

QUALITY IMPROVEMENT AND PRODUCTION INCREASE BY VACUUM ARC HEATING

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We have tried to describe our vacuum refining and heating plant by giving a survey of the technical characteristics followed by a brief description of the processes of refining and heating under vacuum. Then we have dealt with the economics and qualitative advantages of this technology.

The results we have until now obtained in treating austenitic and ferritic steel grades, Ni-base alloys with over 70% Ni as well as alloyed structural and tool steels in these units have fully justified our belief that we had been right in deciding to invest in this facility which has fully answered our expectations.

INTRODUCTION

The reasons for the installation of two plants delivered by Standard-Messo Duisburg for the foundry Gelsenkirchen of the Thyssen Giesserei AG and the Vereinigte Edelmetallewerke (VEW) at Ternitz are discussed.

Design, construction and possibilities of the plants, as well as their operational procedure and their effect on economy and quality are shown.

The plant in operation at the foundry Gelsenkirchen, is a VAD plant working according to the Finkl system, whereas a combination of the VAD and the VOD process (Witten process) has been realized in the VEW at Ternitz (formerly Schoeller Bleckmann).

The VAD System

The foundry Gelsenkirchen produces castings upto 90 tonnes liquid weight, e.g. for non-metallic minerals industry as well as turbine and reactor engineering.

Carbon steels, CrMo steels, CrNiMoV steels and corrosion-resistant qualities such as GX 5 CrNi 13.4 are teemed.

Until the year 1975, the foundry had two electric furnaces with a capacity of max. 18 and 34 tonnes and one open-hearth furnace of 34 tonnes. By the combination of two or three tappings, castings upto 90 tonnes could be teemed.

The insufficiency of the open-hearth furnace, the environmental policy acts and the price collapse on the ingot sector forced them to demolish the open-hearth furnace and to reduce the normal monthly crude steel capacity from 4,400 tonnes to 3,000 tonnes. This, however, had to be done without reducing the single weights below 90 tonnes.

The solution for the foundry Gelsenkirchen was considered to be a VAD plant operating according to the Finkl system.

In cooperation with their supplier, Standard-Messo Duisburg, the erection and commissioning was done in two steps, to allow the demolition of the open-hearth furnace without reducing steel production.

In November 1974, the plant was started with the arc heating only, in order to find out whether the large

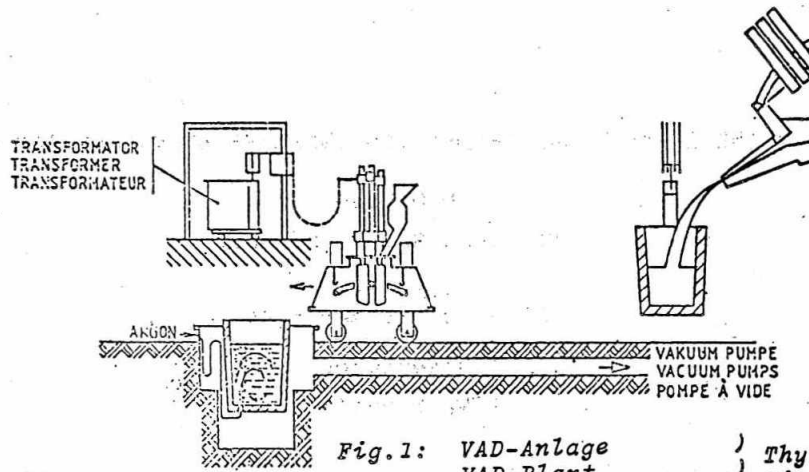


Fig. 1: VAD-Anlage
VAD-Plant
Installation Vad) Thyssen
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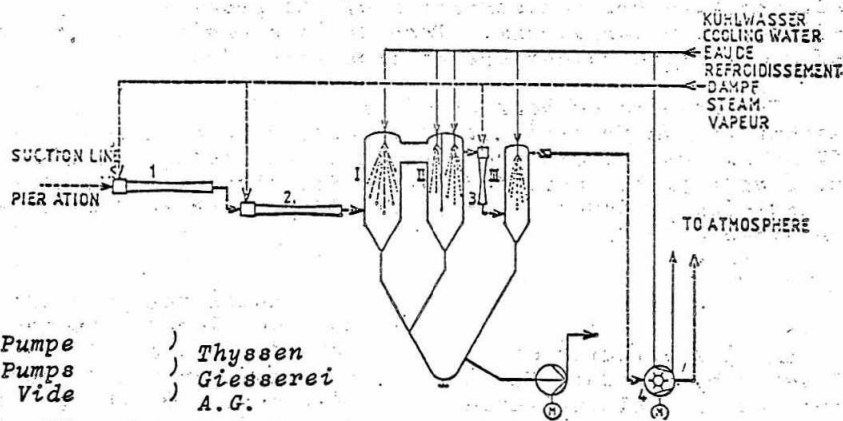


Fig. 2: Vakuum Pumpe
Vacuum Pumps
Pompe A Vide) Thyssen
Giesserei
A.G.

ingots could be produced in this way without an open-hearth furnace. This proved true after a short period only and after 6 months the open-hearth furnace could be demolished. Part of the resulting free space was used for the installation of the steam ejectors and condensers, and the first melts were vacuum-degassed early in 1976.

The first heat from the arc furnace can be heated and metallurgically treated under vacuum in the VAD unit until the next heat has been produced in the arc furnace so that finally both heats can be cast simultaneously.

This way, heats with higher Cr contents could be combined to make larger forging ingots which had not been possible with the open-hearth furnace.

It was finally expected that the VAD unit would achieve an improvement of quality, especially for rolling and forging grade ingots.

DESIGN OF THE PLANT

Figure 1 shows a schematic diagram of the plant. The charged ladle is placed in the vacuum tank, and after temperature measurement, sampling and lime addition, the cover with the electrodes is moved over the tank and then lowered.

Sealing between tank and cover is assured by means of a rubber gasket. A pressure of 300 Torr is reached in 2 minutes by means of the vacuum pump. Arc heating is started at this pressure, and after temperature has been reached, the melt can be held at this temperature until the next heat is ready, or alternatively, after shut-down of heating, the pressure can be reduced to below 1 Torr for vacuum degassing.

Alloying agents can be added at any time through a vacuum hopper.

Transformer rating is 2.2 MVA.

Fig.2 shows the vacuum production system.

Three steam ejector stages with two condensation stages are followed by a water ring pump.

Thus, an operating pressure of approx. 0.5 Torr is reached. The vacuum necessary for VAD heating is produced by the water ring pump only.

Throughout the operation, the melt is stirred by bubbling argon through a porous plug in the base of the ladle in order to reach a large reaction surface between slag and steel bath.

Argon bubbling assures a good homogenization of temperature and analysis throughout the whole treatment time.

Fig.3 shows the arrangement of the porous plug which is installed off-centre in order to obtain circulation. The argon consumption varies between 10 and 50 Nl/min.

Fig.4 shows the refractory brick lining of the ladle. The 65 mm insulation layer is necessary for long time holding-up to 12 hours.

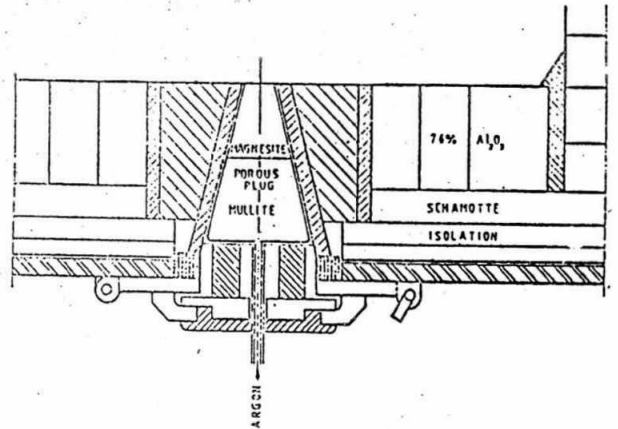


Fig.3: Porous Plug Installation

The composition of the inner lining is as follows:-

Bottom - Allumullit (76% Al_2O_3 ; 0.1% Fe_2O_3)

Wall base - Allubax 80 (80% Al_2O_3 ; 1.6% Fe_2O_3)

60 (64% MgO ; 14% Cr_2O_3 ;

13% Al_2O_3)

Figs.5,6 and 7 show the unit as situated in the steelmaking plant.

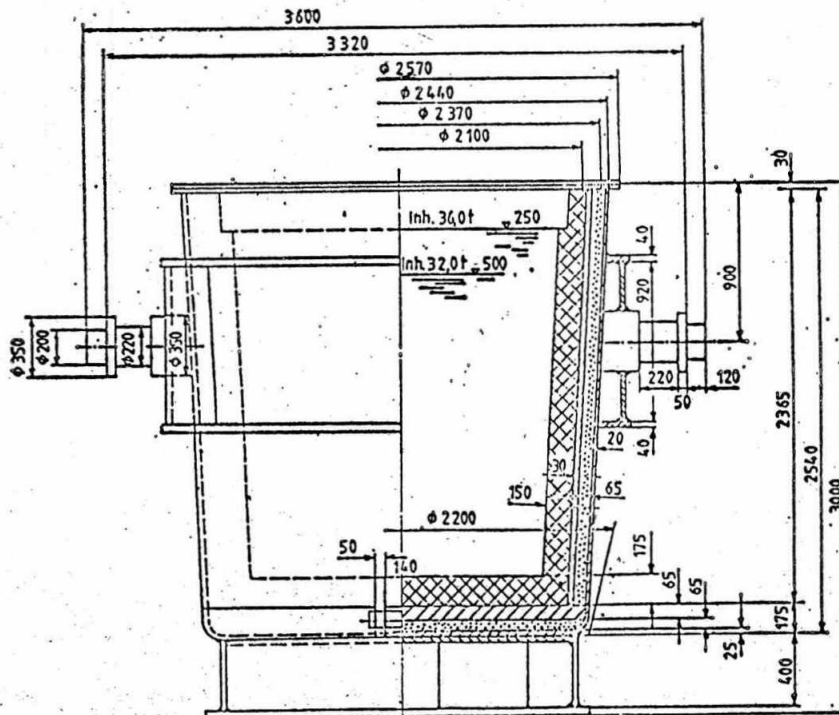


Fig.4: Lining of a 34t VAD Ladle Construction

Fig. 5:

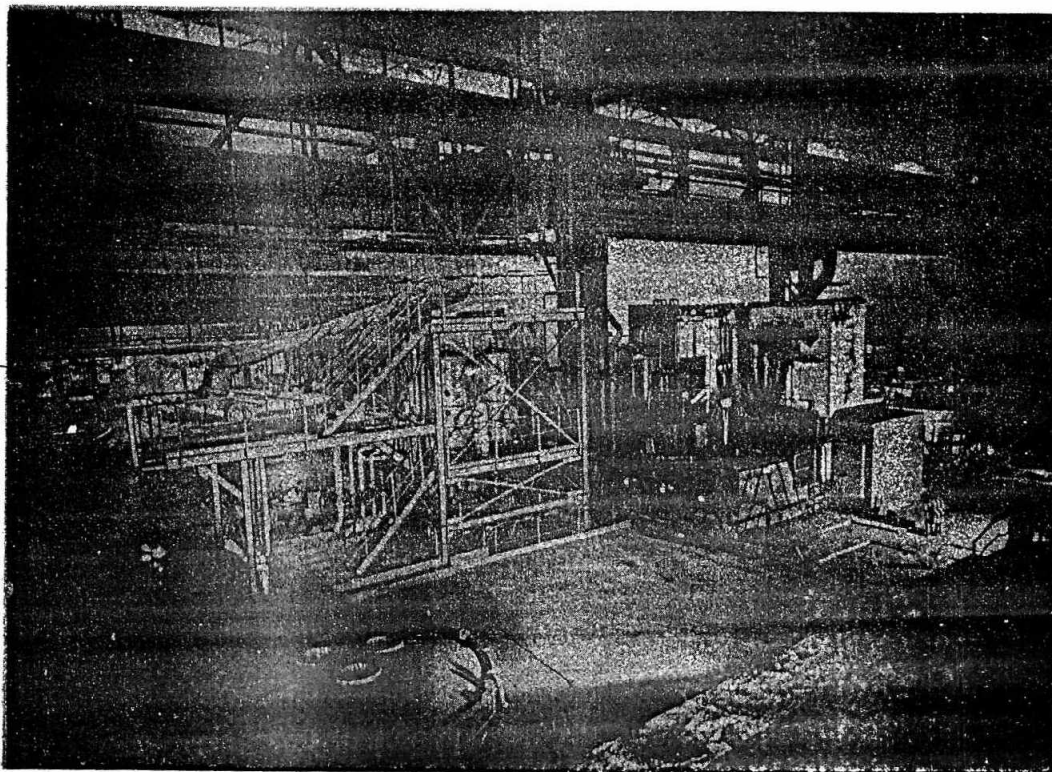
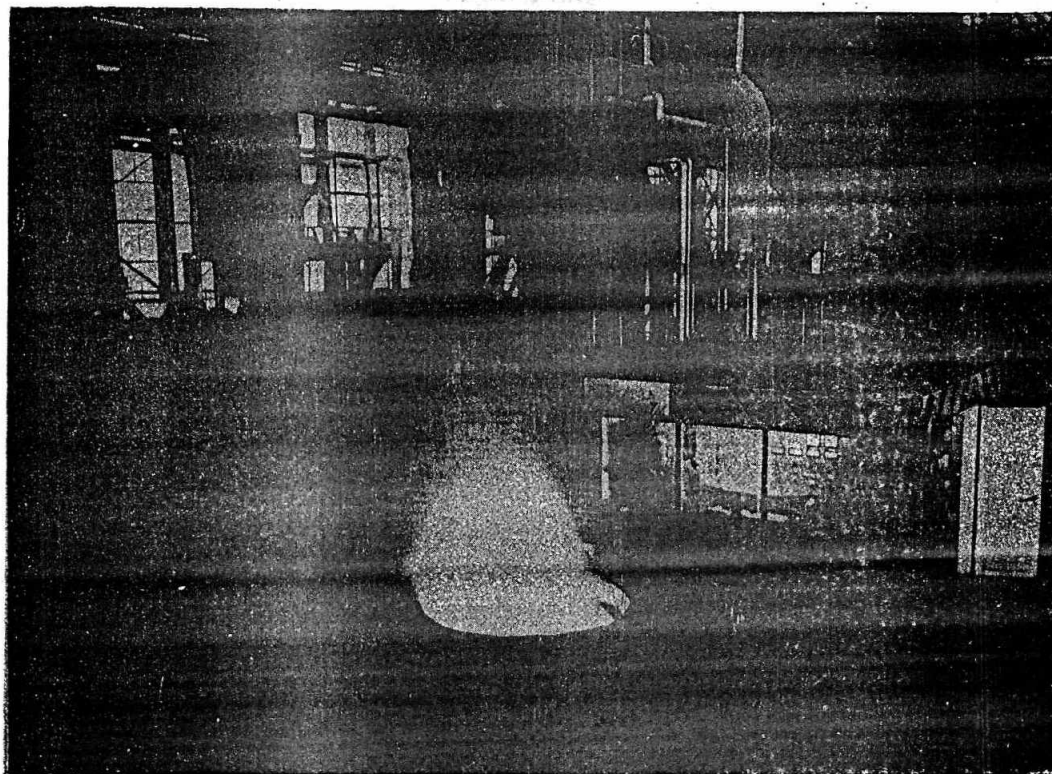


Fig. 6:



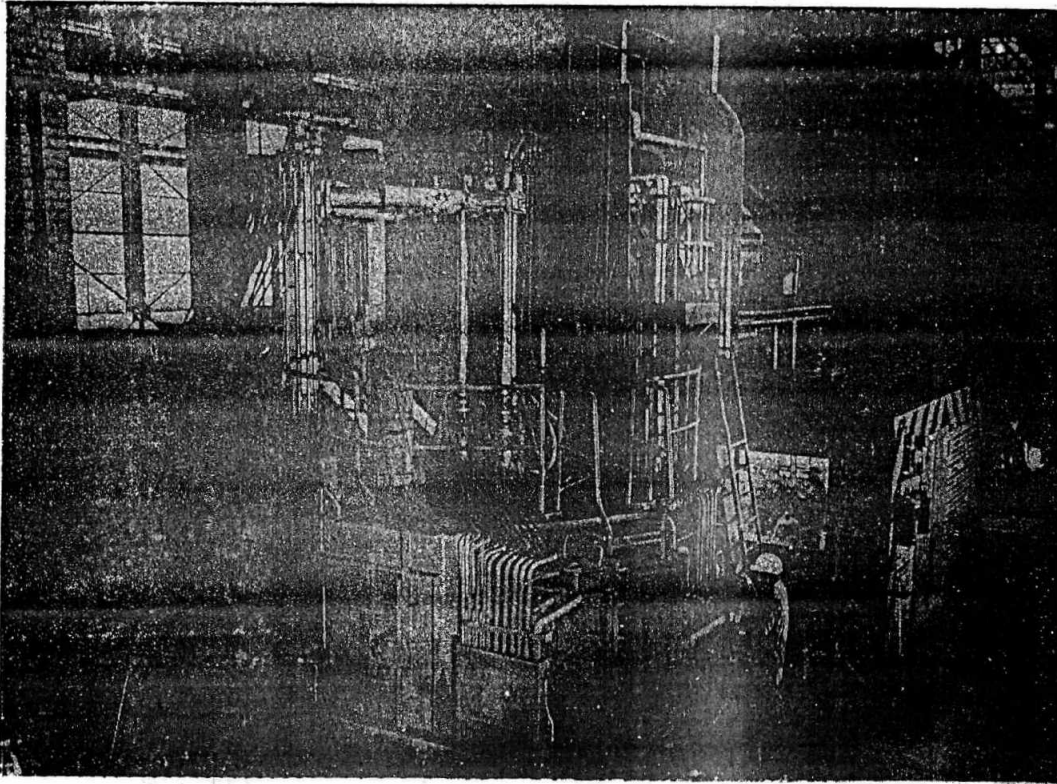


Fig. 7:

Operation Sequence

There are two kinds of operational methods at Gelsenkirchen:

1. Maintaining of temperature of heats until the next one is ready in the electric arc furnace and then, casting both melts into a large ingot; and
2. Heating and degassing of special qualities for steel casting and forging grade ingots.

Fig. 8 shows the sequence of treatment 1.

The high loss in temperature at the start of treatment is compensated within two to three hours by the low heating setting, and the temperature of the melt is maintained at approx. 1590°C until the next heat is nearly ready. Thereafter, the melt is brought to final temperature by switching to higher transformer rating. During this procedure, samples are taken and the analysis is corrected, if necessary. Argon bubbling during the whole duration of the treatment and the use of basic slag results in a good desulphurisation action and an

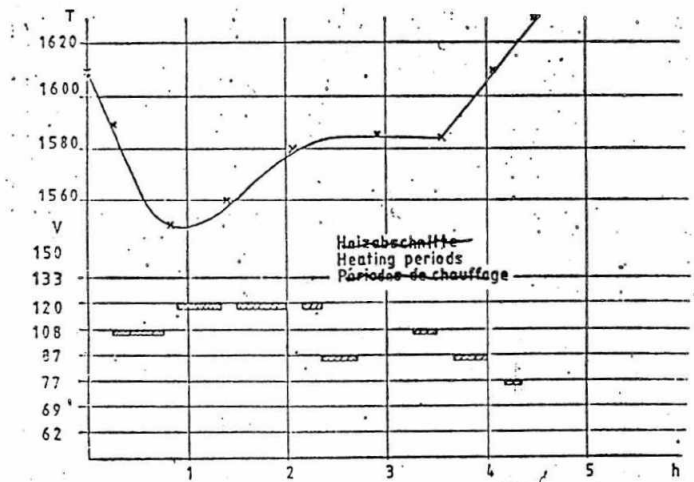


Fig. 8: Typical temperatures during a holding treatment.

improvement of the degree of cleanliness.

Fig. 9 shows the operation sequence of heats to be degassed.

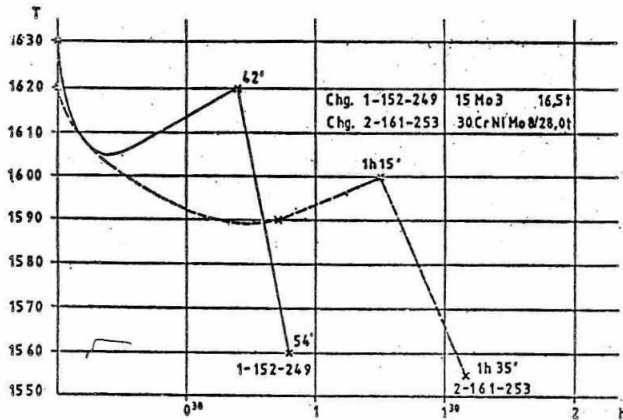


Fig. 9: Typical temperatures during a degassing treatment.

After sampling and the addition of lime, a heating period of approx. 1 hour follows until the desired temperature is attained. Corrections of analysis can be made by the addition of alloying agents through the vacuum hopper. With the operation, the required tapping temperatures remain in the normal range, and the refractory materials furnace and ladle are subject to normal wear.

After heating, degassing of low vacuum is effected resulting in an average temperature loss of 40°C . This can be compensated by a pre-heating period prior to low vacuum treatment, resulting in the accurate achievement of final temperature.

The actual degassing time per tonne of steel treated is 30 sec. However, at least 10 minutes are required if calculated from a vacuum starting at 4 Torr with final values of approx. 0.5 Torr.

After degassing, the steel is cast.

OPERATIONAL RESULTS

Two series, each comprising 125 holding trials and 125 degassing trials were tested and analysed. Some of the results are given below:

1. Holding trials

The average steel quantity held in the ladle was 23.6 tonnes.

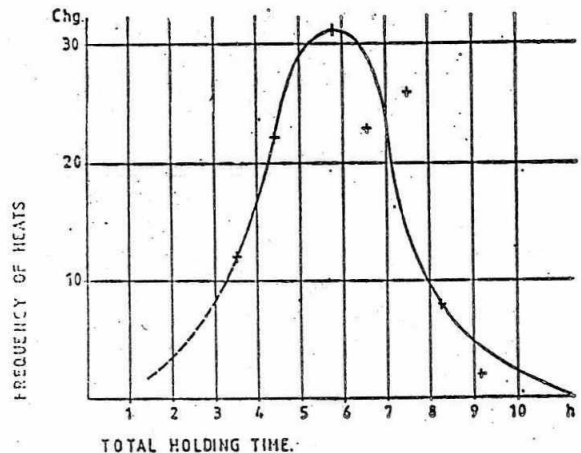


Fig. 10: Frequency distribution of the holding time.

The next heats (43.7 tonnes average weight) which were combined with the steel held in the ladle, were completed after an average period of 5 h 58 min. Fig. 10 shows the frequency distribution of the holding times.

Electrical power consumption for the holding operation was found to be 197 kWh/t for an average holding time of 5 h 38 min.

The average water consumption was $7.1 \text{ m}^3/\text{t}$, including water to produce the heating vacuum.

It turned out that heating operation is most favourable at 300 Torr, i.e. a calm electric arc is assured with a resulting good utilization of the ladle wall life.

2. Degassing trials

Fully killed, alloyed and high-alloyed steels were mainly degassed.

The quantities of steel degassed ranged from 10-34 tonnes, 21.1 tonnes being the average weight.

The average total treatment period was 1 hr 18 min. of which approx. 16 minutes were used for degassing.

Power consumption for the degassed heats was 81 kWh/t on the average.

Water consumption was approx. 1.5m³/t.

Average steam requirement for degassing was found to be 20 kg/t at 14 bar pressure.

3. Refractory life of ladles.

During the above-mentioned trials, the average durability of the refractory lining of the ladles was as follows:

Bottom:	20 heats
Walls:	23 heats
Slag area:	12 heats

It should be noted that the average treatment time in the ladle was 2 h 45 minutes. (Holding trials and degassing trials).

There is an upward trend in respect to refractory life. This is due to the ratio of holding trials with longer holding times of the steel in the ladle and degassing trials with relatively short treatment periods.

Refractory life increases considerably if mainly degassing trials are effected.

The above-mentioned values are based on the first 250 evaluated heats. Upto data, 2100 heats were treated and the above results were further improved. It will be thus possible to actually double the average refractory life time of the bottom and wall sections. However, this does exclude the slag line refractories.

4. Economic efficiency

An improvement of efficiency could be determined, based on the following aspects:

- Ingots upto a weight of 90 t are produced in 2 furnaces having a capacity of 34 t and 18 t only. A third furnace and thus a too high capacity per month could be saved.
- A reduction of tap interval times and thus reduction of furnace operation costs can be achieved if parts of furnace operation (refining and desulphurisation) are done in the VAD unit. This would result in a time saving of

one hour of furnace time by tapping with black slag.

- The higher ladle costs will be compensated by the resulting saving in furnace refractory materials.
- The output of alloying elements was increased. Furthermore, the increased possibility to meet target analytical specifications with higher accuracy resulted in lower target values, e.g. at a specified analysis range of 0.70 - 0.80% Cr, a value of 0.72% is aimed for.
- It was possible to extend the production programme, since large ingots can now also be produced in high-chromium qualities. This was not possible with the open-hearth furnace.
- Although more sophisticated qualities than before were produced in the VAD plant, the rejection rate did not increase.

5. Quality improvements.

Quality improvements have a direct influence on economy, e.g. by rejections, additional surface treatments etc.

The following operational procedures, allowing an improvement in quality, became possible by the use of the VAD plant:

- Accurate adjustment of the specified analysis: During the treatment period, samples are taken and the analysis can be corrected accordingly.
- VAD heating allows a very precise adjustment of the teeming temperature. A special advantage is that original temperatures can be increased.
- Lowering of teeming temperatures: Steel treated in a VAD plant can be teemed at a lower temperature than conventionally treated steel.

Due to the higher purity, lower viscosity of the molten steel, and the good homogeneity teeming temperatures can be approx. 20°C lower. This results in an improved surface quality.

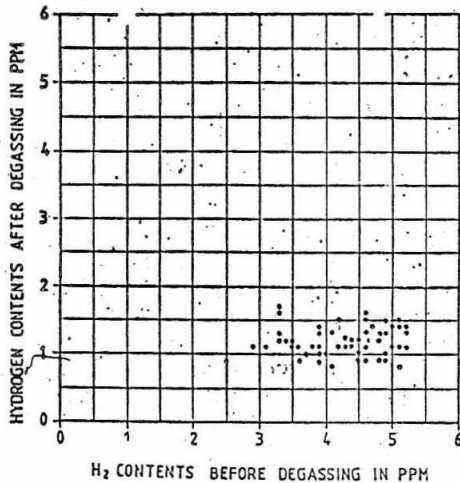


Fig. 11: Hydrogen relation before and after degassing.

- d) **Removal of hydrogen:** The hydrogen content of 4.2 (± 0.8) ppm before treatment could be reduced to an average value of 1.2 ppm in the ladle, and to 1.3 ppm in the ingot after degassing. Fig. 11 shows initial and final values.

Fig. 12 shows the removal of hydrogen in relation to the vacuum treatment time.

- e) **Oxygen removal:** During tapping, the steel is deoxidized, and the resulting deoxidation products are removed by argon bubbling in a given time. This time dependence is shown in Fig. 13.

There is a significant difference between heats held at temperature only and those with subsequent degassing. Heats held at temperature show total oxygen contents from 30 to 50 ppm. Vacuum degassing allows a much quicker attainment of these values. This is due to the direct reduction of oxygen by means of the CO phase on the one hand and the increased stirring effect of argon bubbling under vacuum on the other hand. This results in a quicker separation of the oxide inclusions.

Fig. 14 shows the final values achieved in relation to the initial values.

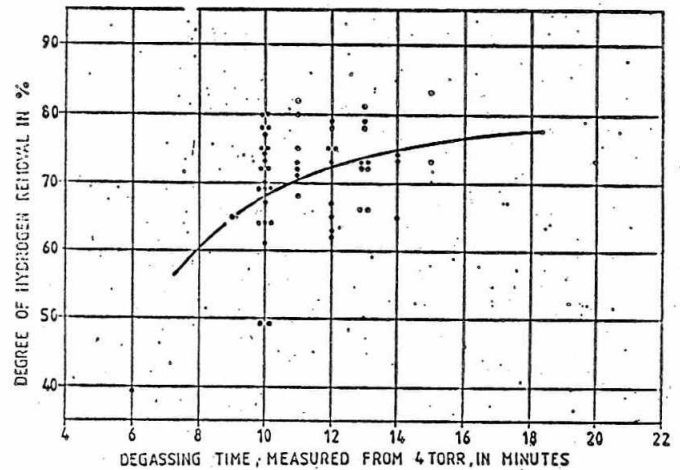


Fig. 12: Hydrogen removal as a function of degassing time.

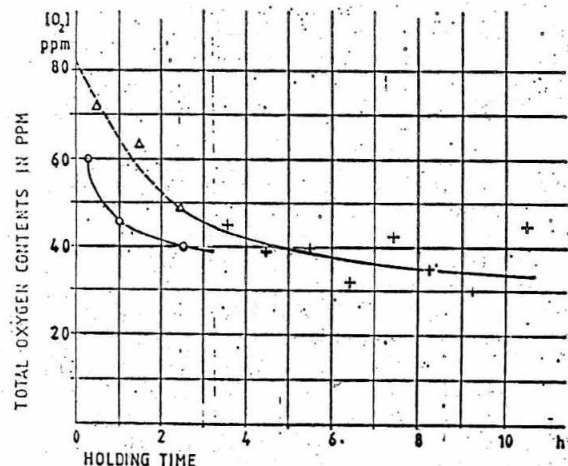


Fig. 13: Oxygen contents during holding treatments.

- f) **Reduction of sulphur:** In case of heats which were heated up and kept at temperature, sulphur is reduced to a large extent by means of a lime-alumina slag and the continuous, intensive argon bubbling during treatment. If necessary, slag composition is corrected in the course of the treatment. Fig. 15 shows the results. It can be seen that final values of lower than 0.001% S are possible.

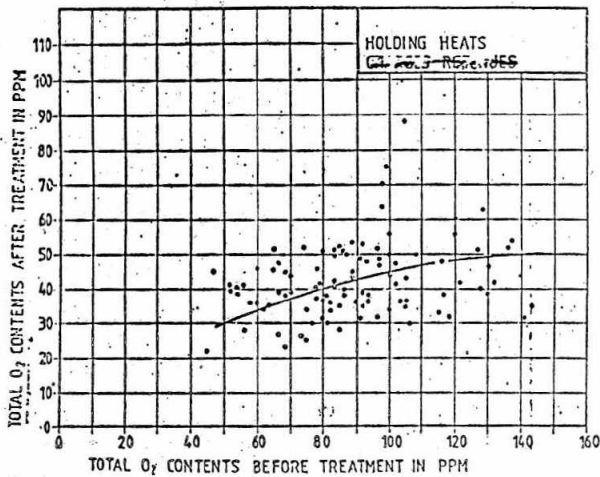


Fig. 14: Oxygen relation before and after treatment Et

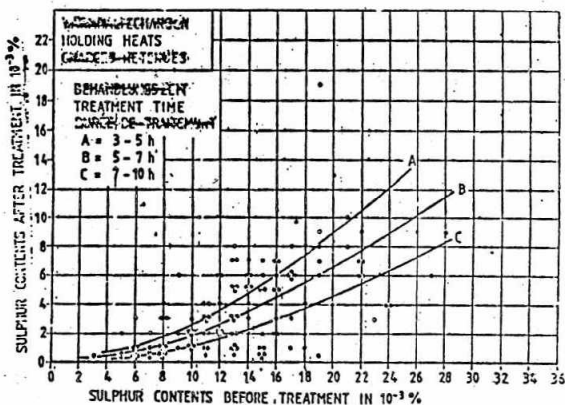


Fig. 15: Sulphur contents before and after treatment.

An average as-tapped value of 0.014% S results in an average final value of 0.004% S. Fig. 15 also shows the influence of treatment time on desulphurisation. As can be expected with the above desulphurisation practice, there is a good proportion between desulphurisation and time.

With respect to degassed heats, no special desulphurisation is carried out because of the different standards regarding product specification, nevertheless, an average degree of

desulphurising of approx. 35% could be achieved.

Based on the favourable reduction of oxygen and sulphur as indicated above, the product quality is enhanced by the increase in steel cleanliness.

POSSIBILITIES FOR IMPROVEMENT OF PLANT

The foundry Gelsenkirchen do not fully utilize the possibilities of the plant due to the special operating situation. It can, however, be stated that the plant fully meets all the requirements which were originally envisaged.

By increasing the production output, the VAD plant could be fully adapted to the increased demands by initiating the following steps:

- Although the transformer rating is adequate for the task envisaged, modern plants have more than double a heating rate. A rating of 2.2 MVA is considered too low for the heat size treated according to latent opinion.
- The Gelsenkirchen-plant is equipped with a vacuum hopper only suitable for small quantities of additioning elements. Modern plants are often equipped with fully automatic alloying systems, including, bunker installation etc., enabling the input of larger volumes and/or complicated additions.
- If graphite electrodes have burnt down too far, they have to be replaced from underneath. This is done between two treatments - after sufficient cooling of the vessel cover. This rather long production stoppage could be avoided by means of suitable constructional solutions.

CONCLUSIONS

For reasons of economy and environment, the foundry Gelsenkirchen of the Thyssen Giesserei AG have demolished their open-hearth furnace and replaced it by a VAD plant of the FINKL system. The production output of large items was not effected.

As a result of the decision to install a secondary steel treatment facility, the purchase of a new furnace was avoided. Environmental damage is ruled out by the use of the VAD plant.

The VAD plant made it possible to produce bigger castings with weights greater than the tap weights of the existing furnaces. The production of sophisticated qualities without special efforts was realized by maintaining and even lowering rejection rates.

The quality improvements are traceable to the remarkable reduction of hydrogen, oxygen and sulphur contents as well as the optimum adjustment of analysis and teeming temperature.

The second plant which is presented, shows a combination of the VAD and the VOD process realized in the Vereinigte Edelmetallwerke at Ternitz.

The VAD/VOD System

In the early seventies, VEW-Ternitz had to increase its production of stainless and heat resisting steel grades considerably owing to the expansion in the stainless steel pipe production. This, and continued rationalization measures taken in the processing shops, i.e. mills and forgings, resulting in performance increases, created a bottleneck situation in the supply of raw-steel for further processing. In order to overcome this, the capacity of the melting shop had to be increased from its annual production of about 85,000 tons to 110,000 tons, i.e. an approximate increase of 30 per cent. Since a further upgrading of the existing installations was impossible, a new investment had to be made.

The conventional method to eliminate this shortage would have been the installation of a 30 to 40 ton arc-furnace. Since the manufacturing program at VEW-Ternitz lies almost exclusively in high alloyed and high-quality steels we could not ignore recent developments and future oriented technologies in producing these steel-grades. 50% of the product range are stainless and heat resisting Cr- and CrNi- steels. A considerable amount is melted as Ti-stabilized and extra-

low-carbon steel, i.e. with carbon contents of under 0.03 per cent. A further 30 per cent are alloyed tool steels where, besides the ledeburitic Cr- steels, most of all the hot working steels dominate. Freedom from flakes, i.e. low hydrogen contents, are desirable in the processing. Low oxygen values for high cleanliness, low S values, and the highest obtainable homogeneity of the ingots, depending on the applicability (use) are required. The same requirements, with emphasis on uniform mechanical values in lengths and cross section, are for tempered steels, which make up about 8% of VEW's manufacturing program. The rest (12%) of raw steel productions are high-speed steels, which, because of their specific melting technology, found no consideration in the decision for a new investment.

For the normal manufacture of stainless and alloyed structural and tool steels we had a 50 t, a 20 t and a 15 ton furnace at our disposal. After investment considerations the 50 ton arc furnace should be used first and the 20 tons arc furnace second, as pre-melt units. After melting down and prereducing of SS or a dephosphorizing at structural and tool-steels, the additional metallurgical work should be performed in the newly-installed equipment.

This work division insured above all that the arc furnace be used predominantly for the steel melting process, for which it lends itself suitably, because it favourably utilizes the installed electrical equipment. The utilization of the transformed-rated output, with regards to the total melt time when melting high quality steels and meeting quality specifications, lies only at approximately 30-40%. A break-off of the arc furnace process as quickly as possible after finishing the melt-in period seems therefore correct. The selection of the units to be used after the arc furnace process to complete the metallurgical work, was influenced above all by the specific quality program, in which a melting program had to be set up that would consist of approximately 60-70% SS steels and 30-40% alloyed structural and tool steels.

The following 3 methods were considered for a closer selection:

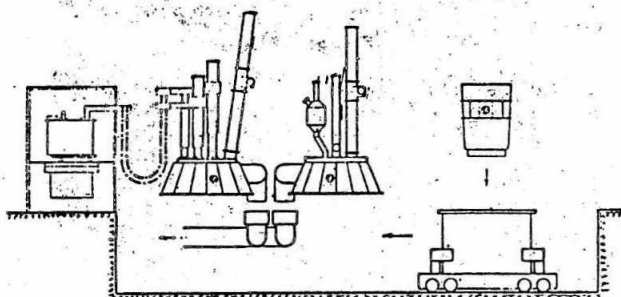


Fig. 16: Vacuum refining and heating system.

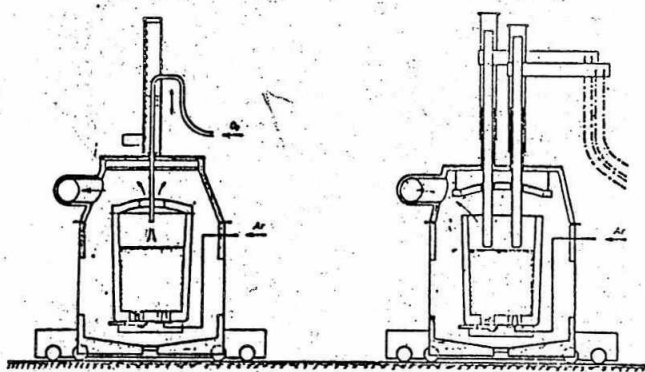


Fig. 17: Schematic representation of the VOD and VAD.

1. AOD-Process
2. ASEA-SKF Process
3. Combined VOD and VAD Process

After thorough study of the processes offered we decided on the Witten-Finkl-Mohr plant for refining and heating under vacuum, as we were of the opinion that this would be the proposition for the product range.

We need not deal with the theory of vacuum refining and vacuum heating here, as we may assume this to be generally known among experts, but shall go straight on to describe the plant itself.

Description and technical data of the system

Fig. 16 shows a schematic outline of the whole plant. It consists of two main parts, the vacuum refining unit for treating austenitic and ferritic grades and the vacuum heating unit for degassing and prolonged vacuum treatment with simultaneous arc heating of alloyed structural and tool steels.

A transfer car carries the vacuum vessel with the ladle containing the molten metal to the vacuum refining or heating unit, depending on the desired

treatment. In both units the vacuum chamber is closed with a hydraulically lowered cover. Exhausting tubes fitted in the side of the two covers are connected with the pump-system. Both covers are equipped with vacuum-alloying hoppers through which upto 500 kg, ferroalloys with maximum lump size of 50 mm can be charged during vacuum treatment.

Fig. 17. Through an opening in the cover of the refining unit the oxygen lance can be lowered. The cover of the heating system supports additionally the set-up of the 3 individually-controlled graphite electrodes.

The difficult problem of sealing the moving electrodes against the vacuum cover was solved in a most efficacious manner in cooperation between Standard-Messo and Schoeller-Bleckmann.

Fig. 18 shows the details of electrode control and sealing in the vacuum heating unit.

The three electrode sealing cylinders are mounted on a base plate which is again attached vacuum-tight on top of the container cover. These double-walled cylinders are anti-magnetic and water-cooled. The outside of the sealing cylinders is polished to provide for a smooth gliding surface for the outer cylinders which are tightly connected with the electrode collar. The sealing between the two cylinders is done with lip-seals.

Flexible joints in vacuum-tight bellows linking the sealing systems and the outer sealing cylinders compensate any distortion or tilted position of the cylinders. Therefore an unobjectionable gliding of the whole system can be obtained. A cover above the electrode collar provides for vacuum tightness of the whole system. The movable sealing cylinder is connected with the operating cylinder by a support arm.

Power supply from the transformer to the unit is led through water-cooled cables and a high-current tube to the electrode clamp. This high current tubular bus serves at the same time for cooling water supply to the electrode clamp. The high current supply runs vacuum-tight and isolated through the electrode collar. Moreover,

the total electrical set-up opposite the vacuum cover is isolated.

The regulation of the electrodes is provided hydraulically by means of a moving coil regulator. The contact of the electrodes to the electrode-clamps takes place with cup springs. The graphite electrodes are replaced from above with nipling like a normal arc-furnace. The electrode string has a length of approximately 7000 mm.

Moreover, we must mention that all live parts of the heating unit are equipped with an isolation monitoring system ensuring immediate power-shutoff if grounding should happen. This also prevents damage to the inner sealing cylinder in case of electrode-breaks.

Transformer capacity is 9600 kVa, the power factor is between 0.83 and 0.86 depending on secondary voltage. On the secondary voltage side, 22 variable voltage steps in the range from 84 to 270 V can be switched under load. In order to ensure an optimum ratio of voltage to current in operation the plant is equipped with an "Optimelt System".

Electrode diameter is 305 mm, pitch line diameter is 800 mm.

The electrical equipment of the vacuum heating system was chosen in such a way as to reach a heat-up speed in a 50-ton melt of at least 30°C/min.

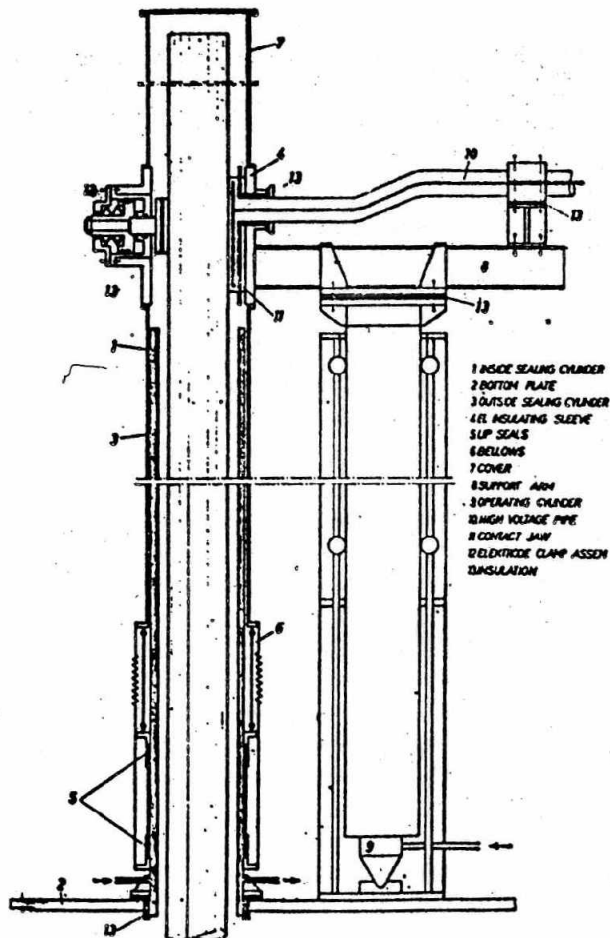


Fig. 18: Electrode control and sealing in the vacuum heating system

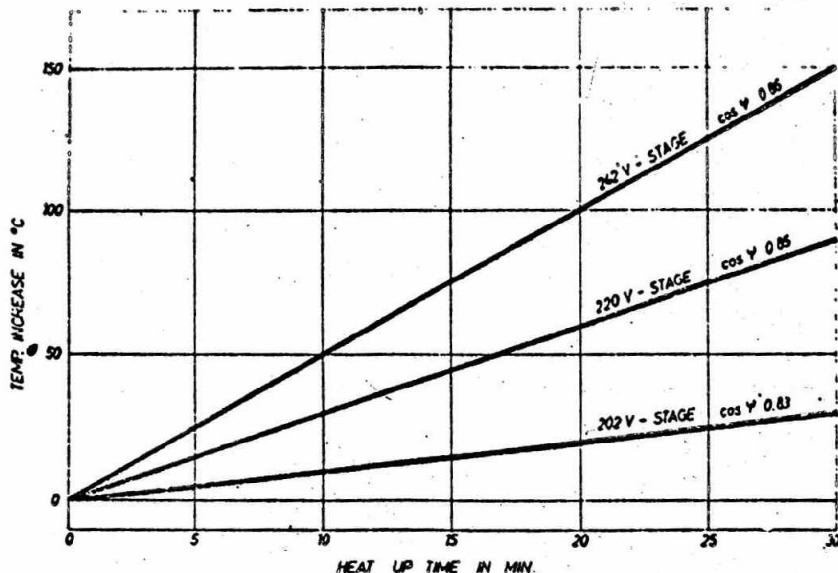


Fig. 19: Heatup speed of a 50 ton melt with various voltage steps.

At the same time it was stipulated that there must not be any pick-up of carbon that can be determined analytically. The actual attainable maximum temperature increase when in operation lies, as can be seen in Fig.19 at $5^{\circ}\text{C}/\text{min}$. This heat-up speed is reached with a voltage step of 242 V, which is equivalent to a real or active power of approximately 8 MW.

In spite of the high power consumption and the small distance of the graphite electrodes from the ladle wall of 450 mm, there is, even at long heating times, no visible wear of the ladle lining in the area of the 3 electrodes. The elimination of formation of the much-feared "hot spots" is attributed to the fact the arc with vacuum heating is essentially softer and shorter than it is when heating under normal atmospheric pressure. Argon purging also effects favourable the life of the ladle, because the inert gas keeps the bath moving and, therefore, the reflection effect of a calm bath surface is not occurring. The fast bath agitation prevents, moreover, overheating in the upper area of the melt, and with that an increased wear in the slag zone is substantially avoided.

The specific power consumption which is required to heat up a 50-ton melt by 50°C lies at approximately 35 kWh/ton. To avoid a carbon pickup and also to gain a maximum temperature increase of $5^{\circ}\text{C}/\text{min}$, the correct regulation of purging gas amount and the optimum arrangement of the purging system at the ladle bottom are of determining significance. The argon purging is before the heat-up period optically adjusted; the purging gas amount is 20-25 Nl/min. The argon purging plug is located approximately 400 mm from the ladle center.

This arrangement of the purging system produces, in connection with the above-mentioned argon amount, an optimum agitation in the melt for our ladle dimensions. See Fig.20.

If the gas purge in the ladle is too low, there will be overheating in the upper area of the melt, which will cause more ladle wear in the slag zone. Besides, the heat-up speed is lowered to under $3^{\circ}\text{C}/\text{min}$. A too strong bath roll leads to erosion in the area of the purging plug in the ladle and also leads to an incontrollable

carbon pickup of the melt from the graphite electrodes.

The ladle life with a thickness of wear lining of 150 mm lies at approximately 40-45 melts when using chrome-magnesite refractory. Approximately after 18-20 melts, the slag zone and the sitting brick are renewed. This ladle life is reached when heating an average time of approximately 30 min/melt.

The vacuum heating is performed at approximately 180 Torr. If the pressure drops below 150 Torr at the high voltage steps (starting approximately 220 V), there can occur luminous current discharges in which the isolation control, in order to avoid great damage, shuts off the system automatically. In order to avoid such interruption of operation, the vacuum is adjusted by air nozzles to a pressure of 150-180 Torr during the heating period, depending on the voltage degree being used.

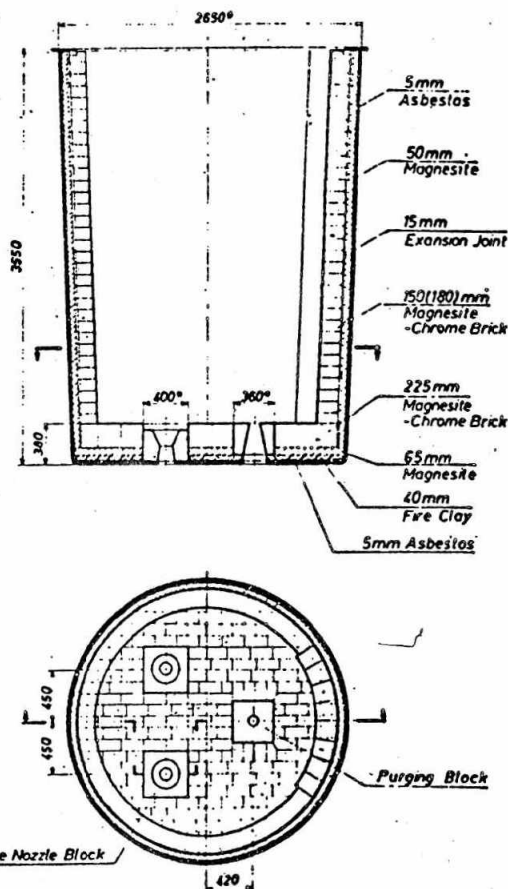


Fig.20: Lining of the 50 ton vacuum ladle.

Refining austenitic and ferritic steels under vacuum

Since the vacuum refining and heating plant came into operation in August 1972, the 50 ton electric arc furnace mainly serves as a melt-down and preliminary refining unit. When a charge is melted in the electric arc furnace and then refined under vacuum, the Cr and Ni content of the heat after melting down will already approach the analysis of the final product. We at SBS use a charge consisting of about 30% mill scrap, charge FeCr-grades and a variety of Ni-bearing compounds. Owing to the use of the cheaper charge FeCr and of FeNi grades with higher C contents, the C content in the charge after melting down is about 2-2.5%. The preliminary refining process reduces this C-content to approximately 0.5%, the level required for vacuum refining. There are no significant Cr-losses with this C-content; so no costly slag reduction is required. After the addition of a cooling material and slag-off, it may be necessary to make some alloy additions in order to achieve the required chemical composition. Then the heat which has a temperature of about 1620 to 1630°C is tapped into the vacuum ladle which has been pre-heated to over 1000°C. The Si content at this stage is 0.20 to 0.25%.

After the ladle has been transferred to the vacuum tank, the argon supply is connected and the argon purging is adjusted optically, 20 to 25 Nm³/minute are needed for the whole refining process. After the refining cover is placed on the ladle, the tank is moved under the vacuum cover. At a pressure of 15 to 20 Torr the oxygen lance is lowered to the required distance from the bath surface, then the oxygen supply is opened. O₂-pressure is 10 atg, O₂-volume is varied between 500 and 1200 Nm³/hr depending on the initial C and Si contents and the final C content of the heat. C reduction during the refining process can be closely watched by means of pressure gauges and instruments recording waste gas volume and waste-gas temperature and waste-gas analysis. Ample operating experience and correct interpretation of the values recorded will permit stopping the process at any C-content desired. Even final C contents of less than 0.01% do not present any great difficulties provided the plant is operated correctly. After closing O₂-supply the refining

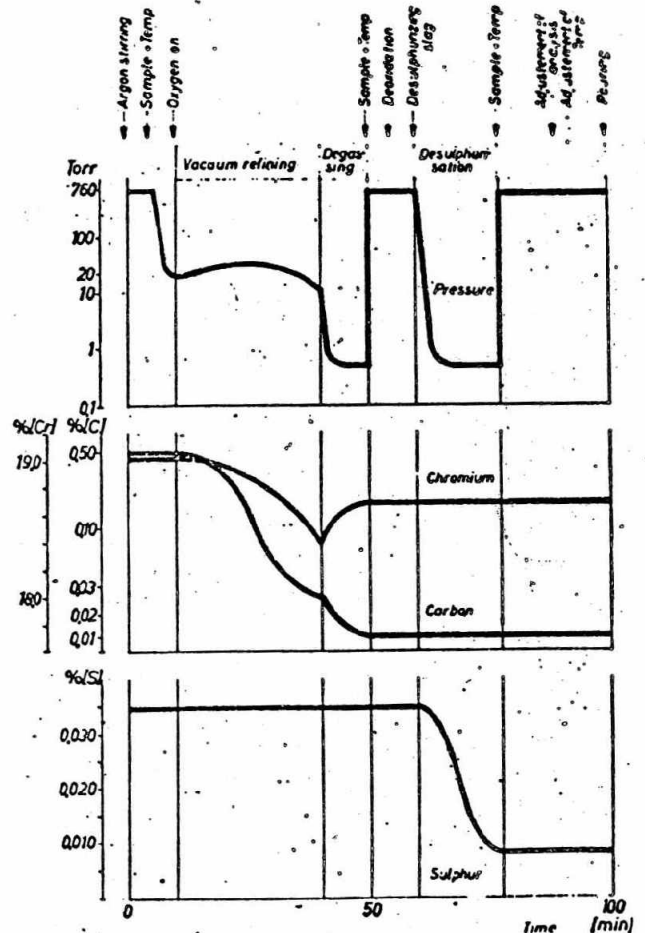


Fig. 21: Flow of process in the VOD

process is followed by another refining treatment at 0.8 Torr, lasting about 10 to 20 minutes and reducing the O₂ content of the heat through the reaction between C and O. This further decreases the C content by about 0.015% corresponding to a removal of about 250 ppm of O₂. Fig. 21 shows a schematic flow of the refining process.

Bath temperature after refining is 1680 to 1700°C and must be lowered to the level required for pouring. For this purpose, the vacuum is broken, the cover removed and a precalculated quantity of cooling material added. Following a preliminary deoxidation with Al and FeSi, a desulphurizing slag in the amount of 2 to 3% of the heat weight, depending on the final S content specified, is charged at the same time. In order to make it dissolve faster and to enlarge the surface of the bath-slag reaction thereby heightening desulphurizing

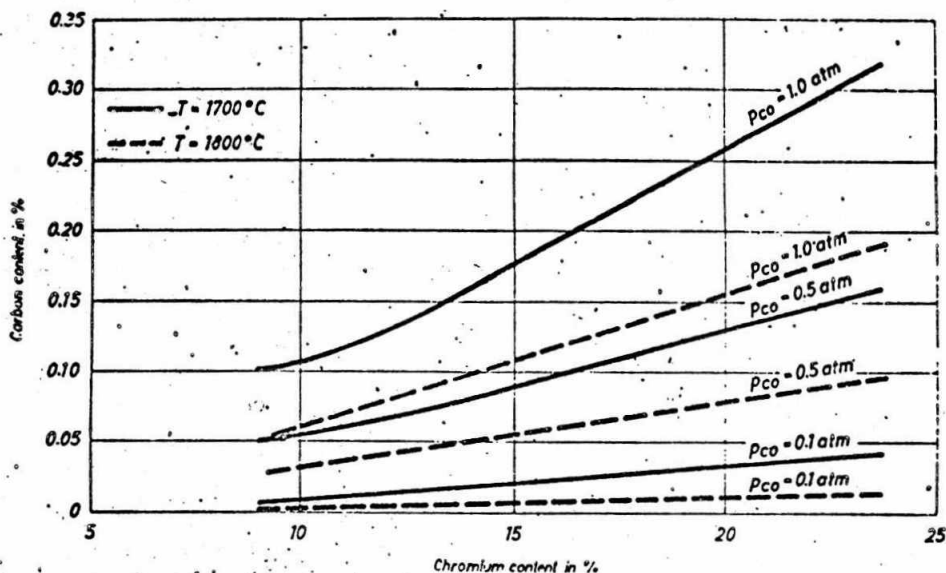


Fig. 22: Dependence of Cr-C-equilibrium in relation to carbon monoxide pressure at 1700°C and 1800°C.

efficiency, the argon volume during this period is increased to about 50 to 80 Nl/minute. This treatment is done at a pressure of about 0.5 Torr and lasts 15 to 30 minutes, depending on the final S content specified. Desulphurizing efficiency achieved in austenitic and ferritic grades is from 70 to 80% which means that final S contents below 0.008% can be guaranteed.

When elements having a high affinity for O₂, such as FeTi, Al, etc., must be added, this is done through the vacuum lock 5 minutes before the end of the desulphurizing period. Later on, it will rarely be necessary to make any major adjustments of the chemical composition, because the individual alloying elements have relatively low melting losses in the vacuum refining process - losses, which moreover, are well known due to long operational experience so that the desired final composition can be adjusted already before tapping from the electric arc furnace.

With a total Al content of 0.03% in the finished steel, O₂ contents in CrNi and Cr steels are about 20-30 ppm. By special deoxidation procedures and prolonged vacuum treatment, levels as low as 10-20 ppm may be obtained. A very important fact to note is, that concentration of deoxidation products in a vacuum refined steel is much lower than in conventionally melted

steels. Also, more favourable inclusion shape and distribution could be achieved.

Cr-recovery in the vacuum refining process

When decarburizing a bath with a high Cr content in the electric arc furnace, the ratio of Cr in the slag to that in the bath will be relatively high, depending on the final C content desired, on the Cr content and on the bath temperature. Even if large amounts of reducing agents are added in the conventional electric arc furnace melting of steels with a final C content of 0.05% and lower, Cr recovery will be about 90-95%. It will, however, always depend on the final C content desired. The metallurgical conditions in the vacuum refining process permit a Cr-recovery of as much as 98% without any slag reduction. This is achieved independent of the final C content of the heat. Fig. 22 compares Cr recovery in the electric arc furnace and in the vacuum refining unit as a function of the Cr content prior to refining and of C-content afterwards. This clearly illustrates the economics of the vacuum refining process.

Production of alloyed structural and tool steels in the vacuum heating unit

The use of the vacuum system in conjunction with the 50-ton arc furnace should accomplish a production increase of the melt units as well as improve the quality of the product. In order

to shorten the duration of the heat, the dephosphorization is largely shifted to the melt-in period in the arc furnace. Deoxidation, desulphurization and alloying are performed in the vacuum heating system.

Before charging the second bucket, an application of 2000 kg burnt lime and 2000 kg ore is made with a chute. Shortly before finishing the melt-in period, oxygen blowing is performed; a sample is taken and immediately after this is the slag-off. In about 90% of the cases, phosphorus at this test is already under 0.020%, so a further dephosphorization is not necessary.

With higher Cr-alloyed melts, the C content is blown down to such a point that the Cr analysis can be adjusted with high carbon FeCr. After a coarse adjustment of the analysis, with the exception of the high O_2 affinity elements, for instance, V, Al and Ti, the melt is then teemed slagfree at a temperature of approximately 1650°C into the at least 100°C pre-heated vacuum ladle.

After placing the ladle in the vacuum vessel, the argon purging is started and the temperature taken.

Figure 23 shows the schematic flow of the standard process for alloy and tool steels in the vacuum heating system.

At the beginning of the process which lasts according to the measured temperature about 15-20 minutes, the O_2 content of the melt is largely lowered by the CO reaction at a pressure of under 1 Torr, and a first reduction of H_2 content performed. This treatment of a non-Si-killed melt in the deep vacuum requires a higher free-board on the treatment vessel because of the violent boiling reaction.

Loss of temperature during this time is on the average $4^{\circ}\text{C}/\text{min}$ so after finishing the first step of the vacuum, the bath temperature is about 1550°C .

After taking a sample and measuring the temperature, the pressure is raised to about 180 Torr and the melt heated up at about $5^{\circ}\text{C}/\text{min}$ to $70-100^{\circ}\text{C}$ above the required pouring temperature for that particular product. Five minutes before finishing the heat-up

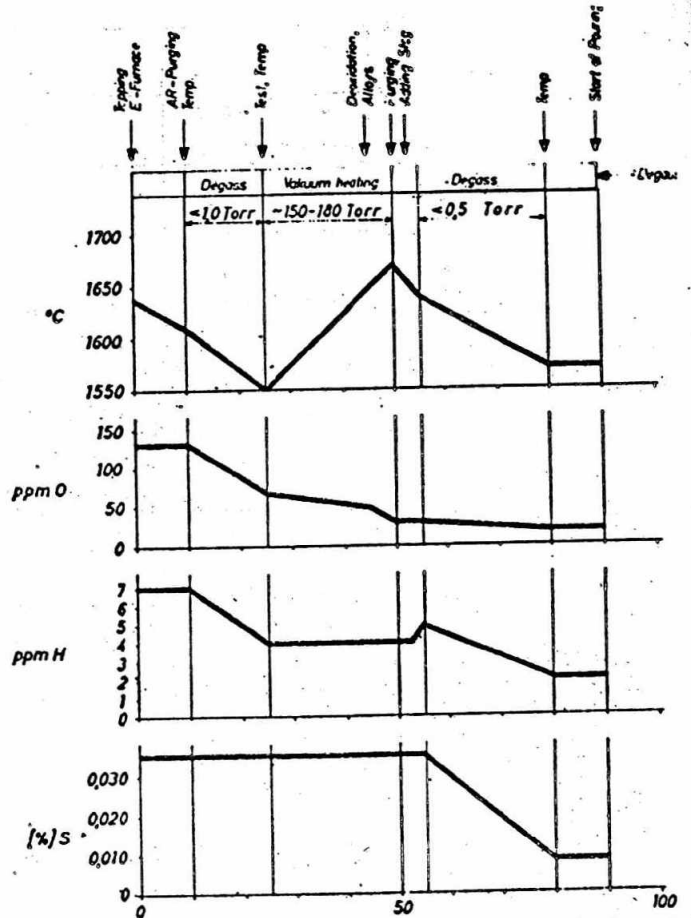


Fig. 23: Scheme of a standard melting process.

process, the deoxidation of the melt and the addition of alloys is made with the vacuum charge valve.

After a short interruption of the vacuum process for the addition of the desulphurization slag which is made from burnt, fine-grained lime and flux material weighing 1.5-2.0% of the melt weight, degassing and, at the same time, desulphurization of the melt takes place.

In this part of the process, the melt is exposed for at least 15 minutes to a vacuum of under 0.5 Torr, so that H_2 values of approximately 2 ppm, determined with the absorption method, are reached. To enlarge the reaction surface between the bath and desulphurization slag, and to increase the agitation in the ladle, the argon purging is intensified. The desulphurization is between 70-80%. The nearly stationary thermal

condition in the ladle after the vacuum heating period causes only temperature losses of approximately 3°C each minute of treatment. After reaching the required pouring temperature, the system is pressurized to atmospheric pressure with air, the melt is covered with insulating material and poured.

For extreme high quality demands, the aforementioned standard process can be changed depending on the metallurgical optimum points of view. For instance, to reach an especially good oxide cleanliness degree, a long-time vacuum treatment can be added to the standard process in the heating period. This long-time vacuum treatment, which is performed at approximately 150 Torr and with a voltage of 202 V, lasts 20-30 minutes. Because of the high temperature present in the area of the 3 arcs, there is, with the relatively good vacuum, a reduction of the deoxidation products by which the cleanliness is further improved. With this special process, O₂ values of 10-15 ppm and sulphur values of under 0.005% are reached. H₂ values of under 1.5 ppm are possible if the degassing process is done without desulphurization slag. If a desulphurization is absolutely necessary, it is a must to slag-off before the final vacuum treatment.

It is also worthwhile to mention, that addition of the total alloy requirements upto 8% of the melt weight can be performed in the heating system. In this case, the melt, depending upon the amount of alloys to be added, is several times heated to approximately 60°C above the pouring temperature and alloyed.

As already mentioned in the beginning, the Finkl-Mohr system was thought of to be used first of all in the production of alloy and tool steels. In the run of business, we found further possible uses for the vacuum heating system, of which we would like to mention the most important.

The production of austenitic, N₂ containing qualities with over 0.30% N₂ is hardly possible with the normal vacuum refining process, because the heat content of the melt after the O₂ refining is not enough to dissolve the required amounts of N₂-FeCr. The vacuum heating system makes it possible for us, after performing the

vacuum refining and the desulphurization, to heat the melt to the required temperature and put into it these amounts of N₂-FeCr. With the help of the heating system, it is possible today to produce qualities of upto 0.50% N₂ without difficulty in the vacuum refining process. After addition of N₂-FeCr for these qualities, we use for purging, in order to avoid N₂ losses, a technical clean N₂ instead of argon. We also have the possibility for treatment of 20 t and 16 t-heats in the order of the heating unit, because we can equalize the higher temperature losses occurring during the treatment of smaller heats.

The use of the vacuum system in conjunction with our 50 ton arc furnace, brought us, as we already mentioned, an approximately 50% higher capacity of the melting units for the manufacture of alloy and tool steels. Aside from the economical advantage, the vacuum heating process remarkably improved the quality in comparison to steels produced by conventional methods.

With an Al-content of 0.02%, the O₂ contents of 20-25 ppm in melts produced with standard vacuum heating process, can be reduced to 10-15 ppm in melts which have a long-time vacuum treatment. Argon purging in a vacuum warrants a very intimate mixing of the desulphurization slag with the steel bath, resulting in desulphurization of 70-80% and final S-contents of under 0.008%, without difficulty. The fact that these high desulphurization degrees are reached with comparatively small amounts of slags, leads us back to this; that in the deep vacuum, beginning at a certain S concentration in the slag, the desulphurization runs over partly into the gas phase.

The H₂ values of the standard process degassed melts lie at 90% at 3 ppm.

With the described special process, these values can be lowered even further.

Since the treatment vessel also serves as pouring ladle, in which an approximate stationary thermal condition exists before the pouring temperature can be kept at the lower limit.

In summary, we can say after 7 years operation time of this modified Vacuum Heating System, it has fulfilled

all requirements relative to quality, technique and economy for the manufacture of high value alloy and tool steels. Together with the Vacuum

Refining System, this is a unit which allows us to vacuum treat practically all qualities of steel which are on our pouring program.