MODERNIZATION OF THE DRAINAGE SYSTEM AND ASH SLURRY HANDLING SYSTEM IN TPP KOSTOLAC A

by

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The paper describes the modernization of ash slurry drainage and handling from Units A1 and A2 devices for receiving, extinguishing and transporting bottom ash and fly ash from the boiler grate to silos and mass/volume process water sumps, with new technical solutions and experiences in exploitation. The main goal of the drainage system modernization and ash slurry handling system in TPP Kostolac A is to improve the system operation and to reduce the number of deadlocks during operation.

Key words*: bottom ash, modernization, drainage, transportation, mixing, sealing, flow rate, overflow*

Introduction

The new system for collection, transport and disposal of ash and slag in TPP Kostolac is characterized by complexity, technical sophistication, technological orderliness, and environmental friendliness. The complexity of the system is reflected in the application of different systems for the transport of solid waste. The transport of ash – a mixture of fly ash and boiler ash, is performed pneumatically, naturally, and freely, the transport of slag is performed mechanically, while the transport of the mixture of ash and slag to the landfill is performed hydraulically. The collection and transport system is designed at an enviable technical level, using modern systems for measuring, guiding, and automatic control by programmable logic controllers. Such a system requires the accurate (numerical) definition of each parameter and complete organization of the technological system. Ecological acceptability is a basic requirement, while such a modernized technology for collecting, transporting, and depositing ash and slag in the form of a dense hydromixture is presently the most modern and widely accepted.

Modernization of the drainage system and slag transport system in thermal power plant Kostolac A is based on empirical research, professional and scientific works of the authors [1-6] who worked on a similar problem in other thermal power systems of the PE Electric Power Industry of Serbia.

There has been installed a new ash slurry handling system at units A1 and A2 TPP Kostolac A. It has been separated 2 × 3 tone per hour of bottom ash with two bottom ash conveyers at unit A1 with a capacity of 100 MW, which consists of two boilers. This

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is the maximum amount of bottom ash that can be extracted during the unit A1 operation. A maximum of 12 tone per hourh of bottom ash is released at 210 MW unit A2, which has only one conveyer. The separated bottom ash needs to be hydraulically transported by pipe-line and after drainage stored in steel Silos with a capacity of 2 × 250 tone per hour. The separated water should be returned to the process with a minimum bottom ash content with which the system could work stably. The following is a description of the identified shortcomings and the offered solutions on the basis of which it will be approached the modernization [7].

Table 1 lists the design data related to mass-flows and bottom ash density on units A1 and A2.

Table 1. Quantities and characteristics of TPP Kostolac A units bottom ash

Unit	Power [MW]	Bottom ash [tone per hour]	Density [kgm^{-3}]	Moisture 31-43% Density [kgm^{-3}]
A1	100	2.5-6	1930-1950	580-630
A2	210	5.0-12.0		
A1 + A2	310	7.5-18		

The bottom ash and boiler ash sampling

In co-operation with the Institute Vinča, the units bottom ash was sampled in order to confirm the project data from tab. 1 [8]. In tabs. 2 and 4, it can be seen that the value of bulk density depends on the moisture content in the bottom ash and that the measured values are in the project data limits from tab. 1.

Figure 1 shows the process measurement of the compacted wet bottom ash thickness.

Figure 2 shows the process determination of a moisture percentage in the bottom ash, laboratory sample

Figure 3 shows the process measurement of the boiler ash mass-flow rate in the Kostolac thermal power plant A.

Table 2 presents the data related to unit A1 bottom ash characteristics.

In tabs. 3 and 4, presented the measured ash mass-flow rate of unit A1 boilers. The obtained values are significantly less than the maximum design value of 0.075 tone per hour per boiler. From the aforementioned, it can be concluded that less water is needed for hydraulic transport of unit A1 boiler ash than for the project set value of 25 m^3 per hour per hydroejector (with the conclusion that unit A1 has four hydroejectors and two hydroejectors on each of the boilers) [9].

Table 5 presents the data related to Unit A2 bottom ash characteristics.

Table 2. Unit A1 bottom ash characteristics

Unit A1– bottom ash at the boiler	Density	Boiler 1	Boiler 2
Bottom ash thickness	kg/m^3	1660	1680
Bottom ash thickness in bulk (dry)	kg/m^3	481	500
Bottom ash thickness compacted (dry)	kg/m^3	562	600
Bottom ash thickness moist (moisture 31-43%)	kg/m^3	630-688	655-715

Table 3. Quantities of ash for unit A1 of boiler 1

Name	Unit of measure	Left	Right
Tare	kg	18.45	18.78
Gross	kg	22.65	22.70
Net	kg	4.2	3.92
Measurement time	hour/minute/sekond	00:21:25	00:20.12
Mass-flow rate	kg per hour	11.77	11.64

Table 4. Quantities of ash for unit A1 of boiler 2

Name	Unit of measure	Left	Right
Tare	kg	18.57	18.63
Gross	kg	24.60	21.82
Net	kg	6.03	3.19
Measurement time	hour/minute/sekond	00:40:17	00:35.12
Mass-flow rate	kg per hour	8.98	5.44

Figure 1. Measurement of the compacted wet bottom ash thickness

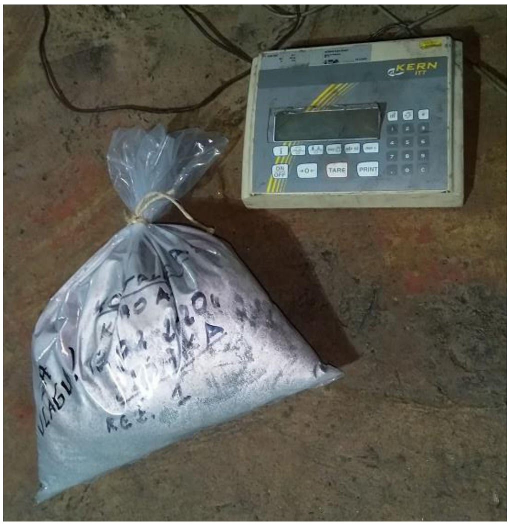

Figure 2. Determination of a moisture percentage in the bottom ash, laboratory sample

Figure 3. Measurement of the boiler ash mass-flow rate

Table 5. Unit A2 bottom ash characteristics

Name	Unit of measure	Value
Tare	kg	2940
Gross	kg	5620
Net	kg	2680
Start of measurement	hour/minute/sekond	12:52:06
End of measurement	hour/minute/sekond	13:08:38
Measurement period	hour/minute/sekond	00:16:32
Measured moisture content	%	50.92
Bottom ash mass-flow rate (water content 50.92%)	tone per hour	9.726
Mass-flow rate of dry bottom ash	tone per hour	4.773

The existing technical solution of units A1 and A2 bottom ash transportation

The Unit A1 bottom ash gravitationally falls from the conveyer on a vibrating screen with a grid of a light opening measuring 15 × 15 mm in order to separate bottom ash pieces of >15 mm. The bottom ash that passes through the grate is transported by the basalt chute to the existing sump in the unit A1 sump station.

The unit A2 bottom ash is separated in a conveyer with a capacity of 12 tone per hour. The conveyor bottom ash gravitationally falls into the crusher, which grinds it. The maximum bottom ash granulation at the outlet of the crusher is 15 mm. The crushed bottom ash is drained from the crusher into the basalt chute. The basalt chute branches (divides) into channels that transport the crushed bottom ash with water to the existing sump and the new sump. A grid with a light opening of 15 × 15 mm was installed in the basalt chute, downwards to the new pumping station in which the newly built collecting sump is located, in order to keep large pieces of bottom ash. Further, the bottom ash slurry is drained via basalt chutes into the collecting sump of the new pumping station.

The transportation of bottom ash from Units A1 and A2 is done by pumps. There are three pumps mounted on each of the Units, from which the one is working and the other two are spare ones. Before storing the slurry into bottom ash silos, the slurry is drained in hydrocyclones. The separated water is brought to the mass volume process water sump. This same water is returned by the pumps, from the pump station, that is connected to the volume process water sump, to the operation [10].

The modernized technical solution for bottom ash transportation

Figure 4 shows the process diagram of the bottom ash transportation system operation with changes and additions. In order to better understanding the mass balance, there were selected characteristic lines of mass and volume flow rate of water and slurry, Q.

For the flow calculation, the maximum values defined in tab. 1 are relevant. These values are taken from the design task and represent the most unfavorable condition for the system operation. For the bottom ash thickness, it is the mean value that was taken instead of the maximum, from the table: ρ = 1.94 tone per m^3, because the measurement determined that the actual density was significantly lower and is: ρ = 1.68 tone per m^3. Based on the input data, it can be calculated the volume flow ratein line 1.

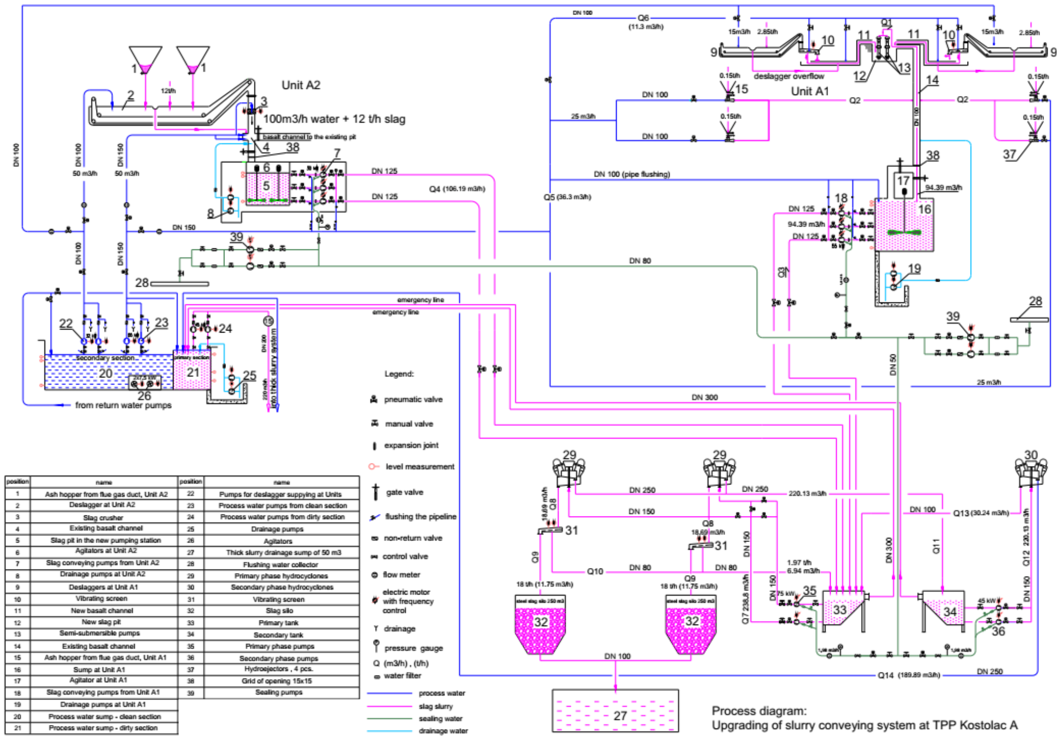

Figure 4. The process diagram

The volume flow rate in line 1, Q_1, represents the total amount of hydraulic mixture transported by semi-submersible pumps (position 13) to the unit A1 existing sump (position 16). Semi-submersible pumps will be installed in the new sump (position 12).

The mass-flow rate of process water of bottom ash is $m_1 = 6$ tone per hour:

$$Qash_1 = \frac{\dot{m}_1}{\rho} = \frac{6}{1.94} = 3.09 \tag{1}$$

The volume flow rate of process water for cooling both conveyers:

$$Qpw = 2 \times Qpw_1 = 2 \times 15 = 30 \tag{2}$$

The volume flow rate in lines 1 and 6:

$$Q_1 = Qash_1 + Qpw + Q_6 = 3.09 + 30 + 11.3 = 44.39 \tag{3}$$

$$Q_6 = 2 \times Qv_1 + 2 \times Qv_2 = 2 \times 3 + 2 \times 2.65 = 11.3 \tag{4}$$

The volume flow rate for nozzles is $Q_6 = 11.3$ m³ per hour. This is the adopted value and represents the maximum consumption of volume process water in the current system operation. The installation of semi-submersible pumps (position 13) and a new sump (position 12) represent a significant change in the unit A1 bottom ash transportation system. In this way, the amount of volume flow rate of process water for bottom ash transportation will be reduced.

The existing basalt chute (position 14) requires the nozzles on every 2.5 m for the slurry to be successfully transported and for that reason, there will be installed rubber ribbed hoses instead of the basalt chute from semi-submersible pumps to the existing sump (position 16).

Table 6. The operation trend of the unit A1 ash slurry handling system and the consumption of process water; system operating hours: 19 and 20 of October 2018

Date and time	Bottom ash transportation, line 2, unit A ash slurry flow rate, Q [m³ per hour]	Unit A1 conveyer cooling water flow rate, Q [m³ per hour]	The volume process water A1 + A2 flow rate, Q [m³ per hour]
October 19, 2018. 15:53 20:27	 297 270	 53.8 53.8	185 185 P = 1.9 bar
October 20, 2018. 11:01 to 15:01	210-296	51.2	160-180 P = 1.5 bar

Table 6 shows the values of bottom ash slurry flow rate and volume process water consumption that exceed the design values.

The maximum flow rate of the slurry measured is 297 m³ per hour, while the flow rate of bottom ash pumps, defined by the project, is 175 m³ per hour. The increased flow rate of the slurry exceeds the capacity of the Hydrocyclone while the significant amount of bottom ash reaches the overflow of the Hydrocyclone and eventually settles in the clean section of the volume process water sump.

The volume flow of the hydraulic mixture of ash for one boiler, Q_2, is installed on four hydroejectors for transporting ash from the flue gas duct. Alternately, 2 hydroejectors with a time sequence of 5 minutes are in operation, and in this way the ash is transported at a maximum of $\dot{m}_2 = 0.15$ tone per hour, or:

$$Qkp_2 = \frac{\dot{m}_2}{\rho} = \frac{0.15}{1.94} = 0.077 \tag{5}$$

with a water consumption of maximum $Qpw_2 = 2 \times 25 = 50$ m³/h, so that we get total ash slurry volume flow rate:

$$Q_2 = Qpw + Qkp_2 = 25 + 0.077 = 25.077 \tag{6}$$

In tabs. 3 and 4 presented the mass of boiler ash which was measured at all four hoppers and their sum is 17.34 kg, which is four times less than the design value. In this case we have volume flow rate of process water reserve that can be used for additional nozzles at the system if necessary. The transportation of boiler ash will take place through rubber ribbed hoses directly to the existing sump, instead of basalt chutes. In this way, the length of transportation and the consumption of process water are reduced. However, the basalt chute does not remain non-functional, because it will be used for overflow from the new sump between the conveyers and due to the depth, there can be installed rubber ribbed hoses. The installation of rubber hoses should be avoided in the zone of increased temperature, such as the zone of the mills proximity.

The flow:

$$Q_3 = Q_1 + 2 \times Q_2 = 44.39 + 2 \times 25.077 = 94.54 \tag{7}$$

and represents the Unit A1 ash slurry which needs to be transported by pumps to the hydrocyclone in the silo complex. Here we notice a significant reduction in the volume flow rate of the bottom ash slurry in relation the design value of 175 m³ per hour. Since the suction manifold of the bottom ash pump has been a place of frequent jams, there will be changes, which are reflected in:

– A new 7.5 kW agitator (position 17) will be installed in the existing bottom ash sump, thus preventing bottom ash precipitation in the suction pipe-line zone.
– The BA pumps will be upgraded with a sealing system in order to extend their service life.

– Each pump will have its own independent suction-line of reduced length. In this way we get a laminar flow rate through the pipe-line without changing the direction of the slurry flow.
– The flushing of the each suction pipe-line, will be provided after stopping the pump. In the previous period of the pump operation, it was recorded a larger number of suction pipe-line jams due to the existence of a manifold. Since the suction pipe-lines were not equiped with compensators, the dismantling of the pipe-lines was not possible due to the rigid connection.
– Rubber expansion joints will be installed on each suction pipe-line in order to provide a flexible connection instead of a rigid one and to compensate the generated vibrations.
– Wolume process water jets intended for agitation of the slurry in the existing sump will be put out of use, and their function will be taken over by the mixer (position 17), thus further reducing the consumption of wolume process water.

The flow rate at line:

$$Q_4 = Qkp_4 + Q\text{ash}_2 + Qpw_4 = 6.19 + 50 + 50 = 106.19 \tag{8}$$

It represents of volume flow rate for ash slurry for unit A2 which is,without significant changes in flow rate compared to the design value of 108 m³ per hour. The input parameters are from tab. 1. The maximum amount of bottom ash is $\dot{m}_4 = 12$ tone per hour:

$$Qkp_4 = \frac{\dot{m}_4}{\rho} = \frac{12}{1.94} = 6.19 \tag{9}$$

However, it is necessary to make changes identical to those on unit A1, and:
– The two mixers will be installed in the existing bottom ash sump (position 6), thus preventing the deposition of bottom ash in the suction pipe-lines area.
– The BA transportation pumps will be upgraded with a sealing system.
– Each pump will have its own independent suction-line of reduced length, thus reducing the possibility of a suction-line jam.
– On each suction pipe-line, it will be provided the flushing after stopping the pump, because the flushing removes bottom ash from the pipe-line and ensures the next start of the pump without jamming.
– Process water jets in the existing sump will be taken out of use after the installation of the agitator, and by removing the nozzles, the excessive amount of wolume process water is reduced.
– Rubber expansion joints will be installed on each suction pipe-line.

The volume flow rate on-line Q_5 of representing the required amount of unit A1 volume process water. As it can be seen in tab. 6, the consumption of wolume process water was significantly reduced, not only due to the introduction of semi-submersible pumps, but also due to the reduction in the number of conveyers from 4 to 2 pieces:

$$Q_5 = Q_2 + Q_6 = 25.077 + 11.3 = 36.4 \tag{10}$$

The volume flow rate on-line Q_6 of 11.3 m³ per hour represents the process water for rinsing the vibrating screen grate and for supplying the nozzles with which the basalt chutes under the vibrating screens are rinsed to the new sump.

The flow rate at line Q_7 represents the filling of the first degree hydrocyclone:

$$Q_7 = Q_3 + Q_4 + Q_{10} + Q_{13} + Qpp = 94.54 + 106.19 + 6.94 + 30.24 + 0.89 = 238.8 \tag{11}$$

The volume flow rate of bottom ash content is 238.8 m³ per hour. In order to the bottom ash better separation, the existing hydrocyclones HK125 and HK100 will be replaced by hydrocyclones consisting of a battery with six lines, four of which will be in operation and two

Figure 5. Primary hydrocyclone

will be spare. Since there are 2 BA Silos, two primary hydrocyclones will also be installed, fig. 5, [11].

The first and second degree hydrocyclones are selected based on the bottom ash and boiler ash granulometric composition, taking into account the flow rate and the pressure at the entrance into the hydrocyclone.

Table 7 shows the granulometric composition (particle size distribution of ash bottom), values based on-linear adjustment of experimental data.

The flow rate at line Q_8:

$$Q_8 = Q_7 - Q_{11} = 238.8 - 220.13 = 18.7 \quad (12)$$

$$Q_8 = Q_9 + Q_{10} = 11.75 + 6.94 = 18.69 \quad (13)$$

where 18.69 [m^3 per hour] represents separated bottom ash from primary hydrocyclones with a water content of 8.4 [m^3 per hour] which should be additionally separated using existing vibrating screens.

The flow rate at line Q_9:

$$Q_9 = Qsw + Qws = 9.3 + 2.45 = 11.75 \quad (14)$$

Table 7. Granulometric composition (distribution of bottom ash particle size), values based on-linear adjustment of experimental data

Particle size [mm]	Unit A1		Unit A2
	Boiler 1 mass [%]	Boiler 2 mass [%]	Boliler mass [%]
+ 6	0.9	1	1.65
–6 + 5	0.6	0.7	1.11
–5 + 4	0.8	1	3.57
–4 + 3	1.1	1.2	6.4
–3 + 1.7	4.8	5.3	24.55
–1.7 + 1	9.2	11.4	19.95
–1 + 0.85	4.2	4.1	4.42
–0.85 + 0.595	11.7	14.8	9.1
–0.595 + 0.425	12.5	14.5	6.88
–0.425 + 0.300	13.9	13.1	6.34
–0.300 + 0.212	15.3	11.8	5.6
–0.212 + 0.150	6.7	8.7	4.17
–0.150 + 0.106	8.8	5.8	2.82
–0.106 + 0.074	3.7	2.3	1.69
–0.074 + 0	5.83	4.3	1.75

The silo filling with the bottom ash at the outlet of the vibrating screens is 18 m^3 per hour, and with a water content of 2.45 m^3 per hour.

The flow rate at line Q_{10} = 6.94 m^3 per hour, *i.e.* the separation of water in the vibrating screen is 6.94 [m^3 per hour] with a bottom ash content of 1.97 tone per hour. This slurry is returned to the primary tank (position 33) and then pumped to the primary hydrocyclones (position 29).

The flow rate at line Q_{11}, the separated water from the hydrocyclone of the primary phase 220.13 m^3 per hour, with a bottom ash content of 8.8 tone per hour, is transported by gravity, with a rubber ribbed hose to the secondary tank (position 34).

The flow rate at line Q_{12}:

$$Q_{12} = Q_{13} + Q_{14} = 30.24 + 189.89 = 220.13 \tag{15}$$

refers to the filling of the secondary phase hydrocyclone 220.13 m^3 per hour, the bottom ash content is 8.8 tone per hour, the selection of the hydrocyclone is based on the calculated flow rate and consists of 24 lines, of which 18 are working and 6 are spare, fig. 6 [12].

Figure 6. Secondary hydrocyclone

The percentage of the bottom ash separation in the primary phase hydrocyclone can be calculated from the enclosed, which is 69%.

In the secondary phase hydrocyclone, the percentage of the bottom ash separation is 32%.

The flow rate at line Q_{13}: The separation of the bottom ash from secondary phase hydrocyclone, with the volume flow rate of 30.24 m^3 per hour, and with the bottom ash content of 6.66 tone per hour, is transported by gravity to the primary tank and further to the primary hydrocyclones for re-separation.

The separated water from the flow rate at line Q_{14} – secondary phase hydrocyclone of 189.89 m^3 per hour, with the bottom ash content of 2.14 tone per hour, is returned to the existing sump of the dirty section. position 6), fig. 7.

The bottom ash that has entered the system will be removed by the existing pumps of the dirty section (position 3) to the horizontal agitators for the preparation of a thick slurry with a capacity of 220 m^3 per hour. The process water is re-entered into the system by the clean section pumps (position 4). The sump is being replenished by existing wolume process water pumps with a capacity of 400 m^3/h, which are located at Units A1 and A2. The Pumps (position 5) provide water for cooling the Units A1 and A2 conveyer.

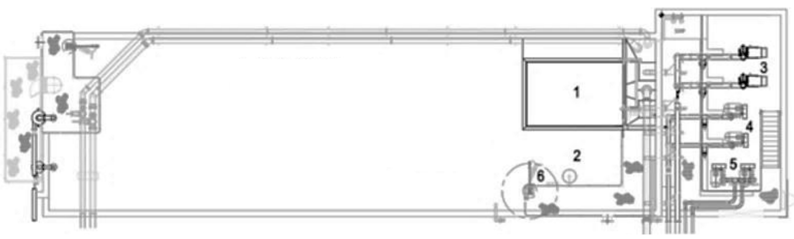

Figure 7. Volume process water sump; *1 – pool of unclean section, 2 – pool clean section, 3 – pumps of unclean section, 4 – pumps of clean section, 5 – pumps for cooling slaghog cleaner, and 6 – mixer*

Conclusion

The ash slurry handling system in TPP Kostolac A requires reconstruction, which is reflected as follows.

- Reducing the amount of water in the process.
- The elimination of the system bottlenecks in due to which there was a delay in the bottom ash transportation.
- Improving the bottom ash separation in hydrocyclones.
- Removal of the unseparated bottom ash after separation from secondary (second phase) Hydrocyclones, which is transported by process water to dirty section.
- The bottom ash that has reached the process water sump can only be discharged by the pumps of the dirty Section the horizontal agitators which are used for the preparation of a thick slurry.
- There will always be small granulations of bottom ash in the process water sump, but with an amount that cannot lead to blockage of the system nozzles.

Nomenclature

$\dot{m}_1$ – mass-flow rate of process water-bottom ash, [tone per hour]
$\dot{m}_2$ – mass-flow rate of process water - maximum ash transported, [tone per hour]
$\dot{m}_4$ – mass-flow rate of process water - maximum amount of bottom ash, [tone per hour]
$Q\text{ash}_1$ – volume flow rate ofprocess water of bottom ash to the Unit A1, [m^3 per hour]
$Q\text{ash}_2$ – volume flow rate of process water for cooling of bottom ash to the unit A2, [m^3 per hour]
Qkp_2 – volume flow rate of process water, maximum ash transported, [m^3 per hour]
Qpp – volume flow rate of process water, [m^3 per hour]
Qkp_4 – volume flow rate of process water, [m^3 per hour]
Qpv_2 – volume flow rate of process water, maximum water of consumption, [m^3 per hour]
Qpw – volume flow rate of process water process consumption for one hydroejector, [m^3 per hour]
Qpw_1 – volume flow rate of process water for cooling both conveyers, [m^3 per hour]
Qpw_2 – volume flow rate of process water consumption for two hydroejectors
Qpw_4 – volume flow rate of process water, [m^3 per hour]
Qsw – volume flow rate of slag with water content
Qv_1 – volume flow rate of process water consumption for rinsing vibrating screen [m^3 per hour]
Qv_2 – volume flow rate of process water consumption for rinsing vibrating screen [m^3 per hour]
Qws – volume flow rate of water with slag content
Q_1 – volume flow rate of process water, in line 1, [m^3 per hour]
Q_2 – volume flow rate of process water, in line 2, [m^3 per hour]
Q_3 – volume flow rate of process water, in line 3, [m^3 per hour]
Q_4 – volume flow rate of process water, in line 4, [m^3 per hour]
Q_5 – volume flow rate of process water, in line 5, [m^3 per hour]
Q_6 – volume flow rate of process water, in line 6, [m^3 per hour]
Q_7 – volume flow rate of process water, in line 7, [m^3 per hour]
Q_8 – volume flow rate of process water, in line 8, [m^3 per hour]
Q_9 – volume flow rate of process water, in line 9, [m^3 per hour]
Q_{10} – volume flow rate of process water, in line 10, [m^3 per hour]
Q_{11} – volume flow rate of process water, in line 11, [m^3 per hour]
Q_{12} – volume flow rate of process water, in line 12, [m^3 per hour]
Q_{13} – volume flow rate of process water, in line 13, [m^3 per hour]
Q_{14} – volume flow rate of process water, in line 14, [m^3 per hour]

Greek symbol

ρ – mean density of ash, [tone per m^3]

Acronyms

TPP – thermal power plant
A1 – name of a unit from thermal power plant
A2 – name of a unit from thermal power plant

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