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IMPROVEMENT OF HYDRIDE HEAT DEVICES PERFORMANCE

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Introduction

Application of Hydride Heat Machines (HHM - hydride heat pump (HHP), refrigerator, heat transformer, compressor, hydrogen accumulator) is justified where are sources of low-potential energy or fulfilled heat quantity is not used. Hydrogen-metal hydride systems promote also improvement of ecological conditions and implantation of cleaner hydrogen technologies.

Results and discussion

Heat machine creation procedure and increase in its efficiency based on periodic circulation of hydrogen needs the detailed information on methods of calculation equilibrium *P-C-T* (pressure – concentration - temperature) of characteristics, thermodynamic, thermophysical (factors of specific heat conductivity and a heat transfer depending on temperature and pressure) and kinetic properties of hydrides. The approach to designing HHP as to particular kind of the HHM can be divide into three component /1/:

- Design hydrides (definition of dependences *P-C-T*, thermodynamic and kinetic properties);
- Design reactor sorbers (increase and optimization of heat conductivity, maintenance of gas-permeability, heat transfer processes coordination between heat carriers, the coordination heat and mass streams and so forth);
- Design heat system (binary, triple, multi-block HHP) - the analysis heat pump dynamics operation, cycle optimization and other parameters.

In heat installations with hydrides use depends efficiency of its work (efficiency, heat (or colds) quantity and heat power) on amount of the hydrogen participating in reaction. Reserved an alloy of hydrogen quantity is characterized *P-C-T* by dependence which results empirically. There are also proposals on calculation obtaining of the uniform diagram of dependence between isothermal concentration of hydrogen with and equilibrium pressure P_{eq} with the help of the Langmuir equation with six constants, and also the equations on the basis free energy function of solid alloy solution.

In periodically running cyclic installations it is important to use hydride systems with the maximal contents of active hydrogen. Revealing of new hydride materials questions are extraordinarily important from the point of view of a prices and efficiency ratio. Concentration of active hydrogen depends on hysteresis $F_h=P_d/P_a$, a slope of plateau $F_s=\ln(P_{C1}/P_{C2})/(C_1-C_2)$. For example, hydrogen amount inversely F_s also can decrease three times at change F_h with 0.9 up to 0.6.

The conversion factor (English abbreviation - *COP*=(useful heat)/(spent heat)) depends on the contents of active hydrogen, the common system thermal capacity and thermal levels of device operation (temperature T_h, T_m, T_l). So, for example, at increase in design factor (K_k=sorber weight/hydride weight) with 0.4 up to 1.5 *COP* can decrease twice.

Duration of a cycle is determined as time required for reaction dehydrogenation-dehydrogenation in pair hydride system. It determines HHP thermal capacity. Cycle duration depends on a reaction hydrogenation kinetics, a heat transfer between the heated up and cooling environment, hydride beds heat conductivities. The kinetics of reactions is proportional to a difference of hydrogen dynamic pressure in HHP sorbers and to constants of hydrogenation chemical reaction. The relation of dynamic pressures is adjusted by characteristics of a heat transfer in particles metal hydride beds (heat transfer of hydride bed depends on its effective specific heat conductivity) and are connected to total factor of a heat transfer of sorber-heat exchanger system. The modified rate constant as function of temperature in isobaric process /1/ can characterize a kinetics of sorption reactions. The amount of transferable hydrogen decreases on time cycle stages is exponentially and is characterized by fast change during the initial moments of time and smooth droop on the basic time interval ("tails"). With certainty it is possible to tell that in HHP dynamics of hydrogen transfer (and therefore process time and output power) is defined with heat transfer hydride beds coefficient and their relation for beds of various hydrides. Average capacity in a cycle has an optimum on cycle time.

The active hydrogen amount circulating in HHP (usual 0.6-1.2 weig. %) has an optimum depending on hydrogen charged in HHP amount (in sorbers system without valves - depending on initial pressure of hydrogen in sorbers). This rule is observed experimentally and confirmed with computer modelling /2/. From a point of view heat and mass transfer processes and weight minimization of sorbers design improvement it is advantageous to operate at a level of hydrogen pressure from atmospheric till 30-50 atm.

The important characteristic for HHM efficiency is alloy power, i.e. the capacity related to weight of hydride alloy. The achieved for today value on the average for a cycle aggregates 40-100 W/kg. At cycle shortening this value grows, but up to achievement of competitive (in comparison with other similar type thermal machines) value in 1000 W/kg /3/ are necessary for increasing cardinally amount of active hydrogen, to increase effective heat conductivity of a hydride bed and to optimize operation of sorber-heat exchanger system. Thus duration of a full cycle is estimated ~ 3-6 minutes.

The amount of active hydrogen depends on change of temperature levels of HHP: it increases with growth T_h and T_l and with decreasing T_m (a refrigerating cycle of HHP). And influence T_l and T_m is insignificant (dependences have a flat kind in a wide interval of temperatures), influence T_h is more essential up to the certain temperature after which achievement the amount of useful hydrogen grows insignificantly, and change *COP* passes through a maximum. It is possible to define limit temperature levels at which the cycle becomes impossible.

Expansion of working temperature levels (T_h and T_l) from average level T_m is possible at use of multistage heat pumps /4/. Thus in a cycle warmly increase can be received superheated steam at a level 120-150°C /5/, and in a cycle of a refrigerator can be received temperatures at a level the minus 20-40°C. Application of heat step-up cycles more preferably because of a fast reaction kinetics and high capacity characteristics. The achieved efficiency (the relation of the allocated energy to spent energy) the HHM is approximately twice lower in comparison with usual devices of compressive type (for heat step-up ≈2.7 against ~5.0).

Heat conductivity of powder hydride beds is insignificant (~0.5 W/(m·K)) and consequently thin powder beds (no more than 3 mm) are effective only. By introduction in beds of a high-temperature matrix (continuous - plates, ribs, crimps; porous metal foams, the sintered powders, microincapsulation by metal hydrides, compounds) is possible to raise coefficient of effective heat conductivity till 10-18 W/(m·K). Thus it is necessary to press towards lower a part of a heat-conducting material in a hydride bed (and in an ideal - to optimize it) not to the detriment of heat conductivity for achievement of the greater sorber fullness by hydride and increase of a specific power-supply, so also efficiency.

The system effectiveness is characterized by the contents of active hydrogen and power of an alloy. From a point of view of increase in HHM efficiency "to improve" hydride means:

- To increase capacity on hydrogen (accumulator of hydrogen, hydrogen compressor, HHP);
- To increase active hydrogen amount in hydride system (HHP);
- To reduce a hysteresis and an slope of pressure plateau of *P-C*.

Conclusions

In present-day conditions for substantial improvement of HHM characteristics it is necessary to raise capacity of hydride on hydrogen a minimum in 2 times (with 1.5 till 3.0-3.5 mass % for a range of working temperatures close to room).

References

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