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The Use of Technical Oxygen for Combustion Processes in Industrial Furnaces

A number of full scale experimental investigations have been carried out in different types of industrial furnaces to study the effect of oxygen enrichment of combustion air on crucial furnace operating parameters such as rise of temperature and rate of combustion, intensification of heat transfer, reduction of heat losses and savings of fuel. Three possible ways for the introduction of oxygen into furnace which include air enrichment, direct blowing and oxygen burners are explained and compared. In addition, the melting and heating furnaces' control systems are discussed. The obtained experimental results for a number of cases are presented showing the advantages and benefits of use of oxygen for cupola furnaces, rotary kilns, glass melting furnaces, metal heating furnaces and electric arch furnaces.

Keywords: *Oxygen enriched combustion, furnace performance, efficiency.*

1. INTRODUCTION

Combustion air enrichment, or the addition of oxygen for increasing the content of oxygen in air used for combustion has been applied in industry for over 30 years. Specific process demands have limited the application of this technique before all to industrial furnaces. Furnaces are aggregates used in all industrial sectors and they are commonly the part of production process. Disturbances in production, changes of production parameters, or load, frequent starts and other problems connected to the improper management highly affect to the furnace energy consumption. Thermal efficiency of furnaces (the ratio of useful heat to total heat input) which use fuel is low (glass melting 0.10-0.20, steel and iron melting 0.15-0.50, metal thermal treatment 0.20-0.50, lime burning 0.40-0.60, clinker production 0.30-0.65). The flue gases waste heat participates 30-50 % in total fuel energy consumed in the furnace, but much higher values, up to 70 % are possible [1]. Reduction of flue gas quantity and decreasing of the flue gas waste heat are the consequences of combustion air enrichment or the use of oxygen instead of air for fuel combustion. Important effect of oxygen introduction is the rise of furnace output, which also decreases specific fuel consumption. These are the essential causes for the existence of significant potentials for energy conservation by the use of technical oxygen. The enrichment of combustion air, or oxy-burners can save 5-15 % of fuel. Fuel consumption can be reduced even up to 30 % in some special cases (cupolas, glass melting) [2].

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2. INTRODUCTION OF OXYGEN

There are three ways to introduce technical oxygen into a furnace:

a. Enrichment of combustion air by introduction of oxygen into the air duct,
b. Direct blowing of oxygen into the furnace using a special lance or nozzle,
c. The use of oxy-burner as the main or auxiliary burner.

Introduction of oxygen into the air duct and enriched air combustion is the oldest and widely used technique. The advantages of it are the simplicity and low investments for oxygen installation. The effects of this way of oxygen application are evident even for a small amounts of enrichment (1-2%) and typical results are the higher furnace temperatures, lower fuel consumption and the rise of furnace capacity.

Direct blowing of oxygen has shown better results than air enrichment in the furnaces where high temperatures are needed (melting and burning of material) in metallurgy and nonferrous industry. The oxygen is introduced by the special lance in the part of the flame close to the material. Very low oxygen concentrations and lower temperatures are kept in the main part of the flame and it serves as a shield protecting the furnace refractory of overheating. Direct oxygen injection into the combustion zone in the case of shaft furnaces (cupola) is performed by means of lances placed through the main air tyres of the furnace. It contributes to the deeper penetration of oxygen in the central parts of material layer.

Development of oxy-fuel combustion was connected to its use as an auxiliary energy source. Typical usage for electrical melting was in the arch furnaces. Disadvantages of the short and sharp flame of oxy-fuel combustion were compensated by the development of high speed oxy-burners contributing to the additional convective heat transfer in glass melting furnaces. Very serious problem of high temperature processes appeared to be the high NO_x emission. The solution was elimination of air nitrogen by oxy-fuel combustion. The adjustments to the needs of melting and burning processes have led to the development of multistaged combustion burner with long and luminous flame. The burners of this type have replaced main conventional burners and influenced the change of furnace construction. The NO_x emissions abatements were up to 90 % compared to those for conventional air burners [3].

3. FURNACE CONTROL SYSTEMS FOR OXYGEN OPERATION

There is an additional task of the furnace control system in the case of oxygen enriched combustion and that is to optimize the level of enrichment. The optimization has to be performed in accordance to the main objectives of the furnace production process. Process control systems for cupola iron melting and for pusher-type heating furnaces developed by the Faculty for Mechanical Engineering are described.

3.1. Control system for cupola iron melting

Cupolas are widely used in foundries because of their good iron melting economy. The use of technical oxygen and process control contribute to the improvement of energy efficiency. The main cupola iron melting process parameters are furnace production rate, air flow rate, melted iron temperature, coke quantity and oxygen content of the air blast. Their relation is shown in Fig. 1 [4]. and for the real furnace it has to be determined by experiments. The furnace cannot operate without the monitoring and control of other process parameters, such as the quality, dimensions and shape of row materials and the content of carbon monoxide and carbon dioxide in flue gases.
The correlation of melted iron temperature to other process parameters, as shown in Fig 1., and other significant relations (air to fuel and oxygen) are incorporated in the process control computer program. Results of the execution of this program are the calculated values for air and oxygen flows and correspondent output signals (commands) issued to the actuators. Another important task of the control system is to reach and to maintain the needed temperature of melted iron (t_{MZ}) and it performs this task in the following steps:

a. Increasing of the air flow rate progressively unless the maximum iron temperature (t_{Mmax}) is achieved (the moment when the iron temperature starts to decrease with further increase of air flow rate, as in Fig. 1.).
b. When the t_{Mmax} value is achieved, and t_{Mmax} is less than t_{MZ} , the enrichment of air blast with oxygen is started and the needed iron temperature t_{MZ} should be achieved by step by step introduction of oxygen together with air flow and coke impute adjustment.
c. If there is no maximum of iron temperature (t_{Mmax}), the coke input is too high and after it's reduction, the procedure should be performed as in b.

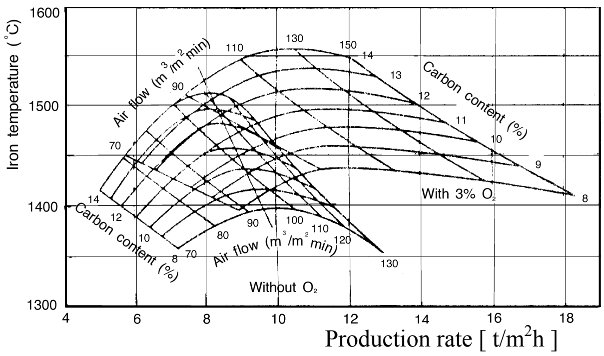

Figure 1. Relations of process parameters for cupola iron melting.

Personal computer program which realizes this procedure is designed to integrate main process control demands (operation / control regime, procedures for program execution, relations of process and regulated values etc.) for the real furnace [5]. It was applied in experimental operation with oxygen introduction to the cupola for mineral wool production. First test was only with data acquisition and oxygen flow control. The program was completed in the next two experiments with material charging control, material balance calculations, with correlation's of furnace output to coke and oxygen consumption and air flow adjustments. Flue gas analysis data for air flow corrections has to be added in the next step.

3.2. Control system for pusher-type furnace

Two basic control strategies and two control system types are applicable for the heating processes in the steel mill furnaces: (1) Control system is based on the manually introduced set-up values for the temperatures measured inside of different heating zones and (2) Control is based on the software model of the heating process which defines the needed process parameters according to the manufacturing requirements.
The control system proposed by the Faculty of Mechanical Engineering for the pusher-type furnaces has a three-level (organization, coordination and execution) hierarchical structure, similar to some systems proposed in literature [6]. The execution level includes sensors and control equipment used in the existing system of the furnace control. The coordination level performs supervisory control functions and primary data processing. It also enables full use of the process model and expert programs functions. The organization level consists of: (1) Process modeling and optimization programs, (2) Set of the expert programs for different critical furnace operating conditions (transient states, inadequate heating, measurement errors, irregular furnace operation, etc.), (3) Man-machine interface and (4) Data base (data on physicochemical features of gases and materials, limit values, process parameters and furnace operation events) [7].
The concept of the control system for pusher-type furnace was developed out of control systems designed

by the Faculty of Mechanical Engineering in Belgrade for the experimental use of technical oxygen in heating furnaces of steel mills in Skopje and Smederevo. These systems were hybrid systems incorporating all sensors and actuators and the part of controllers of existing control systems. Data acquisition and processing were developed. Huge data base and heat and material balance calculation programs were added, together with programs for air enrichment and oxygen consumption control. Long-term experimental runs with oxygen in real operating conditions (15 days for soaking pit and 27 days for pusher-type furnace) have shown the good reliability and easy performance of all functions of applied systems.

The proposed control system allows its easy improvement if needed and it is open for adding new expert programs, as well as for use of modern sensors and processing elements. As an example of the useful expansion can serve the considered introduction of visual flame control equipment and the equipment for the visual control of slab movement in the furnace.

4. THE EFFECTS OF COMBUSTION AIR ENRICHMENT IN DIFFERENT TYPES OF FURNACES

The oxygen was successfully applied in many furnaces and there are a lot of reports on the effects of its application in literature. The specificity of every single furnace in long term operation and the need for the rationalization in oxygen and fuel consumption were the reasons for very careful experimental check of effects reported in literature prior to every new application of oxygen in industry. More than twenty experimental investigations and studies have been carried out by the Faculty for Mechanical Engineering of Belgrade, the Center for High Temperature Processes (CHTP) for Tehnogas, Belgrade, present Tehnogas-Messer, producer of technical gases. Results of these investigations are presented and compared to data found in literature. Review of experiments is given in Table 1. The typical solution of experimental oxygen supply installation is shown in Fig. 2. [2].

4.1. Cupolas

General finding is that the direct blowing of oxygen into the combustion region through lances placed in tyres is more effective than introduction of oxygen in air duct. The economical level of enrichment is up to 4 % (content of oxygen in combustion air: 25 %), but the highest effects are obtained with small amounts of oxygen (up to 2 %).

Cupola furnaces are used for iron melting in foundries and for rocks melting in mineral wool production. Three series of experiments were performed in foundries and three series in“Vunizol”- factory for mineral wool production, as follows: at IRL, Belgrade cupola with the diameter of 0.6 m (1978), at FOB, Belgrade foundry in 1.2 m diameter cupola with preheated air (1984) and in “Potens”, Pozega 1,0 m diameter cupola (1990) for iron melting and in “Vunizol”- factory 1.0 m diameter cupola for mineral wool production (1989, 1995 and 1997). The obtained experimental results are summarized in Table 1. Figure 3. shows the correlation's of main process parameters for mineral wool cupola got by experiments and prepared for the use in computer control program [2].

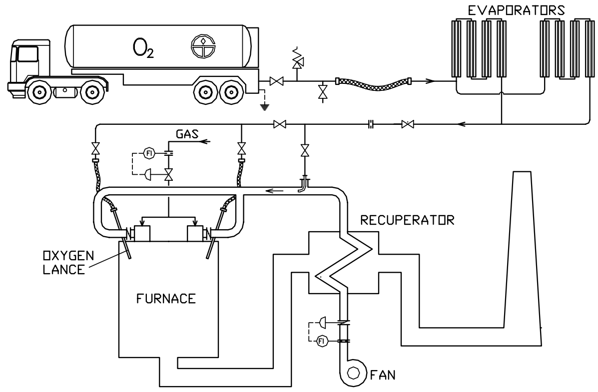

Figure 2. Oxygen supply line for fritted glass furnace (Kikinda).

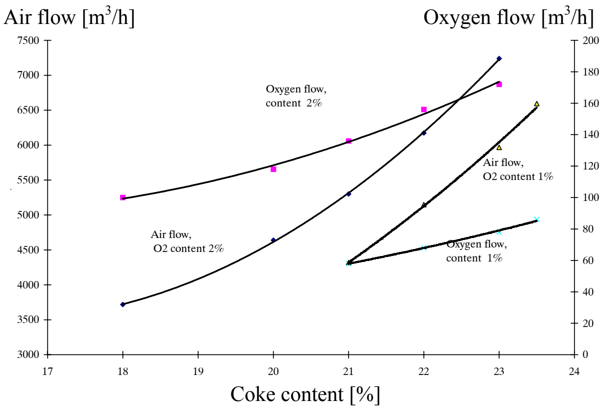

Fig. 3. Dependance of air and tehnical oxygen flows on coke and oxygen content (recomended values for softvare of micropocesor proces control).

4.2. Rotary kilns

The oxygen was introduced in three furnaces of different industrial branches: 90 t/day dolomite calcination kiln at Bela Stena metal magnesium factory (1981), 380 t/day cement kiln at Novi Popovac (1982) and 150 t/day kilns for sintered magnesite production at “Magnohrom, Kraljevo (1985). The observed results are presented in Table1. In these tests the oxygen was introduced in a furnace either through the air duct or through the oxygen lance into the flame root under the burner.

Short and bright flame was noticed during tests when enriched air was used. The flame correction was necessary. The limiting factor was the change of kiln zones position and the exit gas temperature drop with the determining effect on the preheating of the material.

4.3. Glass melting furnaces

Glass furnaces enable economical operation up to enrichment of 30% of the oxygen in air. Following the literature [8] for the enrichment of 27 % - 30% in “U” flame furnaces the production rate rises up to 60 %, the fuel specific consumption is lower to 22 % - 36 % and the arch liner temperature decreases up to 80^0 C - 120

^0C. Our research did not confirm such findings. The tested furnace for flat glass production in Glass Factory Pancevo (1984, 1990) enabled maximum oxygen enrichment of 23 %. The obtained fuel consumption improvement was 0 % - 14.7 %, while the production rate was essentially constant (due to the limitations of the auxiliary equipment of the furnace). Experiments in brick and ceramic tile production factory in Kikinda, where oxygen was used in small furnace for fritted glass production, have shown better results. The 4 % increase of oxygen content in total combustion air results in 22.1 % higher melting capacity and 30.1 % lower specific fuel consumption. Oxygen was introduced into the furnace by the lances under the flame root.

4.4. Electric-arc furnaces

Using oxygen in electric-arc furnaces is possible both during material oxidation and melting if oxygen burners are involved in the process. Our numerical research for the furnace in the foundry Jelsingrad, Banja Luka (Bosnia) shows that if oxygen is injected into melted metal during the process of oxidation the furnace capacity can rise 10 %, while the cycle of the metal treatment decreases up to 15-20%. The ore is eliminated as oxidant. The controlled experiment was not realized, but these effects were confirmed in continuous industrial operation of the same furnace.

4.5. Heating furnaces in steel rolling mills

There is a number of references on pusher type furnaces oxygen use. In general, two conclusions may be withdrawn: the use of technical oxygen in technological sense is reasonable but not in all cases economical. The economical aspect is fulfilled when there is a cheap gaseous oxygen available. In all the cases found in the literature the oxygen was introduced into the preheating and/or in the heating zone where the main energy consumption is in this type of furnaces. The combustion air enrichment was up to 3 %. The furnaces output raised to 15 % while the fuel consumption decreased from 6% to 13 %. It was also possible to raise the temperature of the metal at the exit of the furnace and to perform easier control of the furnace concerning the change of the furnace capacity, dimensions and quality of slabs. Some sources (British Steel) have shown even better results. In the case of 80 t/h pusher-type furnace, the good distribution of technical oxygen onto the burner groups of different zones in furnace, with 2-4 % of air enrichment, the furnace output was raised for 25% [9]. No disadv-antages of any kind were noticed. Two experiments were carried out by the CHTP. Technical oxygen was introduced in 120 t per cycle soaking pit of Iron Works, Skopje (1990). The results were 14 % shorter heating time and 15 % lower fuel consumption for 3.7 % of air enrichment. Second experiment was in Steel Mill of Iron Works in Smederevo (1991). There were nine burner groups on three zone 200 t/h pusher-type furnace and technical oxygen was introduced into the burner collector of each group. The percentage of enrichment varied from 2-6 % in 27 days of continuous operation with oxygen. The results for 2-4 % of enrichment were 7-12 % bigger furnace output and 10 - 14 % lower fuel consumption. The operation with 6 % of enrichment did not show essential improvements.

The application of technical oxygen was always dependant on the economy, as energy efficiency and process improvements were proved in all industrial experiments. The prices of oxygen depend on the technology of oxygen production and on the transportation costs.

The benefits of oxygen application were numerous, as it was shown in this paper and summarized in Table 1. The costs reduction because of the fuel saving alone were never high enough to prove the economy of oxygen application.

It as necessary to concieder the additional effects on the economy: bigger furnace outputs, reduction of failures in material during processing (casting, molding, forming, rolling e.t.c.), efficient process control, reduction in maintenance and man power. The adequate fuel prices in Yugoslavia today would give more to the oxygen application economy.

5. PROSPECTS OF OXYGEN APPLICATION

Efficient use of energy and environment protection are issues of most importance in the future determination of sustainable energy technologies. Considering techniques for oxygen introduction, most efficient, but not always possible for application are multistaged oxygen burners. Reports on the results of the operation of multistaged oxygen burners in glass melting furnaces illustrate the efficiency of this technique in the reduction of pollution from high temperature processes [10,11,12]. Compared to the operation with air reported effects are the following:

- NO_x emissions per tone of glass output were reduced in average by 70-90 %,
- particulate emissions per tone of glass were reduced by 80 %,
- specific energy consumption, what is directly connected to CO_2 emissions, was reduced by 50 % compared to similar air-fuel furnace.

The reported values of NO_x and particulate emissions were under the emission limits for these pollutants in California [9].

Air enrichment technique for oxygen introduction is not so effective than oxy-fuel burners, but in some applications it can not be replaced. Higher flue gas concentrations of NO_x can be expected compared to similar air-fuel furnace, but lower energy consumption and higher furnace output lead to lower emissions per tone of product. We propose that each particular case should be thoroughly investigated.

6. FINAL REMARKS

The paper outlines findings of a number of experimental investigations which have been performed by the authors in different industrial furnaces to studying the effects of oxygen enrichment of combustion air. The obtained results were presented and compared to data found in the literature. The complexity of the issue was proved. In general, it was confirmed that the energy conservation and higher production rates of industrial furnaces were main reasons for the use of technical oxygen in the past, but it is evident that environmental protection becomes very important argument for its application.

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КОРИШЋЕЊЕ ТЕХНИЧКОГ КИСЕОНИКА У ПРОЦЕСИМА САГОРЕВАЊА У ИНДУСТРИЈСКИМ ПЕЋИМА

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У раду се разматрају резултати експриментал-них истраживања примене техничког кисеоника за обогаћење ваздуха за сагоревање, код различитих типова индустријских пећи, кроз утицај на параметре процеса сагоревања, пренос топлоте и губитке топлоте у околину. Примена три начина увођења кисеоника у пећи, која су укључила обогаћење ваздуха, директно увођење и увођење преко кисеоничних горионика, су објашњена и поређена. На основу обављених експерименталних истраживања на пећима за различите технолошке процесе (куполним за топљење метала, ротационим за производњу цемента и ватросталних материјала, кадним за производњу стакла, потисним за загревање метала и др.), дат је преглед ефеката примене техничког кисеоника.

Table 1. Review of technical oxygen application experiments realized by CHTP, Belgrade

Industrial plant.					Technical oxygen application		
Type of process	Factory	Industrial furnace (plant)	Capacity	Fuel	Introduction of oxygen	Oxygen supply	Results:
Introduction of technical oxygen into rotary kilns in "Bela Stena" metal magnesium factory. Realized: 1981.							
Dolomite calcination	"Magnohrom – Bela Stena"	Rotary kiln	75 – 90 t calcinated dolomite / day	Heavy oil	-Oxygen lance -through secondary air duct	Tank for liquid oxygen	▪ Technical oxygen consumption 140 – 340 m^3/h ▪ Increase of oxygen content in combustion air for 1.5 – 3.3 %. ▪ Decrease fuel consumption 6 % - 12 %. ▪ Rotary kiln capacity 99-103 t/day (limited from other plant equipment capacity). ▪ Decrease of outlet flue gas temperature from 370 °C to 290 °C.
Use of oxygen in rotary kiln for cement production in cement factory "Novi Popovac". Realized: 1982.							
Cement clinker production	Cement factory – "Novi Popovac"	Dry process rotary kiln with cyclone preheaters and planetary cooler	360 - 380 t cement clinker / day	Heavy oil	-Oxygen lance -through secondary air	Tank for liquid oxygen	▪ Technical oxygen consumption between 170 and 325 m^3/h. ▪ Increase of oxygen content in combustion air for 0.6 to 1.2 %. ▪ Decrease fuel consumption max. 18 %. ▪ Increase of kiln capacity max.14 %.
Oxygen introduction into glass melting furnaces. Realized: 1984.							
Glass melting	Glass factory – "Pancevo"	Glass melting furnace	60 t/day	Natural gas	-Oxygen lance -air enrichment	Tank for liquid oxygen	▪ Technical oxygen consumption max. 230 m^3/h. ▪ Increase of oxygen content in combustion air for 0.5 to 2.1 %. ▪ lower specific heat consumption for 15,4 %, (with oxygen consumption of. 230 m^3/h).
Introduction of oxygen in cupola furnace in the old "FOB" foundry, Realized: 1984.							
Cast iron production	Foundry "FOB" – Beograd	Cupola furnace	8 t/h of molted iron	Coke	- Blast air enrichment - lances – injection method	Tank for liquid oxygen	▪ Technical oxygen consumption 150 – 460 m^3/h. ▪ Increased iron temperature for 10 – 30 °C, ▪ Increase melting capacity for 1,25 t/h for each 1 % of oxygen. ▪ Reduced coke consumption (0,08 kg/kg molted iron for each 1 % oxygen content).
Introduction of oxygen into rotary kilns (RP-1 and RP2) in "Magnohrom" factory - Kraljevo. Realized: 1985.							
Sintered magnesite production	Magnohrom – Kraljevo	Rotary kiln	150 t sintered magnesite / day	Heavy oil	Through primary air duct	Tank for liquid oxygen	▪ Technical oxygen consumption between 230 and 400 m^3/h. ▪ Increase of oxygen content in combustion air for 1.3 to 2.15 %. ▪ Decrease fuel consumption: 9 - 12 %. ▪ Increase of kiln capacity: 6 -18 %. ▪ Technical oxygen specific consumption between 47 and 83 kg/t sintered
Oxygen introduction in lead and zinc concentrate calcining furnace in "Zletovo lead and zinc smeltery"- Titov Veles, Macedonia, Realized: 1989.							
Agglomeration of sulphid concentrate	Plumb and Zinc smelting plant	Plant for agglomeration	17 t/h of agglome-rated material	Coke	- In the blast air – enrichment method	Mobile tank for liquid oxygen	▪ Consumption of tehnical oxygen 540 – 660 m^3/h ▪ Increased of agglomerate production for 8,4 %. ▪ Better agglomerate quality (strength, low S content). ▪ Higher and stabile SO_2 flue gas content.
Oxygen application in smelt aluminate clinker production in "Cement Factory- Pula", Croatia. Realized: 1988.							
Smelt aluminate clinker production	"Cement factory – Pula" (Croatia)	Shaft kiln	40 t smelt aluminate clinker / day	Pulverized coal	-Oxygen lance -through secondary air duct	Tank for liquid oxygen	▪ Technical oxygen consumption between 100 and 200 m^3/h. ▪ Increase of oxygen content in combustion air for 2.1 to 4.3 %. ▪ Decrease fuel consumption: 11 - 15 %. ▪ Increase of kiln capacity: 10 -37 %. ▪ Technical oxygen specific consumption between 59 and 96 kg / t aluminate
Experimental determination of effects of technical oxygen application in soaking pits of "Skopje Iron Works", Macedonia. Realized: 1990.							
Heating of steel blocks	"Rolling Mill Iron Works" - Skopje, (Macedonia).	Soaking pit	120 tons per cycle	Heavy oil	Introduction in the air duct before the burner.	Main oxygen supply system	▪ consumption of tehnical oxygen max. 375 m^3/h ▪ shorter heating time (14 %) ▪ lower fuel consumption (15 %) ▪ oxygen consumption 18,8 m^3 per ton of steel.

Table 1. (continued)

Industrial plant.					Technical oxygen application		
Type of process	Factory	Industrial furnace (plant)	Capacity	Fuel	Introduction of oxygen	Oxygen supply	Results:
Oxygen introduction into glass melting furnaces for capacity improvements. Realized: 1990							
Glass melting	"Glass factory" – Pancevo	Glass melting furnace	5 t/h	Natural gas	-Oxygen lance	Mobile tank for liquid oxygen	▪ The aim of experiment was to compensate the shortage of air caused by the damage of ceiling in the tunnel of the burner. ▪ Oxygen introduction resulted in better combustion and process control, ▪ All parts of glass production process reached normal conditions.
Oxygen introduction in high temperature reactor for production of clean MgO in "Magnohrom" – factory Kraljevo. Realized: 1990.							
Production of clean magnesium oxide	"Magnohrom" - Kraljevo	High temperature reactor	-	-	Mixture of oxygen and nitrogen	Batteries for O_2, and batteries for N_2	▪ The objective of oxygen introduction was to eliminate toxic exit components. ▪ The oxygen-nitrogen mixture was used with oxygen and nitrogen flows 40 – 50 m^3/h and 25 - 40 m^3/h, respectively. ▪ The use of oxygen was successful. No disturbance of the main process and reactor capacity were shown.
Study of oxygen application in rotary kiln for hydrated alumina calcination of "Alumina Industry"-Mostar (Bosnia and Hercegovina). Realized: 1990.							
Hydrated alumina calcination	"Alumina industry" – Mostar" (Bosnia and Hercegovina)	Rotary kiln	800 t Al_2O_3 / day	Heavy oil	Enrichment through secondary air duct	Tank for liquid oxygen	▪ Technical oxygen consumption (I regime 600 m^3/h, II regime 1250 m^3/h). ▪ Decrease fuel consumption (I regime 3.9 % , II regime 3.2 %). ▪ Increase of kiln capacity (I regime 8 % , II regime 12 %). ▪ Technical oxygen specific consumption (I regime 24 kg/t Al_2O_3, II regime 48 kg/t Al_2O_3).
Oxygen application in three zone pusher-type furnace, in Rolling Mill of "Iron Works"-Smederevo. Realized: 1991.							
Rolling mill	"Iron works" - Smederevo	Three zone pusher-type furnace	200 t/h	-Natural gas, -Blast furnace gas	Air – enrichment	Main oxygen supply system	▪ Technical oxygen consumption between 2100 and 6700 m^3/h. ▪ Increase of oxygen content in combustion air for 2 to 6 %. ▪ Decrease fuel consumption: 10 - 14 %. ▪ Increase of kiln capacity: 7 - 12 %.
Oxygen introduction into fritted glass production furnace, in brick and ceramic tile factory "Toza Markovic" Kikinda. Realized: 1994.							
Fritted glass tile production	Brick and ceramic tile factory	Glass melting	7 t frite / day	Natural gas	-Oxygen lances -air enrichment.	Auto tank for liquid oxygen	▪ Consumption of tehnical oxygen max. 200 m^3/h ▪ Increase of oxygen content in combustion air max. 4 %. ▪ Melting capacity higher for 22,1 % ▪ Lower specific fuel consumption for 30,1 %
Possibilities for introduction of oxygen melting in cupola for mineral wool production. Realized: 1989., 1995., 1997.							
Mineral wool production	"Vunizol" - Surdulica	Cupola furnace	3500 kg molted product / h	Coke	Air – enrichment - lances – injection method	Auto tank for liquid oxygen	▪ Consumption of tehnical oxygen max. 160 m^3/h ▪ Reduced coke consumption (about 26 %, with 1 % rise of oxygen content – injection method). ▪ Increase of melting capacity with very small difference in melting product temperature (about 20 % with 1 % rise of oxygen content – injection method).