REKONSTRUKCIJA KANALA ZA ODVOĐENJE DIMNIH PLINOVA U TERMOELEKTRANI "KAKANJ"

RECONSTRUCTION OF CHANNELS FOR FLUE GASES DISCHARGE IN THERMAL POWER PLANT „KAKANJ"

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REZIME
Pri sagorijevanju goriva u kotlovima Termoelektrane „Kakanj" nastaju plinovi koji su nepoželjni za okolinu, ljude koji žive u okolini termoelektrane, kao i za floru i faunu. Da bi se zaštitila životna sredina treba uložiti mnogo napora i organizacionih aktivnosti i imati na raspolaganju značajna materijalna sredstva. Dimni plinovi koji nastaju procesom sagorijevanja goriva u kotlu se filtriraju, a zatim se pomoću plinovodnih kanala i dimnjaka ispuštaju u okoliš. Za ispuštanje prečišćenih plinova, u Termoelektrani „Kakanj"se već dugi niz godina koristi isključivo 300-metarski dimnjak. U toku remonta na postrojenju bloka 7 i rekonstrukcije 300-metarskog dimnjaka, koji su izvršeni u periodu septembar-decembar 2014. godine, bilo je potrebno preusmjeriti odvođenje dimnih plinova sa blokova 5 i 6 prema 100-metarskom dimnjaku.
U ovom radu opisan je proces rekonstrukcije dimnih kanala i proračun radnih parametara 100-metarskog dimnjaka radi preusmjeravanja dimnih plinova ka istom.

Professional paper

SUMMARY
As the result of combustion process in boilers of the Thermal Power Plant „Kakanj", flue gases develop, which are undesirable for the environment, for people living in the plant neighborhood and for flora and fauna. In order to perform environmental protection a lot of efforts and organizational activities should be put in action and significant resources should be made available. Flue gases from the plant boilers are filtered and discharged in the environment after passing flue channels and the chimney. The Thermal Power Plant „Kakanj" has used 300-meter chimney for flue gases discharge for a long time. During the overhaul of block 7 and reconstruction of 300-meter chimney in period September-December 2014, it was necessary to redirect the flue gases from blocks 5&6 to the 100-meter chimney. This task required certain reconstruction of existing installation and calculation of 100-meter chimney capability.
The performed flue channels reconstruction and calculation of operating parameters of 100-meter chimney are presented in this paper.

1. UVOD

Tokom sagorijevanja goriva u kotlovima termoenergetskih postrojenja, kao nus-produkt nastaju plinovi koji su štetni za okoliš, ljude, kao i floru i faunu. Nakon filtriranja, ovi dimni plinovi se pomoću dimnjaka ispuštaju u okoliš.

Dimnjaci su vertikalne građevinske konstrukcije cjevastog oblika koji se koriste za ispuštanje filtriranih dimnih plinova u atmosferu. Oni se razlikuju po svojim geometrijskim osobinama (širina, visina, debljina stijenke, itd.), vrsti materijala od kojih su napravljeni (kamen, cigla, čelik, armirani beton) i tako dalje, a sve to zavisi od njihove namjene.

1. INTRODUCTION

During fuel combustion in boilers of thermal power plants, flue gases develop, which are harmful for the environment, for people around and for flora and fauna. After filtering, the flue gases are discharged through chimney.

Chimneys are vertical pipe-like constructions that are used to release filtered flue gases into the atmosphere. There are great variation in the design of chimneys referring to their geometric characteristics (depth, height, wall thickness and so on), building material (stone, brick, steel, reinforced concrete) and so on, which depends on their purpose.

Za potrebe odvođenja plinova nastalih u procesu sagorijevanja goriva u blokovima 5, 6 i 7 Termoelektrane „Kakanj" koristi se dimnjak visine 300 m, slika 1. U neposrednoj blizini bloka 6 nalazi se dimnjak visine 100 metara. Tokom remonta na postrojenju bloka 7 i sanacije 300-metarskog dimnjaka, koji je obavljen u period septembar-decembar 2014. godine, bilo je neophodno da se koristi dimnjak visine 100 m.

Zbog toga je bilo potrebno izvršiti njegovu djelomičnu rekonstrukciju, kao i rekonstrukciju plinovodnih kanala [1].

To discharge flue gases from blocks 5, 6 & 7, the Thermal Power Plant „Kakanj" uses the 300-meter chimney, Fig. 1. In the vicinity of the block 6, there is an alternative 100-meter chimney. During the overhaul of block 7 and reparation of 300-meter chimney in period September-December 2014, it showed necessary to use the 100-meter chimney.

For that purpose, it was required to reconstruct the 100-meter chimney and the flue gases channels, [1].

Slika 1. Termoelektrana „Kakanj"
Figure 1. Power Plant "Kakanj"

2. REKONSTRUKCIJA PLINOVODNIH KANALA

Pri revitalizaciji elektrofiltera bloka 6, snage 110 MW, tokom 2012. godine, uklonjeni su tada korišteni dimni ventilatori zajedno sa pripadajućim plinovodnim kanalima na dionici od elektrofiltera do mjesta njihovog spajanja na zajednički kolektorski kanal. Isti su bili dotrajali i predstavljali su smetnju pri rekonstrukciji filtera bloka 6. Pri ugradnji novih kanala iza ventilatora bloka 6 nisu predviđena priključna mjesta, niti kanalski ogranci za korištenje 100-metarskog dimnjaka, koji se koristio prije izgradnje 300-metarskog dimnjaka 1988. godine. Također, nakon rekonstrukcije filtera na ovom bloku 2010. godine, ostali su nepromijenjeni neki dijelovi priključnih kanala bloka 5 na zajedničkom glavnom kanalu. Sistem odvođenja dimnih plinova prije rekonstrukcije 300-metarskog dimnjaka i remonta na postrojenju bloka 7 prikazan je na slici 2.

Za sanaciju i održavanje 300-metarskog dimnjaka potrebno je isključenje iz procesa proizvodnje električne energije (totalni zastoj) sva tri bloka (5, 6 i 7).

2. RECONSTRUCTION OF THE FLUE GASES CHANNELS

During 2012, when the revitalization of electro filter with power 110 MW in block 6 was done, the smoke fans and the associated pipeline on the section from the electro filters to the place of their connection to the common collector channel were removed. These fans were worn out and made obstruction to the reconstruction of filters of block 6. During installation of new channels behind the fans of block 6, the connection points or channel branches were not provided for the need to use the 100-meter high chimney, which was used before the construction of 300-meter chimney in 1988. Also, some parts of the block 5 channels connected to the common main channel remained unchanged after the reconstruction of filter of block 6 in 2010. The system for discharge of flue gases before the reconstruction of 300-meter chimney and reparation of the block 7 is shown in Fig. 2.

During the repair and maintenance of 300-meter chimney, all three blocks (5, 6 and 7) should be stopped and excluded from the production of electricity (deadlock).

Pošto prekid proizvodnje nije bio ekonomski dopustiv, nametnuo se zahtjev da se izvrši priključenje izlaznih plinovodnih kanala blokova 5 i 6 na ranije korišteni 100-metarski dimnjak bloka 6 i time omogući rad postrojenja, a što je zahtijevalo i rekonstrukciju postojećih plinovodnih kanala [1].

Proces rekonstrukcije plinovodnih kanala termoenergetskih postrojenja predstavlja veoma zahtjevan poduhvat. Zbog toga su izvršene detaljne pripreme koje su obuhvatale analizu potrebnog stručnog kadra, analizu potrebne dokumentacije prethodnog i stanja nakon rekonstrukcije, analizu mjesta rekonstrukcije sistema, analizu raspoloživog prostora, analizu potrebne opreme i tako dalje. Pri tome se trebalo težiti tome da rekonstrukcija bude optimalna i da se što manje naruši postojeće stanje. Izgradnja novih kanala trebala bi da doprinese efikasnijem radu blokova 5 i 6.

As this is not an economical solution, the task have been given to specialists to make possible the work and production of electricity in blocks 5 and 6 by using the available 100-meter chimney and flue gases pipeline reconstruction, [1].

The reconstruction of flue gases channels in thermal power plants is a very complex task. Therefore, very detailed preparations were made, which included the analysis of qualified specialists, analysis of the necessary documentation, analysis of the system reconstruction location, analysis of the available space and necessary equipment, and so on. Also, the task was to make an optimal reconstruction and to disturb the status quo the least possible. Construction of new channels should also contribute to more efficient work of the blocks 5 and 6.
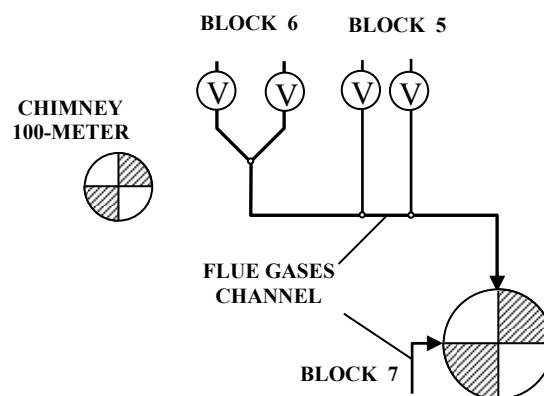
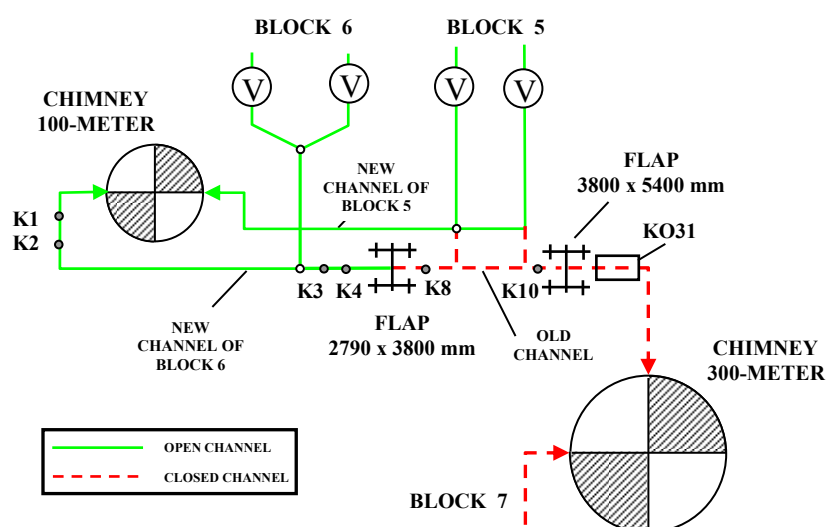**Slika 2.** *Odvođenje dimnih plinova kroz 300-metarski dimnjak – shema (normalni rad)*
Figure 2. *Discharge of flue gases through 300-meter chimney – scheme (normal operating regime)*

Da bi se spriječio protok plinova prema 300-metarskom dimnjaku, ugrađena je klapna dimenzija 3800x5400 mm kod kompenzatora sa oznakom KO31, slika 3. Kod stuba K8 na postojećem kanalu bilo je potrebno ugraditi klapnu dimenzija 2790x3800 mm, da bi se spriječio protok dimnih plinova bloka 5 postojećim kanalom prema 100-metarskom dimnjaku. Spojevi novog kanala bloka 5 u postojeće kanale istog izvedeni su između stubova K8-K10 na postojećem kanalu Φ 3800x5400 mm. Novi spojevi su usmjereni vertikalno naviše. Na zahtjev investitora, a i zbog troškova, trasa novih kanala bloka 5 definirana je iznad postojećih kanala. Novi zbirni kanal bloka 5 nalazi se iznad postojećeg kanala i kod stubova K3-K4 skreće u pravcu bližeg otvora na 100-metarskom dimnjaku.

To prevent the gas flow to the 300-meter chimney, the flap of dimensions 3800x5400 mm was built-in near the KO31 compensator, Fig.3. Also, a flap of dimensions 2790x3800 mm needed to be installed in the existing channel near the column K8 to prevent the flue gas flow of block 5 through the existing channel to 100-meter chimney. The new channels of the block 5 join the existing channels between the columns K8-K10 of the existing channel Φ 3800x5400 mm. The new joints are directed vertically upward. At the request of the investor, and because of the costs, the route of the new channels of the block 5 was set above the existing channels. The new collection channel of the block 5 is located above the existing channels and at the location of columns K3-K4 turns in the

Jednim dijelom trasiran je iznad postojećeg kanala bloka 6, a zatim se spušta i spaja u dimnjak. Ovo rješenje ekonomski je prihvatljivije od rješenja da se kanal bloka 5 spaja u dalji otvor na dimnjaku. Osim toga, postojeći kanal bloka 6 je bilo nemoguće spojiti u bliži otvor na dimnjaku zbog veoma malog raspoloživog prostora. Opisanim rješenjem je smanjena dužina kanala bloka 5, a povećana dužina kanala bloka 6, tako da je ukupna razlika u otporima proticanju dimnih plinova novim kanalima smanjena, slika 3.

direction to the nearest opening of the 100-meter chimney. It is partly traced over the existing channel of block 6, then descends and joins the chimney. This solution is more economical than to connect the channel of block 5 to the farther chimney opening. In addition, the existing channel of the block 6 was impossible to connect to the closer hole because of the small space available. This solution shortened the length of the channel of block 5 and increased the length of the block 6 channel. This resulted in reduced flow resistance of the flue gas channels, Fig. 3.

Slika 3. *Odvođenje dimnih plinova kroz 100-metarski dimnjak – shema*
(tokom zastoja 300-metarskog dimnjaka)
Figure 3. *Discharge of flue gases through 100-meter chimney – scheme*
(during deadlock of 300-meter chimney)

Strujanje dimnih plinova iz bloka 6 prema 300-metarskom dimnjaku u postojeći kanal kod stubova K3-K4 blokirano je ugradnjom klapne dimenzija 2790x3800 mm. Novi kanal dimnih plinova bloka 6 je spojen na postojeći kanal između stubova K1-K2 i K3-K4 na mjestu gdje on mijenja pravac za ugao 90°. Od mjesta spoja, kanal ide novom trasom tako da se mora napraviti čelična konstrukcija do spoja kanala u 100-metarski dimnjak. Visina otvora na dimnjaku IV etape se povećala sa 2800 mm na 4335 mm.

Plinovodni kanali su napravljeni od konstrukcionog čelika sa izvedenom AKZ zaštitom i izolirani tervolom debljine 150 mm uz zaštitu Al-limom debljine 1 mm. Ispred svih klapni na kanalima su ugrađeni revizioni otvori. Sa strane kanala, gdje je pogon klapni,

The flow of flue gases from block 6 to the 300-meter chimney is blocked by installing a flap of dimensions 2790x3800 mm at the location of columns K3-K4. The new flue gas channel of block 6 is connected to the existing channel between the columns K1-K2 and K3-K4 at point where it changes direction for 90° angle. Behind the joining point, the channel goes a new route and a steel construction must be made till the opening of the 100-meter chimney. The height of the chimney openings at the IV stage is extended from 2800 mm to 4335 mm.

Flue gas channels are made of structural steel with a built-in AKZ protection and insulated with tervol of 150 mm thickness and with Al-sheet protection of 1 mm thickness. The inspection holes are made in channels in front of all flaps. The installation of ladders and

predviđena je ugradnja penjalica i podesta sa ogradom, kako bi se moglo prići klapnama i revizionim otvorima. Zavareni i prirubnički spojevi na kanalima moraju biti nepropusni, tako da je presisavanje zraka u dimnim plinovima manje od 0,5% što se utvrđuje mjerenjem količine CO_2.

Novoprojektirani kanali su odvojeni od postojećih kanala 700 mm po visini, tako da se nesmetano mogu ugraditi noseća čelična konstrukcija, kompenzatori, klapne, termoizolacija i prirubnički spojevi kanala. Kanali su dimenzionirani prema projektiranim pogonskim parametrima sa ugrađenim pokretnim osloncima i kompenzatorima [1].

3. PRORAČUN RADNIH PARAMETARA 100-METARSKOG DIMNJAKA

3.1. Polazni podaci

Na osnovu tehničkih podataka i crteža dostavljenih od strane JP Elektroprivreda BiH d.d. Sarajevo - Podružnica Termoelektrana „Kakanj", bilo je potrebno povezati dimne kanale bloka 5 i bloka 6 na dimnjak prečnika 6,5 m i visine 100 m, radi nesmetanog rada ova dva bloka u toku rekonstrukcije na bloku 7 i 300-metarskom dimnjaku.

Za rad kotlova blokova 5 i 6 koristi se ugalj iz rudnika „Srednja Bosna", donje toplotne moći 9,8÷16,7 MJ/kg i ukupne vlažnosti 8÷26 %.

Sastav produkata sagorijevanja je sveden na suhe produkte i dat je u tabeli 1 (čvrsta faza do 10 mg/m^3).

Temperatura dimnih plinova na izlazu iz kotlova je t_p=200°C, pri spoljnoj projektnoj temperaturi t_{amb}=-18°C.

Osnovni geometrijski parametri dimnjaka su: prečnik D_c=6,5 m, visina H_c=100 m, geodezijska visina dimnjaka H_g=235 m.

Osnovni zadatak u okviru rekonstrukcije i proračuna 100-metarskog dimnjaka bio je da se odredi pad pritiska na putanji dimnih plinova pri radu blokova 5 i 6 i pri radu oba bloka zajedno.

landings with a fence should be provided at the flaps drive location, in order to approach and control the flaps and the inspection openings. Welded and flanged joints of the channels must be hermetically sealed so that the flue gases leakage is less than 0,5%, which will be determined by measuring the CO_2 quantity.

The newly designed channels are separated from the existing channels by 700 mm in height, so that all steel structures, expansion joints, valves, insulation and flanged channels can be freely installed. The channels are designed according to the projected operating parameters with embedded mobile supports and joints [1].

3. THE CALCULATION OF 100-METER CHIMNEY OPERATING PARAMETERS

3.1. Input data

Based on the technical data and drawings submitted by JP Elektroprivreda BiH dd Sarajevo – Thermal Power Plant "Kakanj", the task was to connect the flue gases channels from blocks 5 and 6 to the 100-meter chimney of diameter of 6.5 m, for undisturbed operation of the two blocks during the reconstruction of the block 7 and 300-meter chimney.

For the operation of boilers in blocks 5 and 6, the coal from the mine "Srednja Bosna" is used with lower heating value of 9,8÷16,7 MJ/kg and total humidity 8÷26%.

The composition of the combustion products reduced to a dry product (solids to 10 mg/m^3) is given in Tab. 1.

The temperature of flue gases leaving the boilers is t_p=200°C, under the design ambient temperature of t_{amb} = -18°C.

The basic geometric parameters of the chimney are: diameter D_c=6,5 m, height H_c=100 m, geodesic height of the chimney H_g=235 m.

The main task in the reconstruction and calculation of 100-meter chimney was to determine the pressure drop in the path of the flue gases during the operation of blocks 5 and 6 separately and both blocks together.

Tabela 1. *Sastav produkata sagorijevanja*
Table 1. *The composition of the combustion products*

Komponenta / Component	CO_2	O_2	N_2	SO_2
Molski udio / Molar proportion y, %	13÷15	4÷8	81	0.28

Volumenski protok produkata sagorijevanja pri normalnim uvjetima je:

Volume flow of the combustion products under normal conditions is:

$\dot{V}_{p,5,N}$ = 136 m³/s = 489 600 m³/h – za blok 5,

$\dot{V}_{p,6,N}$ = 151 m³/s = 543 600 m³/h – za blok 6,

odnosno, zbirno

$\dot{V}_{p,N}$ = 287 m³/s = 1 033 200 m³/h.

3.2. Proračun svojstava produkata sagorijevanja

Molarna masa produkata sagorijevanja iznosi M_p=29,7 kg/kmol, a specifična masa (gustina) produkata sagorijevanja pri normalnim uvjetima (p=101 325 Pa, t=0°C) je $\rho_{p,N}$ = 1,326 kg/m³, [2]. Ostala termofizička svojstva produkata sagorijevanja u funkciji od temperature su data u tabeli 2, prema [2].

Maseni protok produkata sagorijevanja se izračunava prema izrazu

$$\dot{m}_p = \rho_p \dot{V}_p \; , \qquad (1)$$

što daje vrijednosti:

$\dot{m}_{p,5}$ = 180 kg/s za blok 5,

$\dot{m}_{p,6}$ = 200 kg/s za blok 6,

odnosno, zbirno $\dot{m}_p$ = 380 kg/s.

Volumenski protok produkata sagorijevanja pri radnim uvjetima (ρ_p=0,756 kg/m³ i t_p=200°C) se također analogno izračunava prema jednačini (1) i iznosi:

$\dot{V}_{p,5}$ =239 m³/s=860 400 m³/h za blok 5,

$\dot{V}_{p,6}$ =265 m³/s=954 000 m³/h za blok 6,

odnosno, zbirno

$\dot{V}_p$ =504 m³/s=1 814 400 m³/h.

Tabela 2. *Osobine produkata sagorijevanja u funkciji od temperature*
Table 2. *Properties of combustion products as a function of temperature*

Temperatura/ Temperature	Gustina/ Density	Specifični toplotni kapacitet/ Specific heat capacity	Toplotna provodnost/ Thermal conductivity	Dinamički viskozitet/ Dynamic viscosity	Prandtlov broj/ Prandtl number
t / °C	ρ_p / kg/m³	c_p / J/kgK	λ_p / mW/mK	μ_p / μPas	Pr_p
100	0,958	1041	29,7	19,9	0,699
200	0,756	1057	37,1	24,1	0,684
300	0,624	1072	44,2	27,8	0,673

3.3. Proračun toplotnih gubitaka i pada pritiska kroz dimnjak

Proračun toplotnih gubitaka i pada pritiska kroz dimnjak izvršen je prema literaturi [3].

3.3. Calculation of heat loss and pressure drop through the chimney

The calculation of heat loss and pressure drop through the chimney was made according to the reference [3].

Srednja površina dimnjaka iznosi

$$S_c = \pi\, D_c H_c = 2042 \text{ m}^2. \qquad (2)$$

Srednja brzina strujanja produkata sagorijevanja kroz dimnjak je definirana izrazom

$$w_p = \frac{\dot{m}_p}{\rho_p \dfrac{\pi D_c^2}{4}}. \qquad (3)$$

Rejnoldsov broj izračunava se na osnovu izraza

$$Re_p = \frac{w_p D_c \rho_p}{\mu_p}. \qquad (4)$$

gdje je μ_p dinamički viskozitet produkata sagorijevanja.

Koeficijent prelaza toplote između produkata sagorijevanja i unutrašnje površine donjeg dijela dimnjaka određen je izrazom

The mean cross-sectional area of the chimney is

$$S_c = \pi\, D_c H_c = 2042 \text{ m}^2. \qquad (2)$$

The mean velocity of the combustion products flow through the chimney is defined by the expression

$$w_p = \frac{\dot{m}_p}{\rho_p \dfrac{\pi D_c^2}{4}}. \qquad (3)$$

The Reynolds number is calculated on the basis of the expression

$$Re_p = \frac{w_p D_c \rho_p}{\mu_p}. \qquad (4)$$

where μ_p is the dynamic viscosity of the combustion products.

The coefficient of heat convection between the combustion products and the inner surface of the lower part of the chimney is defined as

$$\alpha_{in} = \frac{\lambda_p}{D_c} \cdot 0{,}037 \cdot \left(Re_p^{0,75} - 180\right) \cdot Pr_p^{0,42} \cdot \left[1 + \left(\frac{D_c}{H_{c,ef}}\right)^{0,67}\right] \cdot \left(\frac{\xi_r}{\xi_s}\right)^{0,67}, \qquad (5)$$

gdje su, prema [4], koeficijent otpora trenja za glatku hidrauličku cijev $\xi_s = 0.015$, a $\xi_r = 0{,}020$ za hrapavu hidrauličku cijev (za usvojenu apsolutnu hrapavost od 5 mm).

Koeficijent prelaza toplote između okolnog zraka i spoljašnje strane izolacije iznosi $\alpha_{out} = 23\,\text{W/m}^2\text{K}$, pri čemu je usvojena brzina vjetra od 4 m/s, [3].

Koeficijent prolaza toplote izračunava se prema izrazu

$$k_c = \frac{1}{\dfrac{1}{\alpha_{out}} + \dfrac{\delta_z}{\lambda_z} + \dfrac{1}{\alpha_{in}}}. \qquad (6)$$

gdje je:
δ_z – debljina stijenke zida,
λ_z – koeficijent provođenja toplote (kondukcije) kroz zid.

Broj jedinica prijenosa definiran je izrazom

$$NTU = \frac{k_c \cdot S_c}{\dot{m}_p \cdot c_p}. \qquad (7)$$

where, according to [4], the coefficient of friction for smooth hydraulic pipe is $\xi_s = 0{,}015$, and for rough hydraulic pipe $\xi_r = 0{,}020$ (for the adopted absolute roughness of 5 mm).

The coefficient of heat convection between the ambient air and the outside of the insulation is $\alpha_{out} = 23\,\text{W/m}^2\text{K}$, where the adopted wind speed is 4 m/s, [3].

The heat transfer coefficient is calculated according to the formula

$$k_c = \frac{1}{\dfrac{1}{\alpha_{out}} + \dfrac{\delta_z}{\lambda_z} + \dfrac{1}{\alpha_{in}}}. \qquad (6)$$

where:
δ_z – wall thickness,
λ_z – coefficient of heat conduction through the wall.

The number of transmission units is defined by

$$NTU = \frac{k_c \cdot S_c}{\dot{m}_p \cdot c_p}. \qquad (7)$$

Temperatura produkata na izlazu iz dimnjaka se izračunava prema izrazu

$$t_{p,out} = t_{amb} + \left(t_p - t_{amb}\right) \cdot exp\left(-NTU\right). \quad (8)$$

The flue gasses temperature at the chimney outlet is calculated by

$$t_{p,out} = t_{amb} + \left(t_p - t_{amb}\right) \cdot exp\left(-NTU\right). \quad (8)$$

Temperatura unutrašnje strane zida dimnjaka na vrhu dimnjaka definirana je izrazom

$$t_{w,out} = t_{p,out} - \frac{k_c}{\alpha_{in}} \cdot \left(t_{p,out} - t_{amb}\right). \quad (9)$$

The temperature of the inner side of the chimney wall at the top is given by

$$t_{w,out} = t_{p,out} - \frac{k_c}{\alpha_{in}} \cdot \left(t_{p,out} - t_{amb}\right). \quad (9)$$

Pad pritiska usljed trenja u dimnjaku, za koeficijent otpora trenja koji prema [3] iznosi ξ_r=0,033, izračunava na osnovu izraza

$$\Delta p_{fr} = \xi_r \cdot \frac{H_c}{D_c} \cdot \frac{\rho_p \cdot w_p^2}{2}. \quad (10)$$

The pressure drop due to friction in the chimney with the coefficient of friction ξ_r=0,033 (according to [3]) can be calculated by

$$\Delta p_{fr} = \xi_r \cdot \frac{H_c}{D_c} \cdot \frac{\rho_p \cdot w_p^2}{2}. \quad (10)$$

Tabela 3. *Rezultati proračuna 100-metarskog dimnjaka*
Table 3. *The results of calculation of 100-meter chimney*

Veličina/ Quantity	Mjerna jedinica/ Units	Blok 5 / Block 5	Blok 6 / Block 6	Blokovi 5 i 6 / Block 5 & Block 6
$\dot{V}_{p,N}$	m³/h	489 600	543 600	1 033 200
$\dot{m}_p$	kg/s	180	200	380
$\dot{V}_p$	m³/h	239	265	504
w_p	m/s	7,20	7,98	15,2
Re_p	-	1 470 000	1 630 000	3 100 000
α_{in}	W/m²K	14,2	15,6	28,1
k_c	W/m²K	0,526	0,528	0,536
NTU	-	0,00564	0,00510	0,00272
$t_{p,out}$	ºC	198,8	198,9	199,4
$t_{w,out}$	ºC	190,8	191,6	195,3
Δp_{fr}	Pa	10	12	44
Δp_{cd}	Pa	599	599	599
Δp_{din}	Pa	20	24	87
p_{ef}	Pa	569	563	468

Pri gustini okolnog zraka ρ_{amb} = 1,365 kg/m³, vuča dimnjaka (razlika ulaznog i izlaznog pritiska) je

$$\Delta p_{cd} = g \cdot \left(H_c + H_g\right) \cdot \left(\rho_{amb} - \rho_p\right). \quad (11)$$

With the ambient air density ρ_{amb}=1,365 kg/m³, the chimney draft (input and output pressure difference) is

$$\Delta p_{cd} = g \cdot \left(H_c + H_g\right) \cdot \left(\rho_{amb} - \rho_p\right). \quad (11)$$

Pad dinamičkog pritiska na izlazu iz dimnjaka definiran je izrazom

$$\Delta p_{din} = \frac{\rho_p \cdot w_p^2}{2}. \quad (12)$$

The dynamic pressure drop at the chimney outlet is given by

$$\Delta p_{din} = \frac{\rho_p \cdot w_p^2}{2}. \quad (12)$$

Efektivni podpritisak u podnožju (korijenu)

The effective pressure at the bottom of the

dimnjaka je

$$p_{ef} = \Delta p_{cd} - \Delta p_{fr} - \Delta p_{din} \,. \qquad (13)$$

Rezultati proračuna 100 metarskog dimnjaka pojedinačno za blok 5 i 6, i ukupni rezultati za oba bloka, dati su u tabeli 3.

3.4. Proračun pada pritiska u kanalu od tlačne klapne do dimnjaka
Pad pritiska u kanalu se izračunava prema izrazu

$$\Delta p = \sum_{i=1}^{n} \Delta p_i = \sum_{i=1}^{n} \zeta_i \frac{\rho_p \cdot w_{p,i}^2}{2}, \qquad (14)$$

gdje su:

ρ_p - gustina produkata sagorijevanja,

$w_{p,i}$ [m/s] - brzina toka produkata sagorijevanja u i-toj dionici,

ζ_i - ukupni koeficijent otpora toku u i-toj dionici računat prema formuli

$$\zeta_i = \lambda_i \frac{L_i}{D_{e,i}} + \sum_{k=1}^{m} \xi_k \,, \qquad (15)$$

gdje su:
λ_i =0,033 –koeficijent linijskog otpora trenja, prema [4],
L_i [m] -dužina i-te dionice cjevovoda,
$D_{e,i}$ [m] - ekvivalentni dijametar i-te dionice,
$\sum_{k=1}^{m} \xi_k$ - suma lokalnih otpora duž i-te dionice plinovoda.

Prvi dio ukupnog otpora u jednačini (15) predstavlja linijski otpor usljed trenja, to jest

$$\zeta_{fr,i} = \lambda_i \frac{L_i}{D_{e,i}} \,. \qquad (16)$$

Ekvivalentni prečnik dionice je u slučaju kružnog poprečnog presjeka jednak unutrašnjem prečniku, a u slučaju pravougaonog poprečnog presjeka dimenzija AxB ekvivalentni prečnik je

$$D_{e,i} = 1,3 \frac{(A \cdot B)^{0,625}}{(A+B)^{0,25}} \,. \qquad (17)$$

chimney is

$$p_{ef} = \Delta p_{cd} - \Delta p_{fr} - \Delta p_{din} \,. \qquad (13)$$

The results of calculation of 100-meter chimney, for blocks 5 and 6 partially and summary, are given in Tab. 3.

3.4. Calculation of the pressure drop in the channel from the pressure flap to the chimney
The pressure drop in the channel is calculated according to the formula

$$\Delta p = \sum_{i=1}^{n} \Delta p_i = \sum_{i=1}^{n} \zeta_i \frac{\rho_p \cdot w_{p,i}^2}{2}, \qquad (14)$$

where is:

ρ_p - density of combustion products,

$w_{p,i}$ [m/s] - flow velocity of the combustion products in the ith pipeline section,

ζ_i - total coefficient of flow resistance in the ith pipeline section calculated by

$$\zeta_i = \lambda_i \frac{L_i}{D_{e,i}} + \sum_{k=1}^{m} \xi_k \,, \qquad (15)$$

in which:
λ_i =0,033 - coefficient of line resistance friction, according to [4],
L_i [m] - the length of the ith pipeline section,
$D_{e,i}$ [m] - equivalent diameter of the ith section,
$\sum_{k=1}^{m} \xi_k$ - sum of local resistances along the ith pipeline section.

The first part of the total resistance in Eq.(15) represents the line resistance due to friction, i.e.

$$\zeta_{fr,i} = \lambda_i \frac{L_i}{D_{e,i}} \,. \qquad (16)$$

The equivalent diameter of the pipeline section in the case of circular cross-section is equal to the internal pipe diameter, and in the case of the rectangular cross-section AxB the equivalent diameter is

$$D_{e,i} = 1,3 \frac{(A \cdot B)^{0,625}}{(A+B)^{0,25}} \,. \qquad (17)$$

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3.4.1. Proračun pada pritiska za blok 5 do dimnjaka

Proračun pada pritiska za blok 5 do dimnjaka je dat za lijevi kanal u tabeli 4. Ukupan pad pritiska u kanalima prirubnice iza tlačne klapne do dimnjaka iznosi $\Delta p_{block\ 5}$=3038 Pa.

3.4.2. Proračun pada pritiska za blok 6 do dimnjaka

Vrijednosti protoka, brzine strujanja i pada pritiska produkata sagorijevanja za blok 6 do dimnjaka dobijene proračunom po dionicama su date u tabeli 5. Ukupan pad pritiska u kanalima prirubnice iza tlačne klapne do dimnjaka iznosi $\Delta p_{block\ 6}$=3524 Pa.

3.4.3. Analiza rezultata proračuna

Zbirni rezultati proračuna dati u tabeli 6 pokazuju da je veći pad pritiska od tlačne klapne do dimnjaka na bloku 6 nego na bloku 5. Ovo je logično, jer su dimovodni kanali bloka 6 veće dužine u odnosu na kanale bloka 5. Zbog toga će na bloku 6 biti potreban veći dio napora ventilatora za savladavanje gubitka pritiska od tlačne klapne do izlaza iz dimnjaka.
Brzine strujanja produkata sagorijevanja u dimnjaku i dimnim kanalima dati su u tabeli 7.

3.4.1. Calculation of pressure drop for block 5 to the chimney

The pressure drop for block 5 to the chimney for the left channel is given in Tab.4. The total pressure drop from the flange behind the pressure flap to the chimney is $\Delta p_{block\ 5}$=3038 Pa.

3.4.2. Calculation of pressure drop for block 6 to the chimney

The values of flow, flow velocity and pressure drop for block 6 to the chimney calculated by pipeline sections are given in Tab. 5. The total pressure drop from the flange behind the pressure flap to the chimney is $\Delta p_{block\ 6}$=3524 Pa.

3.4.3. The analysis of calculation results

Results in Tab. 6 show that the pressure drop from the pressure flap to the chimney is higher in block 6 than in block 5. It is logical, because the flue gas channels of block 6 are longer than those of block 5. Therefore, a higher part of the fan effort will be required on the block 6 to overcome the pressure loss from pressure flap to the chimney outlet.
The velocity of combustion products flows in the chimney and the flue channels is given in Tab. 7.

Tabela 4. *Protok, brzina toka i pad pritiska produkata sagorijevanja po sekcijama (blok 5)*
Table 4. *Flow, flow velocity and pressure drop of the combustion products per sections (block 5)*

Br. / No.	Sekcija plinovoda / Pipeline section	Otpori / Resistances		$w_{prod,i}$ [m/s]	Δp_i [Pa]
1	Od prirubnice iza tlačne klapne do skretanja naviše / From the flange behind the pressure flap to upturns 1) Protok /Flow: 245 000 m³/h, 2) L_1=13 m, 3) $D_{e,1}$=2,13 m, 4) Poprečni presjek / Cross-section: 2700 x 1350 mm	Trenje / Friction: $\zeta_{fr,1}$=0,20		30,5	1674
		Klapna / Flap: ξ_1=0,10			
		Oštro skretanje prema gore / Sharp turning upward: ξ_2=4,47			
		UKUPAN OTPOR U SEKCIJI BR. 1 / TOTAL RESISTANCE IN SECTION NO. 1: ζ_1 =4,77			
2	Od skretanja naviše do uključenja desnog kanala / From upturns to the right channel connecting 1) Protok /Flow: 245 000 m³/h, 2) L_2=16 m, 3) $D_{e,2}$=2,13 m, 4) Poprečni presjek / Cross-section: 2700 x 1350 mm	Trenje / Friction: $\zeta_{fr,2}$=0,25		30,5	87
		Bez lokalnih otpora / No local resistances			
		UKUPAN OTPOR U SEKCIJI BR. 2 / TOTAL RESISTANCE IN SECTION NO. 2: ζ_2 =0,25			

3	Od uključenja desnog kanala do dimnjaka / From the right channel connecting to the chimney 1) Protok /Flow: 490 000 m³/h, 2) L_3=50 m, 3) $D_{e,3}$=3,06 m, 4) Poprečni presjek / Cross-section: 2700 x 2700 mm	Trenje / Friction: $\zeta_{fr,3}$=0,54	30,5	1277
		Spoj lijevih i desnih kanala / Connection of the left and right channels: ξ_1=1		
		Spuštanje / Lowering 2 x 30°: ξ_2=0,12+0,12		
		Skretanje / Turning 90°: Luk / Arch r/D=1: ξ_3=0,25+0,25		
		Skretanje / Turning 30°: ξ_4=0,16		
		Ulaz u dimnjak / Chimney entrance: ξ_5=1,2		
		UKUPAN OTPOR U SEKCIJI BR. 3 / TOTAL RESISTANCE IN SECTION NO. 3: ζ_3=3,64		

Tabela 5. *Protok, brzina toka i pad pritiska produkata sagorijevanja po sekcijama (blok 6)*
Table 5. *Flow, flow velocity and pressure drop of the combustion products per sections (block 6)*

Br. / No.	Sekcija plinovoda / Pipeline section	Otpori / Resistances	$w_{prod,i}$ [m/s]	Δp_i [Pa]
1	Od prirubnice iza tlačne klapne do spajanja lijevih i desnih kanala / From the flange behind the pressure flap to the left and right channels connection 1) Protok /Flow: 271 500 m³/h, 2) L_1=13 m, 3) $D_{e,1}$=2,13 m, 4) Poprečni presjek / Cross-section: 2700 x 1350 mm	Trenje / Friction: $\zeta_{fr,1}$=0,20	33,8	288
		Klapna / Flap: ξ_1=0,10		
		Spoj kanala / Connection: ξ_2=0,37		
		UKUPAN OTPOR U SEKCIJI BR. 1 / TOTAL RESISTANCE IN SECTION NO. 1: ζ_1=0,67		
2	Od spoja kanala do dimnjaka / From the connection of channels to the chimney 1) Protok /Flow: 543 000 m³/h, 2) L_2=40 m, 3) $D_{e,2}$=3,06 m, 4) Poprečni presjek / Cross-section: 2700 x 2700 mm	Trenje / Friction: $\zeta_{fr,2}$=0,43	33,8	3236
		Skretanje / Turning 90°, Luk / Arch r/D=1: ξ_1=0,25		
		Skretanje / Turning 30°: ξ_2=0,16		
		Skretanje / Turning 90°, Luk / Arch r/D=0,678: ξ_3=1		
		Oštro skretanje prema gore / Sharp turning upward: ξ_4=4,47		
		Ulaz u dimnjak / Chimney entrance: ξ_5=1,2		
		UKUPAN OTPOR U SEKCIJI BR. 2 / TOTAL RESISTANCE IN SECTION NO. 2: ζ_2=7,51		

Tabela 6. *Zbirni rezultati proračuna pada pritiska*
Table 6. *Summary of pressure drop calculations*

Veličina / Quantity	Radni režim / Operating regime		
	Blok 5 / Block 5	Blok 6 / Block 6	Blokovi 5 i 6 / Block 5 and 6
Pad pritiska od tlačne klapne do dimnjaka [Pa] / Drop of pressure from the pressure flap to the chimney [Pa]	3038	3524	3524
Efektivni pritisak na dnu dimnjaka [Pa]/ Effective pressure at the chimney bottom [Pa]	569	563	468
Potrebni napor ventilatora za savladavanje gubitka pritiska od tlačne klapne do izlaza iz dimnjaka [Pa]/ Necessary fan exertion to overpower the pressure loss from the pressure flap to the chimney outlet [Pa]	2469	2961	3056

Preporučena brzina strujanja produkata sagorijevanja u dimnjacima je 10 m/s. Kada rade oba bloka (5 i 6), brzina strujanja u dimnjaku se povećava na 15,2 m/s. To je logično jer se količina produkata sagorijevanja povećava skoro dvostruko. Brzina produkata sagorijevanja u kanalima ostaje približno ista i nakon rekonstrukcije, jer se oni u kanalima nezavisno kreću.

The recommended velocity of combustion products in chimneys is 10 m/*s*. The velocity of the flow in chimney increases to 15.2 m/s when both blocks 5 and 6 work. It is logical because the amount of combustion products increase approximately to double. The speed of the combustion products in the channels remains almost the same after the reconstruction, because they move independently through the channels.

Tabela 7. *Brzina toka produkata sagorijevanja u dimnjaku i u dimnim kanalima*
Table 7. *The velocity of combustion products flows in the chimney and the flue channels*

Brzina toka / Velocity of flow	Radni režim / Operating regime		
	Blok 5 / Block 5	Blok 6 / Block 6	Blokovi 5 i 6 / Block 5 and 6
U dimnjaku / In chimney [m/s]	7,20	7,98	15,2
U kanalima / In channels [m/s]	30,5	33,8	30,5 ÷ 33,8

4. ZAKLJUČAK

Proces rekonstrukcije plinovodnih kanala blokova 5 i 6 Termoelektrane „Kakanj" predstavljao je veoma zahtjevan poduhvat. Zbog toga je bilo potrebno izvršiti detaljne pripreme koje su obuhvatale analizu potreba za stručnim kadrom, dokumentacijom i neophodnom opremom, kao i analizu mjesta rekonstrukcije, raspoloživog prostora i drugo. Pri tome se morala obratiti pažnja na to da rekonstrukcija bude optimalna u smislu što manjeg narušavanja postojećeg stanja. Izgradnja novih kanala trebala je također da doprinese efikasnijem radu blokova 5 i 6.

Rekonstrukcija prezentirana u ovom radu ostvarila je navedene ciljeve. Proračunom parametara toka kroz 100-metarski dimnjak bloka 6 pokazano je da se on može koristiti kao alternativa u slučaju remonta na postrojenju bloka 7 i rekonstrukcije 300-metarskog dimnjaka. Izračunati gubici pritiska od tlačne

4. CONCLUSION

The process of reconstruction of the gas channels of blocks 5 and 6 of the Thermal Power Plant "Kakanj" was a very challenging undertaking. Therefore, it was necessary to make detailed preparations, which included the analysis of needs for qualified specialists, technical documentation and necessary equipment, as well as the analysis of location, available space and so on. Special attention had to be put on to achieve an optimal reconstruction in a sense to make the least possible perturbation of the present state. Also, the construction of new channels was aimed to contribute to the efficient work of blocks 5 and 6.

The reconstruction presented in this paper fulfilled all these objectives. Calculation of flow parameters through the 100-meter chimney proved that it could be used as an alternative chimney in case of the block 7

klapne do izlaza iz dimnjaka, koji iznose približno 2500 Pa za blok 5 i 2960 Pa za blok 6, ukazuju na to da postojeći ventilatori imaju potrebnu snagu i kapacitet da se bez problema transportuje cjelokupna količina produkata sagorijevanja kada rade blokovi 5 i 6 i nije potrebna ugradnja novih ventilatora. Dakle, može se zaključiti da blokovi 5 i 6 mogu bez problema raditi kada su priključeni na dimnjak bloka 6 visine 100 metara.

repair and the 300-meter chimney reconstruction. The calculated pressure loss from the pressure flap to the chimney outlet, in amount of approximately 2500 Pa for block 5 and 2960 Pa for block 6, indicated that the existing fans had the necessary power and capacity to easily transport the entire quantity of combustion products from blocks 5 and 6 and that installation of new fans was not necessary. Thus, we can conclude that blocks 5 and 6 can easily work when connected to the 100-meter chimney of block 6.

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