ABSTRACT

A phase-change energy storage system, composed of: one or more tanks (1) containing anhydrous ammonia (or with minimum content of water), in which the liquid ammonia (2) is in equilibrium with its vapor (11) at high pressure; a tank (3) (**at the same temperature** and made so as to facilitate the heat exchange with tanks (1)), containing liquid water - ammonia solution (4), in equilibrium with ammonia vapor (12) at low pressure and with a very low content of water vapor; a reversible compressor / motor (5) connected on the high pressure side with a duct (6) to the high pressure tank (1), and on the low pressure side with a duct (7) to the low pressure tank (3). To store energy, the compressor / motor (5) acts as a compressor and is driven by an electric motor or by otherwise providing mechanical energy, so that it withdraws ammonia vapor (12) at low pressure from tank (3), compresses it and sends it to the high pressure tank (1). In this operation, a part of the ammonia dissolved in the water - ammonia solution (4) will evaporate to maintain the equilibrium conditions in the low pressure tank (3), while in the high pressure tank (1), a part of the ammonia vapor (11) will condense into the liquid (2), maintaining here too the thermodynamic equilibrium. The condensation heat generated in tank (1) will be transferred to tank (3) where it will balance the heat taken away by the evaporation. To release the stored energy, the compressor / motor (5) functions as a motor (providing mechanical energy, driving for example an electric generator): the high pressure ammonia vapor (11) coming from tank (1) is made to expand in the motor (5) and is then released at low pressure in tank (3). In this case, the evaporation will take place in the liquid (2) and the condensation in the liquid (4). The entire system must be airtight in order to prevent the escape of vapors of water and ammonia or the entry of air from the outside**, and furthermore the high-pressure tanks (1) must be completely emptied of their liquid content (2) before being recharged, to prevent the accumulation of liquid water in them**.

Description of the industrial invention entitled:

Phase-change energy storage system with water - ammonia solution

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The invention refers to a phase-change energy storage system, in which the mechanical work supplied to a reversible compressor / motor (5) is used to compress ammonia vapors (12) and make them condense in a high pressure tank (1). The stored energy is then recovered at a later time by evaporating the liquid ammonia (2), and making it expand in the compressor / motor (5), now functioning as a motor and producing mechanical work, and then releasing it in a low pressure tank (3) where it condenses into a liquid solution (4) of water and ammonia.

STATE OF THE ART

Ammonia has many applications as the working fluid in thermodynamic machines, both of the motor type (eg turbines) and of the operator type (for example, heat pumps). The particular properties of solutions of water and ammonia cause them to be employed in absorption heat pumps, and also in several other applications, such as in the thermodynamic processes and machines described in British Patents 2 098 666 by Kalina and 2 411 699 by Turner, in United States patent 4,622,820 by Sundquist, and in the international patent WO 2005/083247 by Ruggieri et al. Ammonia is also used as the working fluid in Chinese patents CN102538534 and CN102312686. Liquid ammonia has also been used to store mechanical energy for use in the propulsion of railway vehicles (streetcars) in Lamm's inventions covered by United States patents 105,581 , 121,527 and 124,495 , which were the starting point for the present invention. In particular, the system invented by Lamm consists of a high pressure tank containing liquid anhydrous ammonia, which is made to evaporate and expand into a motor to then be dissolved in a solution of water and ammonia contained in a tank at low pressure. While, however, Lamm’s system can only work as a motor, being necessary, after its use, to extract the anhydrous ammonia from the solution of water and ammonia through external means, the system object of the present invention is characterized by reversible operation, it being possible to absorb mechanical work and use it to regenerate virtually anhydrous liquid ammonia, at high pressure. This has been achieved by making both the high pressure and the low pressure tanks substantially airtight and completely devoid of air. **A reversible system which has similarities with the present invention, but which is based on a different principle of operation, was patented by Mierisch et al. with the patent US 2013/0118170 A1, in which a compressor / reversible motor is used to store energy by taking vapor from a tank containing saturated liquid, compressing it and making it condense in a tank at a higher temperature and thus also higher pressure; the energy is then re-extracted with the reverse process: the high pressure vapor coming from the high temperature tank is expanded, producing mechanical work, and then discharged into the tank at a lower temperature and low pressure, where it condenses back. Thus, the invention of Mierisch et al. requires, in order to store energy, a temperature difference between the two storage tanks. On the other hand, in the present invention the two storage tanks are in thermal equilibrium with each other, at the same temperature, and the pressure difference is due to the different composition of the liquids: the high-pressure tank contains ammonia with a minimum content of water, while the low pressure tank contains a diluted solution of water and ammonia.**

DESCRIPTION OF THE INVENTION

With reference to the accompanying drawings,

- Fig. 1 is a schematic representation of the system in its simplest form;
- Fig. 2 is a schematic representation of the system in an improved version, in which the high pressure tank consists of several independent tanks;
- Fig. 3 is a particular embodiment of the system shown in Fig. 2, in which the reversible compressor / motor (5) is of the volumetric reciprocating piston type.

With reference to Fig. 1-3, the system object of the present invention is constituted by: one or more high pressure tanks (1) containing virtually anhydrous liquid ammonia (2), in thermodynamic equilibrium with ammonia vapor (11) at high pressure; a low pressure tank (3), constructed so as to easily exchange heat with the high pressure tanks (1), and containing a liquid solution (4) of water and ammonia in thermodynamic equilibrium with ammonia vapor (12) at low pressure; a compressor / reversible motor (5) connected by means of a duct (6) to the high pressure tanks (1), and connected by means of a duct (7) to the low pressure tank (3). The tanks (1) and (3) must be airtight for the good functioning of the system: for this purpose, static seals may be used between the system and the external environment; in the case in which the compressor / motor (5) is of the volumetric reciprocating piston type, as in the embodiment represented in Fig. 3, the movable parts that connect the system with the outside world, such as the piston rod and the valve stems, are equipped preferably with static seals such as the bellows (10) shown in Fig. 3. Finally, with reference to Fig. 2 and 3, each high pressure tank (1) is equipped with an upper valve (8) in the connection with the conduit (6), and with a bottom valve (9) in the direct connection with the tank (3), the bottom valve (9) being only used to discharge the residual liquid from tank (1) when the liquid ammonia (2) contained in it has been used almost completely. With reference to Fig. 3, the operation of the system is described in detail below. For storing energy in the system, mechanical work must be provided to the compressor / motor (5), which in this case acts as a compressor and withdraws low pressure ammonia vapor (12) from tank (3) through duct (7), compressing it and releasing it, through duct (6) and the single open valve (8), in tank (1), where it condenses, raising the level of liquid ammonia (2). When the tank (1) is completely full of liquid ammonia (2), its valve (8) is closed and a different valve (8) is opened, so that another tank (1) may be filled. To extract the stored energy, the system instead proceeds as follows:

the compressor / motor (5) works as a motor, and is supplied with ammonia vapor (11) at high pressure, coming from the tank (1) through the open valve (8) and the duct (6). The ammonia vapor (11) expands and transfers its energy to the motor (5), after which the ammonia vapor, now at low pressure, is discharged through the duct (7) in the tank (3), where it condenses, raising the level of the liquid solution (4) of water and ammonia; at the same time, the level of liquid ammonia (2) in the tank (1) in use diminishes due to evaporation of the same: when this level is very low, the small percentage of water in solution in liquid ammonia (2) begins to increase, as almost only ammonia evaporates, while water remains liquid. This increase of the water content percentage in the liquid ammonia (2) makes the pressure drop, so the tank (1) at a certain point can be considered to be exhausted. It is convenient at this point to completely discharge the residual liquid (2) from the tank (1), briefly opening the discharge valve (9) and discharging the residual liquid into the tank (3). After performing this operation, the tank (1) is devoid of liquid and then both its valves (8) and (9) are closed, until a subsequent recharge step. To continue to extract energy from the system, another tank (1) is selected which still contains liquid ammonia (2), and the corresponding valve (8) is opened. In all this, it is necessary to have a good heat transfer capability between the tanks (1) and the tank (3), so that the heat produced by the condensation of ammonia in one tank is easily transmitted to the other tank, where heat is required for liquid evaporation. The thermodynamic transformations must take place as much as possible in a reversible manner.

CLAIMS

1. A phase-change energy storage system composed of one or more sealed high pressure tanks (1) containing virtually anhydrous liquid ammonia (2) in equilibrium with high pressure ammonia vapor (11), a sealed low pressure tank (3)**, at the same temperature as the high pressure tanks (1) and in thermal equilibrium with them,** containing a liquid solution (4) of water and ammonia in equilibrium with low pressure ammonia vapor (12), and a reversible compressor / motor (5) capable of transferring the ammonia vapor from one tank to the other**, in which system furthermore each high pressure tank (1) is completely emptied of its liquid content (2) before being recharged.**

2. An energy storage system according to claim 1, further characterized by the fact that the reversible compressor / motor (5) is of the volumetric reciprocating piston type, and in which all the seals between the system and the outside are static seals, with bellows seals (10) on the moving parts.