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NADZORNO – UPRAVLJAČKI SISTEM KUPOLNE PEĆI U POGONU ZA PROIZVODNJU MINERALNE VUNE[**]

Izvod

Kupolna peć je jedna od najvažnijih tehničko – tehnološka celina relativno složenog postrojenja za proizvodnju mineralne vune. Mineralna vuna, koja nalazi široku primenu u građevinarstvu i industriji kao materijal za toplotnu i zvučnu izolaciju i zaštitu od požara, dobija se topljenjem kamena u kupolnoj peći. U radu je razmatrana kupolna peć koja je instalirana u Fabrici mineralne vune u Surdulici. Primenom ekoloških veziva, recikliranjem otpadnog materijala i spaljivanjem dimnih gasova koji nastaju u procesu topljenja zadovoljeni su strogi ekološki zahtevi. Rekonstrukcijom upravljačkog sistema peći i prateće opreme poboljšana je energetska efikasnost, povećan je stepen iskorišćavanja sirovina, a procenat otpada je minimiziran. Doziranje materijala i procesi u peći odvijaju se pod nadzorom lokalne upravljačke jedinice koja je povezana sa centralnim sistemom nadzora i upravljanja proizvodnog pogona. Zadavanje i pregled tehnoloških veličina i parametara vrši se na operatorskom panelu koji je povezan sa upravljačkom jedinicom. Posle odgovarajuće obrade informacije se prezentuju operateru (korisniku) u vidu procesnih promenljivih (tagova) koje su funkcije vremena (trendovi) ili u obliku tabela određene strukture.

Ključne reči: *kupolna peć, kamen, mineralna vuna, nadzor, upravljanje*

1. UVOD

Mineralna vuna je izolacioni material neorganskog porekla koja služi kao toplotni i zvučni izolator u građevinarstvu i industriji (termička zaštita vodovodnih i kanalizacionih cevi, naftovoda, toplovoda, gasovoda i sl.). Koristi se i kao materijal za protivpožarnu zaštitu imajući u vidu da se topi na 1000°C. Dobre osobine mineralne vune su i vodootpornost (ne upija vodu), paropropusnost, otpornost na mikroorganizme i insekte, hemijska stabilnost i otpornost na delovanje hemikalija. Sirovine za proizvodnju mineralne vune su: kamen vulkanskog porekla (dijabaz i dolomit, u manjoj meri bazalt). Osnovnim sirovinama se dodaju briketi koji se dobijaju preradom otpada

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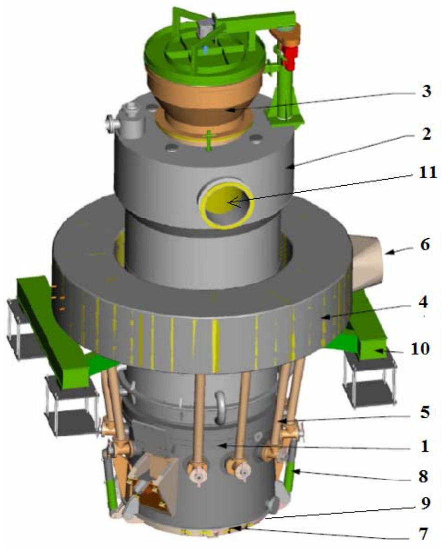
iz tehnološkog procesa uz dodatak cementa, čime se postiže zatvoreni krug potpune reciklaže otpadnog materijala. Osnovna hemijska jedinjenja koja ulaze u sastav navedenih sirovina su oksidi silicijuma, aluminijuma, kalcijuma, magnezijuma i gvožđa. Za proces topljenja sirovina kao energent se koristi koks. Sirovine se po određenoj recepturi doziraju u kupolnu peć u kojoj se tope na temperaturi od 1450°C [1]. Dodatni energent je gas (ili nafta), kojim se napaja poseban gorionik za spaljivanje dimnih gasova nastalih u kupolnoj peći, što omogućava smanjenje emisije gasova ispod dozvoljene granice. Savremen način prečišćavanja dimnih gasova (eliminacija prašine i ugljen monoksida) i vraćanje značajne količine energije u proces proizvodnje doprinosi povećanju efikasnosti. Procesi koji se odvijaju u peći su vrlo složeni i raznoliki: sagorevanje koksa, procesi razmene toplote, topljenje kamena, pri čemu nastaju fizičko-hemijske transformacije materijala iz jednog agregatnog stanja u drugo. Masa dobijena procesom topljenja u kupolnoj peći se kontrolisano dovodi na točkove centrifuga gde se vrši njeno raspredanje [2]. Točkovi centrifuga razbijaju masu u kapljice. Istovremeno se kroz točkove pomoću ventilatora visokog pritiska uduvava vazduh koji nastale kapljice razvlači u vlakna. Ovde se u raspršenom stanju dozira i određena količina vezivnih sredstava. Ranije korišćena vezivna sredstva na bazi forma-ldehida i fenola, koji predstavljaju opasnost po ljudsko zdravlje zbog poten-cijalnih kancerogenih uticaja, zamenjena su vezivnim materijalima od prirodnih sirovina bez dodataka veštačkih boja i aditiva. U osnovi novog veziva je biljni skrob koji se pretvara u inertni polimer tokom procesa proizvodnje mineralne vune. Kroz maglu veziva nastala vlakna se duvaju pomoću ventilatora u sabirnu komoru i tako nastaje primarni filc mineralne vune, koji se dalje termički tretira u polikondenzacionoj komori (temperatura oko 250 °C) gde dobija odgovarajući oblik i stepen tvrdoće. Potom se vrši sečenje prema zadatim dimenzijama [3]. Na ovaj način dobija se mineralna vuna kao ekološki građevinski material, prepoznatljiv po prirodnoj braon boji. Rad kupolne peći, prateće opreme i uređaja odvija se automatski. To obezbeđuje upravljačka jedinica (PLC – programmable logic controller). U sprezi s kontrolerom je operatorski panel, na kome je kreiran određen broj SCADA (supervisory control and data acquisition) ekrana koji služe za vizuelizaciju procesa i prikaz karakterističnih veličina. Preko ulaza analognih (AI) i digitalnih (DI) modula kontrolera dobijaju se sa senzora i prekidačkih elemenata podaci značajni za rad kupolne peći. Sa izlaza analognih (AO) i digitalnih modula (DO) prosleđuju se komandni signali do izvršnih organa u cilju održavanja procesnih veličina i parametara u zadatim opsezima.

2. KONFIGURACIJA KUPOLNE PEĆI I PROCES ŠARŽIRANJA

Na slici 1 prikazan je model kupolne peći za topljenje kamena. Kapacitet peći je 7 ÷ 9 t/h.



Sl. 1. *Model kupolne peći*

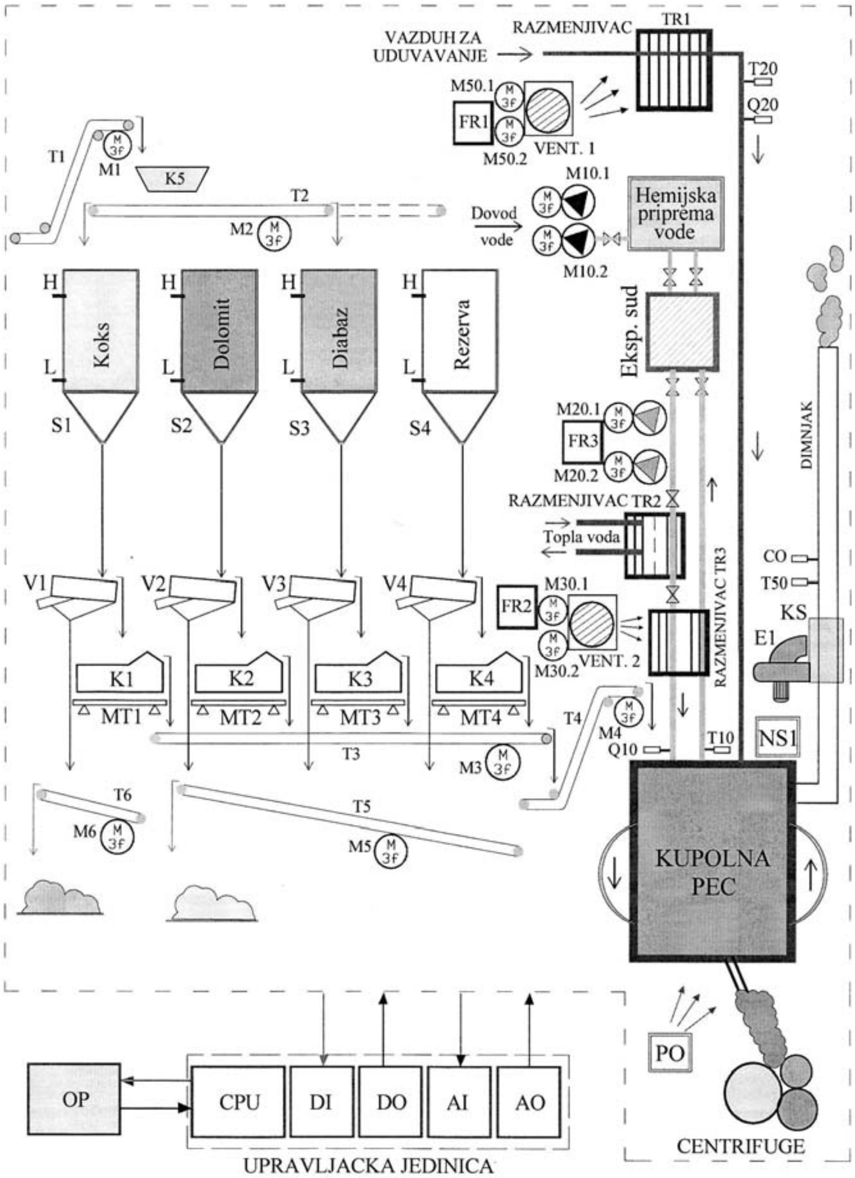
U sklopu peći nalaze se sledeći elementi: 1 – donji deo kupolne peći, 2 – gornji deo kupolne peći, 3 – grlo peći s rotirajućim levkom, 4 – prsten vazduha za uduvavanje, 5 – priključni vodovi vazduhaza uduvavanje, 6 – priključak vazduha za uduvavanje, 7 – podnožje, 8 – hidraulični cilindar za zatvaranje podnožja peći, 9 – držač zatvarača otvora za ispuštanje peći, 10 – nosač kupolne peći, 11 – otvor za ispuštanje gasova.

Za topljenje kamena kao gorivo se upotrebljava koks (1100 kg/h). Količina rastopa je oko 7,7 t/h. U procesu se stvara sirovo gvožđe (oko 0.2 t/h). Za ovu količinu kamena potrebna je određena količina vazduha koji se uduvava u unutrašnjost peći (oko 6500 m^3/h). Temperatura ovog vazduha je od 450°C do 650°C. Potrebna količina kiseonika je oko 300 m^3/h. U toku rada neophodno je hladiti zidove peći. Protok vode za hlađenje je 130 m^3/h, a temperatura 75°C. Na izlazu sistema za hlađenje temperatura vode je 83°C. Količina dimnih gasova je oko 8500 m^3/h a njihova temperatura oko 165°C. Šaržiranje materijala (kamena, briketa, koksa) vrši se preko grla peći, koje je u sklopu rotirajućeg levka pomoću koga se vrši mešanje šarže. Brzina rotacije levka u funkciji je zahteva tehnologije. Na grlu se nalazi poklopac koji se zatvara po završetku procesa šaržiranja. Peć se održava napunjenom zbog sušenja sirovina i hemijskih procesa oksidacije i redukcije, a informacija o napunjenosti dobija se preko senzora NS1 instaliranog na vrhu peći. Kada upravljački sistem dobije informacija da je peć prazna, hidraulički cilindar otvara poklopac i materijal se sipa u peć. Po dostizanju zadatog nivoa prestaje doziranje i poklopac se zatvara. Sastav šarže je promenljiv i zavisi od hemijskog sastava sirovina. Masa šarže je oko 1100 kg. Najšešća kombinacija je koks 110 kg u letnjem periodu (zimi je zbog vlage potrebna veća količina koksa), zatim dolomit 180 kg kao material za korekciju, osnovna sirovina - dijabaz 600 kg i reciklirana mineralna vuna u vidu briketa 200 kg. Hemijski sastav šarže treba da bude odgovarajući, kako bi se dobila odgovarajuća žilavost (viskoznost) rastopa. Ovo je potrebno da bi se omogućilo, pomoću centrifuga, raspršivanje mase u fine kapljice i ispredanje vlakana. Temperatura rastopa je promenljiva i zavisi od hemijskog sastava sirovina. Iznosi oko 1450°C, a meri se optičkim pirometrom PO na izlazu iz peći i prikazuje se na ekranu operatorskog pa-nela. Proces topljenja je kontinualan (peć se drži uvek napunjenom). Trajanje procesa od šaržiranja do pojave rastopa na izlazu iz peći je 1,5h.

3. PRATEĆA OPREMA KUPOLNE PEĆI

Infrastruktura kupolne peći počinje od skladišta sirovina gde se nalaze sirovine diabaz, dolomit, briketi i koks. Na slici 2 prikazana je tehnološka šema kupolne peći s pratećom opremom i uređajima. Sirovine koje su prethodno pripremljene (prosejavanje i određena granulacija) se po određenom redosledu, uz pomoć odgovarajuće mehanizacije, postavljaju na kosi transporter T1, koga pokreće elektromotor M1. Posuda K5 na dvosmernom transporteru T2 (pokretan elektromotorom M2) prihvata dopremljenu sirovinu i sipa je, pomoću hidrauličkog cilindra koji je povezan s posudom, u odgovarajući silos (silosi S1, S2, S3, S4). U silosima se mere diskretno nivoi (L – donji nivo i H gornji nivo). Kada se dostigne gornji nivo u određenom silosu prestaje doziranje odgovarajuće sirovine. Sirovinama iz silosa se zatim pune sudovi koji su povezani s vibracionim elementima (V1, V2, V3, V4) ispod kojih su postavljene posude K1, K2, K3, K4. Težine materijala (sirovina) koji se sipaju u ove posude mere se pomoću mernih traka (MT1, MT2, MT3, MT4). Kada se dostigne programirana težina isključuju se vibracioni

elementi čime prestaje doziranje sirovina. Preko dvo-smernog transportera T3 (elektromotor M3) odmerene sirovine odvoze se na transporter T4 (elektromotor M4) kojim se sirovine ubacuju u kupolnu peć. Transporter T5 skuplja neznatne delove sirovina koje se prosipaju prilikom doziranja.

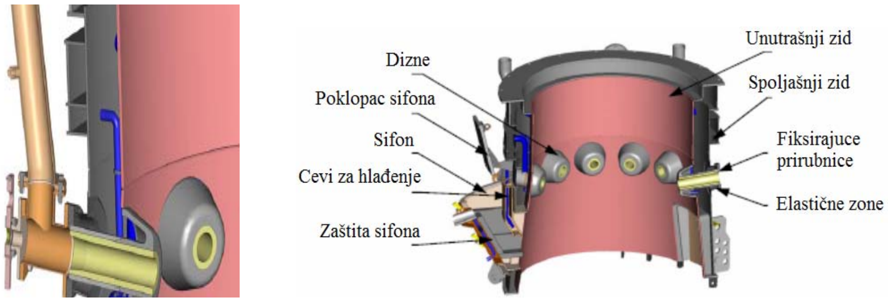


Sl. 2. *Kupolna peć s pripadajućom infrastrukturo, povezana sa upravljačkim sistemom*

Ovaj materijal se kasnije odvozi na skladište sirovina. Prosuti delovi koksa se skupljaju preko transportera T6. Potpalom ubačenih drva na dnu peći pali se koks koji topi kamen u peći, u kojoj se meri nivo i temperatura rastopa.

4. ZAGREVANJE VAZDUHA ZA SAGOREVANJE

Za odvijanje procesa sagorevanja koksa i topljenja sirovina u kupolnoj peći neophodno je uduvavanje vazduha. To je okolni vazduh koji se zahvata od strane frekventno regulisanog ventilatora M50.1 ili M50.2 (slika 2) i vodi se u rekuperator TR (komora za spaljivanje dimnih gasova, koja ima zadatak prečišćavanja gasova spaljivanjem). Rad frekventnog regulatora se odvija na osnovu zadatog protoka vazduha (merač Q20). Zagrejani vazduh, čija se temperature meri senzorom T20, se kroz kružnu cev uduvava preko dizni (slika 3), koje su ugrađene u donjem delu kupolne peći. Povremeno se preko dizni ubacuje i kiseonik. On ima nezavisnu regulaciju počev od postrojenja za uskladištenje do ubacivanja odmerene količine.



Sl. 3. *Instalacija za uduvavanje vazduha u donji deo kupolne peći*

U tehnološkom smislu donji deo kupolne peći je najznačajniji njen element jer se ovde u najvećoj meri odvija proces topljenja, pri čemu se oslobađa velika količina toplotne energije budući da se proces odvija na visokim temperaturama (za predmetnu kupolnu peć temperatura topljenja je 1450 ÷ 1480°C). U ovom delu peć trpi i najveće opterećenje usled visokih temperatura i pritisaka gde dolazi do trenja materijala koji se topi i unutrašnjosti zidova peći. Prilikom sagorevanja koksa i topljenja sirovina u kupolnoj peći oslobađaju se dimni gasovi. Ovi gasovi koji nastaju tokom sagorevanja šarži izlaze iz peći kroz ispusni sistem i odvode se u predgrevač vazduha za uduvavanje, čime se koristi energija ovih gasova. Sami gasovi se spaljuju gorionikom E1, koji je s pogonom na naftu ili tečni naftni gas (TNG). Na ovaj način smanjuje se procenat nastalih gasova ispod dozvoljene granice i zadovoljavaju se strogi ekološki standardi.

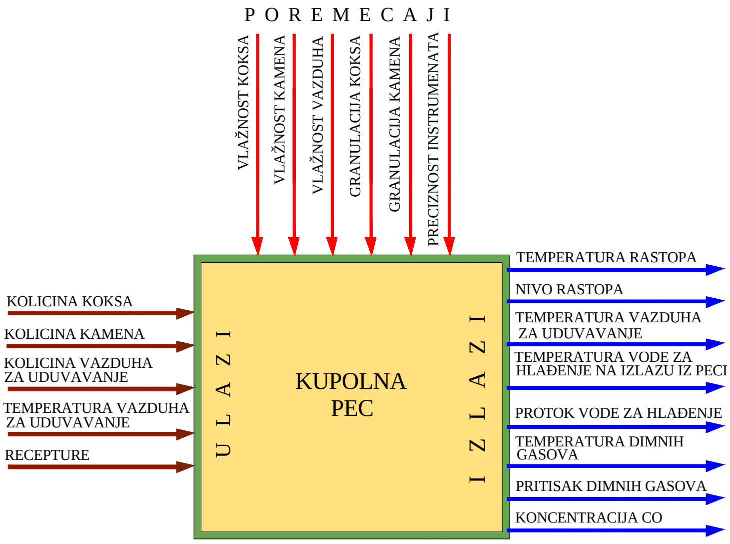
5. HLAĐENJE KUPOLNE PEĆI

Tokom procesa topljenja moraju se zidovi peći kontrolisano hladiti. Hlađenje se vrši vodom. Sistem hlađenja je kružni sa otvorenom ekspanzijom i prinudnom cirkulacijom (slike 2 i 5). Voda se iz mreže najpre dovodi pomoću pumpi M10.1, M10.2 (radna i rezervna) u sistem za hemijsku pripremu, gde se vrši omekšavanje vode. Pomoću centrifugalnih cirkulacionih pumpi M20.1, M20.2 (radna i rezervna) koje su vezane preko frekventnog regulatora FR3, voda odlazi u

dva redno povezana razmenjivača i dalje struji u prostor koji se nalazi između spoljašnjegnjeg i unutrašnjeg plašta kupolne peći. Kriterijum za rad regulatora FR3 je zadati protok vode za hlađenje kupolne peći. Ovde se meri temperaura (Pt100 senzor - T10), pritisak vode u cevovodu (senzor pritiska – P10) i protok vode (merač Q10). Prvi razmenjivač je pločasti i on u primarnom krugu zagreva vodu za sistem grejanja kojim se greje proizvodni pogon. Drugi je vazdušni razmenjivač koga hlade dva ventilatora vođena frekventnim regulatorom FR2. Kriterijum za rad ovog regulatora je održavanje temperature vode za hlađenje (oko 75°C).

6. UPRAVLJANJE I NADZOR

Kupolna peć kao objekat upravljanja predstavlja jedan multivarijabilni sistem čija je strukturna blok šema data na slici 4 na kojoj su prikazani ulazne i izlazne veličine kao i poremećaji.



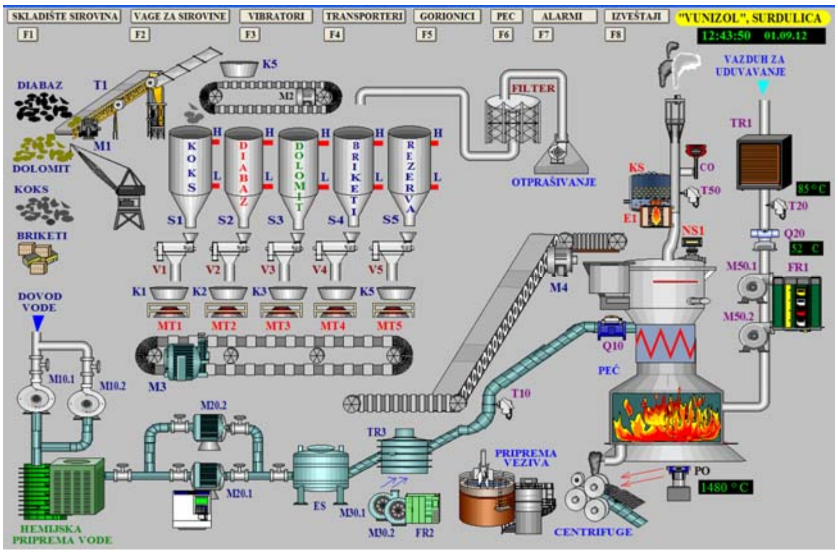
Sl. 4. *Strukturna šema kupolne peći sa aspekta upravljanja*

Rad uređaja i opreme kontrolisan je od strane upravljačke jedinice. To je PLC Siemens S7 1200 koji ima modularnu strukturu. Primenjeni PLC ima mogućnost serijske komunikacije preko protokola RS – 232 i RS – 485, korišćenjem dodatnih modula. Može se koristiti i MODBUS protokol (preko modula RS – 485) kao i USS protokol (Universal Serial Interface Protocol) za komunikaciju sa Simensovim frekvencijskim pretvaračima koji podržavaju ovaj protokol [4, 5, 6]. Ova upravljačka jedinica ima i PROFINET (jedna vrsta otvorenog Ethernet standarda) priključak što joj omogućuje povezivanje s drugim elementima automatizacije i sistemima koji poseduju ovaj priključak. Zahvaljujući ovome moguće je povezivanje više PLC–ova i operatorskih panela preko protokola komunikacije koji se zasnivaju na ethernet i TCP / IP (**T**ransport **C**ontrol **P**rotocol / **I**nternet **P**rotocol) protokolima. Pri izradi projekta relativno lako i brzo se konfiguriše PROFINET komunikacija na relaciji PLC – operator panel. Kreiranje i konfiguracija tagova (simboličkih imena ulaza i izlaza)

ista je i za upravljački program PLC – a i nadzorno – upravljačku aplikaciju operatorskog panela [7, 8].

Zadavanje i pregled parametara kupolne peći i prateće opreme vrši se na operatorskom kolor panelu KTP 1000 koji povezan s PLC – om čini upravljački sistem pod čijim nadzorom su prekidački elementi, senzori i izvršni organi. Konfiguracija i programiranje jedinice S7 1200 i razvoj nadzorno – upravljačkog programa za operatorski panel vrši se pomoću programskog paketa *TIA Portal* koji ima integrisan STEP 7 Basic za kontroler i *WINCC* za vizuelizaciju preko panela KTP. Koncipiranje upravljačke logike sa S7–1200 vrši se izborom i spajanjem različitih modula. Na centralnu procesorsku jedinicu (***C****entral* ***P****rocessing* ***U****nit–CPU*), prema zahtevima procesa kojim se želi upravljati dodaju se različite vrste signalnih i komunikacijskih modula.

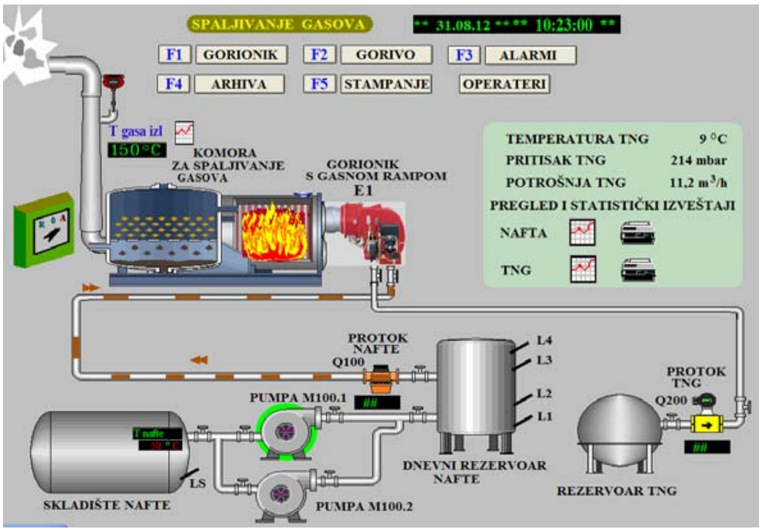
Kreiranje aplikacije u *TIA Portalu* odvija se u nekoliko koraka: koncipiranje projekta; planiranje konfiguracije PLC – a, ulaznih, izlaznih i drugih modula, izrada i konfigurisanje mrežnih veza između uređaja, pisanje upravljačkog programa za PLC, pisanje programa za operator panel, učitavanje napisanih aplikacija u PLC i panel, provera rada i otklanjanje grešaka u aplikacijama. Nakon formiranja novog projekta bira se u *Devices & Networks* meniju opcija *Add new device,* čime se u projekt postavljaju odgovarajući PLC i operator panel. U zavisnosti od izbora dalje se radi s programom *STEP 7 Basic* u kome se razvija upravljački program ako je odabran *SIMATIC PLC*, odnosno sa alatom *WINCC* ako je odabran operator panel, na kome se kreiraju SCADA stranice. Jedan SCADA ekran na kome je predstavljena tehnološka šema kupolne peći prikazan je na slici 4.



Sl. 5. *Tehnološka šema kupolne peći s pratećom infrastrukturom (SCADA ekran)*

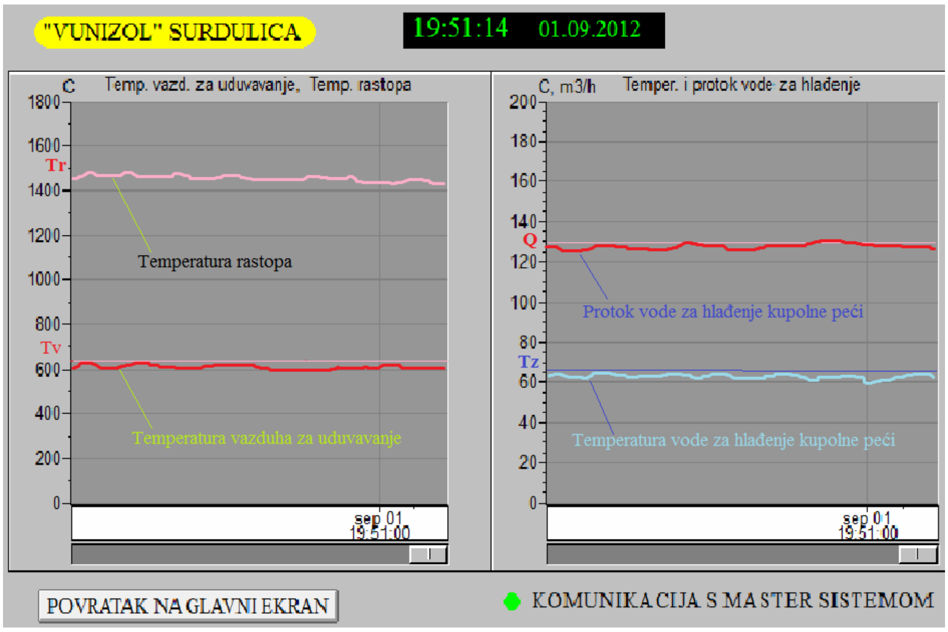
Na SCADA ekranu datom na slici 6 predstavljen je sistem za spaljivanje dimnih gasova. Na pomenutoj slici dati su karakteristični parametri gorionika kada je kao gorivo korišćen TNG. Procesor kontrolera poseduje korisničku i sistemsku memoriju.

Korisnička memorija se sastoji iz memorije za učitavanje (ROM – read only memory), koja je neizbrisiva (nonvolatile) memorija i radne memorije (RAM – random access memory), koja je izbrisiva (volatile) jer se po nestanku napajanja brišu podaci [9, 10]. Aplikativni program i parametri za konfiguraciju kontrolera unose se u ROM memoriju, koja je integrisana u centralnoj procesorskoj jedinici - CPU (central processing unit). Tokom prelaza procesora iz stanja STOP u stanje RUN, kopiraju se iz ROM – a u RAM programi i podaci potrebni za izvršavanje programa. U sklopu CPU jedinice je i sistemska memorija u kojoj se nalaze adrese promenljivih. Adresna područja memorije su: ulazi (I), izlazi (Q), bit memorijski prostor (M), prostor za blokove podataka (DB) i lokalna (privremena) memorija (L).



Sl. 6. *SCADA ekran sistema za spaljivanje dimnih gasova*

Operator panel kao interfejs prema korisniku daje vizuelnu predstavu celog sistema, omogućava zadavanje i pregled karakterističnih veličina i parametara, a PLC izvršava regulaciju rada kupolne peći. Pomoću trend grafova (slika 7) ili tabelarno mogu se pratiti zadate i trenutne vrednosti relevantnih veličina kupolne peći poput temperature rastopa, temperature i protoka vazduha za uduvavanje, temperature i protoka rashladne vode, protoka gasa (nafte) za pogon gorionika pomoću koga se vrši spaljivanje dimnih gasova, potrošene količine sirovina (kamena, koksa, briketa i veziva) za određen vremenski period. Formiraju se i na zahtev štampaju smenski, dnevni i periodični izveštaji. Prate se statusi ventilatora, pumpi, elektromagnetnih ventila, motora transportera, sistema za hemijsku pripremu vode. Ukoliko određene veličine dostignu vrednosti koje su izvan zadatog opsega generišu se alarmi sa opisom mesta i vremena nastanka, uz svetlosnu i zvučnu signalizaciju. Na operatorskom panelu se ispisuje odgovarajuća tekstualna poruka i zahtev operateru da potvrdi alarm. Pojavljuje se lista mogućih uzroka kvarova što olakšava rad službi održavanja i skraćuje vreme zastoja.



Sl. 7. *Trend graf karakterističnih veličina kupolne peći*

7. ZAKLJUČAK

Rekonstrukcija upravljačkog sistema kupolne peći, koji se zasniva na PLC konfiguraciji u sprezi sa operatorskim panelom, doprinela je povećanju efikasnosti rada kupolne peći a samim tim povećana je efikasnost i produktivnost proizvodnog pogona mineralne vune. Mineralna vuna se proizvodi od sirovina koje se nalaze u prirodi i/ili od recikliranih sirovina, a njena vlakna su povezana sredstvom koje je ekološki prihvatljivo i biorazgradivo. Otpaci koji nastaju u procesu proizvodnje ili otpadna vuna s gradilišta drobe se i melju u granulat. Dodavanjem peska i cementa ovim otpacima dobijaju se briketi koji služe kao sirovina. Kamena vuna kao izolacioni materijal u celosti se dobija iz prirodnih sirovina. Tokom procesa proizvodnje iz jednog kubnog metra sirovina dobija se višestruko veća zapremina izolacionog materijala uz minimalnu potrošnju energenata. Spaljivanjem dimnih gasova smanjena je emisija štetnih materija tokom proizvodnje i izloženost radnika na radnom mestu. SCADA sistem na operatorskom panelu poseduje funkcije nadzora i upravljanja. Omogućeno je operateru nadgledanje procesa i eventualna korekcija upravljanja ukoliko nastane neka specifična situacija. Sistem upravljanja i nadzora vrši neposredno merenje tehno-loških veličina i na osnovu implementiranih algoritama upravlja izvršnim organima. Sistem pruža vizuelizaciju tehnološkog procesa i instalirane opreme, alarmiranje u slučaju kvarova i dostizanja kritičnih vrednosti određenih tehnoloških veličina, arhiviranje tehnoloških parametara, događaja i akcija operatera, automatsku zaštitu i blokadu uređaja i opreme pri nastanku kritičnih situacija. Ovim je obezbeđen visok

nivo kontrole i organizacije proizvodnje, smanjeno je vreme zastoja proizvodnje i olakšan je rad službi održavanja. Formirana arhiva i adekvatna interpretacija relevantnih podataka karakterističnih za tehnološki proces, omogućavaju tehnolozima neophodne informacije o toku procesa i olakšavaju im pronalaženje novih tehnoloških rešenja i poboljšanje postojećih.

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*Stanko Stankov**

MONITORING AND CONTROL SYSTEM OF CUPOLA FURNACE AT THE PLANT FOR MINERAL WOOL PRODUCTION**

Abstract

Cupola furnace is one of the most important technical-technological units of the quite complex plant for mineral wool production. Mineral wool, which has wide application in civil engineering and industry as material for thermal and audio isolation and fire protection, is obtained by melting stone at cupola furnace. Cupola furnace, installed in the Factory for mineral wool production in Surdulica, is considered in this paper. The strict environmental requirements are satisfied applying ecological binders, recycling waste material, burning flue gases occurred in melting process. By reconstruction of furniture control system and following equipment control system, the energy efficiency, higher utilization level of raw material and minimization of waste material percentage were provided. Materials dosage and processes in furniture are monitored by local control unit connected with central system of monitoring and production plant control. Setting and review the technological variables and parameters are done on a display terminal connected with control unit. After appropriate processing, information is present to the operator (user) in a form of process variables (tags) which are time functions (trends) or in form of certain structure table.

Keywords: *cupola furniture, stone, mineral wool, monitoring, control*

1. INTRODUCTION

The mineral wool is an inorganic insulation material, used as a thermal and sound insulation in construction and industry (thermal protection of water supply and sewer pipes, oil-pipelines, heating-pipelines, gas-pipelines, etc.). Since it melts at temperature of 1000 °C, the mineral wool is also used as a material for fire protection. Good qualities of mineral wool are water-resistance (does not absorb water), water vapor permeability, resistance to micro-organisms and insects, chemical stability and resistance to the action of chemicals. Raw materials for manufacture the mineral wool are volcanic rocks (diabase and dolomite, small quantities of basalt). The briquettes

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obtained from the processing of waste technological processes with the addition of cement are added to the basic raw materials. It results in a complete closed loop recycling of waste materials. The basic chemical compounds that are the parts of these materials are oxides of silicon, aluminum, calcium, magnesium and iron. Coke is used as fuel for the melting process of raw materials. These materials are dosed in the cupola furnace at a specific prescription and they melt at temperature of 1450 °C [1].

Gas (or oil) is the additional fuel that powers a separate burner for burning waste gases produced in cupola furnace. That allows reducing emissions below allowable limits. Modern way of purification the flue gases (elimination of dust and carbon monoxide) and recurrence of a significant amount of energy in the production process contribute to increasing efficiency. The processes taking place in the furnace are complex and varied: the combustion of coke, processes of heat transfer, melting of rocks. The results are physical and chemical transformation of materials from one physical state to another. The mass produced in the process of melting cupola furnace is led by control to the wheels of centrifuge where its untwisting is done [2]. The wheels of centrifuge break mass in the droplets. At the same time, the air is blown through the wheels by high pressure fan and it stretches formed droplets into the fibers. A certain amount of binder in a dispersed state is fed here. Previously used binders, based on formaldehyde and phenol, which pose a threat to human health because of the potential carcinogenic effects, were replaced by bonding material from natural ingredients with no artificial and color additives. A plant starch is in the base of the new binder that turns into an inert polymer during the manufacturing process of mineral wool. Protein fibers are blown through the fog binders by fans into a collecting chamber and in this way the primary mineral wool felts arise. It is heat-treated in the polycondensation chamber (temperature around 250 °C), where it receives the appropriate form and degree of hardness. After that, cutting by the given dimensions is done [3]. By this way, the mineral wool as eco building material is obtained, known for its natural brown color. Functioning of the cupola furnace, associated equipment and devices are automatic. It is provided by a control unit (PLC - programmable logic controller). Display terminal is in conjunction with a controller, and the certain number of SCADA (Supervisory Control and Data Acquisition) screens is created on it. These SCADA screens are used for process visualization and display the characteristic values. Data from the sensors and switching elements are provided via analog (AI) and digital input (DI) module of the controllers, what is important for cupola furnaces function. From the outputs of analog (AO) and digital modules (DO), the command signals are sent to the executive in order to maintain process variables and parameters within particular ranges.

2. CONFIGURATION OF CUPOLA FURNACE AND CHARGING PROCESS

Figure 1 shows a model of cupola furnace for stone melting. The furnace capacity is 7÷9 t/h.

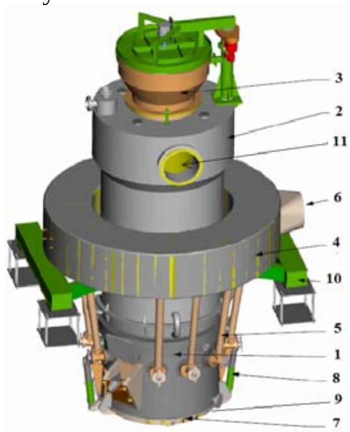

Fig. 1. *Cupola furnace model*

The furnace includes the following elements: 1 - lower part of cupola furnace, 2 - upper part of cupola furnace, 3 - throat of furnace with rotary funnel, 4 - ring for air insufflation, 5 - connecting lines for air insufflation, 6 - connection for air insufflation, 7 - base, 8 - hydraulic cylinder for closing bases of furnace, 9 - shutter holder of aperture for furnace discharge, 10 - support of cupola furnace, 11 - gas-release opening.

Coke is used as a fuel for stone melting (1,100 kg/h). The melt amount is about 7.7 t/h. The process produces crude iron (about 0.2 t/h). This amount of stone requires the certain amount of air that is blown into the furnace (about 6,500 m^3/h). The air temperature is from 450 °C to 650 °C. The necessary amount of oxygen is about 300 m^3/h. It is necessary to cool the furnace walls during the operation. The flow of cooling water is 130 m^3/h and temperature is 75 °C. At the outlet of the cooling system water temperature is 83 °C. The amount of flue gases is about 8,500 m^3/h and their temperature is about 165 °C. Batching of materials (stone, briquettes, coke) is done through the furnace throat, which is the part of rotating funnel, used to mix batches. Rotation speed of the funnel serves technological requirements. There is a cover on the throat which is closed at the end of the charging process. The furnace is maintained charged due to the drying of raw materials and chemical processes of oxidation and reduction, and charge information is obtained through sensors NS1, installed on the top of stove. When the control system receives information that the furnace is empty, hydraulic cylinder opens the lid and the material is poured into the furnace. After reaching the set level, dispensing stops and lid closes. Batch composition is variable and depends on the chemical composition of the raw materials. Batch mass is about 1,100 kg. The most frequent combination is coke 110 kg in summer (due to humidity, higher amounts of coke is needed in winter), and 180 kg dolomite as material for the correction, the basic raw material - 600 kg diabase and recycled mineral wool in the form of briquettes 200 kg. The chemical composition of the batch should be appropriate, in order to obtain the adequate toughness (viscosity) of melt. This is necessary to allow, using a centrifuge, spraying the mass into the fine droplets and spinning of fibers. Melt temperature is variable and depends on chemical composition of raw materials. It is approximately 1,450 °C and it is measured by optical pyrometer PO on the outlet of the furnace, and it is shown on the screen of operator panel. Melting process is continuous (always keeps the furnace filled). Duration of the charging process from batching to occurrence of melt on the furnace outlet is 1.5 h.

3. SUPPORTING EQUIPMENT OF CUPOLA FURNACE

Infrastructure of cupola furnace begins with the raw materials warehouse where raw materials are diabase, dolomite, coke and briquettes. Figure 2 shows the technology layout of cupola furnace with necessary equipment and devices. Raw materials that were previously prepared (sieving and some grit) in a specific order, with a help of appropriate machinery, are put on oblique conveyor T1, which is powered by electrical motor M1. K5 vessels in two-way conveyor T2 (an electrical motor M2) accepts prepared raw material and infuse it into the appropriate silo (silos S1, S2, S3, S4) using a hydraulic cylinder, which is connected to the vessel. Discrete levels are measured in the silos (L - lower level and upper level H). When the upper level is reached, dosing of suitable raw materials stops in a particular silo. Then, raw material from the silo fills the tanks that are connected to vibrating elements (V1, V2, V3, V4) under which the vessels are set K1, K2, K3, K4. The material weights (raw

materials) that are poured into these containers are measured using strain gages (MT1, MT2, MT3, MT4). When the programmed weight is reached, the vibrating elements are off, which stops dosing of raw materials. Over two-way conveyor T3 (M3 motor), the measured raw materials are transported to conveyor T4 (motor M4), which is used to insert the raw materials into cupola furnace. Conveyor T5 collects insubstantial parts of raw materials that are spilled during dosing.

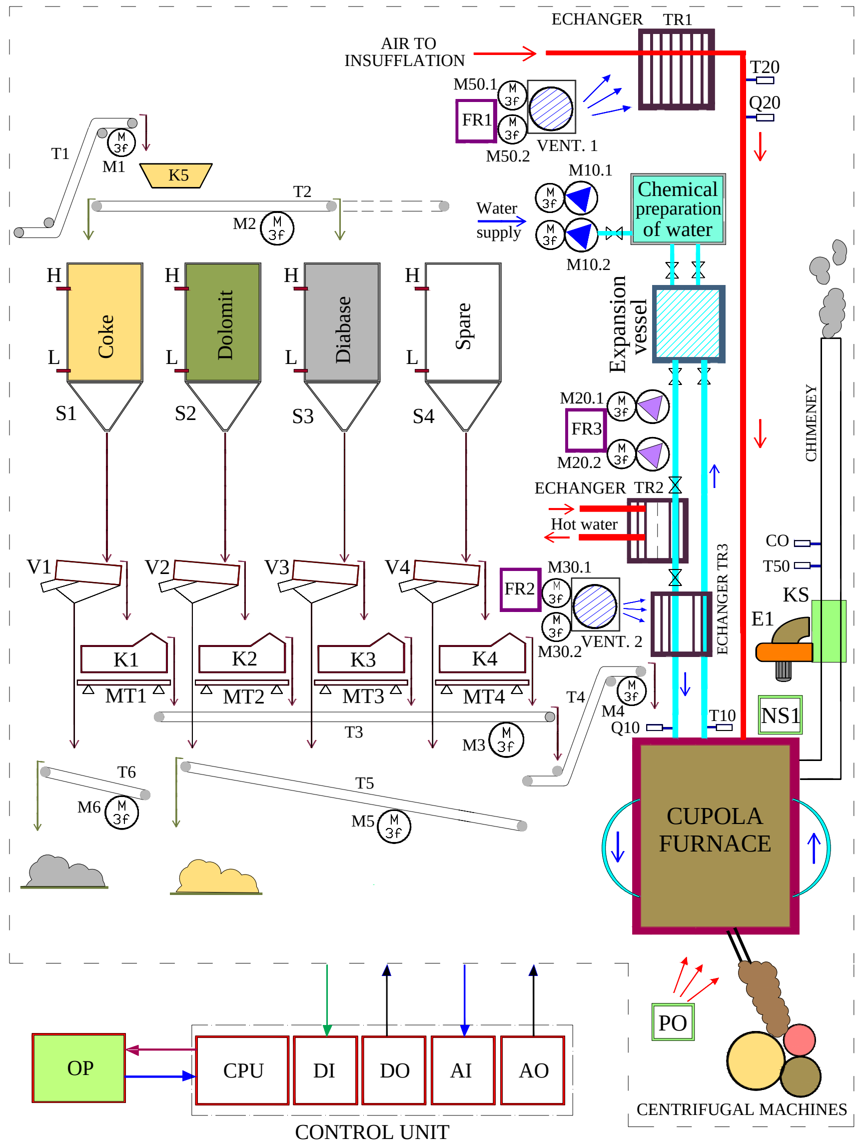

Fig. 2. *Scheme of cupola furnace with associated infrastructure, connected with control system*

This material is later transported to the raw materials storage. Scattered coke parts are collected by conveyor T6. The coke which melts the stone is burned by kindling of the inserted woods at the bottom of furnace, where the level and temperature of the melt are measured.

4 AIR HEATING FOR COMBUSTION

For the process of coke combustion and smelting of raw materials in cupola furnace, the air blowing is necessary. It is the ambient air, which is taken by frequently regulated fan M50.1 or M50.2 (Figure 2) and led to the recuperator TR (chamber for burning waste gases, which has the task of gas treatment by burning). Operation of frequency regulator takes place on the basis of a given air flow (meter Q20). The heated air, which can be measured by temperature sensor T20, is blown through a circular tube over the nozzles (Figure 3). The nozzles are built in the lower part of cupola furnace. Oxygen is periodically injected through the nozzles. It has an independent regulation from the storage facility to the insertion of measured quantities.

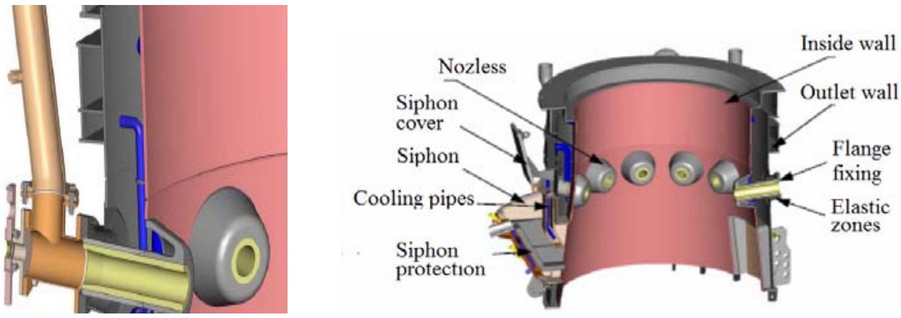

Fig. 3. *Installation for air blowing into the lower part of cupola furnace*

In technological terms, the lower part of the cupola furnace is its the most important element because the melting takes place there, and the result of this is releasing large amounts of heat release due to the process at high temperatures (for this cupola furnace melting temperature is 1,450 ÷ 1,480 °C). In this part the furnace suffers the greatest burden due to high temperatures and pressures what lead to friction of melting material and inside walls of furnace. During coke combustion and smelting of raw materials, flue gases are released in cupola furnace. These gases, generated during combustion of batches, come out through the exhaust system and they are taken to the preheater of blowing air. By this way, the energy of gases is used. Gases are burned with burner E1, which operates with oil or liquefied petroleum gas (LPG). This reduces the percentage of generated gases below permissible limits and adequates strict environmental standards.

5. COOLING OF CUPOLA FURNACE

During melting process, the furnace walls must be controlled cooled. It is done with water. The cooling system is circular with open tank and forced circulation (Figures 2 and 5). At first, water is supplied from the water system using the pumps M10.1, M10.2 (operating and backup) to the chemical treatment system, which is used for water softening. Using centrifugal circulation pumps M20.1, M20.2 (operating and backup) which are connected via frequency converter FR3, water goes in two serially

connected exchangers and continues to flow into the area which is located between the inner and external sheath of cupola furnace. The criterion for regulator FR3 operation is the assigned water flow for cooling cupola furnace. Temperature is measured here (Pt100 sensor - T10) as well as water pressure in pipeline (pressure sensor - P10) and water flow (meter Q10). The first exchanger is laminated and it heats the water in the primary circuit for the heating system that warms the manufacturing plant. The second is an air exchanger which is cooled by two fans driven by two frequency regulator FR2. The criterion for the operation of this regulator is maintaining the temperature of cooling water (about 75 °C).

6. CONTROL AND SUPERVISION

Cupola furnace, as facility mana-gement, is a multivariable system whose structural block scheme is given in Figure 4, which displays the input and output values as well as disorders. Operation of device and equipment is controlled by the control unit.

It is PLC Siemens S7 1200 with modular structure. Applicable PLC is capable of serial communication protocols via RS - 232 and RS - 485, using plug-ins. MODBUS protocol (via module RS - 485) and USS protocol (Universal Serial Interface Protocol) can be also used to communicate with the Simen frequency converters that support this protocol [4, 5, 6]. The control unit has a PROFINET (a kind of open-standard Ethernet) port that allows it to connect to the other elements of automation and systems with this connection. Due to this, it is possible to connect multiple PLCs and operator panels via communication protocols based on Ethernet and TCP/IP (Transmission Control Protocol/Internet Protocol) protocols. In project development, it is relatively easy and quick to configure PROFINET communication between PLCs - the operator panel. Creation and configuration of tags (symbolic names of input and output) are the same for PLC control program and supervision - control application of the operator panel [7, 8].

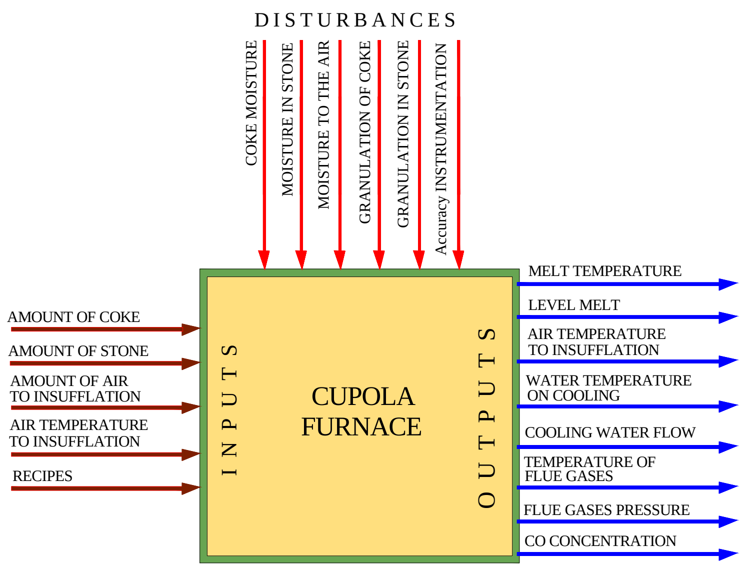

Fig. 4. *Structural scheme of the cupola furnace from control aspect*

Setting and viewing the parameters of cupola furnace and related equipment are performed on the operator color panel KTP 1000 which in connection to the PLC represents a control system under whose supervision are switching elements, sensors and actuators. Configuration and programming of unit S7 1200 and development of supervision - control program of operator panel are done using the software package *TIA Portal* that has the integrated STEP 7 Basic for controller and *WINCC* for visualization via KTP panel. Conception of control logic with S7-1200 is done connecting the different modules. On the Central Processing Unit (*CPU*), according to the requirements of the process which should be controled, different types of signaling and communication modules are added. Creation of the applications in the *TIA Portal* takes place in several steps: designing the project; planning PLC configuration, input, output and other modules, designing and configuring network connections between devices, writing a PLC control program, writing programs for the operator panel, loading of the written applications in PLC and panel, verification the operation and debugging the applications. After creating a new project, the option *Add new device* is selected in the *Devices & Networks* menu. In this way, properly PLC and operator panel are set in the project. If *SIMATIC PLC* is selected, the work with program *STEP 7 Basic* is continued, in which a control program develops. If operator panel is selected, the work is continued with the *WINCC* tools, where SCADA pages are created. Figure 5 shows a SCADA screen with technological scheme of the cupola furnace.

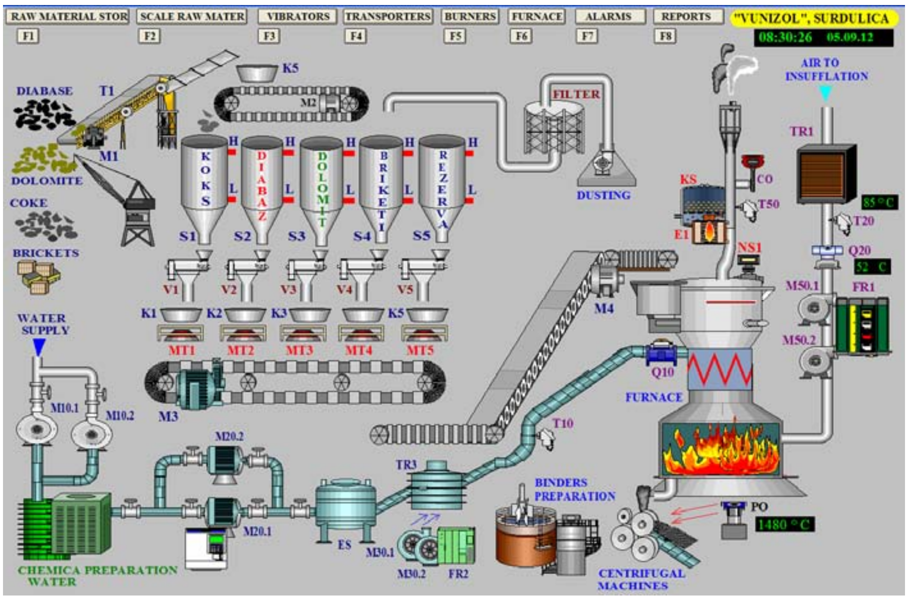

Fig. 5. *Technological scheme of tcupola furnace with supporting infrastructure (SCADA screen)*

Figure 6 shows a SCADA screen with a system for burning waste gases. At the mentioned figure, characteristic parameters of burner, when LPG is used as a fuel, are given. Processor of controller provides the user and system memory. User memory consists of memory to load (ROM - read only memory), which is nonvolatile memory and working memory (RAM - Random Access Memory), which is volatile because

of the erased data in the case of power failure [9, 10]. Application program and configuration parameters of controller are entered in the ROM memory, which is integrated into CPU (central processing unit). During the transition from the state of CPU in STOP to RUN, programs and data, which are necessary to carry out the program, are copied from ROM to RAM. Within the CPU is system memory that contains the address of variables. Memory address ranges are: inputs (I), outputs (Q), bit memory area (M), area for data blocks (DB) and local (temporary) memory (L).

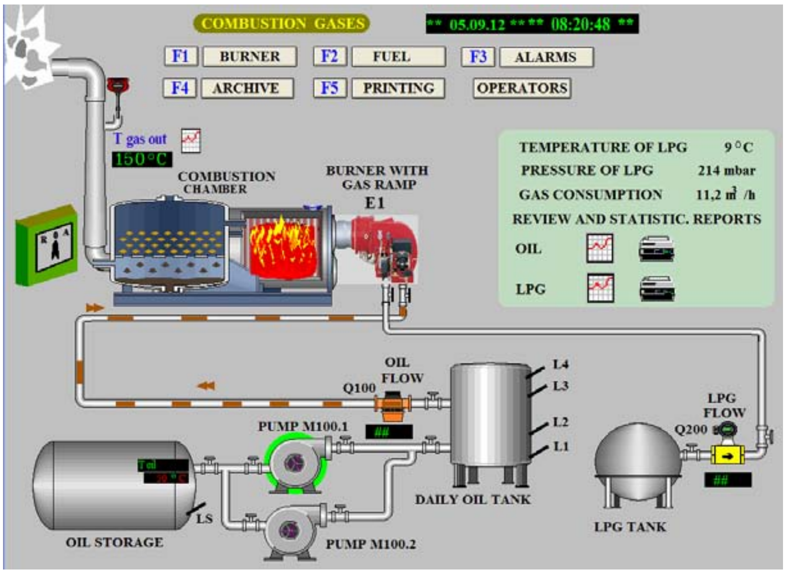

Fig. 6. *SCADA display of systems for combustion flue gases*

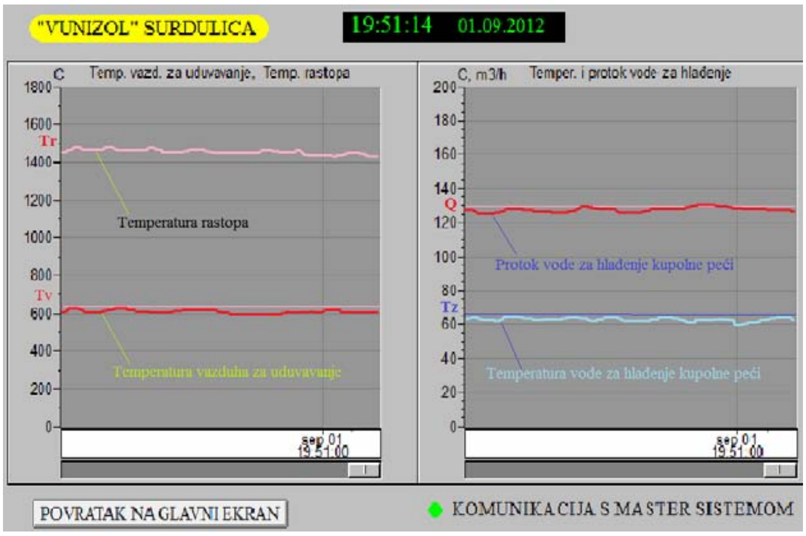

Fig. 7. *Trend graphs of characteristic values of cupola furnace*

Operator panel, as the interface to user, provides a visual representation the entire system, and provides setting and overview of typical values and parameters, and PLC executes regulation of cupola furnace.

Using trend graphs (Figure 7) or Tables, given and current values of relevant size of cupola furnace like melt temperature, air temperature and air flow for blow, temperature and cooling water flow rate, gas flow (oil) for burner operation by which the combustion of the flue gases is performed, used quantities of raw materials (stone, coke, briquettes and binders) for the specified period of time, can be monitored. Shift, daily and periodic reports are created and printed on demand. The status of fans, pumps, solenoid valves, motors of conveyors, systems for the chemical treatment of water are monitored. If certain sizes reach values which are outside this range, alarms with a description of the place and time of origin, with light and sound signaling, will generate. The corresponding text message and request the operator to verify alarms are printed on the operator panel. A list of possible causes of failure appears what makes work of maintenance service easier and reduces downtime.

7. CONCLUSION

Reconstruction of cupola furnace control system, based on PLC configuration in conjunction with display terminal, contributed to increase work efficiency of cupola furnace and in this way increase the efficiency and productivity of mineral wool production plant. Mineral wool is produced from raw materials situated in nature and/or from recycled raw materials, and their fibers are connected with ecological acceptable and biodegradable medium. Trash, which appears in production process or waste wool from site, are crashed and ground into granules. Adding sand and cement to the trash, the briquette is obtained, which is used as the raw material. Rock wool as isolation material is completely obtained from natural raw materials. During production process, from one cube meter raw material we can obtain much greater volume of isolation material with minimal energy sources consumption. Burning flue gasses results in reduction the harmful materials emission during production process and workers safety. SCADA system on display terminal has monitoring and control functions. Process monitoring and possible control correction in the case of specific circumstance are provided to the operator. Monitoring and control system directly measures technological variables and executive devices are controlled using the implemented algorithms. The system allows visualization of technological process and installed equipment, alarming in the case of failures emergence and achieving critical values of technological variables, archiving technological parameters, events and operator actions, automatic protection and device and equipment blocking in the case of critical situations. High rate of control and production organization are provided, plant downtime is decreased and maintenance service work is facilitated. Formed archive and appropriate interpretation of characteristic data for technological process, give necessary process information to the technologists and facilitating discovering the new technological solutions and improvement the existing ones.

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