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THE LATEST EXPERIENCE WITH ADVANCED CHEMICAL ENERGY INTRODUCTION TO SMALLER SIZE FURNACES

NAJNOWSZE EKSPERYMENTY Z ZAAWANSOWANYM WPROWADZANIEM ENERGII CHEMICZNEJ DO MAŁYCH PIECÓW

Chemical energy plays important role in electric arc furnace steelmaking. Large conventional furnaces producing common carbon steel grades typically use significant amount of oxygen, fossil fuels and carbon injected via furnace sidewall. However, application of chemical energy at smaller size furnaces often producing special steel grades create different challenges. The paper describes specific experience from several advanced chemical energy installations at such type of furnaces including practical operating results and tips.

Keywords: oxygen-fuel, supersonic, injectors, foaming slag, chemical energy

Energia chemiczna ma ogromne znaczenie w procesach produkcji stali w piecach łukowych. Podczas produkcji węglowych gatunków stali w konwencjonalnych dużych piecach zazwyczaj stosuje się znaczące ilości tlenu gazowego, stałych paliw oraz węgla wdmuchiwanych poprzez ściany pieca. Jednak zastosowanie energii chemicznej w małych piecach, zazwyczaj produkujących specjalne gatunki stali stwarza duże wyzwania. W artykule przedstawiono opis specjalnych eksperymentów z zastosowaniem kilku zaawansowanych instalacji wykorzystujących energię chemiczną w tego typu piecach łącznie z praktycznymi wynikami oraz wskazówkami.

1. Applied technology description

Chemical energy at the EAF described in this paper is introduced via PTI JetBOx^{TM}system. The essential part of JetBOx^{TM} technology is a water-cooled copper box which facilitates three functions: more rapid scrap melting by an oxy-fuel burner, supersonic oxygen injection for enhanced bath decarburization, and carbon injection for promotion of refining and production of a foamy slag (see Fig. 1). The JetBOx^{TM} promotes increased efficiency in all areas of chemical energy introduction.

Burner research has shown that a supersonic stream decreases rapidly due to turbulent mixing between the jet and the surrounding environment. Therefore, based on the theory of hydrodynamics, PTI Jet burner adopts a high temperature flame to shroud the supersonic jet which dramatically increases the jet length and efficiency. For oxygen injection, theoretical and empirical results show that, even with a shrouding flame, the supersonic

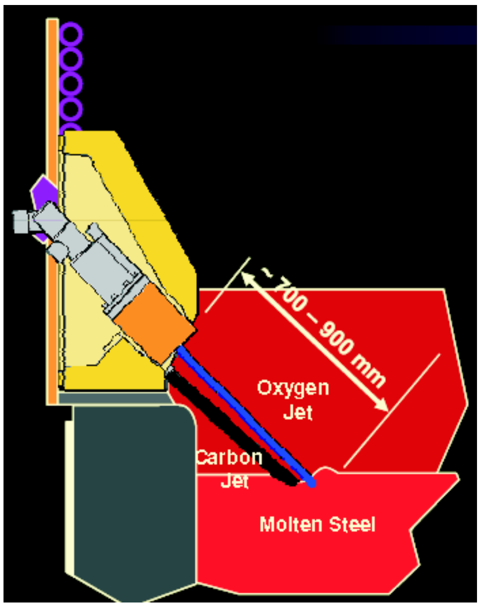

Fig. 1. JetBOx^{TM} principle

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jet will diverge somewhat at extended distances. Therefore, the key to promote oxygen efficiency is to make the stream enter the bath as early as possible, and at the shortest distance possible.

This is particularly important in smaller size of EAF vessels with diameter less than 5 m, where there is generally lower oxygen flow per injector (25 to 30 Nm^3/min compared to typical 35 to 45 Nm^3/min common for large furnaces). Apart from shrouding flame structure and velocity the coherent jet distance is determined by Laval nozzle critical diameter, which is of course smaller for smaller oxygen flow. Therefore the coherent distance for smaller size injectors is generally shorter and minimal travel distance of oxygen to the bath is essential.

The copper box is designed for long life, with the ability to withstand the impact of falling scrap, while at the same time provide excellent cooling. It is located just above the last course of refractory brick with the front face in line with the brick hot face. This provides the following advantages:

- The angle is such that splash from the electrodes or from scrap charging will not block the gas and oxygen orifices inside the combustion chamber (less plugging)
- There is minimal chance of water-cooled panel failures due to aggressive burner programs since the panels are located behind the copper box
- Supersonic jet efficiency is maximized due to the relatively short oxygen jet length and the ability to use the optimal injection angle
- Efficient oxygen use means less electrode oxidation
- Refractory problems in the jet/bath area are minimized since the reaction zone is relatively far away from the brick face
- The increased efficiency with supersonic oxygen also mean less refractory wear at the roof delta
- Injection carbon is applied close to the bath, parallel with the flame/jet, which promotes a better foamy slag and minimizes carbon loss
- The oxidation of iron to the slag is minimized due to the better bath stirring produced by the jets, and the ability to employ several reaction sites
- Decarburization can be accomplished with the door closed most of the time, which yields significant energy savings

PTI has opted to inject carbon as close to the slag/metal interface as possible without redesign of the existing refractory configuration. This is accomplished by the patented JetBOx design, which allows the carbon injection point to be only 50-75 mm above the last course of refractory brick. Carbon is injected by means of a standard carbon steel pipe inserted through a water-cooled orifice. Typically the injection point in PTI design places about 450-600 mm above the hot metal level providing the following advantages:

- Carbon efficiency is excellent since the injection point is normally in the foamy slag
- Carbon trajectory is parallel to the jet/flame and insures that carbon is carried deep into the slag/metal interface without disturbing the supersonic jet
- The proximity of the carbon to the oxidizing shrouding flame promotes excellent evolution of carbon monoxide, which in turn enhances slag foaming
- The carbon is driven deep into the slag, where it reacts with iron oxide to maximize metallic yield, since it promotes conditions closer to equilibrium. **High velocity carbon injection system is also important for the slag penetration. Low velocity systems are not suitable for efficient carbon blowing.**
- The efficient reduction reaction is limiting the slag temperature and optimizing a slag foaming. This is especially important since JetBOx locations in the furnace promote efficient oxidizing reactions in the slag that may superheat it if carbon injection will not be introduced at the same spot.

Typical JetBOx unit including the burner – injector and installation inside hot furnace is shown at Figure 2.

Fig. 2. JetBOx^{TM} unit – stand alone and inside hot furnace

2. Installation at Pilsen Steel

2.1. Plant features

The business activities of the PILSEN STEEL include production and sale of steel, ductile- and grey-iron castings, ingots and finish-machined forgings for various industries, in particular power generation, shipbuilding and rolling mills. The scope of the company activities allows for complete product making and processing "under one roof", i.e. starting with steel making, casting and forging through to rough and finish machining according to the customer needs. Exports represent more than two thirds of the company production. The products can be found in operation all over the world like the "London Eye" Ferris wheel on the bank of the Thames in London where PILSEN STEEL delivered the wheel shaft and other castings of total weight 200 ton. PILSEN STEEL is also the world biggest producer of windmill shafts and one of the big suppliers of large crankshafts for 4-stroke diesel engines.

2.2. Steel qualities

Extremely heavy ingots and castings produced require ultra high purity steel. The general requirements are:

S < 0.005% P < 0,005%

O < 20 ppm H < 1 ppm

The specifications ranges from carbon to low and high alloyed steels with variety of chemical composition. Requirements on very low phosphorus, low oxygen and variable tapping carbon make the operation particularly challenging.

2.3. Furnace

Melt shop is equipped with 60t EAF with sliding gate tapping system. The furnace was upgraded to this size from originally only 30 t vessel. Furnace inner diameter – wall to wall – is 4.3 m. The power supply is limited and transformer size is only 15 MVA. The crane capacity is also from original smaller size furnace so typical heat requires 4 to 5 bucket charging. Due to low installed power furnace used refractory lining up to the top of the vessel to avoid excessive energy loses by water cooling.

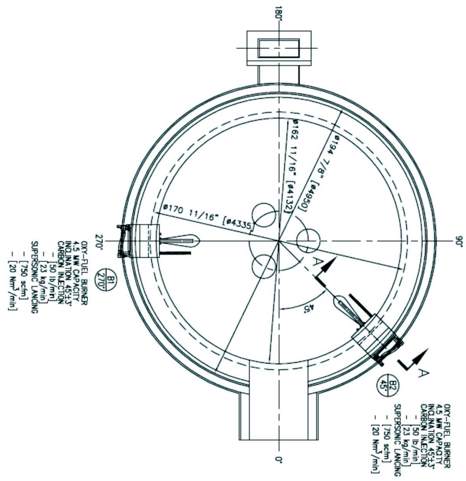

Fig. 3. EAF layout at Pilsen Steel

Prior to PTI JetBOx installation the chemical energy was limited to manual slag door lancing and two post combustion injectors in the upper shell. The furnace layout after JetBOx installation is shown on Figure 3. The burners/ injectors are installed in two positions around the furnace shell. The important feature is 50° oxygen injection angle and 800 mm distance of the jet to the metal line. The furnace is often overcharged up to 80t in which case bath level increase and jet distance to liquid bath is less than 600 mm.

2.4. Operating experience

Small transformer size and large number of charges create relatively long available time for burner operation. The burners located low under the scrap charge, so the operation is fairly effective. There are 3 different operating burner profiles for different grades:

Program 1 is used for light scrap and required tapping carbon below 0,15%. The burners are operated with max. 3.0 MW power in burner mode up to 150 kWh/t of scrap in each basket and up to 20.0 Nm3/min of oxygen in lancing mode at the end of each bucket and refining period. Carbon injection is via each JetBOx position and its flow of 10 – 30 kg/min applied every time when oxygen is injected.

Program 2 is used for melts with higher amounts of return material, which in general consist of very heavy scrap such is ingot tops and gating, and feeders from heavy castings. Operating time of burners in this case is shorter up to 100 kWh/t of scrap and oxygen lancing is used only after 3rd bucket when heavy scrap is molten. The reason is a limited ability of heavy scrap to absorb the energy generated by burners and risk of oxygen deflection and steel – slag splashing when burners operate at lancing mode too early and oxygen bounces from not fully molten heavy pieces of scrap.

Program 3 is used for the melts which require low tapping oxygen < 200 ppm generally used for production of rotors where final dissolved oxygen must be very low. Higher than 200 ppm tapping oxygen lead to excessive treatment time at vacuum ladle furnace which reduces productivity and increase secondary metallurgy cost. Therefore oxygen lancing is used only at the last bucket and later on during refining. Injection time during refining depends on metallurgical analysis checked at the last bucket melting.

2.5. Equipment reliability

The system started operation in February 2007. We did not have any problems with any part of the system since then. There was not any water leak from the JetBOx and only two cases of water leak from the burner copper tip which can be easily changed.

3. Results summary

The results of operation very much depend on type of used program. In general program 1 produces fastest heat because of lighter scrap and higher chemical energy amount. Program 2 and 3 are slower with respect to used charge and steel quality. The long term average results using all 3 programs compared to the results before system installation are summarized in Table 1. Power consumption has been compared to the model by Köhle [2]. The real results are lower, but this is probably caused by the facts that furnace operation is not very typical and furnace walls are refractory lined due to low transformer capacity. However, the difference in power consumption before and after installation of new chemical energy system fits well with model prediction.

Apart from massive production increase and electrical power reduction we have seen significant refractory savings. The campaign time has extended by over 100 heats and gunning consumption has been reduced by over 50%.

TABLE 1

Pilsen Steel EAF #5 – Results summary

Description	Unit	Before	After	diff.	diff %
Tapping Weight	T	61	61	0	0%
Power Input	MW	9	10	1	11%
Tap to Tap Time	Min	250	218	−32	−13%
Power on Time	Min	217	140	−77	−35%
Power off	Min	33	33	0	0%
Electrical Consumption	Kwh/t	534	426	−108	−20%
Fuel (nat. Gas)	Nm^3/t	0	10.5	10.5	
Oxygen Consumption	Nm^3/t	17.0	36.0	19	112%
Electrode Consumption	kg/t	4	4	0	0%
carbon (bulk + injected)	kg/t	20	33	13	65%
Kohle model prediction	kWh/t	667	557	−110	
Productivity		14.6	16.8	2.1	15%
Annual Production capacity	7500	109 800	125 917	16 117	15%

4. Installation at Zeleziarne Podbrezova

4.1. Plant overview

Železiarne Podbrezova a.s (Ironworks Podbrezova) is among the most important producers of hot rolled and cold drawn seamless steel tubes in Europe. Today company works on the principle of a complete cycle of steel manufacturing. This includes meltshop with EAF – LF – CCM cycle, rolling and drawing tube mills with integrated heat treatment capacities.

4.2. The furnace

The original furnace was built in 1992 as part of completely new meltshop. The furnace tapping weight is 54 ton with 6 ton of hot heel and it equipped with 50MVA size transformer.

Inside diameter of upper shell is 5.2 m. The charge is 100% scrap with 3 buckets per heat.

Chemical energy prior JetBOx installation was introduced via slag door burner and supersonic water cooled oxygen – carbon door lance. The door burner power was 5.0 MW and slag door lance capacity 1600 Nm^3/h. Ongoing demand for higher steel production and increasing electrical energy cost led to the decision improve furnace productivity and efficiency by installation of PTI JetBOx chemical energy system.

The furnace layout is shown at Figure 4. There are two JetBOxes at furnace walls and one EBT burner – injector. The applied capacity of each JetBOx burners is 3.0 MW and 30.0 Nm^3/min of supersonic oxygen. The EBT burner capacity is 2.0 MW and 20.0 Nm^3/min of supersonic shrouded oxygen.

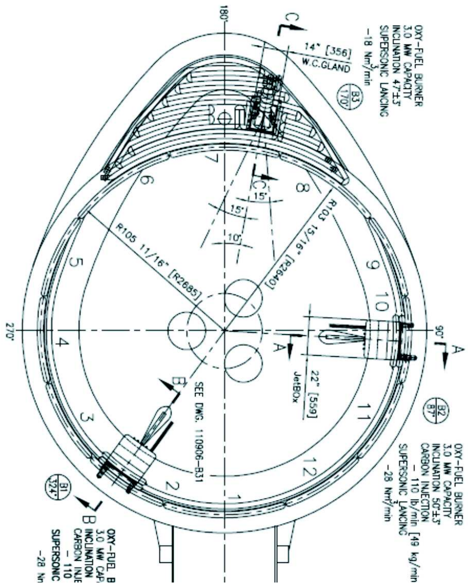

Fig. 4. EAF layout at Zeleziarne Podbrezova a.s.

The oxygen impact angle is 50° and distance to liquid steel bath is 850 mm for the burners – injectors installed in JetBOxes. The EBT burner is installed at 47° and distance to liquid steel is 965 mm at furnace leveled position.

4.3. Operating experience

The JetBox system started in April 2007 with initial focus to minimize power consumption and power-on time. During the first week of operation slag door supersonic lance was used in parallel with JetBOxes. The power consumption was around 350 kWh/t compared to 430 kWh/t before and power on time dropped from 42 to 35 minutes. Oxygen consumption was 43 Nm^3/t. However, the problem was increased scrap consumption due to lack of carbon in the charge for high oxygen consumption. The attempts to increase carbon content were limited by relatively low capacity of fume exhaust system, where increase carbon addition either to a charge or by injection caused furnace and duct system overheating. Second campaign started with strict limitation of oxygen consumption to max. 38 Nm^3/t. Slag door lance is used only for door cleaning (max 4 Nm^3/t). This configuration produces optimal results with metallic charge consumption the same like before (1132 kg/t of good billet including alloys). Despite of relatively small furnace diameter we did not face any problems with splashing to the roof, thanks to steep injection angle, short distance to liquid bath and good efficiency of oxygen injected through the foaming slag. The EBT burner also is used in the lancing mode and the furnace is slightly tilted towards the tapping side during refining period to longer hold a slag in the furnace and to reduce the distance from EBT injector tip to liquid steel.

4.4. Equipment reliability

Since the start-up there was no problem with any part of the control system. There was no leakage of the JetBOxes and only one case of water leak from the copper tip so the equipment reliability is very satisfactory.

5. Results summary

The results are very consistent after initial period of optimization. The key benefits are 4.5 minutes reduction of power on time and over 50 kWh/t power savings. The electrical energy consumption has been compared to the model developed by Köhle. The real results are approximately 20 kWh/t lower than those predicted by the model, but difference between old system operation and JetBOx operation is almost exactly in line with Köhle [2] model prediction. Total conversion cost has been reduced by 1.3 €/t and productivity increased by more than 10%. This ensures fast return of the investment (ROI). Table 2 summarises key parameters before and after PTI JetBOx^{TM} system installation.

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TABLE 2

Average results summary at Zeleziarne Podbrezova a.s.

Description	Unit	Before	After	diff.	diff %
Tapping Weight	T	54	54	0	0%
Power Input	MW	33	33	0	0%
Tap to Tap Time	Min	65	58	−7	−11%
Power on Time	Min	42	37.5	−4.5	−11%
Power off	Min	23	20.5	−2.5	−11%
Electrical Consumption	Kwh/t	432	379	−53	−12%
Fuel (nat. Gas)	Nm^3/t	3.8	5.6	1.8	47%
Oxygen Consumption	Nm^3/t	22.5	36.9	14.4	64%
Electrode Consumption	kg/t	2.27	2.1	−0.17	−7%
Carbon consumption	kg/t	6.2	11.1	4.9	0.00%
Common Scrap	kg/t	1032	1032	0	65%
DRI + HBI	kg/t	0	0	0	
shredded scrap	kg/t	100	100	0	0.00%
Kohle model prediction	kWh/t	458	404	−53.8	
Productivity	t/h	49.8	55.9	6.0	12%
Annual Production capacity	7300 hrs	363 877	407 793	43 916	12%

6. Conclusion

Both installations have proven that PTI JetBOx^{TM} system is efficient and reliable mean of production increase and energy savings. Important rules for smaller size furnaces are steep injection angle, proximity of the jet to liquid bath and consistent slag foaming. Heavy scrap melting and high purity steel production require separate melting profiles, but even in this case the system brings significant benefits. Even relatively low oxygen flow per injector can secure its good penetration and oxygen efficiency when properly installed.

REFERENCES

[1] D. F u f e i, X. F e i h u, W. D o n g, M. C o b u r n, D. S t a n t o n, JetBOxTM Oxygen Efficiency and Consteel Results at Xining Special Steel, Millenium Steel Journal 2007.

[2] S. K ö h l e, Recent improvements in modeling energy consumption of electric arc furnace, 7th European Electrical Steelmakibng Conference proceedings, **I**, 1.309.

[3] J. B r h e l, The JetBOx burner/injector system for EAF steelmaking. Journal - Steel Millenium, s. 87-89 (2006).