MODERN TECHNOLOGIES IN STEEL DEGASSING AND LADLE METALLURGY

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In the field of steel degassing and ladle metallurgy Leybold-Heraeus offers the entire line of processes and equipment that are known today. The paper reviews all these techniques with a particular emphasis towards equipment that incorporates special design features which are derived from the extensive know-how of Leybold-Heraeus in electro- and vacuum-metallurgical processing. Furthermore, a classification is given as to which processes are most suitable or preferable for the different production methods of specific steel grades.

After this general review, characteristics of the Leybold-Heraeus Vacuum-Heating-Degassing (VHD) and Ladle Furnace (LF) designs as well as their applications are being described.

The paper compares various designs of VHD units with different electrode lengths, plant heights, and crane clearances. Using a standard remotely controlled clamping device, which is incorporated in many Leybold-Heraeus Vacuum-Arc-Remelting (VAR) and Electro-Slag-Remelting (ESR) furnaces, electrode changing may be accomplished from below, thus reducing total plant height and avoiding the necessity for crane clearance above the plant.

Vacuum-Heating-Degassing plants as well as Ladle Furnaces can take over part of the production cycle of a steel melting unit. This way, the productivity of the melt shop can be considerably increased as shown with some examples.

INTRODUCTION

While, originally, the vacuum treatment of liquid steel was mainly developed to remove dissolved gases, today this technology, coupled with peripheral equipment like heating, stirring, alloy addition, etc., has a much wider application in the production of high quality steels. In the so-called ladle metallurgy most of the metallurgical work is transferred from the melting unit into the ladle. All these post-metallurgical treatments have in common that while impurities are to be removed from the melt, valuable alloying constituents must be saved. Compared with the conventional treatment of steel in melting furnaces, refining units or mixers, one achieves, besides metallurgical advantages, a higher productivity of the entire plant, lower direct costs per ton of treated steel, and better operational and environmental conditions.

The development of ladle metallurgy was possible when the following accessories became available with sufficient reliability for their repeated use in steel ladles:

- porous plugs
- basic refractory materials
- corresponding lining and firing techniques
- bottom slide gates.

For instance, today, argon blowing through porous plugs in the ladle bottom is state of the art for equalization of temperatures, homogenizing of the steel melt, improvement of reaction kinetics at given thermodynamic conditions, and for better conglomeration conditions as well as improved removal of nonmetallic contaminants. It is a metallurgical prerequisite for ladle metallurgy even if inductive stirring is being used. The life of such a porous plug, made from magnesite, depends on its use; it is, for example, approx. 7 melts in static vacuum degassing in ladles, approx. 5 melts in vacuum-heating-degassing and approx. 2 melts in vacuum refining (1) and still improving.

The development of basic refractory materials was necessary because under the prevailing thermodynamic, chemical and physical conditions in ladle metallurgy linings had to be available with a stability greater than that of silica based refractories. Since such basic linings exhibit a strong sensitivity to rapidly changing temperatures, it must be considered that these ladles must be slowly heated and kept at a temperature of approx. 1000°C between heats. Because of the higher heat conductivity of basic refractory materials such ladles must also be carefully and effectively insulated. The utilization of alumina based or basic refractories may cause problems in regard to crane capacity in existing shops. This is easily understood if one compares the specific weights of the different materials (Table 1).

Table 1: Specific weights of different refractory materials (2)

DESCRIPTION	Range of specific weights (g/cm^3)
Acid masses	1.8 to 2.2
Fire clay (Schamotte)	2.1
High alumina brick	2.7
Dolomite	2.8 to 2.9
Chrom-magnesite brick	2.9 to 3.1

Only the successful development of reliable slide gates made the utilization of basic refractories possible and, thus, allowed to make full use of the advantages of ladle metallurgy. Furthermore, if the ladle of static degassing, stream degassing, and tap degassing units are equipped with slide gates they can be preheated to 1000°C or higher. This way, excessive temperature losses during the vacuum treatment can be avoided which is of particular importance for small heats of 15 tons or less.

FUNDAMENTAL ASPECTS OF VACUUM DEGASSING

The vacuum treatment of steel under reducing conditions is carried out at a pressure ranging from 0.5 to 10 mbar with the goal to lower the hydrogen content to <2 ppm and to use the strong pressure dependence of the carbon-oxygen reaction for deoxidation.

The melt is being degassed either in a stream or a partial quantity while the liquid steel passes more or less continuously from the melting unit or a ladle at atmospheric pressure into an evacuated vessel, or by exposing the entire melt to the vacuum. In the latter case the reaction kinetics must be improved by additionally stirring the melt.

The vacuum treatment is being used for steels which exhibit a danger of cracking due to flake formation at high hydrogen contents and/or for those which can be improved in quality by vacuum deoxidation. Such grades include, for example, CrMoV, CrNiV and other steels for the production of heavy forging parts ball bearing steels, tool steels, steels for wear resistant rails, seamless tubes, etc.

Typical reproducible quality characteristics brought forward by a vacuum treatment under reducing conditions are low hydrogen contents, small variations in chemical composition, which also result in a reduced requirement for alloying, and a marked improvement of cleanliness due to the reduced content of oxidic contaminants.

The vacuum treatment under oxidizing conditions, generally known as vacuum-oxygen-decarburization, results in low carbon contents with little loss in alloying elements, particularly chromium. Thermodynamically this process is based on the temperature dependence of the chromium-carbon reaction, the pressure dependence of the carbon-oxygen reaction and the influence of the carbon-monoxide partial pressure on the chromium-carbon reaction. Since the temperature dependence of the chromium-carbon reaction is already pronounced at atmospheric pressure, a prerefining step with little chromium loss can be carried out in the melting unit. Further decarburization takes place at reduced pressure. Because of the pressure dependence of the carbon-oxygen reaction, carbon oxidation is favoured with respect to the oxidation of chromium; the latter depends upon a high oxidation potential and unfavourable kinetic conditions.

During the oxidizing vacuum treatment the partial pressure of carbon monoxide is continuously reduced; therefore, at constant chromium contents, the chromium-carbon equilibrium is shifted to always lower carbon contents. Thus, it is possible to produce ferritic, austenitic and soft magnetic steels with carbon contents of less than 0.02% and a chromium yield of approx. 98 percent in a large scale operation by top blowing oxygen during vacuum treatment. To achieve this result reliably it is necessary to stir the melt during the oxidizing step.

DESCRIPTION OF THE DIFFERENT DEGASSING AND LADLE METALLURGICAL PROCESS

A. Stream Degassing Techniques

Stream degassing is based on the fact that a molten metal stream is divided into many small droplets when entering the evacuated ladle or vessel. Therefore this technique results in an excellent hydrogen removal as demonstrated by A.Sickbert (Fig.1). The figure shows that even with pressures of more than 10 mbar the hydrogen content after treatment is around 1 ppm.

Tap degassing (TD, Fig.2) is mainly used for small heats of 15 to 25 tons from electric arc or open hearth furnaces. It has the advantage of short treatment times and, consequently, minimal heat losses, as tapping is directly combined with degassing. In the past, tap degassing was also used for the degassing of large heats of up to 120 tons to produce large forging ingots by vacuum ingot teeming (VT, Fig.3). Nowadays, in most cases, the more reliable technique of vacuum-heating-degassing (VHD) is being used for the accumulation of several melts that are necessary for such heavy ingots. The ladle-to-ladle stream degassing (LL, Fig.4) has lost its advantages against static vacuum degassing (VD, Fig.5) in ladles with argon stirring.

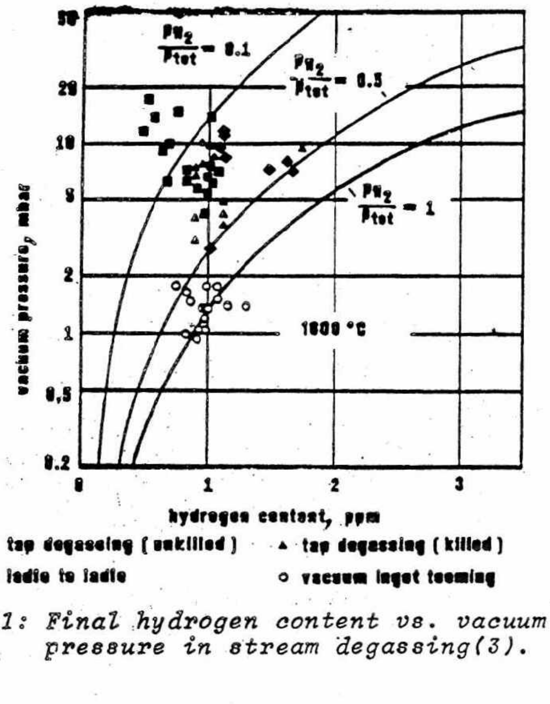


Fig.1: Final hydrogen content vs. vacuum pressure in stream degassing(3).

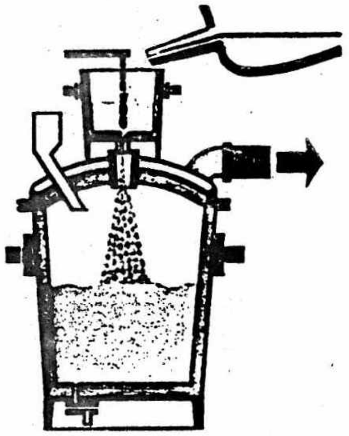


Fig.2: Schematic representation of tap degassing (TD)

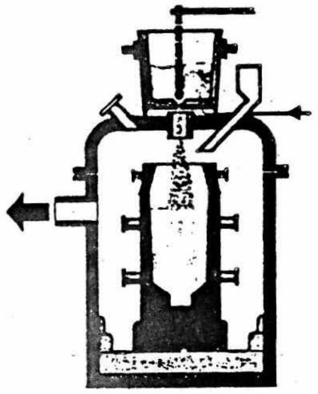


Fig.3: Schematic representation of vacuum ingot teeming (VT)

These processes require low investment costs because normal ladles with only an increased freeboard can be used. Specific reactions can be achieved with basic slags. Inert gas stirring causes turbulence in the steel melt and, thus, larger reaction surfaces between metal, slag, and vacuum chamber atmosphere. This produces a greater homogeneity, a

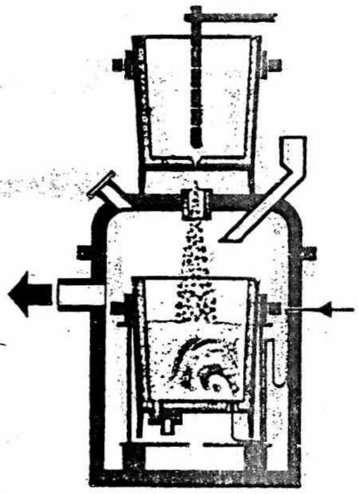


Fig.4: Schematic representation of ladle-to-ladle stream degassing (LL)

more effective elimination of nonmetallic inclusions and a better removal of hydrogen, oxygen, and carbon. However, as heat losses cannot be compensated, the treatment times and alloying possibilities are limited.

B. Partial Quantity Degassing

Today, two processes exist in which degassing takes place in a partial amount of the total steel quantity. One way to accomplish this is the continuous circulation in which the whole quantity is brought into contact with the vacuum by means of argon as a lifting gas (Fig.6).

In this kind of plant, the alloying equipment is a most important part because the conditions for alloying are ideal, as the rate of weighing, adding, dissolution and homogenization are adjustable such that quickly a perfect homogeneity of the melt is achieved (Fig.7). This good and fast mixing effect is explained by the fact that the additions are dissolved before they leave through the backflow snorkel. This is not possible with the second partial quantity method, the lifting process, where the whole vacuum vessel must be moved several times to accomplish the complete treatment of the steel via a single snorkel.

Figure 8 shows the metallurgical possibilities of the vacuum circulation process. The partial quantity processes are being used for mass steels, the quality requirements of which are increasing, such as shipbuilding plates, grain-oriented plate, extra low carbon steel for electro-magnetic applications, enamelling sheet, low alloyed heat treatable steel grades, ball bearing steels and high speed tool steels.

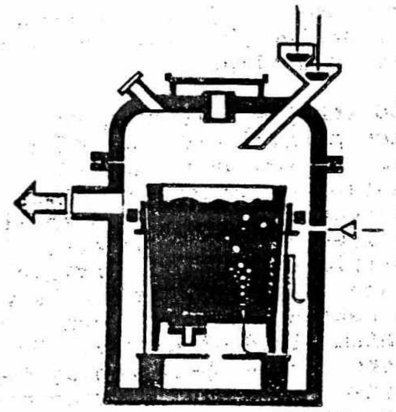


Fig.5: Schematic representation of static vacuum degassing (VD) in ladles with argon stirring.

C. Vacuum Oxygen Decarburization

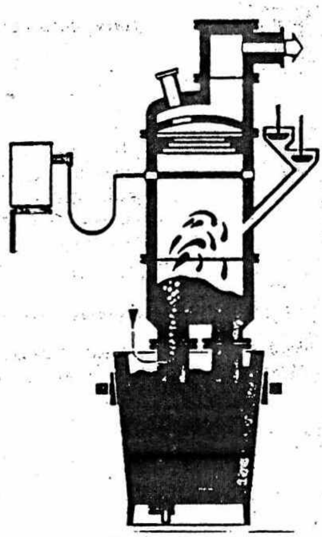
This process is based upon the fact that under vacuum and oxidizing conditions decarburization is favoured against the scorification of chromium. Therefore, this process is being exclusively applied to stainless steel grades and other chromium-bearing steels.

Vacuum oxygen decarburization (VOD) is carried out in several steps as follows:

1. Melting
2. Oxygen pre-blowing at atmospheric pressure for preliminary decarburization and the scorification of Si (as well as Al, Ti, and V, if any)
3. Vacuum treatment under oxidizing conditions by introducing gaseous oxygen into the vacuum chamber
4. Vacuum treatment under reducing conditions
5. Desulphurization.

A schematic of the VOD process in ladles is shown in Fig.9. One of its characteristics is the independent vacuum chamber that may house various VOD-ladles which are all equipped with basic lining, slide gate, porous plug for inert gas stirring and a ladle cover, and feature a ladle freeboard of 1 m.

A lance, fed through the cover, blows oxygen under vacuum onto the metal bath surface in the ladle. The blowing



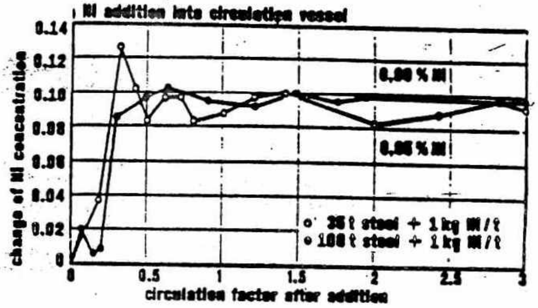


Fig. 7: Mixing of alloying addition during vacuum circulation treatment according to H. Maas and M. Wahlster (4)

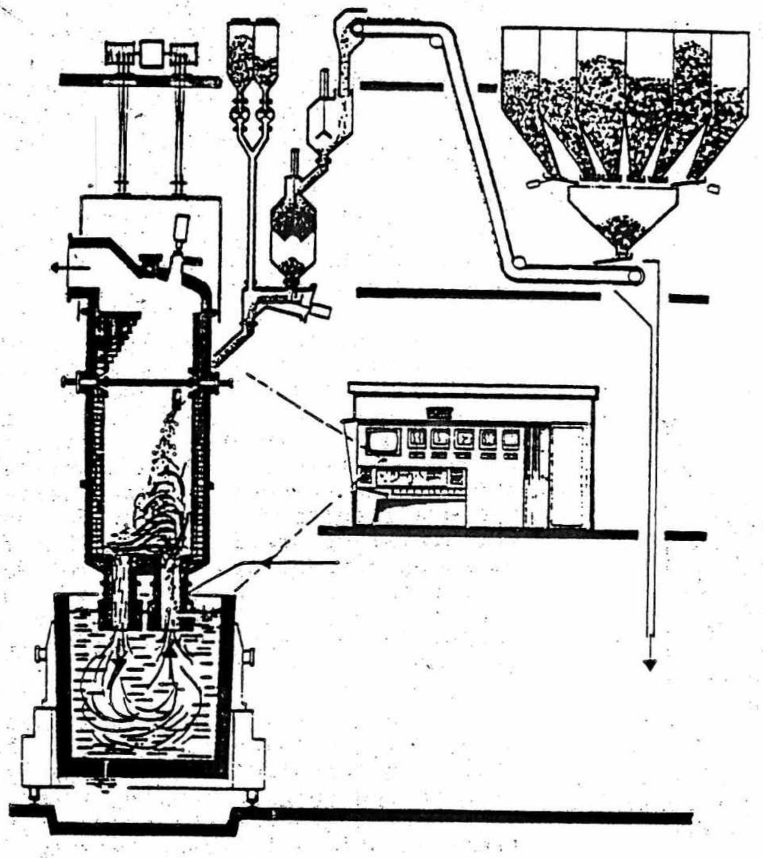


Fig. 6: Schematic representation of the vacuum circulation process (CP)

rates may vary between 500 and 2000 Nm^3/h but most of the ladle VOD plants operate at 600 to 1000 Nm^3O_2/h. The blow rate must increase with the volume to be treated; however, the kinetic conditions are not improved.

The first and most important aim of the VOD process is decarburization at a high chromium yield. This implies perfect process control by observation of pressure, waste gas analysis, and temperature. Final carbon removal and simulta-

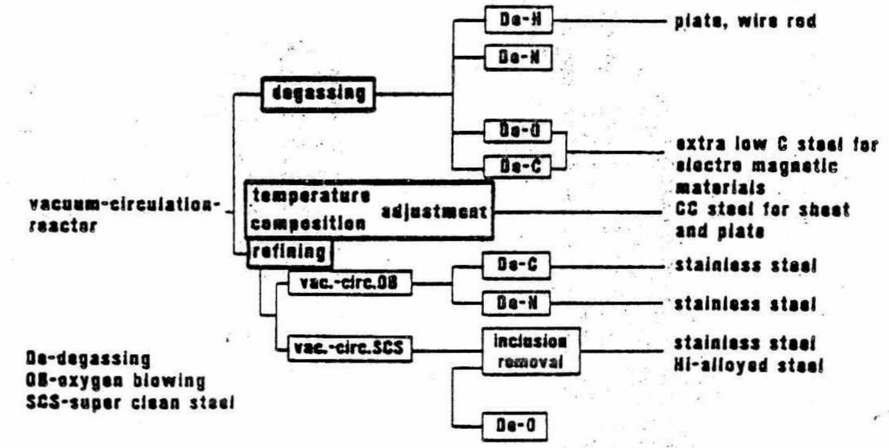


Fig.8: Vacuum circulation process possibilities according to Y. Suzuki (5)

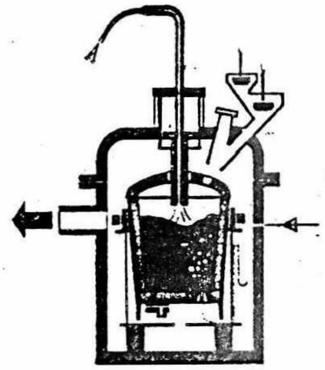


Fig.9: Schematic representation of the vacuum oxygen decarburization process (VOD)

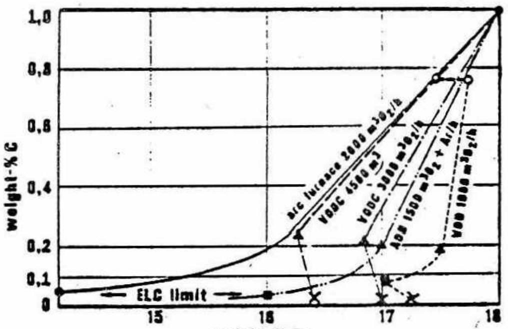


Fig.10: Relationship between carbon and chromium contents at different blow rates according to K.F. Behrens et al.(8)

• first step, o second step,
△ third step, ■ fourth step,
× fifth step.

neous deoxidation take place during the formation of CO at a vacuum in the range of 20 to 1 mbar. During step 4, the oxygen dissolved in the melt at the end of blowing is consumed and some oxygen is recovered from the slag, thus leading even to a slight increase in chromium. Obviously, as such inclusion-free deoxidation and a chromium-recovery cannot be achieved with a "pseudo-vacuum" as practised in the AOD or CLU process. To the contrary, in these processes the chromium content must decrease if low carbon and nitrogen contents are required. This decisive difference between the various processes which are being promoted for the production of stainless steel grades is demonstrated in Fig.10.

The removal of hydrogen, lead and zinc may be considered as a byproduct of the VOD process. Final deoxidation and desulphurization are achieved during steps 4 and 5 with best reducing conditions prevailing. Oxygen contents below 100 ppm and sulphur contents below 50 ppm are results of standard VOD practice for stainless steel grades. The final nitrogen content was subject of detailed investigations leading to a special technique developed in Japan for ferritic grades (9,10), called strong-stirred VOD (SS VOD).

Today, the VOD process is applied in approx. 30 plants throughout the world. Mostly ladles are being used with charge weights ranging from 15 to 90 tons. With growing charge weights the treatment times increase because for a reasonable ladle freebcard the blow rate is limited to max. 2500 Nm^3O_2/h.

Since a converter has sufficient boiling space, the blow rate in such a vessel can be increased to approx. 4500 Nm^3O_2/h. Thus, favourable conditions can be achieved for avoiding chromium scorification at a more intensive argon

Table 2: Comparison of characteristic operational data for the VOD, SS VOD, VODC and AOD processes for 50 t heats (11)

Example	VOD 304 L	SS VOD 18/2 CrMo	VODC 304 L	AOD 304
Preblow				
Initial C-content	0.8 to 1.5 %	1.0 to 3 %	1.0 to 3.0 %	1 to 3 %
Final C-content	0.6 to 0.8 %	0.8 to 2 %	0.2 to 0.3 %	0.02 to 0.08 %
Oxygen blow rate	2000 m^3/h	3000 m^3/h	4000 m^3/h	} 1500 m^3/h
Argon blow rate	-	-	500 l/min	
Vacuum oxidising				
Initial C-content	0.6 to 0.8 %	0.8 - 2.0 %		
Final C-content	0.04 to 0.08 %	0.01 to 0.02 %		
Oxygen blow rate	1000 m^3/h	1500 m^3/h		
Argon blow rate	30 l/min	1000 l/min		
Argon purity	99 %	99.999 %	99 %	99 %
Vacuum pressure	50 mbar	50 mbar	-	-
Vacuum reducing				
Final C-content	100 to 300 ppm	3 to 10 ppm	150 to 300 ppm	
Final N-content	200 to 300 ppm	20 to 30 ppm	100 to 200 ppm	
Final O-content	100 ppm	100 ppm	100 ppm	
Argon blow rate	60 l/min	2000 l/min	500 l/min	
Vacuum pressure	1 mbar	1 mbar	1 mbar	-
Desulphurisation				
Initial S-content	200 to 400 ppm	100 ppm	200 to 400 ppm	200 to 400 ppm
Final S-content	40 to 80 ppm	20 to 50 ppm	40 ppm	40 ppm
Number of slags	1	1	1	2
Vacuum pressure	1 mbar	1 mbar	1 mbar	-
Consumption figures				
Total Cr-scorification	0.7 %		1.5 %	> 2 %
Si for reduction	3 kg/t		9.5 kg/t	14 kg/t
Ar consumption	0.2 Nm^3/t		1 Nm^3/t	20 Nm^3/t
N_2 consumption			-	10 Nm^3/t
steam consumption	200 kg/t		60 kg/t	-
water consumption	9.5 m^3/t		3.2 m^3/t	-
power consumption	5.5 kWh/t		1.8 kWh/t	-

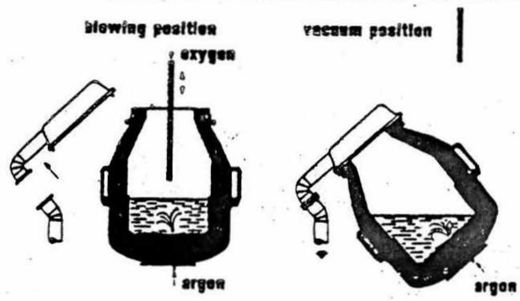


Fig.11: Schematic representation of the VODC process steps according to K.F.Behrens et al. (8).

stirring. This technique, called VODC, is shown in Fig.11.

Some characteristic operational data and results of VOD, SS VOD, VODC and, for comparison, also for AOD are compiled in Table 2 for 50 ton heats.

D. Calcium Injection Refining

Since a long time ago the injection of powdered solids into steel melts by means of a suitable gas has been a way of performing particular metallurgical treatments like dephosphorization with oxygen and lime, decarburization with oxides,

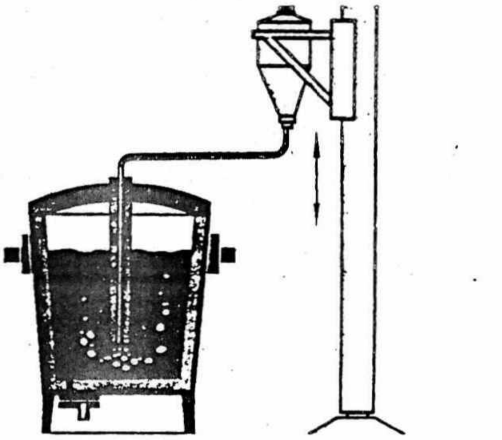


Fig.12: Schematic representation of the calcium argon blowing plant (CAB)

alloying, deoxidation, inoculation, recarburization, etc. Figure 12 shows schematically a calcium argon blowing plant (CAB). The main task of this treatment is "inclusion shaping" while desulphurization is a byproduct of this treatment. It complements the ladle metallurgical vacuum processes. In CAB as shown in Fig.12 vacuum is not required, only an exhaust for dust and fumes is advisable; however, it should be stressed that the injection of powdered solids is also possible in modern ladle metallurgical plants, e.g. VHD, as part of the total treatment cycle.

E. Vacuum Heating Degassing

The temperature loss associated with all ladle metallurgical treatments can be compensated by several means:

- Overheating

  Overheating takes place in the melting furnace or the converter. It is very costly, results in an increased refractory wear and limits the flexibility that is necessary in a modern steel melting shop.

- Heating in ladles at atmospheric pressure.

  Heating at atmospheric pressure is achieved either by inductive heating in specially designed ladles or by arc heating. The latter design, which is similar to electric arc furnaces, is called ladle furnace (LF).

- Vacuum arc heating

  The combination of vacuum treatment and arc heating in ladles coupled with (continuous) inert gas stirring of the melt is called vacuum heating degassing (VHD).

In those cases where relatively small melt shops producing a variety of steel grades seek the flexibility to accumulate several melts for large castings and/or wish to perform occasionally complex ladle metallurgical treatments, which are time consuming, the installation of a simple ladle furnace (Fig.13) coupled with static vacuum degassing (VD), vacuum oxygen decarburization (VOD) or calcium injection refining (CAB) stations may be the answer.

Although inductive stirring coils have been developed for ladles and are

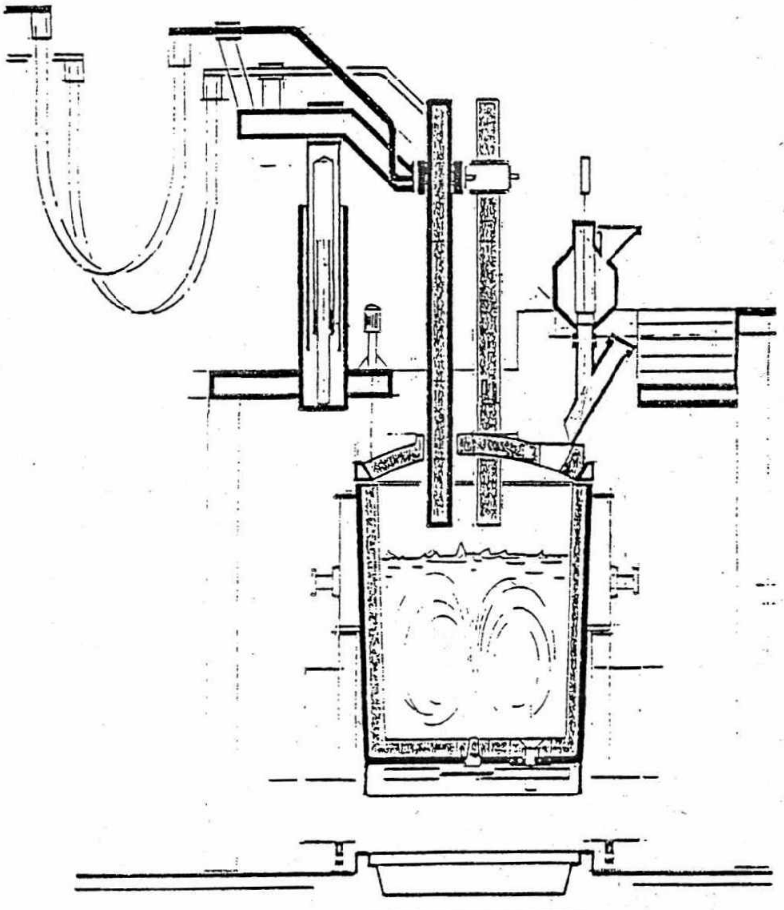


Fig.13: Schematic representation of the ladle furnace (LF)

available for incorporation into ladle metallurgical plants such as ladle furnaces, the development of linings, slide gates, and porous plugs for inert gas stirring have made so much progress during the past ten years that, today, in most cases, there is no longer a need or a commercial justification for the costly investment required for an induction stirring coil with separate power supply and frequency generator.

It is obvious that operational advantages are obtained if heating, degassing, alloying, desulphurization, and quality control are done in one piece of equipment without interruption and without exposing the melt to ambient atmospheric conditions during the treatment. This is being achieved in the vacuum heating degassing (VHD) process (Fig.14). Precise electrode regulation, compactness of the entire electric part resulting in small inductive losses, advanced process control, small thermal losses, and increased ladle life due to optimal linings have produced best metallurgical results and have made the VHD process an economic and flexible tool guaranteeing highest quality levels.

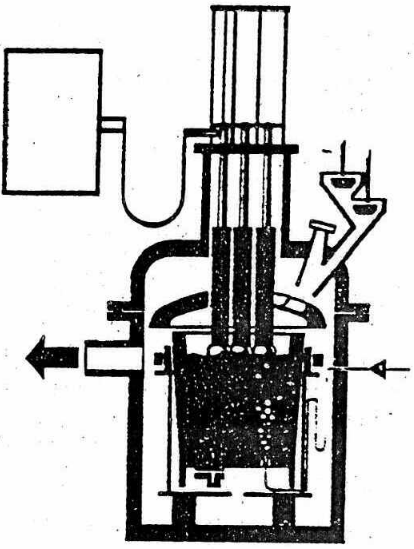


Fig.14: Schematic representation of vacuum heating degassing (VHD)

Briefly the possibilities of VHD are as follows:

- Degassing: Because there is no real limit to the treatment time, levels of less than 1.5 ppm hydrogen can be guaranteed. Furthermore, due to the basic lining of the ladle the oxygen content can be lowered by CO-formation while oxidic contaminants are optimally removed during the extended stirring under vacuum; thus, e.g., 25 ppm oxygen are a standard in VHD-treated low alloyed steel grades.
- Heating: Precise adjustment of the required teeming temperature is easily obtained during the VHD treatment and holding for the accumulation of hot metal has already been done for up to 12 hours.
- Alloying: Means for sampling the melt and adding alloying constituents without breaking the vacuum, allows to adjust and keep the chemical composition of the steel within extremely narrow limits. It is also possible to make large carbon additions with a high yield and good accuracy. Carbon pick-up from the electrode is negligible.
- Desulphurization: Slag work is quick and effective. Sulphur levels below 50 ppm can be guaranteed.
- Calcium injection: Calcium bearing compounds, particularly CaO, CaF_2, $CaSi$ and CaC_2 can be injected to perform "inclusion shaping" and desulphurization.
- Process control: Electrode regulation, adjustment of stirring, temperature measurement, sampling, alloying, and observation of the bath can all be done without breaking the vacuum. The uninterrupted operation in a closed system allows an accurate and economic control of the VHD-process and avoids pollution.
- Economy: The main economic advantages of the process are due to short furnace time, good yield of alloying additions, savings in lining costs per ton of steel, lack of reoxidation and gas pick-up, reduction of overall electrode consumption, and low energy requirements.
- Heating rates: Heating rates of up to 5°C per minute are possible.
- Heat efficiency: With sufficiently preheated and insulated ladles the heat efficiency of VHD is considerably greater than that of electric arc furnaces.

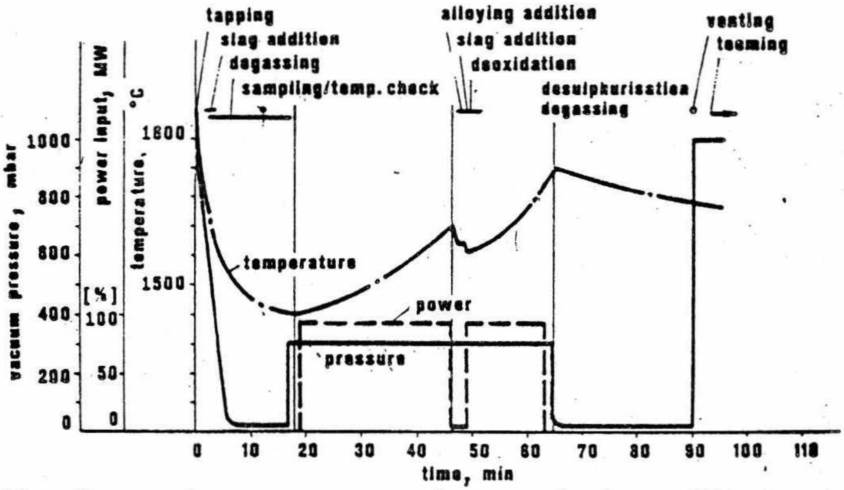


Fig.15: Temperature,pressure and power during a VHD- treatment

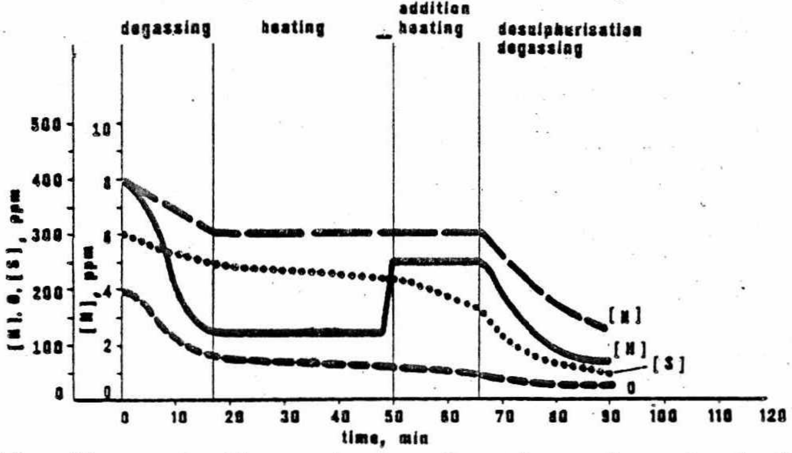


Fig.16: Change in the contents of various elements during a VHD-treatment according to W.Schiager et al.(14)

- Flexibility: The following contribute to the high operational flexibility of a VHD-plant; short standard treatment cycles of less than one hour, long holding capability for accumulated and split heats, possibility to produce electric arc furnace grades with converter metal, decarburization of stainless steel grades with oxide-rich slag, etc.

Figures 15 and 16 show the characteristic evolution of temperature, pressure, power input and chemical composition during a VHD-cycle including desulphurization.

Applications of the vacuum heating degassing process are characterized by the requirements for accurate temperature control, e.g. the teeming of critical ingots, continuous casting, etc., and/or for vacuum degassing to meet severe quality specifications, like off-shore, defence, aeronautic, and nuclear grades.

DESIGN CONSIDERATIONS FOR MODERN STEEL DEGASSING AND LADLE METALLURGICAL PLANTS

Leybold-Heraeus is a company designing, building and commissioning - among other vacuum equipment - a great number of various electro- and vacuum-metallurgical plants for the production and/or improvement of high quality steel grades. Based on this extensive know-how and an interdisciplinary approach the design of the individual equipment is constantly reviewed and can be adapted to specific requirements. At all times new Leybold-Heraeus plants represent the latest state of the art incorporating related experience from earlier or other installations as well as the most modern instrumentation and controls. Below, as an example, the design criteria developed for the latest generation vacuum heating degassing (VHD) units is being reviewed (15).

The main requirements on the design of the heating unit are the sturdiness and compactness of the heating part, i.e., the system of electrodes, arms, and masts with the corresponding electrode drive. The electrode arm mast-system may be a generator of vibrations due to a relationship between the electro-magnetic and the mechanical forces. Furthermore, electrode breakage was experienced due to a normally large electrode length and the regular movement of the stirred bath. Thus, a basic requirement, which corresponds also with the desire for short conducting elements when AC-current is being used, is the design of a very stiff and compact heating unit.

Obviously, short arms can only be obtained if the masts are close to the electrodes. The best way to achieve this is to use an independent vacuum chamber with a movable cover and to mount the electrode masts with the electrode drive, arms and clamps on this cover. This new design is in contrast to the older layout of VHD-units where vacuum covers were directly placed on the ladle with stationary electrode masts mounted on foundations next to the heating degassing station.

The new electrode support system has become a stiff and sturdy construction. Clearances between guides are minimized and absorbing elements are being used in the design to reduce vibrations. The correct choice of the position of the porous plug in the ladle and the proper adjustment of the gas flow during treatment has been optimized. As compared with the uniform inductive stirring pattern, the more irregular movement of the melt resulting from inert gas flushing is advantageous, as a correlation between mechanical and electro-magnetic forces cannot develop easily.

Fig.17 and Table 3 show three designs of VHD-units featuring different electrode lengths, plant heights and clearances necessary for crane movement. All three designs are for melt weights of 40 to 70 tons and for a ladle freeboard from 600 to 1200 mm, a lid lifting height of 500 mm, an electrode diameter of 350 mm, and a pitch diameter of 1000 mm. In all cases the clamp design, the distance between masts and electrodes, and the electrode drive system (hydraulic)are the same.

The conventional design "A" has the greatest height and requires a crane clearance of more than 14 m above the

Table 3: Characteristic dimensions of various VHD designs (20)

	A	B	C	
Ladle freeboard max.	1200	1200	1200	mm
Ladle freeboard min.	600	600	600	mm
Lid lifting height	500	500	500	mm
Electrode stroke	1500	1500	1700	mm
Electrode unit length	1830	2100	915	mm
Electrode free length max.	6500	4500	2745	mm
Electrode free length min.	5000	3600	1830	mm
Height of VHD part with cover closed				
- lower position	5800	4800	4000	mm
- upper position	7300	6300	5700	mm
Crane clearance (above VHD cover)	14500	12500	6300	mm

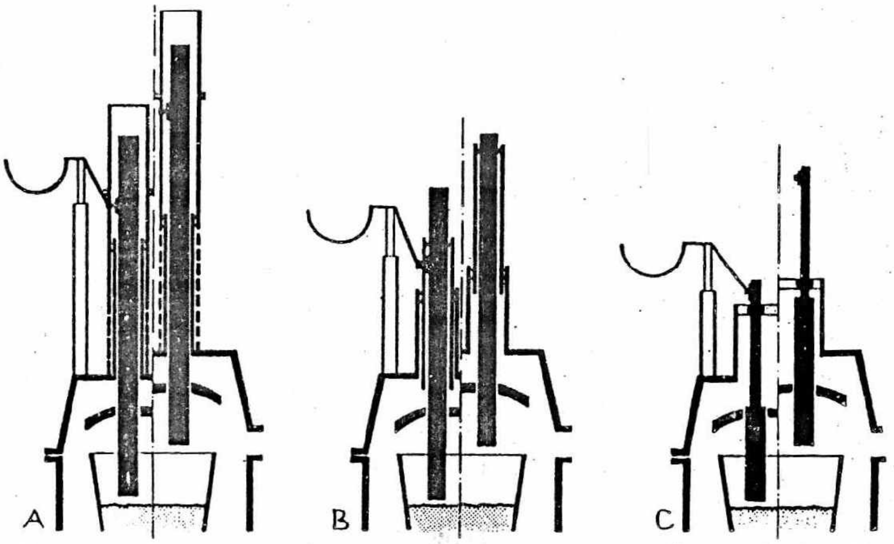


Fig. 17: VHD-designs with different compactness (see also Table 3)

chamber cover. The newer design "B", developed by Leybold-Heraeus, features fixed outer water jackets and inflatable electrode seals resulting in reduced electrode length and lower total plant height while still permitting an electrode stroke of 1.5 m. Both designs "A" and "B" are for continuous feeding of electrodes from the top.

The solution "A" has a number of further disadvantages:

- The rigid inner pipe might be hit by the vibrating electrode.
- The relative movement between the two telescopic pipes is being compensated by a flexible element; as a result electrode movement must overcome the frictional force and, therefore, becomes rather irregular.
- The electrode cover at the top must be such that an entire electrode length can be added. For lengthening the electrode this cover is a handicap because it must be removed first.

The solution "B" represents a marked progress:

- The electrode length is reduced to approx. 4 meters.
- The gap between telescopic tube and electrode may be doubled and, thus, damage by hitting is avoided.
- Vibrations of the electrode are reduced to a minimum.
- The inflatable seal at the top is designed for good accessibility and easy electrode lengthening.
- As compared with design "A" approx. 2 meters in total plant height are saved by solution "B".

The continuous feeding of electrodes from the top requires a crane clearance above the plant that can accommodate the length of an entire assembled electrode or, respectively, of the pieces to be attached. To reduce the electrode length further and to avoid an additional crane clearance above the plant the solution "C" was developed (16). It splits the electrodes in a lower removeable graphite part and an upper permanent copper pipe. In this case, electrode changing is accomplished from below using a remotely controlled clamping device (Fig.18) which is a standard item in many Leybold-Heraeus Vacuum-Arc-Remelting (VAR) and Electro-Slag-Remelting (ESR) units. Using this technique for electrode change, it is not necessary to observe a waiting time for cooling the refractory lid or to remove the electrodes. Half-length electrodes of 0.9 m are being used, the electrode stroke is 1.7 m, the total graphite electrode length is 2.7 m (equal to 3 pieces of 0.9 m each), and no clearance above the unit (crance clearance) is required. A further advantage of this type of clamping is the self-locking in case of a power failure.

Because there is no electrode dipping in VHD and electrode breakage is avoided with the advanced new designs, the utilization of high-density graphite electrodes becomes interesting. Instead of 355 mm

Table 4 : Comparison of four different melt shops producing 350 tons per day of liquid steel

	1 UHP	2 UHP	1 UHP + 1 VHD	1 UHP + 1 LF
Melting Capacity	50 t	35 + 15 t	35 t	35 t
Transformer	26 MVA	18 + 8 MVA	18 MVA	18 MVA
VHD/LF Capacity	-	-	35 t	35 t
Transformer	-	-	6 MVA	6 MVA
Total Power	26 MVA	26 MVA	24 MVA	24 MVA
Tap-to-Tap (2 slag-work)	3,4 h	3,4 h	2,4 h	2,4 h
Heats per day	7	7 + 7	10	10
Tons per day	350 t	350 t	350 t	350 t
Equipment required				
Furnace vessels	1	2	1	1
Covers	1	2	2	2
Transformers	1	2	2	2
Vacuum System	0	0	1	0
Ladles	3	6	4	4

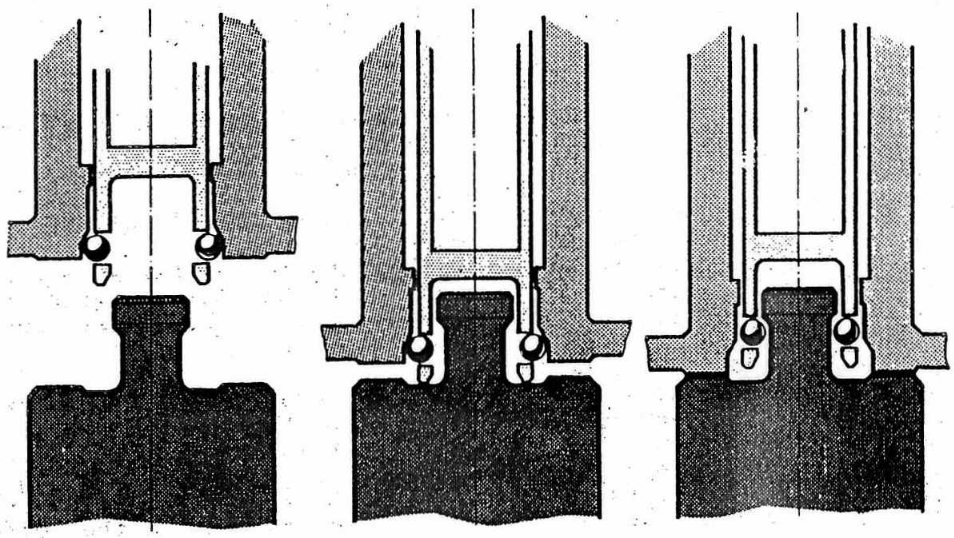


Fig.18: Remotely controlled electrode clamping

Table 5: Absolute consumption figures of vacuum heating degassing plants (VHD 30 - 100 t)

Item	Consumption	Remarks
Electrodes	0,2 - 0,5 kg/t	depending on production sequence and electrode quality
Power	35 - 60 kWh/t	depending on production sequence and condition of ladle
Slag	10 - 20 kg/t	depending on desulphurization work
Ladle lining	3 - 7 kg/t	depending on type and duration of treatment, type of lining, condition and design of ladle
Cover lining	0,5 - 0,7 kg/t	
Argon	50 - 70 Nl/t	
Steam	20 - 30 kg/t	
Water	4 - 5 m³/t	

(14") diameter ordinary grade electrodes it is possible to use high-density electrodes of , e.g. 305 mm (12") diameter. Strength and conductivity of the electrodes are maintained. Since the surface area of the electrodes is reduced by approx. 15 percent the electrode consumption, which in VHD is only due to surface related effects like sublimation and oxidation, is also lowered.

ECONOMIC CONSIDERATION OF LADLE METALLURGY

A vacuum heating degassing plant is a ladle furnace operating under vacuum. Therefore, it should be considered to what extent a VHD-unit can take part in the production cycle of a steel mill.

Table 4 compares four different melt shops all of which produce 350 tons per day of liquid steel with different layouts and equipment. It is obvious that a UHP-VHD-combination is advantageous if compared with the installation of two UHP-furnaces. This is also the case if the capacity of a melt shop with an initial production of 245 tons per day (one 35 t UHP furnace) must be increased to 350 tons per day (addition of a 2nd 15 t UHP furnace or a VHD unit). However, the advantage of the installation of "UHP plus VHD" or "UHP plus LF" versus one single UHP furnace of appropriate size becomes only evident if the production program and the operating costs are considered.

Generally, it can be stated that VHD is to be preferred if 2-slag work or any degassing is necessary as, e.g. for heavy forgings, low alloyed steels for construction purposes, highly alloyed grades, etc. Any cost comparison should take into account the commercial advantage obtained from the higher quality product in respect to gas content, cleanliness and homogeneity.

The total decrease in running costs for the UHP-VHD combination is approx. 10%. This is mainly due to:

- the reduced requirements on the cleanliness of the burden.
- the lower overall consumption of electrodes and refractories,

- the smaller expenses for conditioning a white slag, and
- the better yield of additives.

If the UHP-VHD combination is compared with a UHP plant producing single slag grades the cost advantage is less and only based upon reduced costs for electrodes and refractories as well as the higher alloying yield. However, a flexibility is obtained that allows easy adjustments of the program to sudden changes in the market place.

Table 5 summarizes typical absolute consumption figures of VHD plants.

CONCLUSION

In conclusion, it can be stated that steel degassing has developed from the simple vacuum treatment to melts to remove dissolved gases to a rather complex Ladle Metallurgy that, in addition to degassing, allows to carry out a number of different important metallurgical treatments. While these possibilities are limited in many cases by the loss of temperature during treatment, this problem is overcome if ladle heating equipment is being used.

The paper reviewed the different methods for steel degassing and ladle metallurgy which are presently being supplied by Leybold-Heraeus with a particular emphasis towards special design features derived from related Company experiences. Modern vacuum heating degassing plants offered by Leybold-Heraeus profit from the know-how gained in the many vacuum technology plants that were designed, built, and commissioned by this Company. It was shown the vacuum heating degassing plants in combination with UHP furnaces (or other primary melting equipment) offer metallurgical and cost advantages.

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