By adapting models and technologies used in stainless steel making Uvån Hagfors Teknologi AB (UHT) has been able to create an environment for development, process control and production management which is unmatched in the ferroalloy sector. UHT’s solutions include the combined blown CLU-process, the UTCAS-process control system as well as general converter design details and production technologies common in stainless steelmaking but not yet adopted in the ferroalloy sector.

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Photo Uvån Hagfors Teknologi AB

Production of MC FeMn and LC FeMn by decarburization of HC FeMn is a metallurgical challenge due to the low oxygen potential and high vapor pressure of Mn. To reach carbon levels of below 2%, decarburization has to be performed at high temperatures. By diluting the partial pressure of CO - in the same manner as for stainless steel refining – decarburization is performed at more reasonable temperatures and lower final carbon contents can be achieved.

To minimize losses to slag and vaporization of Mn, the main focus during decarburization is on temperature control. The CLU process is a unique tool in this respect. Through the availability of steam as a process gas, dilution of the partial pressure of CO and the decomposition of steam favours the fundamentals for the decarburization.

**Metallurgy fundamentals of manganese refining**

The most important reactions to describe the decarburization process are:

\[
\begin{align*}
  C + \frac{1}{2} O_2 (g) &\Rightarrow CO (g) \quad (1) \\
  Mn + \frac{1}{2}O_2 (g) &\Rightarrow MnO \quad (2)
\end{align*}
\]

The sum reaction is expressed as:

\[
C + MnO \Rightarrow Mn + CO (g) \quad (3)
\]

Also important is the effect of the Mn evaporation:

\[
Mn(l) \Rightarrow Mn(g) \quad (4)
\]

The carbon removal is favoured by a high temperature, low CO partial pressure, high MnO activity in the slag, high C activity in the metal and low Mn activity in the metal. Added oxygen is mainly distributed between MnO and CO formation. The MnO formation
in Combined

Equilibrium partial pressures of CO and Mn for typical FeMn-refining systems have been calculated and published by Olsen et al [2]. The data have been used to create figure 1.

Figure 2 shows that decarburization to a level of about 1.3% C can only be reached if the process temperature is above 1,800 oC at a CO partial pressure of 1 bar. At 1,800 oC, the partial pressure of Mn is 0.44 bar.

By reducing the CO partial pressure to 0.5 bar the same carbon level, i.e. 1.3%, can be reached at a process temperature of 1,700 oC. At this temperature the partial pressure of Mn is only 0.28 bar.

The CLU Mn refining concept

The CLU refining concept is a combined blowing technique in a converter vessel. Oxygen is blown through a top lance to the surface of the metal and oxygen, steam and argon is blown through submerged tuyeres from the bottom of the converter. At lower carbon concentrations, the carbon removal requires a dilution of the CO partial pressure which is performed by blowing inert gas through the submerged tuyeres. The inert gas lowers the partial pressure of the carbon monoxide PCO , eq. 1. Due to the low vapor pressure of manganese, the Mn-gas also assists in lowering PCO.

\[ P_{CO} = \frac{Q_{CO}}{(Q_{CO} + Q_{Inertgas} + Q_{Mn})} \times P_{tot} \quad \text{eq. 1} \]

The addition of an inert gas however also decreases the partial pressure of manganese, eq.2.

\[ P_{Mn} = \frac{Q_{Mn}}{(Q_{CO} + Q_{Inertgas} + Q_{Mn})} P_{tot} \quad \text{eq. 2} \]

For this reason, the manganese vapor losses increase as the inert-gas amounts increase, given that the CO formation and temperature are constant.

As the carbon level decreases, the formed manganese vapor acts as an important inert gas and assists in lowering the partial pressure of CO. This enables top-blowing to lower carbon concentrations than would otherwise be possible - but at a cost of increased Mn losses.

The submerged oxygen reacts with carbon according to mechanisms described in papers about the AOD-process [4]. Inert gas is blown in increasing I(g)/O2-ratio as the carbon content decreases. This gives the side effect that the partial pressure of Mn - PMn - decreases with an increasing evaporation rate of manganese.

![Fig 1. Equilibrium pressures for finalization of FeMn refining.](image1)

![Fig 2. The hot spot behaviour in top blown FeMn refining.](image2)
By combining top and submerged blowing, the positive effect of the hot spot and high oxygen flow rates can be utilized at high carbon contents with high carbon removal efficiency and moderate manganese losses. At lower carbon contents, the decarburization is finalized with submerged blowing only.

**Temperature control**

As discussed above, the formed CO along with the temperature forces Mn to vaporize. The vaporization itself is not only an in-situ inert gas provider but an important temperature controller in this system as it is strongly endothermic.

In the CLU process, steam is used as a process gas. When steam is injected in the metal it is reduced according to reaction (5) while consuming heat.

\[
H_2O(g) \rightarrow H_2(g) + \frac{1}{2}O_2(g) \quad (5)
\]

Formed hydrogen gas acts as an inert gas while the oxygen takes part in the carbon oxidation.

A particular advantage of steam in this respect is that steam is relatively cheap compared to argon which is the main inert gas alternative in the lower carbon regimes of the process. As the solubility of nitrogen is high in manganese, nitrogen gas cannot be used unless nitrided products are being made.

**Development opportunities**

During 2009 the UTCAS model package was updated with a manganese vaporization model based on thermodynamic data.
by Kolbeinsen and Lee [10,11]. This model has been able to predict carbon removal and manganese loss for a number of different process configurations, and for a wide range of raw materials and products. Results from a typical combined blown refining simulation of a 20 t HC FeMn meltdown to 0.2% C is displayed in Figure 3. As discussed previously, the loss of Mn as vapor becomes very high at low carbon concentrations, and this is also true for losses of Mn to the slag. Even if it is possible to prolong the blowing past 0.2% C it is hardly practical as the slag amount and vapor losses then become unreasonable.

Ferroalloy refining is a closed world with limited interaction between the different plants. The protection of technologies is fierce and thus there is room for improvement in most plants by letting new solutions in. UHT’s technology does not infringe on any other patent or license and is available for any producer who is interested in it. This is unique for this environment where the tradition is for the technology owner to also be the producer.

Given the present situation where over 1,000,000 tonnes of electrolytic manganese is used at a total consumption of 6,000 kWh/ton, and comparing it with the use of ULC FeMn [12] that is produced with half the electricity demand, there should be a significant opportunity to grow the LC and ULC FeMn market with the right tools for efficient production.

**Fig 3. Refining of HC FeMn to 0.2% C.**

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**Usvan Hagfors Teknologi AB**

UHT AB is a privately-owned company and was founded in 1927 from the engineering department of Uddeholm Technology AB.

UHT AB provides engineering, processes, systems and machines to the iron and steel industries and their raw material suppliers.

UHT AB mainly focuses on granulation in the Granshot process and refining using AOD and CLU processes, an area in which the UTCAS level 2 process control system is a key product.

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**Fundamentals of the CLU converter process**

The CLU converter process was developed in the early 1970’s. Steam is used as an additional process gas in the CLU process. The use of steam makes the CLU process flexible with several benefits, such as, reduced consumption of high cost argon gas and possibilities for improved energy management in the converter.

The fundamentals of using steam in the process lie in the reduction of steam. The effect of steam is two-fold. When superheated steam is introduced in the converter it is decomposed into oxygen and hydrogen according to reaction:

\[ H_2O(g) \rightarrow H_2(g) + \frac{1}{2}O_2(g) \quad DH = +241.9 \text{kJ/mol} \]

The formed hydrogen gas acts as an inert gas while the oxygen takes part in the carbon oxidation.

The second effect comes from the fact that the reduction of steam is an endothermic reaction and consumes heat. This means an additional cooling benefit is obtained by utilizing steam in the process. In ferromanganese production this is a very valuable feature as temperature control is vital in order to minimize manganese vaporization.