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INCREASE THE STEELS PURITY CAST IN VACUUM

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ABSTRACT

The need to develop products with special characteristics and high mechanical properties led to the introduction of plastic deformation of semi-finished materials. Special purpose products are produced from slabs, blooms, billets or from different size ingots. One of the critical conditions to meet quality expectations after plastic deformation is that the material must be as high quality as possible. For refining steels, a range of methods have been developed that can remove harmful elements from the physical and mechanical product properties. For these products, the chosen casting method is one of the most important factors that can ensure product quality because casting can easily remove the beneficial effects of the refining process conducted during the development of the steel melt by contamination with refractory material from the casting assembly, re-oxidation of the metal bath and others. Depending on the complexity of the casting product and to obtain a superior quality product, several methods of casting have been developed.

The usual method of casting high quality large ingots is in vacuum, the advantage is that the steel stream is protected from the surrounding atmosphere, this paper aims to highlight the benefits of vacuum casting with wide stream on the improvement of ingot quality by increasing purity and decreasing gas content.

KEYWORDS: vacuum casting, big ingots, increase the purity, decreasing gas content

1. Introduction

The wide range of applications for steel products made it necessary to develop certain methods and equipments for developing and refining steels leading to increased productivity and improved quality. Product quality is given by the chemical composition and physico-mechanical properties, therefore, to be able to obtain them, steel undergoes a series of processes to increase its purity. Imposing special treatment installations is due to the negative influence of endogenous and exogenous inclusions on steel quality.

Appearance of nonmetallic inclusions (exogenous) in cast steels is a common problem because it involves additional costs for repairs or can lead to the rejection of the product. The results of mechanical properties are closely related to the degree of the steel purity, as the size, composition, morphology and distribution of inclusions have a huge impact on product quality. For example, ductility and tensile strength decreases significantly with increasing oxides or sulfides content in the material. It is important that the number and size of inclusions be controlled.

2. Necessity of refining steels

Refining on secondary treatment installations is successful in removing these inclusions through chemical reactions and slag making but great attention must be paid to the chosen method of casting and molding equipment used because steel can absorb gases from the atmosphere forming defects on the surface of the casted steel part. The exposure of the steel melt to the uncontrolled atmosphere during casting is very harmful because liquid steel absorbs atmospheric gases (N, O and H) to form compounds that prevent solidification in optimal conditions (appearance of gas pockets, internal and external shrinkage hole, fissures and cracks).

Nitrogen influence

Nitrogen is generally unwanted in steel because of its influence on steel properties: it lowers cold deformability (deep drawing) and resilience, resistance to corrosion and shock. In combination with hydrogen, it causes the formation of small pockets of gas and steel aging in castings because of nitrides forming on the structural grain boundaries [3]. Nitrogen is absorbed in the liquid steel from the metal scrap charge, de-oxidation and alloying elements and from the furnace atmosphere as a result of dissociation taking place in the electric arcs of the electric arc furnace.

Hydrogen influence

Hydrogen is always present in the metal bath, but completely unwanted because it produces flakes and porosities during the solidification process. Hydrogen is one of the main causes of porosities in steel ingots and castings it also reduces the plasticity and toughness and affects electrical and magnetic properties [3].

Oxygen influence

Oxygen is a main element in the development of steel, the energy released from burning gas or solid fuel is used to melt the scrap metal, gaseous compounds resulting from combustion help removing non-metallic inclusions from the liquid metal.

Oxide inclusions resulted from reactions between oxygen and metals or non-metals cause an increase in susceptibility to brittle fracture, they reduce fatigue (especially in bearings, springs, and machine parts) and affect the surface quality of parts [3].

Depending on the steel destination, it can be molded into various shapes that can ensure good conditions in the next stages of processing, depending on the shape and size of the products, costs and quality.

To maintain the purity and quality of cast steel ingots, it is necessary to take into account the advantages and disadvantages of the main methods of casting (castings, vacuum castings, bottom pouring).

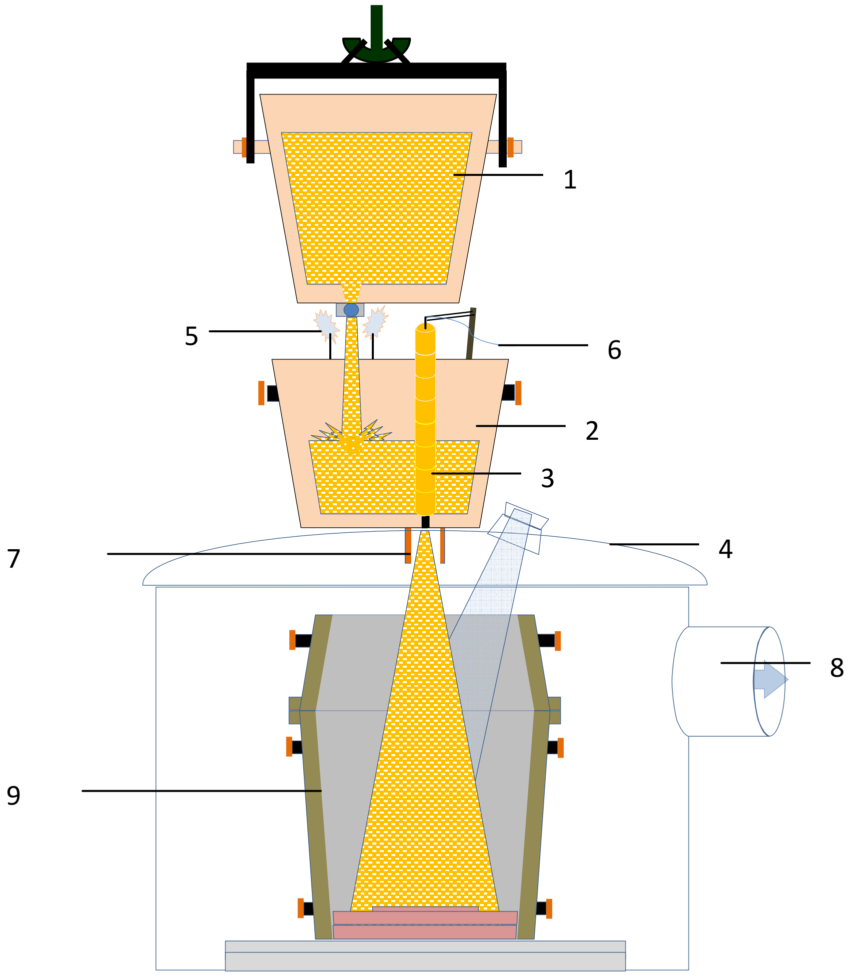


Fig. 1. *Pouring assembly:*
1 – refining ladle; 2 – pony ladle; 3 – stopper rod; 4 – vacuum tank; 5 – argon protection; 6 – argon to the stopper rod; 7 – stream jet; 8 – steam ejector; 9 – mold.

3. The methods casting and refining

This paper presents the benefits obtained from vacuum casting with wide stream.

Using this method (Fig. 1), an advanced degassing of the liquid steel is achieved due to the vacuum created in the casting tank (4), obtaining a high quality ingot. To obtain the necessary vacuum, a pony ladle is required (2) with a stopper rod (3). Argon is injected inside lance (6) to ensure the formation of wide stream (7) in order to obtain a bigger contact surface between the steel droplets and the vacuum inside the tank.

This also helps avoiding the appearance of strong convection currents that could transport inclusions to the ingots center, letting them float to the surface metal bath. To emphasize the degassing efficiency of steels during casting, nine heats of carbon steel were analyzed, material S34MnV and weighing 71Tons, each used in the manufacture of crankshafts for the marine industry.

To achieve the required mechanical properties imposed by the operating conditions, the cleanliness of the material must be increased by removing trace elements and gas from the metal bath during secondary treatment.

The analyzed heats were melted and refined on an electric arc furnace (Fig. 2) with the following features:

Construction type → Water cooled roof and side panels;
Capacity → 55-73 T;
Lining → Magnesia-carbon;
Hearth interior diameter → 5500 mm;
Transformer power →30 MVA;
Electrode diameter → Ø500mm (UHP);
Electrode placing diameter → 1350 mm;

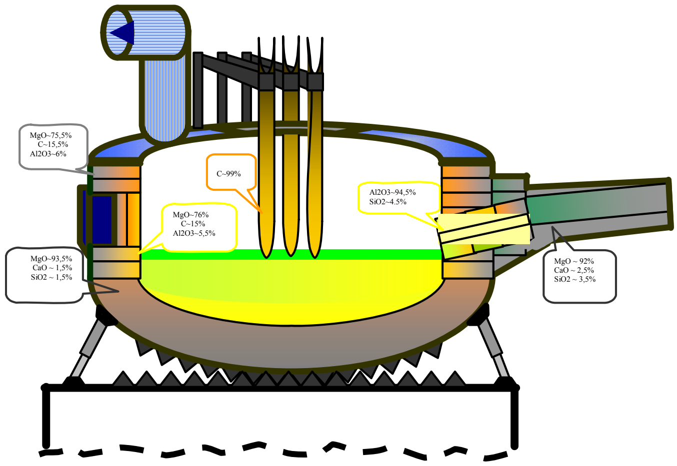


Fig. 2. *Electric Arc Furnace*

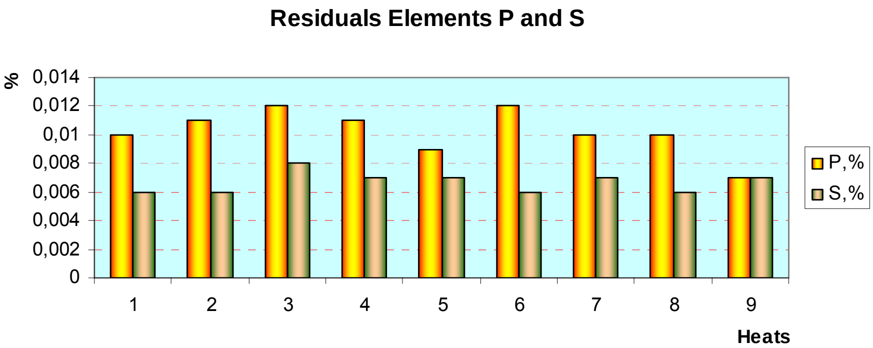


Fig. 3. *Residual elements P and S at the end of the EAF refining*

The reduction of residual elements P and S was made by classical methods: phosphorus removal - intense oxidation of metal bath, slag removal and sulfur removal - high temperature and the use of synthetic slag. The oxidation of the metal bath is made to reduce the residual elements by oxidation and by transferring them in the slag.

The order of oxidation reactions is:

$$[Si] + 2[FeO] = (SiO_2) + 2[Fe]; \quad (1)$$
$$[Mn] + [FeO] = (MnO) + [Fe]; \quad (2)$$
$$2[Fe_2P] + 5[FeO] = (P_2O_5) + 9[Fe]; \quad (3)$$
$$[C] + [FeO] = \{CO\} + [Fe]; \quad (4)$$

The oxidation of carbon and release of CO causes a stirring effect on the liquid metal bath ("boiling effect") increasing the contact area between slag and metal bath, ensuring homogeneous temperature and chemical composition of the metal bath also eliminating much of the gases (hydrogen and nitrogen) and nonmetallic inclusions contained in the liquid steel [1]. For the reduction of oxygen contained in the metal bath, such powerful de-oxidation materials were used as, Al, SiCa, FeSiMn. By injecting an inert gas (argon) during the de-oxidation period, some of the gasses contained in the liquid metal are removed.

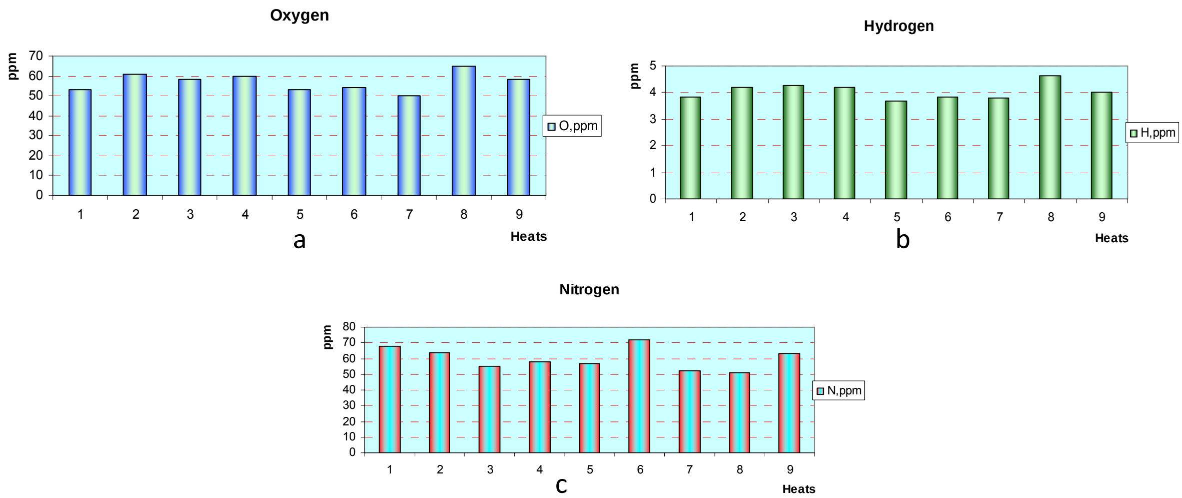


Fig. 4. *Gases present in the metal bath at the end of the EAF refining period:*
a - Oxygen, b - Hydrogen, c-Nitrogen

4. Gas absorption in metal bath

To tap the steel from the EAF a ladle must be preheated to a temperature of 1150°C in order to reduce temperature loss and thermal shock. To ensure optimal pouring temperature (1580+/-5ºC) the liquid metal will be tapped from the EAF at 1700°C. The big temperature difference between tapping and pouring is due to time losses (Fig. 5), transport and re-ladling the liquid steel into the pony ladle (Fig. 6).

Fig. 5. *EAF tapping in ladle*

Fig. 6. *Steel re-ladling*

Pouring speed, spout length and the distance between the ladle and spout are critical factors in the absorption of gases from the atmosphere into the liquid metal. When re-ladling, to reduce the harmful effects of exposing the steel stream to the surrounding atmosphere an intermediate device between the ladle and pony ladle is used that protects the steel stream by injecting argon gas.

The transfer between the ladles takes about 4 minutes, at the end the temperature is close to the steel pouring temperature. Gas analysis from the molten steel bath after tapping from the EAF indicates a slight increase, especially hydrogen and oxygen (Fig. 7.)

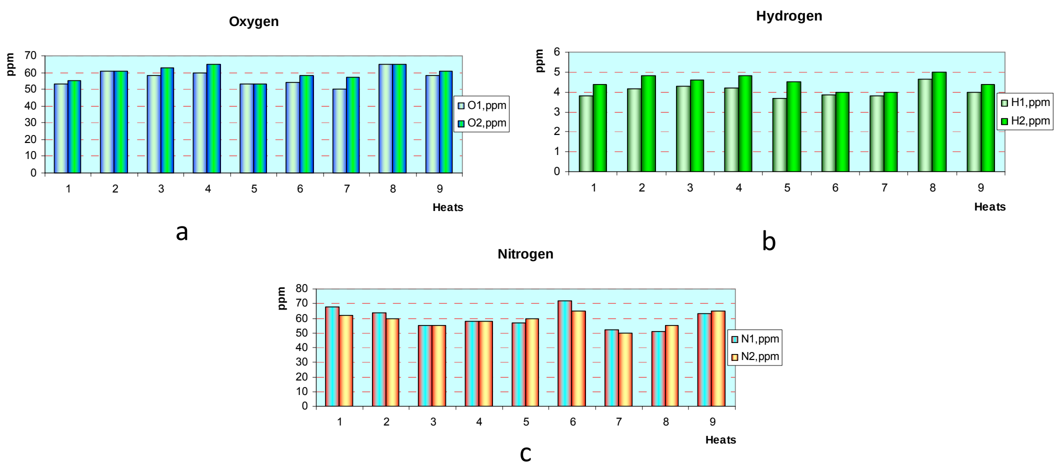


***Fig. 7.** Gases present in the metal bath after tapping from EAF:*
a - Oxygen; b – Hydrogen; c-Nitrogen.

The pouring assembly has an important role in ensuring product quality because it can contaminate the liquid metal with oxides and refractory materials, so it is very important to properly clean and preheat (to lower the humidity). Low vacuum is an important factor to achieve because the degassing efficiency is even higher when the pressure is at its lowest point [2].

The vacuum pump type used is ULVAC, the vacuum is made by steam ejectors. The steam must have a minimum temperature of 200° C and a pressure of 20 (see Table 1).

***Table 1.** The vacuum pump features*

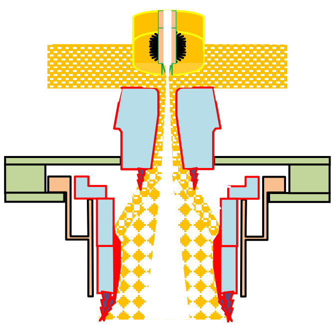
Capacity	**Ejectors**	**Condensers**	**Steam pressure**	**Min. Steam temperature**	**Lowest vacuum**
[kg/h]			[Bar]	[ºC]	[Torr]
650	7	3	20	200	0,250

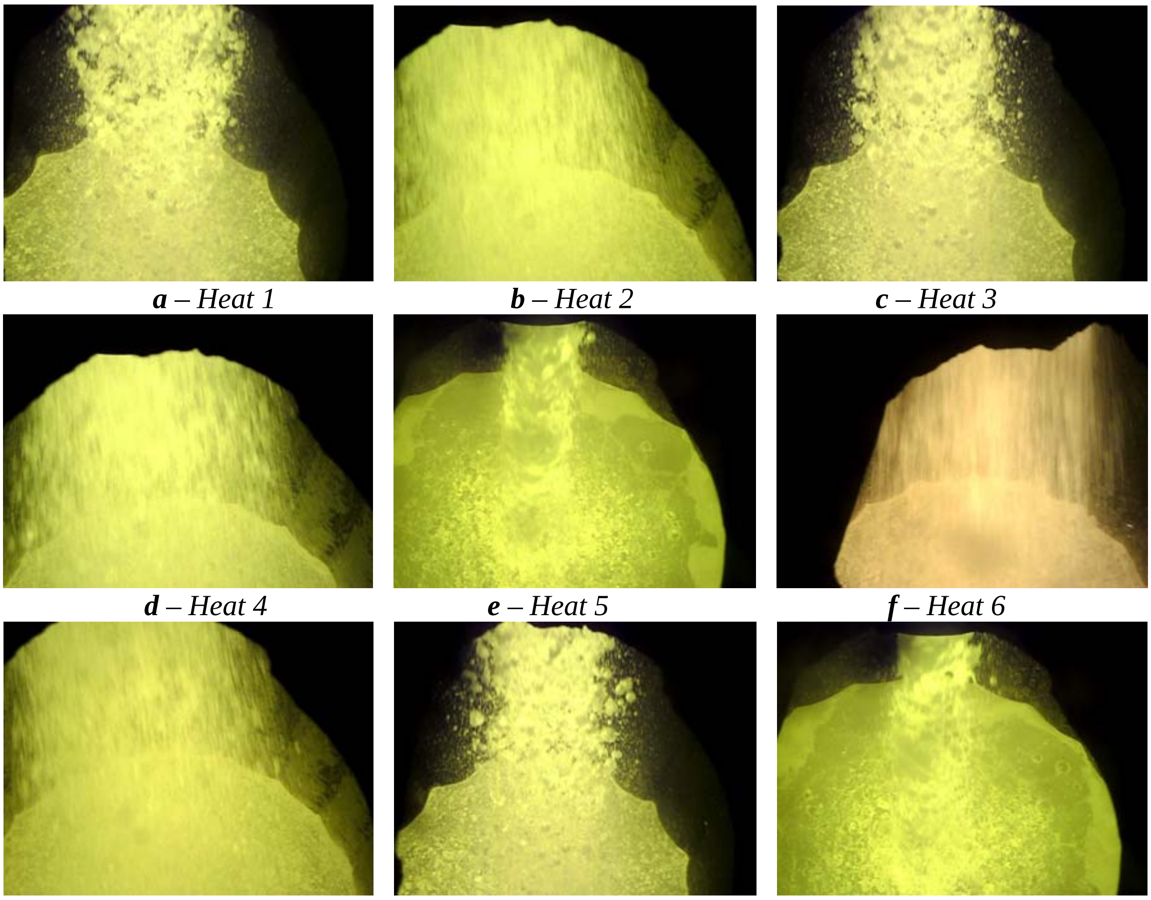
5. Stream Degassing

The injected argon flow in the stopper rod during pouring directly influences the steel stream. It is established according to the following: temperature steel (fluidity), the amount of steel that is present in pony ladle, distance between stopper head and pony ladle nozzle (pouring speed) and the inside diameter of the pony ladle nozzle used.

Excessive flow of argon leads to a large stream of steel that can adhere to the cold pouring equipment thus contaminating the steel (future mass ingot crystallization centers) but a low flow decreases the metal degassing efficiency [2].

For the analyzed heats, the wide stream was done differently by increasing or decreasing the speed of ingot pouring, keeping a constant argon flow and pressure (5 bar) in the stopper rod, the casting speed was modified by decreasing or increasing distance between the stopper rod and the pony ladle nozzle obtaining different types of wide stream: large, medium and strong.





***a** – Heat 1*   ***b** – Heat 2*   ***c** – Heat 3*

***d** – Heat 4*   ***e** – Heat 5*   ***f** – Heat 6*

***g** – Heat 7*   ***h** – Heat 8*   ***i** – Heat 9*

***Fig. 8.** Stream Jet in pouring time:*
b, d, f, g – wide stream; a, c, h – medium stream; e, i – narrow stream.

***Table 2.** Degassing efficiency*

Stream		WIDE				MEDIUM			NARROW	
Heats		Heat 2	Heat 4	Heat 6	Heat 7	Heat 1	Heat 3	Heat 8	Heat 5	Heat 9
Casting rate [t/min]		6.0	6.1	6.3	6.2	6.8	7.0	6.7	7.5	8.2
Vacuum degree [Torr]		**0.360**	**0.314**	**0.337**	**0.333**	**0.388**	**0.330**	**0.303**	**0.325**	**0.363**
Hydrogen	Before Tapping [ppm]	4.18	4.2	3.85	3.8	3.83	4.28	4.65	3.7	4
	After Tapping [ppm]	4.8	4.8	4	4	4.4	4.6	5	4.5	4.4
	After Pouring [ppm]	1	1.1	1.25	1.2	1.3	1.3	1.3	1.6	1.8
	η degassing. [%]	**79.2**	**77.1**	**68.8**	**70.0**	**70.5**	**71.7**	**74.0**	**64.4**	**59.1**
Oxygen	Before Tapping [ppm]	61	60	54	50	53	58	65	53	58
	After Tapping [ppm]	61	65	58	57	55	63	65	53	61
	After Pouring [ppm]	27	24	25	24	25	27	25	25	25
	η degassing. [%]	**55.7**	**63.1**	**56.9**	**57.9**	**54.5**	**57.1**	**61.5**	**52.8**	**59.0**
Nitrogen	Before Tapping [ppm]	64	58	72	52	68	55	51	57	63
	After Tapping [ppm]	60	58	65	50	62	55	55	60	65
	After Pouring [ppm]	35	40	36	35	40	37	45	32	40
	η degassing. [%]	**41.7**	**31.0**	**44.6**	**30.0**	**35.5**	**32.7**	**18.2**	**46.7**	**38.5**

A wide stream is supposed to cover around 80% of the ingot bottom surface while medium stream covers about 50% (below this value it is considered to be narrow stream. resulting low degassing efficiency).

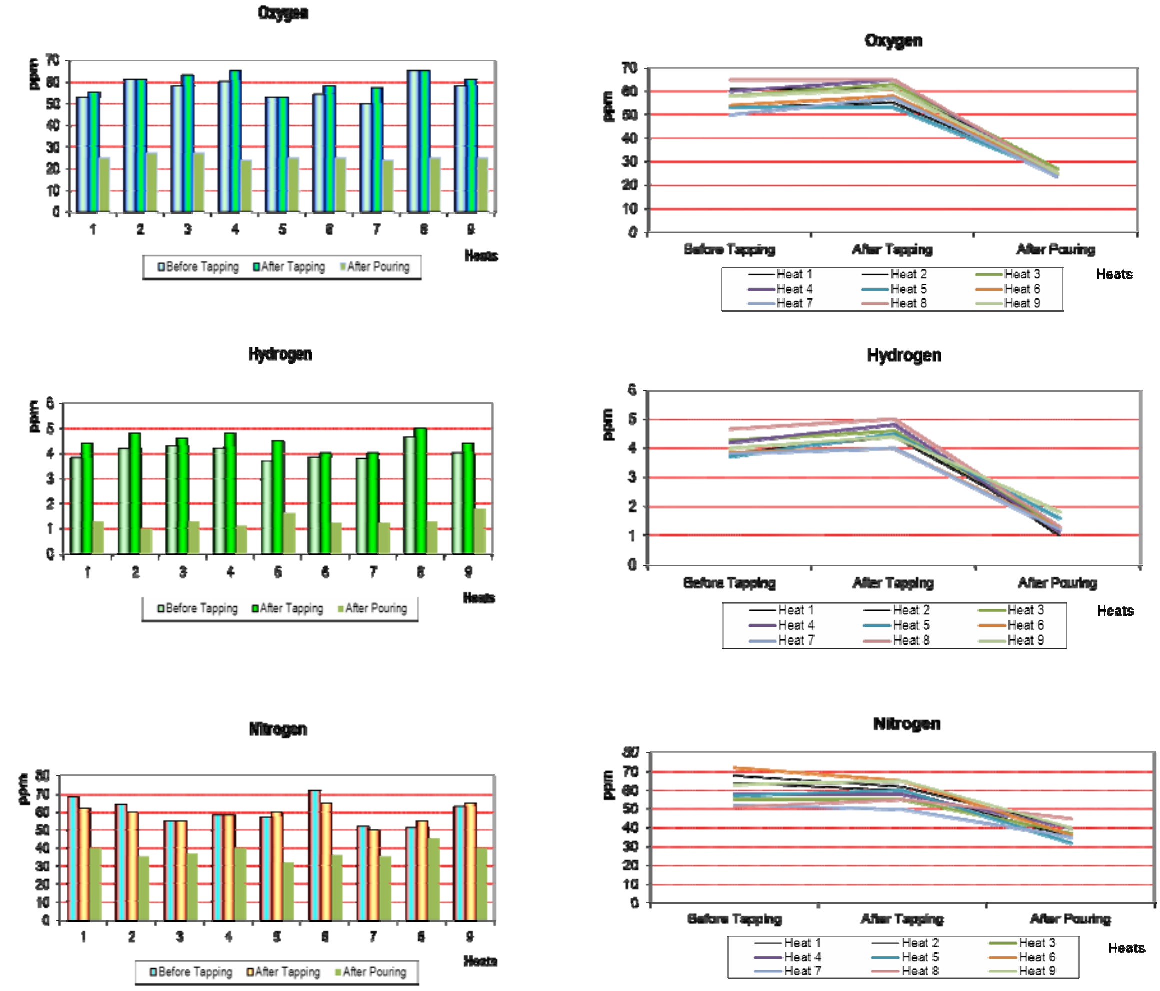


Fig. 8. Graphical representation of the gas evolution on heats

The importance of obtaining wide stream when pouring can be easily observed. The steel stream is divided into small drops after argon gas injection in the stopper rod. the pouring stream looking like a summer rain. Increasing the contact surface between the droplets of steel and the vacuum is the main factor that can boost the degassing process.

Fig. 9.

The metal bath is not agitated by the strong convection currents like we would have seen if we had had narrow stream and the risk of inclusions in the body of the ingot is small. Non-metallic inclusions with lower density always remain on top of the ingot, remaining in the hot top.

6. Conclusions

Vacuum pouring with wide stream helps increase purity by decreasing gas content and keeping the inclusions to the surface. You can see a very good degassing yield from the analyzed heats as follows: for [H] - η = 79% for [A] - η = 63% for [N] - η = 46%;

The condition of the stream during the pouring process directly affects the degassing and purity of the cast ingot because a narrow jet has a smaller contact surface with the vacuum atmosphere (low efficiency degassing) and it creates a high convection current which causes inclusions to appear in the ingots body.

After the assessment of the wide stream it has been shown that the stream created by argon injection through the stopper rod creates optimal conditions for advanced degassing. obtaining increased purity and uniform distribution of spherical particles that stimulates floating inclusions and prevent creating convection currents.

Acknowledgment

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