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UZROCI NASTAJANJA UDESA NA FLOTACIJSKIM JALOVIŠTIMA U SRBIJI***

Izvod

Flotacijska jalovišta sa aspekta tehnologije predstavljaju neophodan rudarski objekat, a u pogledu životne sredine realnu opasnost po ekološke faktore životne sredine bilo da su u funkciji ili je završen proces odlaganja. U Srbiji i u svetu, dogodili su se brojni udesi na flotacijskim jalovištima usled havarija. Pojave udesa zaslužuju da budu predmet istraživanja u cilju otkrivanja mehanizma njihovog nastajanja, obima i dometa ugrožavanja životne sredine kako bi se inicirali zahtevi za projektovanje i ugradnju zaštitnih sistema čija pouzdanosti treba da bude veća od ukupne verovatnoće opasnosti. Sve vrste sistema za suzbijanje, otkrivanje i alarmiranje opasnosti imaju svoju cenu nabavke, ugradnje i korišćenja koja je u principu srazmerna verovatnoći pouzdanosti i sigurnosti rada. Na taj način se us-postavlja funkcionalna veza između troškova ugradnje sistema sigurnosti i verovatnoće sigurnosti od nastajanja udesa (havarija). U radu su dati uzroci nastajanja udesa svrstani po uzroku nastajanja.

Ključne reči: *flotacijsko jalovište, havarija, životna sredina.*

1. UVOD

Flotacijska jalovišta predstavljaju prirodne ili veštački pregrađene prostore za akumuliranje hidromešavine (usitnjenog materijala i hemijski zagađene vode). Prema gradnji, flotacijska jalovišta svrstavaju se u: brdsko - dolinski, ravničarski, dubinski, podvodni i kombinovani tip odlaganja. Brdski (dolinski) i ravničarski tip u suštini imaju iste konstruktivne karakteristike i sličan način građenja. Kod ovih vrsta odlagališta grade se osnovne brane (inicijalne ili startne), čija visina zavisi od zapremine akumulacionog prostora i načina gradnje brana. Flotacijska jalovišta su najčešće locirana u blizini flotacija i grade se prema topografiji terena. Formiranje flotacijskih odlagališta može da se vrši u dolinama reka i potoka, na ravnom terenu i u prirodnim depresijama i otkopanim prostorima površinskog kopa. Prostor flotacijaskih odlagališta koristi se za:

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*** *Rad je proizašao iz projekta broj 37001 „Uticaj rudarskog otpada iz RTB-a Bor na zagađenje vodotokova sa predlogom mera i postupka za smanjenje štetnog dejistva na životnu sredinu“ koji je finansiran sredstvima Ministarstva za prosvetu, nauku i tehnološki razvoj Republike Srbije*

deponovanje flotacijske jalovine, potpuno izbistravanje vode, i akumuliranje tehnološke vode potrebne u procesu flotacijske koncentracije.

Flotacijska jalovišta su važni objekti u procesu rudarske proizvodnje. Bezbednost flotacijskih jalovišta se ne odnosi samo na proces rudarske proizvodnje i izgradnju, već se odnosi i na bezbednost ljude koji žive nizvodno od jalovišta i okoline [1].

Potencijalni proboj brane i izlivanje jalovine je katastrofalan pri čemu nastaje poplavni talas velike energije koji se kreće nizvodno [2].

2. KRITERIJUMI ZA IZBOR LOKACIJE FLOTACIJSKIH ODLAGALIŠTA

Za formiranje flotacijskih jalovišta postoje kriterijumi koji utiču na izbor lokacije i oni su ekonomske, tehničko–tehnološke i ekološke prirode.

Ekonomski kriterijum podrazumeva da na lokaciji ne treba da nema rezerve korisnih mineralnih sirovina, kulturnih, arheoloških spomenika i spomenika prirode, da je rastojanje lokacije jalovišta od flotacije najmanje.

Tehnički kriterijumi uključuju topografske, hidrološke i geološke karakteristike terena.

Za **Tehnološki kriterijum** važan je kapacitet odlagališta, način transporta flotacijske jalovine i mogućnost korišćenja povratne vode.

Ekološki kriterijum podrazumeva da se ne ugrožava staništa retkih biljaka i životinjskih vrsta, površinskih, podzemnih voda i zemljišta uzvodno i nizvodno od jalovišta.

3. NAJVEĆA FLOTACIJSKA JALOVIŠTA U EVROPI I SRBIJI

U tabeli 1. date su lokacije najvećih flotacijskih jalovišta u Evropi.

***Tabela 1.** Najveća flotacijska jalovišta u Evropi i Srbiji*

Država	mesto	Količina jalovine m^3	Površina jalovišta m^2
Nemačka	Culmitzsch	90 000 000,00	2 280 000,00
	Helmsdorf	50 000 000,00	2 500 000.00
	Trunzig	19 000 000,00	1 080 000,00
Francuska	Escapiere	12 000 000,00	820 000,00
Mađarska	Pecs	16 000 000,00	1 540 000,00
Bugarska	Elesnitza	8 000 000,00	500 000,00
	Buhovo	11 000 000,00	700 000,00
Češka republika	Straz	33 000 000,00	1 360 000,00
	Rozna	15 000 000,00	400 000,00
	Mydlovary	15 000 000,00	2 600 000,00
Estonia	Sillamae	8 000 000,00	330 000,00
Srbija	Bor (odlagalište Bor)	12 436 160,00	600 000,00
	Bor(RT-H)	17 903 019,00	500 000,00
	Krivelj Polje 1	94 000 000,00	810 000,00
	Krivelj Polje 2	89 000 000,00	1 270 000,00
	Majdanpek	187 879 000,00	

U "World Register of Mine and Industrial Tailings Dams" su navedene osam flotacijskih brana višljih od 150 m, 22 višljih od 100 m i 115 višljih od 50 m.

Za šest zatvorenih se zna da zauzimaju površinu veću od 100 km^2 a zapremine su preko 50 000 000 m^3. [3].

3.1. Udesi na flotacijskim jalovištima u svetu

Poznati katastrofalni događaji u vezi sa izlivanjem flotacijske jalovine i vode koji su ugrozili životnu sredinu u svetu su:

1. Bivša ČSSR,
2. Čile (1967. god, poginulo više od 200 ljudi),
3. SAD,
4. Nemačka (Saksonija 1960 - tih god., izliveno 250 000 t jalovine u rečno korito),
5. Rumunija (Baia Mare 30. januara 2000. godine, zatrovane reke cijanidima: Mura, Tisa i Dunav).
6. Makedonija

Najveća slatkovodna ekološka katastrofa pogodila je države u slivu Dunava na dužini od 2000 kilometara kada je 30. januara 2000. godine, došlo do proboja brane na taložnim jezerima za jalovinu na postrojenjima fabrike i rudnika zlata Aurul SA Company, u mestu Baia Mare na severozapadu Rumunije.

Tom prilikom iscurelo je oko 100 000 kubnih metara odložene jalovine koja je sadržala u sebi između 50 i 100 tona cijanida kao i teške metale, uključujući i bakar.

Do pucanja brane došlo je kombinacijom propusta učinjenih još u izgradnji brane i nepovoljnim vremenskim uslovima brzog otapanja snega. Poplavni otrovni talas je putovao rekama Lapoš, Samoš, Tisom i Dunavom oko četiri nedelje pre nego što je stigao do Crnog Mora.

Tokom proteklih godina došlo je do tri proboja brana koje su izazvale katastrofe u Republici Makedoniji. Svi su prouzrukovali značajne štete posebno na vazduh, vode i zemljišta. Takve nesreće su se desile u rudniku olova i cinka Zletovo u Probišipu, rudniku bakra Bučim i poslednja u rudniku olova i cinka Sasa (Septembar 2003). [4].

Kolpas na flotacijskoj brani u Sasi napravio je krater od 120-160 m na dubine od 30-40 m. Posle katastrofe preko 1 000 000 tona jalovine sa teškim metalima izlilo se u Reku Kamenica, i dalje u jezero Kalimanci, reku Bragalnicu i okolni prostor. [4].

4. UZROCI NASTAJANJA HAVARIJA NA FLOTACIJSKIM JALOVIŠTIMA

Havarije ili udesi na flotacijskim jalovištima nastaju usled prirodnih nepogoda, tehničkih nedostataka i kombinacijom ova dva uzroka. Tom prilikom dovode do pojave opasnih rizika po životnu sredinu gde se zagađuju vode, zemljište, biljke, uništava se stanište životinja i plave kuće ljudima. U cilju predviđanja obima pojedinih udesa potrebno je odmah pri projektovanju flotacijskih jalovišta izvršiti procenu verovatnoće nastajanja havarija i štete na terenu. To se vrši na osnovu matematičke statistike i korelacije sa zbivanjima na sličnim jalovištima i primenom teorema iz teorije verovatnoće i pouzdanosti flotacijskih odlagališta pri radu u uslovima delovanja tehničko - tehnoloških nedostataka i prirodnih nepogoda (atmosferskih padavina, poplava, oluja, zemljotresa) i ratnih dejstava .

Istraživanjem je zaključeno da najčešći uzroci havarija kod nas i u bivšoj Jugoslaviji prouzrokovani su uslovima delovanja tehničkih nedostataka i nepoštovanjem projektnih rešenja. Od šesnaest zabeleženih havarija na flotacijskim odlagalištima na prostoru bivše Jugoslavije, devet slučajeva se odnosi na oštećenje betonske obloge kolektora i prodor flotacijske jalovine kroz **betonsku** oblogu kolektora (neotporan na kiselu sredinu). Jedan slučaj se odnosi na **oštećenje** obloge tunela i jedan slučaj kroz betonsku cev za vodu, dok se dva slučaja odnosi na prelivanje poplavnog talasa atmosferske vode preko istaložene flotacijske jalovine u jalovištu i brane, dva slučaja isticanja vode ispod tela brane i jedan slučaj kroz "odžak" karstnog terena i pećinu. Zabeleženi primeri proboja flotacijskog odlagališta dati su u tabeli 2.

Havarije nastaju usled istovremene pojave opasnih stanja izazvanih tehničkim nedostacima i prirodnim pojavama na odlagalištima usled kojih dolazi do proboja flotacijskog mulja i njegovog oticanja u obliku poplavnog talasa u slivu područja.

Opasna stanja mogu da dovedu do iznenadnih klizanja podloge i kvarova na drenažnom sistemu i prelivnom organu na flotacijskim odlagalištima, pojave pukotina na kolektoru usled pritisaka sedimentovane jalovine, propadanja obloge kolektora usled dejstva kisele sredine i destabilizacije čitavog jalovišnog sistema.

Tabela 2. *Poznati uzroci havarija do sada kod nas i u bivšoj Jugoslaviji*

Prodor flotacijske jalovine kroz beton oblogu cevi za vodu	Prodor flotacijske jalovine kroz oblogu kolektora	Isticanje flotacijske jalovine i vode ispod tela brane	Prelivanje poplavnog talasa atmosferske vode preko brana	Prodor flotacijske jalovine kroz betonsku oblogu tunela	Prodor flotacijske jalovine kroz pećinu
1.Probištip	1. Kriva Feja – Besna Kobila	1. Rudnica – Leposavić	1. Šaški Potok Majdanpek	1. Sasa - Makedonska Kamenica	1. Valja Fundata Majdanpek
	2. Trepča	2. Rudnik – Rudnik	2. Kišnica – Priština		
	3. Leposavić				
	4. Probištip				
	5. Toranica – Kriva Palanka				
	6. Staro Borsko jalovište				
	7 .Jalovište V. Krivelj				
	8. Sasa- Makedonska Kamenica				
	9. Bučim – Radoviš Makedonija				

Kod nas i u svetu, dogodile su se havarije flotacijskih odlagališta sa vrlo velikim posledicama po životnu sredinu u području rudnika i u slivovima reka. Poznata je ugroženost sliva reke Timoka iz Borskog flotacijskog odlagališta preko Borske reke, reke Peka i Šaške iz flotacijskih odlagališta u Majdanpeku, zatim Kriveljske reke iz flotacijskog odlagališta u Velikom Krivelju. Slične ekološke katastrofe su nastajale i kod susednih zemalja (Mađarske, Rumunije, Bugarske, Makedonije).

5. IZVORI NASTAJANJA HAVARIJA NA FLOTACIJSKIM ODLAGALIŠTIMA

Analizom je utvrđeno da nastanak havarija na flotacijskim jalovištima najčešće je usled: tehničkih nedostataka (propusta) i prirodnih katastrofa. Često ova dva uslova se kombinuju i tada štete od nastalih udesa su većih razmera.

Pojava havarija na flotacijskim odlagalištima izazvanim **tehničkim nedostacima** su:

1. Neadekvatna projektna rešenja (loša procena),
2. Nepoštovanja projektnih rešenja (nepouzdana gradnja: brana, kolektora ispod jalovišta i brana, drenažnih sistema i prelivnog organa),
3. Odsustva kontrole i ne poštovanja propisa,

Izvori havarija na flotacijskim odlagalištima izazvanim **prirodniim katastrofama** (nepogodama) mogu biti usled:

1. Klizanja podloga, odnosno promene fizičkih i geoloških procesa koji dovode do klizanja obala u akumulacioni prostor i stvaranja poplavnog

talasa koji može ugroziti branu i dovesti do njenog rušenja, takođe dovodi do zatrpavanja prelivnog organa,
2. Pojava pukotina i kaverni u kraškom terenu,
3. Dugotrajnih kiša i naglog otapanja snega u vidu velikih voda koje dovode do erozije brana i obodnih nasipa jalovišta,
4. Zemljotresi (tektonski, vulkanski, urvinski i veštački usled miniranja),
5. Vetrovi orkanske jačine koji izazivaju peščane oluje i eroziju brane - premeštanje ciklonskog peska sa brana u okolinu i
6. Ratnih dejstva na prostoru flotacijskih odlagališta, koja bombardovanjem dovode do oštećenje kolektora i flotaciskih brana.

5.1. Neadekvatna projektna rešenja

Najčešći vid neadekvatnih projektnih rešenja su:

- loše procene pri izboru i pripremi lokacije za gradnju brana i flotacijskog jalovišta,
- loše određivanje dozvoljenih napona za betonsku konstrukciju kolektora i prelivnog organa,
- greška u dimenzionisanju kolektora i izboru oblika
- izbor vrste i količine cementa za spravljanje betona,
- način spravljanja i ugrađivanja betona i
- kvalitet primenjene armature (kompaktna i homogena struktura).

Zbog velike cene izgradnje obloge kolektora od kiselo otpornog betona po m', pribegava se uštedi u materijalu primenom portland cementa za spravljanje betona, umesto cementa otpornog na hemijske uticaje, takozvani "pucolan" za gradnju obloge kolektora otpornog na agresivne vode iz flotacijskog odlagališta.

Primer kako može doći do greške u dimenzionisanju ili nepouzdanosti gradnje kolektora je kolektor ispod Polja 2 i brane 3A u Velikom Krivelju. Prema projektnom rešenju, visina brane iznad kolektora trebala je da iznosi 100 m, a već pri dostizanju visine od 56 metara pojavile su se pukotine na oblozi kolektora. Da bi se dostigla visina brane od 100m unutar kolektora je ugrađena dodatna obloga debljine 40 cm. Drugi primer havarija na kolektoru i tunelu usled agresivnog dejstva kisele sredine dogodio se u rudniku bakra Bučim i olovo-cinkanom rudniku Sasa u Makedoniji.

5.2. Nepoštovanje projektnih rešenja

Verovatnoća pojave havarije pri normalnim uslovima rada sitema na flotacijskim odlagalištima i ugrožavanje životne sredine može nastati usled nepoštovanja projektnih rešenja, odnosno odstupanja radnih parametara od projektovanih pri čemu dolazi do:

1. Kvarova na hidrauličnom i gravitacionom transportu pulpe (pucanja cevi i pojave pukotina na betonskim kanalima, zapušenja i prelivi).
2. Pojave kvarova na drenažnom sistemu na brani (odsustva poroznog drenirajućeg sloja iznad kolektora ili smanjenja poroznosti usled sabijanja),
3. Kvarova na sistemu za povratnu vodu iz taložnog jezera (plovećoj pumpnoj stanici),
4. Nefunkcionisanja prelivnog (ispusnog) organa,
5. Pojave pukotina i oštećenja na kolektoru ispod jalovišta ili njegovog rušenja celom dužinom ili samo na pojedinim delovima zbog uštede u materijalu i nesolidne gradnje i dejstva hemijske erozije i
6. Nefunkcionisanja sistema za orošavanje suvih površina brana.

U zavisnosti od ispoljavanja potencijalne opasnosti od nepoštovanja tehničkih uslova i verovatnoće da do pojave havarije pri normalnim uslovima rada na flotacijskim odlagalištima dođe, ugrađuju se sistemi za otkrivanje opasnosti radi sprečavanja havarija. Verovatnoća efikasnosti sistema za otkrivanje opasnosti i suzbijanja havarija je u vezi sa pouzdanošću predviđenog sistema i primenjenog načina primene sistema u otklanjanju havarija.

Na flotacijskim odlagalištima zbog prirode poslova, sistemi za otkrivanje ispoljavanja potencijalne opasnosti i otklanjanje havarija su kombinovani. Sastoje se od ugrađenih uređaja na brani (piezometri) koji služe za merenje vode unutar brane i flotacijskog odlagališta (pokazuju položaj linije provirnih voda, koje utiču na stabilnost brane) i postupaka zaposlenih radnika određenih za otkrivanje pojava opasnosti na odlagalištu (kontrolu ispoljavanja opasnosti vrše svojim čulima). Ovakav vid zaštite od nastajanja havarija, koji uglavnom zavisi od ljudskog faktora ne može biti visok. Veličina verovatnoće sigurnosti od nastajanja havarija primenom kombinovanog sistema za otkrivanje i spre-čavanje havarija se kreće od 0,2 do 0,8. Verovatnoća efikasnosti (sigurnosti) ovakvog načina otkrivanja opasnosti i suzbijanja nezgoda bliža je nuli, a opasnost od nastanka havarije bliža jedinici. Efikasnost sistema za otkrivanje opasnosti je u zavisnosti od verovatnoće **apriori**:

Odsustva kontrole i nepoštovanja propisa

Havarije izazvane tehničkim nedostacima (ljudskim faktorom) u normalnim (projektovanim) uslovima rada na flotacijskimodlagalištima, smatraju se kao havarije grešaka ili havarije usled odsustva kontrole i ne poštovanja propisa. One nastaju zbog nepoštovanja tehnologije odlaganja flotacijske jalovine predviđene projektom, nepažljivog rada i upravljanja nivoom vode taložnog jezera unutar jalovišta, nepravilnog dimenzionisanja ili nepozdanosti gradnje kolektora (primenom betona neotpornog na kiselu sredinu) ispod polja i brane jalovišta i sistema odlaganja u celini.

Veličina štete na ekosistemima i ekološkim faktorima životne sredine izazvane odsustvom kontrole i nepoštovanja propisa

Veličina štete na ekosistemima i ekološkim faktorima životne sredine izazvane odsustvom kontrole i nepoštovanjem propisa zavise od: veličine havarije (udesa), veličine odlagališnog prostora (zapremine), vrste odlaganog materijala, agregatnog stanja štetnih materija, količine štetnih materija koje mogu dospeti u životnoj sredini, pravca i dometa štetnih materija i osetljivosti eko sistema na štetne materije iz flotacijskih jalovišta.

Oštećenje okosistema prodorom flotacijske jalovine može biti lokalnog, regionalnog i međunarodnog karaktera. Lokalna i regionalna oštećenja ekosistema su mala u prostoru i vremenu (prodor flotacijske jalovine u Šašku reku i Pek na području Majdanpeka). Međunarodna oštećenja ekosistema su velika u prostoru, a mala u vremenu (prodor flotacijske jalovine i cijanida iz rudnika Baja Mare u Rumuniji u reku Tisu, Dunav sve do Crnog Mora). I lokalna i međunarodna oštećenja ekosistema posle nastajanja vremenom se smanjuju jer se štetne materije razgrađuju ili se oštećene površine raščišćavaju, a zatim rekultiviraju što dovodi do regeneracije ekosistema.

Verovatnoća ekoloških katastrofa usled havarija (udesa) grešaka na lokalnom ili međunarodnom nivou se određuje na osnovu odnosa ukupnih i mogućih površina na ugroženom području, vremena trajanja ugrožavanja i prisustva osetljivih članova ekološkog sistema na ispoljavanje povećanje koncentracije štetnosti u okolinu.

6. AGRESIVNO DEJSTVO VODE IZ FLOTACIJSKOG JALOVIŠTA NA BETONSKU OBLOGU KOLEKTORA I TUNELA

Flotacijsko odlagalište sa svojim pratećim objektima kao što su: peščani nasip, akumulacioni prostor, drenaže, tuneli i kolektori, predstavlja specifičan rudarski objekat. Hidrohemijski procesi kako u samoj akumulaciji, tako i peščanim nasipima su prisutni i veoma složeni. Tome doprinosi usitnjenost minerala sadržanih u flotacijskoj jalovini, zatim prisustvo vode, vazduha, temperature i pritiska. Pojedini procesi imaju štetno dejstvo na betonske obloge od kojih su izgrađeni prateći objekti.

Hemijski zagađene vode na flotacijskim odlagalištima agresivno deluju na betonsku oblogu kolektora. Ta agresivnost se ogleda u sposobnosti hemijski zagađene vode da izoluje iz betona sastavne delove, odnosno da uz pomoć rastvorenih soli i gasova ruši beton. Vezivni sastojak betona je cement, koji u prvom redu predstavlja smešu silikata kalcijuma. Kvalitet cementa se određuje hidrauličkim modelom koji predstavlja odnos bazne komponente CaO prema kiselijim:

–SiO_2, Al_2O_3, Fe_2O_3

$$\left(-\frac{\%CaO}{\%(SiO_2 + Al_2O_3 + Fe_2O_3)} \geq 2 \right) \quad ....(1)$$

Agresivnost vode u flotacijskom jalovištu na betonski kolektor se ispoljava na nekoliko načina u zavisnosti od hemijskog sastava vode:

1. agresivnost ugljene kiseline, agresivnost izlučivanja kreča, kiselinska agresivnost:

Ugljokiselinska aktivnost sastoji se u rastvaranju $CaCO_3$ pod dejstvom agresivne ugljene kiseline po formuli:

$$CaCO_3 + H_2CO_3 \leftrightarrow CO^{++} + 2HCO_3^{+} \quad (2)$$

Agresivnost izlučivanja teče na račun rastvaranja $CaCO_3$ i izdvajanja $Ca(OH)_2$ iz betona.

Opšta kiselinska agresivnost je vezana za sadržaj slobodnih jona vodonika. Voda je agresivnija ako je pH = 5 ÷ 6,8.

2. Sulfatna i magnezijumova agresivnost:

Sulfatna i magnezijska agresivnost prisutna je kod voda koje imaju visok sadržaj jona SO_4^{--} Pri prolasku vode kroz beton dolazi do kristalizacije i obrazovanja soli $CaSO_4\,2H_2O$, koje ruše beton.

Magnezijska agresivnost, se pojavljuje pri visokom sadržaju jona Mg^{+++} i u vezi je sa sadržajem $SO_4^{--} \geq +50$ mg/l. Sve ove vrste agresivnosti su prisutne u manjoj ili većoj meri na svim flotacijskim jalovištima kod nas.

Redovna pojava je **sulfatno razgrađivanje** betona naime prelaz iz bazne u kiselu vodu u donjim slojevima odloženog mulja na flotacijskim jalovištima je posledica oksidacije pirita FeS_2 i drugih sulfidnih minerala. Pri dejstvu kiseonika i kontaktu sa vlagom, sulfidi reaguju u smislu stvaranja sumporne kiseline H_2SO_4 i ferosulfata $FeSO_4$. Fero sulfat se dalje oksidiše do trovalentnog feri sulfata, koji potom hidrolizira dok se ne stvori kiseliji. Sledeći pojednostavljenim jednačinama ilustruje se mehanizam piritne oksidacije.

$$2FeS_2+7O_2+H_2O \rightarrow 2FeSO_4+2H_2SO_4 \;..\; (3)$$

Proces je u tesnoj vezi sa vremenskim uslovima, količinom pirita, stepenom njegove usitnjenosti i kvalitetom izrade betonske obloge sulfatno razgrađivanje je efikasnije u delu gde je ugrađen “posan beton”. Naime usled segregacije šljunka na pojedinim delovima obloge stvaraju se uslovi za brže reagovanje kiselih voda te i iznošenje komponente betona.

Sadržaj jona SO_4^{--} u vodama flotacijskog jalovišta u Majdanpeku prema istraživanjima je sledeći:

lokalitet istraživanja	SO_4^{--}	pH vrednost
• Drenažna voda	534 mg/l	6-7,8
• Jezerska voda	368 mg/l	11,4-11,8
• Voda koja ističe kroz oblogu kolektora	317 mg/l	6-8,28

Na jalovištima olovo cinkanih rudnika bivše Jugoslavije joni SO_4 se kreću iznad 1000 mg/l, a pH vrednost od 4,5-9,5.

7. ZAKLJUČAK

Uzroci nastajanja havarija na flotacijskim jalovištima su tehnički nedostaci i prirodne katastrofalne nepogode. Mere koje treba preduzeti u borbi protiv tehničkog nedostatka je izrada kolektora ispod flotacijskih jalovišta od kiselootpornog betona ili primena plastičnih cevovoda. Nažalost na prostorima bivše Jugoslavije, svi tuneli i kolektori za devijaciju reka ispod flotacijskih odlagališta izgrađeni su od betona neotpornog na kiselu sredinu. Zbog toga su svi tuneli i kolektori pretrpeli manja ili veća oštećenja usled sulfatnog razgrađivanja betona. Pri izgradnji flotacijskih odlagališta (jalovišta) treba sprovesti da havarije grešaka budu minimalne pooštravanjem kontrole i predviđenih propisa.

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CAUSES OF ACCIDENTS ON THE FLOTATION TAILING DUMPS IN SERBIA**

Abstract

Flotation tailing dumps from the aspect of technology are necessary mining facility, and in terms of environmental present a real threat to the ecological environmental factors that are either in operation or the process of disposal is completed. In Serbia and in the world, numerous accidents occurred on the flotation tailing dumps due to the accidents. Occurrences of accidents deserve to be the subject of research in order to identify the mechanism of their formation, extent and scope of threats to the environment in order to trigger the requirements for design and installation of security systems, whose reliability should be greater than total probability of danger. All types of systems for prevention, detection and alarming shave their price of procurement, installation and use, which is generally proportional to the probability of reliability and operational safety. In this way, a functional link is established between the cost of installing the security and probability system on occurrence the accidents. This paper gives the causes of accidents classified by the cause of formation.
Keywords: *flotation tailing dump, accident, environment*

1. INTRODUCTION

Flotation tailing dumps are natural or artificially dammed spaces for accumulation of hydro mixtures (ground material and chemically contaminated water). By construction, the flotation tailing dumps are classified as: hilly - valleys, plains, deep, deep and combined type. Hilly (valley) and plain type have essentially the same design characteristics and a similar way of construction. In these types of landfills, the primary dams are built (initial or starting), with the height which depends on the volume of accumulation space and dam construction methods. Flotation tailing dumps are usually located near the flotation plants and they are built

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according to the terrain topography. Formation of flotation tailing dumps can be done in the valleys of the rivers and streams, on the flat terrain and in natural depressions and excavated areas of the open pit. The space of flotation tailing dumps is used for: disposal of flotation tailings, full clarification of water, and accumulation of industrial water, needed in the process of flotation concentration.

Flotation tailing dumps are important facilities in the process of mining production. Safety of flotation tailing dumps is not only for the process of mining production and construction, but also it is applied to the safety of people living downstream of the tailing dumps and environment [1].

A potential breakthrough of a dam and spills of tailings is disastrous where the flood wave of high-energy is formed moving downstream. [2].

2. CRITERIA FOR SELECTION OF A SITE OF FLOTATION TAILING DUMPS

There are criteria for formation the flotation tailing dumps that influence the selection of a site and they are of economic, technical, technological and environmental nature.

Economic criterion implies that there is no reserve of valuable mineral resources, cultural, archeological monuments and monuments of nature, and that a distance from the site of flotation tailing dump to the flotation plant is minimum.

Technical criteria include topographic, hydrologic and geologic characteristics of the terrain.

Capacity of landfill, transport way of flotation tailings and possibility of use the feedback water are important for **technological criterion.**

Ecological criterion means that there is no threatening the habitats of rare plants and animal species, surface water, groundwater and soil, upstream and downstream of tailing dumps.

3. THE LARGEST FLOTATION TAILING DUMPS IN EUROPE AND SERBIA

Table 1 gives the locations of the largest flotation tailing dumps in Europe.

Table 1. *The largest flotation tailing dumps in Europe and Serbia*

Country	Place	Amount of tailings, m^3	Surface of tailing dump, m^2
Germany	Culmitzsch	90 000 000.00	2 280 000.00
	Helmsdorf	50 000 000.00	2 500 000.00
	Trunzig	19 000 000.00	1 080 000.00
France	Escapiere	12 000 000.00	820 000.00
Hungary	Pecs	16 000 000.00	1 540 000.00
Bulgaria	Elesnitza	8 000 000.00	500 000.00
	Buhovo	11 000 000.00	700 000.00
Czech Republic	Straz	33 000 000.00	1 360 000.00
	Rozna	15 000 000.00	400 000.00
	Mydlovary	15 000 000.00	2 600 000.00
Estonia	Sillamae	8 000 000.00	330 000.00
Serbia	Bor (Tailing dump Bor)	12 436 160.00	600 000.00
	Bor(RT-H)	17 903 019.00	500 000.00
	Krivelj Polje 1	94 000 000.00	810 000.00
	Krivelj Polje 2	89 000 000.00	1 270 000.00
	Majdanpek	187 879 000.00	

“The World Register of Mine and Industrial Tailings Dams” specifies the eight flotation dams higher than 150 m, 22 higher than 100 m and 115 higher than 50 m. It is known for the six closed that they have the surface area higher than 100 km^2, with volumes over 50 000 000 m^3 [3].

3.1. Accidents on the flotation tailing dumps in the world

The known disastrous events concerning the spills of flotation tailings and water, which threatened the environment in the world, are:

1. The former CSSR,
2. Chile (1967, killed more than 200 people),
3. USA,
4. Germany (Saxony, in the sixties, 250 000 t of tailings spilled in the river bed),
5. Romania (Baia Mare 30 January 2000, the rivers Mura, Tisza and Danube poisoned with cyanide),
6. Macedonia.

The biggest freshwater ecological disaster affected the countries in the basin of the Danube in the length of 2000 km when on 30 January 2000, the breakthrough of dam occurred at the sediment lakes for tailings in the factory plants and gold mine Aurul SA Company, in Baia Mare in the north-west of Romania.

On that occasion, about 100 000 m^3 of disposed tailings spilled containing between 50 and 100 tons of cyanide as well as heavy metals, including copper.

Breaking of the dam occurred by a combination of failures incurred in the construction of dam and adverse weather conditions due to the rapid melting of snow. Toxic flood wave traveled down the rivers Lapos, Samos, Tisza and Danube about four weeks before it came to the Black Sea.

Over the past year, there have been three breakthroughs of dams that caused the disasters in the Republic of Macedonia. All have caused the significant damages to air, water and soil. Such accidents have occurred in the lead and zinc mine in Zletovo in Probištip, the copper mine Bučim and copper mine and the last one in the lead and zinc mine Sasa (September 2003) [4].

Breaking of the flotation dam in Sasa made a crater of 120-160 m at depth of 30-40 m. After the disaster over 1 000 000 tons of tailings with heavy metals spilled into the River Kamenica, and further into Kalimanci lake, river Bregalnica and surrounding area [4].

4. CAUSES OF ACCIDENTS ON THE FLOTATION TAILING DUMPS

Accidents or incidents on the flotation tailing dumps are caused by natural disasters, technical failures, and the combination of both. On this occasion they result into ocurrence of dangerous threats to the environment where they pollute the water, soil, plants, destroy the habitat of animals and flood the houses of people. In order to forecast the volume of individual incidents, it is necessary to assess the probability of accidents and damage on the site immediately in design of flotation tailing dumps. It is done on the basis of mathematical statistics and correlation with events on similar tailing dumps using the theorems of probability theory and reliability of flotation landfills at work in the conditions of action the technical-technological defects and natural disasters (atmospheric precipitation, floods, storms, earthquakes) and war activities.

It was concluded by research that the most common causes of accidents in our country and former Yugoslavia were caused by the conditions of technical deficiencies and disrespectance the design solutions. Of the sixteen recorded accidents on tailing dumps in the former Yugoslavia, the nine cases relate to a damage of concrete lining of collector and flotation tailings penetration through the **concrete** lining of collector (not resistant to the acidic environment). One case relates to a **damage** of tunnel lining and one case through a concrete pipe for water, while two cases relate to the overflow of storm water flood wave through deposited tailings in the tailing dump and dam, two cases of water spilling under the dam body and one case through the "chimney" of the karst terrain and cave. The recorded examples of breakthroughs are given in Table 2.

Accidents are caused by simultaneous occurrence of hazardous conditions, caused by technical defects and natural phenomena on landfills that are the subject for breaking the flotation slime and its outflow in the form of flood into the basin areas.

Hazardous conditions can lead to sudden slippage of surface and failures on drainage system and overflow body on flotation tailing dumps, appearance of cracks on collector due to the pressure of sedimented tailings, deterioration of collector lining due to the effects of acidic environment and destabilization the entire system of tailing dump.

Table 2. *The known causes of accidents until now in our country and in the former Yugoslavia*

Breakthrough of flotation tailings through a concrete lining of pipe water	**Breakthrough of flotation tailings through a collector lining**	**Leaking of flotation tailings and water under dam body**	**Overflow the flood wave of atmospheric water over dam**	**Breakthrough of flotation tailings through a concrete lining of tunnel**	**Breakthrough of flotation tailings through a cave**
1. Probištip	1. Kriva Feja – Besna Kobila	1. Rudnica – Leposavić	1. Šaški Potok Majdanpek	1. Sasa - Makedonska Kamenica	1. Valja Fundata Majdanpek
	2. Trepča	2. Rudnik – Rudnik	2. Kišnica – Priština		
	3. Leposavić				
	4. Probištip				
	5. Toranica – Kriva Palanka				
	6. Staro Borsko jalovište				
	7 .Jalovište V. Krivelj				
	8. Sasa- Makedonska Kamenica				
	9. Bučim – Radoviš Makedonija				

There have been accidents of flotation tailing dumps in our country and in the world with very large consequences for the environment in the mine area and river basins. It is known a threat to the Timok River Basin from the Bor flotation tailing dump through the Bor River, river Pek and Saska River and the flotation tailing dumps in Majdanpek, then the Krivelj River from the flotation tailing dump in Veliki Krivelj. Similar environmental disasters were also created in the neighboring countries (Hungary, Romania, Bulgaria, Macedonia).

5. SOURCES OF ACCIDENTS ON THE FLOTATION TAILING DUMPS

Analysis determined that the occurrence of accidents on the flotation tailing dumps is usually due to the: technical problems (failures) and natural disasters. Often these two conditions are combined and then the damages, caused lby accidents, are large-scale.

The appearance of accidents on tailing dumps, caused by **technical deficiencies**, is:

1. Inadequate design solutions (bad assessment)
2. Failure to comply with design solutions (unreliable construction of: dams, collectors below the tailing dumps and dams, drainage systems and overflow body),
3. Lack of control and breaching the rules.

Sources of accidents on tailing dumps, caused by **natural disasters**, may be due to:

1. Sliping of surfaces, i.e. a change of physical and geological processes that lead to sliping of coasts into the accumulation space and creation of flood wave that could endanger a dam and lead to its demolition, also leading to backfilling of overflow body,
2. Appearance of cracks and caverns in the karst terrain,
3. Long rains and rapid melting of snow in the form of floods which lead to the erosion of dams and peripheral dikes of tailing dumps,
4. Earthquakes (tectonic, volcanic, and artificial due to blasting),
5. Hurricane force winds causing dust storms and erosion of the dam - moving cyclone sand from dams in the environment, and
6. Effects of war actions on the territory of flotation tailing dumps, which leads to a damage of collector and flotation dams by bombing.

5.1. Inadequate design solutions

The most common form of inadequate design solutions are:

- inadequate assessments in the selection and preparation of location for construction of dams and flotation tailing dumps,
- bad determining the allowable stresses for concrete construction of collector and overflow body,
- error in the collector sizing and selection of forms,
- selection of the type and quantity of cement for concrete making,
- method of preparation and insertion of concrete, and
- quality of applied fitting (compact and homogeneous structure).

Due to the high cost of construction the collector lining of acid resistant concrete per m', it is resorted to savings in materials using the portland cement for concrete making instead of cement resistant to the chemical impacts, called "pozzolan" for building the collector lining resistant to aggressive water from the flotation tailing dump.

An example of how error can occur in sizing or unreliability of collector building is a collector below the Field 2 and dam 3A in Veliki Krivelj. According to the design solution, the height of dam above the collector is supposed to be 100 m, but on reaching the height of 56 m, the cracks appeared in the lining of collector. To reach the dam height of 100 m within the collector, an additional coating thickness of 40 cm was built. Another example of accident on collector and tunnel, due to the aggressive effect of acidic medium, occurred in the copper mine Bučim and lead-zinc mine Sasa in Macedonia.

5.2. Failure to comply with design solutions

Probability of occurrence the accident under normal operation conditions on the flotation tailing dumps and endangering the environment can result due to the failure to comply with design solutions, i.e. deviations from designed operating parameters, which cause:

1. Breakdowns in hydraulic and gravitational transport of pulp

(cracking of pipes and appearance cracks in concrete channels, clogging and overflows),
2. Occurrence of breakdowns in drainage system at the dam (the absence of a porous drainage layer over the collector or porosity reduction due to compaction),
3. System failures to return water from settling lake (floating pump station),
4. Dysfunction the overflow (discharge) body,
5. Appearance of cracks and damages on collectoe below the tailing dump and its collapse along the entire length or only in the certain parts due to the savings in material and non-solid construction and effects of chemical erosion, and
6. Dysfunctional spraying system for dry surfaces of dams.

Depending on the expression of potential risks of failure to comply the technical requirements and probability of accident occurrence in normal operation conditions on the flotation tailing dumps, the systems are installed to detect hazards to prevent accidents. Probability of the system efficiency for detection the hazards and disaster prevention is connected to the reliability of predicted system and applied method of system use in the elimination of accidents.

On tailing dumps, due to the nature of work, the systems for detecting a potential hazard and elimination the accident are combined. They consist of installed devices at dam (piezometers) that are used for water measurement inside dam and flotation tailing dumps (indicating the lines of protruding water that affect the dam stability) and actions of responsible employees for detection the occurrences of hazards at the landfill (control of danger manifesting is done by their senses). This kind of protection from accidents, which mainly depends on the human factor, can be high. A size of safety probability on accidents using the combined system for detecting and preventing the accidents ranges from 0.2 to 0.8. Probability of efficiency (safety) of this type of hazard detection and prevention of accidents is closer to zero, and the risk of accidents is close to one. The efficiency of the system to detect the danger depends on the **priori** probabily:

Absence of control and non-compliance the rules

Damages caused by technical deficiencies (human factor) in normal (designed) conditions of operation the flotation tailing dumps, are considered as the accidents of errors or accidents due to the absence of control and non-compliance the rules. Those resulting from non-compliance the technology of disposal the flotation tailings, proposed by the design, careless operation and management of water level in the sedimentary lake inside the tailing dump, improper sizing or unreliable construction of collector (using the resistless concrete to acidic media) below the field and dam of tailing dump and disposal system as a whole.

Size of damage to ecosystems and ecological factors of the environment caused by the absence of control and non-compliance the rules

Size of damage to ecosystems and ecological factors of the environment, caused by the absence of control and non-compliance the rules depend on: the size of accident, size of landfill space (volume), type of delayed material, aggregate state of harmful substances, amount of harmful substances that may enter the environment, direction and range of harmful substances and sensitivity of ecosystem to harmful substances from the flotation tailing dumps.

Damage to ecosystems by breakthrough of flotation tailing can be of local, regional or international character. Local and regional damages of ecosystem are small in space and time (breakthrough of flotation tailings into the Saska River and Pek in Majdanpek). International damages of ecosystem are large in space and small in time (penetration the flotation tailings and cyanide s from the mine Baia Mare in Romania in the river Tisza, the Danube to the Black Sea). Both local and international damages to ecosystem after the formation decreased with time due to degradation of harmful substances or damaged areasare cleared, and then remediated what leading to the regeneration of ecosystem.

Probabailityof environmental disasters due to the accident errors at the local or international level is determined on the basis of the ratio of total and potential surfaces at the endangered area, duration of endangerous and presence the sensitive members of the environment system on the expression of increasing the concentrations of harmful effects to the environment.

6. AGGRESSIVE EFFECT OF WATER FROM THE FLOTATION TAILING DUMP ON CONCRETE LINING OF COLLECTOR AND TUNNEL

Tailing dump with its supporting facilities such as: sand dike, accumulation space, drainage, tunnels and collectors, is a specific mining facility. Hydrochemical processes, both in the accumulation itself and sand dikes, are present and very complex. This is helped by the fragmentation of minerals, contained in the flotation tailings, then the presence of water, air, temperature and pressure. Some processes have a harmful effect on the concrete lining of which the supporting facilities are built.

Chemically contaminated water at the flotation tailing dumps, act aggressively on concrete lining of collector. This aggressiveness is reflected in the ability of chemically contaminated water to isolate the components of concrete, or with the help of dissolved salts and gases destroy the concrete. Bonding ingredient of concrete is cement, which primarily represents the mixture of calcium silicates. The quality of cement is determined by the hydraulic model that represents the ratio of base component CaO to acidic ones:

$-SiO_2$, Al_2O_3, Fe_2O_3

$$\left(- \frac{\%CaO}{\%(SiO_2 + Al_2O_3 + Fe_2O_3)} \geq 2 \right) \quad (1)$$

Aggressiveness of water in the flotation tailing dump on concrete collector is manifested in several ways, depending on the chemical composition of water:

1. Aggressiveness of carbonic acid, aggressiveness of lime leaching, acid aggressiveness:

Carbonic acid activity consists in dissolution $CaCO_3$ under the influence of aggressive carbonic acid by the formula:

$$CaCO_3 + H_2CO_3 \leftrightarrow CO^{++} + 2HCO_3^{+} \quad (2)$$

Aggressiveness of leaching flows at the expense of $CaCO_3$ dissolution and separation of $Ca(OH)_2$ iz from concrete.

General acid aggressiveness is related to the content of free hydrogen ions. Water is more aggressive if pH = 5 ÷ 6,8.

2. Sulphate and magnesium aggressiveness:

Sulphate and magnesium aggressiveness is present in water with igh content of SO_4^{--} ions. In the water passage through concrete, the salt crystallization and formation of $CaSO_4$ $2H_2O$ salt is developed, which demolish the concrete.

Magnesium aggressiveness appears at high content of Mg $^{+++}$ ion and it is associated with the content of $SO_4^{--} \geq +50$ mg/l. All these types of aggressiveness are present in a greater or lesser extent in all flotation tailing dumps in our country.

The regular appearance is the **sulfate degradation** of concrete, namely the transition from base into acid water in the lower layers of deposited slime on the flotation tailing dumps is the result of pyrite oxidation FeS_2 and other sulphide minerals. At the effect of oxygen and in contact with moisture, sulfides react in terms of creating the sulfuric acid H_2SO_4 and ferrous sulfate $FeSO_4$. Ferrous sulfate is further oxidized to the trivalent ferric sulfate, which is then hydrolyzed until it becomes more acidic. The following simplified equations illustrate the mechanism of pyrite oxidation.

$$2FeS_2+7O_2+H_2O \rightarrow 2FeSO_4+2H_2SO_4 \quad ...(3)$$

The process is closely related to the weather conditions, amount of pyrite, degree of its fragmentation, and quality concrete lining construction. Sulphate degradation is more effective in a part where the "fast concrete" is built. Namely, due to segregation of gravel in some parts of the lining, the conditions for faster reaction of acid water are created and out of concrete components.

Content SO_4^{--} ions in the water of the flotation tailing dump in Majdanpek is, according to the research, the following:

Research site	SO_4^{--}	pH value
1.Drainage water	534 mg/l	6-7.8
2.Lake water	368 mg/l	11.4-11.8
3.Spilling water through collector lining	317 mg/l	6-8.28

On the tailing dumps of the lead zinc mines of the former Yugoslavia, SO_4 ions move above 1000 mg/l, and pH value of 4.5 to 9.5.

CONCLUSION

Causes of accidents in the flotation tailing dumps are technical defects and natural catastrophic ndisasters. Measures to be taken to combat the technical absencence are construction a collector of acid resistant concrete or the use of plastic pipelines below the flotation tailing dumps. Unfortunately, in the former Yugoslavia, all tunnels and collectors for deviation of rivers below the flotation tailing dumps were built of concrete not resistant to acidic media. Therefore, all tunnels and collectors suffered minor or major damages due to sulfate degradation of concrete. In building the flotation landfills (tailing dumps), the measures have to be applied that the accident errors would be minimum by tightening the controls and anticipated regulations.

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