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CLEANING OF THE EQUIPMENT OF RESIDUAL SODIUM BY MEANS OF WATER-VACUUM TECHNOLOGY

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Abstract

Results of investigation into a problem of equipment decontamination from sodium, that have been conducted in OKBM since 1960 are given.

The investigations performed have shown that a water-vacuum washing process is the most optimal method for equipment decontamination from sodium residues.

The essence of the method is in conduction of sodium-water reaction under reduced pressure in a leak-tight tank. Boundary conditions are selected experimentally which not allow sodium to be melted during the process, that gives possibility to control the sodium-water reaction. Continuous removal of H_2 and reaction products creates safe conditions for the process conduction.

More that 20-year period of operation of a stationary water-vacuum facility and washing the electromagnetic pump for BN-350 fast nuclear reactor directly at is test rig are the best proofs of the proposed method.

This method is well suitable for washing the equipment contaminated by radioactive sodium, because by-products of the process are simply utilized. The method is used in a number of Russian enterprises, and recommended for implementation at BN-350 and BN-600 reactor plants.

1. Introduction

Operation of first sodium test facilities in OKBM (early 60s), where the equipment items of BN-350 fast nuclear reactor were tested, put forward problems of tested equipment and test facilities components washing from sodium residues.

The equipment which need washing from sodium residues in the course of its operation may be divided into several groups:

1) small units and assemblies (e.g: valves, pipeline sections, sodium vapours traps etc.);

2) large size units and assemblies (e.g.: pumps, heat exchangers, dump tanks etc.);

3) large size units and assemblies, as well as test facility equipment, which need to be washed directly at the place of their location.

Taking into account, that decontaminated equipment should retain its working characteristics a method proposed for washing-off should not result in any serious damages caused by thermal, mechanical or chemical impacts.

At present time a steam-gas method for sodium washing-off is used at BN-350 and BN-600 reactor plants. The washing-off process is performed in a special well, which is preliminary heated. Steam flowrate is controlled by both a washing medium temperature and hydrogen volumetric content in the well. The end of washing process is determined by both termination of hydrogen release and washing medium alkalinity decrease to the neutral reaction. Disadvantages of this method are as follows:

a) alkaline corrosion;

b) incomplete removal of sodium from narrow gaps.

Washing by spirit was not widely spread in spite of the fact, that spirit reacts with sodium weaker. Disadvantages of the spirituous washing method are as follows:

a) fire hazard;

b) high cost;

c) incomplete removal of sodium from gaps.

Equipment washing-off from sodium with the help of vacuum distillation process is performed at 500 °C and vacuum level less than 3 mm Hg gauge. Sodium vapours are removed by vacuum pump and condensed in a trap at 200°C. This method is not widely used due to:

a) complexity of the process hardware;

b) impossibility to remove sodium from equipment with complex configuration;

c) high cost.

The both methods, i.e. spirituous washing and vacuum distillation are not widely used.. Research and development works for the search of a simple and safe method for decontamination from sodium have been carried out in OKBM for a long time.

2. Requirements for the sodium decontamination method

The proposed method of the equipment washing-off from sodium should meet the following requirements:

1) to provide the decontamination process safety;

2) to exclude impact to the environment;

3) to provide high purity and multiple use of decontaminated equipment;

4) to provide complete utilization of products obtained as a result of washing-off process;

5) to be economically expedient.

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3. Theoretical substantiation of the vacuum sodium washing-off method

Sodium and water interaction is a spontaneous heterogeneous reaction, having a complex dynamically unstable character. Depending on the reaction progress conditions hydrogen $(H)_2$, sodium oxide (Na_2O), sodium hydride (NaH), sodium hydroxide (NaOH) are formed. From the thermodynamics point of view the process of sodium and water interaction is a rapidly running process with release of much amount of heat even at indoor temperature. This process pertains the reactions, the balance of which is practically irreversibly shifted to the forming of reaction products. Heat released in the reaction changes a phase state of the reagents, so that sodium is melted and water boils. At such state of the reagents the reaction has uncontrollable explosive character.

The first task that was set for the investigation was to transfer the uncontrollable sodium-water reaction into a controllable region. Changing the character of sodium-water reaction, that is moderation of the reaction is possible by effective heat removal from the reaction zone, thus excluding a sodium melting process. In most effective manner this process can by realized at water evaporation. But because water boils at 100 ^{0}C while sodium is melted at 97.8 °C this process is impossible under normal conditions. Therefore, it is necessary to create the conditions when water boils at the temperature lower than the sodium melting point.

Pressure in the reaction zone ($P_{r.z.}$) may be expressed through the following parameters:

- pressure of hydrogen released at sodium-water reaction, P_{H_2};
- pressure of saturated water vapours at given temperature, P_{H_2O};
- environment pressure, that is external pressure, P_{ext}, as follows:

$$P_{r.z.} = P_{H_2} + P_{H_2O} + P_{ext} \qquad (I)$$

It is evident from the equation (I), that decreasing external pressure we create the conditions, when pressure in the reaction zone becomes lower, than atmospheric one. As the external pressure decreases water boiling temperature also decreases, evaporation heat value rises, water steam density reduces and consequently the quantity of hydrogen released at sodium-water reaction is also reduced. So, by reducing external pressure it is possible to control the sodium-water reaction.

Experiments have shown that the sodium-water reaction without sodium melting is possible under the following boundary conditions:

P_{ext} = 180 mm Hg gauge, T_{H_2O} = 0 °C

P_{ext} = 22 mm Hg gauge, T_{H_2O} = 27 °C.

Specified conditions might be met in case when sodium-water reaction is conducted in a closed leak-tight tank with its continuous vacuuming.

All above-mentioned is true in the situation when sodium freely floats in the excess of water. The character of the reaction changes considerably if the reaction goes at shortage of water. Experiments has shown, that 15 grams of water are necessary for one gramme of sodium. At lesser quantity of water sodium is melted, the reaction products in a form of grey friable mass ("cap") accumulate on an upper surface of sodium which is not in contact with water. If aqueous alkaline solution (NaOH) is used as a solvent instead of water, the safe mode of the equipment washing from sodium may be realized in wider range of temperatures and pressures.

Fig. 1 shows a graphical representation of the experimental results. The obtained data show that as the alkaline (NaOH) concentration in the solvent increases the allowable values of external pressure and solvent temperature are also increased. The reaction rate is simultaneously increased. Its maximum value (0.6g/s) is attained at the following parameters:

- pressure P_{ext} - 440 mm Hg;
- solvent temperature - 65÷70 °C;
- alkaline concentration - 24÷26 wt. %.

As alkaline solution concentration is increased further the reaction rate decreases.

4. Technological principles of water-vacuum washing-off method

The washing facility should include the following main components:

- Reaction tank,
- Vacuum system,
- Dump tank,
- Control and signalling devices.

Upon the equipment to be decontaminated is loaded into the reaction tank it is necessary to take into account the following factors:

a) the quantity of sodium residues on the equipment;

b) geometry of the equipment to be washed.

During the washing process it is important to select correctly the solvent and optimum method for its supply; i.e. water or aqueous alkali solution. The presence of hydrogen at the reaction tank outlet in concentration lower than 1 vol.% testifies the termination of washing process. The equipment in the reaction tank is covered by water and left there for several hours, after that water is discharged, the reaction tank is connected to the atmosphere and cleaned equipment is removed from it.

To define the corrosion of the equipment structural material following the decontamination by this method, a number of experiments with specimens of different thicknesses made of stainless steel has been performed. The specimens after keeping in sodium were washed off during 12 hours. Metallographic analysis has shown that there is no corrosion traces on the surface of the plates.

5. Practical use of water-vacuum washing method

Since 1980 more than 350 pieces of small and large size equipment items have been washed off from sodium, so as about 600 kg of sodium were removed and transferred into aqueous alkaline solution. An example is given below how the method was used for the large-size equipment decontamination directly at a test facility. The secondary circuit electromagnetic pump of BN-350 reactor was decontaminated in 1986 before shipping to the plant. The pump has vessel-type design configuration. The main dimensions and weight of the pump was:

- internal plenum volume - 3 m^3;
- working channel length - 3000 mm;
- the area of contact with sodium - 18 m^2;
- pump weight - 17000 kg.

The pump's head chamber has 20 mm gap and 2500 mm long channel. During the tests the pump was operated for 226 hours at 300 °C sodium temperature. After tests completion, sodium was discharged to dump tanks, the pump was purged by argon, cooled and then cut off from the circuit. Suction and discharge nozzles were plugged by the plugs with rubber gaskets, the sodium plenum is filled with argon. Fig.2 shows a schematic diagram of the pump washing process. As a vacuum pump operates 30-50 °C water steam was pumped through the working channel of electromagnetic pump. The major part of water steam was condensed on the pump working channel walls and reacts with sodium, a small portion of water steam was condensed in a special condenser. Alkaline solution flowed down to the evaporator along the electromagnetic pump working channel walls. The rate of washing process and consequently a steam-water reaction was controlled by hydrogen release through the waterlock and alkaline concentration built up in the evaporator water. The temperature of the working channel wall was continuously measured, it does not exceed 30°C. When the alkalinity became higher than pH=11÷12, water in the evaporator was substituted by pure water until the alkalinity concentration built-up terminates. Washing process was terminated in 112 hours when hydrogen finished to pass through the waterlock and alkaline concentration increase in the evaporator practically terminated. For the final check of washing process effectiveness 40 liters of 45 °C water were pumped through the working channel and then vacuum drying of the channel was performed. Opening of the plugs and inspection of internal surfaces of the working channel have shown that the channel surfaces are clean, the traces of white deposit are absent.

6. Water-vacuum washing method advantages and problems

The water-vacuum method for the equipment decontamination from sodium residues has the following advantages:

- Environmental cleanness
- Absence of alkaline corrosion
- High quality of decontamination.

To provide safety of this method hydrogen is continuously removed from the reaction tank and the reaction between sodium and water instantly terminates as the solvent supply is stopped. Temperature and pressure control is performed in the reaction tank, visual control is carried out through the sight-holes.

The problems of water-vacuum washing method are the following:

a) impossibility to remove sodium from narrow gaps;

b) quantity of sodium loaded into the reaction tank should be strictly regulated;

c) presence of hydrogen in this method is potentially dangerous, however in contrast to other methods (steam-gas, water, alcohol) its danger is by some orders lower.

Conclusion

The described water-vacuum method for washing sodium contaminated equipment proved itself to be good in the course of long-term utilization in OKBM and in other Russian organizations. This method is environmentally clean and excludes alkaline corrosion of decontaminated equipment. High safety of this method is provided due to:

a) continuous removal of hydrogen from the reaction tank;

b) continuous removal of solvent and other liquid wastes from the reaction tank;

c) pressure and temperature control in the reaction tank and visual control through sight-holes.

This method of sodium-contaminated equipment washing-off is recommended for the use in BN-350 and BN-600 reactor plants.

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Change of gas mixture pressure, solvent temperature and reaction rate depending on concentration of NaOH in water

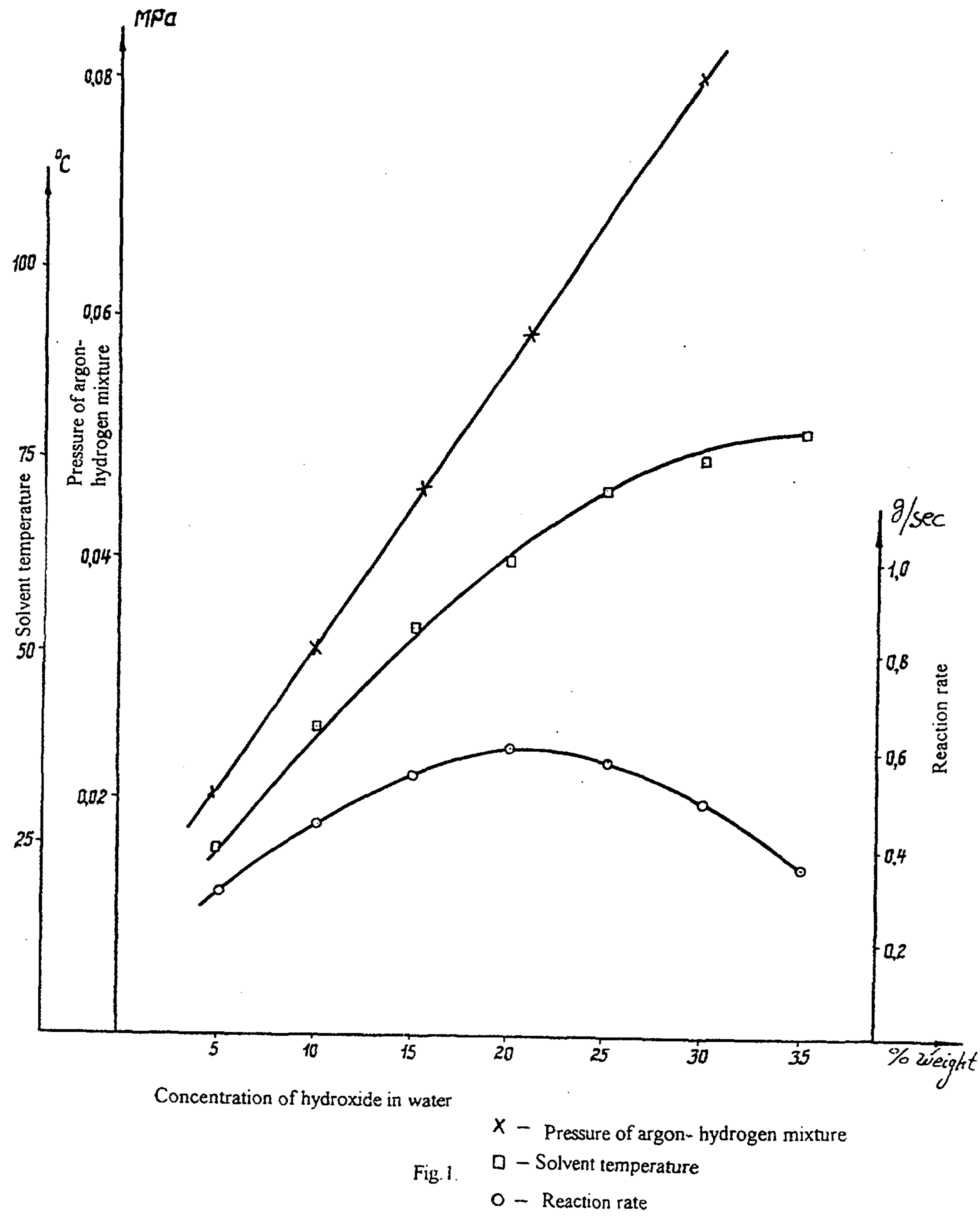
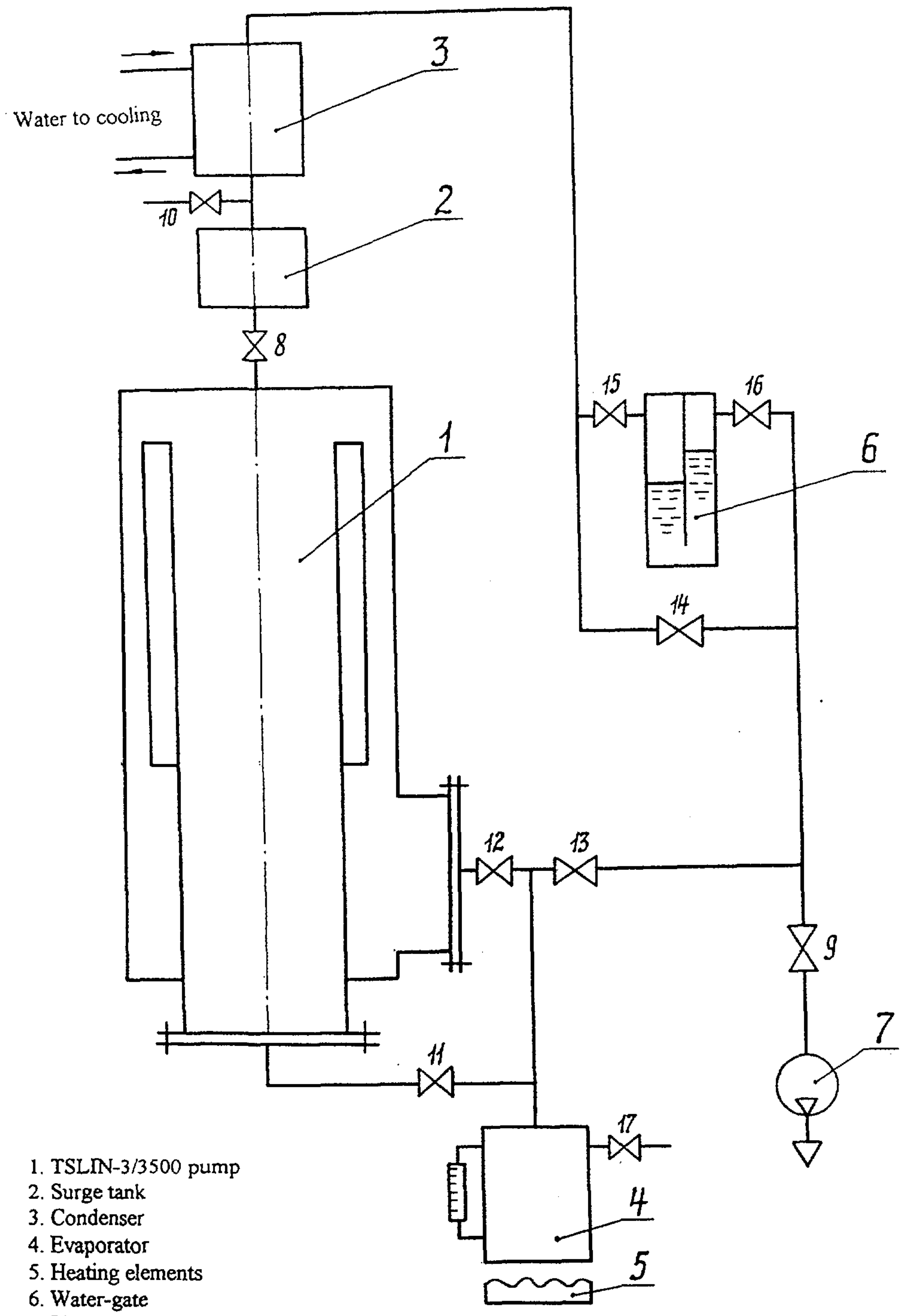


Fig. 1.

Scheme of TSLIN-3/3500 pump washing-off



1. TSLIN-3/3500 pump
2. Surge tank
3. Condenser
4. Evaporator
5. Heating elements
6. Water-gate
7. Vacuum pump
8. Valve of equivalent diameter 40
9. Vacuum seal

10-17. Valves of equivalent diameter 15

Fig.2