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ASH AND BOTTOM ASH DENSE HYDROMIXTURE TRANSPORT

TRANSPORT PEPELA I ŠLJAKE U VIDU GUSTE HIDROMEŠAVINE

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Abstract: *The results of the tests on the most suitable concentration for the ash and bottom ash hydromixture transport are presented in the paper. The tests were accomplished at the semi-industrial installations. As the decisive parameters, the changes of the flow and the pressure in relation to the concentration change were analyzed. The results achieved shows that the transport should be accomplished with ash and bottom ash concentration below 50% of solids, but above 40% of solids. In this concentration range, there is a decrease of both the flow (per volume) and the pressure. However, this decrease is considerably small regarding the quantity of the ash and bottom ash transported during a time unit..*

Key words: *ash and bottom ash, thermal power plant Nikola Tesla B, hydromixture transport, flow decrease, pressure decrease, mass concentration*

Apstrakt: *U radu su prikazani rezultati ispitivanja najpovoljnije koncentracije za transport hidromešavine pepela i šljake. Ispitivanja su obavljena na poluindustrijskoj instalaciji. Kao opredeljujući parametri analizirani su promene protoka i pritiska u funkciji promene koncentracije. Dobijeni rezultati su pokazali da transport treba obavljati sa koncentracijama pepela i šljake ispod 50 %, ali i iznad 40 % čvrstog. Pri tim koncentracijama dolazi do pada protoka (posmatrano zapreminski) i pritiska, ali su oni zanemarljivo mali posmatrano preko količine suvog pepela i šljake koji se u jedinici vremena transportuje.*

ključne reči: *pepeo i šljaka, termoelektrana Nikola Tesla-B, transport hidromešavine, pad protoka, pad pritiska, masena koncentracija*

1 INTRODUCTION

The definition of the most suitable conditions for the dense ash and bottom ash hydromixture transport is a problem considered for past 20 years by the professionals. During that time, several plants for the ash and bottom ash transport in the form of the, so called, dense hydromixture were built (2 plants at the former SFRJ were built as well), but designed for operation with different solid concentrations and with different slurry pumps [Knežević et al., 1988.]. According to the

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Definisanje najpovoljnijih uslova za transport hidromešavine pepela i šljake velike gustine je problem koji zaokuplja stručnu javnost poslednjih 20-ak godina. U tom periodu izgrađeno je više postrojenja za transport pepela i šljake u vidu tzv. guste hidromešavine (2 postrojenja su izgrađena i na prostorima bivše SFRJ), ali su ona projektovana za rad sa različitim koncentracijama uz primenu različitih vrsta muljnih pumpi [Knežević et al., 1998.]. Prema iskustvu stečenom izgradnjom experience acquired by the build-up of the "Gacko" and "Kosovo-B" thermal power plants, the application of the centrifugal slurry pumps proven to be both justified and suitable, and the rationalization of the transport parameters had no key role, for the deposition conditions were dictated the solid/liquid ratio [Grbović et al 1990., Knežević, Moračić al., 1997.]. The ash and bottom ash of the "Nikola Tesla" thermal power plant show no tendency towards spontaneous (self) solidification, hence the solid/liquid ratio is only secondary, and therefore remained primarily connected with the transport conditions. Starting from these facts, the detailed tests at the semi-industrial installation were accomplished in order to define the conditions and transport parameters [Knežević et al., 2001.].

General facts on dense hydromixture

The concept of the "dense hydromixture" is not uniquely defined, which is not a common property of the technical concepts. The practical standard claims that when the concentration of the solid particle transported near to the maximally allowed concentration, the hydromixture is dense. Similarly, the dense hydromixture is the one with the concentration of at least 75% of the maximum transportable concentration.

Maximally allowed volume concentration depends on the type of the pump used for transport and the properties of the raw material transported.

For the centrifugal slurry pumps, which are most commonly used, the maximal allowed solids concentration ranges from 36% (Iron ores) to 42% (specifically light materials) [Knežević et al., 1998.]. Hence, the hydromixtures transported by the centrifugal slurry pumps, with the volume concentration over 30% are considered as dense.

With the piston pumps (and all of its variations and superstructures) the higher concentration can be achieved, depending on the raw material properties. When the material particles are smaller, and contain (even as an additive) some binding materials (such as lime, clay or cement) that preserve the hydromixture consistency, the higher concentration in transport can be achieved than while transporting the coarser and unbound materials. In the first mentioned case, the concentration reaches 80%, while in the latter they decrease to about 50%. With these pumps, the hydromixture is considered to be dense when the volume concentration crosses 40%.

postrojenja za transport guste hidromešavine pepela i šljake na termoelektranama »Gacko« i »Kosovo-B« primena centrifugalnih muljnih pumpi se pokazala opravdanom i pogodnom, a racionalizacija transportnih parametara nije imala primarnu ulogu jer su uslovi deponovanja primarno diktirali odnos čvrste i tečne faze [Grbović et al. 1990., Knežević, Moračić et al., 1997.]. Pepeo i šljaka sa termoelektrane »Nikola Tesla-B« ne pokazuju tendenciju ka spontanom (samo) očvršćavanju pa je sa aspekta deponovanja odnos čvrste i tečne faze sekundaran i time, primarno postao vezan za uslove transporta. Polazeći od ovakvih saznanja izvedena su detaljna ispitivanja na poluindustrijskoj instalaciji kako bi se definisali uslovi i parametri transporta [Knežević et al., 2001.].

Opšte o gustoj hidromešavini

Pojam "gusta hidromešavina" nije jednoznačno nedefinisan, što obično nije odlika tehničkih pojmova. U praksi, kada je zapreminska koncentracija čvrstih čestica, koje se transportuju, bliska maksimalno dozvoljenoj koncentraciji govori se o gustoj hidromešavini. Odnosno, kao gusta hidromešavina se smatra ona hidromešavinu kod koje je zapreminska koncentracija najmanje 75 % maksimalno moguće koncentracije koja se može transportovati.

Maksimalno dozvoljena zapreminska koncentracija zavisi od vrste pumpe koja se koristi za transport i karakteristika mineralne sirovine koja se transportuje.

Kod, najčešće korišćenih, centrifugalnih muljnih pumpi maksimalna koncentracija čvrstih čestica se kreće od 36 % (kod ruda gvožđa) do 42 % (kod specifički lakših materijala) [Knežević et al., 1998]. Dakle, hidromešavine koje se transportuju centrifugalnim muljnim pumpama i kod kojih zapreminska koncentracija pređe 30% smatraju se gustim.

Kod klipnih pumpi (i svih njenih varijacija i nadgradnji) postižu se veće koncentracije u zavisnosti od karakteristika mineralne sirovine. Kada je sirovina sitnija, a u građi (ili kao dodatak) ima vezivnih materijala (kreč, glina, cement) koji održavaju konzistentnost hidromešavine mogući su transporti sa većim koncentracijama nego kada se transportuju krupniji i nevezani materijali. U prvom slučaju koncentracije idu i do 80%, a u drugom padaju na 50%. Kod ovih pumpi se o gustim hidromešavinama govori uvek kada zapreminska koncentracija pređe 40 %.

The problem of the definition of the maximum achievable density for the transport of different sorts of ash and bottom ash is considered in several papers. Sive and Lazarus [Sive, A.W., Lazarus, J.H., 1987] have reached the conclusion that the centrifugal slurry pumps are applicable when the mass concentration is kept below 48%, based on their tests in the closed test circuit with varying flow (up to 100 dm^3/s) and with different velocities (up to 6.4 m/s). Verkerk [Verkerk C.G., 1994] tested the transport conditions for the South African thermal power plant ashes. The conclusion reached was that the mass concentration of 45% is the boundary value for the substitution of the centrifugal slurry pumps with the piston pumps.

The tests ascertained that the hydromixture with lower ash and bottom ash concentration acts as fluid, while as the concentration increases it become more like a "sliding panel". The boundary value of this change is set at 69±1% of mass concentration. The research of the Hungarian scientists [Debreczeni, E., Ladanyi, G., 1996] was accomplished at hydromixture densities between 1250 and 1400 kg/m^3, i.e. mass concentration ranging from 45 to 60% and volume concentration from 27 to 43%. It was concluded that the transport of the dense hydromixture alongside its economy benefits and improved safety enables the increase in the deposition height and lowers the probability of possible incidents. The major conclusion is that the future opportunities in ash and bottom ash transport lies in dense hydromixtures. Bunn and Chamers [Bunn T.F., Chamber A.J., 1993] have chosen the mass concentration of 56% of solids, resulting in density of 1400 kg/m^3, for the design of the dense hydromixture hydraulic transport system at the TPP "Vales Point". Singh have tested maximum concentration with pumpable hydromixture. This research resulted in a conclusion that the maximum concentration is 72% (mass). The pilot plant, assembled at the "Gledstone" thermal Power Plant in 1988, worked with the maximum concentration of 66.5% resulting in hydromixture density of 1600 kg/m^3 and the mixture viscosity of 90 mPa·s.

The tests on the TPP "Kosovo-B" [Knežević D., Moračić M., 1997] shows that the continual transport by centrifugal slurry pumps can be provided with an average mass concentration of 50% of solids (hydromixture density is 1412 kg/m^3). The hydromixture viscosity with this concentration is 20 mPa·s. As the concentration increases, the transport conditions sharply become poorer, and the viscosity reaches

Problem definisanja maksimalne gustine koja je ostvarljiva pri transportu različitih vrsta pepela i šljake razmatran je u više radova. Sive i Lazarus [Sive, Lazarus, 1987.] su svojim ispitivanjima u zatvorenoj test-petlji sa različitim protokom (do 100 l/s) i pri različitim brzinama (do 6,4 m/s) došli do zaključka da su centrifugalne muljne pumpe primenljive kada je masena koncentracija manja od 48%. Verkerk je ispitivao transportne uslove za pepele iz južnoafričkih termoelektrana. Pri tom je zaključio da je masena koncentracija od 45% granica na kojoj centrifugalne muljne pumpe treba zameniti klipnim.

Istraživanjima je utvrdio da se hidromešavina pri manjim koncentracijama pepela i šljake ponaša kao fluid da bi se povećanjem koncentracije počela ponašati kao "klizna ploča". Granica ove promene je pri masenim koncentracijama od 69±1%. Istraživanja mađarskih naučnika [Debreczeni, Ladanyi, 1996.] vršena su pri gustinama hidromešavine između 1250 i 1400 kg/m^3, odnosno pri masenim koncentracijama od 45 do 60 % i zapreminskim od 27 do 43%. Pri tome je konstatovano da transport guste hidromešavine pored ekonomičnosti i veće sigurnosti omogućava povećanje visine deponovanja i smanjuje verovatnoću i posledice eventualnih havarija. Kao zaključak se ističe da je budućnost transporta pepela i šljake u gustim hidromešavinama. Bunn i Chambers, 1993, su za projektovanje sistema hidrauličkog transporta guste hidromešavine na TE "Vales Point" odabrali rad sa masenom koncentracijom od 56% čvrstog što daje gustinu od 1400 kg/m^3. Singh je istraživao maksimalne koncentracije koje daju pumpabilnu hidromešavinu. Istraživanja je završio sa zaključkom da je to koncentracija od 72% (meseno). Pilot postrojenje koje je montirano na TE "Gledstone" 1988. radilo je sa maksimalnim koncentracijama od 66,5% što je davalo gustinu hidromešavine od 1600 kg/m^3 i viskozitet smeše od 90 mPa·s.

Istraživanja na pepelu TE Kosovo-B [Knežević, Moračić, 1997] pokazala su da je u industrijskim uslovima moguće obezbediti kontinualan transport centrifugalnim muljnim pumpama sa prosečnom masenom koncentracijom od 50% čvrstog (gustina hidromešavine je 1412 kg/m^3). Viskozitet hidromešavine pri toj koncentraciji je 20 mPa·s. Povećanjem koncentracije uslovi transporta se naglo pogoršavaju pa viskozitet

161 mPa·s. In industrial conditions, it is proved that the mixing and transport are accomplished in a satisfactory manner when the mass concentration is kept below 57% (density of 1500 kg/m^3). Any further concentration increase (even in time intervals of 1-2 minutes) threatens to block the transport because the mounted propeller blender can not accept all of the ashes and form the hydromixture, and both the suction power and hydrostatic pressure at the pump feed are insufficient for the provision of its continual feed.

pri koncentraciji od 60% čvrstog narasta na 161 mPa·s. U industrijskim uslovima je dokazano da se mešanje i transport obavljaju na zadovoljavajući način kada je masena koncentracija pepela ispod 57% (gustina 1500 kg/m^3). Svako dalje povećanje koncentracije (čak i periodima od 1-2 minuta) preti da blokira transport jer, montirani, propelerni mešač ne može da prihvati sav pepeo i formira hidromešavinu, a usisna moć pumpe i hidrostatički pritisak na ulazu u pumpu su nedovoljni da obezbede njeno ravnomerno hranjenje.

Dense hydromixture application

At the foreign thermal power plant, the incentives for the application of the dense hydromixture were the deposition conditions and ecological benefits that work with small quantities of water brings. However, in all of these conditions, the economy of the hydromixture transport (from the TPP to the disposal site) and the reclaim water (from the disposal site to the TPP) was also emphasized.

At the biggest Japanese thermal power plant (the planned power of the plant after its completion is 3400 MW), the old system of ash and bottom ash transport in the form of sparse hydromixture (mass concentration approx. 7% of solids) was replaced by the new transport system of dense hydromixture with the mass concentration of 60 to 70% of solids [Kronenberg J., 1993]. The reasons for the replacement of the old transport system can be expressed by the three facts, namely the significant deterioration of pumps, pipes and valves, huge energy consumption, especially for the reclaim water transport, and also the ecological problems induced by the presence of the large quantities of polluted water at the disposal. During the adjustments of transport conditions, the gypsum from the desulfuration of smoke gases plant was added to the ash and bottom ash as well. The piston pump KOS 2180 with an "S" curve, built by the "Pultzmeister" factory is used for the transport. The pipeline is 150 mm wide (in diameter) and the length varies from 300 m (at the beginning of the disposal exploitation), to 800 m (at the ending phase of the disposal exploitation), with transport velocity of 1.5 m/s. The actual capacity of the plant is 33 m^3/h, and the pressure needed for the transport ranges from 15 to 20 bars.

The similar system is applied at the "Vales point" thermal power plant in Australia [Bunn T.F., Chamber A.J., 1993]. The "Pultzmeister" KOS 1460 piston pump with an "S" curve is used for the transport of 45 m^3/h ash and bottom ash mixture

Primena guste hidromešavine

Na inostranim termoelektranama osnovni poticaj za primenu transporta guste hidromešavine bili su uslovi deponovanja i ekološke povoljnosti koje rad sa malim količinama vode donosi. Međutim, u svim uslovima je naglašavana i ekonomičnost transporta hidromešavine (u pravcu do TE do deponije) i povratne vode (u pravcu od deponije do TE).

Na najvećoj japanskoj termoelektrani (planirana snaga termoelektrane kada se potpuno završi izgradnja je 3400 MW) stari sistem transporta pepela i šljake u vidu retke hidromešavine (masena koncentracija oko 7% čvrstog) je zamenjen sa novim sistemom transporta guste hidromešavine sa masenom koncentracijom od 60 do 70 % čvrstog [Kronenberg, 1993]. Razlozi za zamenu starog transportnog sistema su iskazani u sledeće tri tačke: veliko habanje pumpi, cevi i ventila, velika potrošnja energije, posebno za transport povratne vode i ekološki problemi izazvani prisustvom velike količine zagađene vode u deponiji. Pri promeni transportnih uslova pepelu i šljaci je dodan i gips iz postrojenja za odsumporavanja dimnih gasova. Za transport se koristi klipna pumpa KOS 2180, sa "S" krivinom, fabrike "Pultzmeister". Cevovod ima prečnik 150 mm, dugačak je od 300 m (na početku eksploatacije deponije) do 800 m (u završnoj fazi eksploatacije deponije), a transportna brzina je 1,5 m/s. Stvarni kapacitet postrojenja je 33 m^3/h, a za transport je potrebno obezbediti pritisak od 15 do 20 bara.

U Australiji je na termoelektrani "Vales Point" primenjen sličan sistem [Bunn, Chamber, 1993.]. "Pultzmeisterova" pumpa KOS 1460, sa "S" krivinom, je upotrebljena za transport 45 m^3/h mešavine pepela i šljake do deponije koja je od termoelektrane udaljena 1740 m. Transport se to the disposal located 1740 m far from the TPP. The transport is accomplished through the pipeline wide 150 mm in diameter, with the pressure of approximately 60 bars. The technological flow sheet of this plant is presented at the Fig. 1.

obavlja kroz cevovod prečnika 150 mm, a pritisak potreban za transport je oko 60 bara. Tehnološka šema ovog postrojenja je prikazana na sl. 1.

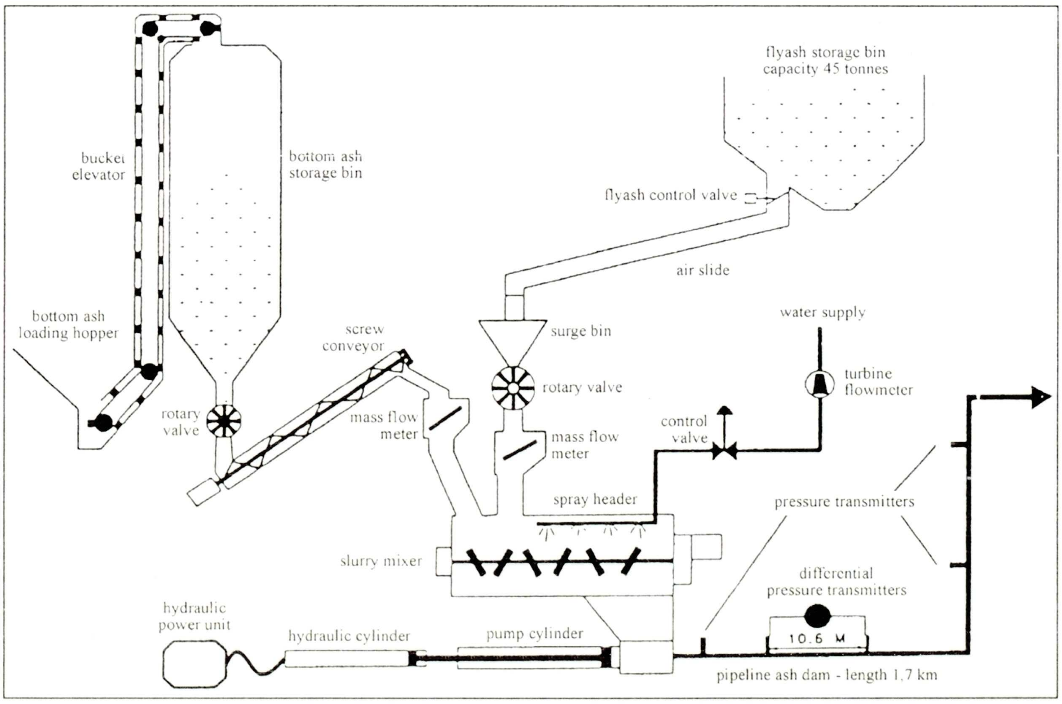

Figure 1 Flowsheet of the ash and bottom ash dense hydromixture transport at the "Vales point" TPP (Australia)

slika 1 Tehnološka šema postrojenja za transport guste hidromešavine pepela i šljake na TE "Vales Point" (Australija)

At the large South-African thermal power plant "Matia" (6x600 MW), the transport of dense ash and bottom ash hydromixture is applied [Sive, A.W., Lazarus, J.H., 1987]. Three working routines were designed: the transport of ash only (330 t/h with the solids concentration of 50%), the transport of the ash and bottom ash hydromixture in mass ratio 2:1 (220 t/h with the solids concentration of 50%), and the transport of bottom ash only (100 t/h with the solids concentration of 15%). The system was dimensioned for the fixed rate flow of 480 m^3/h, while the concentration varies depending on the solids quantity. The transport is accomplished through three pipelines of 250 mm in diameter. The length of the pipeline varies from 4526 to 8125 m, and the pump strain needed is accomplished by the line of five centrifugal slurry pumps. The reclaim water from the disposal is used for the hydromixture preparation.

Na velikoj južnoafričkoj termoelektrani "Matla" (6x600 MW) primenjen je transport guste hidromešavine pepela i šljake [Sive, Lazarus, 1987.]. Projektovana su tri radna režima: transport samo pepela (330 t/h sa koncentracijom od 50% čvrstog), transport mešavine pepela i šljake u masenom odnosu 2:1 (220 t/h sa masenom koncentracijom od 50 % čvrstog) i transport samo šljake (100 t/h sa masenom koncentracijom od 15%). Sistem je dimenzionisan za fiksni protok od 480 m^3/h, a u zavisnosti od količine čvrste faze menja se koncentracija. Transport se vrši kroz tri cevovoda prečnika 250 mm. Dužina cevovoda varira od 4526 do 8125 m, a potrebni napor se ostvaruje pomoću pet serijski vezanih centrifugalnih muljnih pumpi. Za pripremu hidromešavine koristi se i povratna voda sa deponije.

At the Australian thermal power plant "Bayswater" (2640 MW), the transport of the dense ash and bottom ash hydromixture to the disposal situated at the open pit 10 km far from the power plant is applied [Venton Ph. Et al., 1996]. The flowsheet is presented at the Fig. 2.

Na australijskoj termoelektrani "Bayswater" (2640 MW) primenjen je transport guste hidromešavine pepela i šljake do deponije locirane u površinskom kopu udaljenom 10 km od termoelektrane [Venton et al., 1996.]. Tehnološka šema je prikazana na slici 2.

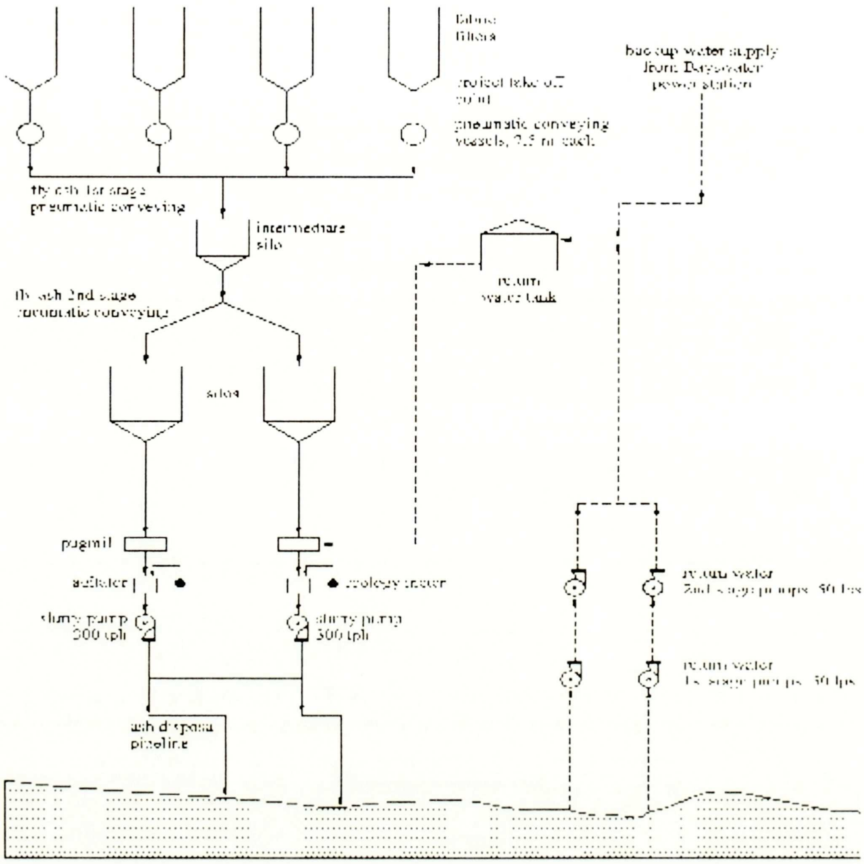

Figure 2 Flowsheet of the preparation and the transport of ash and bottom ash at the TPP Bayswater (Australia)

slika 2 Tehnološka šema pripreme i transporta pepela i šljake na TE Bayswater (Australija)

Dry ash is collected in two silos of 2000 m^3 in volume. From the silo, the ash is transported to the two-stage mixing and hydromixture formation. The hydromixture mass concentration varies from 65 to 75% (45 – 48% by volume) of solids. The plastic viscosity of the hydromixture vary from 80 to 200 mPa·s. The designed flow of the hydromixture is 250 m^3/h, but the pump can transport only 300 m^3/h. The reclaim water from the disposal is used for hydromixture preparation. The transport is accomplished with the high pressure pumps ("GEHO" triplex piston pump with a diaphragme), with the maximum pressure of approximately 15 MPa. At the nominal flow of approximately 250 m^3/h, the working pressure of the piston pump is 9.2 MPa, while for the purpose of removing blockades and restarting at the flow of 20 m^3/h, the pump can provide maximal pressure of 15 MPa. Two steel pipelines ND 200 are used for the transport. The restart of the transport system is planned within 24 hours from the halt moment. If the system is not started before this deadline, the pipeline is rinsed. The system is automated.

Suvi pepeo se skuplja u dva silosa zapremine od po 2000 m^3. Iz silosa pepeo odlazi na dvostepeno mešanje i formiranje hidromešavine. Masena koncentracija hidromešavine varira od 65 do 75 % (45 – 48 % zapreminski) čvrstog. Plastični viskozitet hidromešavine varira od 80 do 200 mPa·s. Projektovani protok hidromešavine je 250 m^3/h, s tim da pumpa može da transportuje maksimalno 300 m^3/h. Za pripremu hidromešavine se koristi povratna voda sa deponije. Transport se obavlja visokopritisnim pumpama ("GEHO" tripleks klipna pumpa sa dijafragmom) pri maksimalnom pritisku od oko 15 MPa. Radni pritisak klipne pumpe pri nominalnom protoku od 250 m^3/h iznosiu 9,2 MPa, a za deblokiranje i restartovanje pumpa za protok od 20 m^3/h obezbeđuje maksimalni pritisak od 15 MPa. Za transport se koriste 2 čelična cevovoda ND 200. Predviđen je restart transportnog sistema u roku od 24 časa od trenutka stajanja. Ako system ne startuje u tom roku vrši se ispiranje cevovoda. Sistem je automatizovan.

In our thermal power plants, the dense hydromixture was applied in 1988 at the Gacko TPP for the first time [Grbović M. et al., 1990]. The reason for the application of the dense hydromixture was neither a transport nor its optimization, but disposal conditions (and benefits) of this ash with some special features. In other words, the decision on the transport conditions was based on the flowsheet presented at the Fig. 1, for the calcium ash to be disposed at the "problem" soil (karsts). The system of dense hydromixture transport worked discontinuously. The ash was transported by the tank trucks to the stirred, situated near the disposal. After the mixing process with water in 1:1 ratio, the ash was released into the disposal space. The transport was gravity based, through the pipeline of 150 mm in diameter, with maximum length of approximately 1000 mm. The flowsheet of the preparation process and the transport of dense hydromixture at the "Dražljevo" disposal of the TPP "Gacko" is presented at the Figure 3.

Na našim termoelektranama gusta hidromešavina je primenjena prvi put 1988. na TE Gacko [Grbović M. et al., 1990.]. Razlog za primenu guste hidromešavine nije bio transport niti njegova optimizacija već uslovi (i povoljnosti) deponovanja ovoga pepela specifičnih karakteristika. Odnosno, odlučivanje o transportnim uslovima baziralo se na šemi prikazanoj na slici 1, za kalcijski pepeo koji treba deponovati na "problematičnom" terenu (kras). Sistem transporta guste hidromešavine je radio diskontinualno. Do mešača, lociranog neposredno uz deponiju, pepeo je dovožen autocisternama. Nakon mešanja sa vodom u masenom odnosu 1:1 ispuštan je u prostor za deponovanje. Transport je bio gravitacijski kroz cevovod prečnika 150 mm, a maksimalna dužina transporta bila je oko 1000 m. Tehnološka šema pripreme i transporta guste hidromešavine na deponiji "Dražljevo" TE "Gacko" prikazana je na sl. 3.

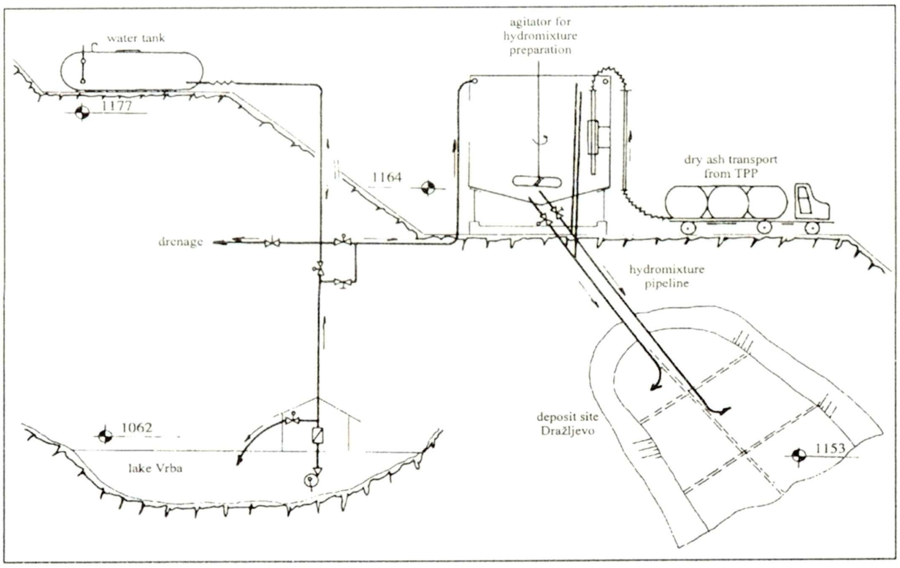

Figure 3 Flowsheet of the dense hydromixture transport at the TPP Gacko
slika 3 Tehnološka šema transporta guste hidromešavine na TE Gacko

At the TPP Kosovo B, where the transport in the form of dense hydromixture is applied since 1997, there are two reasons for the application of dense hydromixture: the lack of water and properties of ash (silica-calcium) [Knežević D., Moračić M., 1997]. The ash and bottom ash are stirred in the conditioner, accomplishing concentration (by weight) of 50%. The transport is accomplished through the pipeline of 200 mm in diameter, while the length is approximately 2200 m. Centrifugal slurry pumps are used for the transport. Only one pump is sufficient for the first phase, and in the second phase the two pumps will make a serial connection, because the total strain needed is approximately 10 bars. The flowsheet of preparation and the transport of dense hydromixture at the "Kosovo – B" TPP is presented at Figure 4.

Kod TE Kosovo-B, kod koje se transport u vidu guste hidromešavine primenjuje od 1997.g., imaju dva razloga za primenu guste hidromešavine: manjak vode i karakteristike pepela (silikatno-kalcijski) [Knežević D., Moračić, 1997.]. Pepeo i šljaka se mešaju u kondicioneru ostvarujući pri tome koncentraciju (po masi) od 50 %. Transport se obavlja kroz cevovod prečnika 200 mm, a dužina cevovoda je oko 2200 m. Za transport se koriste centrifugalne muljne pumpe. U prvoj fazi dovoljna je samo jedna pumpa, a u drugoj fazi će se dve pumpe serijski vezati jer je potreban ukupni napor od oko 10 bara. Tehnološka šema pripreme i transporta guste hidromešavine na "TE Kosovo-B" prikazana je na sl.4.

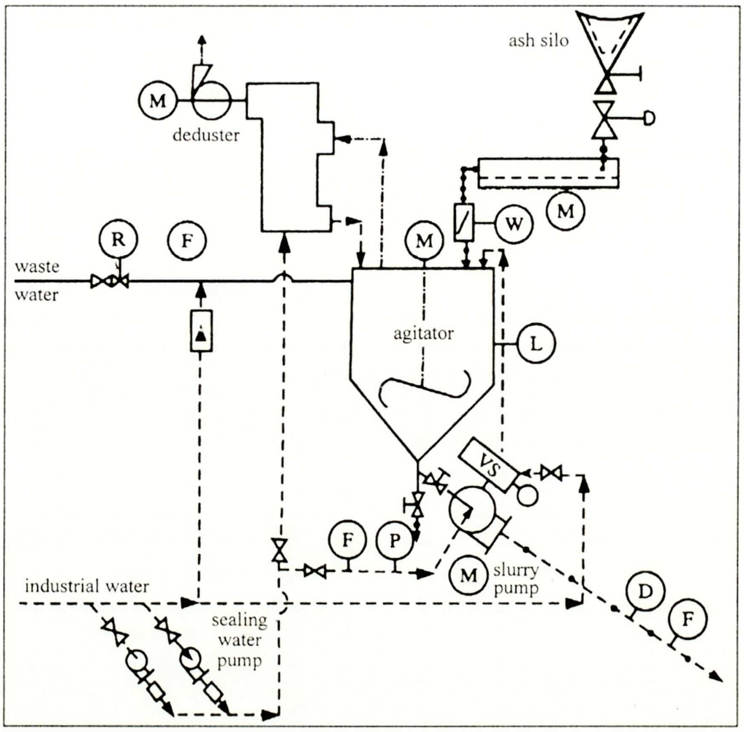

Figure 4 Flowsheet of the dense hydromixture transport at the TPP Kosovo B
slika 4 Tehnološka šema transporta guste hidromešavine na TE Kosovo-B

At our other thermal power plants, the ash properties did not dictate the transport conditions in particular (except for the TPP "Kosovo-A"), and handling with large quantities of water (and its inadequate evaluation), lead to the application of hydraulic transport in the form of sparse hydromixture (C_w < 10%). It was only in recent years when the transport of dense hydromixture has become a regular industrial practice, and consultations on the application of dense hydromixture transport have begun, wtih technical benefits and savings (in energy, water, money) as the main reasons for this.

Kod naših ostalih termoelektrana karakteristike pepela nisu posebno diktirale uslove transporta (sem kod TE Kosovo-A), a raspolaganje dovoljnim količinama vode (i njeno nedovoljno vrednovanje) doveo je do primene hidrauličkog transporta u vidu retke hidromešavine (C_w<10%). Tek poslednjih godina kada je, u industrijskim uslovima, zaživeo transport guste hidromešavine počeli su razgovori o transportu i silikatnih pepela u vidu guste hidromešavine. Kao razlog počinje pominjanje tehničkih povoljnosti i ušteda (energije, vode, novca itd.).

For the dense hydromixture transport of ash and bottom ash, the papers of Sellgren and associates are of significance.

Za transport pepela i šljake u vidu guste hidromešavine interesantni su radovi Sellgrena i saradnika

Samples

For the purpose of the transport conditions definition at the future TPP "Kolubara-B", laboratory tests on the ash and bottom ash transport conditions as the dense hydromixture were accomplished. The tests were completed on the mixtures of ash and bottom ash, with the quantity ratio of 9:1. The moisturized bottom ash is sampled from the thermal power plant "Nikola Tesla-B" Block 1 belt conveyor, and the dry ash from the pneumatic ejector of the same Block.

Uzorci

Za potrebe definisanja uslova transporta na budućoj TE "Kolubara-B" obavljena su laboratorijska ispitivanja uslova transporta pepela i šljake u vidu guste hidromešavine. Ispitivanja su obavljena na mešavinama pepela i šljake, sa međusobnim masenim odnosom od 9:1. Ovlažena šljaka je uzorkovana sa trake bloka 1 termoelektrane »Nikola Tesla-B«, a suvi pepeo na izlazu iz pneumetskog ejektora istog bloka.

For the hydromixture preparation, drinking water of Belgrade water supply was used.

Za pripremu hidromešavine korišćena je voda za piće iz beogradskog vodovoda.

General properties of ash and bottom ash

Osnovne karakteristike šljake i pepela

Size distribution of ash was determined by wet sieving on the Tyler series of sieves, and is presented in Table 1.

By mixing the ash and bottom ash in mass ratio 9:1, a mixture with the top boundary size of 0.9 mm, and the medium particle diameter of 0.1 mm. This shows that the material is of fine size and that it should form a heterogenous hydromixture with water.

The results of ash and bottom ash chemical analysis are given in Table 2.

Granulometrijski sastav pepela određen je mokrim prosejavanjem na seriji sita Tyler, a prikazan je u tabeli 1.

Mešanjem pepela i šljake u masenom odnosu 9:1 dobija se mešavina sa gornjom graničnom krupnoćom zrna od 0,9 mm i srednjim prečnikom zrna od 0,1 mm. Ovo ukazuje da se radi o fino usitnjenom materijalu koji treba da sa vodom formira heterogenu hidromešavinu.

Rezultati hemijske analize pepela i šljake dati su tabeli 2.

Table 1 Size distribution
Tabela 1 Granulometrijski sastav

Size intervals, mm	Undersize, cumulative, %
-4.699+3.327	100.00
-3.327+2.362	99.57
-2.362+1.651	98.9
-1.651+1.168	97.87
-1.168+0.833	96.26
-0.833+0.589	94.47
-0.589+0.417	92.48
-0.417+0.295	90.47
-0.295-0.417	86.18
-0.208-0.295	75.98
-0.147-0.208	65.07
-0.104-0.147	55.75
-0.074+0.0	37.48
Medium particle diameter	0.19

Table 2 Chemical analysis results
Tabela 2 Rezultati hemijske analize

Component	Part, %	
	Without heat loss	With heat loss
SiO_2	54.31	50.92
Al_2O_3	22.53	21.12
Fe_2O_3	6.44	6.04
CaO	6.33	5.93
MgO	4.41	4,13
SO_2	2.80	2.63
P_2O_5	0.090	0.084
TiO_2	1.08	1,01
Na_2O	0.43	0.40
K_2O	1.37	1.28
LOI	-	6.25

On the basis of chemical analysis results, it can be concluded that the ash and bottom ash belong to the silica ashes group. The main components are silica, alumina and iron oxides which participate with approximately 80% in ash and bottom ash structure.

Na osnovu rezultata hemijske analize može se konstatovati da pepeo i šljaka spadaju u grupu silicijskih pepela. Osnovne komponenete su oksidi silicijuma, aluminijuma i gvožđa koji zajedno učestvuju sa oko 80 % u građi pepela i šljake.

Test installation

The installation for transport condition tests was built at the Mineral Processing Department laboratory of the Mining and Geology Faculty in Belgrade. The flowsheet of the installation for condition testing is presented at the Figure 5, while the block scheme of measuring system is presented at the Figure 6.

Ispitna instalacija

Instalacija za ispitivanje uslova transporta formirana je u laboratoriji na Katedri za PMS Rudarsko-geološkog fakulteta u Beogradu. Tehnološka šema instalacije za ispitivanje uslova transporta je prikazana na slici 5., a blok šema merenja na slici 6.

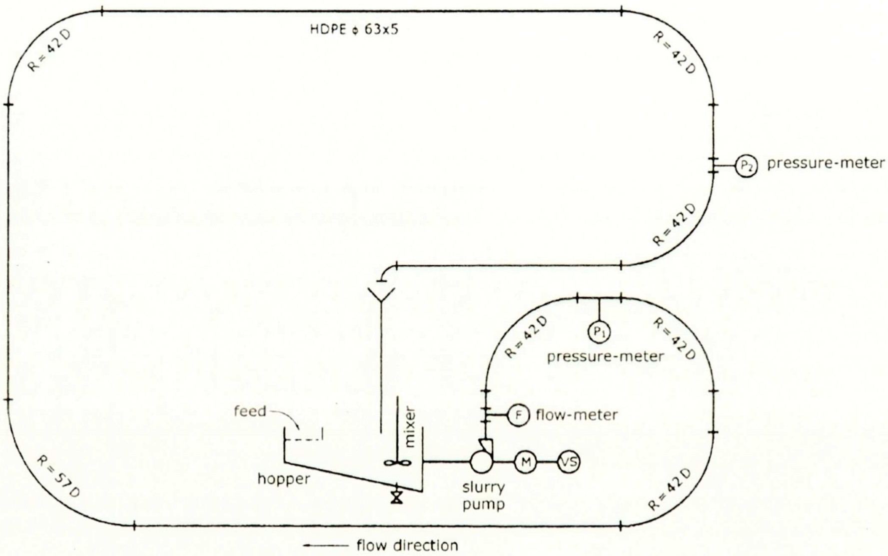

Figure 5 Flowsheet of the test installation
slika 5 Tehnološka šema ispitne instalacije

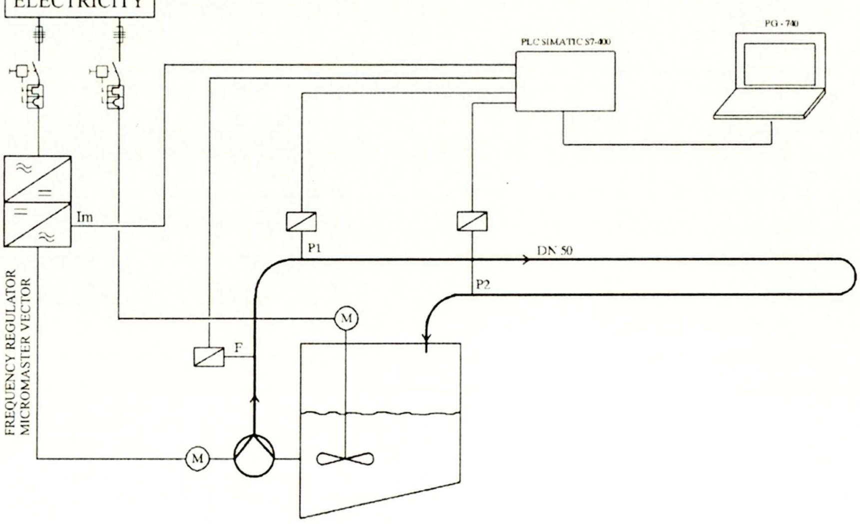

Figure 6 Block scheme of the measuring system
slika 6 Blok-šema merenja

The plan and the procedure of testing

The tests were accomplished by completing the water transport and monitoring of parameters for water. After that, in this water (of the unchanged quantity), ash and bottom ash mixture was added, until the desired mass concentration is reached. The tests were accomplished with the following concentration of solid and liquid components: 1:1.92 (C_w = 34.2%); 1:1,485 (C_w=40.2%); 1:1,015 (C_w=49.6%) and 1:0.9 (C_w=54.6%).

Hydromixture feature

Different behavior of hydromixtures formed of the solid phase of different size at different concentrations, lead to the general division of hydromixtures to homogenous and heterogeneous [Wasp et al., 1977]. The homogenous hydromixtures are also called the non-settling hydromixtures, while heterogeneous are called two-phased and settling hydromixtures.

The homogenous hydromixtures are best described by reological parameters. For the definition of the transport regime, it is essential to know the Reynolds' number, because it presents the ratio of inertia and viscosity forces. On the contrary, the heterogeneous hydromixtures can not be described precisely enough by the Reynolds' number, because the viscosity (due to the different behavior of two independent phases on the different parts of the pipeline cross section) does not define the behavior of the hydromixture in whole. The heterogeneous hydromixtures are best described by the Froude's number which is the ratio of the forces of inertia and gravity. The justification of the gravity force is originated from the heterogeneous hydromixture property of particle settling at the bottom of the pipe.

According to the size analysis results, the top boundary size of the ash and bottom ash is approximately 1.5 mm (1,500μ), and this size of particles puts the hydromixture among the heterogeneous. However, during the work on the test installation it was noted that:

- when the mass concentration of the hydromixture is below 40% of solids, the hydromixture behaves as the heterogeneous, because in every moment, the two phases can be independently spotted in the slurry pump box. At the end of the thrust pipeline (placed vertically) the discharge occurs at the pipe brim, while at the time of decrease in flow, the "burst" of the stream can be viewed easily at the pipe exit,

Plan i procedura ispitivanja

Ispitivanja su obavljena tako što je najpre obavljen transport vode i snimanje parametara za vodu, da bi se potom u tu vodu, čije količina je ostajala nepromenjena, dodavala mešavina pepela i šljake do postizanja odgovarajuće masene koncentracije. Ispitivanja su obavljena sa sledećim koncentracijama čvrste i tečne komponente: 1:1,92 (C_w = 34,2 %); 1:1,485 (C_w = 40,2 %); 1:1,015 (C_w = 49,6 %) i 1:0,9 (C_w = 54,6 %);

Karakter hidromešavine

Različito ponašanje hidromešavina formiranih od čvrste faze različite krupnoće pri različitim koncentracijama dovelo je do opšte podele hidromešavina na homogene i heterogene [Wasp et al., 1977]. Homogene hidromešavine se nazivaju i netaložne hidromešavine. Heterogene se zovu dvofazne i taložne hidromešavine .

Homogene hidromešavine se najbolje opisuju reološkim parametrima. Za definisanje režima transporta bitno je poznavati Reynolds-ov broj zato što on predstavlja odnos sila inercije i viskoziteta. Nasuprot njima, heterogene hidromešavine se ne mogu dovoljno precizno definisati Reynolds-ovim brojem jer kod njih viskozitet (zbog različitog ponašanja dve nezavisne faze, na različitim delovima poprečnog preseka cevovoda) ne definiše ponašanje celokupne hidromešavine. Heterogene hidromešavine se najbolje opisuju Froude-ovim brojem koji predstavlja odnos sila inercije i gravitacije. Opravdanost uvođenja sile gravitacije proizilazi iz osobine heterogenih hidromešavine da se čestice talože na dnu cevi.

Prema rezultatima granulometrijske analize gornja granična krupnoća mešavine pepela i šljake kreće se oko 1,5 mm (1.500 μm) te ova krupnoća svrstava hidromešavinu među heterogene. Međutim, tokom rada na ispitnoj instalaciji uočeno je sledeće:

- kada je masena koncentracija hidromešavine ispod 40 % čvrstog hidromešavina se ponaša kao heterogena jer se u svakom momentu vizuelno uočavaju obe faze u sanduku muljne pumpe, na kraju potisnog cevovoda (postavljen je vertikalno) pražnjenje se obavlja po obodu cevi, a pri smanjenju protoka lako se uočava »kidanje« mlaza na izlazu iz cevi,

- when the mass concentration reaches 50% of solids, the behavior of hydromixture changes completely, because visually, it can be noted that the mixture have the look of a "paste", in which only by touch the coarser particles impact can be spotted. Besides, at the end of the thrust pipeline, the discharge takes place through the middle part of the pipe (discharge in the form of "rope", like the one at hydrocyclone with the overflow opening under dimensioned), and regardless of the flow, the stream "burst" does not occur.

From the previous observations, it can be concluded that all the tested hydromixtures behaves as the heterogeneous while the mass concentration is below 40%, or as quasi-homogenous with concentration above 50% of solids. Somewhere in between, a transition of one form into another occurs.

From the practical point of view, this behavior of hydromixture suggests that it should be treated as the heterogeneous and that all calculations must be adjusted accordingly.

The influence of solids concentration on the flow

It is known from the literature that the high concentration of hydromixture influence the hydromixture flow, i.e. the capacity of the slurry pump, but different hydromixture behaves differently. The most dramatic decrease is noted with the ash transport (approximately 50%), while with the red slime the decrease is approximately 6%, and with the kaolines and phosphates approcimately 3% [Sellgren A., Addie G., 1995].

The task of this part of the research was to determine by which concentrations the flow decrease occurs, and how big it is. The results were statistically processed and presented at Figure 7.

From the results shown at the diagram on Fig. 7, and the Table 3, it is evident that the significant flow decrease does not occur until the mass concentration reaches the level of approximately 50% of solids. This results confirms the observation that the hydromixture features are changed with the change of concentration.

If the flow decrease is analysed at the fixed slurry pump revolution (1500 min^{-1} is adopted) in relation to the flow achieved during the pure water transport, the results obtained are presented in Table 3.

- kada masena koncentracija dostigne 50 % čvrstog ponašanje hidromešavine se u potpunosti menja jer se vizuelno uočava da mešavina ima izgled »paste« kod koje se tek pod rukom mogu uočiti udari krupnijih zrna, potom na izlazu iz potisnog cevovoda pražnjenje se obavlja kroz središnji deo cevi (pražnjenje u obliku »užeta« kao kod hidrociklona kod kojega je poddimenzionisana veličina otvora za »pesak«), a bez obzira na protok ne uočava se kidanje mlaza.

Iz prethodnih zapažanja može se zaključiti da se sve ispitivane hidromešavine ponašaju kao heterogene dok im je masena koncentracije ispod 40 %, a kao kvazihomogene kada im koncentracija pređe 50 % čvrstog. Negde između ovih koncentracija vrši se prelaz iz jednog oblika u drugi.

S praktičnog aspekta ovakvo ponašanje hidromešavine upućuje da je treba tretirati kao heterogenu i da sve proračune treba tome prilagoditi.

Uticaj koncentracije čvrstog na protok

Iz literature je poznato da visoka koncentracija hidromešavine ima uticaj na protok hidromešavine, odnosno kapacitet muljne pumpe, ali se različite hidromešavine različito ponašaju. Najdramatičniji pad se beleži pri transportu pepela (oko 50%), dok kod crvenog mulja pad iznosi oko 6, a kod kaolina i fosfata oko 3 % [Sellgren, Addie, 1995].

Zadatak ovog dela ispitivanja bio je da se utvrdi pri kojim koncentracijama dolazi do pada protoka i koliko iznosi. Rezultati su statistički obrađeni i prikazani na slici 7.

Iz rezultata prikazanih na prethodnom dijagramu i tabeli 3 evidentno je da se značajniji pad protoka beleži tek kada masena koncentracija dostigne nivo od oko 50 % čvrstog. Ovakav rezultat potvrđuje zapažanja po kojem se karakter hidromešavine menja sa promenom koncentracije.

Ako se pri fiksnom broju obrtaja muljne pumpe (usvajamo 1500 min^{-1}) analizira pad protoka u odnosu na protok pri transportu čiste vode dobiju se rezultati prikazani u tabeli 3.

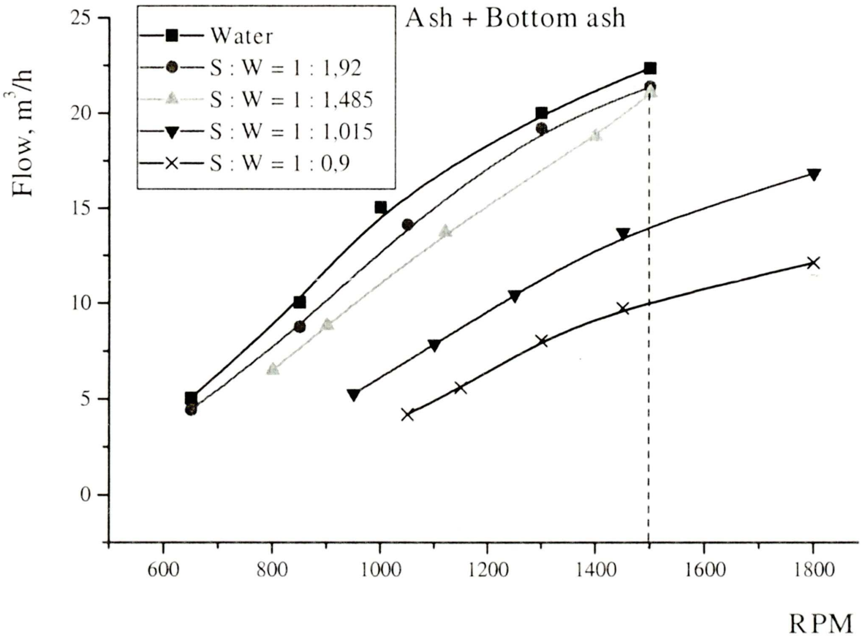

Figure 7 The influence of solids concentration on the flow decrease during the ash and bottom ash transport
slika 7 Uticaj koncentracije čvrstog na pad protoka pri transportu pepela i šljake

Table 3 The comparison of the flow at the slurry pump revolution of 1500 min^{-1} depending on the hydromixture concentration
Tabela 3 Poređenje protoka pri broju obrtaja muljne pumpe od 1500 min^{-1} u zavisnosti od koncentracije hidromešavine

Concentration		HM* density, kg/m^3	HM flow, m^3/h	HM flow in relation to the water flow, %	HM flow in relation to the flow of HM with the smallest density
solid : liquid	C_w, % solid				
-	-	1.000	22.371	100.00	-
1:1.92	34.2	1.200	21.379	95.57	100.00
1:1.485	40.2	1.240	21.040	94.05	98.41
1:1.015	49.6	1.340	13.717	61.32	64.16
1:0.9	52.6	1.400	9.743	43.55	45.57

* HM-Hydromixture

If the flow is observed by the volume as the quantity of hydromixture being transported during one time unit, then it is evident that the flow decrease is 6% at concentrations below 40%, at the concentrations of approximately 50%, the decrease reaches approximately 35%, while at the concentration of 52.6%, the decrease is above 55%.

If the data collected are recalculated to the quantity of dry ash and bottom ash transported at this flows, the data presented in Table 4 are obtained.

Ako se protok posmatra zapreminski kao količina hidromešavine u koja se transportuje u jedinici vremena onda je evidentno da je pri koncentracija ispod 40 % čvrstog smanjenje protoka do 6 %, a kod povećanja koncentracije na oko 50 % smanjenje protoka je oko 35 %, da bi pri koncentraciji od 52,6 % smanjenje bilo iznad 55 %.

Ako se dobijeni podaci prevedu na suvu količinu pepela i šljake koji su transportovani pri ovim protocima dobiju se podaci prikazani u tabeli 4.

Table 4 The recalculated quantity of ash and dry ash being transported with the concentration change and the fix revolution rate of slurry pump (1,500 min^{-1})

Tabela 4 Preračunata količina suvog pepela i šljake koji se transportuju pri promeni koncentracije i fiksnom broju obrtaja muljne pumpe (1.500 min^{-1})

Concentration		HM* density, kg/m^3	HM flow, m^3/h	Dry ash and bottom ash quantity, t/h	Changes in the quantity of the ash and bottom ash transported
solid : liquid	C_w, % solid				
-	-	1.000	22.371	100.00	-
1:1.92	34.2	1.200	21.379	95.57	100.00
1:1.485	40.2	1.240	21.040	94.05	98.41
1:1.015	49.6	1.340	13.717	61.32	64.16
1:0.9	52.6	1.400	9.743	43.55	45.57

The results obtained shows that the transport of the dense hydromixture is more favorable than the transport of sparse hydromixture below densities of approximately 50%, despite the actual flow decrease with the same working conditions of the pumps. The mass concentration of approximately 40% of solids is proven to be the most profitable. It is important to notice that the hydromixture transport with mass concentration of 50% is more favorable than the one with 34%, despite the actual flow decrease by ½.

Dobijeni rezultati pokazuju da je transport guste hidromešavine povoljnije od transporta retke do gustine od oko 50 % č, uprkos faktičkom padu protoka pri istim radnim uslovima pumpe. Kao najisplativija se pokazuje masena koncentracija od oko 40 % čvrstog. Važno je primetiti da je povoljniji transport hidromešavine masene koncentracije od 50% nego 34%, uprkos faktičkom smanjenu protoka za 1/2.

The influence of solids concentration on the pressure decrease in pipeline

From the literature [Sellgren A., Addie G., 1993] is known that the high concentration of hydromixture has the influence on the pressure decrease in the pipeline. The results of the monitoring of the influence of ash and bottom ash concentration on the pressure decrease in the pipeline were statistically processed and presented at Figure 8.

It is evident that with the increase of the solid component part, the pressure decreases more and more, and that difference is growing as the hydromixture flow increases. In conditions of lower concentration by 40%, the pressure decrease is only just bigger from the decrease when the water is transported, but with the concentrations above 50%, a more significant increase can be observed.

The influence of the solid phase concentration on the pressure decrease at the fixed revolution rate of the slurry pump (1500 min^{-1} was adopted), is presented in the Table 5.

Uticaj koncentracije čvrstog na pad pritiska u cevovodu

Iz literature [Sellgren, Addie, 1993.] je poznato da visoka koncentracija hidromešavine ima uticaj na pad pritiska u cevovodu. Rezultati snimanja uticaja koncentracije pepela i šljake na pad pritiska u cevovodu su statistički obrađeni i prikazani na slici 8.

Evidentno je da se sa povećanjem učešća čvrste komponente povećava i pad pritiska te da razlika raste sa povećanjem protoka hidromešavine. U uslovima kada je koncentracija niža od 40 % pad pritiska je relativno malo veći od pada pritiska kada se transportuje voda, ali se kod koncentracija iznad 50 % beleži značajno povećanje.

Uticaj koncentracije čvrste faze na pad pritiska pri fiksnom broju obrtaja muljne pumpe (odabrano 1500 min^{-1}) je prikazan u tabeli 5.

Table 5 Pressure decrease at different concentration of ash and bottom ash and the fixed revolution rate of the slurry pump of 1500 min^{-1}

Tabela 5 Pad pritiska pri različitim koncentracijama pepela i šljake i fiksnom broju obrtaja muljne pumpe od 1500 min^{-1}

HM concentration		Flow, Q	Pressure difference, Δp	Δp/Q		Quantity of dry ash and bottom ash, R	Δp/R	
solid : liquid	C_m	m^{3}Ðh	bar	bar m^{3}Ðh	%	t/h	bar/t/h	%
-	%, solids							
1	2	3	4	5	6	7	8	9
Water		22.371	0.760	0.03397	82.54	-		
1:1.92	34.2	21.379	0.880	0.04116	100.00	8.723	0.10088	100.00
1:1.485	40.2	21.040	0.961	0.04567	110.96	10.488	0.09163	90.83
1:1.015	49.6	13.717	0.981	0.07152	173.75	9.117	0.10760	106.66
1:0.9	52.6	9.743	0.930	0.09545	231.90	7.175	0.12962	128.49

Comment: The data in columns 1,3 and 4 are originated from measurements, while the data from columns 2, 5, 6, 7, 8 and 9 are calculated.

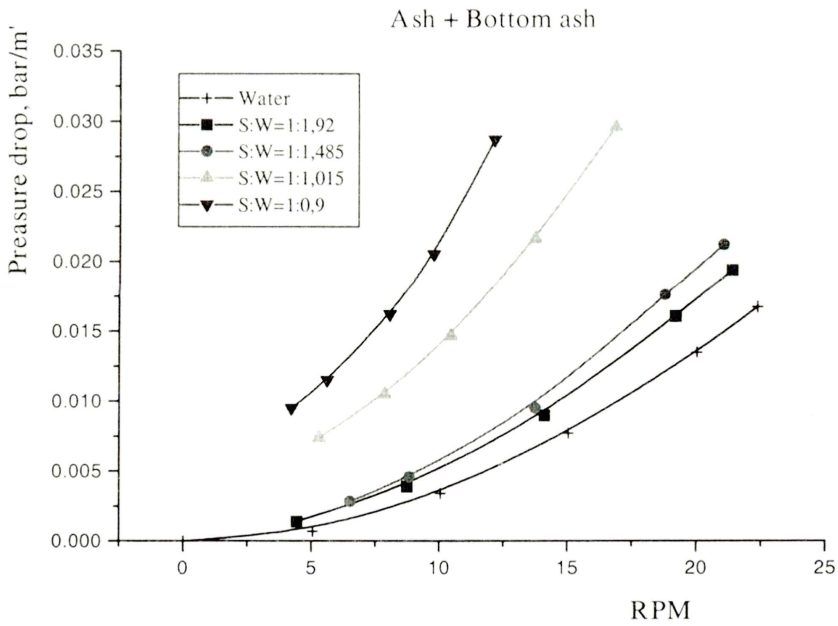

Figure 8 The influence of ash and bottom ash concentration on the pressure decrease
slika 8 Uticaj koncentracije pepela i šljake na pad pritiska

The results obtained shows that the energy consumption (pressure decrease) increases as the concentration increase, despite the nominal flow decrease. At the same time, the results presented in columns 8 and 9 shows that the real energy consumption, calculated on the basis of the transport of one tone of dry material, is the lowest at 40% solids, and approximately equal during the transport of hydromixtures with 34 and 50% solids concentration. This again points out that the transport of ash and bottom ash hydromixture should be accomplished at mass concentrations below 50%, but above 40%.

Dobijeni rezultati pokazuju da se potrošnja energije (pad pritiska) povećava sa povećanjem koncentracije uprkos nominalnom padu protoka. Istovremeno rezultati prikazani u rubrikama 8 i 9 pokazuju da je stvarna potrošnja energije, kada se preračuna na transport tone suvog materijala, najmanja pri koncentraciji od oko 40 % čvrstog, a da je približno jednaka pri transportu hidromešavine koncentracije 34 i 50 % čvrstog. Ovo ponovo ukazuje da transport hidromešavine pepela i šljake treba obavljati pri masenim koncentracijama ispod 50%, a iznad 40%.

CONCLUSIONS

The tests on the influence of the ash and bottom ash concentration on the change of flow and pressure in the conditions of hydraulic transport of dense hydromixture were accomplished in order to define the most favorable concentration of the hydromixture for the hydraulic transport. The tests were accomplished in the concentration range from 34.2% to 52.6% (by weight).

It was shown, that as the concentration increases, the significant changes in flow occurs, namely, it decrease by more than a half when the concentration is higher than 50% of solids.

However, the success of the transport is measured by the quantity of dry material transported during one unit of time, hence if the calculation is completed on the basis of the dry ash and bottom ash quantity, it can be seen that the mass decreases by 20% at the highest concentration tested (52.6%) in comparison with the lowest concentration tested (43.2%). It is also of importance to notice that the quantity of the material being transported increases, for the transport of concentrations between 40 and 50%.

The tests on the pressure decrease have shown that the energy losses are the highest when the concentration crosses 50% of solids, and the transport with concentrations between 40 and 50% is the most favorable. The tests and observations of the hydromixture features have shown that the hydromixture with concentration below 40% of solids behaves as the heterogeneous, or as quasi – homogenous, when the concentration is higher than 50%. Therefore, concentrations considered to be the most favorable are those in the transition zone from the heterogeneous (which is the actual state of the hydromixture, according to size distribution of ash and bottom ash) to quasi – homogenous (as the result of concentration increase).

From the practical point of view, the performed tests have discovered a relatively wide range within which the balanced ratio of the solid and liquid phase should be looked for. As the next step, the tests should be directed toward the more precise definition of the concentration, by leading the tests only in the concentration range between 40 and 50% of solids.

ZAKLJUČCI

Izvedena su ispitivanja uticaja koncentracije pepela i šljake na promene protoka i pritiska u uslovima hidrauličkog transporta guste hidromešavine radi definisanja najpovoljnije koncentracije hidromešavine za hidraulički transport. Ispitivanja su obavljena u dijapazonu koncentracija od 34,2 do 52,6 % (maseno).

Pokazano je da povećanjem koncentracije dolazi do značajnih promena protoka tako što se on više nego prepolovi, u odnosu na protok vode, kada koncentracija pređe 50 % čvrstog.

Međutim, uspešnost transporta se meri količinom suve materije koja je transportovana u jednici vremena, pa ako se proračun svede na količinu suvog pepela i šljake vidi se da je smanjenje mase pri najvišim ispitivanim koncentracijama (52,6 %) za oko 20 % u odnosu na najnižu ispitivanu koncentraciju (43,2 %). Pri tome je važno zapaziti da se pri transportu u koncentracijama između 40 i 50 % količina transportovanog materijala povećava. Ispitivanja pada pritiska su pokazala da su i energetski gubici najveći kada koncentracija pređe 50 % čvrstog te da je najpovoljniji transport sa koncentracijama između 40 i 50 % čvrstog.

Ispitivanja i posmatranja karaktera hidromešavine pokazala su da se hidromešavina do koncentracije od oko 40 % čvrstog ponaša kao heterogena, a kada koncentracija pređe 50 % čvrstog kao kvazihomogena tako da se kao najpovoljnije koncentracije pokazuju koncentracije u prelaznoj zoni kada se karakter hidromešavine menja iz heterogene (što ona po granulometrijskom sastavu pepela i šljake faktički jeste) u kvazihomogenu (posledica povećanja koncentracije).

Prevedeno u praktično rešenje izvedena ispitivanja su pokazala relativno širok dijapazon unutar kojeg treba tražiti racionalni odnos čvrste i tečne faze. U narednom koraku ispitivanja treba usmeriti na preciznije definisanje racionalne koncentracije vođenjem ispitivanja unutar masenih koncentracija od 40 do 50 % čvrstog.

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