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STEEL CLEANLINESS IMPROVEMENT THROUGH TUNDISH CONFIGURATION OPTIMIZING

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In continuous casting process, liquid steel flows through the tundish, which is supposed to operate as a continuous refining finisher. To provide a functionality of such a device, a pack of tundish metallurgy techniques must be applied, whose efficiency is conditioned especially with optimal symmetrical and dynamical melt flow. Flow optimizing can be achieved through the shaping of inside tundish configuration, using flow control devices such as turbulence inhibitors, impact pads, baffles, weirs, dams, etc. The theme of the present paper is the precise employment of a turbulence inhibitor, commercially known as TURBOSTOP™, together with a pair of baffles & a flat impact pad in slab custer to improve steel cleanliness and a fluid flow phenomenon in a two strands tundish.

Key words: *steel refining, steel cleanliness, tundish metallurgy, flow control devices*

Pročišćavanje čelika optimiranjem konfiguracije međulonca. Tijekom procesa kontinuiranog lijevanja tekući čelik prolazi kroz međulonac koji funkcionira kao kontinuirani uređaj za završnu doradu rafiniranjem. Za osiguranje funkcioniranja takvog uređaja mora se primijeniti tehnika metalurgije međulonca čija učinkovitost je uvjetovana naročito optimalnim simetrijskim i dinamičkim tečenjem taline. Optimalizacija protoka se može postići oblikovanjem unutrašnje konfiguracije međulonca uporabom takvih uređaja za kontrolu protoka kao što su inhibitori turbulencije, zadebljanje za ublažavanje udaraca, pregradne ploče, brane itd. Tema ovog rada je točna primjena inhibitora turbulencije poznatog pod trgovačkim nazivom TURBOSTOP™, zajedno s parom skretnih pregrada i ravnim zadebljanjem za ublažavanje udaraca u lijevanom slabu radi poboljšanja čistoće čelika i fenomena toka fluida u dvije žile međulonca.

Ključne riječi: *rafinacija čelika, pročišćavanje čelika, metalurgija međulonca, uređaji za kontrolu protoka*

INTRODUCTION

Tundish is the last refractory reactor in which the liquid steel is continuously processed before solidification in the mold, providing us with an excellent opportunity to perform the final metallurgical operations - tundish metallurgy operations [1].

The assignment of today's tundish metallurgy is to handle the tundish problems when optimizing its function as a refining device and thus a transformation of a device which has degraded the quality of steel into the device fully supporting the technology of high cleanliness steel manufacturing.

Demands for high level of steel cleanliness must be understood as a dynamic process, otherwisw so-called "clean steel" according to nowadays criteria will not meet the standards of a near future and related requirements for reliable applications under hard exploitive conditions.

The goal of this study is to identify the most suitable configuration of continuous casting tundish, caster # 2, on the basis of results, which have been reached when testing the impacts of two various tundish configurations on their refining abilities.

FLOW AND REFINING CHARACTERIZATIONS OF THE TUNDISH

Each tundish is designed in a way as to provide an optimal flow and therefore higher cleanliness of cast steel. Tundish inside configuration should provide [2]:

- as high a value of average retention time as possible,
- minimum "turbulence & dead & short-circuit volumes",
- maximum space for laminar flow of molten steel,

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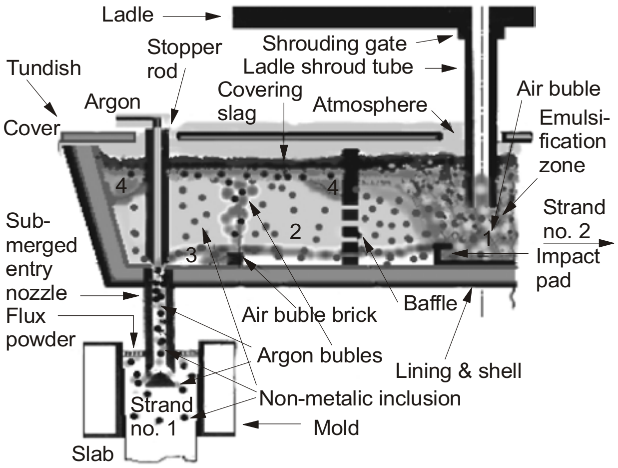
- forced coagulation and flotation of non-metallic inclusions, assimilated by cover slag,
- protection against "open (red) eye" creating (uncovered surface of molten steel) [3].

Following the above, flow character may significantly impact final steel quality and therefore it is necessary to optimize the flow. When considering existing tundish geometry, flow optimization may be reached through the modification of the tundish inside geometry using a controlled installation of flow deflectors (Figure 1.) [4].



Flow volumes: 1 - Turbulent, 2 - Piston, 3 - Short-circuit, 4 - Dead

Figure 1. **Schematic view of tundish flow - refining cross-section**
Slika 1. **Shematski prikaz presjeka toka rafiniranja u međuloncu**

When looking at the tundish cross-section in the Figure 1., we can analyze the tundish in dependence on both flow and refining characterizations, from the inflow towards the outflow point of view and thereby obtain specific flow-refining zones. An evaluation of tundish flow-refining characterizations along with possible applications of tundish metallurgy techniques in individual tundish zones is presented in Table 1. Present world of tundish metallurgy is being by the idea of FOSECO [5] which offers probably the best-known impact pad TURBOSTOP™ as a complex flow regulator.

OPERATIONAL TESTING OF TWO DIFFERENT TUNDISH CONFIGURATION ALTERNATIVES AND THEIR IMPACTS ON THE STEEL QUALITY IMPROVEMENT

Increasing requirements of steel products customers are focused on the improved cleanliness of steel slabs. In terms of this wide range of problems degree of steel cleanliness regulation through the tundish flow regulation was observed using two different CCM # 2 tundish configurations. Because of unknown internal steel cleanliness in the section of tundish - mold, samples were taken during the single tundish casting sequence. After solidification, the samples were analyzed in order to observe the following

Table 1. **Tundish flow-refining characterizations**
Tablica 1. **Karakter toka rafiniranja u međuloncu**

Areas in tundish	Inlet (central)	Others (peripheral)
Flow volumes	⇒Turbulent ⇒Short-circuit ⇒Reverse	⇒ Laminar ⇒ Dead
Phenomena affecting of steel cleanliness	+ Collision and coagulation of non-metallic inclusions - Vortex generation under slag surface - Slag emulsifications and air gap entrainment	+ Forced coagulation and floatation of non-metallic inclusions, which are assimilated by covering slag - Short circuit - Thermal inverse
Application of the tundish metallurgy techniques	⇒Micro-alloying ⇒De-sulfuration ⇒Modification of non-metallic inclusions ⇒Slag rafination ⇒Agitate of molten steel	⇒Filtration molten steel ⇒Heatings ⇒Slag rafination ⇒Soft bubbling - Ar ⇒Flow control

elements: Si, Al_{tot}, $Al_{met.}$, O_{tot}, N_2. The chemical cleanliness of package grades and deep-drawing automotive grades was analyzed. The research was performed in CCM # 2. In case of the first trial, **A** tundish configuration was tested: equipped with shaped impact pad and two pairs of dams (Figure 2.). In case of the second trial, **B** tundish

Figure 2. **"A" tundish, equipped with advanced pouring box and two pairs of dams**
Slika 2. **Međulonac "A", opremljen modernim sandukom za lijevanje i s dva para zapreka od troske**

configuration was tested: equipped with flat impact pad and a pair of baffles and dams (Figure 3.).

Figure 3. **"B" tundish, equipped with flat impact pad & a pair of baffles & dams**
Slika 3. **Međulonac "B", opremljen ravnim zadebljanjem za ublažavanje udaraca i pârom otklonih ploča i zaprekom od troske**

EXPERIMENT AND USED EXPERIMENTAL METHODOLOGY

Used experimental methodology when taking the samples on CCM # 2

"A" tundish configuration

Samples were taken using LECO immersion samplers, from 3 various places at various time intervals (Figure 4.).

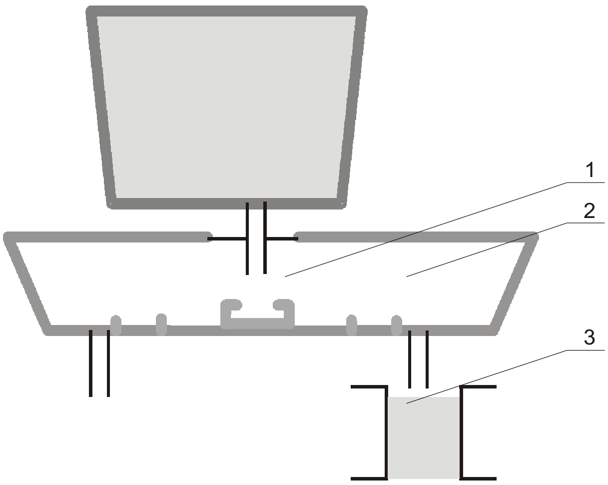


Figure 4. **"A" tundish configuration - the places of samples taking and their coding**
Slika 4. **Konfiguracija međulonca "A" - mjesta uzimanja uzoraka i njihovo označivanje**

1 code: Taking from tundish in the area of ladle shroud tube, tundish contains 100 tons.
2 code: Taking from tundish in the area of stopper rod, tundish contains 60 tons.
3 code: Taking from the mold in the area of submerged entry nozzle (SEN), ladle contains 50 tons.

"B" tundish configuration

The same as at the first measurement, but the second sample from the stopper bar area was not taken (Figure 5.):

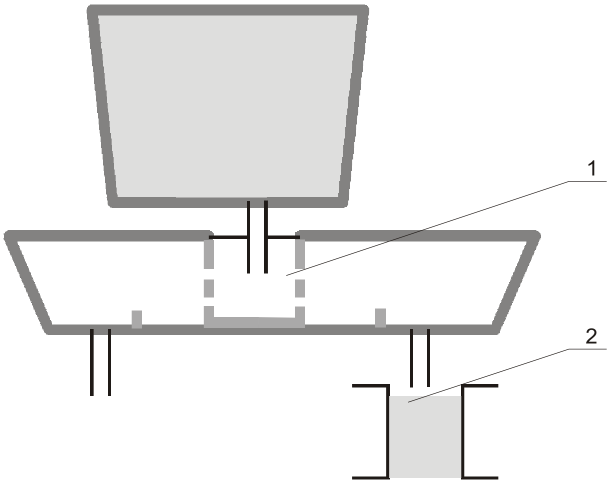


Figure 5. **"B" tundish configuration - the places of samples taking and their coding**
Slika 5. **Konfiguracija međulonca "B" - mjesta uzimanja uzoraka i njihovo označivanje**

1 code: Taking from tundish in the area of ladle shroud tube, tundish contains 100 tons.
2 code: Taking from the mold in the area of SEN, ladle contains 50 tons.

Used experimental methodology when visually observing the "red eye"

The experiment consisted in visual monitoring of steel surface in the tundish central (inflow) area near the ladle shroud tube. The experiment was performed at the same time with the samples taking on the both tested tundish configurations "A" and "B". The red eye occurrence was recorded with digital camera. The experiment was performed on CCM #2 when casting the same grade (package) and under the same casting speed about 1.1 m per min. In both cases the same cover slag was used. Casting sequence lengths were also the same (12 hours).

DISCUSSION AND EVALUATION OF THE IMPACT ON THE STEEL QUALITY IMPROVEMENT

"A" tundish configuration

Silicon

Predominant increase of Si contents may be involved by SiO_2 absorption from the rise glumes and the working lining. During the first cast an increase of 10 ppm was observed, which is caused by Si-reversion according to equation (1) [6]:

$$4[Al] + 3(SiO_2) = 3\,[Si] + 2(Al_2O_3) \qquad (1)$$

From the sixth to the thirteenth heat, the values of Si contents in the taken samples stayed at the constant level. The contents of silicon is marked in the third sample taken from the mold. This trend is probably caused by Si reversion from the flux powder.

Al_{metal}/Al_{total} ratio

In most cases, a decrease was observed, that indicates an Al_{met} re-oxidation and an occurrence of clogging in submerged entry nozzle (SEN), according to the curves development we can also deduce an air leaching in the area of SEN gripping (Figure 6.). A significant decrease was

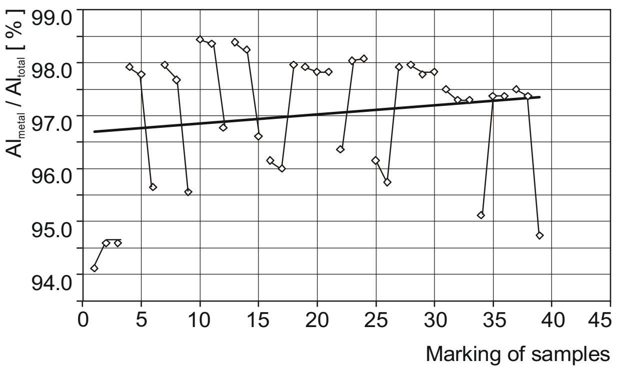


Figure 6. **Al_{metal}/Al_{total} ratio ("A" tundish configuration)**
Slika 6. **Al_{metal}/Al_{total} omjer ("A" konfiguracija međulonca)**

observed at 2nd - 5th heats, when we were able to notice an intensive reoxidation and consecutive scab creation on the SEN walls.

During both 6th and 7th heat, clogging works as a filtering element. When the molt is cast on a new Ladle shroud tube and SEN (1st and 8th heat) the ratio increases thanks to the cover slag absorption abilities.

Oxygen

The flow lines of oxygen values, especially for the second half of the casting sequence, have mostly raising and consequently falling trend, which is caused by cover slag reoxidation and a weakening of its absorptive abilities, Oxygen decline is created by genesis of aluminates (nozzle clogging) on the walls (Figure 7.).

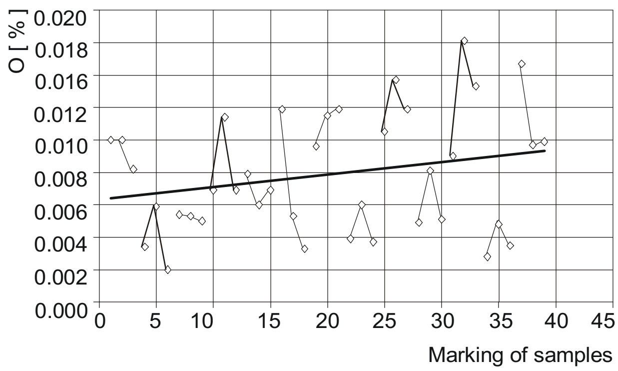


Figure 7. **Measured values of total oxygen contents ("A" tundish configuration)**
Slika 7. **Izmjerene vrijednosti ukupnog sadržaja kisika ("A" konfiguracija međulonca)**

Nitrogen

Nitrogen values move from 30 to 90 ppm, and similarly to oxygen, total nitrogen contents is increases during a single sequence, which is caused by sucking a false air and an occurrence of "red eye".

On the other side, maximum nitrogening of 7 ppm was observed under the "A" tundish , which is a favorable result (Figure 8.).

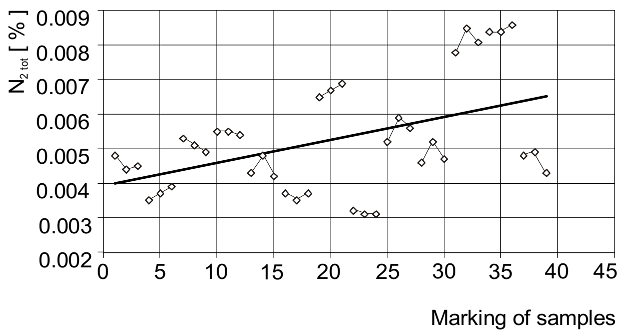


Figure 8. **Measured values of total nitrogen contents ("A" tundish configuration)**
Slika 8. **Izmjerene vrijednosti ukupne količine dušika ("A" konfiguracija međulonca)**

"B" tundish configuration

Silicon

Predominant increase of Si proportion may be explained similarly to the precedent "A" configuration, there is a reduction of Si from the rice glumes and the furring, both cover and ladle slag, as well as an impact of protective fill /$SiO_2 + Cr_2O_3 + Fe_2O_3$ sand/ that weighs about 20 kg per single heat. Maximum silicification of 5th heat is 40 ppm that represents a double value compared to a configuration using the Turbostop™.

$Al_{metal.}/Al_{total}$ ratio

This ratio is an excellent indicator of reoxidation of steel, which is cast on CCM. The lesser value of $Al_{met.}/Al_{tot}$ ratio, the more metal aluminum is burnout. To order to reason this, we have to state a general equation between various forms of aluminum (2):

$$Al_{tot} = Al_{met} + Al_2O_3 + AlN = 100\ \% \quad (2)$$

The observed ratio was educed from this equation. The effort is to maximize this ratio - near to 100 %. Its increase is directly proportional to the decline of $a_{[O]}$ in the steel. Under the condition in CCM # 2, there is no possibility to figure out the correlation between Al_{tot}, $Al_{met} \leftrightarrow a_{[O]}$, due to missing oxygen activity determination. At the second cast, decline of more than 4 % was observed, that indicates a steel re-oxidation during second heat (Figure 9.).

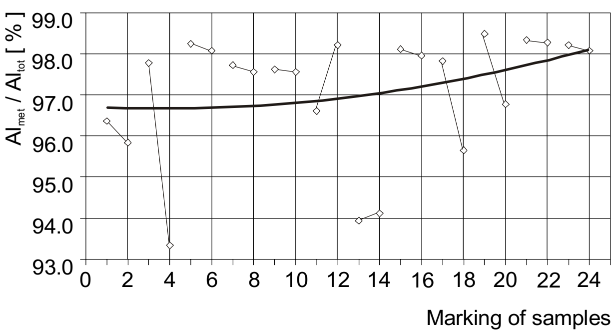


Figure 9. **Al_{tot} / Al_{met} ratio (“B” tundish configuration)**
Slika 9. **Omjer Al_{tot} / Al_{met} (“B” konfiguracija međulonca)**

Oxygen

At the first, third and fifth heat, an increase of total oxygen values was observed (Figure 10.) as well as at the last three casts in the sequence. At the first three casts it may be argued by the fact, that at the start of the sequence the system of cover slag doesn’t work in a way it is supposed to, and, as a result, a steel re-oxidation happens. The last three heats are cast under the conditions of cover slag system with minimum absorption abilities which rather reoxidizes the steel than protects it against re-oxidation. A double-slag technology should be the solution.

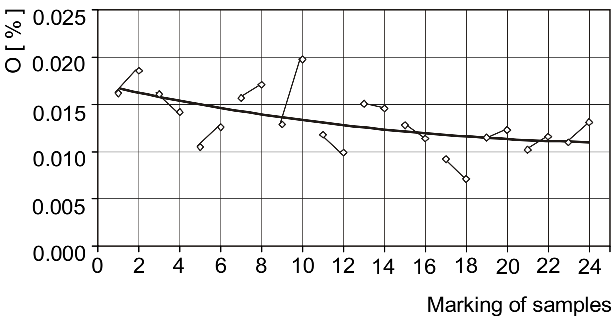


Figure 10. **Measured values of total oxygen contents (“B” tundish configuration)**
Slika 10. **Izmjerene vrijednosti ukupnog sadržaja kisika (“B” konfiguracija međulonca)**

Nitrogen

N behavior is inhomogeneous similar to “A” configuration and its contents moves from 25 to 65 ppm. The contents of total nitrogen in a sequence is increasing and partly corresponding with the contents of total oxygen. In comparison with “A” configuration, where we found out a maximum nitrogening of 7 ppm, in this configuration the value is the same, a favorable value was observed the at second heat at weirs - 8 ppm (Figure 11.).

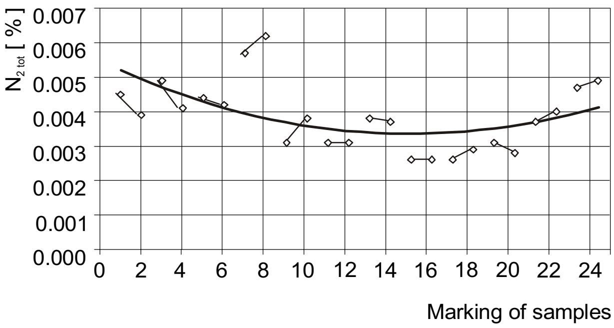


Figure 11. **Measured values of total nitrogen contents (“B” tundish configuration)**
Slika 11. **Izmjerene vrijednosti ukupne količine dušika (“B” konfiguracija međulonca)**

DISCUSSION ON RESULTS OF RED EYE PHENOMENON VISUAL OBSERVATION

In the both monitored configurations, incoherent and incompact cover slag system was observed at the sequence start during the first, second and third heats. That means, that the quantity of applied cover and fill sand is insufficient. Local zones with uncovered steel surface are created then. These are centered in the areas, where both cover and isolations powders have not been applied in adequate quantity. This phenomenon is partly caused by human factor and can be solved through the automation of tundish surface pelt system along with interoperation of on-line camera monitoring.

Local concentration of dead zones was minimized directly proportionally with a growing number of heats. The reason of this change is primarily adding of both cover and isolation powders, but also a harmful penetration of ladle slag into the tundish. Dramatic changes of cover slag chemical composition suggest the penetration of synthetic slag. A ladle fill sand is also an unfavorable element, which changes the slag chemical composition. Each cast produces about 20 kg of sand - silicate, the volume of this sand increases with a growing number of casts exceeding the value of 200 kg at the last heats, which is a larger volume than total volume of added cover and isolation mixtures.

Regarding red eye occurrence, it was observed during 1^{st} - 7^{th} heats in "A" configuration. Tendency to create a red eye was observed also at the last few heats in a sequence. However, this tendency was minimized through the addition of cover and isolation powders (Figure 12.).

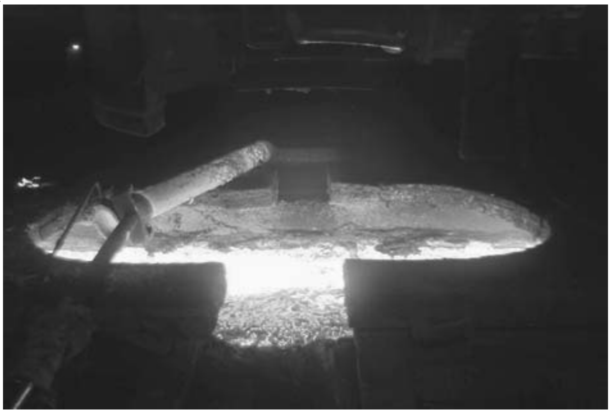


Figure 12. **Red eye in "A" tundish configuration**
Slika 12. **Crveno oko u "A" konfiguraciji međulonca**

Tundish with baffles (Figure 13.), that divide it into primary (active) zone and two secondary (peripheral) zones generated a red eye during the first three heats in a sequence. After consistent covering of steel surface in an active zone, we didn't remark a red eye creation anymore (Figure 13.).

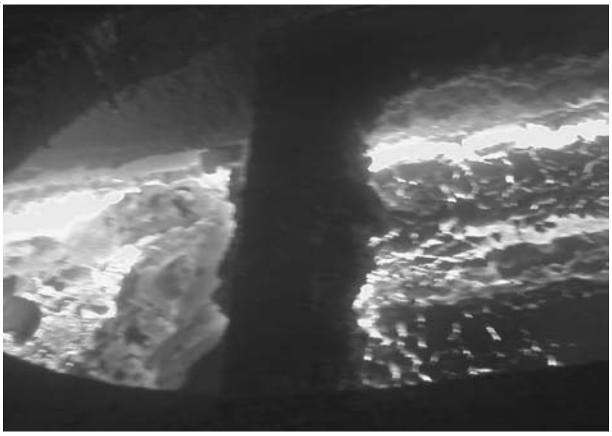


Figure 13. **Red eye in "B" tundish configuration**
Slika 13. **Crveno oko u "B" konfiguraciji međulonca**

Another remark is the fact that a dosing of cover and isolation fills is individual in the second half of a sequence and it depends on the cover system operation. Consumption of both cover and isolation powders during a sequence increases with repeated red eye occurrence and decreases with increasing quantity of fill sand and ladle slag in the tundish. Generally, according to our findings, when considering only the frequency of red eye occurrence, a consumption of both cover and isolation powders is higher in the configuration with Turbostop™.

CONCLUSIONS

1. In addition to optimal configuration, a refining efficiency of the tundish is conditioned also with prevention of ladle slag outflow, activation & control of cover slag absorption abilities during a tundish cast sequence, as well as the range of applied techniques of both secondary and tundish metallurgy and finally a critical human factor.

2. In this critical point of continuous casting, steel reoxidation and nitrogening processes occur.

3. After evaluation of impacts of both the tundish configurations on their refining abilities, we may confirm approximately equal extent of molten steel refining and therefore it is difficult to advice a more suitable tundish configuration.

4. In this stage there are two fair solutions for selection of suitable tundish configuration:
   - first, to select a tundish configuration according to its equipment expenses amount;
   - secondly, when casting hard grades (IF, ULC) the solution is so-called "combined luxury tundish" which, however, hasn't been tested in operation yet. It represents a very expensive (luxury) configuration, which can hardly be applied for casting common grades due to high acquisition cost.

5. We can confirm, that the existence of red eye in the area of ladle shroud tube is markedly degenerative factor of steel cleanliness, set up by the tundish metallurgy processes. This effect is even more intensive when casting the hard grades ULC, IF ...

6. After experimental observation of red eye phenomenon in two compared configurations we can present opinion, that the expectations have not been met of applying the Turbostop™ to minimize the occurrence of red eye. Much better result has been achieved in configuration with flat impact pad & baffles, which is also cheaper.

7. Despite the above, "A" configuration with Turbostop™ is being more preferred nowadays. Its main benefit is a certain operation safety and delimited splash at ladle start.

FUTURE WORK

Following the above, we propose to test the compromising tundish inside configuration design, which is based on implantation of Turbostop & 2 baffles & 2 small dams, or argon bubble bricks respectively. Such a COMBINED LUXURY TUNDISH (Figure 14.) should provide the specific benefits described for the both configurations, but at the expense of its equipment cost.

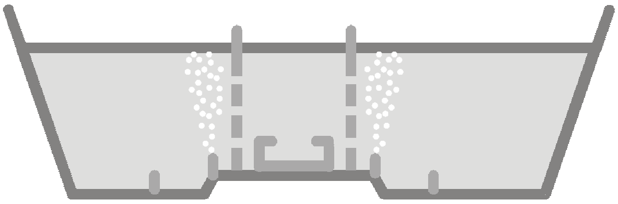


Figure 14. **Combined luxury tundish**
Slika 14. **Kombinirani luksuzni međulonac**

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