

# Development of Sorption Technology Leaching of Gold-Containing Ores to Reduce Slip and Loss of Gold with Tails

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**Abstract**— When analyzing the current technological schemes of sorption leaching of gold, it was found that the main losses of saturated resin occur in the dispensing unit from the mole for regeneration, and the sources of losses are chips and jigging sands. To reduce these losses, it is proposed to carry out additional flotation of saturated resin, both from the pulp of sorption leaching, and from chips and from jigging sands separated in the resin dispensing unit for regeneration. The optimal technological parameters for obtaining saturated resin from wood chips and jigging sands isolated in the resin dispensing unit for regeneration have been determined, which include: flotation mode (conditions, duration ) of saturated resin contained in wood chips and jigging sands; collector flow rate and depressant flow rate for efficient flotation of rich resin. Cyanidation and sorption leaching of gold sorption leaching tailings were carried out under laboratory conditions. Gold recovery was 65%, which is an encouraging figure.

**Keywords**— gold, extraction, sorption, tank, metal-loss.

## 1. INTRODUCTION

One of the problems of gold recovery plants operating according to the sorption leaching scheme is the loss of gold-saturated resin with process waste. Resin losses during sorption leaching are divided into “external” (in the form of tar and its fragments in tailings) and “internal” (with sand sent for regrinding and with wood chips sent for burning) [1].

According to the current technology of sorption leaching using ion exchangers, saturated resin from the first tank is continuously fed to the drum screen of the resin dispensing unit for regeneration to wash off the pulp. The pulp after separation returns to the sorption tank. The crude resin is separated from coarse sands in jigging machines. Jigging sands (jigging concentrate) are sent for grinding. The resin enters the wood chip screen, where the wood chips, under the action of the rotational-translational movement of the screen spiral, move to the discharge funnel, fall into the container, then are sent for drying and incineration (Fig.1.). The oversize product is chips, the undersize product is saturated resin, which is supplied for desorption (regeneration) [2].

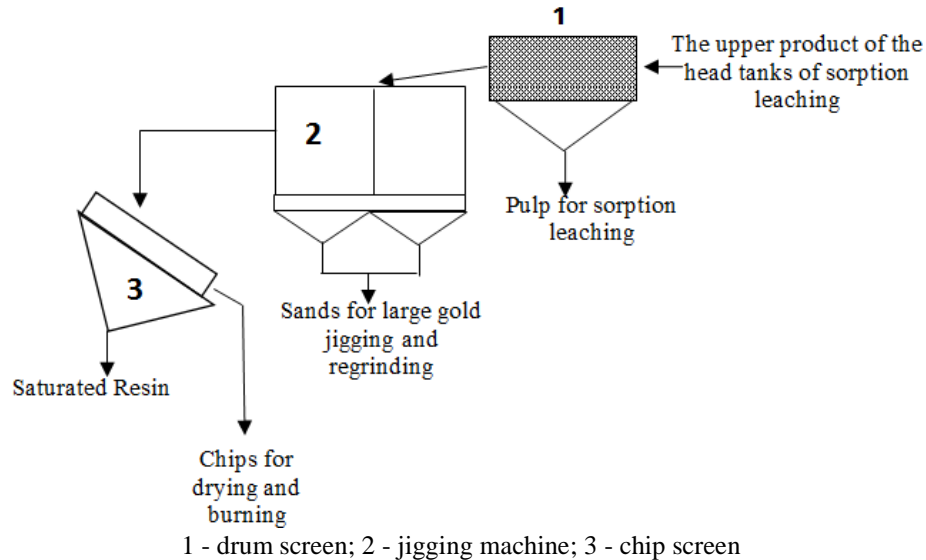
However, the use of jigging and chip separation operations in the resin dispensing unit for regeneration does not allow complete extraction of saturated resin from sands and chips [3].

Resin saturated with gold gets entangled in wood chips, which are burned together with it. In the sands of jigging, mainly fragments are concentrated resins, which are sent together with sands for regrinding. In this case, the loss of expensive ion-exchange material occurs [4].

The problem of small chips was faced even at the beginning of the development of sorption technology for the extraction of uranium at the Hydrometallurgical Plant - 1 (HMP-1) of the Navoi Mining and Metallurgical Combine. Chips entered the processing chain with ore from mines where timber structures were used as fasteners [5]. Previously, chips were separated in the mill department on drum screens with a grid with a cell installed on them. 5 mm, however, small chips passed through the cells of the grid. Small chips from the head sorption pack, together with the ion exchanger, were pumped out into the washing columns, from which they were carried out by an ascending water flow [6]. The separation of the ionite from the chips was organized as follows: the flow of water with the chips from the columns was directed to the concentration tables. Ionite, having a greater specific gravity than wood chips, was concentrated between wood and table corrugations and then returned to the technological process. Small chips were washed away by the stream of water and dumped into the tailing dump [7].

Chips and sands of jigging isolated in the resin dispensing unit on regeneration, are not only the main sources of ion exchange resin losses, but also have a negative impact on the technological indicators of gold recovery [8-12]:

- wood chips absorb gold-bearing solutions, cause increased consumption of reagents for resin regeneration operations, clog mesh drainages of sorption packs;
- coarse sand of class + 0,15 mm, settling in tanks, reduces their working volume, as a result of which the duration of cyanidation and sorption leaching processes required by the technological regulations is not maintained, the abrasiveness of the pulp increases, as a result of which the mechanical wear of the ion-exchange resin and equipment increases.



**Fig.1. Scheme of the circuit of the apparatuses of the resin dispensing unit for regeneration**

Until now, the problem of obtaining (separating) a saturated resin from gold sorption leaching waste (chips and sands of jigging) has not been studied in detail, however, in the scientific literature there are studies on the possibility of isolating ion-exchange resins from pulps using flotation, which can also be used to isolate resins from wood chips and jigging sands separated in the resin dispensing unit for regeneration [13].

In this regard, the development of methods for isolating saturated resin from the waste of the resin dispensing unit for regeneration (chips and sands of jigging), the selection of appropriate flotation reagents, the development of optimal technological parameters for the most complete extraction of saturated resin from the waste of the resin dispensing unit for regeneration, the study of additional extraction of gold from tailings sorption leaching are of certain scientific and practical interest in terms of reducing the cost of finished products [14].

The purpose of this dissertation is to develop an effective technology of sorption leaching, including the reduction of irretrievable losses of imported ion-exchange resin and additional recovery of gold from sorption leaching tailings [15].

Within the framework of this goal, the following scientific and technical tasks were solved [17-19]:

- An analytical review of information obtained from the patent and scientific and technical literature in the field of sorption leaching of gold in order to eliminate irretrievable losses of saturated resin and additional extraction of gold from sorption leaching tailings, industrial experience in this direction was analyzed and summarized, which made it possible to justify the choice of research direction;
- Physical and chemical studies of the starting materials (chips and sands of jigging, separated in the resin dispensing unit for regeneration, anion-exchange resin, sorption leaching tailings) were carried out;
- The technological schemes of sorption leaching of gold were analyzed in order to identify the main sources of loss of saturated resin;
- Methods for additional extraction of gold from sorption leaching tailings were investigated.

## 2. MATERIALS AND METHODS

Analysis of various products of sorption leaching showed that saturated resin is mainly lost with saturated resin jigging sands and with chips isolated on chip screens in the resin dispensing unit for regeneration, which served as the objects of research.

OF ion-exchange materials, an anion-exchange resin of the AM-2B brand was used, which is used for the sorption of precious metals from cyanide solutions at the gold recovery plants of the Navoi Mining and Metallurgical Combine.

The presence of chips in the process of sorption leaching is due to the content of vegetable products in the processed ores: wood, tree roots, parts of wooden structures used as supports in mines and mines, etc.

Chips have a negative impact on the technological performance of sorption leaching, because. causes an increase in the cost of reagents for resin regeneration operations, clogs drains and absorbs gold-containing solutions.

In addition, fine chips are in the form of fibers capable of being bundled into balls, like mineral wool, in which the saturated resin is entangled and does not separate into a separate product during the chip separation operation.

The results of studies on the distribution of chips in various classes and the content of saturated resin in them are presented in Table 1.

**Table 1. The distribution of chips in different classes and the content of saturated resin in it**

Class, mm	Mass fraction, %	Saturated resin content, %	Saturated resin distribution, %
+3	48.08	-	-
-3+1.72	6.41	3.05	1.75
-1.72	45.51	24.15	98.25
Total	100	11.2	100

Taking into account that the main amount of saturated resin is concentrated in class -1,72 mm, this class was accepted as an object of flotation with subsequent recleaning of flotation concentrates on a micropanner (a kind of concentration table).

Photos of wood chips of various classes highlighted in the issuing node resins for regeneration are shown in Fig.1 a, b, c.

Grade coarse sand +0,15 mm in the sorption leaching slurry mainly consists of waste rock and iron scrap generated by abrasion of mill balls. With the counterflow of pulp and resin, sands accumulate in the first and second tanks of the cascade together with saturated resin, reducing their working volume, as a result of which the duration of cyanidation and sorption leaching processes required by the technological regulations is not maintained.



a - class + 3 mm; b - class -3 mm; in - class - 1.72 mm

**Fig.1. Photo of wood chips**

Iron scraps, being abrasive particles, intensively abrade the saturated resin. In this case, mechanical wear of the resin and equipment occurs. For this reason, the sands are separated from the saturated resin by jigging, which are then sent for regrinding. During the jigging process, it is not possible to achieve complete separation of the saturated resin from the sands. The content of saturated resin in the sands sent for regrinding is 0.22%.

Sands were classified into classes + 1,72 mm, -1.72+ 0,55 mm, -0,55 mm. In class ax + 1,72 mm and -0,55 mm, no saturated resin was found. For this reason, in order to reduce the volume (quantity) of processed materials, these classes were not studied as an object for obtaining saturated resin from them. Taking this into account, the class of sand-1.72 + was chosen as the main object of study 0,55 mm. The average content of saturated resin in jigging sands of -1.72+ class 0,55 mm is 1.9%.

The results of studies on the distribution of sands by different classes and the content of saturated resin and magnetic fraction in them are given in Table 2.

**Table 2. Distribution of jigging sands by different classes and content of saturated resin in them**

Class, mm	Mass fraction, %	Resin content, %	Resin distribution, %
+1.72	2.57	-	-
-1.72+0.55	11.72	1.9	one hundred
-0.55	85.71	-	-
Total	one hundred	0.22	one hundred

Coarse resin with a positive surface charge is floated at a low collector flow rate.

At the gold recovery plants of Uzbekistan, working on sorption technology, anion-exchange resin of the AM-2B brand or its analogues is used as an ion-exchange material for the sorption of precious metals from cyanide solutions.

To study the possibility of flotation of the anion-exchange resin contained in wood chips and jigging sands, we used anion-exchange resin of the AM-2B brand in air-dry form.

Some quality indicators of resin AM-2B are presented in Table 3.

**Table 3. Quality indicators of resin AM-2B**

The name of indicators	Normative values of the indicator
Appearance	opaque spherical granules of white-yellow color
Grain size in air-dry state, mm	0.63-2.00
polymer matrix	porous copolymer of styrene and divinylbenzene
Functional groups	benzyl dimethylamine and benzyl trimethylammonium
Ionic form	chloride
Full exchange capacity	1.1 meq / cm <sup>3</sup>
Specific surface area	40 m <sup>2</sup> /g
Maximum operating temperature	70 °C
Moisture content	30-60%

On Fig.2 shows the appearance of the AM-2B anion-exchange resin used in the sorption of cyanide complexes of noble metals.



**Fig.2. Appearance of anion-exchange resin brand AM-2B**

The results of granulometric analysis are given in Table 4.

**Table 4. Granulometric composition of resin AM-2B**

Ionite	Grain diameter, mm									
	0.25 -0.315	0.315 -0.4	0.4 -0.63	0.63 -0.8	0.8 -1.0	1.0 -1.2	1.2 -1.4	1.4 -1.6	1.6 -2.0	+2.0
AM-2B %	0	0	1	1	11	43	2	37	5	0

Another important property of the AM-2B ion-exchange resin, which affects the ability to sorb ions from solutions and the possibility of its flotation, is swelling when immersed in aqueous solutions.

Swelling is accompanied by stretching of the resin spatial network and an increase in its volume, which facilitates the penetration of ions into the ion exchanger grain and accelerates ion exchange. Swelling is expressed by the swelling ratio, equal to the ratio of the specific volume of the swollen resin to the specific volume of the resin in air-dry form.

The swelling coefficient in our case for the investigated resin AM-2B is 2.6.



When choosing reagents for flotation of saturated resin contained in chips and jigging sands, they were guided by considerations of their availability.

Alkyl sulfate was chosen as a collector - a sulfanate -type detergent (Iranian-made NUR washing powder), which has not only collecting, but also foaming and washing properties, as well as sodium oleate and butyl xanthate.

Alkyl sulfates (Sodium Alkyl Sulfate) - salts of alkyl sulfuric acids (sodium salts of sulfoesters of aliphatic alcohols) with the general formula  $ROSO_3M$ , where R is the primary or secondary radical,  $M = Na$ , can be  $NH_4^+$ , or triethylammonium. Soluble in water, lower alcohols. Aqueous solutions are stable in the presence of acids, alkalis, calcium and magnesium salts.

Alkyl sulfates - anionic surfactants are used in the composition of detergents (washing powders, liquid soap, technical detergents), foaming agents, wetting agents, flotation reagents, cosmetics and hygiene products. Physico-chemical parameters of sodium alkyl sulfate, which is part of the NUR washing powder used as a collector, are given in Table 5.

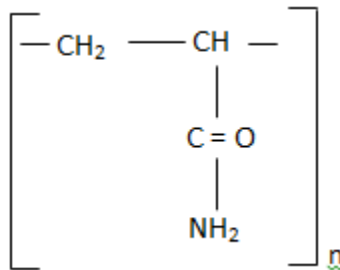
**Table 5. Physical and chemical indicators of sodium alkyl sulfate**

Name of indicator	Standard value of the indicator
Appearance at 20-25 °C	clear liquid without sediment
Smell	characteristic fat
Density at 20 °C, kg / m <sup>3</sup>	1000-1200
Kinematic viscosity at 20 °C, mm <sup>2</sup> /s, no more	one hundred
Hydrogen index, pH	7.0 - 11.0
Concentration, %, no more	35

Used as a depressant for wood chips, fine sand and sludge polyacrylamide.

Polyacrylamide is a solid, amorphous, white or partially transparent odorless substance, soluble in water, obtained as follows. First, acrylonitrile  $CH_2 = CH - CN$  is hydrolyzed with sulfuric acid monohydrate in acrylamide, and then, after sulfuric acid is neutralized with lime or ammonia, acrylamide is polymerized in the presence of potassium persulfate or sodium hydrosulfite at a temperature of 25-30 °C.

Polyacrylamide  $[-CH_2CH(CONH_2)-]_n$  has the following chemical structure:



Polyacrylamide is soluble in water, morpholine, formamide, glycerol, ethylene glycol, glacial acetic acid, swells in propionic acid, dimethyl sulfoxide and propylene glycol, insoluble in alcohols, ketones and non-polar solvents.

#### 4. RESULTS AND DISCUSSION

According to the current technology, finishing of saturated resin is carried out at a separate stage - at the resin dispensing unit for regeneration and consists of several operations:

- To separate the remnants of the pulp of the head tanks - screening on a drum screen with a mesh with a cell opening size of 0.4x0.4 mm;

- For separation of sands - jigging;

- For the separation of chips - self- ballast screen.

Saturated resin is mainly lost in the chips recovered from the chip screen and the sands recovered during the jigging process.

Losses of saturated resin in chips and jigging sands can be prevented by flotation in pneumatic flotation machines or cyanidation packs equipped with foam collectors, when compressed air, a collector (detergents), and a polyacrylamide (PAA) sludge depressant

are supplied [18] to obtain a concentrate with a high content of saturated resin. The sorption tank is similar in design and operation to a pneumatic coal flotation machine. In the air mixture flow, hydrophobic particles of saturated resin and hairs of small chips rise, carrying ferrocyanides of silver and nonferrous metals. In ore dressing, the process of removing such particles is called submicroflotation.

And jiggling sands 4,2 kg were taken from the resin dispensing unit for regeneration in the amount of 3,12 kg. To study the flotation properties of saturated resin, used anion-exchange resin brand AM-2B.

For flotation of anionite AM-2B from chips and jiggling sands, an anionic collector sodium alkyl sulfate (detergent) was used.

Flotation was carried out at a ratio of W : S = 20:1, the flow rate of the collector was 150 mg/kg of resin, the pH of the flotation pulp was 6–7, and the temperature was room temperature. The duration of flotation depended on the maximum extraction of resin into a froth product. Pulp mixing is pneumatic.

The results obtained for the extraction of resin into a foam product using are shown in Table 6.

As can be seen from the data shown in the data table, the extraction of resin into a foam product was 94.12%.

**Table 6. The results of AM-2B resin flotation by various collectors**

Reagent name	Foam product yield, %	Resin extraction, %	Collector Formula	Radical structure
alkyl sulfate	61.2	94.12	$R \text{---} \text{C}_6\text{H}_{11} \text{---} \text{SO}_3^- \text{Na}^+$	$\text{C}_{16}\text{H}_{33}$
			$[\text{RO-SO}_3]^- \text{Na}^+$	$\text{C}_8\text{H}_{17}$

The hydrophobization of the resin surface depends on the length of the hydrocarbon chain of the used collector. The longer the hydrocarbon chain of the collector, the more resistant to water is the adsorption layer of the collector on the surface of the floated particle (resin), due to the increase in the dispersion attraction of these chains in the layer. The more and at a greater distance from this surface the hydration layers around the resin are destroyed, the more it is hydrophobized by this collector.

Optimal collectors for imparting hydrophobicity to anion-exchange resin (AM-2B) are collectors with a hydrocarbon chain length of 8-16. With a hydrocarbon chain length of more than 17-20  $\text{CH}_2$  groups, the efficiency of the collector decreases due to the very low solubility.

Studies have established that the surface of ion exchange resins is usually not hydrophobic enough for flotation using only a blowing agent. Therefore, for the flotation of ion exchangers, it is necessary to use collectors that, being adsorbed on a solid surface, hydrophobize it and facilitate the adhesion of resin particles to air bubbles.

To determine the required consumption of the sodium alkyl sulfate collector, an unsaturated swollen anion exchange resin of the AM-2B brand was floated from pure solutions.

Were selected 9 sample swollen in an aqueous solution of unsaturated resin. The average weight of 9 samples in air-dry form 9.7 g, its specific gravity is  $0.42 \text{ g/cm}^3$ . The resin swelled in water during the day.

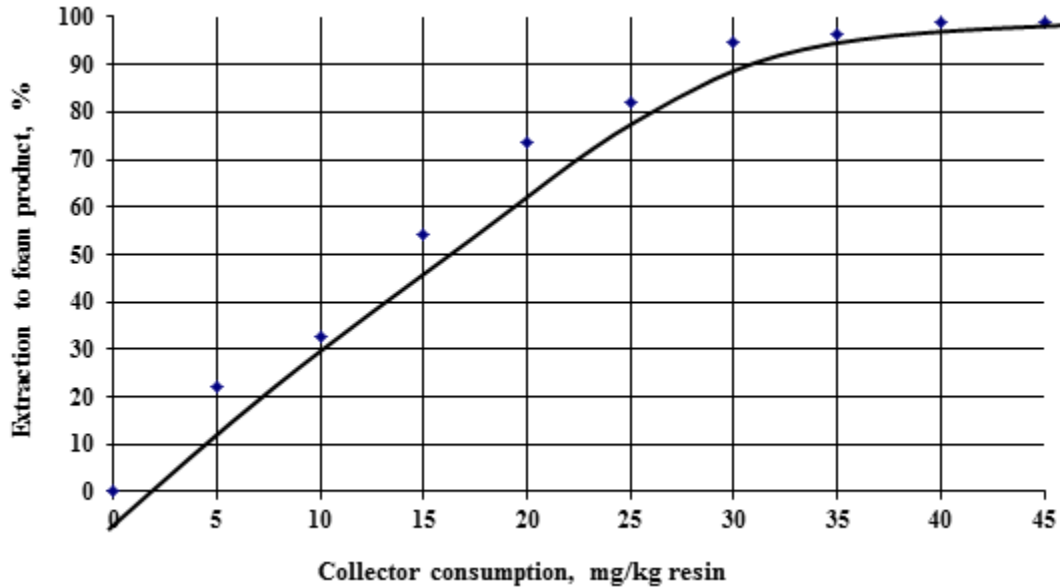
The results of extracting the resin into the foam product from the consumption of the collector are shown in Table 7 and in Figure 3.

**Table 7. Dependence of extraction of resin into a foam product on the consumption of a collector**

Collector consumption, mg/kg resin	5	10	15	20	25	30	35	40	45
Resin extraction into foam product, %	22.3	32.8	54.3	73.4	82.1	94.6	96.3	99.0	99.1

As a result of the research, it was found that the optimal rate of extraction of resin into a foam product is achieved at a collector consumption of 40-45 mg/kg of resin.

A further increase in the collector consumption does not lead to such a significant increase in the transition of the resin into a foam product, apparently, at a collector consumption of 40 mg/kg, the resin surface is already completely hydrophobized and an additional amount of the collector does not contribute to further hydrophobization of the resin surface.



**Fig.3. Dependence of the degree of extraction of unsaturated resin into the foam product on the consumption of the collector**

To establish the effect of chips on the process of flotation of saturated resin, 9 samples were also selected from chips. The weight of the wood chips was 10 g. The average resin content in the sample is 27.16%. Samples were filled with water, the ratio W : S was 20:1. To swell and saturate resin grains and its fragments with a collector, a sample of wood chips was left for 1 day.

When flotation of saturated resin from chips at a collector flow rate of 40-45 mg/kg of resin, it was not possible to achieve high recovery rates obtained by flotation of resin from pure aqueous solutions (Table 8).

**Table 8. Dependence of the degree of extraction of saturated resin from chips into a foam product on the consumption of the collector**

Collector consumption, mg/kg resin	5	10	15	20	25	30	35	40	45
Extraction of saturated resin into a foam product, %	7.5	16.7	22.7	32.3	38.2	39.3	40.3	45.6	48.8

An increase in the collector consumption leads to an increase in the extraction of saturated resin (Table 9), however, in this case, a more contaminated foam product is obtained due to the transfer of a fine fraction of wood chips into it.

Based on the data obtained, the dependence of the degree of extraction of saturated resin from wood chips on the consumption of the collector was plotted (Fig.4).

**Table 9. Dependence of the degree of extraction of saturated resin from chips into a foam product on the amount of collector**

Collector consumption, mg/kg resin	50	55	60	65	70	75	80	85	90	95	100
Extraction of saturated resin into a foam product, %	52.4	53.6	62.1	64.7	69.3	74.6	81.3	83.4	88.4	94.8	95.0

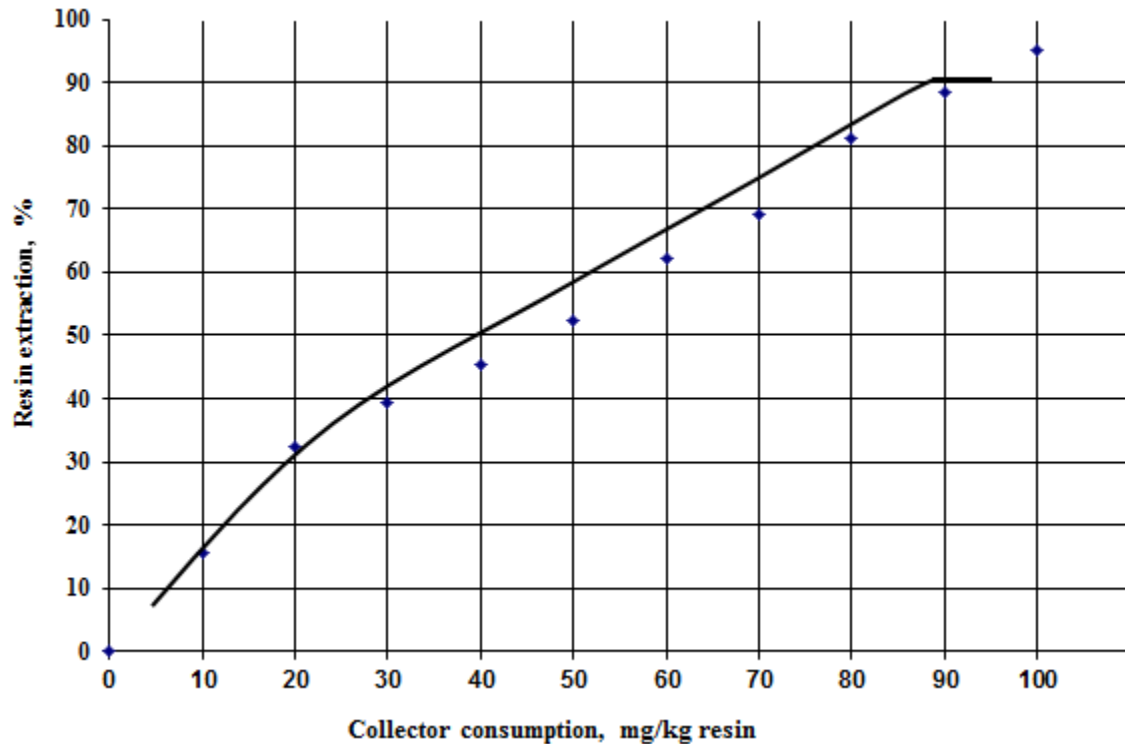


Fig.4. Dependence of the extraction of saturated resin from wood chips into foam product on the consumption of the collector

It can be seen from the dependence curve that in order to achieve the recovery of saturated resin from chips obtained by flotation of unloaded resin from pure solutions, the collector consumption increases by 2.5-3 times. The optimal amount of collector is 97-100 mg/kg resin.

The increase in collector consumption is due to the fact that part of the collector is adsorbed on the surface of the chips. This is confirmed by the obtained dependence of the extraction of resin into a foam product on the content of wood chips in the initial sample at a collector amount of 50 mg/kg of resin (Fig.5).

From the course of the curve in Fig.5 it can be seen that increasing the amount of wood chips in the sample to 70% reduces the degree of resin extraction into the foam product from 94 to 23%.

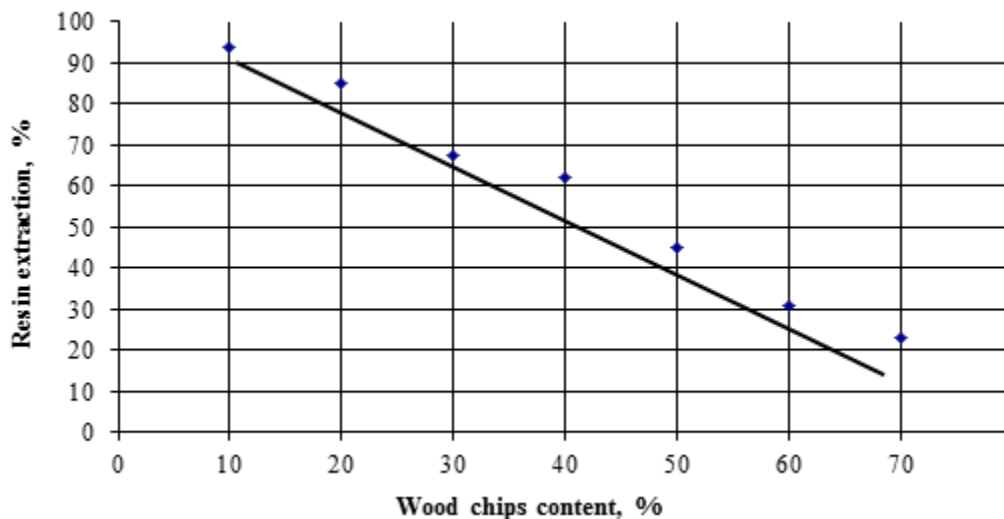


Fig.5. Saturated Resin Recovery Dependence into the foam product from the content of wood chips



#### 4. CONCLUSION

The following conclusions can be drawn from the results of the laboratory studies:

- For flotation of anion-exchange resin AM-2B, an anion-exchange collector sodium alkyl sulfate (detergent “NUR”) with a hydrocarbon chain length of 16 CH<sub>2</sub> groups is optimal;
- Consumption of the anionic collector of sodium alkyl sulfate for flotation of the swollen resin AM-2B from pure aqueous solutions was 30-35 mg/kg of resin, the resin recovery was 99.1%;
- flocculant used in thickening operations was chosen as a depressant for the flotation properties of chips and waste rock contained in jigging sands polyacrylamide (PAA), the consumption of which was 100 mg/kg of solid. The addition of PAA results in an increase in the content of saturated resin in the froth product from 39.8 to 46.77% in the flotation of saturated resin contained in the chips, and from 7.2 to 10.0% in the flotation of saturated resin contained in the jigging sands;
- When flotation of saturated resin contained in wood chips, the optimal consumption of the collector was 97-100 mg/kg of resin with a degree of extraction of saturated resin equal to 97.62%. The increase in collector consumption is due to the fact that most of it is sorbed by wood chips;
- During flotation of saturated resin from jigging sands, the optimal consumption of the collector was 70-75 mg/kg of resin with a resin recovery rate of 97.22%;
- In cyanidation and sorption leaching of sorption leaching tailings, the maximum gold recovery was 65%.

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