The production of creep-resistant steels with a chromium content of 1 to 3 % and a molybdenum content of 0.5 to 1 % makes particularly high demands on the minimum amounts of certain chemical elements contained in the steel, such as phosphorus, antimony, tin, arsenic, and also manganese and silicon. At the 400 to 500° C service temperature range for these steels, these elements cause embrittlement of the steel and thus a greater risk of failure. Since various specifications for these steels include an additional requirement that the steel be melted in an electric arc furnace, the following is intended to demonstrate that the electric arc furnace, due to its feed materials, incurs significant disadvantages compared to the LD converter process.

Top oxygen blowing, widely referred to as the LD converter process, and steelmaking in the electric arc furnace, are nowadays the two most widely used steelmaking processes. In Germany, LD steelmaking accounts for around 75 % of production, while the electric arc furnace is used for 25 %. The worldwide situation is rather different. In this case, LD steelmaking amounts to some 60 % of production, while practically 40 % of steel produced is made in the electric arc furnace. Other steelmaking methods, such as the open-hearth process, have only subordinate commercial significance nowadays.

The LD converter process is characterized by the fact that it functions with 80 % to 90 % liquid hot metal and 10 % to 20 % cooling scrap as its metallic charge. A large range of variation in the proportions of hot metal and scrap are possible in electric arc furnace steelmaking. With purely scrap operation at one end of the scale, the electric arc furnace can also be operated with a charge of only 30 % scrap and 70 % liquid hot metal. Under normal circumstances, however, the electric arc furnace charge should be 100 % scrap.

This signifies that the classical forms of these two steelmaking processes differ very greatly in terms of scrap input. The use of scrap simultaneously imports tramp and alloying elements into the steelmaking process. The two steelmaking processes are comparatively examined for their respective achievable tramp element contents below.

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This signifies that the classical forms of these two steelmaking processes differ very greatly in terms of scrap input. The use of scrap simultaneously imports tramp and alloying elements into the steelmaking process. The two steelmaking processes are comparatively examined for their respective achievable tramp element contents below.

The term tramp element signifies, by definition, an element which is not deliberately added to the steel or is present in the heat as a result of the process. A large number of elements may constitute tramp elements, depending on the grade of steel and on its intended subsequent use (Table 1). In many cases, the tramp elements mentioned in the table are undesirable elements which have to be removed during the steelmaking process.

Both LD converter and electric arc furnace steelmaking take place under oxidizing conditions. The question therefore arises of which of the tramp elements mentioned can be removed from the heat under the prevailing oxidizing conditions of the primary steelmaking process. The so-called Richardson-Jeffes diagram provides initial information on the affinity of the various elements for oxygen (Figure 1). This diagram shows the free formation enthalpy of the elements with oxygen for formation of the respective oxides, as a function of temperature. The following order of oxygen affinities for the elements shown here thus results at a steelmaking temperature of 1600° C: Copper has the lowest affinity for oxygen; nickel, arsenic, antimony, tin, molybdenum, phosphorus, iron, zinc and chromium (with the highest affinity for oxygen) then follow. The curve for an oxygen
partial pressure of $10^{-8}$ bar is also plotted in this diagram. This is the oxygen partial pressure which normally prevails in the steel heat during the steelmaking processes. Only oxidation of iron, zinc or chromium would thus be possible at 1600°C.

It must be stated here by way of qualification, however, that the Richardson-Jeffes diagram provides only initial information on the slagging behaviour to be anticipated from the individual tramp elements. The diagram is relevant to the actual steelmaking process only to a limited extent, since it applies only to pure elements and their pure oxides, and the tramp elements under examination here are present in the steelmaking process in dissolved and diluted form, while the oxides produced are also present in the slags in dilute form and may form complex compounds with other oxides.

If the removal of tramp elements by means of oxidation and the formation of the corresponding oxides is not possible, there remains the possibility of their removal under vacuum. The question then arises of down to what residual contents removal low pressure, i.e., evaporation from the iron heat, is possible. Figure 2 shows the vapour pressures calculated from thermodynamic data for various elements in an iron heat at 1600°C, assuming ideal behaviour, i.e., the Raoult's activity coefficient is 1. The vapour pressure of the respective element increases as dissolved contents increase. The pressures of approx. 1 mbar to 5 mbar achievable under industrially generated vacuum are also shown. It therefore follows that a reduction of nitrogen contents to around 20 ppm is possible under vacuum. Copper and tin cannot be removed under vacuum at all.

The tramp elements can be subdivided into three groups on the basis of the circumstances discussed above and of further metallurgical potentials during the secondary metallurgy phase (Figure 3). It is thus necessary to differentiate between non-removable tramp elements, tramp elements removable to a limited extent, and easily removable tramp elements. There are a large number of routes for the importation of tramp elements. Comparative analysis indicates that most tramp elements are imported with the scrap. A further significant input of tramp elements occurs in the hot metal. Scrap is the principal source of non-removable tramp elements, however. The charge scrap must be particularly carefully sorted if it is necessary to keep contents of these elements as low as possible. The consequence is, of course, correspondingly higher scrap costs.

In the case of the tramp elements removable only to a limited extent, Figure 4 shows a comparison of the residual arsenic, tin and antimony contents achievable. EAF operation with 70% alloyed plant-rejects scrap and ferrous alloys, and with sheet-metal scrap and ferrous alloys, are compared here against the LD converter process. Average arsenic contents of 70 ppm occur here in the case of poorly sorted scrap. These contents can be reduced to 50 ppm by means of preliminary scrap sorting of the EAF charge. The LD converter process produces figures of below 25 ppm. The electric arc furnace supplies values of 50 ppm and 35 ppm, respectively, for tin. The LD process achieves figures lower than 10 ppm. Antimony contents are lower than 10 ppm in both the EAF and the LD process. Here too, however, the LD converter process achieves the lower figures.

Figure 5 shows a similar assessment for achievable copper, tin, zinc and arsenic contents. Copper contents of practically 5000 ppm, i.e., 0.5%, are indicated for EAF operation with scrap only as the charge. Charging of sponge iron in the EAF makes it possible to decrease achievable copper contents by a power of ten, to around 500 ppm. Even so, the LD converter process with hot metal as the charge continues to produce significantly lower copper contents, of approx. 200 ppm. The results for tin are similar. Reduction of zinc and arsenic concentrations can also be achieved in the electric arc furnace via the use of pre-reduced charge material, starting from 100% scrap charging.
The EAF produces significantly higher overall figures than the LD converter process in this case, too, however. Finally, we should examine the capacity of the two steelmaking processes for removal of phosphorus. Figure 6 shows the metallurgical principles of phosphorus transfer into the slag for a steel temperature of 1700° C with a lime-saturated slag, the iron content of which is 22 %. LD converter operation with an MgO content of 2 % in the converter slag, a slag quantity of 100 kg and a hot metal phosphorus content of 0.09 % is assessed against EAF operation with a 10 % MgO content in the EAF slag, 60 kg slag, and a phosphorus input equating to a phosphorus content of 0.04 %.

A phosphorus content of less than 100 ppm, i.e., below 0.01 %, can be achieved in the crude steel using both process routes. The lower phosphorus input into the electric arc furnace via the scrap compared to the higher phosphorus content of the hot metal charged in the LD process must be set, on the one hand, against the lower amount of slag in the EAF process. In addition, it is widespread production practice to operate electric arc furnaces with higher MgO contents in the slag. This procedure is intended to counteract premature refractory wear. The higher MgO contents also impair dephosphorization, however. The result is that neither of the two processes offers any advantage in terms of achievable phosphorus contents. Lower phosphorus contents can be attained in the EAF only if this furnace is operated in a relatively expensive manner, with lower MgO contents in the slag and larger slag quantities. In the case of the LD converter process, it is possible, on the one hand, to reduce phosphorus input into the LD process by appropriate selection of BF feed materials and, on the other hand, to use the two-converter process for achievement of ultra-low phosphorus contents of less than 50 ppm. These variants of the two processes can definitely not be regarded as acceptable everyday practice, however, since they all give rise to correspondingly high costs.

It can be stated, by way of summary, that the EAF process incurs significant disadvantages vis-à-vis the LD converter process in terms of achievement of low non-removable tramp element contents. This signifies that, in general, tungsten, copper, molybdenum, nickel and cobalt contents in steel from the EAF are higher than in the case of LD steelmaking. The electric arc furnace also produces higher tin, arsenic and antimony contents than the LD converter process. There is no significant difference between the two processes in terms of achievable phosphorus contents; phosphorus contents of below 50 ppm can be achieved by means of additional provisions in EAF operation, involving artificially raised slag quantities, and in the LD converter process, using the two-stage converter system.

References

2. VDEh Werkstoffausschuß, Arbeitskreis Begleitelemente in Edelbaustählen, March 7, 1995
Definition tramp element:

A tramp element signifies an element which is not deliberately added to the steel or is present in the heat as a result of the process.

Depending on the grade of steel the following elements may constitute tramp elements:

- Si, P, S
- Cr, Mo, Ni, Cu
- Nb, V, Ti
- Al, N
- B, As, Sn

Gibb's enthalpy of formation as a function of temperature

Vapour pressure for various elements in an iron heat
### Importation of tramp elements in steel and their removal

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- **Non-removable**
- **Removable to a limited extent**
- **Easily removable**

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### Comparison of the residual tramp elements for EAF- and BOF-process

- **EAF with 70% alloyed plant-rejects scrap + ferrous alloys**
- **EAF with sheet-metal scrap and ferrous alloys**
- **BOF process**

**Figure: 4**
Residual content in EAF steel versus sponge iron ratio compared to BOF process\textsuperscript{5)}

Figure: 5

Straight-line chart for the determination of achievable phosphorus contents (T=1700\textdegree C, Fe=22%)  

Figure: 6