of the installation.

After final identification of the group of tubes containing the tube which exhibits leakage, the mode of operation which is adopted calls for adjustment of the reactor power in order to bring the sodium within the heat exchanger to a substantially isothermal temperature in which the thermal power transferred through the tubes is practically zero; this temperature is evidently compatible with the mechanical strength of the apparatus as a whole and with the general operation of the installation while being preferentially higher than the melting temperature of sodium hydroxide (NaOH) which is in the vicinity of 320° C. or more generally higher than the temperature of incipient appearance of impurities which are liable to obstruct the leak from the exterior of the tube. At the same time, the pressure of the steam within the heat exchanger tubes is reduced to a slightly higher value than that of the sodium in order to prevent penetration of this latter through the tube leak which it is sought to detect. During the following stage, the pressure within the tubes of the selected group can be maintained by means of an inert gas such as argon or nitrogen which is supplied from an auxiliary external source. Said intermediate inert gas is intended to replace the steam within the tubes of the group under consideration and has the advantage of preventing corrosion of the tubes as well as facilitating the necessary handling operations. The pressure of the inert gas is either equal to or higher than the steam pressure in the previous stage.

The final stage then consists in injecting a hydrogenated fluid through an opening which is specially provided in the tubes or through the tube ends and by producing action on each tube in turn, said fluid being constituted, for example, by demineralized and degassed water in the liquid or vapor state or by hydrogen or even by any other fluid or mixture of fluids which have the property of liberating hydrogen as a result of chemical reaction with the sodium. Said fluid is introduced at the pressure of the inert gas and is accordingly intended to replace this latter in each tube in turn. In the case of water, the temperature of this latter is equal to the isothermal temperature of the sodium. When the tube in which a leak has developed is thus put under pressure of hydrogenated fluid, the hydrogen which escapes through the leak is distributed within the external sodium. The response of the hydrogen detection system then makes it possible to locate said tube immediately. During the final stage, it may prove desirable to reduce the flow rate of sodium within the heat exchanger in order to increase the detection sensitivity and bring the pressure of the hydrogenated fluid within each tube in succession to the nominal steam pressure in normal operation so that the leak should be placed under the same pressure conditions as those which prevail during said operation. Moreover, it should thus be noted that there is little reason to expect any accidental stopping of the leak by the sodium or by the reaction products since all the operations are carried out in such a manner as to modify the operating conditions to the least possible extent with respect to the normal conditions during which the leak was initially detected.

When the tube in which a leak is present has thus been determined, the steam tube circuit which is placed under inert gas pressure is depressurized to a value which is slightly higher than atmospheric pressure in order to prevent admissions of air during the final operation involving plugging of the faulty tube and disconnecting this latter from the circuit. Once the plugging operation has been completed, the heat exchanger is put back into service without having drained the sodium and even without having totally interrupted the sodium circulation at any moment. Furthermore, in the alternative embodiment in which liquid water is employed as tracer fluid, it is possible to prevent any admission of air into the steam circuit. In the other alternative embodiments, the air admission always remains as low as possible. In consequence, outage of the installation is on the whole of very short duration and the operation involving identification of the leaking tube does not in itself involve any substantial disassembly. In addition, this operation does not call for special equipment or skilled personnel, only the monitoring equipment which is already installed being employed for carrying out the detection of hydrogen within the sodium in known manner.

Further properties of the method under consideration will become apparent from the following description of a number of exemplified embodiments of devices for the practical application of said method, said devices being given by way of non-limitative indication and forming part of the present invention.

In the accompanying drawings:

FIGS. 1 and 2 are diagrammatic sectional views of a heat exchanger comprising a tank and an assembly of steam circulation tubes which are mounted through said tank;

FIG. 3 is a sectional view of an equipment unit comprising an external reservoir for putting the different tubes forming part of any preselected group under pressure of a hydrogenated fluid and possibly of an inert gas;

FIGS. 4 and 5 are detail views on a larger scale showing a part of one of the heat-exchanger tubes;

FIG. 6 is a sectional view of another embodiment of a heat exchanger which makes use of an alternative form of the method according to the invention.

In FIGS. 1 and 2, the heat exchanger which is illustrated comprises in a very diagrammatic manner a tank **1** which is adapted to the continuous circulation of a primary fluid and especially liquid sodium **2** which is derived either directly or indirectly from the core of a nuclear reactor (not shown in the drawings), said sodium being intended to penetrate into the tank **1** through a pipe **3** and to be discharged through a pipe **4**. The circulating sodium is thus in contact with the external surface

of a series of tubes such as the tube **5** which pass in leak-tight manner through the tank **1**, said tubes being connected externally of the tank to an input manifold **6** and to an output manifold **7** which serves to circulate within said tubes a secondary fluid and especially water in the state of liquid and/or steam for exchanging heat with the sodium. The example which is shown diagrammatically in FIG. 1 illustrates a particular assembly of the tubes **5** in which these latter are suspended within the tank **1** while the example illustrated in FIG. 2 shows said tubes which pass through the tank substantially axially; this last-mentioned arrangement of the so-called drainable tube type makes it possible in particular to purge said tubes.

FIG. 3 illustrates an external reservoir which makes it possible in accordance with the method of the invention to inject into each heat-exchanger tube a suitable quantity of hydrogenated fluid and in particular demineralized and degassed water **12** in the state of liquid or steam under the given conditions of temperature and pressure which will be specified hereinafter. Said reservoir **10** comprises mainly a shell **11** within which the depth of water is measured by means of a suitable device consisting of an external gage **13**, for example, which is connected to the shell **11** by means of pipes **14** and **15**. Said shell is surrounded externally by a suitable layer **16** of heat-insulating material and provided at the lower portion thereof with a heating element **17** for bringing the water **12** to a given temperature as measured by means of the temperature transducer **26**. The reservoir **10** is also connected to a pressurization circuit comprising pipes **18**, **19** and **20** which are connected to a pipe **21** for supplying an inert gas such as argon or nitrogen, pressure gages **22** and **23** being employed for measuring the pressure of said gas and of the water within the reservoir. A valve **24** serves to connect the reservoir **10** to a pipe for the make-up supply of water; finally, discharge from the reservoir is carried out through a valve **25** which serves to connect said reservoir to any one of the heat-exchanger tubes **5** in accordance with either FIG. 1 or FIG. 2.

In order to permit of connection between the reservoir **10** and the tubes **5**, said tubes are preferably provided with a lateral opening **30** as shown more especially in the enlarged views of FIGS. 4 and 5, said opening being normally closed by a plug **31** which compresses a seal **32**. When the reservoir **10** is to be connected to the tubes **5**, the plug **31** is removed and the extremity of the delivery-pipe **33** of the valve **25** is fitted in the opening **30**, said pipe **33** being preferably provided with a ball-valve **34** which is controlled by a spring **35** and performs the function of a check-valve so as to prevent return flow to the reservoir **10** or to the atmosphere.

The method of monitoring and measurement is carried out in the manner which has already been explained in detail. After a group of tubes including the tube which exhibits a leak has been identified among all the heat-exchanger tubes **5** in an initial stage and during normal operation of the installation, said leak having previously been detected by an ancillary measuring assembly of the diffusion-membrane type (not illustrated) for detecting hydrogen in the sodium and having been classified according to the value of flow rate in the category of micro-leaks which do not require complete shut-down of the installation, the conditions of isothermal temperature and of pressure in accordance with the characteristics already mentioned are established within said installation. The steam circuit is then put under a pressure of inert gas corresponding to a value which is slightly higher than that of the sodium, whereupon the devices of the type shown in FIG. 5 are adapted successively to each tube of the selected group. In the case of a heat exchanger of the type illustrated in FIG. 2, it is also necessary to form a leak-tight separation between the device according to FIG. 5 and the bottom manifold **6** in order to prevent tubes other than that on which it is desired to operate from being filled as a result of a communicating-vessel effect. This precaution is optional in the case of the heat exchanger of FIG. 1 subject to the condition that the manifolds **6** and **7** are located substantially in the same horizontal plane. If this is not the case and so far as the heat exchanger according to FIG. 2 is concerned, it is preferable in order to provide said separation to make use of a "stability diaphragm" as normally fitted at the inlet of each tube and constituted by an orifice having a sufficient pressure drop to ensure that the flow rate to all the heat-exchanger tubes is substantially constant and uniform and to replace said orifice with a full diaphragm. Whatever form of device may be employed, it is in fact advisable to ensure that said device is capable of carrying out the three diaphragm functions of damping hydrodynamic instabilities of the heat exchanger, of providing leak-tightness in the direction of the bottom manifold and of providing a nozzle for the injection of the tracer fluid.

When this operation has been completed, the pressure of inert gas within the exchanger is increased to a value such that, in the case of the isothermal temperature to which the sodium has previously been brought, the demineralized water which performs the function of hydrogenated fluid remains in the liquid state after injection into each tube of the selected group in place of the inert gas. Furthermore, in order to prevent harmful thermal shocks during the injection, it is desirable to bring the water of the reservoir **10** to the same temperature. Transfer of the water into each tube is checked by means of the external gage **13**. However, in an alternative form which affords complete safety in guarding against the risk of overflow of the tube during filling within adjacent tubes, the useful volume of the reservoir **10** is calculated in order to be just sufficient to fill one tube.

When the tube which has thus been connected exhibits a leak, detection of the leak is carried out immediately by determination of the presence of hydrogen resulting from a flow of the demineralized water within the sodium through said leak. The defective tube having thus been identified, it is only necessary to plug the tube, especially outside the end manifolds **6** and **7** after having replaced the demineralized water with inert gas whose pressure is then maintained at a value which is slightly higher than atmospheric pressure in order to prevent admission of air during the plugging operation itself. The installation can then be rapidly restored to normal operation, only the plugged tube being out of service.

A particular case is to be contemplated when access to the different tubes of the heat exchanger cannot be gained without discharging the steam within the circulation tubes to the atmosphere; this is especially the case in which the tubes **5** extend through and have their openings in two front plates **40** and **41** which are provided on the tank in the manner which is shown in FIG. 6. An alternative form of the method accordingly consists in carrying the operation as follows: after complete depressurization of the steam circuit and release of the front plates **40** and **41**, which has the disadvantage of connecting the circuit to the atmosphere although to a very limited extent, a seal plug **42** is fitted in one end of each tube **5** whilst the other end is connected either to a reservoir of the type shown in FIG. 3 or to a cylinder **43** fitted with a pressure gage **44** and an expansion valve **45** for the direct admission of hydrogen into the tube considered. The detection of hydrogen in the sodium is then carried out in the same manner as in the previous case, the remainder of the operations being identical. It should be noted that the advantage of employing hydrogen instead of water arises from the fact that, in this case, it is possible to operate at a lower pressure than in the previous embodiment in which the tracer fluid is demineralized liquid water. The sensitivity of detection of the micro-leak to be identified is thus improved to a certain extent.

As will be readily understood, the invention is not limited in any sense to the examples which have been described with reference to the accompanying drawings but extends on the contrary to all alternative forms.

What we claim is:

1. A method for locating a steam micro-leak within the tank of a heat exchanger having circulation tubes for water surrounded by liquid sodium and consisting as an initial step without modifying the pressure and temperature regime of the heat exchanger in locating and classifying the leakage in the category of micro-leaks by detection of hydrogen in the sodium then selecting from all the heat-exchanger tubes a group of tubes containing the particular tube in which the micro-leak has developed, then bringing the heat exchanger to a constant temperature at which the thermal power exchanged between the sodium and water in the tubes is substantially zero, simultaneously depressuring the steam within all the tubes of the heat exchanger to a pressure which is slightly higher than the pressure of the sodium, connecting each tube of the group successively to a reservoir containing hydrogenated fluid, introducing said fluid into said tubes at a pressure equal at a maximum to the pressure of the steam under normal operating conditions and at the temperature of the sodium, detecting the presence of hydrogen in the sodium, selecting the tube in which a leak has developed and then plugging said tube externally of the tank.

2. A method according to claim 1 including the step, prior to introduction of the hydrogenated fluid into each of the tubes of the selected group, of filling said tubes with an inert gas at the pressure of the steam prior to depressurization of the heat exchanger.

3. A method according to claim 2 including the step, prior to plugging of the tube which exhibits a leak in the selected group, of replacing the hydrogenated fluid introduced into said tube by the inert gas, said gas being brought to a pressure slightly higher than atmospheric pressure.

4. A method according to claim 1, including the step, during introduction of the hydrogenated fluid into each tube of the selected group, of reducing the rate of flow of sodium within the heat-exchanger tank to increase the sensitivity of detection of the hydrogen through the leak.

5. A device for locating a steam micro-leak within the tank of a heat exchanger having circulation tubes for water surrounded by liquid sodium including an external reservoir for hydrogenated fluid, means for varying the pressure and the temperature of said fluid, means for introducing said fluid into said tubes, and means for determining the mass of fluid introduced successively into each of the tubes of a selected group of said tubes.

6. A device according to claim 5, wherein the hydrogenated fluid is demineralized and degassed water.

7. A device according to claim 6, including a heating element bringing the demineralized and degassed water to the isothermal temperature of the sodium within the tank said heating element being in contact with the wall of said reservoir.

8. A device according to claim 6, the volume of said reservoir being substantially equal to the volume of a heat-exchanger tube.

9. A device according to claim 5, wherein the hydrogenated fluid is steam.

10. A device according to claim 5, wherein the hydrogenated fluid is hydrogen gas.

11. A device according to claim 5, the hydrogenated fluid liberating hydrogen by chemical reaction with sodium.

12. A device according to claim 5, said reservoir including a discharge pipe, means for connecting said pipe successively to each tube of the selected group of tubes including an opening in the lateral wall of each tube and a detachable pipe-coupling in said opening and a non-return valve in said pipe-coupling.

13. A device according to claim 12, each tube of the selected group of tubes including means for temporarily shutting-off said opening.

14. A device according to claim 12, said discharge pipe being connected in parallel with a supply of inert gas under pressure.

15. A device according to claim 5, said reservoir being a compressed-hydrogen cylinder connected successively to one extremity of each tube of the selected group of said tubes through a front plate in the wall of said tank, and a seal plug closing the other tube-extremity at a second front plate in the wall of said tank.

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