

Materie Prime

Minerali



Altoforno



Convertitori



Operazioni fuori forno



Colata

Rottami



Forni elettrici

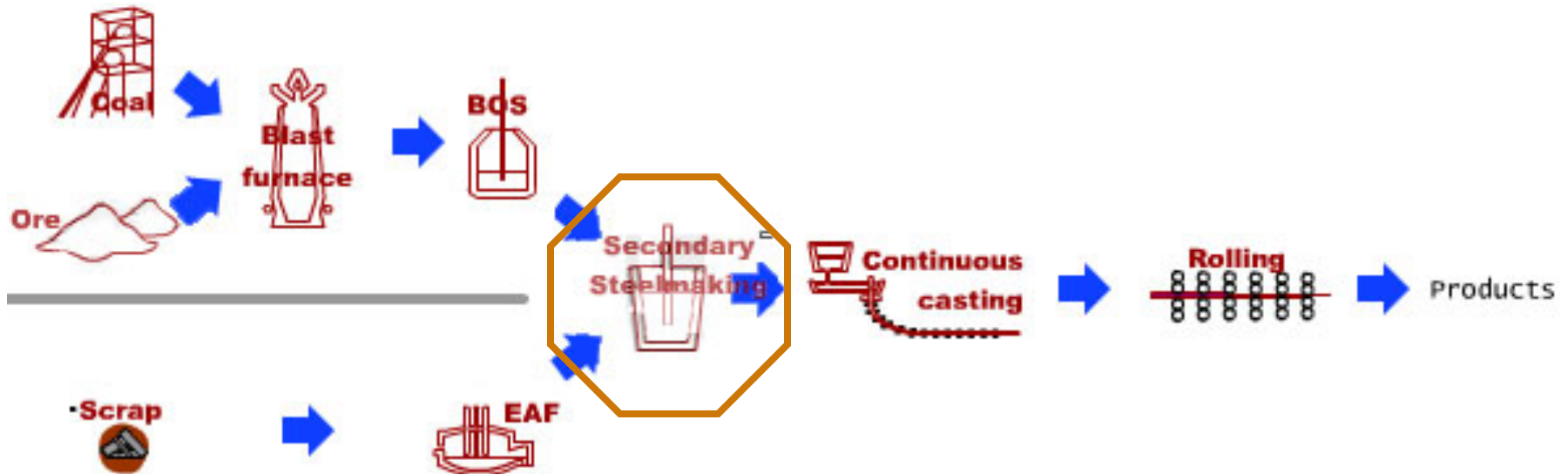


OPERAZIONI FUORI FORNO - SECONDARY STEEL MAKING

On completion of primary steel making (either in the Basic Oxygen Furnace or Electric Arc Furnace), the molten steel is 'tapped' into a ladle and transported to the casting facility.

While in the ladle, the steel may be subjected to a number of different treatments, such as composition adjustments, stirring, degassing and reheating.

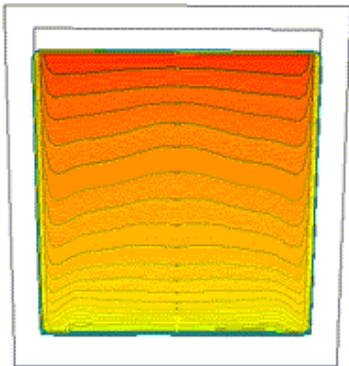
The most important functions of secondary refining are final desulfurization, degassing of oxygen, nitrogen, hydrogen, etc., removal of inclusions, and final decarburization for ultra-low carbon steel.



The final steel chemistry and casting temperature from a basic oxygen furnace (BOF) or electric arc furnace (EAF) is attained by secondary steel making or secondary metallurgy.

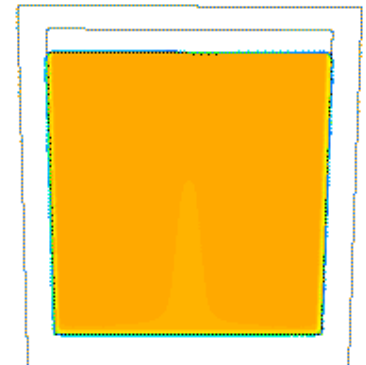
As the liquid steel is tapped from the furnace, tap-time additions and heat loss create a highly dynamic thermo-physical process in the liquid bath. During the subsequent holding period, the liquid layers in the ladle undergo thermal stratification resulting from natural convection.

Thermal stratification is detrimental to quality casting. Tap temperature, holding time, ladle preheat and ladle life significantly influence the rate of stratification. **Argon gas purging through the liquid steel bath helps to generate enough bath turbulence to cause rapid thermal homogenization. Stirring with argon also enhances the mixing rate for chemical additions.**



T. after 20 min holding of a 130 ton steel ladle

T. after 3 min of homogenization by bottom purging of Ar through the steel ladle



DEOXIDATION

Deoxidation is one of the most important processes in secondary steel making

Why deoxidize? The oxygen content of liquid steel in the ladle at the start of the secondary steel making process is 400-1000 ppm (0.04 - 0.1%).

The solubility of oxygen in liquid steel is 0.16% but in solid steel it is only 0.003% therefore, steps have to be taken to reduce the O₂ content (deoxidize) of the steel before it solidifies in order to prevent blowhole formation during casting and a porous product being created or large quantities of FeO being precipitated.

Sources of oxygen

O₂ enters the liquid steel in a number of different ways

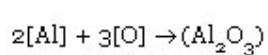
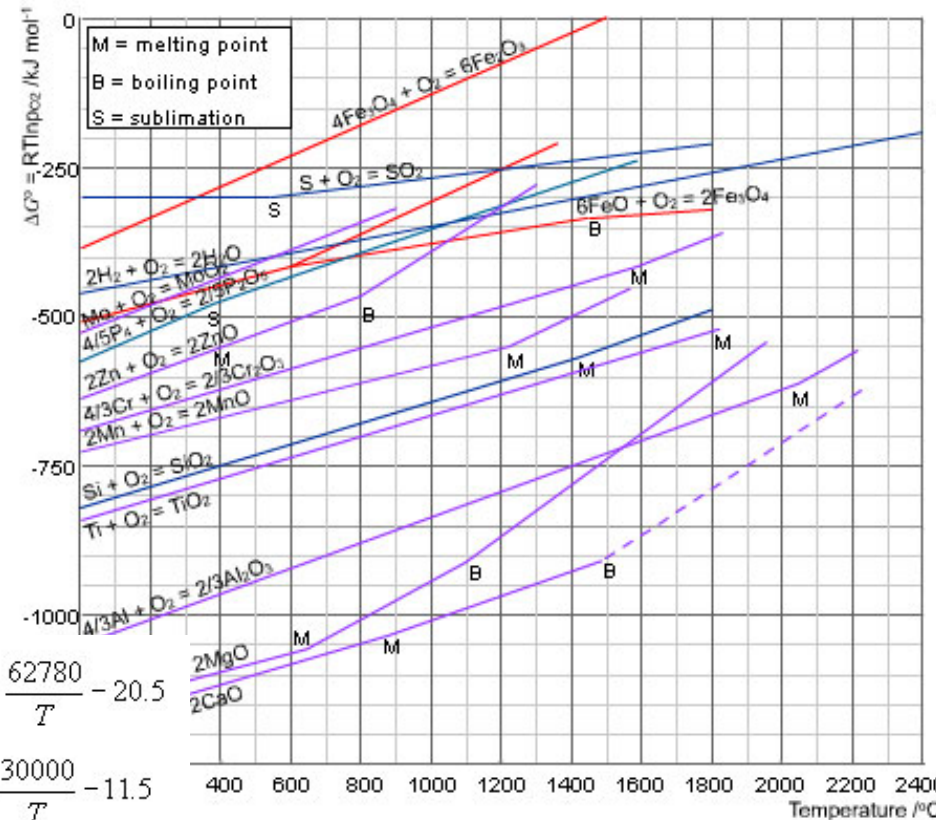
Which one is the most important?

Atmosphere	X	No, but this is one of the sources.
Dissociation of water	X	No, but this is one of the sources.
Oxygen added to primary steelmaking vessel (BOS or EAF)	✓	Yes
The Blast Furnace	X	No, but this is one of the sources.
Rusty scrap	X	No, but this is one of the sources.
Slag		
Iron ore	X	No, but this is one of the sources.
Refractories	X	No, but this is one of the sources.

REDUCING THE OXYGEN CONTENT

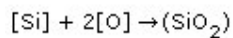
The addition of a strong oxide forming element is the most commonly used method of reducing the oxygen content of liquid steel.

The use of the Ellingham diagram can help you decide which of the following may be suitable (cheapest) choices for this.



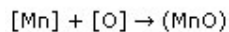
$$K_{\text{Al-O}} = \frac{a_{\text{Al}_2\text{O}_3}}{a_{\text{Al}}^2 \times a_{\text{O}}^3}$$

$$\log K_{\text{Al-O}} = \frac{62780}{T} - 20.5$$



$$K_{\text{Si-O}} = \frac{a_{\text{SiO}_2}}{a_{\text{Si}} \times a_{\text{O}}^2}$$

$$\log K_{\text{Si-O}} = \frac{30000}{T} - 11.5$$



$$K_{\text{Mn-O}} = \frac{a_{\text{MnO}}}{a_{\text{Mn}} \times a_{\text{O}}}$$

$$\log K_{\text{Mn-O}} = \frac{12440}{T} - 5.33$$

Steel cleanliness

There are a variety of sources of inclusions:

indigenous (small):

» deoxidation product and MnS

exogenous (large)

» reoxidation (reaction with air or slag)

» entrainment of slag

» eroded refractories

Inclusions are formed by chemical reactions (deoxidation, reoxidation and precipitation) or by physical conditions (turbulence or wear).

Most inclusions have a detrimental effect on properties. Solid oxides (alumina or certain calcium aluminates) can cause nozzle blockage during continuous casting and disrupt the process and have to be burnt out. Some inclusions can cause cracking and defects, slivers and delamination in rolled products and also fracture during hot/cold forming and wire drawing.

Which of the following are examples of non-metallic inclusions?

Al_2O_3	Yes
CO	No
MnO	Yes
SiO_2	Yes
MnS	Yes
TiN	Yes
Mn	No

To understand the AOD process, it is necessary to examine the thermodynamics governing the reactions that occur in the refining of stainless steel, that is, the relationship among carbon, chromium, chromium oxide (Cr_3O_4), and carbon monoxide (CO).

The overall reaction in the decarburization of chromium-containing steel can be written as:



The equilibrium constant, K , is given by:

$$K = \frac{(a_{\text{Cr}})^{3/4} (P_{\text{CO}})}{(a_{\text{Cr}_3\text{O}_4})^{3/4} (a_{\text{C}})}$$

At a given temperature, there is a fixed, limited amount of chromium that can exist in the molten bath that is in equilibrium with carbon.

By reducing the partial pressure of CO , the quantity of chromium that can exist in the molten bath in equilibrium with carbon increases.

.

The partial pressure of CO can be reduced by injecting mixtures of oxygen and inert gas during the decarburization of stainless steel.

Figure 1 illustrates the relationship among C, Cr, and temperature for a partial pressure of CO equal to 1 and 0.10 atm (1000 and 100 mbar, or 760 and 76 torr).

The data shown in Fig. 1 indicate that diluting the partial pressure of CO allows lower carbon levels to be obtained at higher chromium contents with lower temperatures

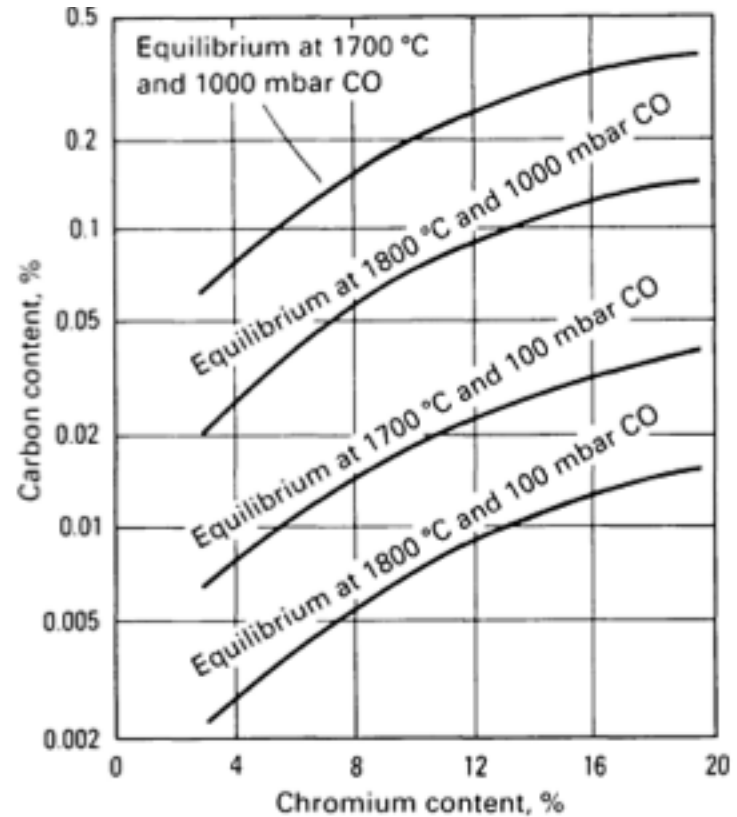


Fig. 1 Carbon-chromium equilibrium curves

Dopo Convertitore.

- Acciaio colato in siviera a $T=1600^{\circ}\text{C}$,
- composizione chimica: C% 0.2-0,05 dipende dal grado ossidazione totale: C%=0,05, parziale: C% = 0,2

Durante riempimento siviera →

Nel caso degli acciai dolci (acciai per usi generali secondo UNI) vengono fatte:

- a) aggiunte metalliche \Rightarrow composizione dell'acciaio a quella stabilita,
- b) aggiunte di leghe silicio-manganese o alluminio-manganese-silicio \Rightarrow fluidificano il bagno passando nella scoria, \Rightarrow eliminano *parte (acciai effervescenti) o tutto (acciai calmati), l'ossigeno contenuto,*



(il contenuto di ossigeno controlla la qualità finale dell'acciaio)

Nel caso degli altri acciai (*acciai speciali*) \Rightarrow **elaborazioni fuori forno** :

- produzione di acciai puliti, a composizione chimica stabilita.
- Operazioni a complessità crescente in funzione dei requisiti di qualità richiesti all'acciaio (pipelines, off-shore, componenti per propulsori ecc.)

ELABORAZIONI FUORI FORNO (metallurgia secondaria)

- *Trattamenti dell'acciaio fuso al termine della conversione o dopo fusione nel forno elettrico fatti in secchia o in altre stazioni,*
- usati in origine per gli acciai speciali, progressivamente applicati agli acciai di massa man mano aumentavano le potenze dei forni elettrici, (fusione in tempi brevi). In queste condizioni, infatti, è conveniente eliminare l'affinazione dal forno di fusione e portarla in siviera,
- circa il 70% degli acciai sottoposto ad elaborazioni fuori forno

Trattamenti:

- *decarburazione*
- *riduzione dei gas: ossigeno, idrogeno, azoto;*
- *riduzione degli elementi nocivi: P,S;*
- *riduzione delle inclusioni non metalliche minimizzando quelle pericolose: ammassi di allumina e solfuri, controllo della grandezza e forma delle inclusioni;*
- *tolleranze composizionali molto strette per assicurare costanza nelle proprietà;*
- *superfici di elevata qualità ed omogeneità anche su scala microscopica.*

Come si eseguono: a pressione atmosferica o sotto vuoto

- 1) *producendo estese superfici di reazione in fase eterogenea: liquido – scoria di opportuna composizione; insufflaggio di polveri nella massa liquida tramite veicolo gassoso;*
- 2) *rimescolando la massa metallica liquida con agitazione elettromagnetica o con insufflaggio di gas inerte;*
- 3) *esposizione della massa metallica liquida a bassa pressione (trattamenti sotto vuoto).*

B) Rifusione sotto vuoto: vengono effettuate in:

- forni ad induzione sotto vuoto (VIM: vacuum induction melting)
- forni ad arco sotto vuoto (VAR: vacuum arc remelting) ad elettrodo consumabile \Rightarrow metallo fuso colato in lingotti fino a 10 t

- operano senza scoria
- la composizione non può essere modificata;
- degassificazione spinta,
- eliminazione delle inclusioni non metalliche

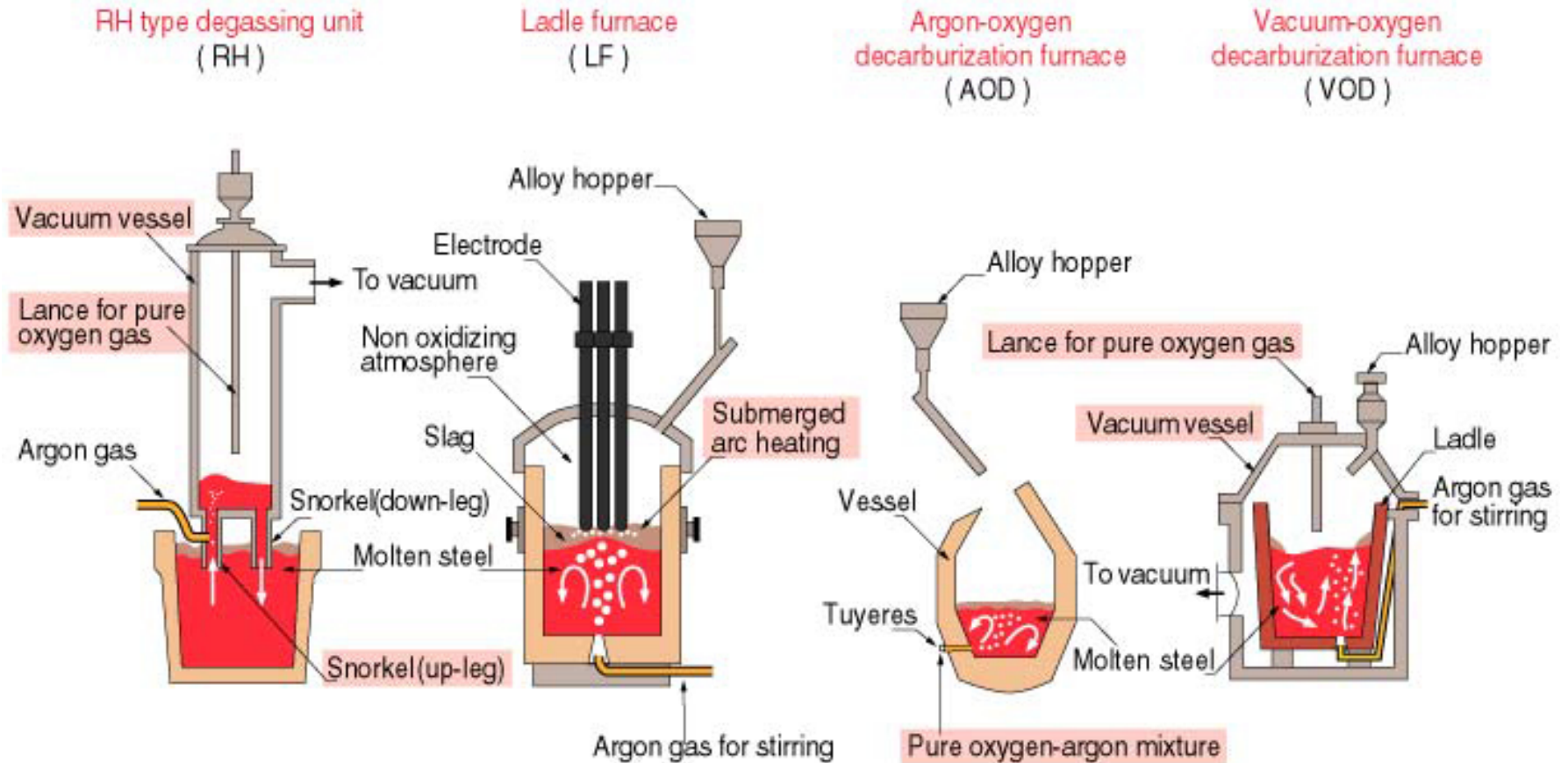
- forni di rifusione sotto scoria fusa (Electro Slag Remelting):

fusione dell'elettrodo consumabile immerso nella scoria fusa;

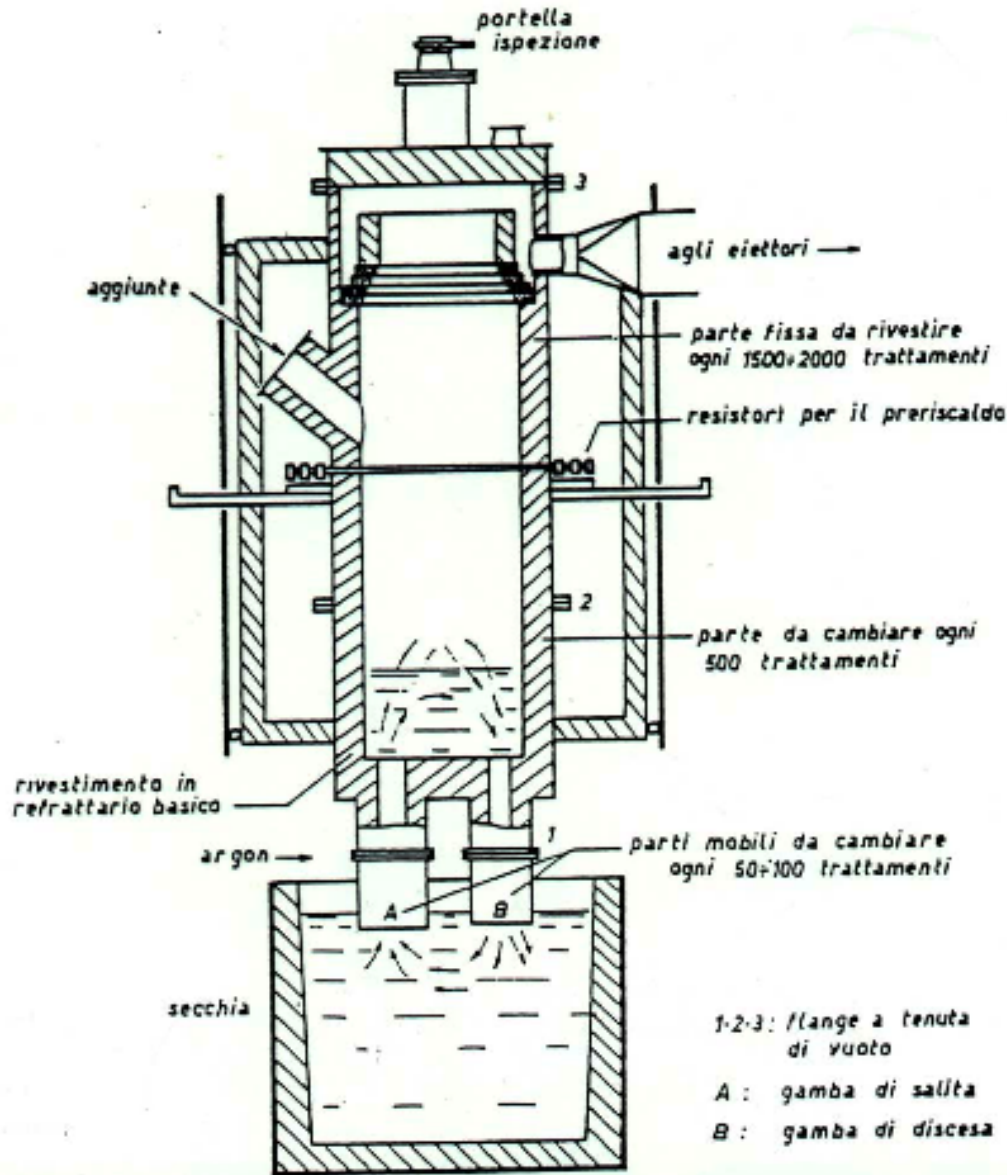
CaF_2 forma una scoria adatta: con aggiunta di allumina e calce \Rightarrow defosfora e desolfora, ($\text{S} \rightarrow 0,002\%$).

- *non agisce sui gas disciolti in particolare su H_2 .*

Typical Facilities for Secondary Refining

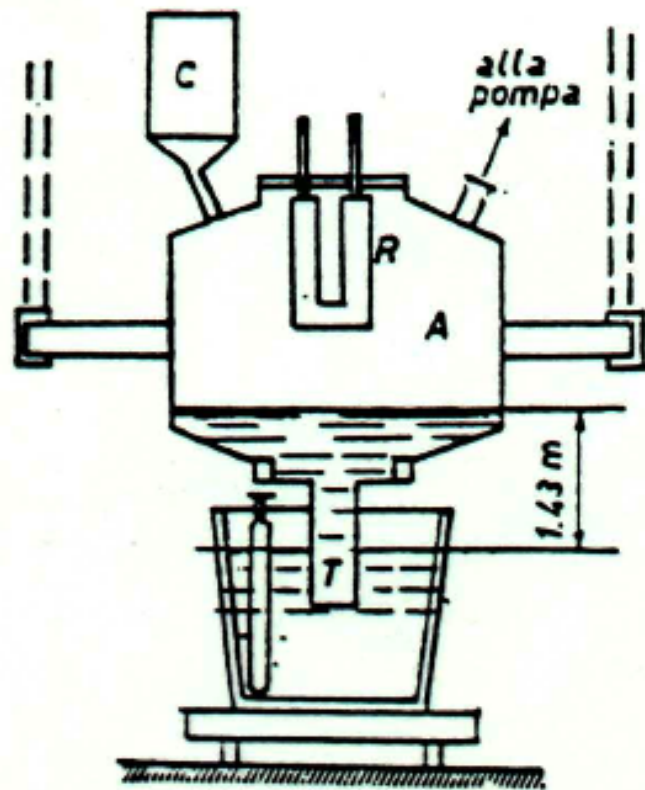


Schema Di elaborazione per circolazione sotto vuoto Ruhrstahl-Heraeus

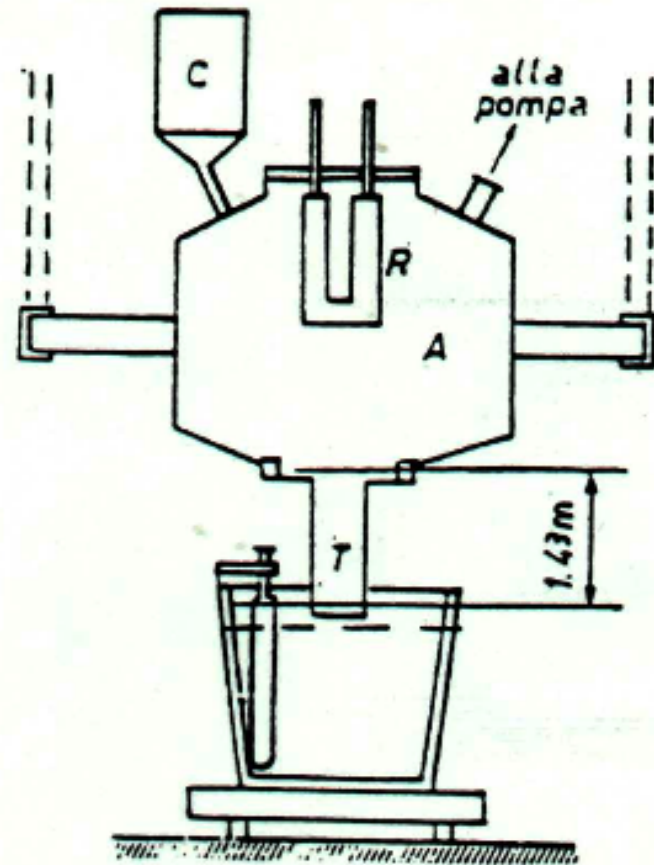


The RH equipment injects Ar into one (suction tube) of the two tubes (snorkels) immersed in the molten steel in the ladle, and the molten steel in the ladle is drawn through the suction tube into the vacuum vessel by the operation of air-lift pumping. After being exposed to the vacuum in the vessel, the molten steel flows back into the ladle through the down snorkel. Since the recirculation rate is relatively high, the RH process is suitable for rapid degassing of a large amount of molten steel.

Schema del processo Dortmund-Hörder per l'elaborazione per circolazione sotto vuoto



(a)



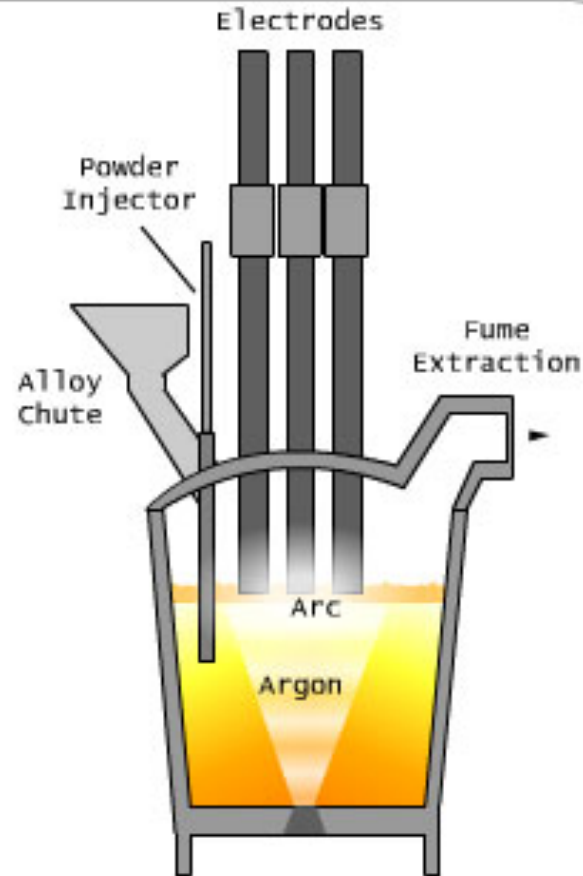
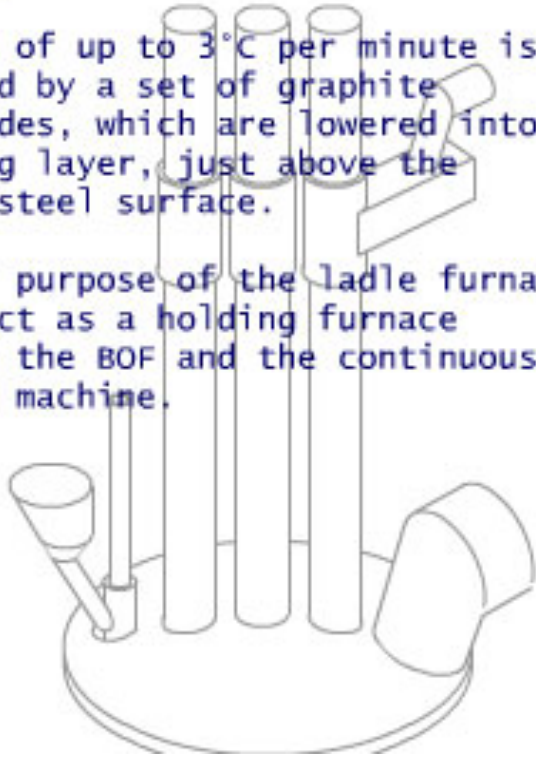
(b)

Ladle (Arc) Furnace

The ladle furnace is used to heat the steel. Argon bubbling is applied to homogenize the steel composition and temperature.

Heating of up to 3°C per minute is achieved by a set of graphite electrodes, which are lowered into the slag layer, just above the molten steel surface.

Another purpose of the ladle furnace is to act as a holding furnace between the BOF and the continuous casting machine.



The LF equipment offers strong heating functions, permits the addition of a large amount of alloys, and enables precise temperature control. It also provides outstanding desulfurization by high-temperature treatment with reducing fluxes and the removal of deoxidation products.

Recirculating Degasser with O₂ Top-Blowing Lance

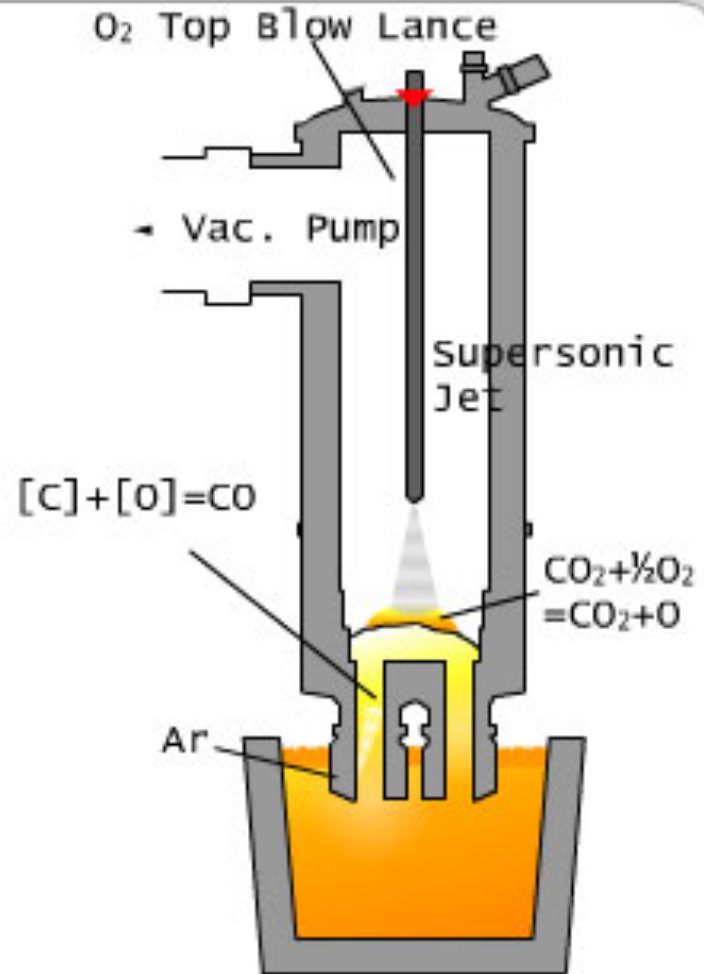
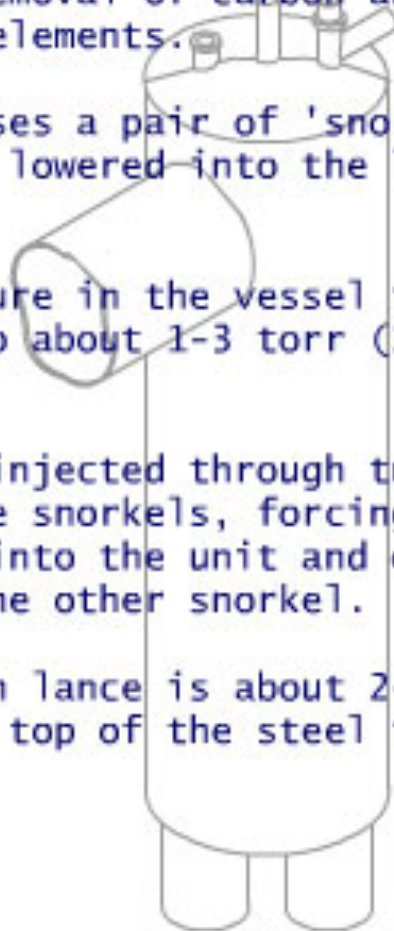
The Recirculation Degasser is used for the removal of carbon and other impurity elements.

It comprises a pair of 'snorkels' which are lowered into the liquid steel.

The pressure in the vessel is reduced to about 1-3 torr (1 torr = 1 mmHg).

Argon is injected through tuyeres in one of the snorkels, forcing the steel up into the unit and out again through the other snorkel.

The oxygen lance is about 2-3 m above the top of the steel in the unit.



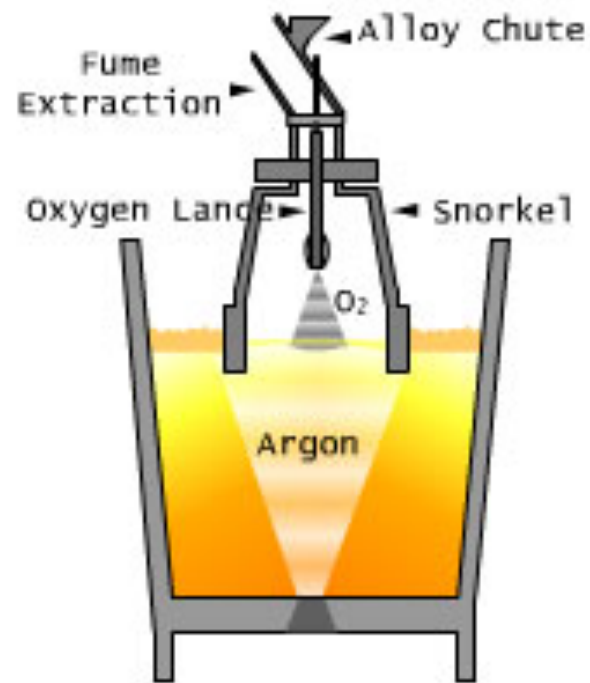
CAS-OB

The CAS-OB (Composition Adjustment by Sealed Argon Bubbling - Oxygen Blowing) allows alloy additions to be made under an inert argon environment.

The unit is lowered onto the liquid steel over an 'eye' in the slag formed by argon bubbling.

In particular, it allows the simultaneous addition of Al and O₂ gas blown through a top lance. These react to form Al₂O₃ plus considerable exothermic heat energy - the steel temperature can be raised by up to 10°C per minute.

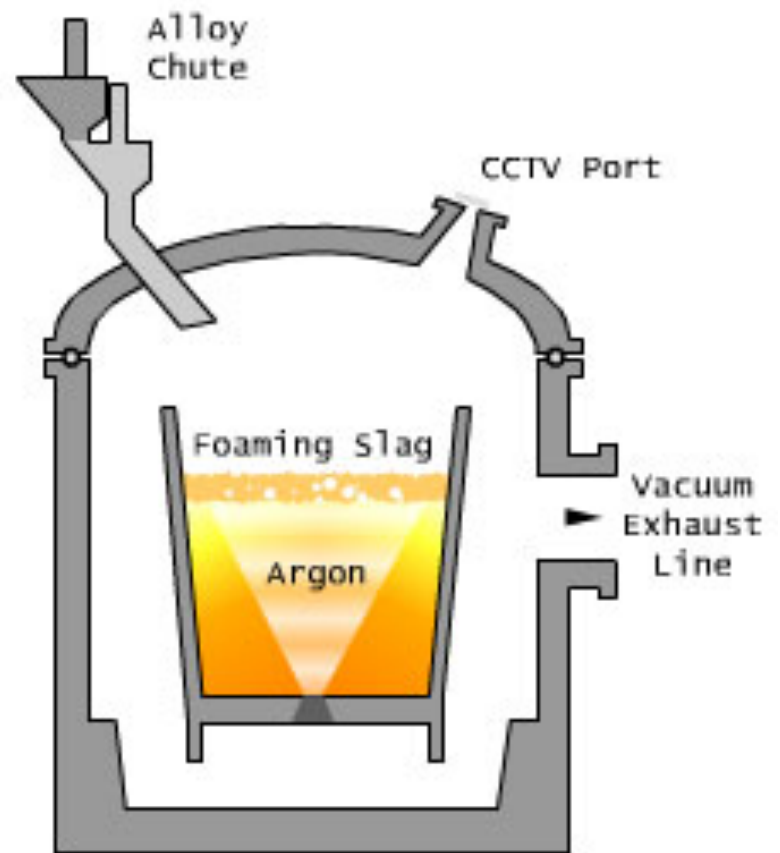
The CAS-OB is therefore used for CHEMICAL REHEATING. Note however that the Al₂O₃ must subsequently be removed.



Degassing Tank

The tank degasser is used to remove gaseous elements and sulfur from the steel.

The removal of sulfur is achieved through slag-metal reactions, which are promoted by strong argon 'flushing' (bubbling) within the vacuum envelope.



CLEAN AND ULTRACLEAN STEELS

The production of liquid metal under vacuum in an induction-heated crucible is a tried and tested process (**VIM**)

Vacuum induction melting can be used to advantage in many applications, particularly in the case of the complex alloys employed in aerospace engineering.

The following advantages have a decisive influence on the rapid increase of metal production by vacuum induction melting:

- Flexibility due to small batch sizes
- Fast change of program for different types of steels and alloys
- Easy operation
- Low losses of alloying elements by oxidation
- Achievement of very close compositional tolerances
- Precise temperature control
- Low level of environmental pollution from dust output
- Removal of undesired trace elements with high vapor pressures
- Removal of dissolved gases, for example, hydrogen and nitrogen

INDUCTION FURNACES

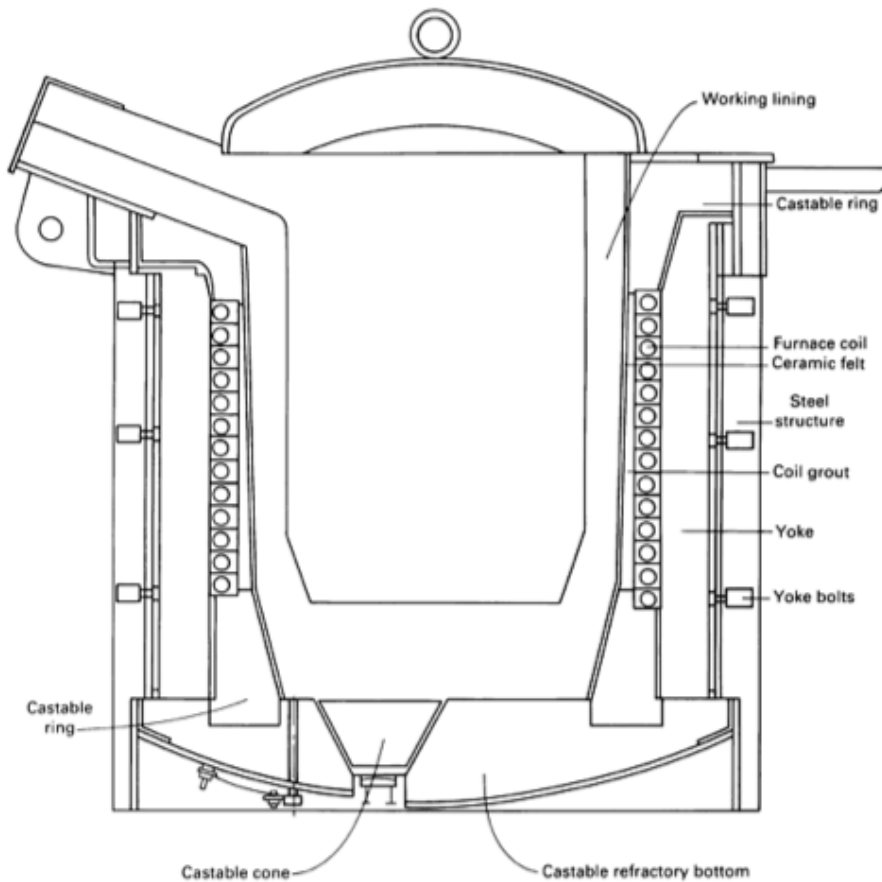


Fig. 1 A cross section of a coreless-type induction furnace showing water-cooled copper induction coil and key structural components. The entire molten metal bath (which serves as the secondary) is surrounded by the coil (the primary) that encircles the working lining.

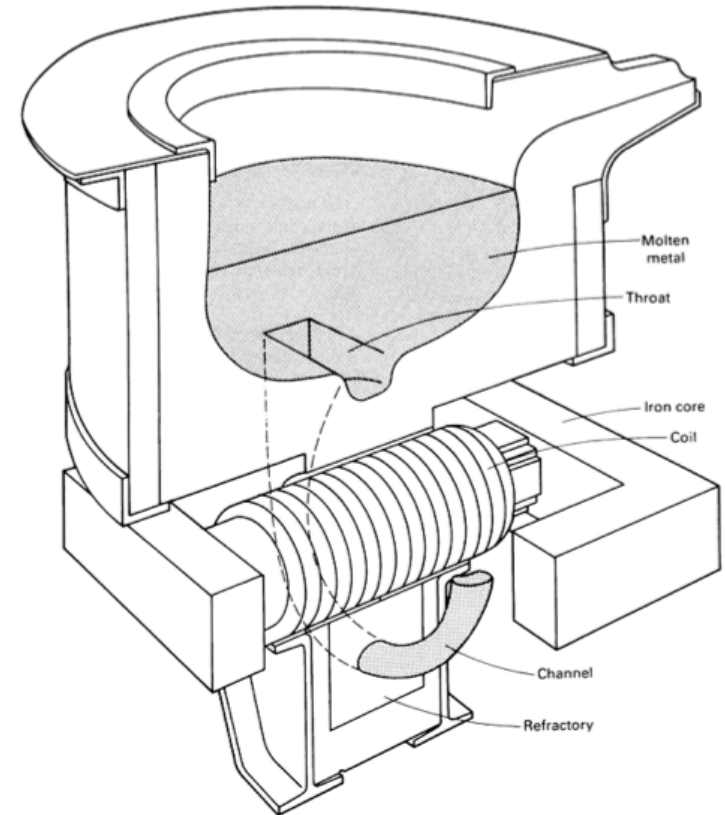
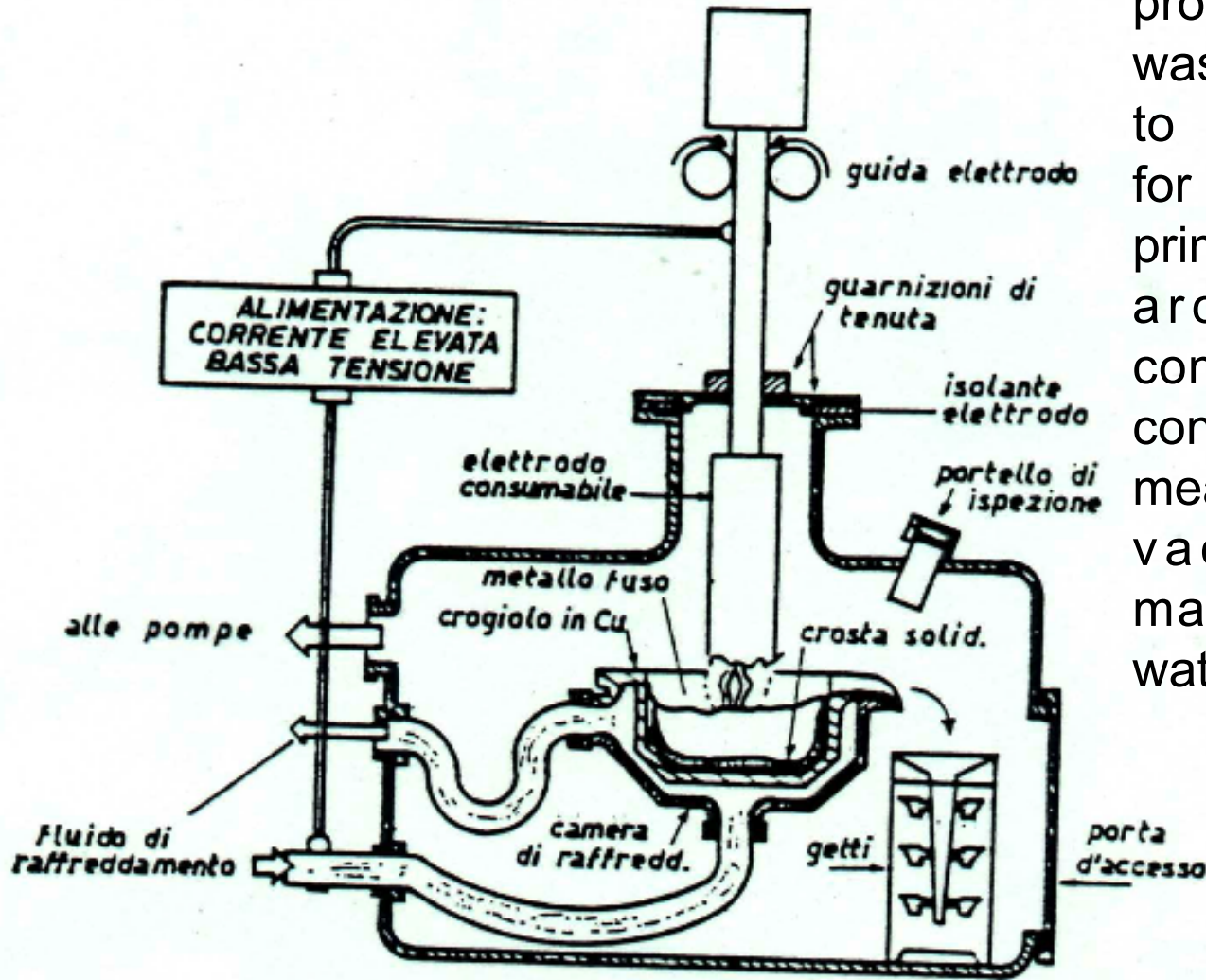


Fig. 2 A cross section of a channel-type induction furnace showing the water-cooled copper induction coil, which is located inside of a 360° loop formed by the throat and channel portion of the molten metal vessel. It is the channel portion of the loop, which serves as the secondary of the electrical circuit in which the copper coil is the primary.

VAR (Vacuum Arc Remelting)



The VAR process was the first commercial remelting process for superalloys. It was used in the late 1950s to manufacture materials for the aircraft industry. The primary feature of vacuum arc remelting is the continuous melting of a consumable electrode by means of a dc arc under vacuum. The molten material solidifies in a water-cooled copper mold.

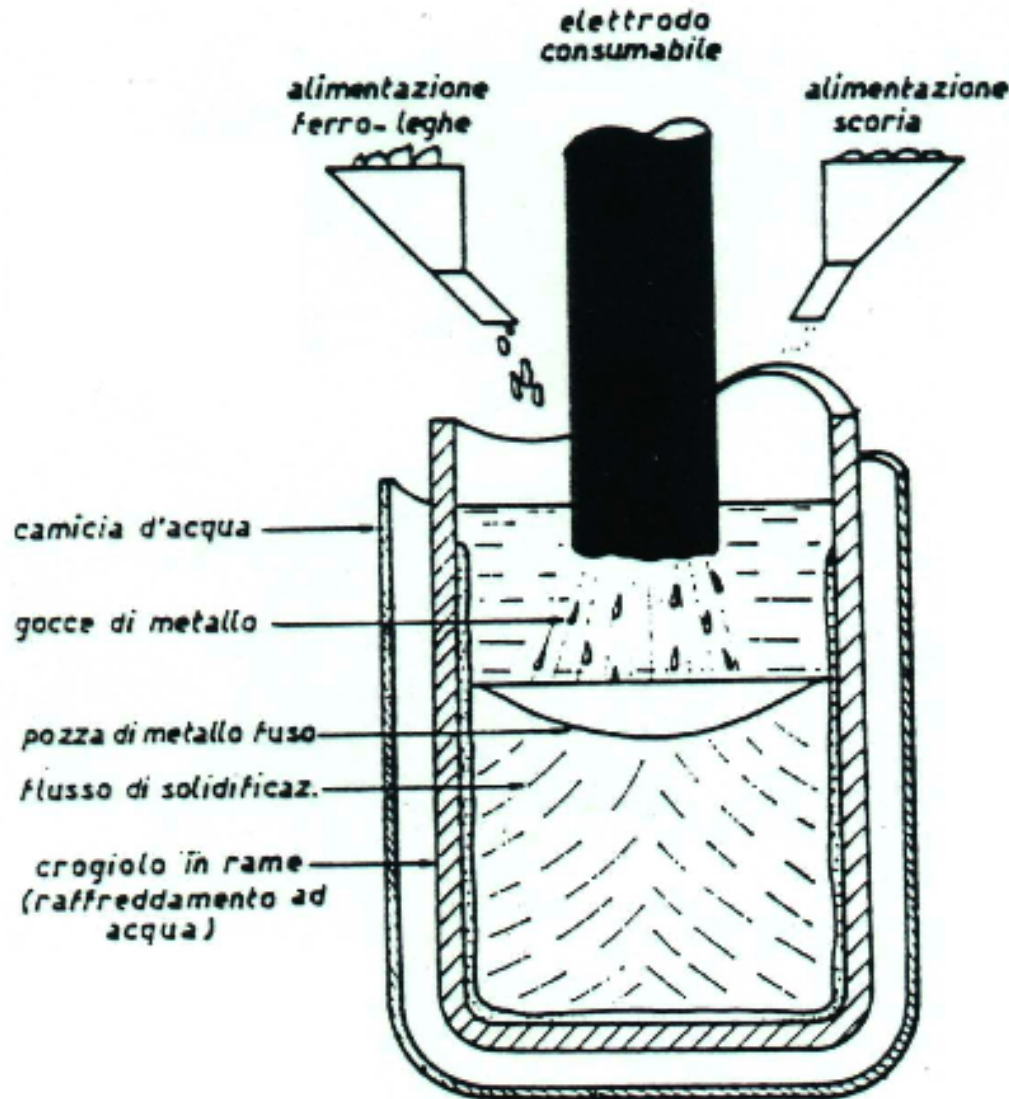
The primary benefits of melting a consumable electrode under vacuum are:

- Removal of dissolved gases, such as H₂ and N₂
- Minimizing the content of undesirable trace elements having high vapor pressures
- Improvement of cleanliness by removal of oxides
- Achievement of directional solidification of the ingot from bottom to top in order to avoid macrosegregation and to minimize microsegregation

Oxide inclusion removal is optimized because of the relatively short reaction paths during melting of the hot electrode end and because of a good drop dispersion in the plasma arc.

However, in superalloys and in high-alloy steels, the nonmetallic inclusions (for example, alumina and titanium carbonitride) are very stable. The removal of these inclusions during remelting takes place by flotation.

ESR (Electro Slag Remelting)



In contrast to vacuum arc remelting (VAR), the remelting in the ESR process does not occur by striking an arc under vacuum. In electroslag remelting the ingot is built up in a water-cooled mold by melting a consumable electrode immersed in a superheated slag.

The intensive reactions between metal and slag result in a significant reduction in S and nonmetallic inclusions. The remaining inclusions are very small and are evenly distributed in the remelted ingot.

ELECTRON BEAM MELTING

In electron beam melting, the feedstock is melted by impinging high-energy electrons.

Electron beam refining takes place in vacuum in the pool of a water-cooled copper crucible, ladle, trough, or hearth.

In electron beam refining, the material solidifies in a water-cooled continuous casting copper crucible or in an investment ceramic or graphite mold.

- Large power (0 to 1200 kW)
- Long free beam path of 250 to 1500 mm
- adjustable beam power distribution
- Usable vacuum pressure range between 1 and 0.0001 Pa (10⁻² and 10⁻⁶ mbar)

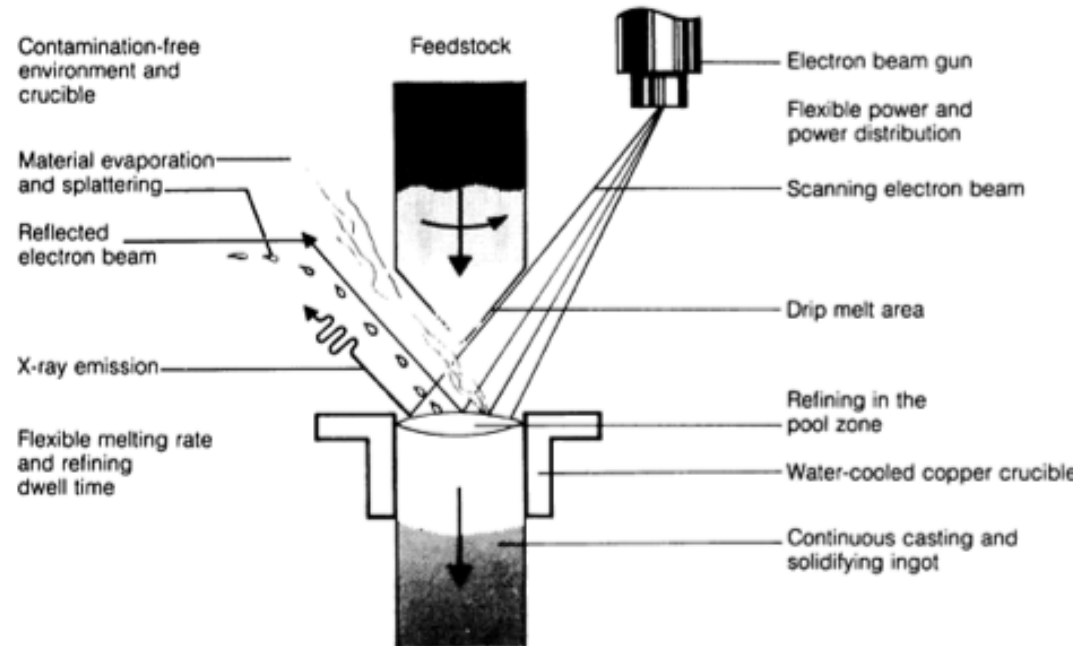


Fig. 33 Schematic of the electron beam melting process.

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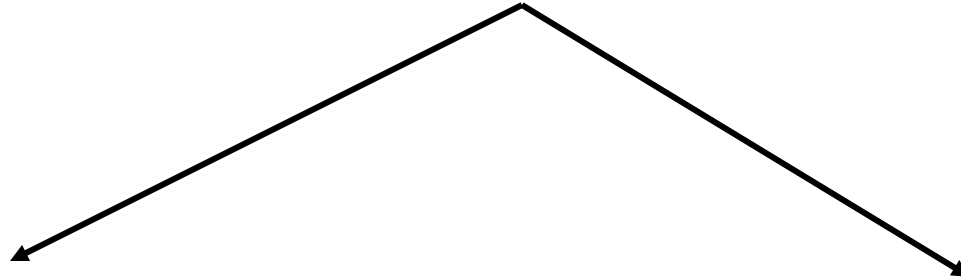
Forni elettrici



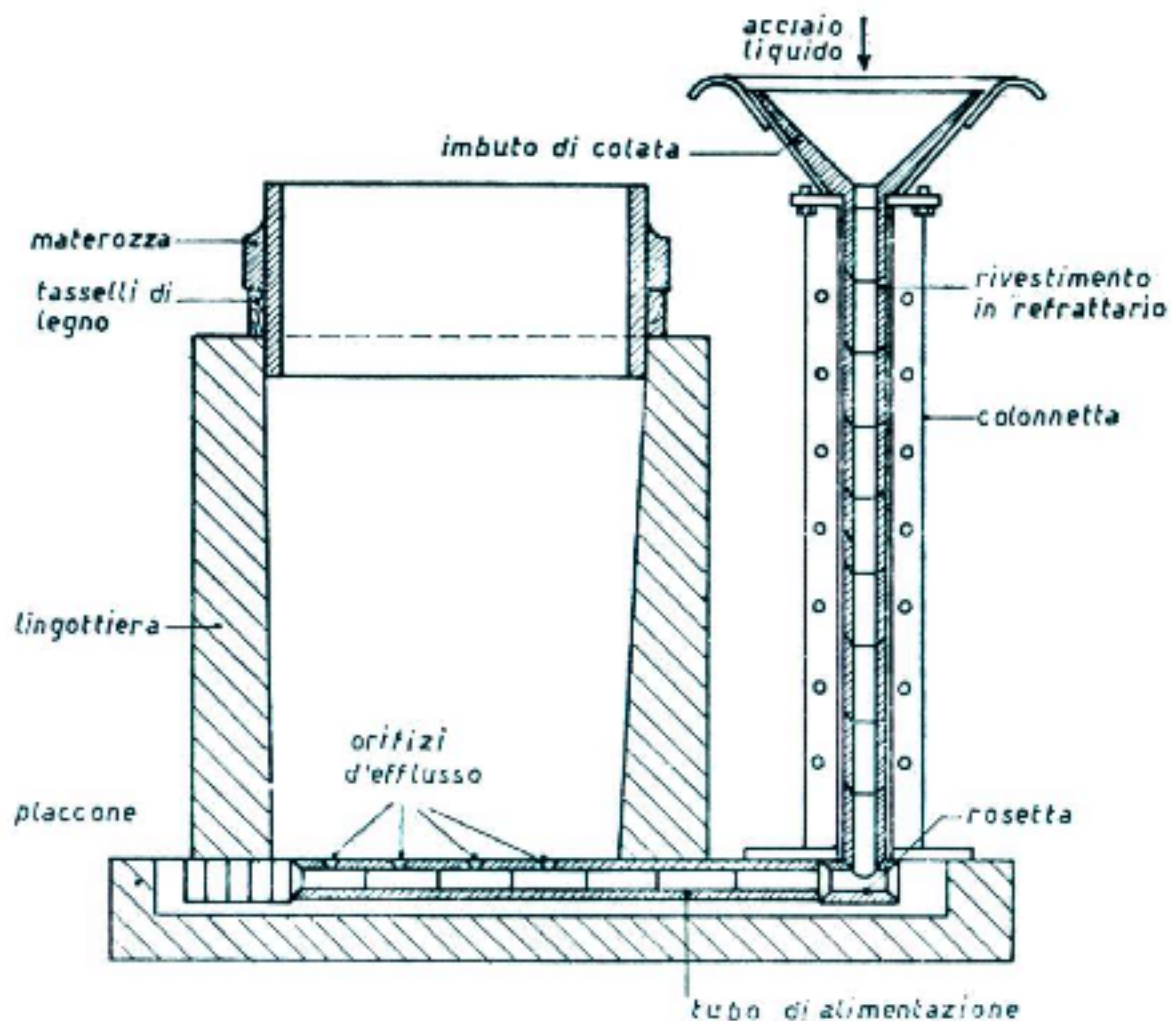
2 tipi di colata

Colata in lingotti

Colata continua



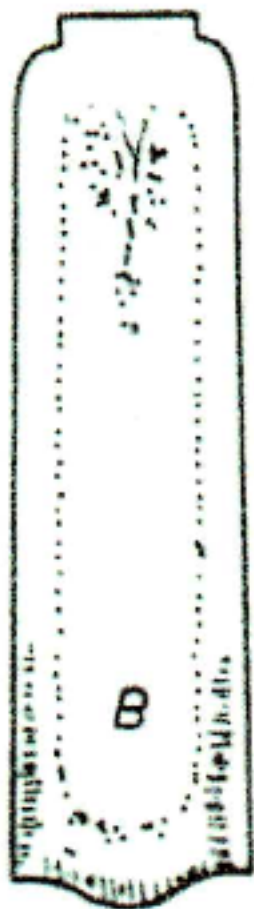
Colata in lingotti



Disposizione schematica della colata in sorgente.

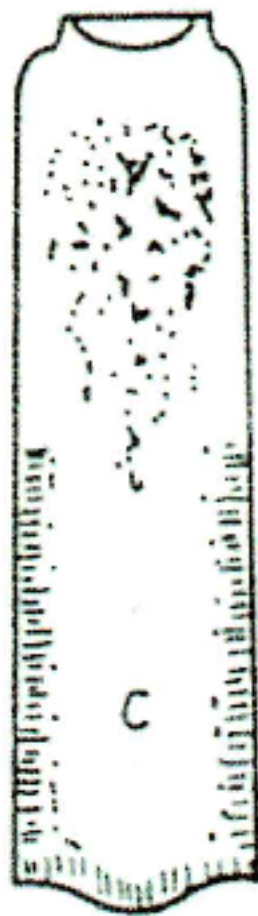
Colata in lingotti

Sezioni schematiche di lingotti in acciaio



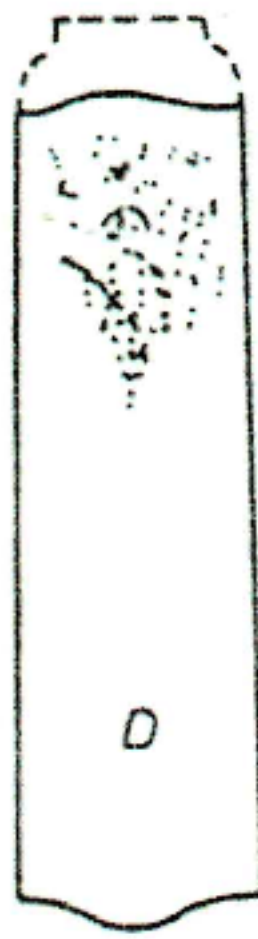
(a)

effervescenza libera



(b)

effervescenza bloccata



(c)

semicalmato

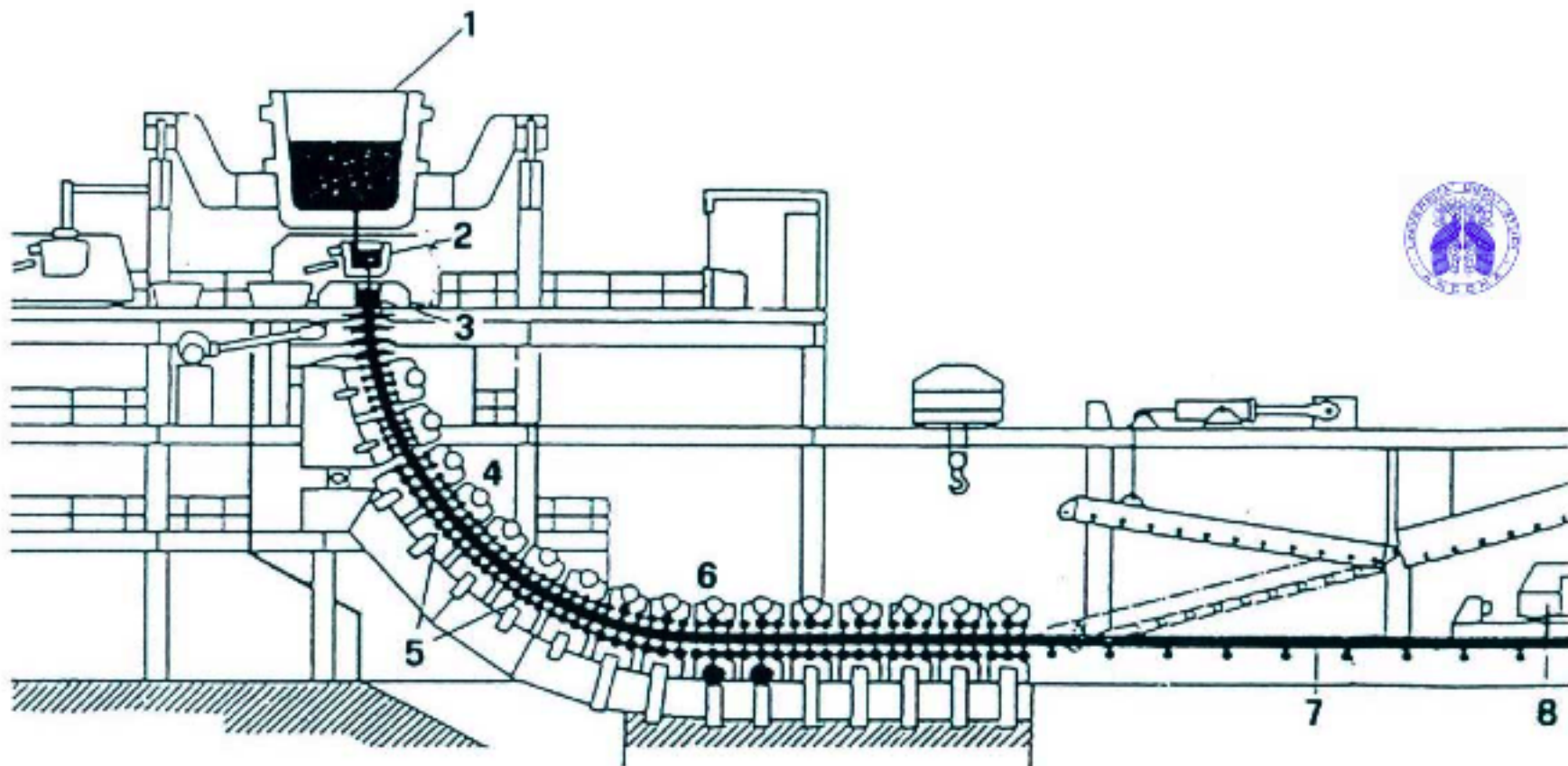


(d)

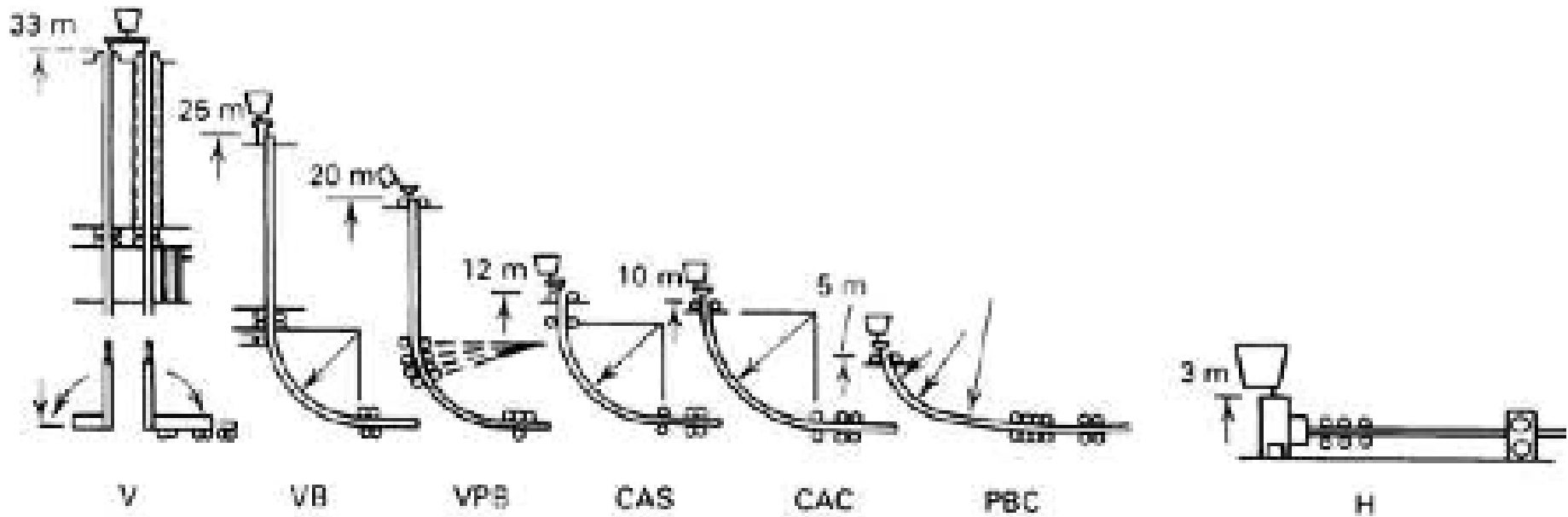
calmato



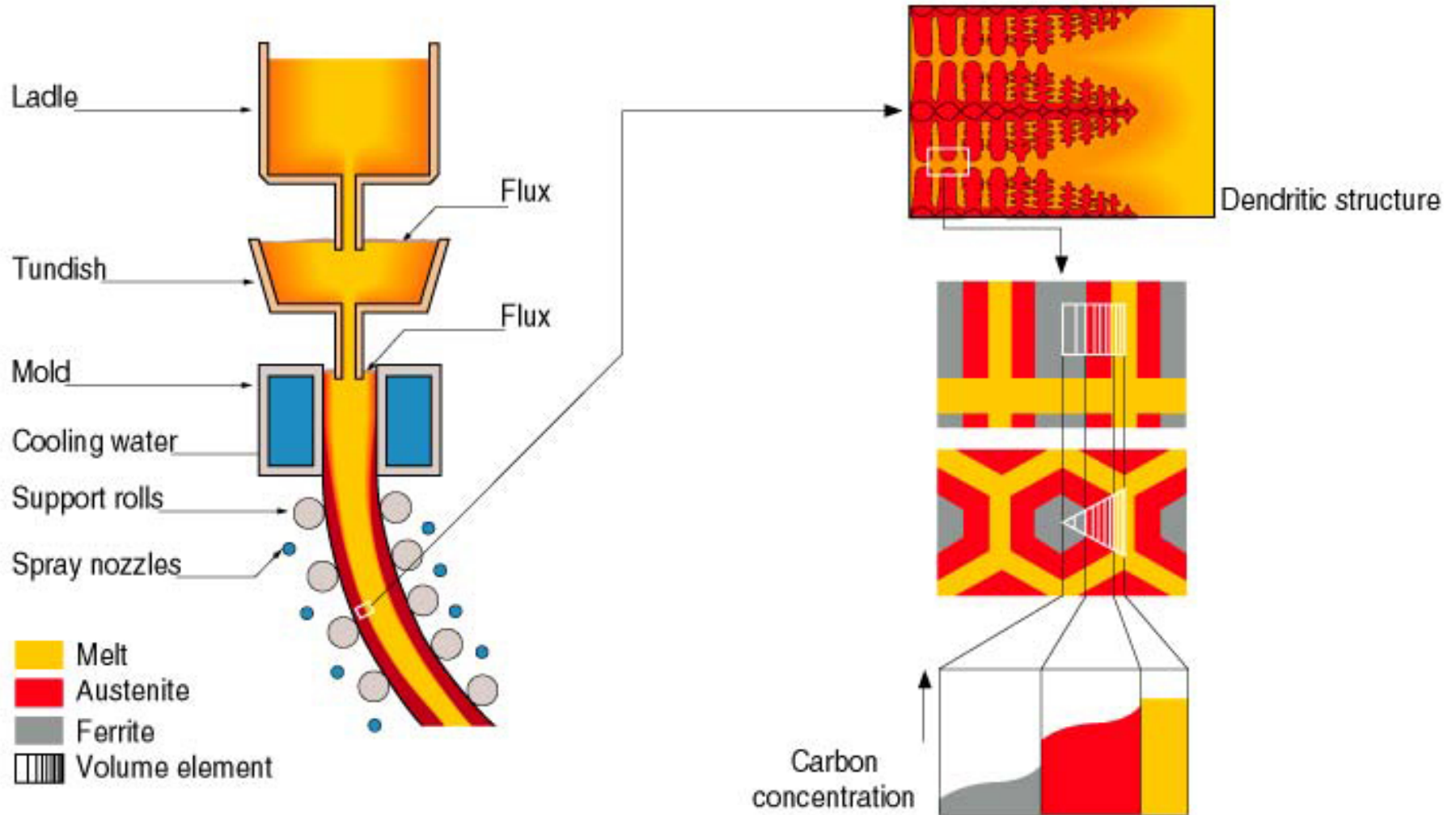
Colata continua



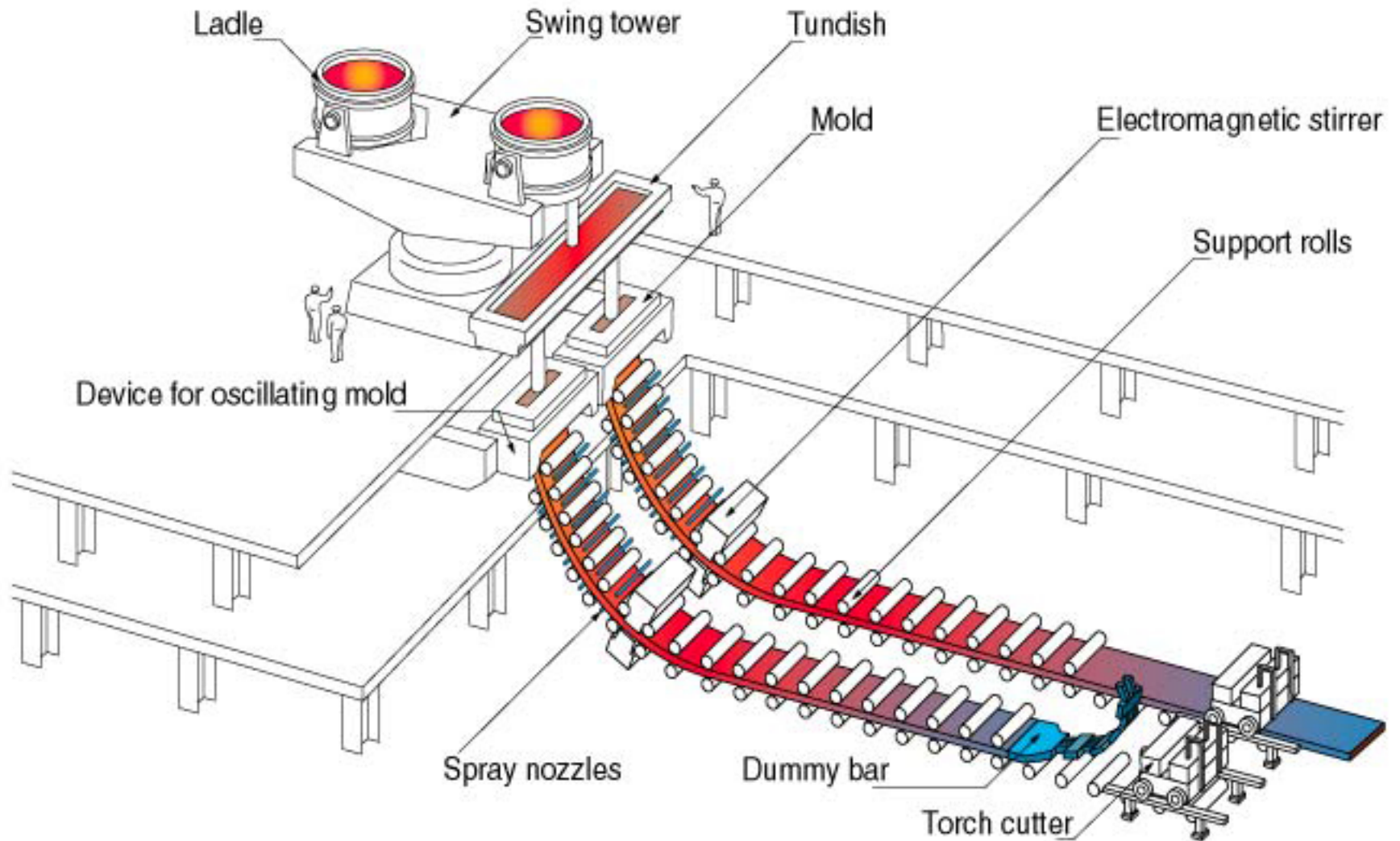
Macchina per la colata continua: 1) siviera; 2) paniera; 3) lingottiera; 4) zona di raffreddamento secondario; 5) rulli trascinatori; 6) zona di raddrizzatura; 7) barra solidificata; 8) stazione mobile di taglio.



Simulation of Solidification and Segregation in Continuous Casting of Steel



Two-strand Continuous Slab Caster



Continuous Caster Operation

