

DEVELOPMENT OF BLAST FURNACE SLAG PROPERTIES  
AT SSAB Svenskt Stål AB, or  
A BLAST FURNACE VIEW ON SLAGS

by

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ABSTRACT

In 1982 SSAB, Luleå Works converted the blast furnace ferrous burden from an acid to an olivine pellet with a high Fe-content. This change made it possible to gradually reduce the slag volume to 150 kg per metric ton of hot metal with huge positive effects on the blast furnace operation. SSAB, Oxelösund Works can present a similar development, initially by increasing the Fe-content in sinter and lately by converting to a 100% olivine pellet operation in 1995.

In addition to a description of the historical development of the slag properties of SSAB blast furnace slags, this paper describes the technical means and issues as well as the environmental constraints governing future developments of slag volume and chemistry, including effects of changes in burden quality and possible tuyere injection of slag formers.

## 1 INTRODUCTION

The blast furnace operation at SSAB Svenskt Stål AB is characterized by the use of a high-quality ferrous burden resulting in a low slag volume of 150-160 kg per metric ton of produced hot metal (kg/tHM), which could be compared to an EU average of 260 kg/tHM.

Operating a blast furnace at low slag volumes demands a tight control over both raw material quality and process. On the other hand, low slag volumes results in a number of advantages such as lower cost of production, higher productivity and improved hot metal quality. Slag volume reduction has always been an important part in the development of blast furnace operations. As the slag properties to a large extent are decided by raw material quality, low slag volumes has mainly been reached by reducing the gangue content of the ferrous burden.

In most metallurgical processes slag is not just a unwanted by-product. In the case of blast furnace iron making the slag is the recipient of impurities such as alkalis and sulphur. Therefore, a reduced slag volume has to be met by a reduction of the amount of raw material impurities, changes in slag chemistry, process refinement and / or implementation of external treatment of hot metal (e.g. desulphurization).

Regardless of the actual volumes of produced slag it has always been natural to look for adequate ways to take care of the slag after it has been tapped from the blast furnace. Dumping is really not an option. This means that a compromise has to be made between the demands placed by the blast furnace process and the possibility to find suitable markets for the slag.

## 2 A HISTORICAL REVIEW

### 2.1 SSAB, Luleå Works

#### 2.1.1 From sinter to a 100% pellet operation

SSAB Luleå Works was one of the first plants to operate a blast furnace with a slag volume below 200 kg/tHM. The first blast furnace (BF1), put into operation in 1951, ran on an all sinter burden until 1973 when the larger blast furnace (BF2) was commissioned. As the increase in blast furnace hot metal capacity could not be met by the works own sinter plant an acid pellet with high iron content was added to the ferrous burden. With a pellet / sinter mix consisting of 50 to 70% acid pellet slag volumes around 300 kg/tHM was reached (Figure 1).

When the sinter plant, for economical and environmental reasons, was closed down in 1978 the blast furnaces converted to a 100% acid pellet operation. Even though the pellet gangue content was substantially less in comparison with sinter the change did not result in a decrease in slag volume. At the time it was thought that for the sake of a stable operation the slag volume should not be lowered. Instead, to compensate for a decrease in gangue in the ferrous burden additional slag formers had to be charged.

Adding limestone and recycled BOF-slag (i.e. steelmaking slag) in order to reach the aimed slag basicity was not enough to maintain the desired slag volume. This could only be done by adding more limestone together with an acid slag former.

For a smooth operation good slag forming conditions inside the blast furnace is of utmost importance. Therefore, from a blast furnace point of view there is a basic difference between having all the slag forming materials integrated with the ferrous burden, which is the case with sinter, and adding large amounts of slag formers which are both physically and chemically separated from the ferrous materials.

In the case of slag formation in the blast furnaces a generalized way to look at the process is to define four types of slags [1], illustrated in Figure 2:

<u>Primary slag</u> ,	formed by gangue from ferrous materials
<u>Bosh slag</u> ,	the primary slag after dissolving all components of fluxes and additives charged from the top, including some ash content contained in coke consumed for reduction and carburization
<u>Tuyere slag</u> ,	formed by the ash of fuels burnt in front of the tuyeres.
<u>Final slag</u> ,	the mixture of bosh slag and tuyere slag, deducting the amount of reduced oxides.

It is evident that the slag forming process will become quite complexed with an increased addition of slag forming materials. The problem can be illustrated by putting the composition of each individual raw material and the different slags formed in the process into a three-phase diagram of the  $\text{Al}_2\text{O}_3$ - $\text{CaO}$ - $\text{SiO}_2$ -system (Figure 3).

After the change to a 100% pellet operation problems with unstable slag formation were soon experienced. In the case of the limestone, poor melting behavior and low mechanical strength caused occasional operational disturbances. Problems were also experienced in regards to the melting behavior of the type of quartzite used. Sometimes it would not melt at all, leaving the furnace through the taphole "untouched".

To improve the slag formation inside the blast furnaces it was decided to replace the quartzite with gabbro (more commonly known as gravel), consisting mainly of calcium-alumina-silicates. It was found that in regards to slag formation the gabbro functioned well with the acid pellet. It seems that the gabbro melting properties are close to the pellet melting properties. However, a major disadvantage with gabbro was its high alkali content ( $\sim 1,2\%$   $\text{Na}_2\text{O}$  and  $\sim 0,3\%$   $\text{K}_2\text{O}$ ).

Figure 4 illustrates the slag formation when using gabbro instead of quartzite. It can be seen that the introduction of gabbro increased the alumina level and it is likely that the improved slag formation to some extent should be explained by the fluxing effect of alumina.

### 2.1.2 From acid to olivine pellet

The acid pellet (MPB = Malmberget Pellet for Blast furnaces) used in the Luleå furnaces was produced by the Swedish mining company LKAB in their Malmberget plant. In the early 80's SSAB was asked to test a new product, the olivine pellet (MPB-O). Tests in the laboratory had revealed that this pellet showed superior melting and reduction properties compared to the acid pellet. The first MPB-O pellet was added to the blast furnaces at the end of April 1982 [3]. The test resulted in such immediate improvements that it was decided to continue operating the blast furnaces with the olivine pellet as the sole ferrous burden.

The olivine pellet is lower in gangue (and higher in MgO) compared to the acid pellet. Hence the opportunity was there to reduce the slag volume. But again, as when changing over from sinter to acid pellet in 1978, it was thought that the slag volume should not be reduced for the sake of a stable furnace operation. This meant continuing with addition of large amounts of limestone and gabbro. Figure 5 illustrates the slag formation in the blast furnace in the case of olivine pellet, limestone, BOF-slag and gabbro.

Compared to the acid pellet olivine pellet has a higher melting point and a narrower melting range which has a large positive effect on the furnace productivity. However, it was soon found that the gabbro was fluxing the olivine pellet raising and widening the melting zone [5]. Fortunately a new additive, silica-lime, was "discovered". Silica-lime was a micro-crystalline by-product from the mining of limestone for the cement industry and consisting of some 60%  $\text{SiO}_2$  and 40%  $\text{CaCO}_3$ . This material proved to have melting properties which functions well with the olivine pellet. Figure 6 illustrates the slag formation in the blast furnace in the case of olivine pellet, limestone, BOF-slag and silica-lime.

### 2.1.3 Development of low slag volume operation

Adding large amounts of slag forming materials into the blast furnace is not really desirable. Besides from a non-uniform slag formation it results in high production costs, often increased alkali and sulphur inputs, poor hot metal quality and limits the furnace productivity. So after one year of olivine pellet operation it felt to be the right time to start reducing the addition of slag formers and hence the slag volume. The confidence grew as the slag volume was lowered through a decreased addition of slag forming materials, and during the autumn of 1984 a slag volume of 170 kg/tHM was reached, a reduction of slag volume by 100 kg/tHM. At this level only limestone and BOF-slag was added on order to balance the  $\text{SiO}_2$  and  $\text{Al}_2\text{O}_3$  from coke and pellet and to reach the aimed final slag basicity. Figure 7 illustrates the slag formation in the blast furnace after the reduction of slag volume.

Compared to the higher slag volume the new practice eliminated the addition of any acid slag formers and reduced the addition of limestone with almost 100 kg/tHM. The removal of most of the slag forming materials and the subsequent reduction in slag volume resulted in a 15-20% increase in furnace productivity (measured as the hot metal production per day and hearth area, i.e. tHM/d/m<sup>2</sup>), a 15-20 % reduction in coke consumption and a 50% reduction in the hot metal silicon content (Figure 8).

As the slag is important for the alkali and sulphur removal it had always been feared that a reduction in slag volume would lead to an increase in alkali recirculation inside the furnace and higher sulphur levels in the hot metal. However, the alkali problem solved itself as the reduction of acid additives led to a decrease of the alkali input with some 75% (Figure 9a). At the same time the sulphur input was reduced by lowering the sulphur content in the coke.

As for the feared increase in hot metal sulphur, this did not happen. Even though the lime-silica ratio in the slag was lowered, the sulphur capacity of the slag was raised due to the increase in MgO content and thereby the three component slag basicity  $(\text{CaO} + \text{MgO}) / \text{SiO}_2$ . Hence, with a burden high in MgO it was possible to lower the slag volume and still produce a slag with high enough sulphur capacity to maintain the sulphur level in the hot metal (Figure 9b).

### 2.1.4 Present status

Injection of pulverized coal was introduced on Luleå's BF2 in 1985 and on BF1 in 1990. This has not had any major impact on the slag chemistry as the coal and coke have similar ash compositions.

As described earlier, running a blast furnace at low slag volumes leads to increased productivity and lower fuel consumption, but there are also some negative effects. An experienced drawback with a low slag volume and the present slag composition is a decreased 'margin of error'. With such high MgO and  $\text{Al}_2\text{O}_3$  contents in the slag it starts to solidify already at around  $1350^\circ\text{C}$ , just  $100^\circ\text{C}$  under normal tapping temperature (Figure 10a). At the same time the slag viscosity will increase very rapidly with decreasing temperature (Figure 10b). This means that if there is a sudden fuel deficiency in the lower part of the furnace (in the worst case a 'chilled hearth') slag tapping may not be possible until the thermal state has been restored. It is therefore evident that increases in MgO and / or  $\text{Al}_2\text{O}_3$  input should be avoided.

Most of the MgO comes with the pellet. In the case of an increased MgO content in the pellet the total MgO input could be maintained by a decrease in the addition of BOF-slag. However, there is no immediate counter-measure to an increase in  $\text{Al}_2\text{O}_3$  content of the coke ash.

Tight control of the slag basicity is also important when operating at low slag volumes. The right balance has to be found between the optimum sulphur distribution (between slag and hot metal) on the one hand and proper alkali removal (with the slag) on the other.

## 2.2 SSAB Oxelösund Works

### 2.2.1 Increased Fe-content in sinter

The development at Oxelösund has taken a slightly different path compared to the Luleå plant, but the "end result" can be said to be the same. The two blast furnaces at Oxelösund, BF2 and BF4, were put into operation in 1954 and 1961 respectively. When the Luleå plant closed the old sinter plant in 1982 and began its 100% pellet operation the Oxelösund plant continued to operate with a ferrous burden consisting of roughly 2/3 sinter and 1/3 pellet (Figure 11).

Without the help of an increased ratio of a pellet with high Fe-content reduced slag volumes for the Oxelösund furnaces could only be achieved by improvements in the sinter quality. By gradually increasing the sinter Fe-content to 62% and the lime-silica ratio to 1,7-1,8 it was possible to reach almost as low slag volumes as in Luleå (Figure 12).

As was the case in Luleå lower slag volumes for the Oxelösund blast furnaces has led to increased productivity, improved hot metal quality and lower fuel consumption (Figure 13).

### 2.2.2 To a 100% pellet operation (1995) and present status

Coal injection was introduced in 1987 and in 1995 SSAB Oxelösund closed its sinter plant and converted to a 100% olivine pellet operation. So today the blast furnace operation, as far as burden materials, resembles the situation in Luleå (Figure 14), except for the level of coal injection. There is however an important difference in the blast furnace slag chemistry, where the Oxelösund furnaces aim towards a lower basicity compared to the Luleå furnaces. This is mainly due to demands on a maximum sulphur level in the slag, which will be discussed later.

## 2.3 Blast furnace slag applications

### 2.3.1 Environmental issues

The blast furnace slag stands for some 40% of the total quantity of by-products at the two SSAB integrated steel works. For environmental reasons it is therefore of great importance to find ways to utilize the slag and minimize dumping, which in the long run will prove very costly, even not including future penalties. It will also reduce the use of "virgin" materials.

In the "old days" it was natural not to let anything go to waste. One common way to utilize the blast furnace slag was to cast it into moulds and use the solid slag as building blocks. In more modern times the blast furnace slag is widely used as a raw material in cement manufacturing and as filling material.

Table 1 gives the current range of slag composition for the SSAB blast furnaces. In a comparison to other European blast furnace slags, what stands out is the high MgO content in SSAB blast furnace slags. There is an important difference between SSAB Luleå Works and SSAB Oxelösund Works, namely the basicity. Oxelösund operates at a lower basicity in order to avoid high sulphur levels in the slag for slag application reasons.

### 2.3.2 SSAB Luleå Works

At SSAB Luleå the blast furnace slag is handled by a local transportation company, Lulefrakt, who processes the slag after it has been poured on the ground and left to slowly cool down. By doing so the slag is crystallized and natural minerals are formed. These minerals are very stable and could be compared with crushed rock. All the slag produced in the Luleå blast furnaces is used locally as a filling material.

One advantage of using blast furnace slag is that it does not contain as high levels of heavy metals (e.g. cadmium and lead) compared to some types of natural gravel. Any manufacturing of gravel through crushing rock gives the gravel fresh surfaces from which heavy metals could be leached out. Table 2 shows a comparison of the environmental load between roads constructed with either gravel or blast furnace slag as a base material underneath the bitumen.

With a high MgO-content it is well suited for this purpose, especially due to the climatic conditions in Sweden and the Luleå area in particular. With 3-4 months with an average daily temperature below zero degree centigrade the ground may freeze to rather great depths. If water is present this will cause the earth to expand and hence rise. In the spring when the temperature in the ground increases the earth warms up and contracts leaving cracks in the during the cold period risen parts.

A comparably high MgO/CaO ratio of 0,5-0,6 makes the slag less hygroscopic than "standard" blast furnace slags with the same basic/acid ratio. An other major advantage is that the blast furnace slag is a better insulating material than gravel, hence reducing the risk for the ground to freeze. Thus, by using the high MgO blast furnace slag as a base material in roads and under buildings, damaging ground movement can be avoided.

### 2.3.3 SSAB Oxelösund Works

The slag from the SSAB Oxelösund furnaces are processed by Merox, a subsidiary company within the SSAB Group. The slag is either poured on the ground and left to cool down or water granulated. In the latter case the quick cooling prevents crystallization and formation of stable minerals. Instead an amorphous, glassy slag structure is obtained.

The slag from the Oxelösund blast furnaces has, because of the two ways of solidification, a quite diverse use which can be seen in Table 3. All of them has an upper limit of 1,6% for the sulphur content. This requirement would not be so difficult to meet if there were no demands on slag basicity and hot metal sulphur content. The equation could be solved by increasing the slag volume through extra additions of slag forming materials (e.g. quartzite and limestone). This method was practiced during a limited time period but proved to be extremely costly, mainly because of a substantial increase in fuel consumption and decreased productivity.

A more economical solution, not demanding any major process changes had to be adopted. Almost all sulphur charged into the blast furnace originates from the fuel, i.e. coke and injectants. By lowering the sulphur level in the fuel materials, even though to a slightly higher cost, it has been possible to meet the sulphur demands placed on both slag and hot metal.

## 2.4 An international comparison

Looking at the data in Table 1 there are few similarities between SSAB blast furnace slags and slags from other European blast furnaces. The latter are much lower in MgO and have a higher lime to silica ratio, which is more favorable when considering slag application options.

## 3 FUTURE DEVELOPMENT OF BLAST FURNACES SLAGS

### 3.1 Improved liquid properties

Even though the introduction of fuel injection has not lead to any significant changes in the chemistry of the final slag it has an indirect effect on the behavior of the slag within the blast furnace. Any fuel injection in the lower part of the furnace means a decrease in the ratio between coke and ore in the materials charged from the top and hence in the furnace burden. This leads to an increased rate of production and liquid load in the lower part of the furnace. For the blast furnace operator this does not result in any problems as far as the hot metal is concerned. As a normal hot metal temperature of 1475°C is more than 300°C above the 1153°C eutectic in the Fe-C system, tapping the hot metal from the furnace will not be a problem even if there is a sudden disturbance leading to a large temperature drop in the liquids. The slag will however start to solidify at temperatures just below 1350°C. Poor slag fluidity, for any reason, will lead to improper slag tapping and most likely result in furnace instability.

As described in section 2.1.4 the SSAB blast furnace slag is, due to its relatively high MgO content, sensitive to changes in temperature. Considering the effect of slag composition on the liquidus (Figure 10a) and the viscosity (Figure 10b) it is evident that the viscosity can be decreased by either a reduction of the lime-silica ration, the magnesia and / or alumina.

Reduction of the magnesia and the alumina can be done either by reducing the input of these components or by increasing the slag volume through an increased input of lime and silica. This leads to a lot of different solutions, but they would all mean changes in chemistry of some of

the burden materials. This is often easier said than done and all such changes must be preceded by thorough investigations. Of course it would be nice to find a fluxing agent, which already at very low levels of addition could substantially increase the slag fluidity at temperatures down to say 1200°C.

### 3.2 Basic research

The blast furnace slag chemistry is not always a result of direct actions, rather a result of changes in composition of the burden materials based on economical or process reasons. This could to a large extent be said about the present situation for the SSAB blast furnaces, where the reduction of slag volume has been more important than the slag chemistry itself.

Another "forgotten" issue has been a more deeper understanding of the slag formation in the furnace and how this can be improved and optimized. This became very apparent some years ago when testing new pellet qualities. These bad experiences triggered a number of research activities of which some will be presented at this conference [8].

### 3.3 Lower slag volumes

It is any researchers and developers responsibility to question and evaluate current procedures and try to overcome process limitations. As illustrated earlier today's slag volumes may not be the lowest possible from a process point of view. One direct effect of further decrease in slag volume would be an increased hot metal production capacity, as the slag would take up less space in the furnace hearth (Figure 15).

The slag volume can only be lowered by an increase of the iron content in the iron bearing materials, in SSAB's case either through a reduction of the gangue content in the pellet and / or through introduction of purer types of iron bearing materials (e.g. scrap and prereduced ore).

Operating the blast furnace at lower slag volumes will only be a problem if proper control of the slag chemistry is not maintained. It is therefore clear that any attempt in reducing the slag volume must be coupled with actions regarding the input of elements that have a strong influence on the slag formation and also regarding the strategies of impurity removal.

### 3.4 Tuyere injection of slag formers

A rather new approach to the problem of slag formation in a blast furnace with a 100% pellet burden is the idea of injecting some or all the slag formers through the tuyeres [1]. The first step would be to inject as much as is needed to raise the basicity of the tuyere slag to a level close to that of the final slag (Figure 16). It would be preferable to inject BOF-slag and not lime(stone), both for technical and metallurgical reasons. Already small additions of BOF-slag lowers the melting point of the fuel ashes considerably [8] and it seems that the iron oxide in the BOF-slag has a strong positive influence on the combustion of the injected fuel [10]. The latter is, for process stability reasons, extremely important in when injecting pulverized coal.

The final aim with tuyere injection could be to only charge ferrous material and coke at the top of the blast furnace and to inject all needed slag formers via the tuyeres and operating at slag volumes below 120 kg/tHM. This would not only involve the development of new ferrous burden qualities. An increased understanding about the behavior of the slag inside the furnace



is needed and also studies aimed at improving the sulphur and alkali capacity of the slag. Even though there is a lot of ground to cover before tuyere injection of slag formers will be an operational reality, it is evident that this technique could result in significant improvements in the practice of a 100% pellet blast furnace operation, and especially on larger furnaces.

### 3.5 Effects of new environmental legislations

Today we know that new environmental legislations effecting the blast furnace operation is waiting just around the corner. Penalties will soon, if not already, be imposed on any type of depositing of in-plant fines and sludge. There will most likely be only a temporary respite for blast furnace slags. It is therefore important that the blast furnace operation, if needed, is adjusted to facilitate a 100% reuse of the blast furnace slag. This could only be accomplished by changes in the burden chemistry.

## 4 CONCLUSION

The slag chemistry of the SSAB Luleå blast furnaces went through some major changes in the mid 1980's and at Oxelösund somewhat later. The driving force for the change to lower slag volumes, resulting in a blast furnace slag with a comparably high MgO content, were issues such as improved productivity, hot metal quality and reduced fuel consumption. It could be said that these changes were made without too much thought regarding slag formation in the furnaces.

It should be emphasized that the reduction of slag volume and increased MgO content has led to major savings in operational costs, not only at the blast furnaces, but also in the steel shop. However, the margin of error has decreased and the process is sensitive even to rather small variations in the composition of the burden materials and also to process disturbances which results in fuel deficiencies.

Injection of slag formers through the tuyeres will most likely be an important tool for improvement of the slag formation in the blast furnace, especially for furnaces which are operated with large additions of slag formers (i.e. 100% pellet operation). But as tuyere injection of slag formers results in a fluxing of the tuyere slag, this technique could also be interesting for blast furnaces with a high proportion of sinter and for furnaces with high levels of coal injection.

It is clear that a broader and deeper understanding of the slag chemistry of the blast furnace is needed for future process developments. Therefore it is reassuring to know that resources are spent on basic research and plant trials, and that the SSAB blast furnace operators are aware of the fact that the difference between success and failure could depend on future improvements of the slag chemistry and in the slag formation.

No changes of the slag chemistry should be made without studying what impact these changes will have on the marketing possibilities of the slag. This will be even more important in the near future when environmental fees will most likely be imposed on any type of slag depositing.

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Figure 1

### Development of ferrous burden and slag volumes at SSAB Luleå Works, Blast Furnace 2.

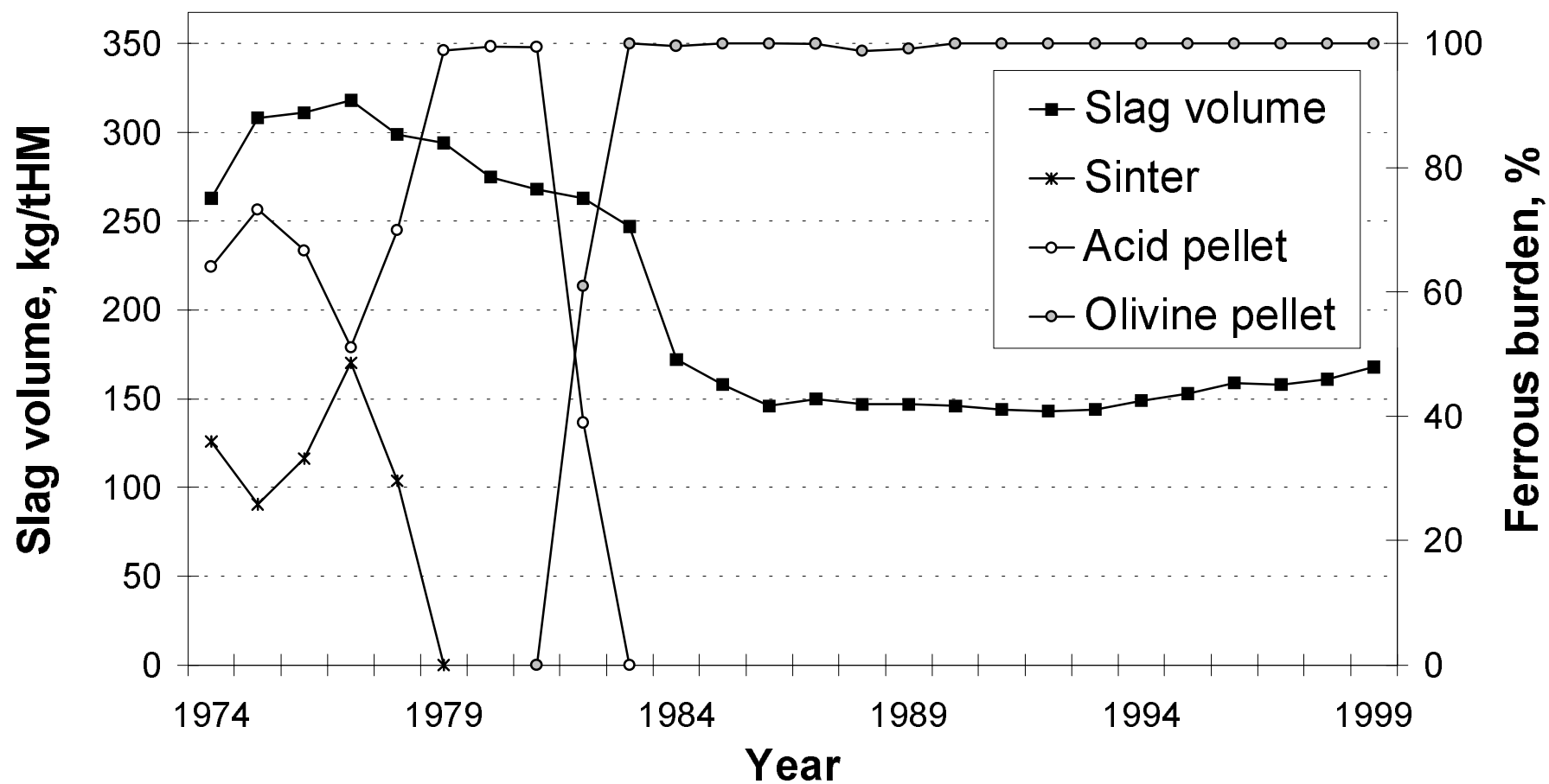


Figure 2

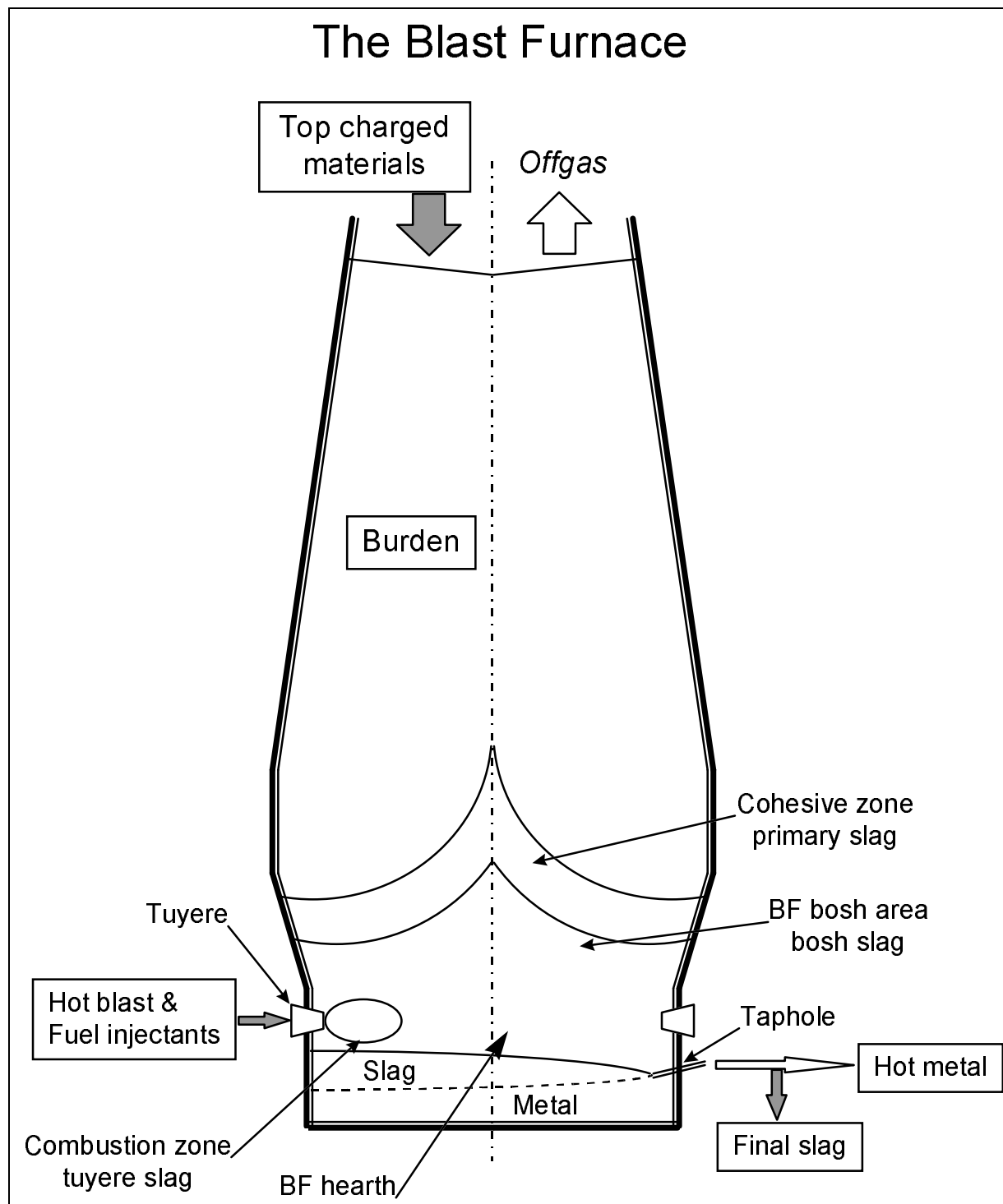


Figure 3

## The system $\text{Al}_2\text{O}_3\text{-CaO-SiO}_2$ [2].

Approximate compositions for burden materials and blast furnace slags in the case of an acid pellet, additional basic slag forming materials and with quartzite.

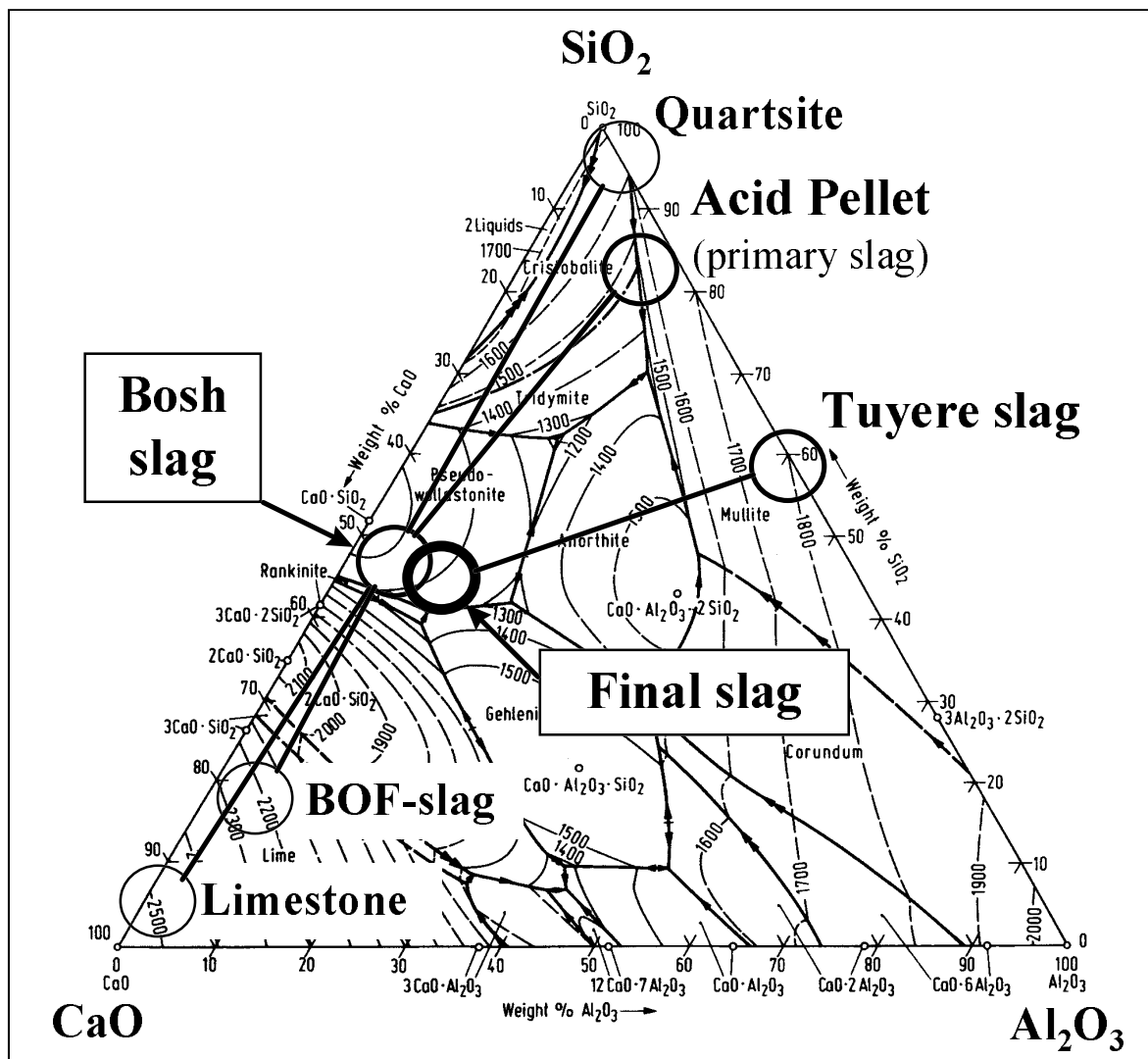


Figure 4

## The system $\text{Al}_2\text{O}_3\text{-CaO-SiO}_2$ [2].

Approximate compositions for burden materials and blast furnace slags in the case of an acid pellet, additional basic slag forming materials and with gabbro.

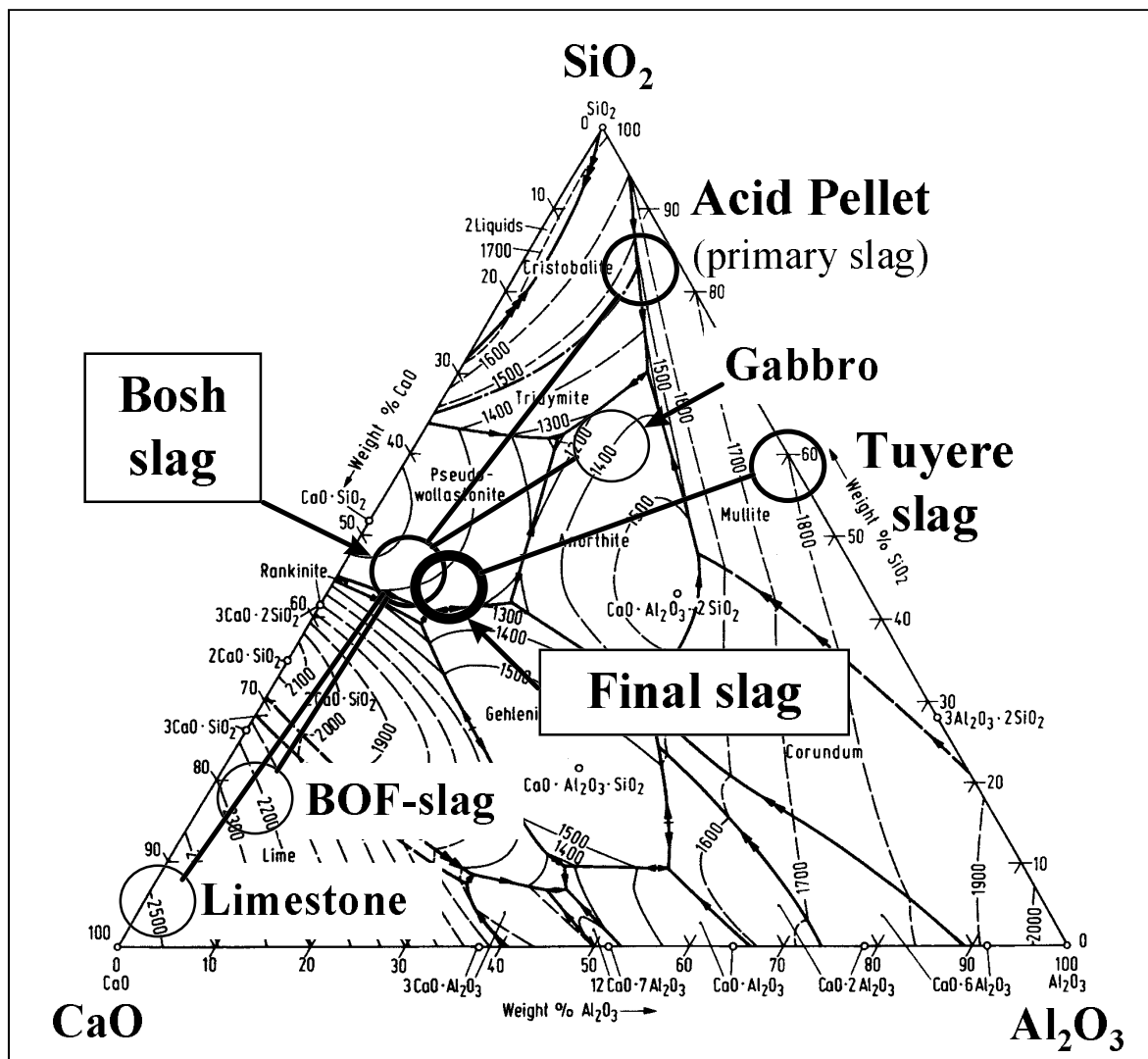


Figure 5

## The system $\text{CaO-MgO-SiO}_2$ [4].

(Note that the alumina has been added to the silica for simplicity reasons.)

Approximate compositions for burden materials and blast furnace slags in the case of an olivine pellet, additional basic slag forming materials and with gabbro.

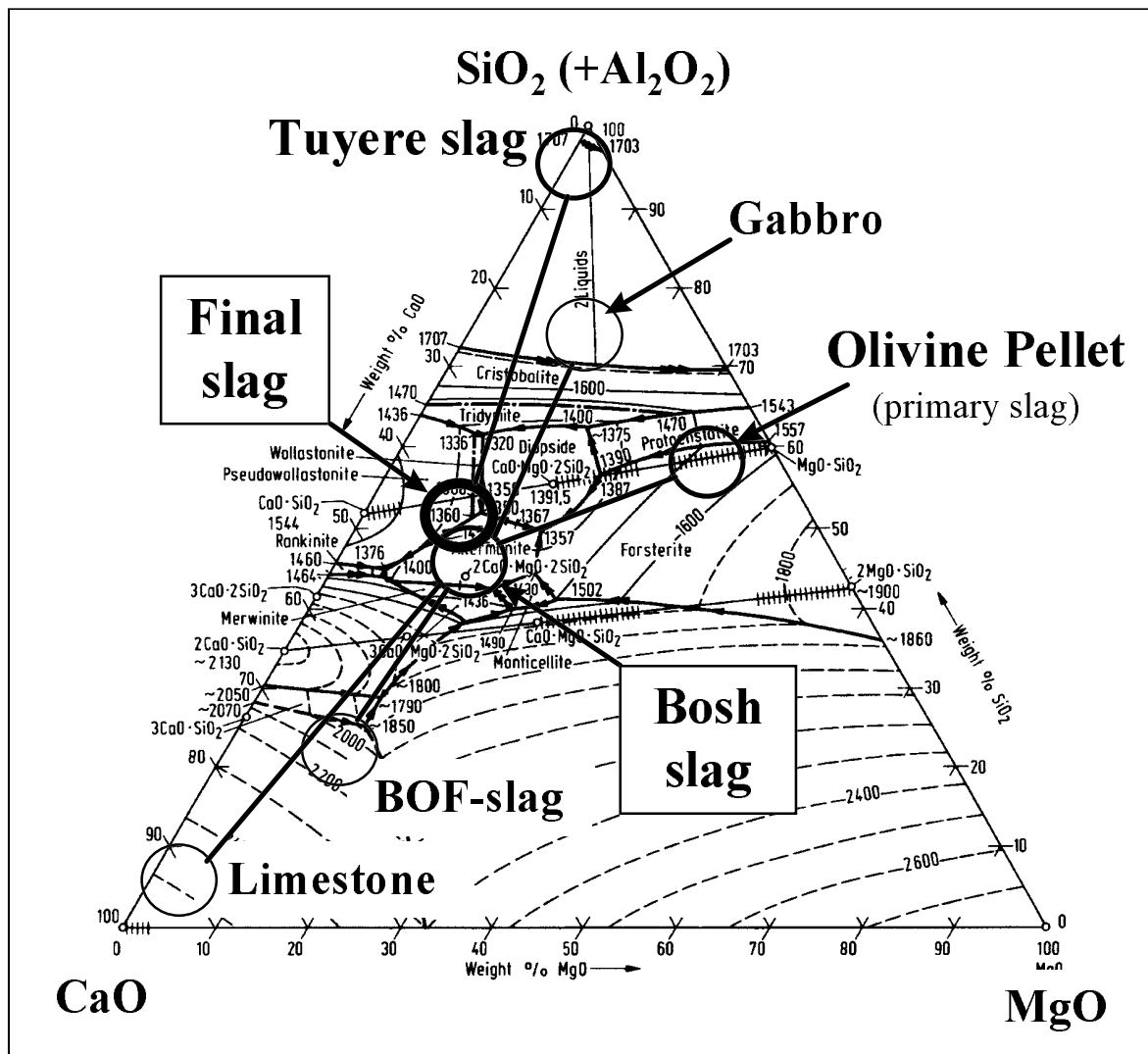


Figure 6

## The system $\text{CaO-MgO-SiO}_2$ [4].

(Note that the alumina has been added to the silica for simplicity reasons.)

Approximate compositions for burden materials and blast furnace slags in the case of an olivine pellet, additional basic slag forming materials and with silica-lime.

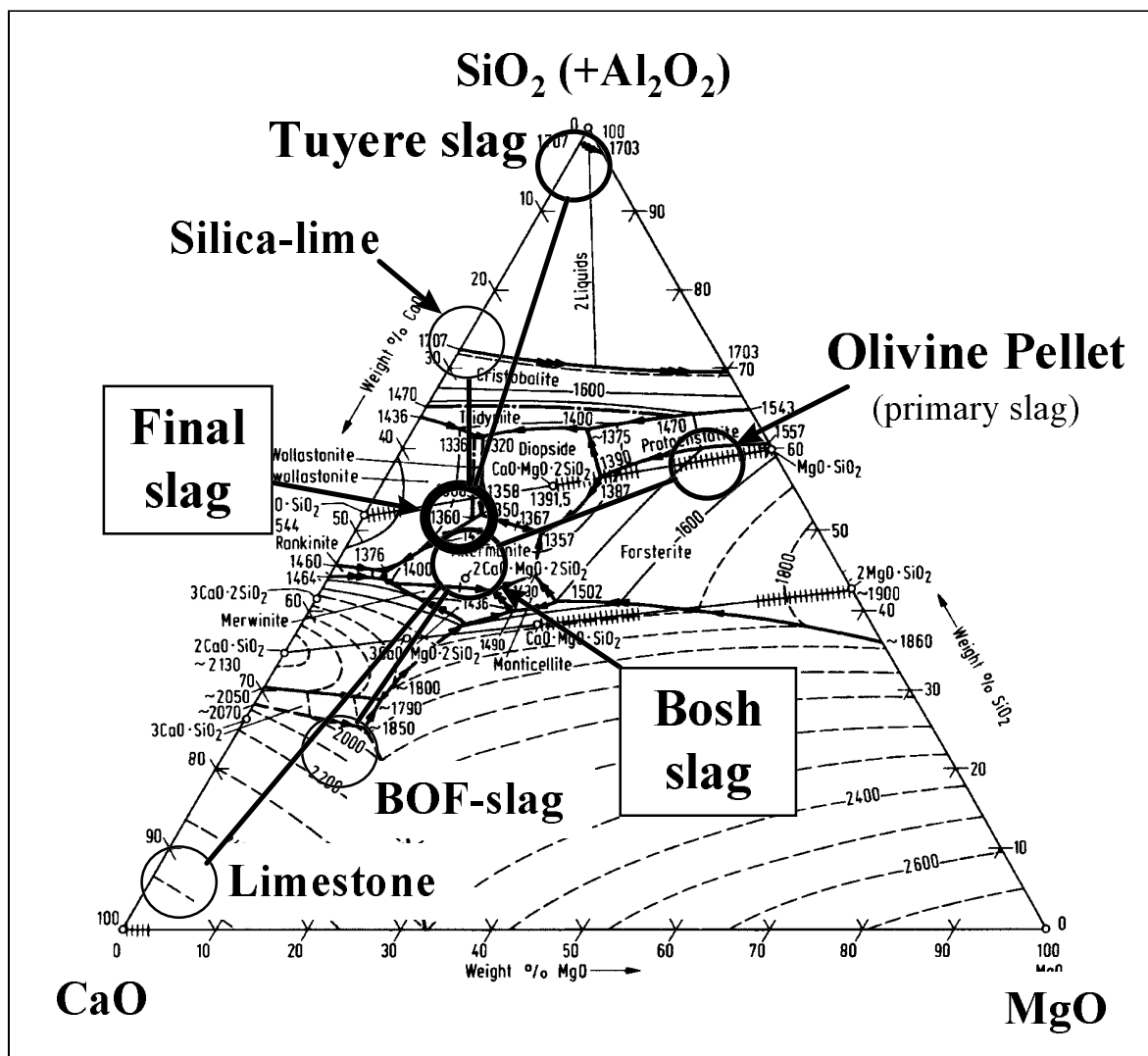




Figure 7

## The system $\text{CaO-MgO-SiO}_2$ [4].

(Note that the alumina has been added to the silica for simplicity reasons.)

Approximate compositions for burden materials and blast furnace slags in the case of an olivine pellet and additional basic slag forming materials at low slag volumes.

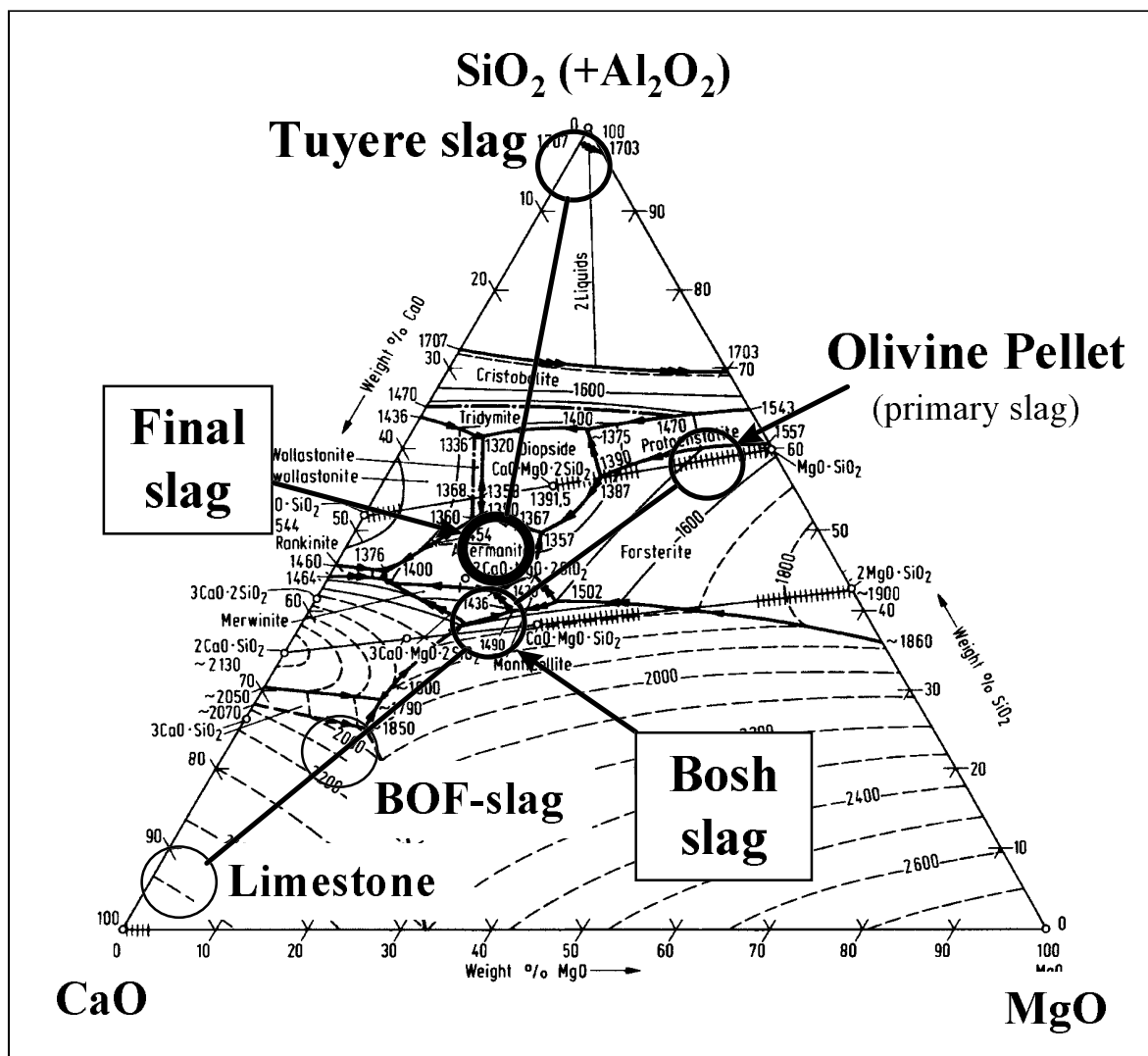


Figure 8

The influence of slag volume on fuel rate, hot metal quality and productivity for SSAB Luleå, Blast Furnace 2.

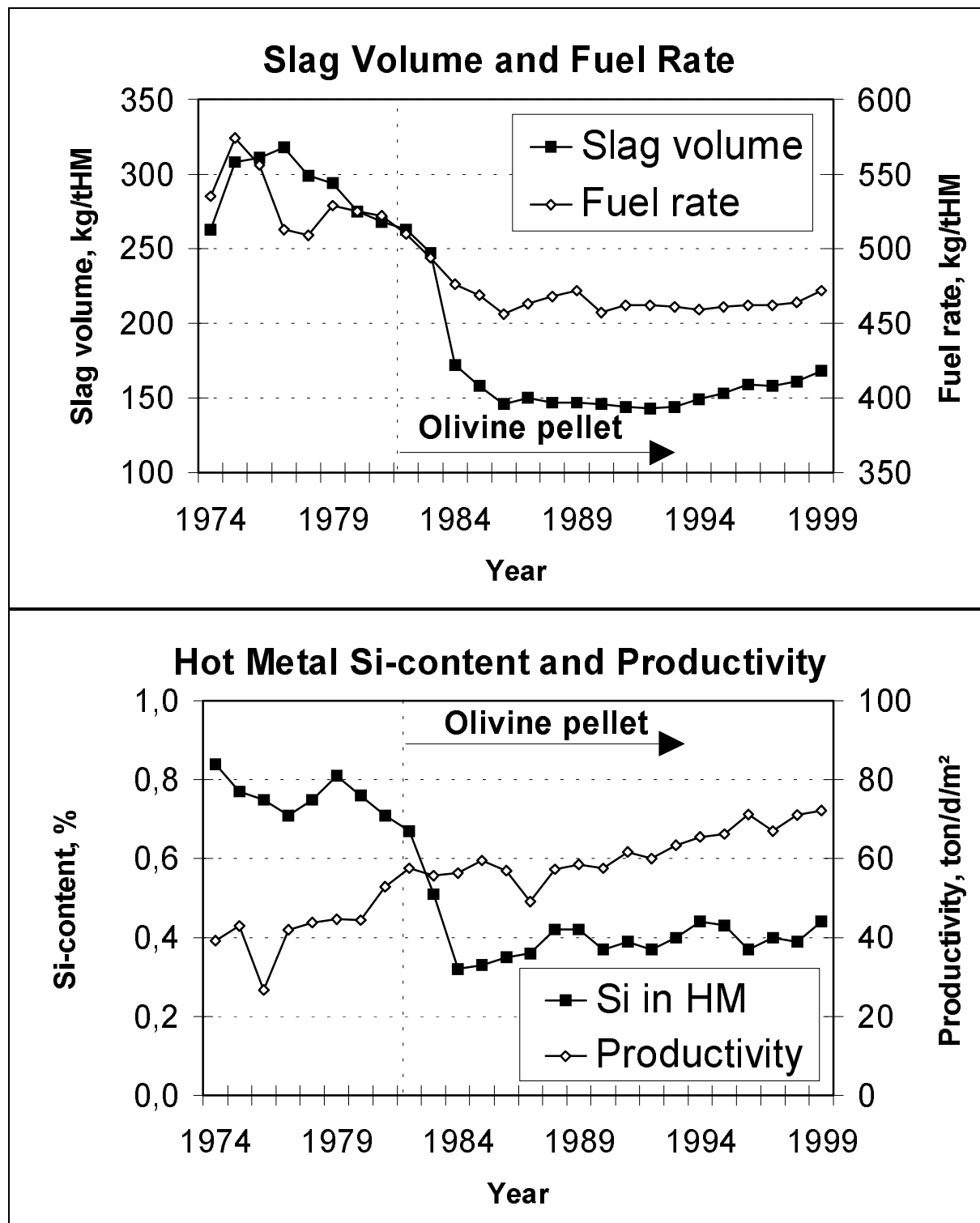


Figure 9a & b:

**Reduction of alkali and sulphur inputs and influence of slag basicity on the distribution of sulphur between slag (%S) and hot metal [%S].**

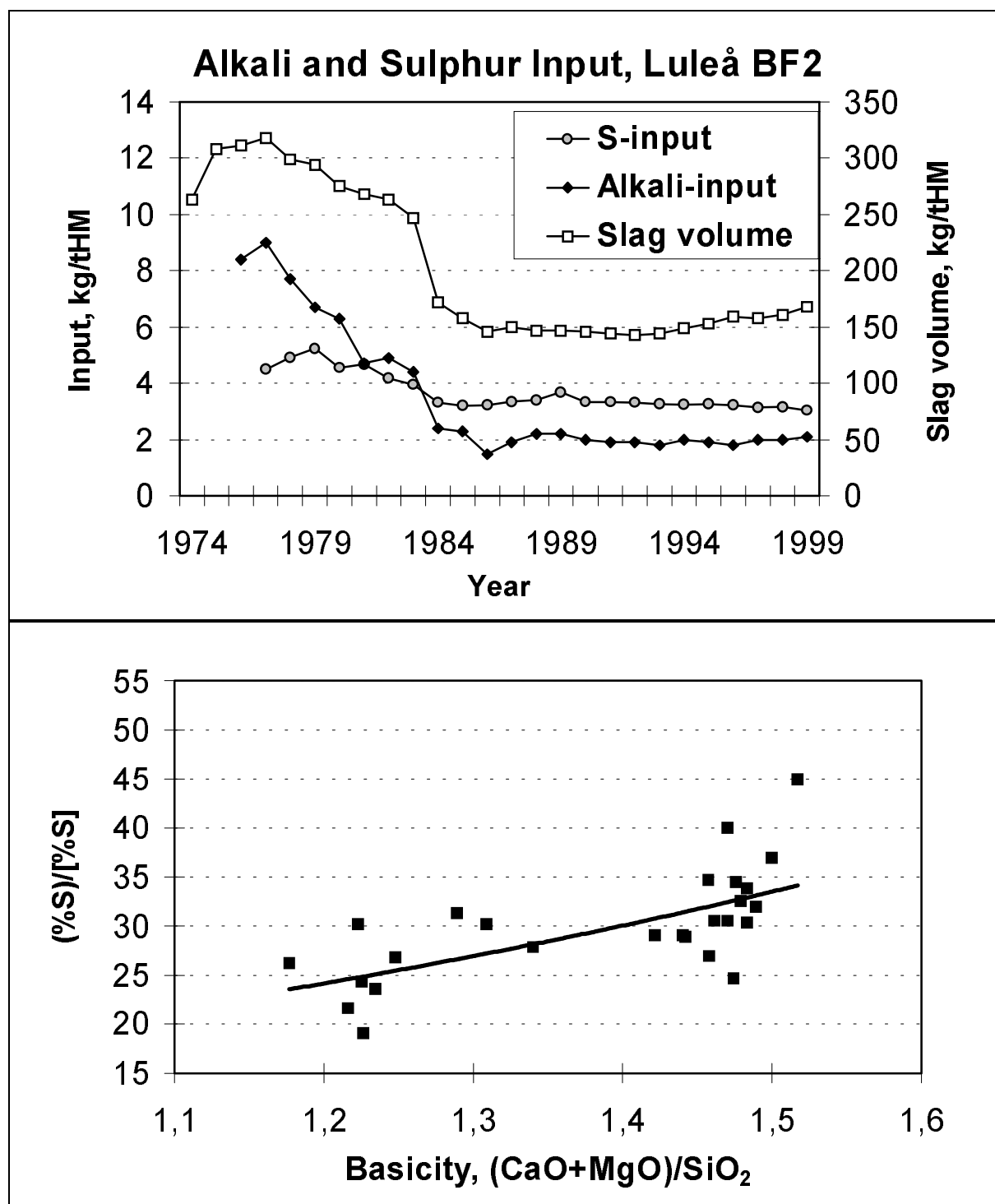
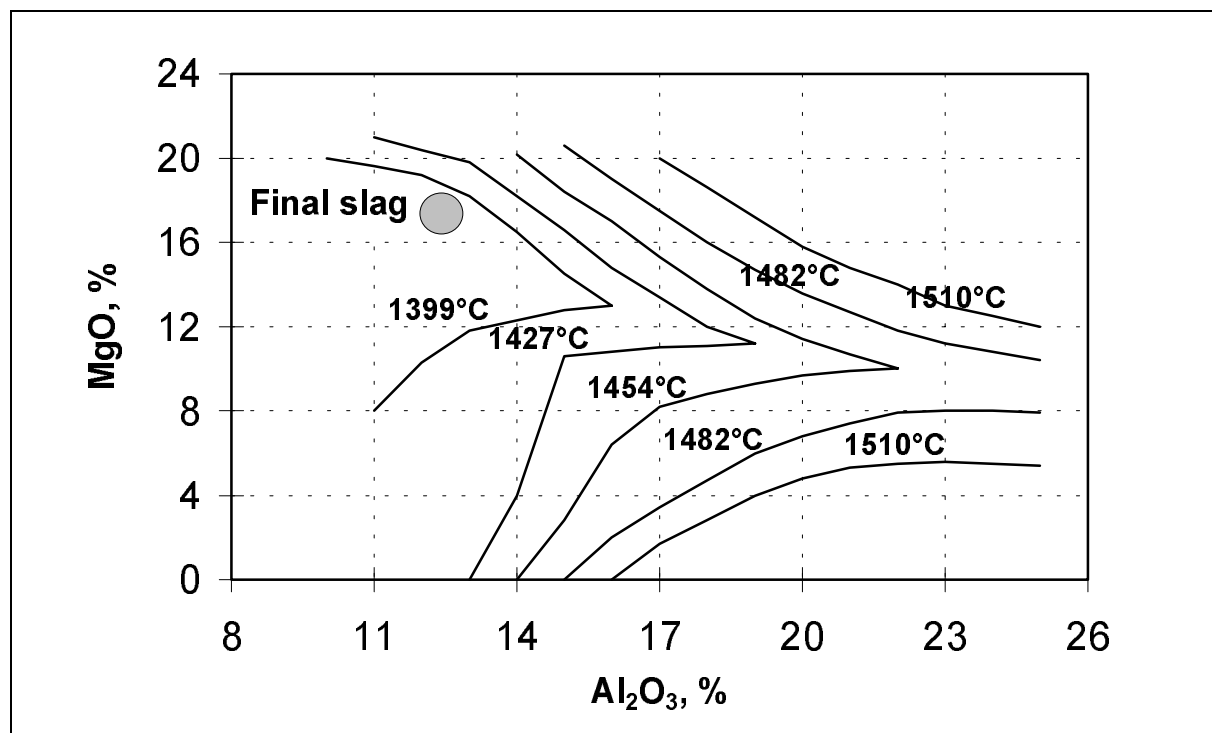


Figure 10a & b:

**Influence of MgO and Al<sub>2</sub>O<sub>3</sub> on the slag liquidus in the case of (CaO+MgO)/(SiO<sub>2</sub>+Al<sub>2</sub>O<sub>3</sub>) = 1 [6].**



**Influence of temperature and basicity on the slag viscosity at a MgO-content of 18% [7].**

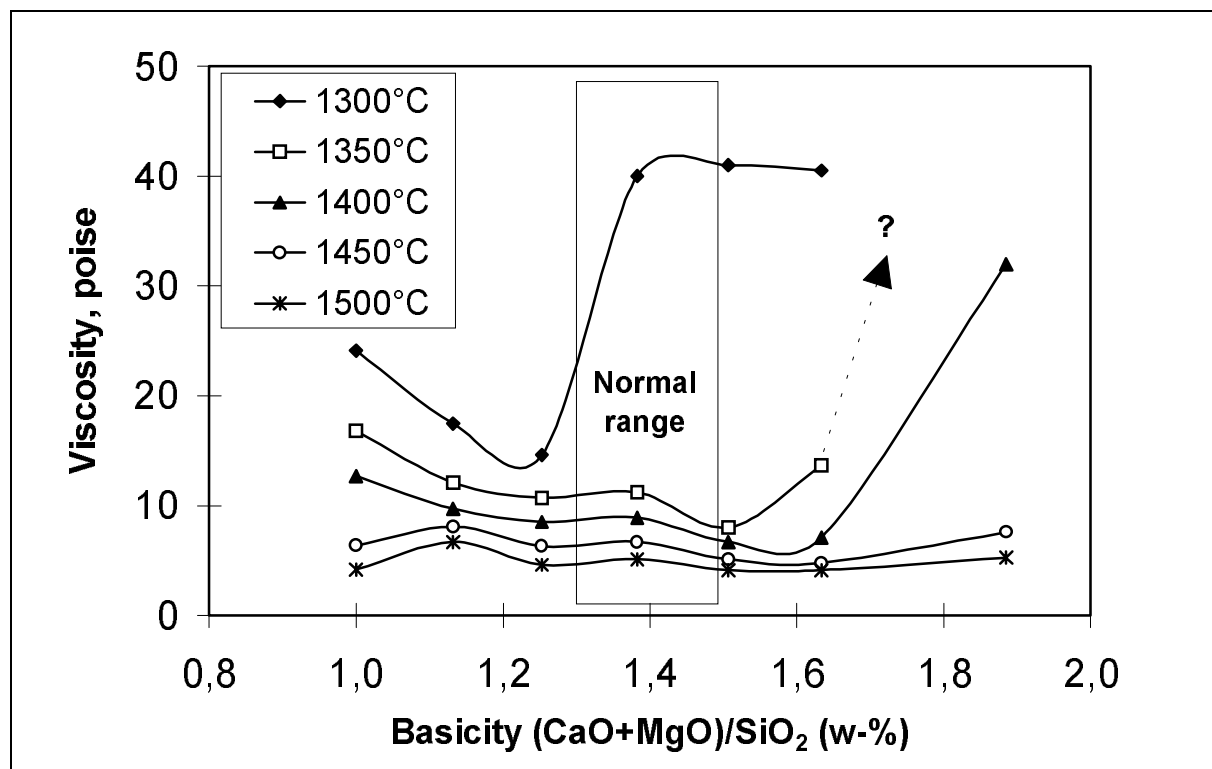


Figure 7

## The system $\text{CaO-MgO-SiO}_2$ [4].

(Note that the alumina has been added to the silica for simplicity reasons.)

Approximate compositions for burden materials and blast furnace slags in the case of an olivine pellet and additional basic slag forming materials at low slag volumes.

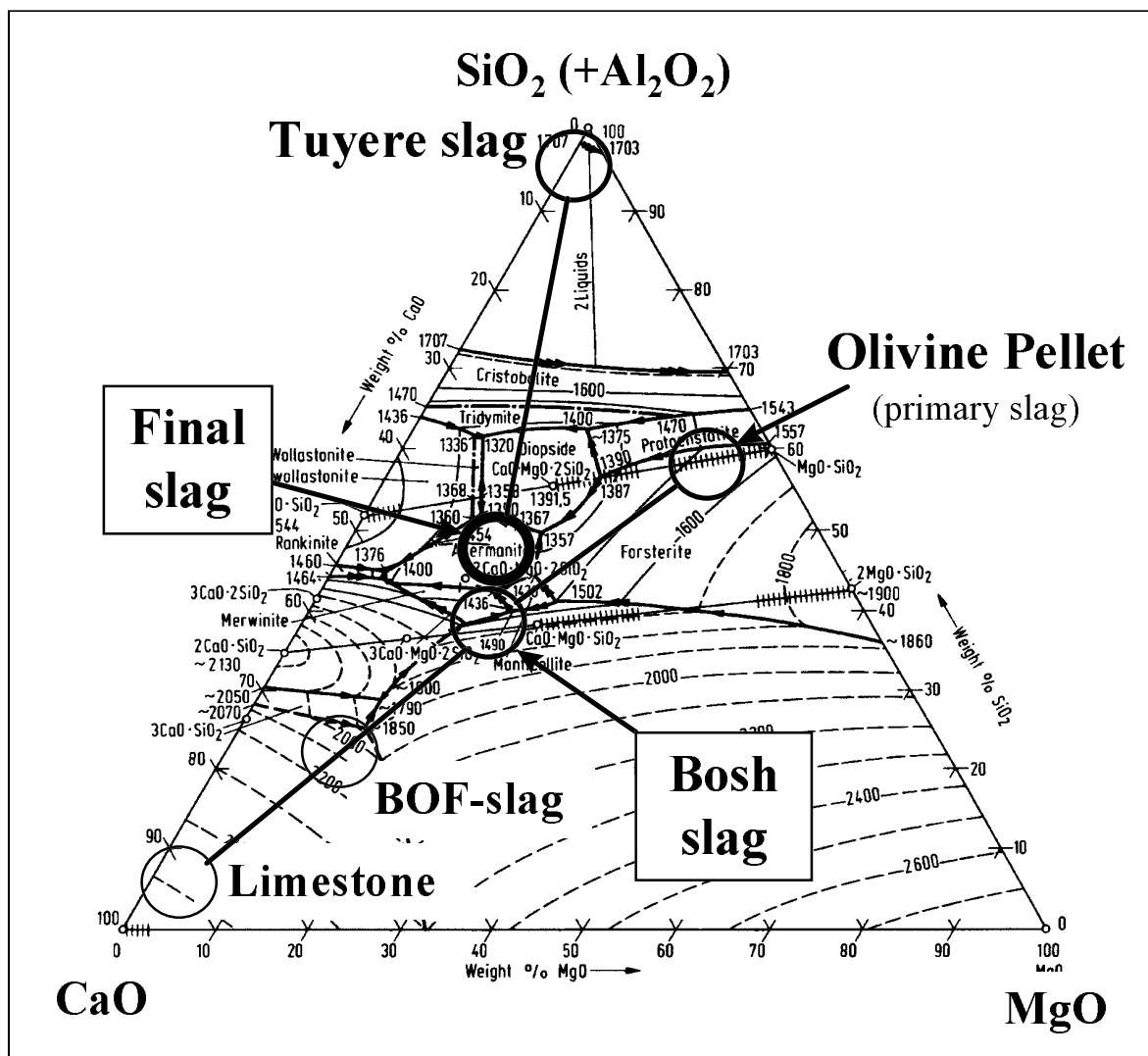


Figure 12

# Development of sinter quality for a low slag volume operation at SSAB Oxelösund.

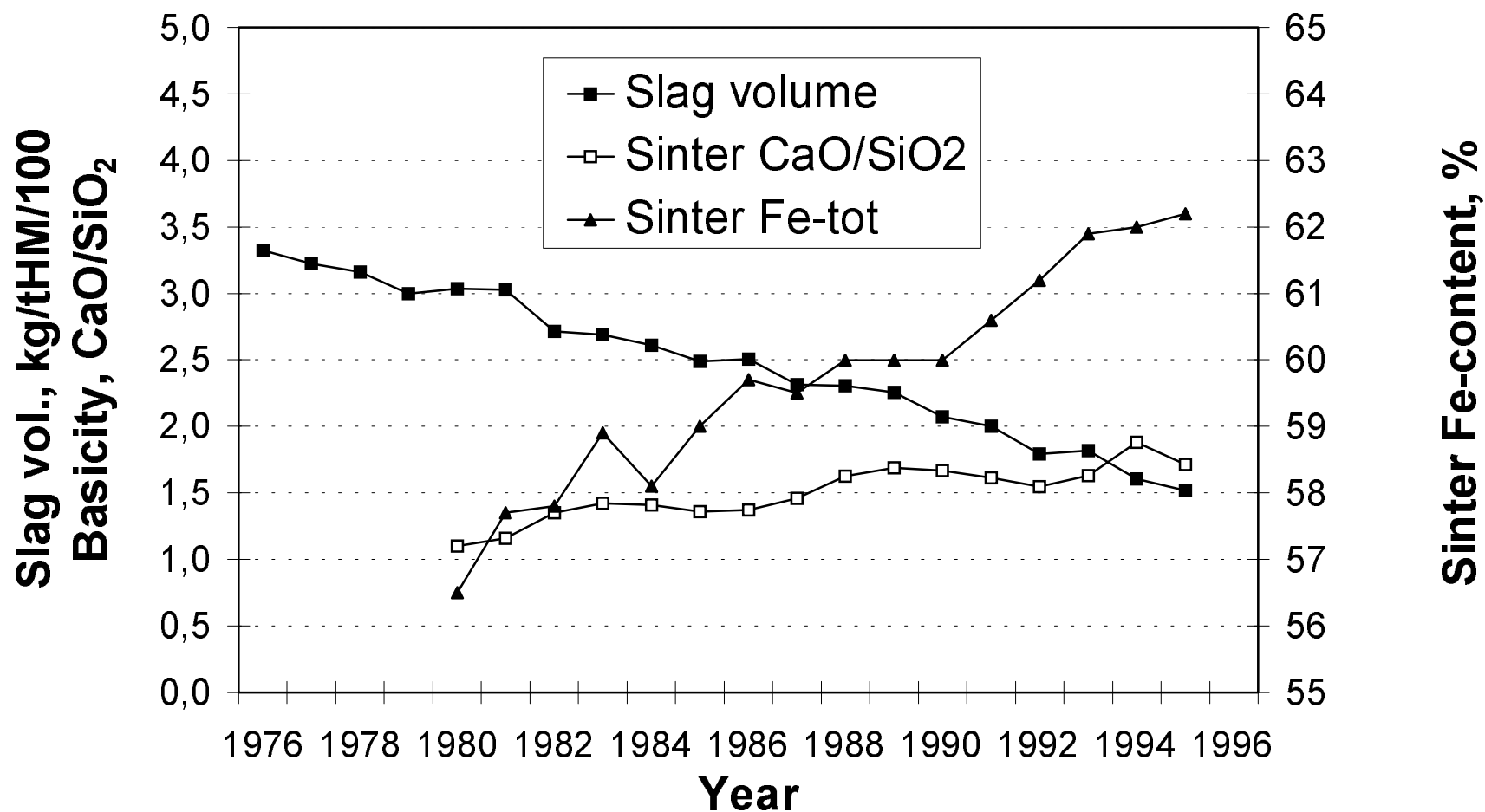
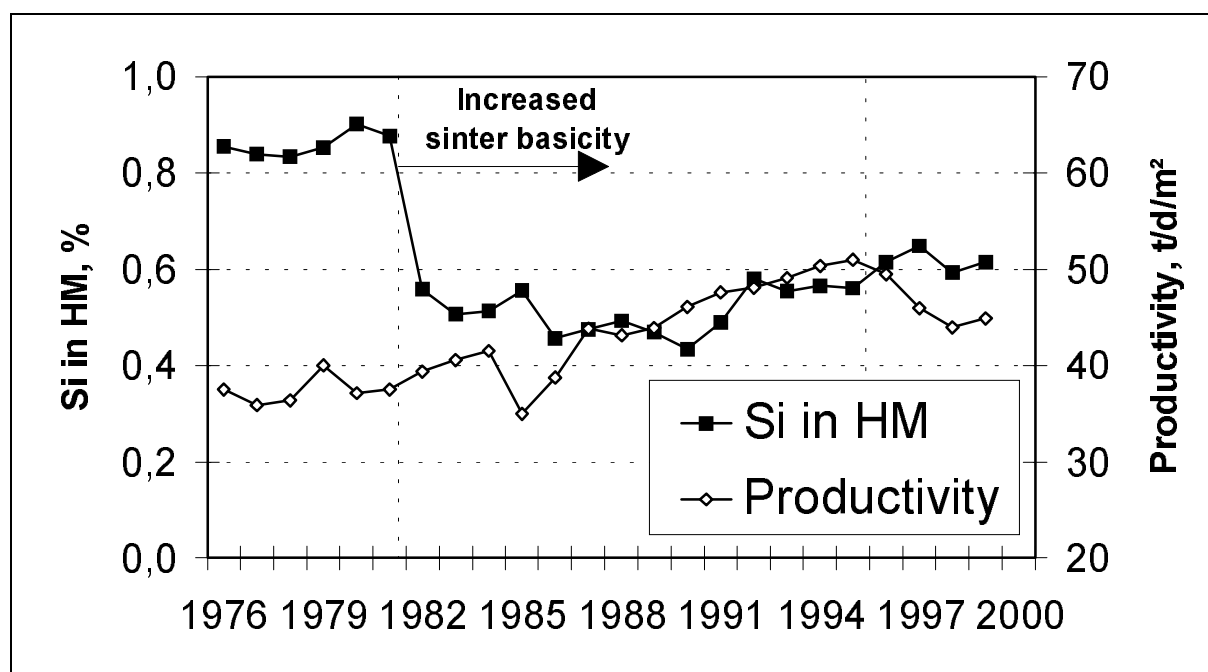
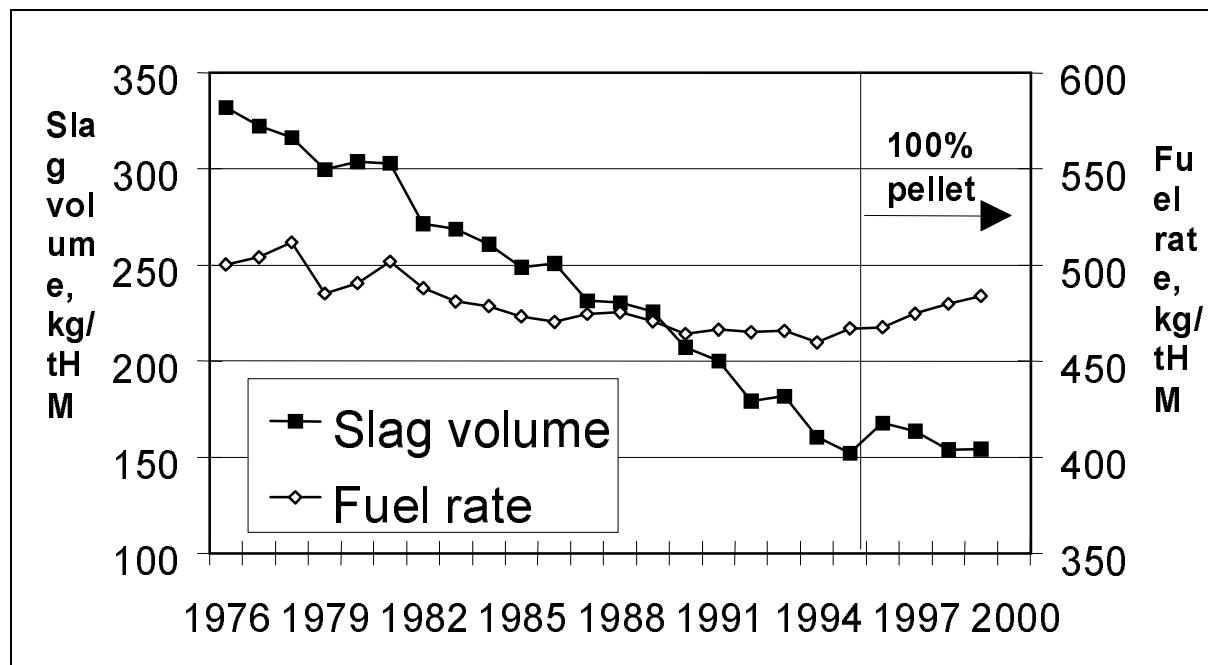


Figure 13

# **Influence of low slag volume on the blast furnace operation at SSAB Oxelösund.**



(Note that the alumina has been added to the silica for simplicity reasons.)



Figure 15

**Influence of slag volume and density on blast furnace maximum productivity, PF [9].**

$$PF = (15 \times \rho_{\text{metal}} \times \rho_{\text{slag}}) / (\rho_{\text{metal}} \times V_{\text{slag}} + \rho_{\text{slag}}), \text{ tHM/d/m}^2$$

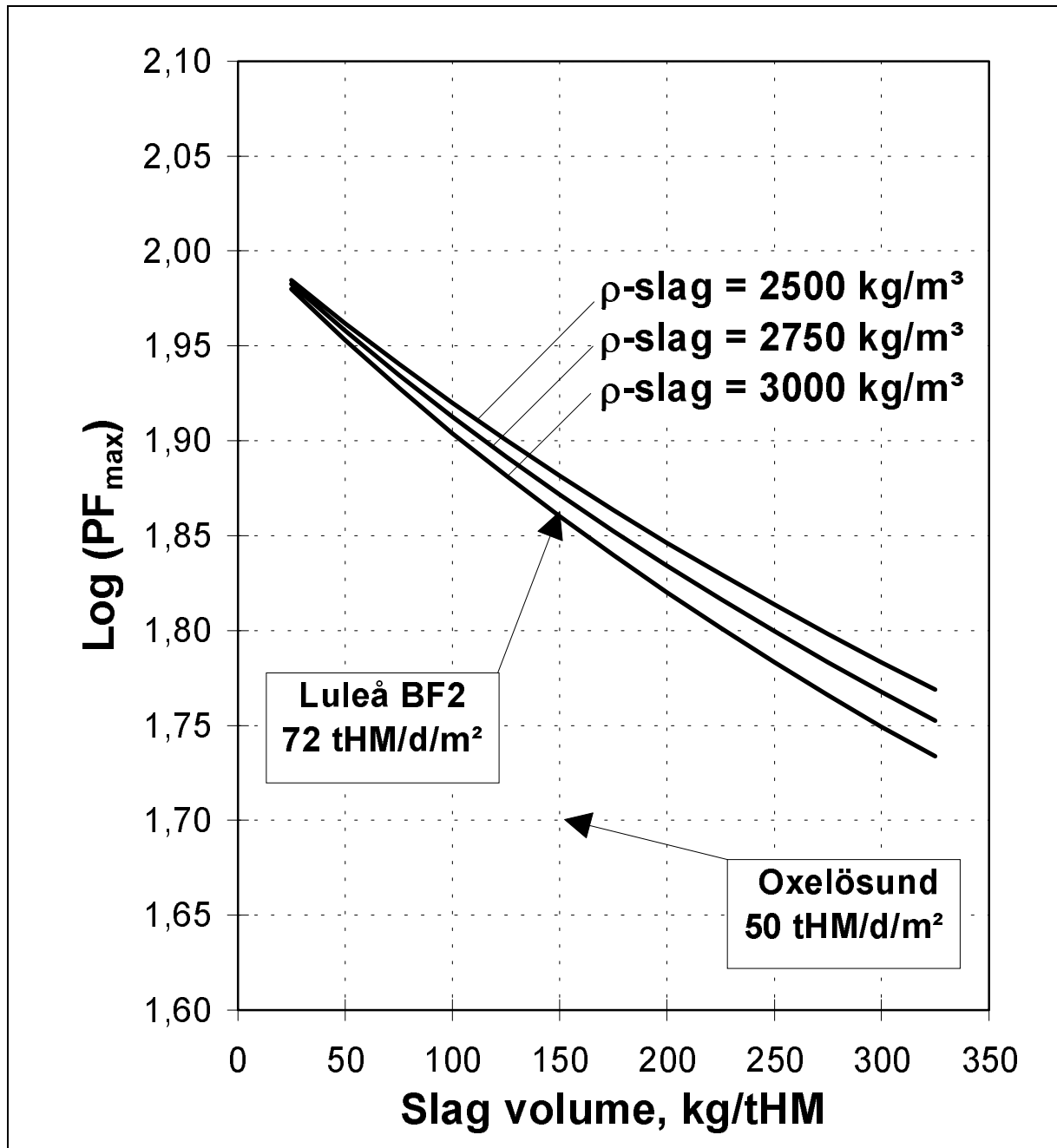
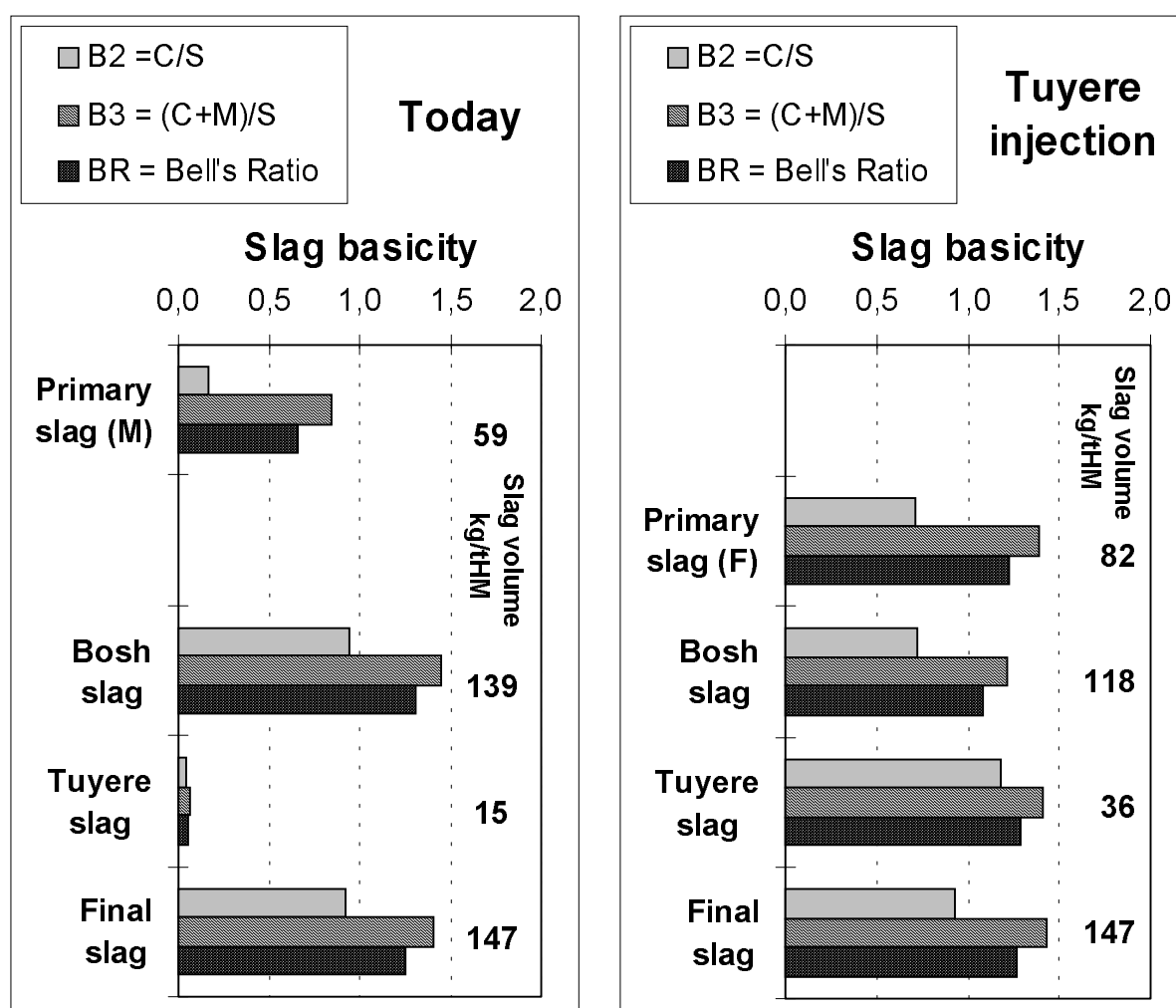


Figure 16

## Effect of tuyere injection of BOF slag on the slag formation in the blast furnace.

An example with data based on SSAB Luleå BF2, assuming injection of an amount of BOF-slag equivalent to 2/3 of today's usage and that the rest of the BOF-slag and all the limestone together with the present olivine pellet is incorporated into a "new" fluxed pellet.



**Table 1. Slag from SSAB and other EU blast furnaces.**

Parameter	Unit	Luleå	Sample	Oxelösund	EU (1998)
Volume	kg/tHM	164	-	155	254
CaO	%	32,6	33,0	30,9	39,6
MgO	%	16,8	16,3	17,2	9,2
SiO <sub>2</sub>	%	33,5	35,3	34,2	36,4
Al <sub>2</sub> O <sub>3</sub>	%	12,1	13,8	12,8	11,3
S	%	1,5	1,6	1,4	1,2
K <sub>2</sub> O	%	0,65	0,25	0,60	0,44
CaO/SiO <sub>2</sub>	-	0,97	0,93	0,90	1,09
(CaO+MgO)/SiO <sub>2</sub>	-	1,47	1,40	1,41	1,35
Optical basicity 4 components (*)		0,668	0,663	0,662	0,671
<u>Melting test:</u> - liquidus	°C	-	1336	-	-
- solidus	°C	-	1327	-	-

(\*) Optical basicity according to [11].

**Table 2. A comparison of the environmental load between roads with either gravel or blast furnace slag as road base material. (in kg during 6 years for a 11 km stretch).**

Base material	Lead	Cadmium	Arsenic	Chromium	Copper
Gravel	3 - 130	0,5 - 2	10 - 19	0,4 - 29	2 - 132
BF slag	0,44	0,03	2	0,6	< 1

**Table 3. Customer quality demands for blast furnace slag produced at SSAB Oxelösund.**

Type of slag	Application	Quality demands
<b>Granulated</b>	Binder	S<1,6%, MgO<18%, Al <sub>2</sub> O <sub>3</sub> >8,8%, CaO/SiO <sub>2</sub> >0,88%.
	Road fill	Low density favored. S<1,6%.
<b>Crushed</b>	Road fill	Must meet standards. Environmental tests including leaching is performed. S<1,6%.
	Cement	S<1,6%
	Mineral wool	S<1,6%, <1% preferred
	Fertilizer	S<1,6%