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## Status and future of vacuum treatment of liquid steel development

Among the known methods of secondary metallurgy, the vacuum treatment of steel directly in the ladle or so called ladle vacuum treatment plays a big role.

There are a lot of different variants of technological process, however the most spread are VD methods (vacuum degassing) and VOD methods (vacuum oxygen decarburization) of vacuum treatment. Simultaneous use of oxygen blowing together with the vacuum treatment provides an opportunity to produce very low carbon grades of steel (electric steel, stainless steel, automobile-body sheet with deep drawing qualities, etc).

Combined equipment VD/VOD or VD-OB (vacuum degassing - oxygen blowing) are notably spreading lately.

Comparative simplicity of the design and a wide range of technological parameters of ladle vacuum degassers contribute to their wide spread; appr. 65 % of the existing vacuum units are the ladle type ones [1, 2, 3].

This trend can be also observed for the new units: since 2000, more than 90 units for treatment of melts weighing 30 - 330 t have been installed or planned to start in the nearest years, most of them combined, providing possibility of VD and VOD classical processes on the separate or combined stands. During these processes, ladle with treated metal is either directly covered by vacuum-airtight lid (LD vacuum degassers - lid degassing) or (more often) located in the special vacuum chamber, covered by lid. This type of vacuum units is named as tank (VTD - vacuum tank degassing) in modern special literature. However, the technological process itself, achieved metallurgical results, the main advantages and problems encountered doesn't depend on sealing methods of the working area and type of ladle vacuum unit. Both of these variants have proven their efficiency and usability in practice, however vacuum tank units have got the widest spread. Using of airtight vacuum lids, installed on the ladle board flange, requires smooth connection of joint flanges clean from slag and metal buildup which is difficult to realize in industrial conditions.

Treated melts weight varies from 10 to 330 t, however the largest number of ladle vacuum units are used for vacuum treatment of 30 t melt weight (Fig. 1) and are located usually inside the melt shops.

The only example of a ladle vacuum unit used for heavy weight melts treatment more than 300 t is the unit installed at the "Severstal" converter shop. For a wide-scale use of ladle vacuum units at high productivity converter shops, there is a necessity to provide conditions for steel treatment intensification including metal underfilling in the ladle elimination as well as efficient and uniform melt stirring.

The wide spread of ladle vacuum degassers is explained by their comparative simplicity, good adaptability within the

existing shops conditions, wide range of technological abilities, including degassing, nonmetallic inclusions removal, efficient multicomponent alloying with high precision of necessary chemical composition achievement and high degree of alloying components recovery, deep steel decarburization and desulphurization.

Essence of ladle refining process is in vacuum treatment, alloying under vacuum and treatment by synthetic highly basic slag of the surface metal, which is constantly renewed during gas-dynamic bath stirring by inert gas blowing (mainly by argon) through bottom plugs. Vacuum creation above the surface melt metal and simultaneous argon blowing result in strong foaming and rise of metal and slag level, intensity of which depends on vacuum gathering rate and its depth, argon consumption and metal oxidation rate. To avoid too large metal and slag level rise and its eventual overflow over the ladle board, the vacuum level increase and argon blowing intensity rates are forcedly decreased while assuring a free board reserve above the melt metal in the ladle, which is much larger in comparison with the nominal volume of melt metal. During long-term experience of operation of ladle vacuum degassers, average recommendations to choose the height of free board reserve were made for different variations of technological process independent from treated melt metal weight:

- ladle vacuum treatment by VD method - 0.8-1.0 m;
- oxidizing vacuum treatment by VOD method - 1.0-1.3 m.

In accordance to some recommendations, free board reserve during VOD-process must be even more (up to 1.5 m) for vacuum tank degassers, and for vacuum units with airtight

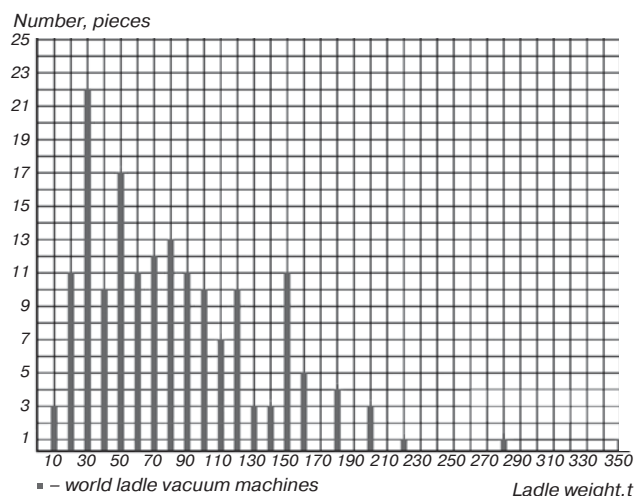


Fig. 1. Ladle vacuum units distribution, installed and intended for installation since 2000, by treated weight melt

lid, installed on the ladle, it is useful to increase this reserve 20 % more [4]. This can be surely explained by heavier consequences in case of possible overflow of metal over the ladle board compared to tank type vacuum degassers.

Free board height increase can be achieved through the total height of ladle increase or through the metal weight in the ladle decrease. In the first case the ladle weight and necessary casting crane lift capacity increase irrationally. In addition to this, highest ladle part, lifted above casting stand of continuous casting machine usually determines total shop height therefore during the new shops construction large additional capital expenses are required. During the adoption of ladle vacuum treatment into the existing melt shops such possibility is practically impossible. In some cases an increase of the ladle refractory weight due to the adoption of secondary metallurgy processes and usage of more dense high quality refractory materials corresponds to all existing reserves of cranes lift capacity.

Free board height increase during simultaneous preservation of common ladle height and distance between trunnions can be achieved by using oval form-section ladles or step-type cylindrical form ladles [5]. However, both of these variants are associated with more complicated producing conditions of ladles and their refractories. For the plants in operation the replacement of existing ladles is a quite expensive procedure.

That's why the only one practical way is remained for providing reserve of free board in ladle vacuum degassers in the existing shops – involuntary reduction of metal weight in the ladle, which results in serious capacity losses of vacuum degasser and the whole melt shop and has negative effect on product cost and competitive performance. Reduce of comparative capacity is especially noticeable in the case of lesser treated melt weights. For example, according to the 375 t ladle with required free board height as large as 1.2–1.3 m [6], reduction of melt weight and capacity reduction are equal to 12–15 %. And for the melt weight of around 80 t, metal underfilling according to the same requirements to the free board will be increased up to 16–22 %. Meanwhile ladle vacuum treatment is much more widespread with less than 100 t weight casting ladle production.

It is important to note, that any free board increase doesn't give a guarantee of metal and slag splash elimination with simultaneous increasing of vacuum speed rate and with serious increase of argon consumption rate. Accordingly, the total vacuum treatment time during the ladle vacuum treatment, which is necessary for achieving proper results, and total treatment cycle time including preparation operations are longer than the same time for the circulating type vacuum degassers with higher capacity. For instance, comparison of two types of degassers in the identical conditions in the melt shop of Belorussian metallurgical plant showed, that the full vacuum treatment process, using circulating type vacuum degasser (including necessary operations with the ladle) lasts for 30–40 min, and with the use of VD-type vacuum degasser it lasts for 50–70 min [7].

The average time of vacuum treatment excess in the existing VD/VOD-type units is around 5–8 min in comparison with RH/RH-OB-type vacuum units.

Consequently, taking into account the rapid increase in continuous casting machines number at our metallurgical plants, tendencies of combining the steel-making, secondary steelmaking and continuous casting into consolidated technological processes while increasing the numbers of sequence casting melts, there is a strong need to increase the ladle vacuum treatment efficiency and, first of all, to eliminate the necessity of metal underfilling inside the ladle.

Another disadvantage of the ladle vacuum treatment is that the refinement processes can occur only in comparatively thin active surface ladle zone, but power of natural stirring is not enough to lift the lower layers of metal. During the refinement processes it is very important to provide enough stirring of metal bath, because it improves the kinetics of degassing processes and metal and slag interaction.

During steel treatment with intense decarburization (VOD-process), due to the high temperatures achieved there are ladle border, overheating problems with its following deformation take place and can lead to early ladle breakdown. Even without oxygen blowing, temperature of metal constructions may grow up to 500 °C depending on the metal level in the ladle. This problem is especially important during production of special and stainless steel with long vacuum treatment cycle. The solution of this problem with forced cooling of the ladle border is technically difficult.

To resolve these above-mentioned problems, the fundamentally new process VDF/VODF (Vacuum Oxygen Decarburization Full) was developed by the specialists of VNIIMETMASH and "Severstal" metallurgical works [8–11], which allows to reduce mentioned disadvantages and to increase ladle vacuum refinement efficiency. Vacuum degasser is equipped with special reaction chamber with membrane, which is supported on the vacuum chamber flange. During the vacuum treatment because of gas-slag-metal emulsion level rise, the formed hydraulic gate separates vacuum chamber parts in two zones with different vacuum levels (I and II zones). As a result, the raise of slag-metal emulsion level raise that will eventually overflow over the ladle border during the normal VD/VOD vacuum treatment of completely filled ladle, now is localized within the additional reaction chamber.

The technological process is based on the principle of localization of degassing metal volume, which is implemented by installation of reaction chamber with separating of vacuum chamber internal area into two zones with different vacuum levels which allows to carry out metal degassing exceptionally within the reaction chamber space alone (Fig. 2). Simultaneously there is an intensive metal circulation along 1-2-3-4 directions within the chamber area and refinement is made over the whole ladle volume which reduces the treatment time.

The raise of gas-slag-metal foam level takes place only inside the reaction chamber, and absence of metal overflow over the board is granted by hydraulic gate effect, which guarantees stable vacuum level increase in the zone II in comparison with zone I during the degassing process.

Process and equipment were tested in the industrial conditions of the converter shop at "Severstal" metallurgical





**Fig. 4. Installation of reaction chamber to the vacuum degasser during the industrial tests**

less steel, comparative losses will be even higher. Revamping of the existing vacuum treatment units regardless of unit type, with their conversion to VDF/VODF technology is rather simple, doesn't require high material and time expenses and allows to increase substantially economical efficiency of production. Erection and commissioning works required for revamping can be done during the scheduled repairs without long time shutdown of the existing equipment. Payback period of the revamping does not exceed 1 year.

The peculiarity of Russian economy at the moment is a serious excess of production ability in comparison to domestic consumption volume. Development of Russian metallurgy in recent years usually originated from the export trade with low added cost production. Continuing financial crisis of the world economy, rapid increase of China metallurgical industry and possible Russia integration into the World Trade Organization keep away from export increase expectations.

Consequently there are no prerequisites for significant expansion of metallurgical production in Russia, especially for new plants start-up. At the same time possible problems with production sales will require mastering of new high quality steel grades difficult to produce, serious improvement of production quality and production costs reduction.

In these conditions, secondary steelmaking becomes especially important, and the dominant way of metallurgy development apparently will be plants revamping. Major necessity in secondary steelmaking modernization exists also at foreign metallurgical plants which have lots of ladle vacuum units including the outdated ones. That is why the ability of quick, cost effective and efficient enhancement of the existing ladle vacuum units that might be based on VDF/VODF process and equipment has good implementation prospects not only in Russia but in many metallurgical plants of former Soviet Union and abroad.

It is very reasonable to use this technical solution during new ladle vacuum units installation because new ladle vacuum treatment process provides essential reduction of treatment time and allows its adoption into production process with serial casting of vacuum treated melts.

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