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USE OF DRUM FILM DEVICES IN RADIOACTIVE WASTE CONDITIONING TECHNOLOGY

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Advantages of the evaporation equipment developed on the basis of a method of evaporation of liquid from the surface of thin films in rotating drums with possibility of continuous cleaning of heating surfaces from deposits are shown. Examples of using drum film devices both for concentrating of LRW solutions and autoclaving of still residues for the purpose of thermal decomposition of ammonium nitrate in a hydrometallurgical chain of processing of nitride fuel from fast neutron reactors are given.

Key words: processing of liquid radioactive waste, conditioning, film evaporation, autoclaving, drum film devices

INTRODUCTION

So far, the common practice of radioactive waste treatment in Russia was controlled temporary storage - the so-called "procrastinated decision". In Russia, the total amount of accumulated liquid radioactive waste (hereinafter LRW) is 477 million, and 77 millions of solid radioactive waste. However, as the world and Russian practice shows, that the controlled storage of radioactive waste in the long term results their accumulation and is not acceptable as a strategy of RAW treatment. Such strategy does not lead to the final safe solution of the problem, but requires the permanent overhead costs without clear prospect [1]. Thus, high production complexes for LRW treatment are needed. Key consumers interested in of liquid radioactive waste treatment plants are:

- enterprises of spent fuel treatment;
- existing nuclear power plants with power and research reactors;
- enterprises involved to decommissioning of boats and ships with nuclear power plants;
- enterprises involved to decommissioning of nuclear power plants and research reactor installations;
- enterprises involved in the liquidation of the consequences of nuclear accidents (Chernobyl, Fukushima , etc.).

Nowadays, mainly thermal and sorption methods are used for treatment of liquid radioactive waste. Using these methods, the main part of liquid radioactive waste, produced during the operation of nuclear installations of various purposes and other facilities using radioactive substances, is treated. These methods cannot be called original or specific for the treatment of radioactive waste (hereinafter RAW), because they were taken from various conventional industries and modified. Mainly these are methods, usually used in purification, treatment and desalination of water.

For implementing of treatment methods of non-nuclear industry and their modification, the specific requirements of industries related to radiation must be taken into account [2]:

- leak tightness of the equipment, excluding the possibility of radioactive contamination of buildings, staff and the environment;

- feasibility of the equipment operation to minimize the need for maintenance services in the radiation conditions, which require complicated and expensive works of equipment decontamination.

The most universal method for treatment of almost all types of LRW is a thermal method, in which LRW solution is evaporated to concentrate radioactive products in a small volume.

Practice of LRW treatment shows that the main source of problems in evaporation equipment are the heat exchange pipes. During the operation, their surface is covering inevitably by sediments, which have to be removed periodically by chemical washing, with interruption of the treatment process and at the same time with producing a large amount of secondary LRW. This inevitability is caused by evaporator's design including heat exchange tubes - the process of sedimentation of the tubes cannot be prevented, it can only be decreased by using different methods: increasing the circulation velocity in heat exchange tubes or addition of special chemicals additives. The inevitability of foam-and-droplets entrainment from the evaporator is also caused by its design, so the additional special equipment have to be used for steam and condensate purification from radionuclides. Moreover, it is necessary to perform periodically the mechanical cleaning of heat exchange tubes which leads to important radiation doses to personnel.

All these problems existing in LRW evaporation technology are well known and studied, and some alternative methods are considered in [2], but it is concluded that these methods have a low productivity and heat transfer because of the lack of an organized circulation of evaporated solution [2].

The ideal comprehensive solution of the problem of LRW treatment is to create a continuous LRW evaporation technology with cementation of the concentrate at the same time, and the possible addition of used sorbents and sludge to the resulting cement compound. The main factor limiting the use of evaporation technology is a high energy costs, but with the appearance at energy market such installations as E-Cat, this problem disappears.

For comprehensive solution of the problems of LRW concentration and its subsequent cementation it is proposed to establish a technological process based on the two following principles:

1. To perform the process of LRW concentration in the evaporator equipment, that helps to prevent droplet entrainment and excludes degradation of technological parameters in time (to exclude interruptions in work of evaporation equipment due to fouling of the heating surface).
2. To make the processes of evaporation (secondary evaporation) and conditioning of LRW (inclusion in cement matrix) sequental and continuous, thereby eliminating the need for a large number of intermediate containers and dosing of separate portions.

USING OF DRUM FILM EVAPORATORS FOR LRW TREATMENT

Implementing the principles outlined above for LRW treatment, it is required to assure constant technological parameters of evaporation equipment, including heat transfer through the heating surfaces. Thus, it is necessary to maintain the heating surfaces of evaporator at the same state, i.e. to ensure the absence of salt deposits on heat transfer surface during the entire operating cycle. Obviously, the use of heat exchange tubes in heat exchangers cannot ensure this requirement. A device to satisfy the requirement of constant thermal resistance is, for example, the rotary evaporator, in which rotor rotates its blades inside a cylindrical shell, surface and "smears" with its blades the liquid product along the cylindrical wall. However, a disadvantage of this technical solution is the need for accurate adjustment of the mechanisms during, for example, preventative maintenance.

In the document [3] the simpler method of evaporation of liquid solutions with the possibility of continuous cleaning of heating surfaces from salt deposits is proposed, which allows designing special equipment - drum-film evaporators (hereinafter DFE) on the principles given below.

The principle of DFE operation is based on the evaporation of solvent (water) from the surface of the liquid film spreading on the inner heated surface of the rotating drum. Film evaporation process eliminates fragmentation solution by film rupture bubbles and carryover of fine droplets (aerosol), together with steam in a condensation unit, which ensures a high degree of purification of condensate of secondary vapor from inclusions of radioactive salts.

The physical principles of operation of such installations are well known on example of rotary evaporators commonly used as laboratory equipment. The most significant difference of DFE from rotary evaporators is that the process in it can be continuous, and the cleaning of the surface is proceeding directly while operation.

DFE construction can vary significantly depending on the heating method, capacity, requirements for the tightness, secondary vapor condensation method, steps number, etc.

Figure 1 shows a schematic diagram of the evaporation treatment of liquid radioactive waste in a DFE

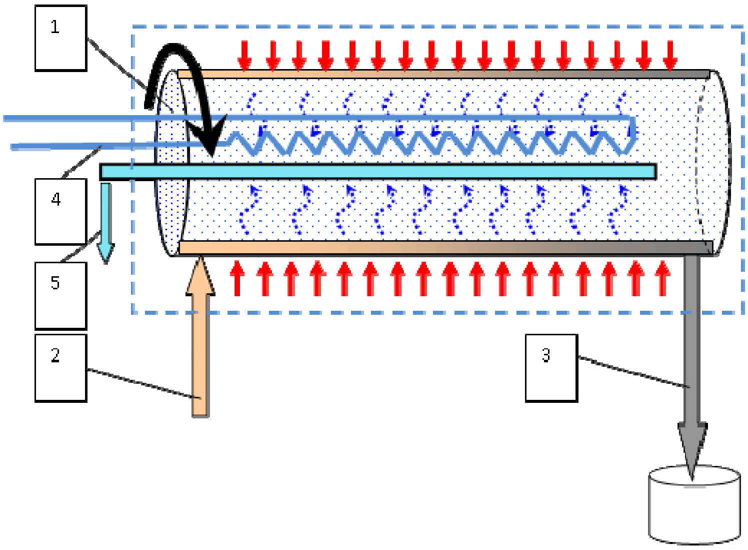

Figure 1. Diagram of the evaporation treatment of the liquid radioactive waste in the DFE: 1 - drum evaporator; 2 - supply of initial solution; 3 - discharge of the concentrate; 4 - secondary steam condensation circuit; 5 – secondary steam condensate discharge

In the illustrated case, the secondary steam condenses immediately inside the rotary drum and the condensate is discharged through a special channel.

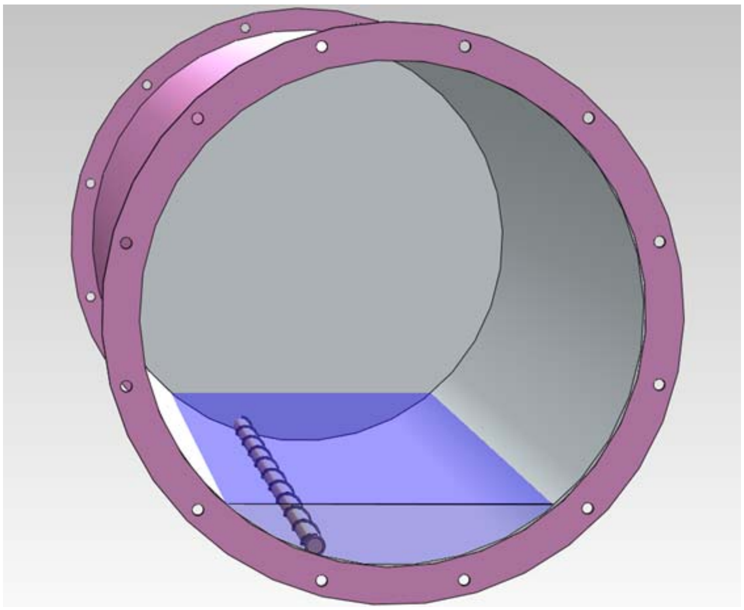

Figure 2 - Example of the system of continuous cleaning of the heating surfaces from salt deposits using rolled rod with cleaning edges

The system of continuous cleaning of the heating surface from the salt deposits represents rolling rod with cleaning edges (Figure 2). It reduces operation stops for chemical cleaning equipment and thus drastically reduces the amount of secondary LRW and allows to avoid using of chemical agents. This makes DFE exceptionally economical, especially when there is a need to minimize the volume of conditioning of LRW in containers (including secondary LRW) and to reduce space for storage. Evaporation without reagents reduces the costs not only by eliminating of the purchase of chemicals, but also saves on the secondary evaporation of liquid radioactive waste and reduces the volume of the final product.

An example of DFE design with ceramic infrared heaters is shown in Figure 2. The initial solution is supplied by the tube 4 to the rotated drum 2 which is partially filled by the evaporated solution. The final product is discharging into the channel 3, which can send the concentrate directly on cementing. The heat input is provided by infrared ceramic heaters 6, disposed within the case 1. Inside the drum there is a bundle of cooling tubes 7, on which the steam is condensed. The installation with electrical heating suits very well for operation of technological process of vat residue secondary evaporation, because of the possibility to control accurately the amount of supplied energy and the evaporation degree of the product.

Absence of pumping equipment operating with LRW in conditions of ionizing radiation can significantly increase evaporation system reliability as well as to reduce radiation doses on staff. The only one element with a mechanical drive is a rotation drive of the drum-evaporator. Small size of the installation allows to make it mobile.

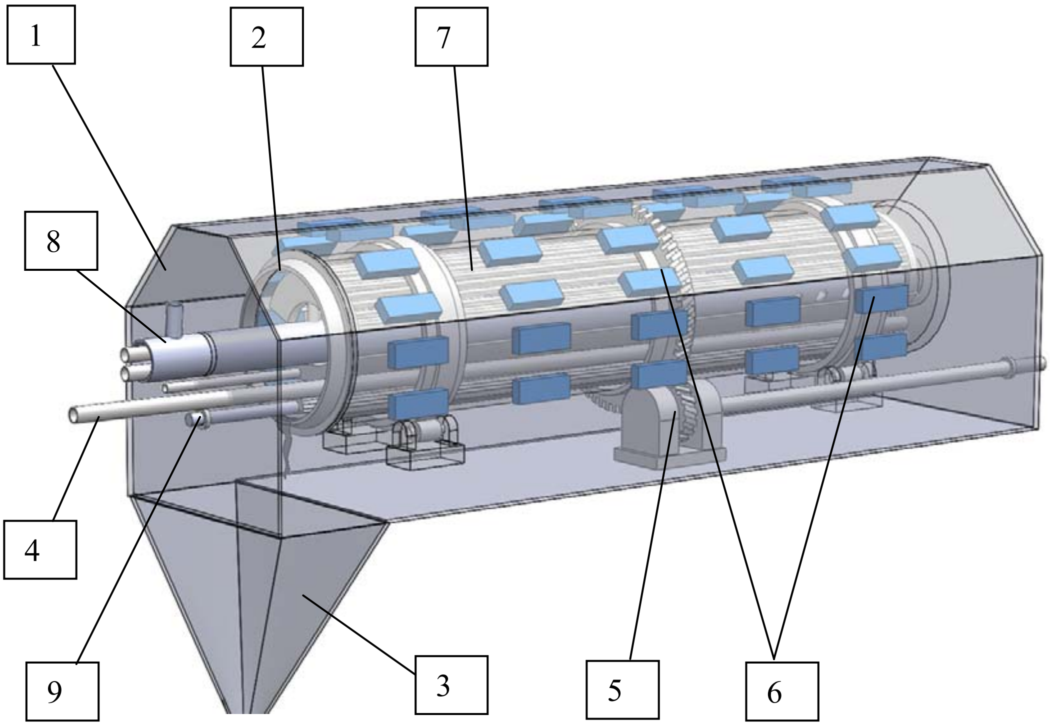

Figure 2. Scheme of the main components of drum-film evaporator:
1 - case; 2 - drum evaporator; 3 - drain channel; 4 - initial solution supply pipe; 5 - rotation drive of the drum; 6 - ceramic heaters (electric heating elements); 7 - tubes for condensed steam; 8 - central support tube; 9 - drive shaft for mechanisms of surface cleaning from sediments

For the evaporation of solutions with low salt concentration, (for example, such as service water) a three-step DFE shown in Figure 3 is the most appropriate in terms of efficiency and costs. The operation principle is based on a three-step evaporator technology, when the secondary steam produced in the first step becomes a heating steam for the next step. This allows the most efficiently using of the heat energy at maximum capacity. Moreover, the treated solution can be fixed into the cement compound right after evaporation.

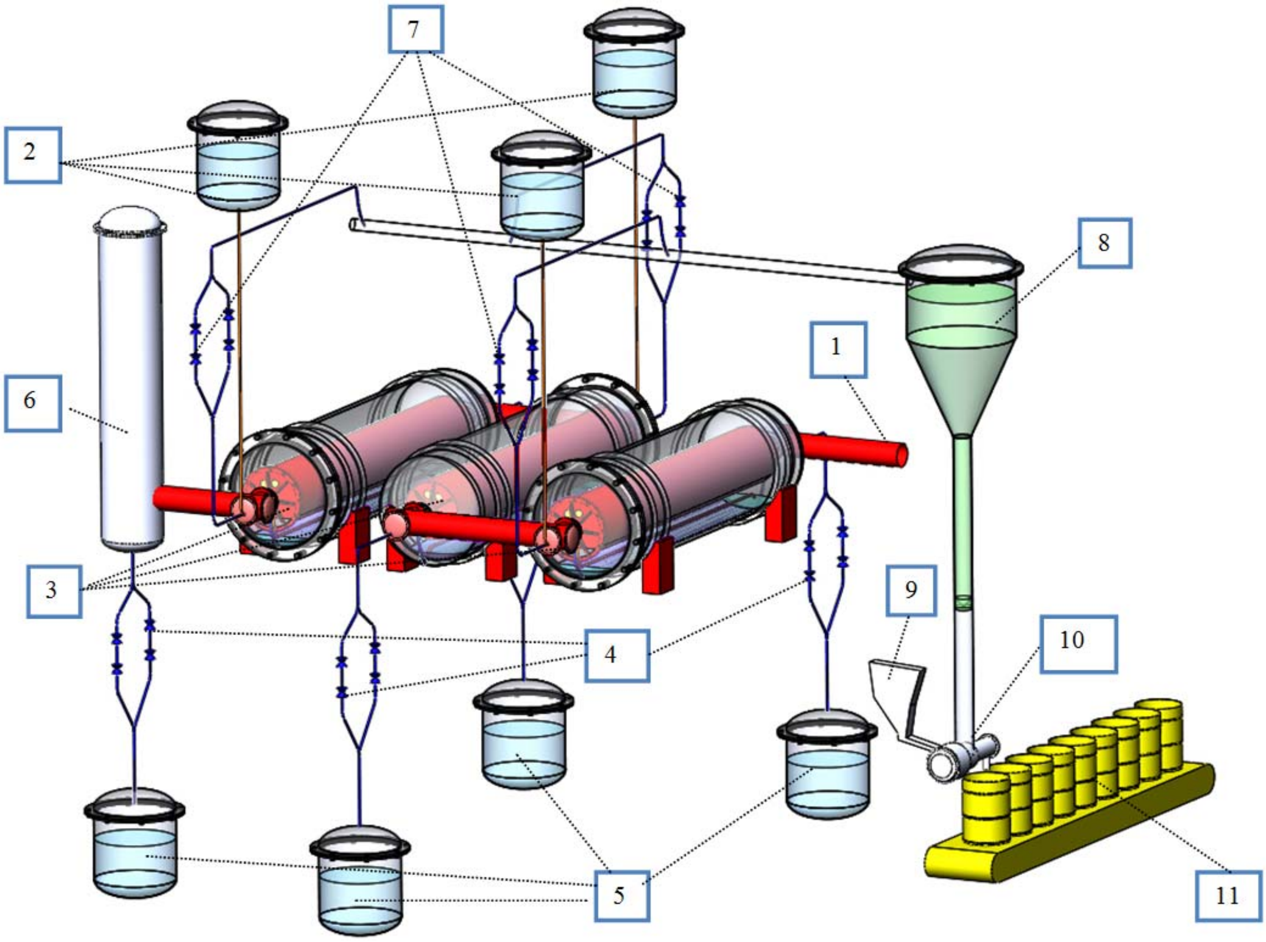

Figure 3. Scheme of a three-step DFE with secondary evaporation and steam heating:
1 - supply of heating steam; 2 – input solution tank; 3 –drum film evaporators; 4 – valves of condensate discharge; 5 – condensate collection container; 6 – condenser after the last step; 7 – valves of condensate supply; 8 – concentrate collection tank; 9 – cement mixture supply unit; 10 – cement compound preparing unit; 11 –containers filling by cement compound

The comparative characteristics of widely used installation for «deep evaporation» UGU-500, and a three-step DFE evaporator are given in Table 1.

Obviously, if the level of secondary steam purification allows using this steam for heating the next step of the evaporator, the efficiency of LRW thermal treatment will increase significantly. If also one take into account, that the cleaning of the heating surface is not required, and thus the secondary LRW are not produced, the advantages of the LRW treatment using DFE technology become even more pronounced.

Table 1

Parameter	UGU-500	Three-step DFE (3 pcs., L=6m; D=1,6m)
Capacity (initial solution), kg/h	450	1800
Heating steam pressure, relative, MPa	from 0.25 till 0.9	0.6; 0.38; 0.22
Secondary steam pressure, MPa	0.1	0.39; 0.23; 0.15
Thermal power of supplied steam, kW	320	500
Thermal power considering secondary steam, kW	-	1210
Estimated vapor decontamination factor in relation to the evaporated solution	1000	100000
Evaporation level	from 5 to 10	from 2.5 to 500
Heat transfer surface, m^2	12.4	30.2
Device mass, kg	5000	30000
Construction material	Corrosion resistant steel	Corrosion resistant steel
Medium	radioactive, corrosive	radioactive, corrosive
Dimensions H×L×W	2000×7000×2000	2200×7000×8000
Required duration of the installation continuous operation for secondary evaporation of 1000 m^3 of vat residue till melted salt, days	107	28.5
Maximum annual capacity of the initial solution treatment taking into account the required outages, m^3/year	1500	12000

Comparative characteristics of –UGU-500 and three-step DFE installation

ECONOMICAL ASPECTS OF DFE USING FOR RAW TREATMENT

Using of various technological solutions is possible for treatment and final storage of RAW. To assess the expediency of using certain technologies, as well as to optimize the entire process scheme, the authors of [4] proposed to use economic and mathematical models allowing to evaluate the operational costs of the various methods of RAW treatment as well as the feasibility of these methods.

Evaluation of optimal variants of RAW treatment can be carried out using two different parameters – minimization of the treatment cost or minimization of final volume of treated RAW [4]. To assess the technology efficiency and to choose the most optimal RAW treatment, the figures 4 and 5, which show the assessment of final RAW volume and treatment cost as a function of initial RAW volume, can be used.

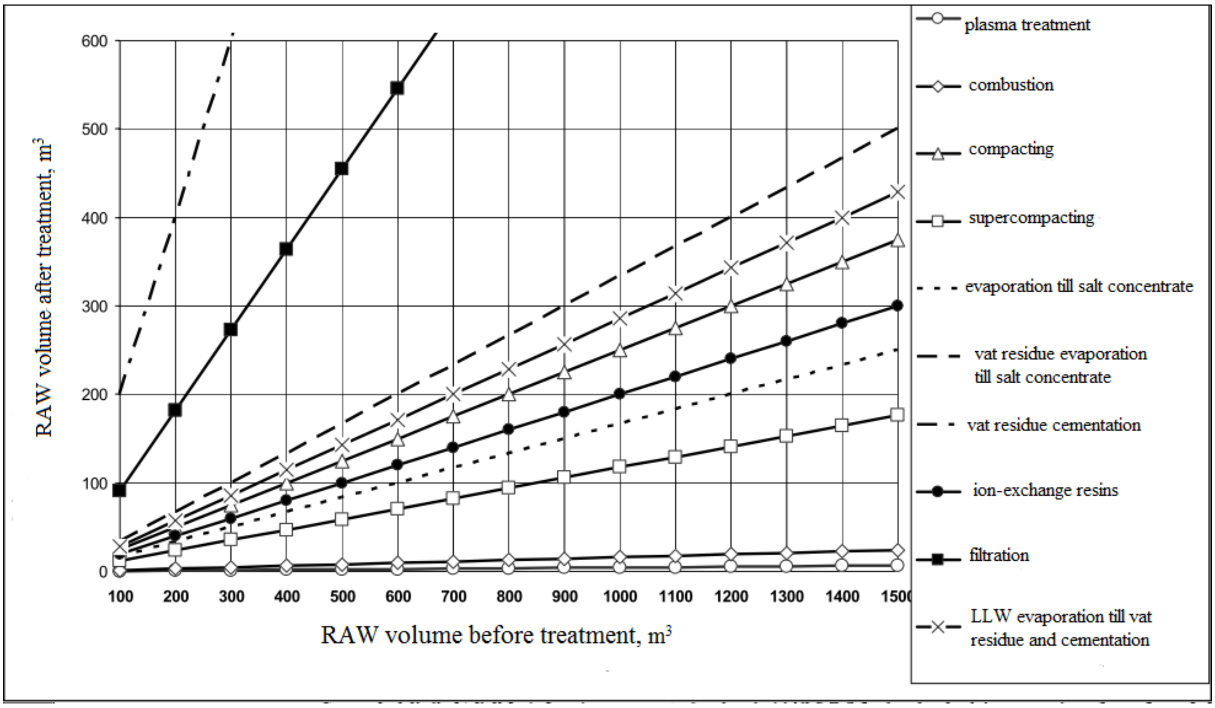

Figure 4. Assessment of the final RAW volume depending on applied technical solutions

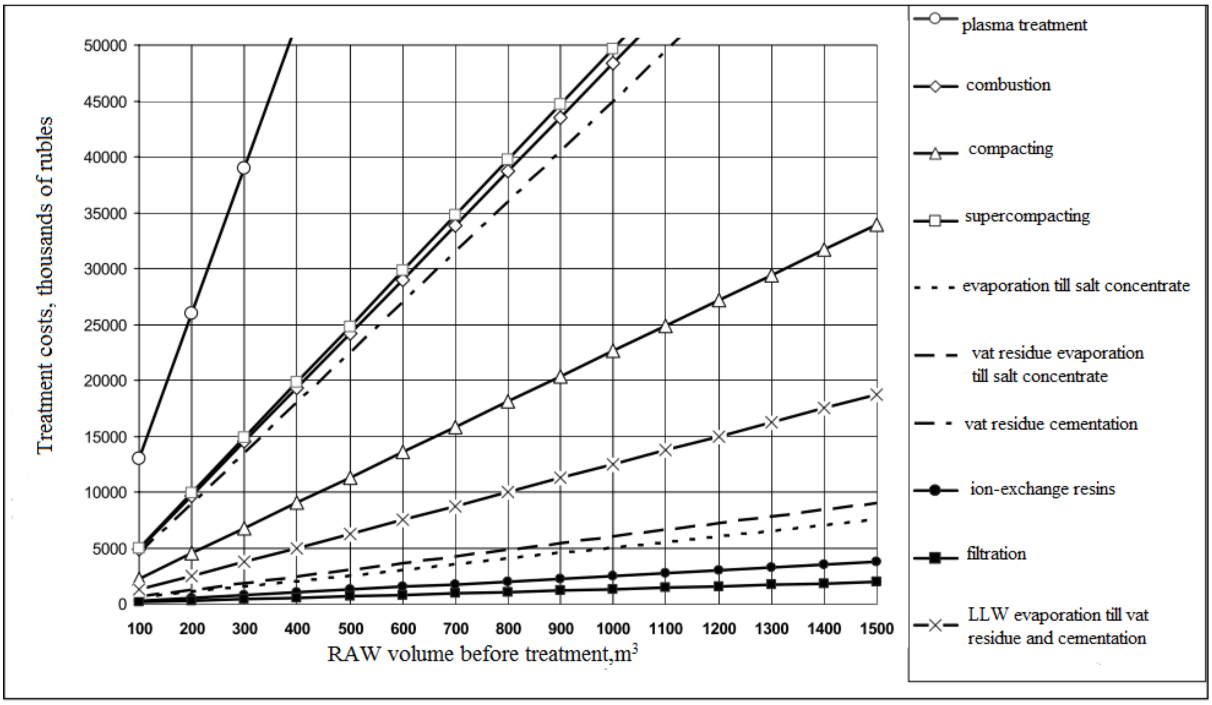

Figure 5. The cost of RAW preparing for final disposal, depending on applied technical solutions

Evaporation of vat residue until salt melts is the most advantageous treatment process both in cost and volume parameters. But this method doesn't allow to cement the RAW, which leads to restrictions for its final storage. In case of cementation of the final RAW, the secondary evaporation until 700-800 g/l before cementation is the most effective method [3].

According to the experience of UGU-500 operation, this technology doesn't allow providing salinity parameters in required range because of its design features, and using of two-step evaporators is impossible because of fouling of heat exchange tubes.

The DFE with electrical heating is the most appropriate for vat residue secondary evaporation and cementation. If we know the initial vat residue salt content and flow rate for secondary evaporation, the regulation of electrical power of heaters will easily provide the required salt concentration at DFE outlet. Maintaining the salt content in a strictly specified range of 700-800 g/l ensures a high quality of cement compound. The continuity of the process allows to use compact mixer for continuous production of the compound into the process chain (Figure 6).

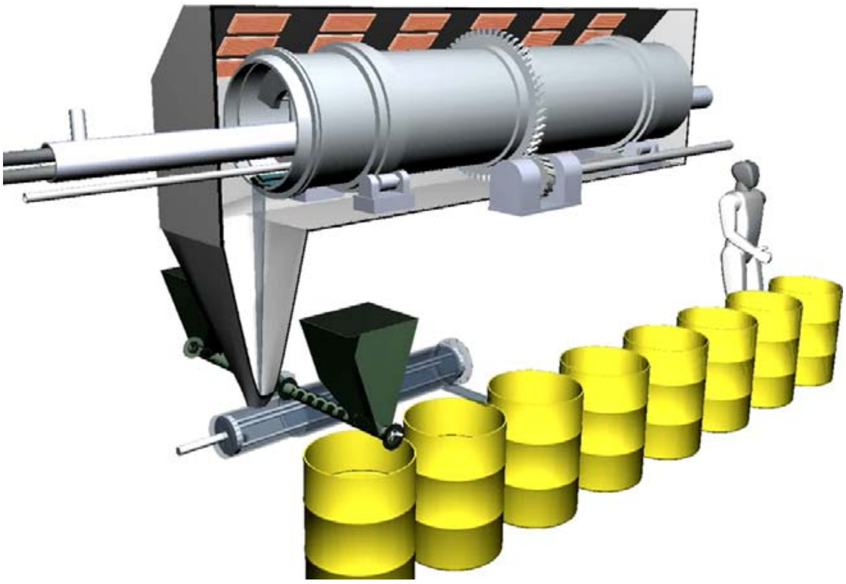

Figure 6. Continuous technological process of vat residue secondary evaporation in electrical heated DFE and concentrate conversion into cement compound

However, three-stage evaporation circuit (Figure 3) is economically more advantageous for the evaporation of large amounts of liquid radioactive waste with a low salt content (less than 50 g / l). The amount of supplied energy is reduced to 2.5 times approximately by using the energy of the secondary steam. It should be noted that the demand for the processing of low salt concentration LRW is particularly high, as this is the main type of liquid radioactive waste of medium and low activity level. The major part of operating costs for such treatment is the cost on energy supply, so the solution of the problem of input heat cost reduction will provide a cost-effective treatment of large amounts of liquid radioactive waste and inclusion to cement matrix in accordance with the IAEA.

The absence of frequent stops in the process can significantly reduce the cost of the process, the amount of secondary LRW for equipment washing, the qualification requirements for personnel, the staff quantity, as well as the radiation exposure to personnel.

Conclusion

Analysis of possibilities to use drum film evaporators, which are resistant to salt sedimentation on heated walls, revealed the following:

1. DFE with electrical heating is more rational to use for evaporation of vat residue and subsequent concentrate cementation.
2. DFE with steam heating is more rational to use by three-step scheme, when the secondary steam of one step is used as the heating steam of the next step. It allows to decrease significantly energy consumption of evaporator without decreasing its efficiency.
3. Constructive solutions of DFE allow deep evaporation of large amounts of LRW in a continuous mode with a high degree of purification of the evaporated water, and

significantly reduce the cost of installation maintenance, secondary LRW generation and radiation doses to personnel due to continuous cleaning of the drum surface.

4. Technology advantages in the evaporation of DFE in the presence of a cheap energy source, such as E-Cat, allows the treatment of large amounts of accumulated liquid radioactive waste of low and medium level of activity in accordance with the IAEA at a minimum cost of treatment for final disposal.

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