

The Use of the Vanyukov Process for Processing Nickel Containing Charge

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ABSTRACT

The Vanyukov Process is a high-intensity smelting system that has been proven over the last 20 years for various metallurgical operations including the smelting of copper, nickel, copper-zinc, antimony concentrates, municipal waste treatment and pig-iron production. Extensive pilot plant tests on copper and copper-nickel concentrates have provided information for the design of the commercial furnaces. The thermodynamic analysis, design idea and the data obtained from commercial furnaces have shown that Vanyukov Process would be the best choice to smelt copper-nickel and nickel sulphide concentrates as well as oxide nickel ores.

VANYUKOV PROCESS CONCEPT

A schematic longitudinal isometric cross-section of the Vanyukov Furnace is shown in Figure 1. Detailed longitudinal cross-sections are shown in Figures 2 and 3.

The principle of the Vanyukov Furnace is as follows. The process employs a rectangular or circular stationary furnace. Wet feed is dropped into the intensive intermixing melt through roof ports. Feed of the Vanyukov furnace can include fine sulphide concentrate or lump ore, solid or liquid reverts, flux and lump coal. Oxygen-enriched air is injected into the slag layer through side tuyeres at approximately 0.5 m below the surface of the bath. Blowing provides intensive for intermixing of the melt, for oxidation of sulphides with the sulphur removal from melt to gas, and for fuel combustion if needed. Intensive intermixing of the melt provides for a rapid and uniform distribution of the charge particles in the melt volume, resulting in a high rate of chemical reaction.

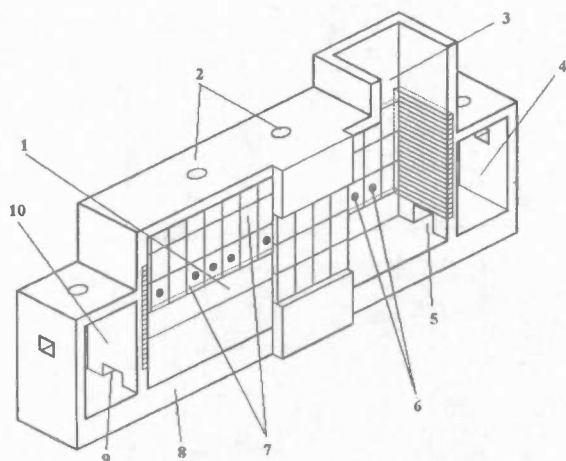


FIG 1 - Vanyukov Furnace outline: 1 - smelting zone, 2 - roof port, 3 - off-gas system, 4 - slag chamber, 5 - slag channel, 6 - tuyeres, 7 - water jackets, 8 - refractories, 9 - matte channel, 10 - matte chamber.

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Matte-slag emulsion

The melt in the upper part of the furnace represents a so-called slag-matte emulsion that contains by volume from 90 to 95 per cent of slag and ten to five per cent of sulphides or metal droplets. In the forceful intermixing conditions the droplets of metal or metal sulphide are coalesced and produce droplets with a stable size of 0.5 to 5 mm, with the size being dependent on the smelting parameters. The slag-matte emulsion separates into slag and matte in the lower part of the smelting zone, below the tuyere level, which is a region of low turbulence. The flow of slag is through the slag channel to the slag chamber and matte flow is through the matte channel to the matte chamber. The slag and matte chambers have syphons so that matte and slag are continuously evacuated from the furnace.

Jackets

The Vanyukov furnace provides for the containment of highly agitated and aggressive bath conditions. It is well-known that metallurgical slags are aggressive towards refractory containment, because of the solubility of unsaturated oxides in the slag. The problem is solved in the Vanyukov process through the use water or steam-cooled jackets for containment of the slag. The molten slag from the process freezes onto the wall and forms a protective layer from the melt being processed such that the slag itself forms the containment crucible. The side walls in direct contact with the intensively agitated upper region of the bath thus are constructed of water or steam-cooled jackets.

Siphons

Another feature of the Vanyukov furnace design is the use of siphons for the continuous discharge of melt from the furnace. These siphons are arranged to give counter-current flow of the matte and slag phases. The use of siphons allows for the continuous discharge of both melts from the furnace. The design is based on the laws of hydrostatics. The melt level in the furnace is dependent on the height of slag and matte skim levels in the siphons. Therefore, in the case of a variety of feed rates or a variety of matte and slag flows, the melt level in the furnace remains essentially constant.

Tuyeres

Tuyeres with the blowing pressure of about 0.1 mPa are located in the lower section of the water-cooled side walls, approximately 0.5 m below bath surface. The tuyere design in the Vanyukov furnace is similar to that of a conventional Peirce-Smith converter. The differences relate to the use of tuyere lances that provide natural gas to the process and allow access for tuyere scopes and cleaning and stopping rods. Another feature of the Vanyukov furnace is the use of water cooling on the tuyeres, which results in extended tuyere campaigns.

The level of the tuyeres divides the furnace into two layers. In the top layer, above the tuyeres, intensive mixing in the melt occurs and this region of the bath can be considered to be an ideally mixed emulsion of matte and slag. This flow regime accelerates heat and mass transfer processes. In the bottom layer, below the tuyeres, the bath is relatively quiescent and conditions for the rapid settling of large matte droplets are established.

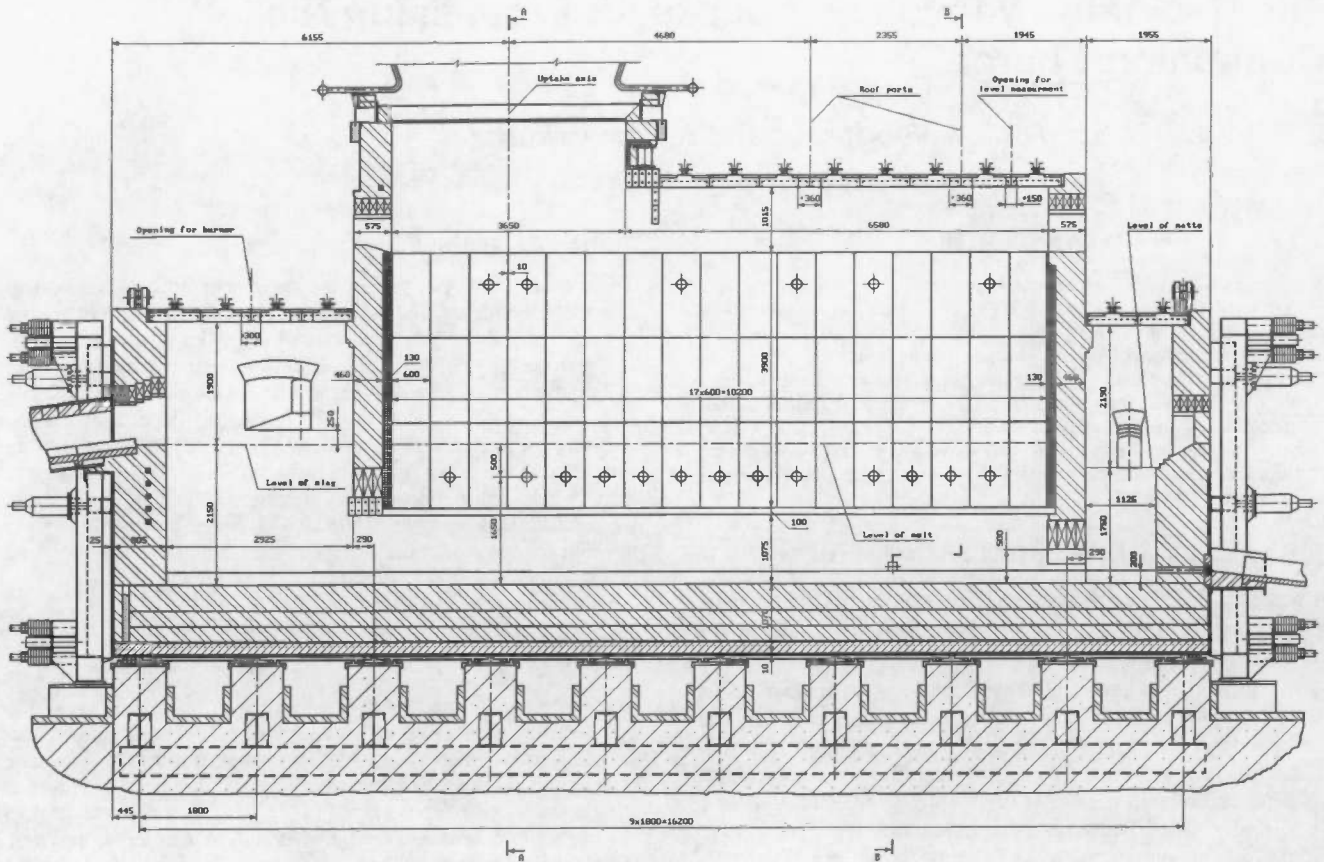


FIG 2 - Vanyukov furnace outline.

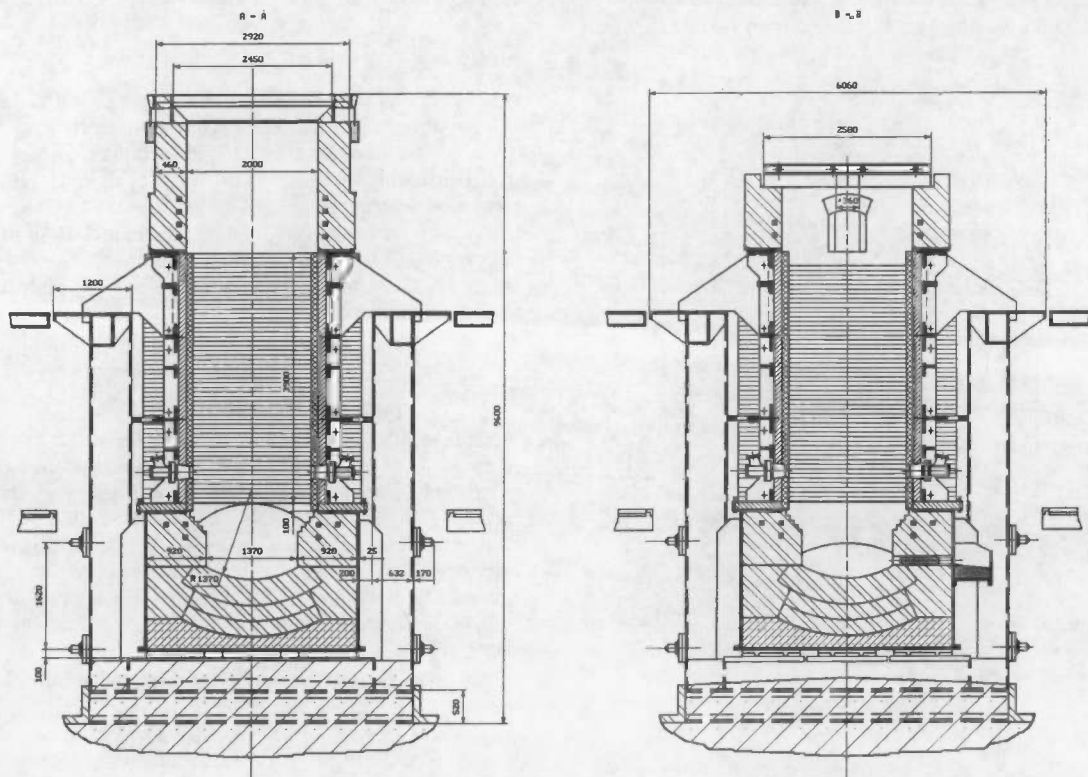


FIG 3 - Vanyukov furnace outline.

Furnace shaft

The typical horizontal cross-sectional width at the tuyere level is 1.5 to 2.5 m, the height of the furnace can be varied from 5.5 to 6.5 m and the length can be varied from 3 m to 20 m. The hearth is constructed from four to five courses of chrome-magnesia refractory bricks as in ordinary blast furnace and reverberatory furnaces. The cooling elements are installed in the upper part of the bricks which may be in a contact with the slag.

The furnace walls are water or steam-cooled copper jackets or caissons of various designs. The side wall cooling elements are constructed by stacking square sectioned copper pipes, (about 65 mm square) which are cooled with water or other liquid. The three courses of cooled wall jackets are constructed of copper plate with the section dimensions of 1.2 x 0.6 m and width from 0.07 to 0.1 m. These cooling jackets have inside channels with circulating cooling liquid. The objective of the cooling jacket is to prevent the destruction of the walls by intensive intermixing slag.

In the upper and lower layers of the cooled jackets there are several tuyeres for blowing. Tuyere design is usually similar to the standard tuyere in the traditional Peirce-Smith converter, although gaseous and liquid fuel can be also put into the furnace through the tuyere. The copper-cooled nozzle provides for the build-up of frozen slag within the tuyere which prevents slag flow into the tuyere if a blowing stoppage is necessary.

The upper part of the walls is constructed of refractory bricks. The furnace roof can be constructed by bricks or water-cooled jackets. The furnace has a bricked or water-jacketed gas uptake, an off-gas cooling system and a port for the introduction of the starting melt. The draft in the furnace is established in the range from 30 to 80 Pa, so feed can be dropped into the furnace directly from the feed belt without an air-sealed device. The starting melt is poured into a spoon and flows down a launder that protrudes through the port into the furnace.

Channels

Slag and matte (metal) are continuously discharged through siphons that are heated using a burner. Siphons are constructed of refractory bricks similar to the furnace hearth and cooling elements are installed in the slag siphon baffle.

The matte channel is 0.5 m in height and is permanently filled by molten matte. The slag channel is 1 to 1.3 m in height and it is permanently filled by molten slag in the upper part. The required levels of the matte and slag in the furnace are set by the heights of the discharge openings in the siphons. The locations of the openings can be controlled and the levels can be changed.

Chemical transformations

High temperature processes involving gases or intensively intermixed melts with low viscosity are characterised by fast kinetics. Such processes operate close to equilibrium and thus phase diagrams or equilibrium models provide important predictions of the final practical result or permit a diagnosis of process variations from equilibrium.

Therefore the development of new intensive processes should be accompanied by the creation of equilibria models of the processes. These models consist of sets of equations which can generate phase diagrams and predict the 'practical' dependence of various process parameters. The most useful and convenient method is to diagrammatically present calculated or experimentally established phase equilibria and thermodynamic properties as lines and fields with the coordinates of partial pressures of sulphur and oxygen.

THERMODYNAMIC ANALYSIS

The problem of the thermodynamic analysis in modern metallurgy has acquired great importance. This is the result of a change in scientific interest from the accumulation of data, to its direct application into metallurgical processes. Fundamental physical and chemical research into reaction mechanisms plays an important role in metallurgy but the application of the theory to complex metallurgical processes remains limited. In contrast, thermodynamic models allow the investigation of complex chemical reactions, and provide for the application of fundamental data to provide useful practical results.

Models

Several groups of scientists in various countries have conducted comprehensive investigations for the last two decades to execute mathematical modelling using computers. The most productive approach was offered by Kellogg (1987) for the pyrometallurgy of non-ferrous metals. Melts of non-ferrous metals, for example mattes, cannot be described as solutions with a single solvent. Copper smelting matte, for example, can contain from zero up to 100 per cent of copper sulphide. This circumstance has necessitated a search for such forms of thermodynamic models of melts, which comply with both limiting laws (Raoult and Henry) and which can be used for any melt composition. Moreover, models which fulfill the limiting laws enable the number of model species to be consistently increased or, on the contrary, enable multicomponent systems to be reduced to more simple forms. The base equation for the description of non-ideality was chosen to be the three suffix (sometimes four suffix) Margules model for which thermodynamic consistency is strictly proven.

However an analysis of the experimental dependencies of activities and activity coefficients on melt composition has shown that even the models of very high orders cannot adequately describe some experimental data, since the lines of activity dependence on composition are grouped so as to imply the existence of various stable associations within the solution. In order to describe such solutions by a uniform model, Professor Herbert Kellogg has advocated the use the associate solution model, investigated earlier by Prigogine (1990). The concept of this model, for example in application to an Me-X system, is that not only elements Me and X exist as species of the melt, but associate species such as MeX, Me₂X and so on also exist.

Computer package

Since the middle-1980s pyrometallurgical process evaluations with the use of the associated melt model were conducted within the Faculty of Heavy and Precious Metals (MS & AU) by pupils of Professor Andrew Vanyukov. A comprehensive package of computer programs was developed by these researchers. The package allows the user:

- To create an internally consistent base of thermodynamic data for substances used in metallurgy;
- To generalise the data on interaction parameters in metal, matte and slag melts with use of regular, sub-regular and associated melt models;
- To conduct parameter identification for various melt models with the use of experimental data about phase diagrams, vapour pressure, EMF measurements, heterogeneous areas, etc;
- To process data of industrial operations and semi-industrial experiments;
- To predict the behaviour of components in open and closed systems, as well as in industrial batch-processes, where the substances are instantly entered and removed from a reactor: Vanyukov process, flash smelting, Mitsubishi process, converting, fuming, etc;

- To build potential diagrams in systems with several phases of variable composition; and
- To generate emulators for staff training at industrial enterprises and for students at educational institutions.

Systems

The construction of thermodynamically consistent melt models based on all available information was the kernel of these activities. Associated solution models for the following systems were developed:

- Metal: Fe-Ni-Co;
- Oxide: CoO-SiO₂, Cu-O, Cu-O-SiO₂, Cu-Fe-O, Cu-Fe-O-SiO₂, FeO-Fe₂O₃-CoO, FeO-FeO_{1.5}-SiO₂-CoO, Cu-FeO-FeO_{1.5}-SiO₂, Zn-FeO-FeO_{1.5}-SiO₂;
- Sulphide: Fe-Co-S, Fe-Ni-Co-S, Cu-Fe-S, Cu-Fe-Ni-S;
- Oxysulphide: Fe-S-O;
- Carbon containing Fe-C, Fe-C-S.

Nickel containing charge

Now let us briefly consider the technique of model construction for the Ni-Fe-S-O-Si system and its use for the consideration of the Vanyukov process. The smelting of nickel raw material and the converting of nickel matte can be considered using a model of the Ni-Fe-S-O-SiO₂ system. Similar analysis for the smelting and converting of copper materials was carried out by Yazawa (Yazawa, 1974; Yazawa, 1979). The analysis allowed the determination of the optimum conditions for the processes.

The method used by A Yazawa for the copper system cannot be used easily for nickel for two reasons. Firstly, there is a wide field of the liquid matte in the Ni-Fe-S system with a high level of sulphur deficiency such that the nickel matte composition cannot be described by simple linear equations. Secondly, there are a comparatively small number of the experimental works available which provide data on the nickel system. Hence the thermodynamic model of the nickel system can be evaluated only using computer calculations.

Construction of potential diagrams

The diagrams were modelled using the thermodynamic approach with a free energy minimisation algorithm. Usually the search of the equilibrium composition at which the free energy of the system becomes minimal is carried out under the mass balance constraint. The situation is changed for the system where the partial pressures of oxygen and sulphur are established at every point. In this case the mass balances for oxygen and sulphur are not satisfied. Two constraints for oxygen and sulphur potentials should be used instead of two mass balance equations. The analysis of the well-known algorithm has shown that the direct replacement of the constraint types is not possible. Hence a transformation of the free energy function is needed.

The transformation of the standard free energy minimisation problem includes the following steps:

- two mass balance equations for oxygen and sulphur were excluded from the set of the constraints;
- the free energy for each compound was recalculated using another state of oxygen and sulphur. The state of oxygen and sulphur for each point of the diagram is gaseous state with the pressure identical to the diagram point.

This transformation of the free energy function allows the application of conventional computer procedures for the free energy minimisation.

The first step in thermodynamic modelling is the selection of the potential phases that can be formed in the system. Four melt phases and several invariant condensed phases were used as a possible phase combination. The review of literature has shown that four solutions at the temperature below 1850 K can be

formed in the system: liquid matte, liquid slag, solid alloy and oxysulphide. The last melt has been the subject of a number of investigations (Olshansky, 1951; Harvie, Greenberg and Weare, 1987). However the thermochemical data for oxysulphides are poor. The only data available are for the Ni-S-O system (Kellogg, 1987). This phase does not include iron and silica, so some care should be expressed regarding the field of the oxysulphide on the diagram.

The gas phase is taken to be ideal. The matte, slag, alloy and oxysulphide are described by an associated solution model using the 'three suffix' Margules equation. The invariant condensed phases taken into account here are: FeS, NiS, FeS₂, Ni₃S₂, FeO, Fe₃O₄, Fe₂O₃, NiO, FeSO₄, Fe₂(SO₄)₃, NiSO₄ and NiO-FeO-Fe₂O₃. The data for the spinel are according to the recommendations of Kellogg (1987).

The special procedure allows the calculation of the equilibrium compositions of the coexisting phases using a set of the computers assembled in a net. Ten IBM compatible computers were used: two were IBM-AT/486 and eight were IBM-AT/386. For each diagram the equilibria were calculated at about 3000 points.

CALCULATION AND DISCUSSION

The calculation of the equilibrium composition of the phases was required to establish the Fe/Ni ratio, silica activity and temperature. The Fe/Ni ratio in industrial processes varies from 30:1 to 1:10. The preliminary calculations have shown that the Fe/Ni ratio and silica activity do not impact significantly on the shape of the diagram. Thus it was decided to calculate diagrams at silica activity equal to one (solid state) and at Fe/Ni ratios of 3:1 and 1:1.

Diagrams

The temperature was established at 1573 K. The calculated diagrams are shown in Figures 4 to 6. It is evident from the figures that all solutions exist on the diagram. At the upper part silica coexists with Fe-Ni alloy at low sulphur pressure and with matte at high sulphur pressure. A further increase of oxygen pressure leads to the precipitation of NiO and then magnetite, Fe₃O₄. At the atmospheric pressure of oxygen (P_{O₂} = 0.2 atm) spinel is formed. The oxysulphide field (VIII) is very narrow.

The field of matte and slag coexistence is restricted and lies in the range of oxygen pressure from 10⁻¹¹ to 10⁻⁵ atm and in the range of sulphur pressure from 10⁻⁵ to 1 atm. These values are in agreement with the practice of industrial smelting and converting. A comparison of Figures 5 and 6 shows that the range of conditions to produce matte and slag with a nickel content less than 0.3 per cent is very narrow. It should be noted that there is one possibility to extend the range — using lime as flux.

A comparison of Figures 4 and 5 with industrial practice indicates the conditions which control the smelting. Smelting in blast and electric furnaces in the presence of coke leads to low oxygen partial pressure and the smelting conditions will be in the fields V-III or IV-I. Such a condition results in the production of low grade matte or ferronickel and slag with comparatively low nickel losses. The preceding roasting decreases the sulphur partial pressure and increases the nickel content of the matte. For slag cleaning, one should decrease the oxygen partial pressure and, therefore, establish a reducing condition. In order to increase reaction kinetics in flash smelting, extra oxygen is used. This leads to an increase of oxygen partial pressure and, hence, to an increase of nickel content of slag in comparison with the equilibrium state. For the Vanyukov process the speed of the reactions is very high and the equilibrium is established within the melt residence time. The oxygen is fully consumed by the melts. So, the control of the oxygen/carbon and oxygen/sulphide ratios provides for the control of the partial pressures of oxygen and sulphur. This possibility permits the optimisation of the smelting conditions.

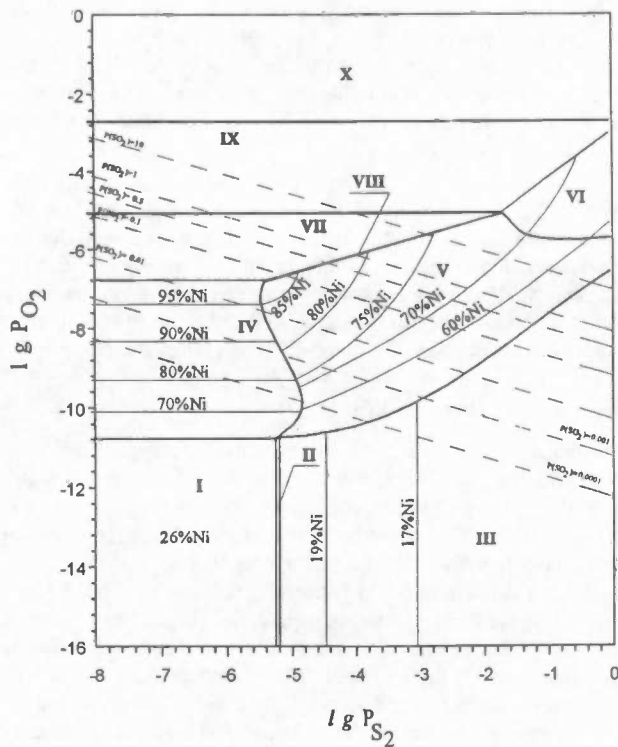


FIG 4 - Potential diagram at T = 1573 K and Fe/Ni ratio of 3:1;
 I - solid alloy + SiO₂; II - solid alloy + matte + SiO₂; III - matte + SiO₂;
 IV - solid alloy + slag + SiO₂; V - matte + slag + SiO₂;
 VI - matte + magnetite + SiO₂; VII - slag + NiO + SiO₂;
 VIII - oxysulphide + SiO₂; IX - magnetite + NiO + SiO₂;
 X - spinel + SiO₂.
 Values on the lines are nickel content of matte and alloy,
 in mass per cent.

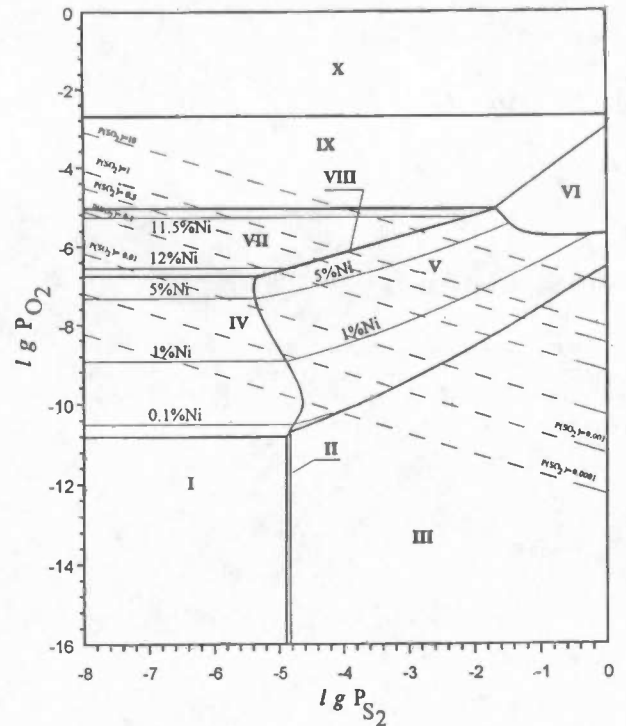


FIG 6 - Potential diagram at T = 1573 K and Fe/Ni ratio of 1:1.
 Values on the lines are nickel content of slag, in mass per cent.

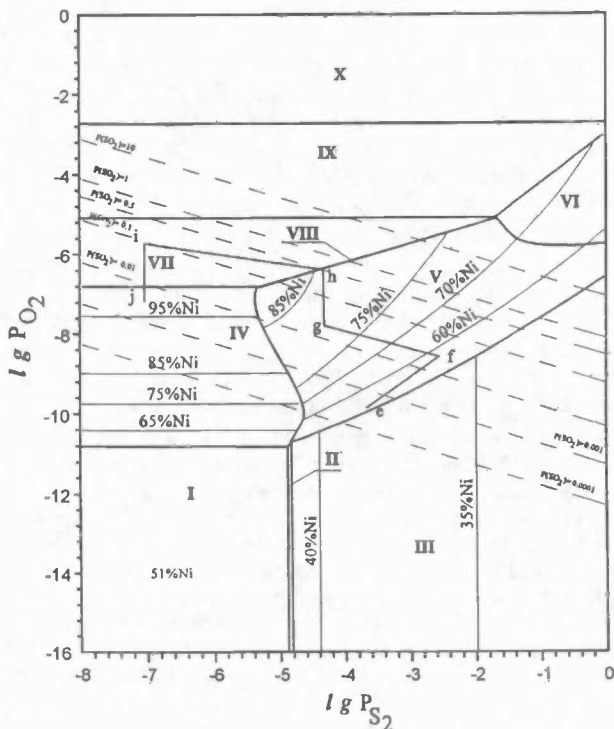


FIG 5 - Potential diagram at T = 1573 K and Fe/Ni ratio of 1:1.
 Values on the lines are nickel content of matte and alloy,
 in mass per cent.

Direct metallic nickel production

It is interesting to consider the problem of direct metallic nickel production in a smelting process. The opportunity to convert nickel matte with metallic nickel production has attracted researchers since the beginning of the 20th century. In the first publication to describe a practical attempt to solve the problem using an industrial scale converter (Hanus, 1976), high grade matte blowing mainly resulted in slag formation.

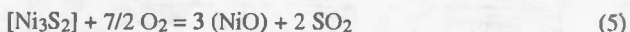
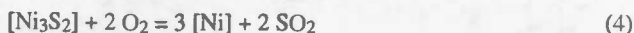
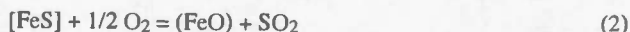
After a series of works, carried out under the supervision of Professor Vaisburd and Professor Tsemehman (Vaisburd *et al*, 1968), the problem was considered as unsolved, although it was constantly discussed among metallurgists. The series of work published in the 1970s was initiated by a publication (Bronson and Sohn, 1983), where an opportunity for the carbothermic reduction of nickel sulphide was considered (Jha, 1993).

Now interest in the opportunity of metallic nickel production using matte converting has revived again. Phase equilibrium diagrams of the Ni-S-O system (Yazawa, 1979), have allowed more detailed thermodynamic analysis of the process in a system free of iron and silica. These diagrams were the basis of an experimental smelting of WMC nickel sulphide raw material using Ausmelt technology (Baldock *et al*, 1993).

Another work (Sorokin *et al*, 1995) was devoted to the thermodynamic analysis of metallic nickel production by the converting of nickel matte using earlier developed thermodynamic models for the sulphide, metal and slag phase. The analysis objective was to clarify the conditions that allow the production of metallic nickel with low residual contents of iron and sulphur.

Primary process

The initial phase of the process is a sulphide raw material. Its composition can be considered within the Ni-Co-Fe-S system. During matte oxidation by oxygen-containing blast several parallel reactions are proceeding:



The mechanism of matte converting can be separated into four consequent stages (Sorokin *et al*, 1994). The three initial stages are characteristic of the ordinary periodic process proceeding in a Peirce-Smith converter, as shown on Figure 7.

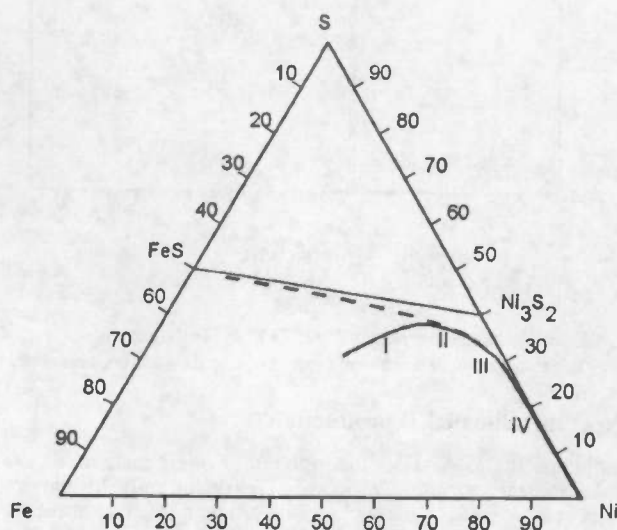


FIG 7 - Variation of matte composition during the converting.

In the first stage an intensive oxidation of metallic iron (reaction 1) is predominantly observed. In the second stage the main process is the oxidation of iron sulphide, with formed oxides passing to the slag (reactions 2 - 3). The line of matte composition at this stage moves practically in parallel to the FeS-Ni₃S₂ join. Simultaneously the reactions of sulphide nickel oxidation occur (reactions 4 - 5). This causes some deviation of the matte path from the pseudo-binary join. In the third-stage, reactions (4 - 6) become prevailing and a sharp turn of the matte path to the nickel corner is observed. Ordinary converting is usually stopped, when the residual iron contents of matte reaches two to four per cent. The sulphur content of the final matte is about 18 per cent. Continuation of the converting would cause, first, the formation of solid metallic nickel due to reaction (4). Second, it would lead to saturation of slag by nickel oxide (reactions 5 - 6), which has a high melting point, and this precipitates in the solid state. In summary, an attempt to continue nickel converting will cause the formation in a unit of two solid phases: solid metallic nickel and solid nickel oxide.

Objectives

For realisation of metallic nickel production by matte converting it is thus necessary to solve the following tasks:

- the prevention of solid metallic nickel formation;
- the prevention of nickel oxide precipitation in slag; and
- the production of an alloy containing not more than three per cent of both iron and sulphur.

Obviously, the first task can be solved, if the temperature of the process is higher than the nickel melting point, ie 1728 K. Saturation of slag by nickel oxide depends on temperature and slag composition (ie the fluxing regime). The residual contents of iron and sulphur in alloy also depend on all of the above parameters.

Early attempts to apply the thermodynamics of ideal melts (Vaisburd *et al*, 1968) and later the use of simple melt models have shown that the simplified approaches do not provide an exact prediction of residual iron and sulphur contents of the alloy. To achieve this, it is necessary to execute calculations using complex solution models which describe the thermodynamic of melts over a wide range of composition and temperature.

High temperature diagrams

Calculated potential diagrams of the converting system with the co-ordinates $\lg P_{\text{S}_2}$ - $\lg P_{\text{O}_2}$ and with the lines of iron and sulphur contents of the sulphide-metal phase are shown in Figures 8 through to 12. The widest area of matte and slag coexistence corresponds to the Fe/Ni ratio of 1:1; that is when ordinary matte is used as the initial phase of converting (Figure 9). The use of a sulphide concentrate as the initial material (Figure 8) results in the matte disappearing at low oxygen potential in comparison with Figure 9. On the line of NiO precipitation, the iron content of matte is one per cent by weight but the sulphur content of matte is greater than ten per cent. The use of high grade matte as the initial phase (Figure 10) permits a decrease in the residual iron content. However the residual sulphur content at the point of nickel oxide precipitation is about ten per cent. The use of ordinary matte as the initial phase of converting (Figure 9) even permits using an oxygen enriched blast (50 vol%O₂) to produce matte with considerably lower residual sulphur contents from four to five per cent. This appears to be a satisfactory value for further refining using the Sherritt-Gordon flow sheet (Baldock *et al*, 1993).

Thus an important conclusion from the diagram analysis is the essential dependence of the product composition on initial phase composition at 1800 K. It should be noted that such an opportunity was not considered early, although it follows from the Gibbs Phases Rule. This could be the reason that the data of various authors regarding residual sulphur and iron contents at the same temperatures do not coincide.

The analysis of the diagrams, Figures 8 to 10, shows also that a decrease of the SO₂ content of the off-gases permits the production of alloy (matte) with smaller residual sulphur contents, which coincides with earlier conclusions (Baldock *et al*, 1993). For example, use of a dilute air blast would cause the production of an alloy with a residual sulphur content of one per cent. However, it should be noted that in the last case it would be necessary to put in much fuel to compensate for heat losses.

A comparison of Figures 8 to 10 (at 1800 K) with Figures 11 to 12 (at 1900 K) allows clarification of the influence of temperature in the process. It is apparent, that although the area of matte and slag coexistence is expanded at 1900 K in comparison with diagrams at 1800 K, the borders are raised considerably in the direction of P_{O₂} increase. Total reduction of slag occurs also at a higher oxygen pressure as the temperature is increased. With temperature increase the lines of SO₂ pressure shift also. The residual sulphur and iron contents are considerably reduced at the point of NiO precipitation at 1900 K compared to 1800 K. For instance, at P_{SO₂} = 0.5 and 1900 K the residual content of sulphur is about one per cent, and iron content is less than 0.5 per cent at Fe/Ni ratio of 1:1 and 1:15. Thus, the residual content of impurities at high temperature does not depend too strongly on composition of the initial material.

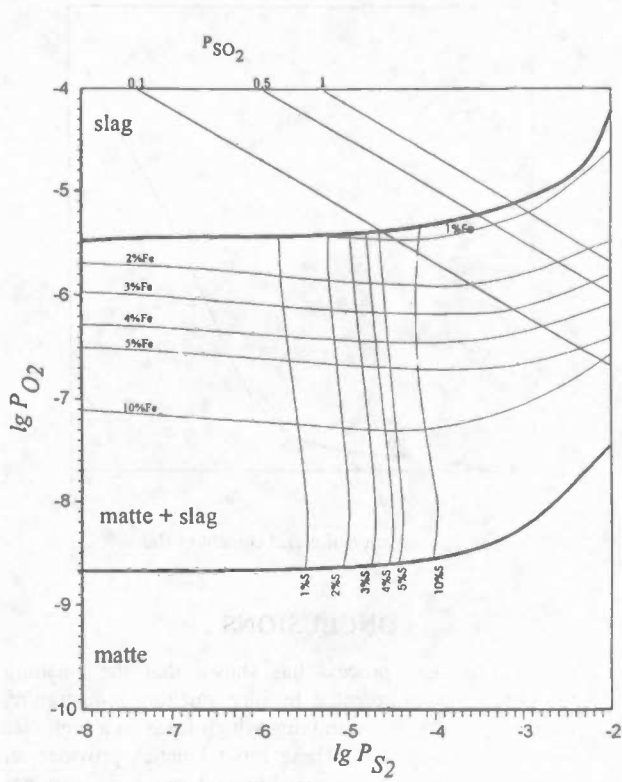


FIG 8 - Potential diagram at T = 1800 K and Fe/Ni ratio of 3:1. Values on the lines are Fe and S content of matte, in mass per cent.

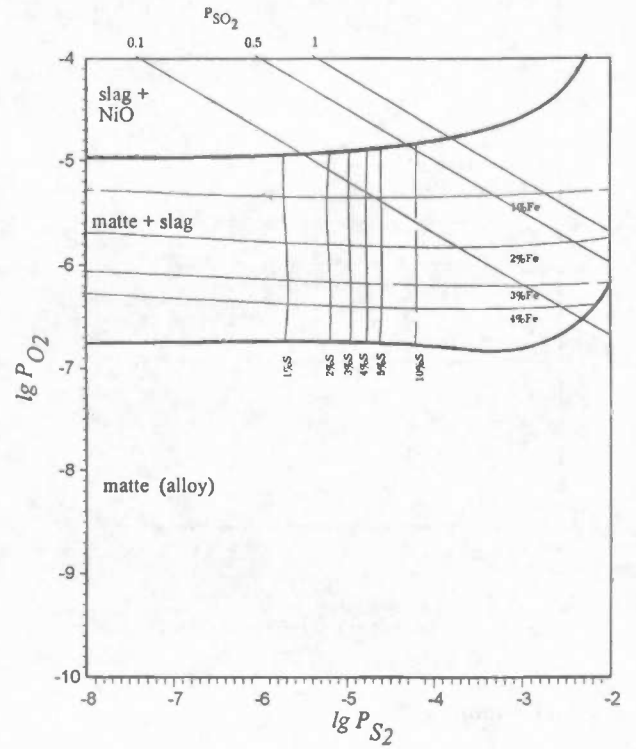


FIG 10 - Potential diagram at T = 1800 K and Fe/Ni ratio of 1:15.

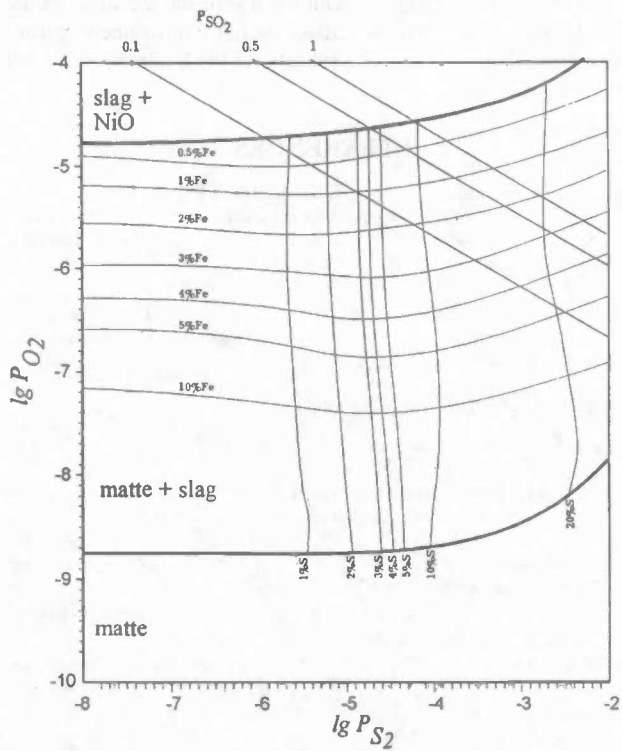


FIG 9 - Potential diagram at T = 1800 K and Fe/Ni ratio of 1:1.

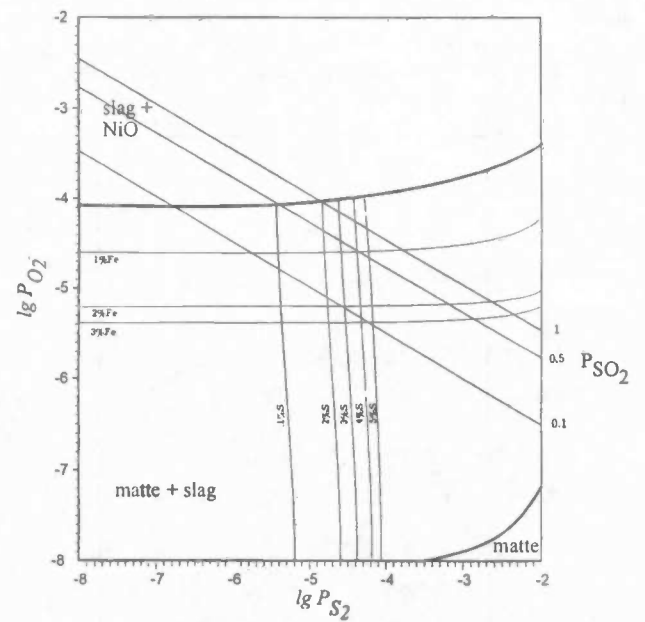


FIG 11 - Potential diagram at T = 1900 K and Fe/Ni ratio of 1:1.

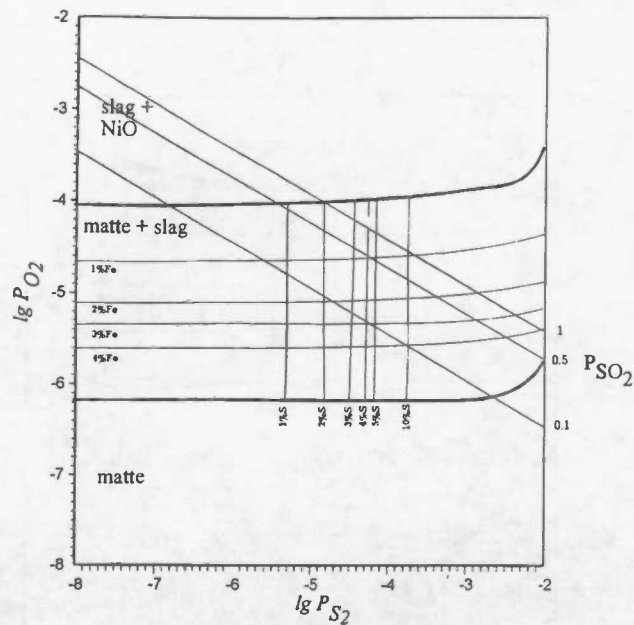


FIG 12 - Potential diagram at T = 1900 K and Fe/Ni ratio of 1:15.

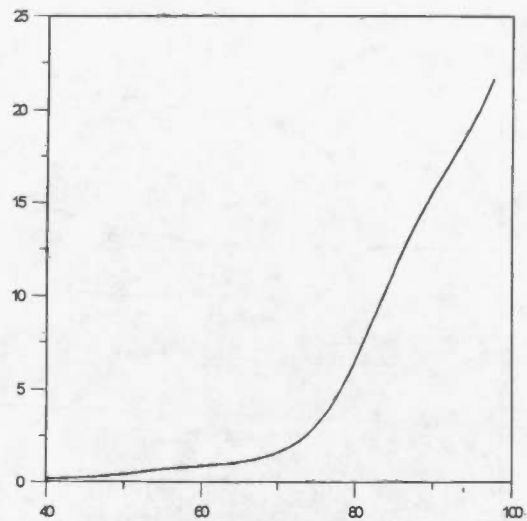


FIG 14 - Variation of nickel content of slag.

Residual sulphur

The influence of temperature on the residual sulphur content at the crossing point of the $PSO_2 = 0.5$ line and NiO precipitation line is shown on Figure 13. Some experimental and industrial data (Tsemehman and Vaisburd, 1966; Tsemehman, Vaisburd and Shirikova, 1968) are also added on the figure. It is apparent that the calculated curve adequately describes the general trend of the experimental and industrial data, especially in the region of high temperatures. With temperature increase the residual sulphur content decreases and at temperatures greater than 1900 K it becomes less than one per cent. Nickel content of slag is also an important parameter of the process. The variation of nickel content of slag is shown in Figure 14. Obviously, in the progress of the blow, the nickel content of slag increases; at 1900 K it reaches 25 mass per cent.

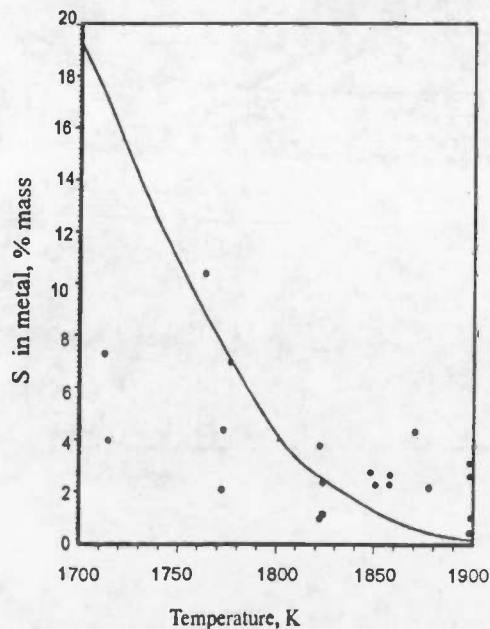


FIG 13 - Residual sulphur content at the crossing point of $PSO_2 = 0.5$ line and NiO precipitation line.

CONCLUSIONS

A study of Vanyukov process has shown that the smelting technology has a wide potential to vary smelting temperature, feed rate and intensity of intermixing which leads to a high rate of chemical transformation. These rapid kinetics provides an opportunity to realise various metallurgical processes that are close to the equilibrium state.

The development of thermodynamic models that describe phase equilibria allows the forecast of the composition of the smelting products and general parameters of the Vanyukov process for various initial charges. The accumulation of the experimental data, combined with the use of the thermodynamic models and achievements in furnace design improvement, permit the suggestion of optimum flowsheets for the treatment of nickel containing charge.

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