ISSN: 0975-8585

Research Journal of Pharmaceutical, Biological and Chemical Sciences

Feasibility Study on Tangential Filtering Of Process Solutions for Removal of Solid Suspended Impurities.

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ABSTRACT

Feasibility study was carried out on tangential (dynamic) filtering method of suspended impurities removal from the process solutions in the borehole underground leaching facilities. Existence of tangential component of flow velocity near the filtering surface causes sweeping of some suspended particles from the wall (filtering surface) back to the flow or to the periphery, this slowing down filter loading with the impurities and increasing lifetime of filter as purification device. It has been demonstrated that the effectiveness of this process and some limitations of its use are determined by hydrodynamics of purified liquid flowing about the flat filtering surface, characteristics of the liquid as dispersive medium and the size and density of particles to be removed. Analysis has shown that tangential filtering primarily assures removal of coarse particles ($d \geq 50$ μm).Taking into account properties of process solutions, the use of this method appears promising as applied to both product solutions reprocessing (instead of clarification in setting vessels) and desorption and regeneration of ion exchange resins in the course of cleansing solutions purification (instead of using bag filters), however, only on condition of preliminary coarsening of particles by their coagulation. Key design approaches were studied and proposed for the development of the relevant filtering equipment.

Keywords: borehole leaching solutions, purification, tangential filtering, suspension, filter, particle size.

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Review of methods of uranium containing solutions purification

Borehole technology of uranium mining with production of ammonium polyuranate implies overacidification of producing blocks in the section of product solutions upon completion of geophysical operations and borehole drilling.

As a result of acid solutions supply to the boreholes and their further pumping to the sand traps (capacity up to 100 m^3/hour), slurry and sand are removed from the solutions [4].

Sedimentation purification is time consuming process, this influencing performance of uranium mining facility. In the product solutions there are mainly coarse solid particles (d ≥ 50 μm) with their concentration of ~ 50 g/m^3 and higher, and so it seems viable to study the possibility of using an alternative purification method based on dynamic filtering. This means that tangential stream is formed in addition to the frontal stream on the filtering surface, thus enabling hydrodynamic "self-cleaning" of the filtering surface owing to sweep of the better part of particles back to the flow and/or to the peripheral area followed by their capture by the filter gravity trap. Hence the continuous operation time of the filter to its plugging increases. As a result, conditions can be provided for acceleration of preliminary purification of the product solutions to prepare them for the further reprocessing [7].

Cleansing solutions used in the stage of desorption in sorption columns (ion-exchange resins) upon completion of product solutions purification within the framework of borehole uranium mining technology are also to be filtered. Upon reaching maximum sorbent saturation with ammonium polyuranates and carrying out further procedure of desorption and regeneration of ion-exchange resin in order to remove slurry (clay) from it, bag filters are now used for purification of cleansing solutions from suspensions. However these filters are rather rapidly loaded with the small particles, thus requiring their frequent replacement and related manual work. It should be also noted that there is a lack of knowledge about concentration and particle size distribution of solid impurities in cleansing solutions. According to preliminary evaluations by the experts, these solutions mainly contain colloidal size particles with concentration up to ~2 mg/L [14].

In this colloidal system, which is thermodynamically unstable, coarsening of particles may occur because of their coagulation under certain conditions. Apparently, in case of tangential filtering application, the stage of coarsening of colloidal particles is necessary.

Joint Stock Company – State Scientific Center of the Russian Federation – Institute for Physics and Power Engineering named after A.I. Leypunsky (JSC "SSC RF – IPPE") is one of those organizations, which were the pioneers in the development and broad-scale introduction of method of tangential filtering for removal of suspensions from liquid disperse systems. In the middle of 1990-ies, specialists of the Institute created a series of tangential filters [16] as applied to the purification of the liquid foodstuff, which have found their demand on both domestic and foreign market to the present day. For instance, based on the results of studies, FM, F-01,

F-01M, F-03, FN-35 and other filters have been created, which have a great run.

Effective operation of this system requires appropriate value of liquid flow tangential velocity along the membrane (meshwork) surface determining laminar sublayer thickness and its ratio to the size of particles suspended in the flow. Besides, optimum ratio between the above tangential velocity and frontal velocity, i.e. filter capacity is required. In this view, technics and computer codes had to be developed for carrying out "computational experiment" for chosen filter design and conditions of liquid flow in this filter, and obtaining the results showing effectiveness of specific design [2].

Since there is a lack of knowledge about particle size distribution in uranium-bearing solutions and suspensions concentration for the two types of filtering, analytical study was carried out using special code as applied to specific conditions. These conditions concerned size and density of particles, as well as hydrodynamics of liquid flowing about filtering surface for determining the minimum size of particles, which could be swept from this surface by the tangential flow. Analysis was focused on the movement of solid particles of various density, their size not exceeding laminar sublayer thickness, however, being larger than min size of pores of the filtering surface (particles having diameter larger than laminar sublayer thickness value were disregarded for evident reason). Issue of particle size and disperse medium properties effect on particles behavior in laminar sublayer is discussed in detail in [10].

Based on examples given in [10] and results of calculation, conclusion was made on that only relatively large particles (>50 μm) follow "hydrodynamic" filtering laws, while vector of movement of small particles (≤10 μm) practically coincides with the flowline of carrying medium.

Selection of pumping equipment and necessity to assure optimum hydraulic mode in the filtering system are important factors of creation of the system with frontal-tangential flow. Indeed, low flow velocity and high pressure drop on the filtering element are conditions of the frontal filtering mode. It was shown that in case of absence of frontal velocity, particles were thrown back to the flow core more intensively than in case when frontal velocity exists. Moreover, if the frontal velocity value is significant, then particle could reach filtering surface. In [4], there is also detailed analysis of the issue of optimum relationship of frontal and tangential velocity components and recommendations are made on choosing these components.

Design approaches to purification systems

Taking into account information presented in [10], a series of tangential filters was designed for purification of solutions in the various process stages including those of borehole uranium mining technology.

System of solid suspensions removal from solutions in the stage of overacidification of producing blocks

Fig. 1 shows one of the modules of preliminary purification of liquids, including product solutions [9], its functional principle being described below. Liquid with the impurities enters the upper section of the vessel through the inlet nozzle and flows to the channel formed by the cover and filtering element (mesh with 0.063 mm cells). Liquid flow is distributed over the filtering surface. Flow velocity in the channel has tangential and frontal vector components. Tangential velocity component assures sweeping of the coarse suspension particles from the central section of filtering element to its periphery and accumulation of particles in the lower section of the vessel. In addition, conditions are created for the filtering of liquid owing to the frontal velocity component, as well as for self-cleaning of the filtering surface by means of tangential flow present on significant part of this surface.

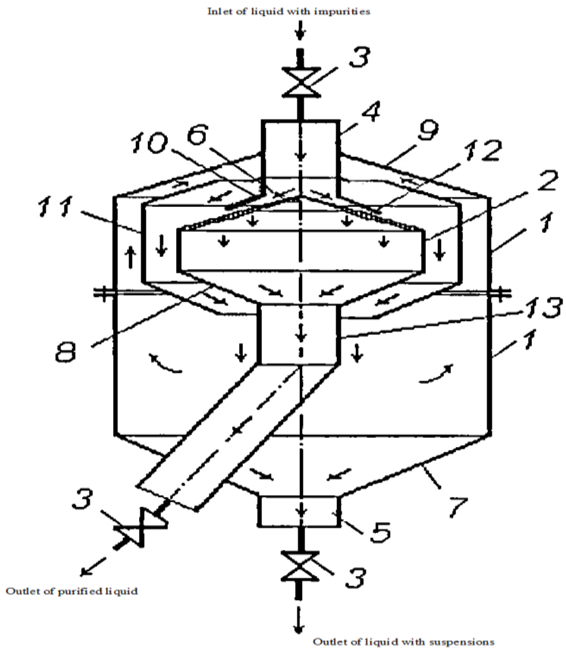

Figure 1: Module for preliminary purification of liquids

1 - vessel sidewall; 2 - collecting chamber sidewall; 3 - valve; 4 - inlet nozzle; 5 - outlet nozzle; 6 - baffle; 7 - vessel bottom; 8 - collecting chamber bottom; 9 - cover; 10 - pilot insert; 11- sectionalizer; 12 - filtering element; 13 - central tube.

Liquid purified by the filtering element enters collecting chamber, then flows to the central tube and leaves the module; the other part of liquid flow bearing large size particles enters the lower section of the vessel. Liquid is partially accumulated at the vessel bottom, while the liquid flow changes its direction moving along the sidewall of the vessel and reaching the space between the upper part of sectionalizer and peripheral section of filtering element. Thus, existence of the inner recirculation of the liquid in the flow channel of the module is an attribute of this design. Closed flow circuit facilitates additional purification of liquid, i.e. removal of coarse particles, resulting in the increase of suspensions concentration in the gravity trap in the lower section of the vessel.

It should be noted that liquid flow in the closed circuit is assured by the pressure drop in this circuit owing to the low static pressure in the space between the pilot insert and filtering element caused by high velocity of liquid flowing in this space [3].

In order to check module's availability, its full-scale test was carried out using natural water containing solid suspension particles of size within 200 μm. Water temperature was 20 ^{o}C and pressure at the inlet nozzle was 0.4 MPa. Water flow rate in the inlet nozzle was 1.0 m^3/hour. Effectiveness of the module in terms of suspension removal was 90.0 % with filtering rate equal to 50 μm.

System of solid suspensions removal from solutions in the stage of cleansing solution desorption

In view of uncertainty of particle size distribution in the cleansing solution, it is necessary to carry out preliminary study concerning choice of purification method as a function of the main characteristics of disperse system. If rather large particles (d > 30-50 μm) predominate in the liquid solution (this, presumably, corresponding to the product solution conditions), then, according to Stockes law, these particles can be easily removed by either sedimentation (in case of high particles concentration), or microfiltering (if particles concentration is comparatively low) [5].

As it has been mentioned above, data on concentration of particles and their size distribution in the cleansing solution is rather uncertain. Apparently, there is colloidal state of fine particles. One can assume particles size to be about d < 1.0 μm, and they can be removed by microfiltering causing relatively rapid plugging of the small pores of filtering membrane [15].

In Fig. 2 presented are the areas of application of various methods of particles removal from liquid disperse medium depending on particles diameter (μm) and their concentration (1/ cm^3) [6]. If the cleansing solution is thermodynamically stable as colloidal system, then coagulation-averse particles existing in this system determine lifetime of the filtering element to its max loading with the impurities.

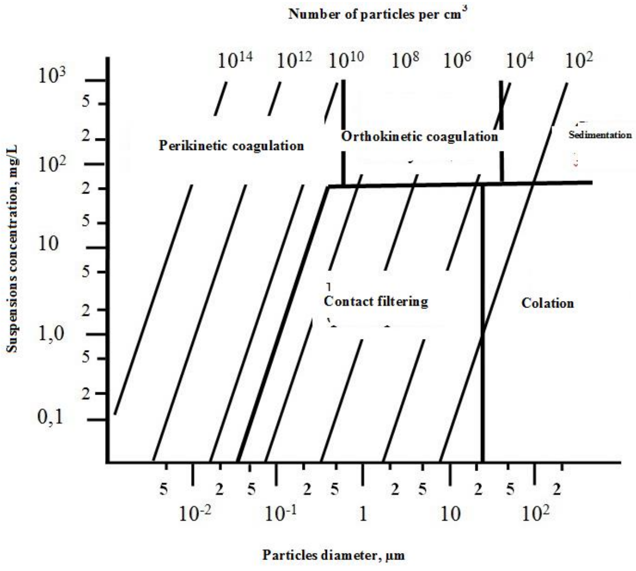

Figure 2: Areas of application of various methods of particles removal from liquids

In thermodynamically unstable colloidal system, there are conditions for growth of small size particles and further setting-out of solution during moderate time. However, this is only possible if particles concentration is sufficiently high to assure significant probability of their mutual contacts. This is especially important for disperse system with small colloidal particles (d <1.0 µm) in case of perikinetic coagulation, i.e. when contacts between particles mainly occur owing to Brownian motion (diffusion). In this case, the rate of particles concentration decrease is determined by the following relationship from [6]:

$$-\frac{dn}{dt} = (4\alpha kT/3\mu)n^2, \qquad (1)$$

where n – particles concentration (1/cm^3); t – time; α – collision effectiveness factor showing physical and chemical characteristics of particles; T – absolute temperature; μ – viscosity of liquid; k – Boltzmann's constant.

It follows from relationship (1) that time of stable concentration of particles is high (t > 1 hour) even with $\alpha = 1$, if this concentration is lower than 10^9 particles/cm^3. Under these conditions, the number of collisions between particles is low. In this case, only contact filtering can provide sufficient probability of contact (with $n < 10^9$ particles/cm^3), however on condition of significant thickness of filtering layer if, for instance, granulated filling is used as filtering material. If surface filter is used with frontal liquid flow, the problem arises concerning the necessity of frequent replacements of filtering element or its regeneration.

For the large size particles (d > 1.0 µm), attractive force increases the probability of contact between particles, i.e. orthokinetic coagulation takes place (see Fig. 2) with kinetic decrease of particles concentration in the liquid volume according to the following relationship taken from [6]:

$$-\frac{dn}{dt} = (\frac{4}{\pi})\alpha \cdot G \cdot n, \qquad (2)$$

where G – parameter (time^{-1}) characterizing frequency of realization of contacts between particles in the course of mass transfer (increases with the increase of mixing rate); the other designations – see those for relationship (1).

Relatively large particles are easily removed by frontal filtration, however because of concentration of captured particles in the area near the filtering surface the lifetime of this filter is limited. If suspended particles concentration is over 50 mg/L, then orthokinetic coagulation followed by sedimentation or clarification in suspended layer is more appropriate option. However the very sedimentation process is rather time-consuming, this being inadmissible for majority of technologies including ammonium polyuranate production. So, within the framework of adopted approach to the removal of suspended finely-dispersed impurities from colloidal solutions (even with high concentration of the impurities when coagulation is possible followed by sedimentation), filtering is an optimum option. However, for instance, bag filters assuring high purification effectiveness are rapidly plugged with suspensions thus requiring frequent replacements and considerable manual work.

In this view, it seems viable to study the possibility of using an alternative approach to purification of cleansing solutions in the stages of desorption and regeneration of ion-exchange resin. This method implies the following two steps:

1) preliminary coarsening of particles in the solution followed by their removal by tangential filter; this coarsening can be achieved by dosed supply of coagulant to the reactor vessel ($\alpha \rightarrow 1$) and solution mixing (G) – see relationship (2);
2) purification phase: filtering of solution by plasma-chemical nanostructured membrane filtering elements [12] with required fineness and the possibility of repeated regeneration of filters by the reverse flow of treated medium.

So, the system of filters connected in parallel for purification of cleansing solutions in the stages of desorption and regeneration of ion-exchange resin is capable of assuring required capacity and filtering rate (to 3 µm), as well as filter regeneration assuming no interruption of desorption purification of solution [8].

It should be noted that owing to positive experience gained in regenerating membrane filters after plugging with colloidal particles of micrometer and smaller size (clay particles), stage of preliminary coarsening of colloidal particles followed by tangential filtering can be eliminated. Everything hangs on the real concentration of colloidal particles in solution: if the concentration is high, then plugging of filtering elements occurs requiring frequent regeneration cycles. In this case, preliminary coarsening of particles in solution and their filtering mentioned above is viable [13].

In contrast to the bag filters, membrane filtering elements being nonexpendable material do not require manual work attributed to their cleaning etc., and, hence, these can be considered as an alternative means for purification of cleansing solutions in the up-to-date borehole uranium mining technology.

Work package was performed at the JSC "SSC RF – IPPE" on creation of filtering elements with nanostructured membranes and filters based on these membranes for highly effective systems of purification of various application liquids [11]. The basic advantages of filtering elements with nanostructured membranes include assurance of removal of impurities of over 0.2 µm size with at least 99 % effectiveness and the possibility of carrying out over 1000 regeneration cycles using neither chemical agents, nor filter dismantling.

Filtering system based on the above plasma-chemical nanostructured membrane filtering elements (Figs. 3 and 4) assuring required system capacity, effectiveness and filtering rate (within 3 µm), as well as the possibility of its regeneration by reverse liquid flow is recommended for purification of cleansing solutions in the stage of ion-exchange resin desorption and regeneration [1].

In order to assure required liquid flow rate, several packages of MSF-5.0 membrane modules are connected in parallel, each of them including 30 filtering elements and having 5 m^3/hour capacity.

To assure continuous operation of cleansing solutions purification system while filters package (3 pieces) is regenerated by the reverse liquid flow, it is expedient to put into operation the backup unit also consisting of three filter packages.

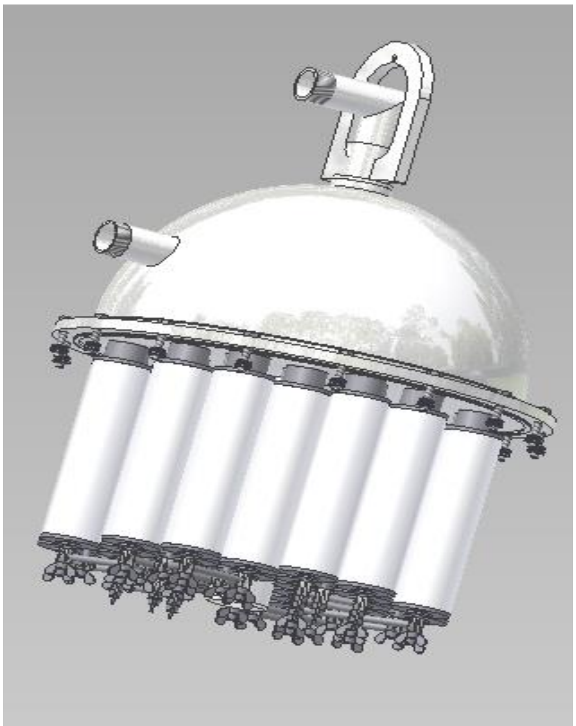

Figure 3: Cartridges of MSF-5.0 membrane module

Figure 4: MSF-5.0 membrane module

As it was mentioned above, if concentration of colloidal particles in the cleansing solution is high, it is reasonable to provide preliminary purification stage including particles coarsening by their coagulation followed by removal of large size particles (d >10÷50 µm) by tangential filter [9].

CONCLUSION

- Presence of tangential flow at the filtering surface perpendicular to the flow going through this surface, assures microfiltering effect with simultaneous particles sweeping from the surface, this in large increasing filtering device lifetime (operation time to replacement or cleaning of filtering unit). Min size of particles removed from the surface is comparable with hydrodynamic laminar layer thickness and equal to ~10 µm. Particle with diameter d > 50 µm are most effectively removed.
- Fundamental design approaches are represented, which are recommended for application in the stage of designing filtering equipment for purification of product solutions (suspensions concentration up to 50 mg/L) and cleansing solutions. Proposed design option and recommendations are based on the experience gained in carrying out earlier similar developments at the JSC "SSC RF – IPPE", as well as on commercial operating experience of these purification devices.
- In view of high degree of dispersion and concentration of suspensions in the cleansing solutions, as well as exclusive requirements to their purification effectiveness, it is proposed to use filtering elements with nanostructured membranes. These filtering elements assure required effectiveness

and rate of filtering, as well as the possibility of filter regeneration by the reverse liquid flow. Preliminary purification stage provided as the backup option is implemented using the following equipment:

- Unit for coarsening of the impurities based on adding coagulating (flocculation) agent to the liquid flow or the use of electroflotation device;
- Tangential filter for removal and capture of coarsened particles provided upstream membrane filter used for the final purification of the liquid.

Acknowledgment

Studies were carried out within the framework of Agreement No.14.625.21.0001 of 21.08.2014 between the Ministry of Education and Science of the Russian Federation and JSC ñSSC RF ï IPPEò(unique identifier of the project is RFMEF162514X0001).

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