

## **2. Fundamentals of LF technology**

***FOLADSAZI.IR***

## Fundamental of ladle furnace technology

**Steel** is an **alloy** comprised mostly of **iron**, with a **carbon** content between 0.02 % and 1.7 % by weight, depending on grade. Carbon is the most cost-effective alloying material for iron, but various other alloying elements are used such as manganese and tungsten

The maximum solubility of carbon in iron is 1.7 % by weight, occurring at 1130 °C; higher concentrations of carbon or lower temperatures will produce **cementite** which will reduce the material's strength.



# FOLADSAZI.IR

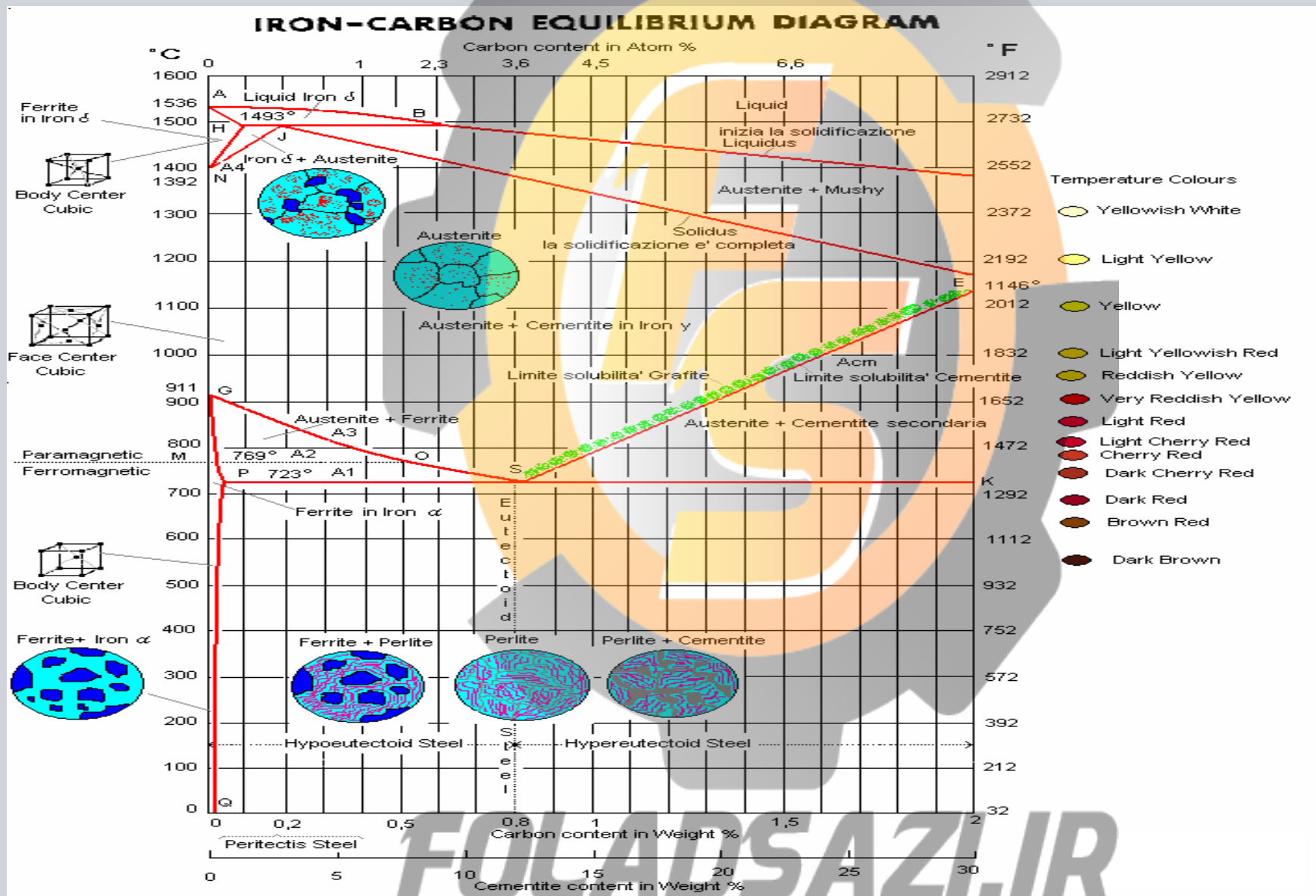
# Fundamental of ladle furnace technology

## LIQUIDUS AND SOLIDUS TEMPERATURE

- Pure Fe melts at 1536°C.
- If the liquid iron contains other elements, it will no longer have a fixed melting point, but will rather melt within a solidification interval, determined by a solidus and liquidus temperature.
- Fe is typically alloyed with Carbon, which changes the melting point from pure iron to a liquidus line

**FOLADSAZI.IR**

# Fundamental of ladle furnace technology



## Fundamental of ladle furnace technology

The calculation method considers the presence of alloyed elements in the steel

(The logarithm, widely used for calculation, is based on statistically evaluated results of metallurgical laboratories).

$$T_{liq} = 1536,6 - (\%C * Z) - (\%E * W)$$

C%	Z	E	W
0.06-0.10	89	Si	8
0.11 -0.50	88	Mn	5
0.51-0.60	86	P	30
0.61-0.70	84	S	25
0.71-0.80	83	Cr	1.5
0.81-0.90	82	Ni	4
		Cu	5
		Mo	2
		V	2
		Al	5.1

$T_{liq}$  = liquidus temperature

%C = carbon content

Z = multiplying factor for carbon

%E = content of elements listed in the table

W = multiplying factor for the listed elements



# Fundamental of ladle furnace technology

The steel analyses is obtained using the optical emission spectrometer assuming that each element has an individual spectrum.



Table 4. Data (2000-2001) Data (2002-2003) Data (2004-2005)

Year	Age	Sex	Height	Weight	Body Mass Index	Body Fat Percentage
2000	18	M	1.75	75.0	24.2	15.0
2001	19	F	1.65	60.0	21.7	18.0
2002	20	M	1.80	85.0	26.3	12.0
2003	21	F	1.70	70.0	24.2	15.0
2004	22	M	1.85	95.0	27.8	10.0
2005	23	F	1.75	80.0	25.7	13.0
2006	24	M	1.90	110.0	30.9	8.0
2007	25	F	1.80	90.0	27.8	11.0
2008	26	M	1.95	120.0	31.2	7.0
2009	27	F	1.85	100.0	29.4	9.0
2010	28	M	2.00	130.0	32.5	6.0
2011	29	F	1.90	110.0	30.9	8.0
2012	30	M	2.05	140.0	33.8	5.0
2013	31	F	1.95	120.0	31.2	7.0
2014	32	M	2.10	150.0	35.0	4.0
2015	33	F	2.00	130.0	32.5	6.0
2016	34	M	2.15	160.0	36.3	3.0
2017	35	F	2.05	140.0	33.8	5.0
2018	36	M	2.20	170.0	37.5	2.0
2019	37	F	2.10	150.0	35.0	4.0
2020	38	M	2.25	180.0	38.8	1.0
2021	39	F	2.15	160.0	36.3	3.0
2022	40	M	2.30	190.0	40.0	0.0
2023	41	F	2.20	170.0	37.5	2.0
2024	42	M	2.35	200.0	41.3	0.0
2025	43	F	2.25	180.0	38.8	1.0
2026	44	M	2.40	210.0	44.0	0.0
2027	45	F	2.30	190.0	40.0	1.0
2028	46	M	2.45	220.0	46.3	0.0
2029	47	F	2.35	200.0	42.5	0.0
2030	48	M	2.50	230.0	48.0	0.0
2031	49	F	2.40	210.0	44.0	0.0
2032	50	M	2.55	240.0	50.0	0.0
2033	51	F	2.45	220.0	46.3	0.0
2034	52	M	2.60	250.0	54.0	0.0
2035	53	F	2.50	230.0	50.0	0.0
2036	54	M	2.65	260.0	58.0	0.0
2037	55	F	2.55	240.0	54.0	0.0
2038	56	M	2.70	270.0	62.0	0.0
2039	57	F	2.60	250.0	58.0	0.0
2040	58	M	2.75	280.0	66.0	0.0
2041	59	F	2.65	260.0	62.0	0.0
2042	60	M	2.80	290.0	70.0	0.0
2043	61	F	2.70	270.0	66.0	0.0
2044	62	M	2.85	300.0	78.0	0.0
2045	63	F	2.75	280.0	72.0	0.0
2046	64	M	2.90	310.0	86.0	0.0
2047	65	F	2.80	290.0	80.0	0.0
2048	66	M	2.95	320.0	94.0	0.0
2049	67	F	2.85	300.0	90.0	0.0
2050	68	M	3.00	330.0	100.0	0.0
2051	69	F	2.90	310.0	94.0	0.0
2052	70	M	3.05	340.0	108.0	0.0
2053	71	F	2.95	320.0	100.0	0.0
2054	72	M	3.10	350.0	112.0	0.0
2055	73	F	3.00	330.0	108.0	0.0
2056	74	M	3.15	360.0	120.0	0.0
2057	75	F	3.05	340.0	112.0	0.0
2058	76	M	3.20	370.0	130.0	0.0
2059	77	F	3.10	350.0	112.0	0.0
2060	78	M	3.25	380.0	140.0	0.0
2061	79	F	3.15	360.0	128.0	0.0
2062	80	M	3.30	390.0	150.0	0.0
2063	81	F	3.20	370.0	130.0	0.0
2064	82	M	3.35	400.0	160.0	0.0
2065	83	F	3.25	380.0	136.0	0.0
2066	84	M	3.40	410.0	170.0	0.0
2067	85	F	3.30	390.0	140.0	0.0
2068	86	M	3.45	420.0	180.0	0.0
2069	87	F	3.35	400.0	150.0	0.0
2070	88	M	3.50	430.0	190.0	0.0
2071	89	F	3.40	410.0	160.0	0.0
2072	90	M	3.55	440.0	200.0	0.0
2073	91	F	3.45	420.0	170.0	0.0
2074	92	M	3.60	450.0	210.0	0.0
2075	93	F	3.50	430.0	180.0	0.0
2076	94	M	3.65	460.0	220.0	0.0
2077	95	F	3.55	440.0	190.0	0.0
2078	96	M	3.70	470.0	230.0	0.0
2079	97	F	3.60	450.0	200.0	0.0
2080	98	M	3.75	480.0	240.0	0.0
2081	99	F	3.65	460.0	210.0	0.0
2082	100	M	3.80	490.0	250.0	0.0
2083	101	F	3.70	470.0	220.0	0.0
2084	102	M	3.85	500.0	260.0	0.0
2085	103	F	3.75	480.0	230.0	0.0
2086	104	M	3.90	510.0	270.0	0.0
2087	105	F	3.80	490.0	240.0	0.0
2088	106	M	3.95	520.0	280.0	0.0
2089	107	F	3.85	500.0	250.0	0.0
2090	108	M	4.00	530.0	300.0	0.0
2091	109	F	3.90	510.0	260.0	0.0
2092	110	M	4.05	540.0	320.0	0.0
2093	111	F	3.95	520.0	280.0	0.0
2094	112	M	4.10	550.0	330.0	0.0
2095	113	F	4.00	530.0	300.0	0.0
2096	114	M	4.15	560.0	340.0	0.0
2097	115	F	4.05	540.0	320.0	0.0
2098	116	M	4.20	570.0	350.0	0.0
2099	117	F	4.10	550.0	320.0	0.0
2100	118	M	4.25	580.0	360.0	0.0
2101	119	F	4.15	560.0	330.0	0.0
2102	120	M	4.30	590.0	380.0	0.0
2103	121	F	4.20	570.0	340.0	0.0
2104	122	M	4.35	600.0	390.0	0.0
2105	123	F	4.25	580.0	350.0	0.0
2106	124	M	4.40	610.0	400.0	0.0
2107	125	F	4.30	590.0	370.0	0.0
2108	126	M	4.45	620.0	410.0	0.0
2109	127	F	4.35	600.0	380.0	0.0
2110	128	M	4.50	630.0	420.0	0.0
2111	129	F	4.40	610.0	390.0	0.0
2112	130	M	4.55	640.0	430.0	0.0
2113	131	F	4.45	620.0	400.0	0.0
2114	132	M	4.60	650.0	440.0	0.0
2115	133	F	4.50	630.0	410.0	0.0
2116	134	M	4.65	660.0	450.0	0.0
2117	135	F	4.55	640.0	420.0	0.0
2118	136	M	4.70	670.0	460.0	0.0
2119	137	F	4.60	650.0	430.0	0.0
2120	138	M	4.75	680.0	470.0	0.0
2121	139	F	4.65	660.0	440.0	0.0
2122	140	M	4.80	690.0	480.0	0.0
2123	141	F	4.70	670.0	450.0	0.0
2124	142	M	4.85	700.0	490.0	0.0
2125	143	F	4.75	680.0	460.0	0.0
2126	144	M	4.90	710.0	500.0	0.0
2127	145	F	4.80	690.0	470.0	0.0
2128	146	M	4.95	720.0	510.0	0.0
2129	147	F	4.85	700.0	480.0	0.0
2130	148	M	5.00	730.0	520.0	0.0
2131	149	F	4.90	710.0	490.0	0.0
2132	150	M	5.05	740.0	530.0	0.0
2133	151	F	4.95	720.0	500.0	0.0
2134	152	M	5.10	750.0	540.0	0.0
2135	153	F	5.00	730.0	510.0	0.0
2136	154	M	5.15	760.0	550.0	0.0
2137	155	F	5.05	740.0	520.0	0.0
2138	156	M	5.20	770.0	560.0	0.0
2139	157	F	5.10	750.0	530.0	0.0
2140	158	M	5.25	780.0	570.0	0.0
2141	159	F	5.15	760.0	540.0	0.0
2142	160	M	5.30	790.0	580.0	0.0
2143	161	F	5.20	770.0	550.0	0.0
2144	162	M	5.35	800.0	590.0	0.0
2145	163	F	5.25	780.0	560.0	0.0
2146	164	M	5.40	810.0	600.0	0.0
2147	165	F	5.30	790.0	570.0	0.0
2148	166	M	5.45	820.0	610.0	0.0
2149	167	F	5.35	800.0	580.0	0.0
2150	168	M	5.50	830.0	620.0	0.0
2151	169	F	5.40	810.0	590.0	0.0
2152	170	M	5.55	840.0	630.0	0.0
2153	171	F	5.45	820.0	600.0	0.0
2154	172	M	5.60	850.0	640.0	0.0
2155	173	F	5.50	830.0	610.0	0.0
2156	174	M	5.65	860.0	650.0	0.0
2157	175	F	5.55	840.0	620.0	0.0
2158	176	M	5.70	870.0	660.0	0.0
2159	177	F	5.60	850.0	630.0	0.0
2160	178	M	5.75	880.0	670.0	0.0
2161	179	F	5.65	860.0	640.0	0.0
2162	180	M	5.80	890.0	680.0	0.0
2163	181	F	5.70	870.0	650.0	0.0
2164	182	M	5.85	900.0	690.0	0.0
2165	183	F	5.75	880.0	660.0	0.0
2166	184	M	5.90	910.0	700.0	0.0
2167	185	F	5.80	890.0	670.0	0.0
2168	186	M	5.95	920.0	710.0	0.0
2169	187	F	5.85	900.0	680.0	0.0
2170	188	M	6.00	930.0	720.0	0.0
2171	189	F	5.90	910.0	690.0	0.0
2172	190	M	6.05	940.0	730.0	0.0
2173	191	F	5.95	920.0	700.0	0.0
2174	192	M	6.10	950.0	740.0	0.0
2175	193	F	6.00	930.0	710.0	0.0
2176	194	M	6.15	960.0	750.0	0.0
2177	195	F	6.05	940.0	720.0	0.0
2178	196	M	6.20	970.0	760.0	0.0
2179	197	F	6.10	950.0	730.0	0.0
2180	198	M	6.25	980.0	770.0	0.0
2181	199	F	6.15	960.0	740.0	0.0
2182	200	M	6.30	990.0	780.0	0.0
2183	201	F	6.20	970.0	750.0	0.0
2184	202	M	6.35	1000.0	790.0	0.0
2185	203	F	6.25	980.0	760.0	0.0
2186	204	M	6.40	1010.0	800.0	0.0
2187	205	F	6.30	990.0	770.0	0.0
2188	206	M	6.45	1020.0	810.0	0.0
2189	207	F	6.35	10		

# Fundamental of ladle furnace technology

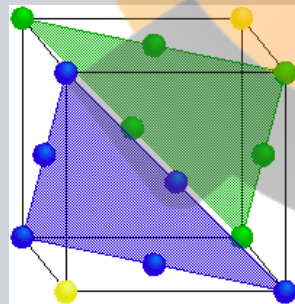
STEEL ANALYSIS SAMPLES								
ELEMENTS	MIN	MAX	AIM	11:08	10:28	10:20	07:36	06:23
				A	A	A	A	M
C	0,120	0,200	0,150	0.178	0.178	0.163	0.155	0.160
Si	0,120	0,300	0,150	0.195	0.195	0.150	0.145	0.160
Mn	0,300	0,700	0,420	0.430	0.430	0.415	0.410	0.400
P	0,000	0,045	0,030	0.011	0.011	0.011	0.010	0.013
S	0,000	0,045	0,030	0.016	0.016	0.017	0.018	0.017
Cr	0,000	0,300	0,000	0.030	0.030	0.030	0.030	0.030
Mo	0,000	0,000	0,000	0.001	0.001	0.001	0.001	0.001
Ni	0,000	0,300	0,000	0.030	0.030	0.030	0.030	0.030
Al	0,015	0,040	0,020	0.024	0.027	0.001	0.001	0.025
As	0,015	0,040	0,020	0.000				
Ca	0,000	0,000	0,000	0.004	0.004	0.001	0.001	0.004
Cu	0,000	0,300	0,000	0.015	0.015	0.010	0.010	0.010
Nb	0,000	0,000	0,000	0.010	0.010	0.006	0.006	0.007
Ti	0,000	0,000	0,000	0.001	0.001	0.001	0.001	0.001
V	0,000	0,000	0,000	0.005	0.005	0.003	0.004	0.004
Alt	0,000	0,000	0,000	-99.999				

Typical process analyses results database for one heat

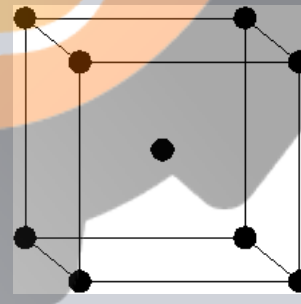
FOLADSAZI.IR

## Fundamental of ladle furnace technology

- The C-Fe diagram defines the existence two crystalline structure:
- Ferrite: solid solution of carbon in  $\alpha$ -iron and  $\delta$ -iron (b.c.c. structure)
- Austenite: solid solution of carbon in  $\gamma$ -iron (f.c.c structure)



face-centered-cubic



body-centered cubic



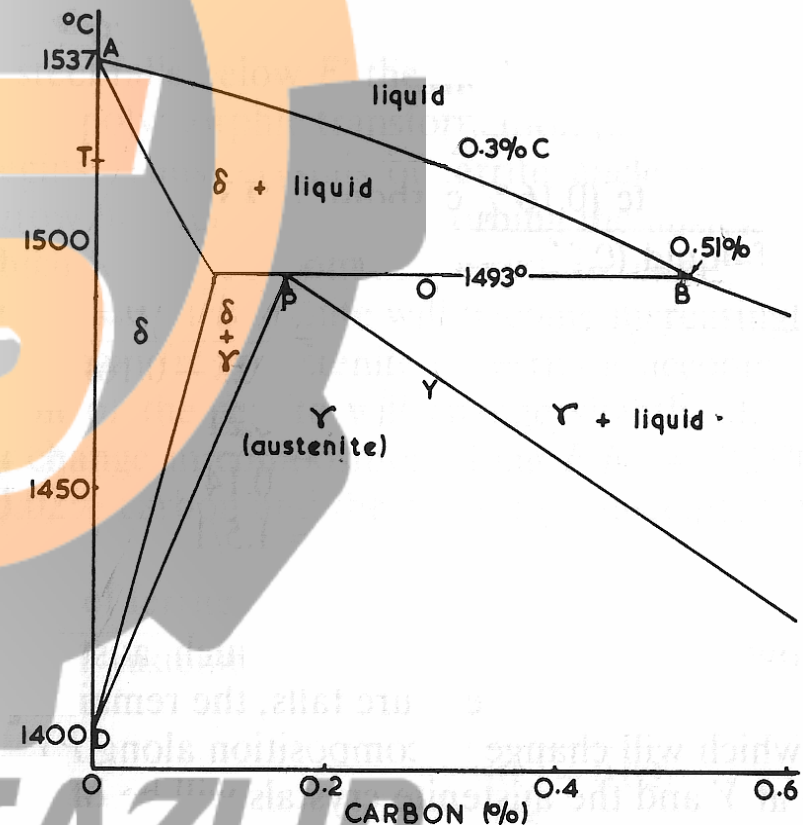
## Fundamental of ladle furnace technology

The C-Fe diagram shows three characteristic transformations: Peritectic, Eutectic (not important in our study) and Eutectoid.

Peritectic:

At the temperature of  $1493^{\circ}\text{C}$ , in the carbon range  $0.1 < \%C < 0.51$ , the solid solution of carbon in delta iron reacts with the liquid steel, during solidification, to give origin to a solid solution of carbon in gamma iron

In particular way for peritectic transformation around of 0.1%C the contraction is very high

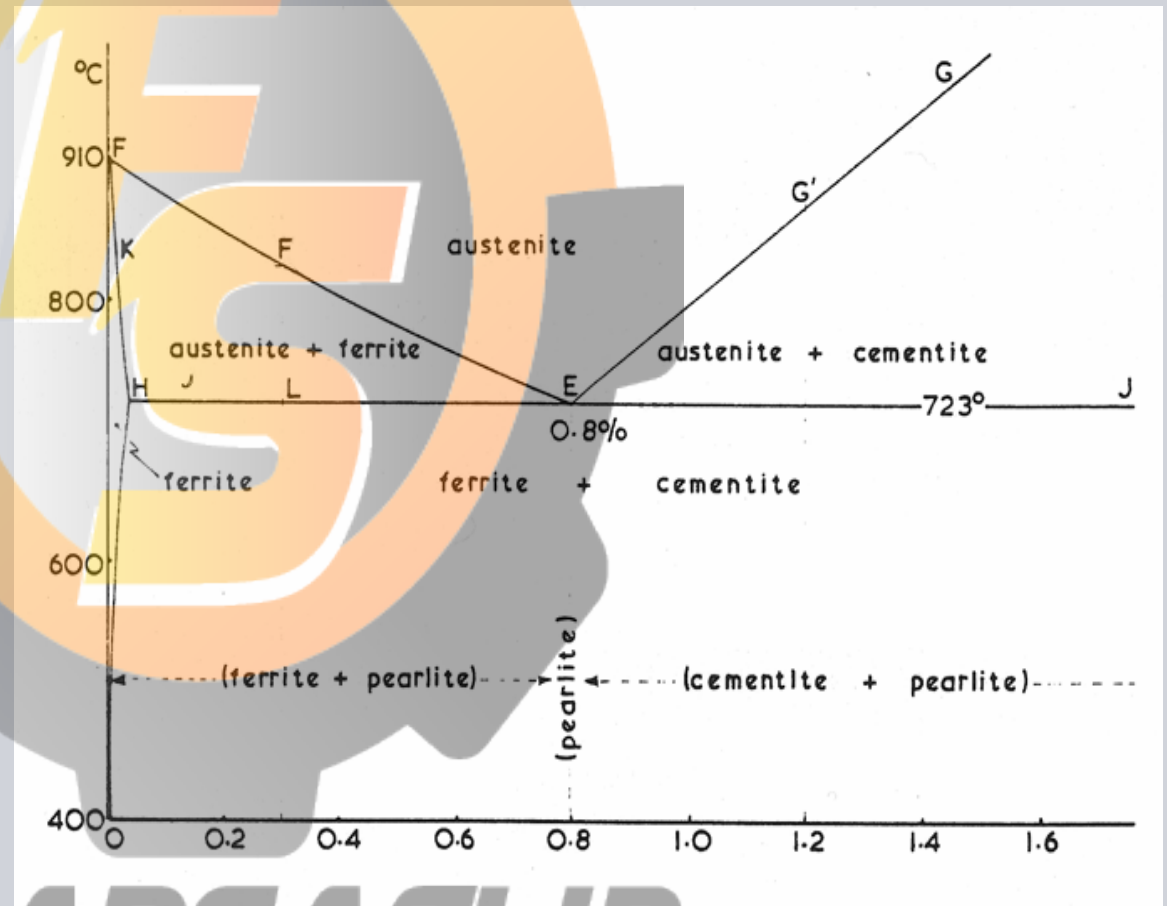


## Fundamental of ladle furnace technology

Eutectoid:

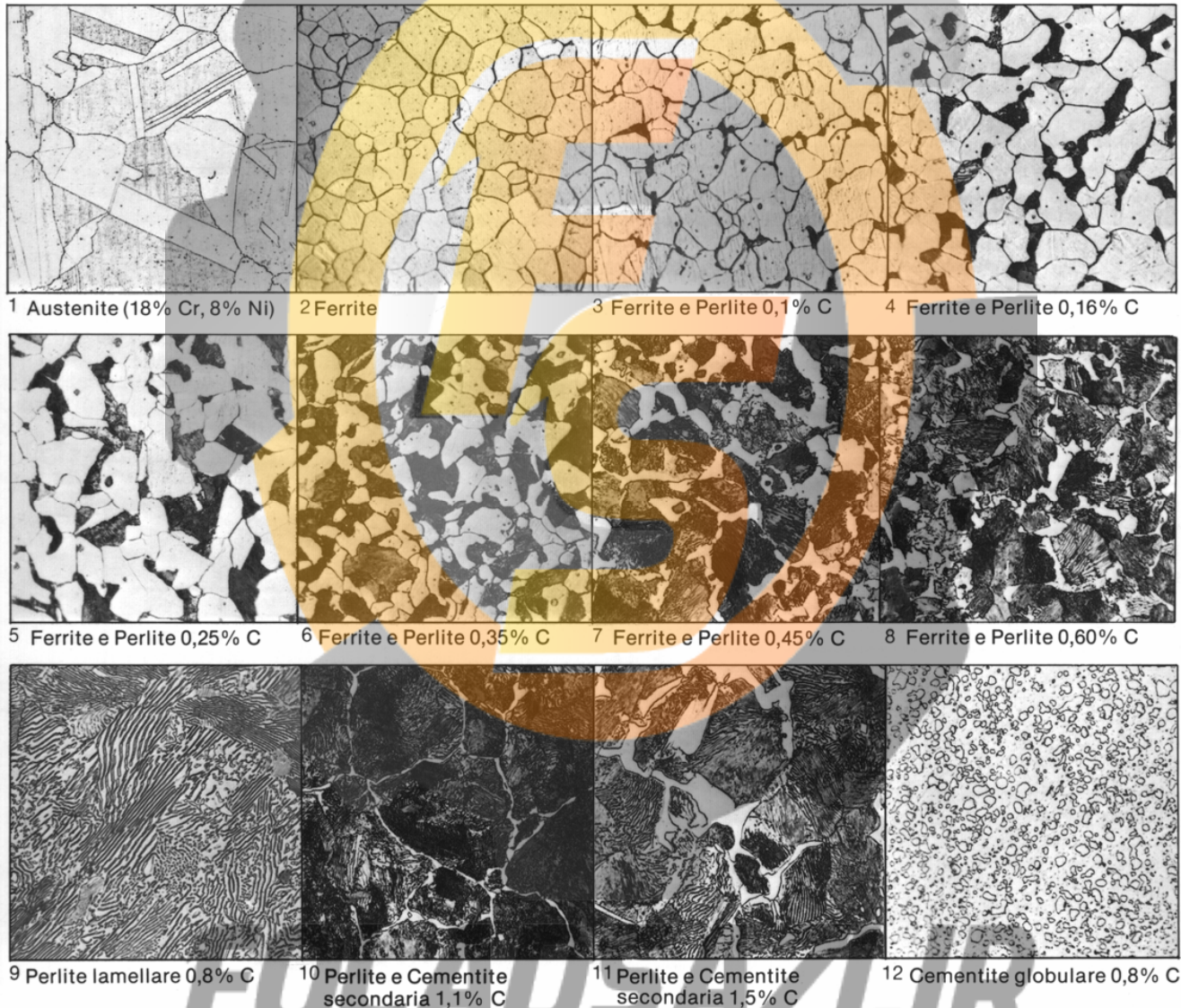
At the temperature of  $723^{\circ}\text{C}$  the austenite transform itself in pearlite

At room temperature is the result of different mix of ferrite, pearlite and cementite in function of carbon and other alloy elements. Some steel grade however has an austenitic structure



**FOLADSAZI.IR**

# Fundamental of ladle furnace technology

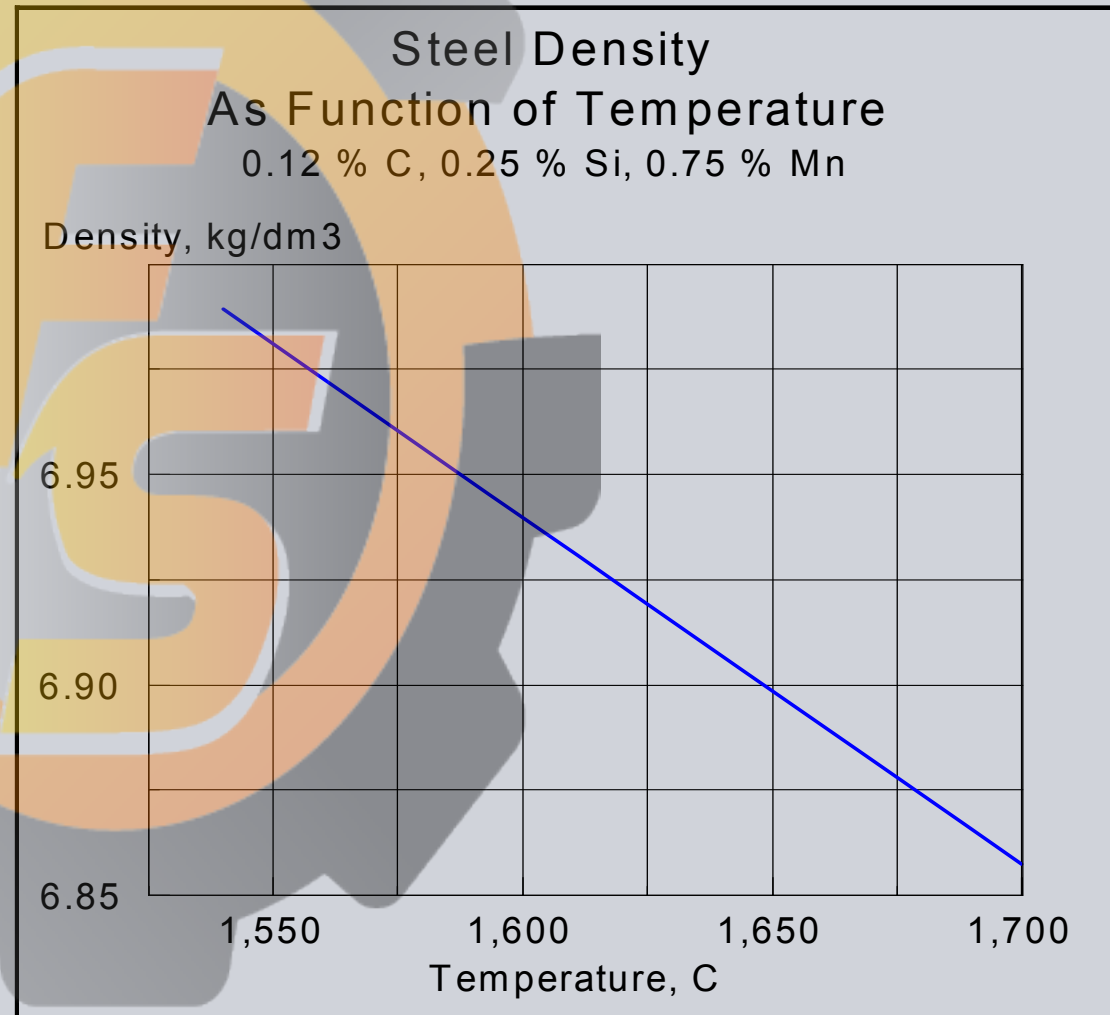




## Fundamental of ladle furnace technology

### HEAT CAPACITY

The specific heat of liquid steel is relatively independent of its composition and temperature. For ordinary steel it has the value 0.22 kWh/(ton,°C).



**FOLADSAZI.IR**

# Fundamental of ladle furnace technology



**STEEL MAKING IS A PROCESS OF CONTROLLED  
OXIDATION**

**LF FURNACE IS PART OF THE SECONDARY METALLURGY**

***FOLADSAZI.IR***

## Fundamental of ladle furnace technology

**Secondary metallurgy is divided into two steps.**

- Operating steps
- Techniques

**The basic steps are as follows**

1. Mixing and homogenization
2. Temperature adjustment (heating by chemical and/or electrical sources)
3. Charging of additives (deox., fe-alloys, slag building materials)
4. Desulphurization
5. Inclusions removal

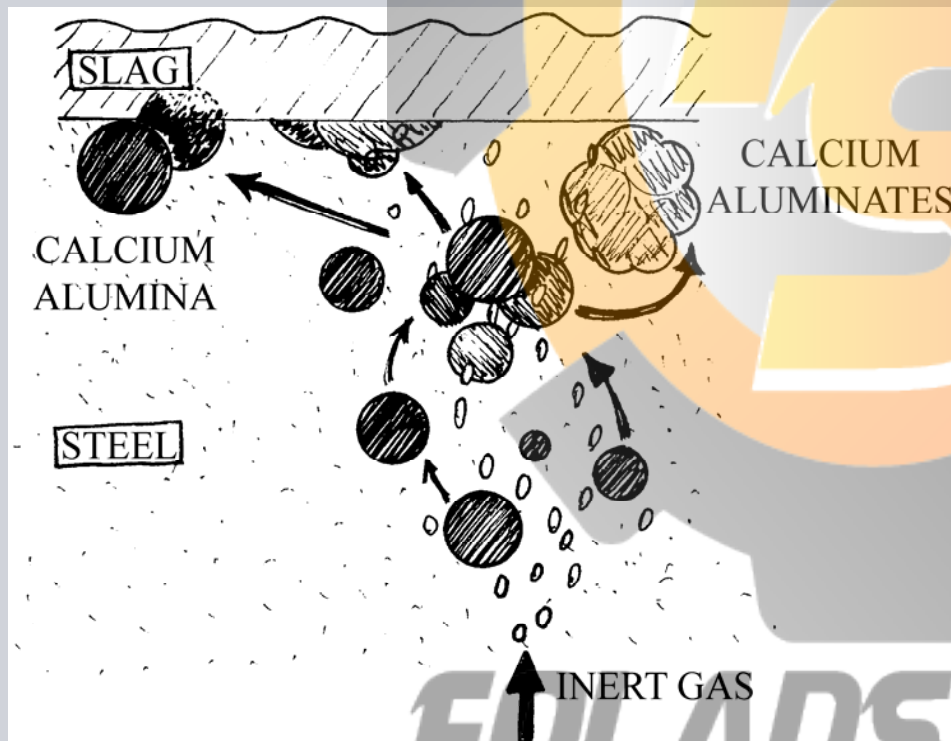
**FOLADSAZI.IR**



# Fundamental of ladle furnace technology

## REFINING REACTIONS.

Refining of steel normally means the removal of one or several elements from the metal bath. Such refining is brought about by slag metal reactions, gas-metal reactions or metal bulk reactions. Refining of the following elements will be discussed: S, H, N, C, O.



Inclusion  
modification

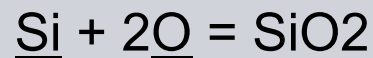
# Fundamental of ladle furnace technology

## DEOXIDATION.

Deoxidation is the process by which the content of dissolved oxygen is reduced in the metal. One distinguishes between three different techniques for bringing about deoxidation

1. PRECIPITATION DEOXIDATION
2. TOP SLAG DEOXIDATION.
3. VACUUM CARBON DEOXIDATION.

Single Element



Note, soluble versus total oxygen, soluble is determined from O-sensor. Total by chemical analyses.

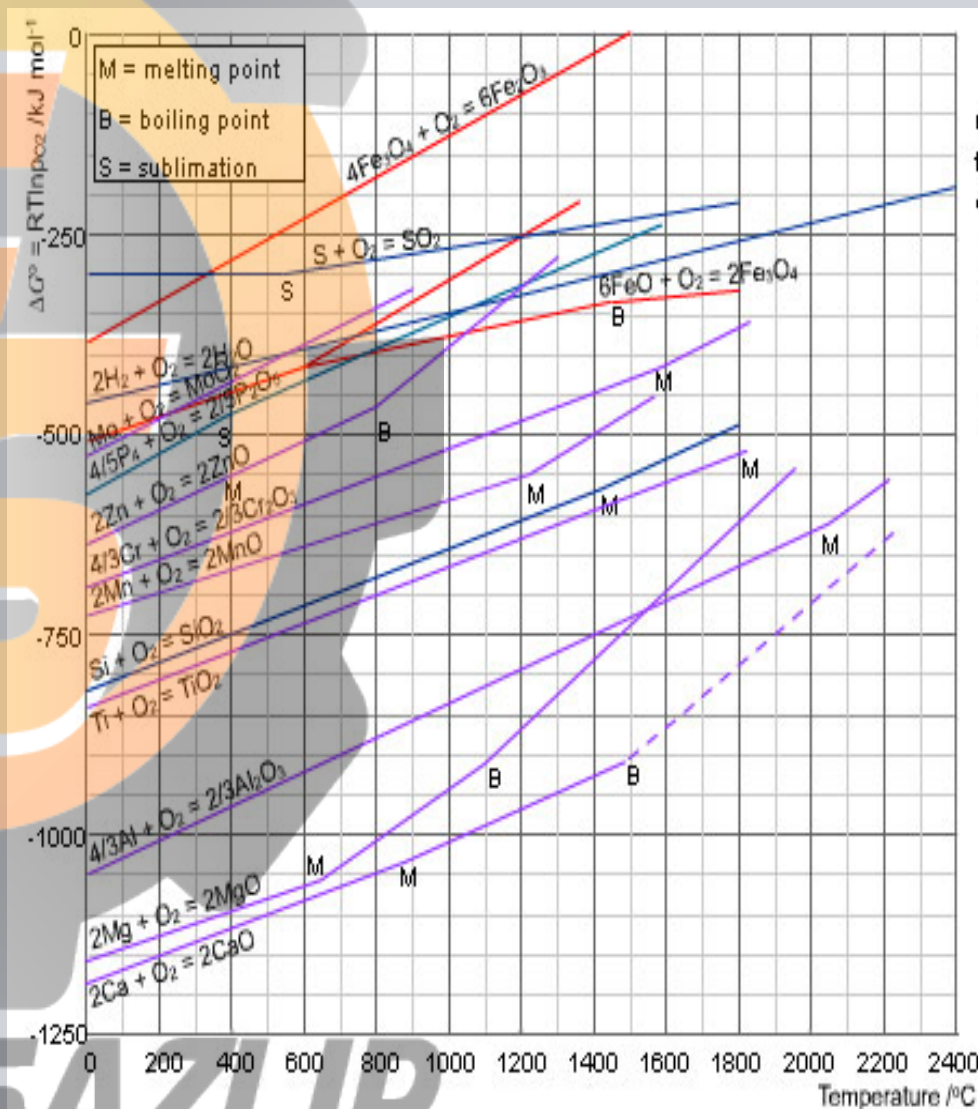
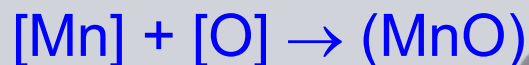
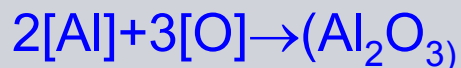
**FOLADSAZI.IR**

## Fundamental of ladle furnace technology

### PRECIPITATION DEOXIDATION - REMOVAL OF SLAG INCLUSIONS.

Precipitation deoxidation is by far the most common deoxidation method. As the name suggests, a deoxidiser normally Al, Si, Si-Mn or Ca is added to the metal bath.

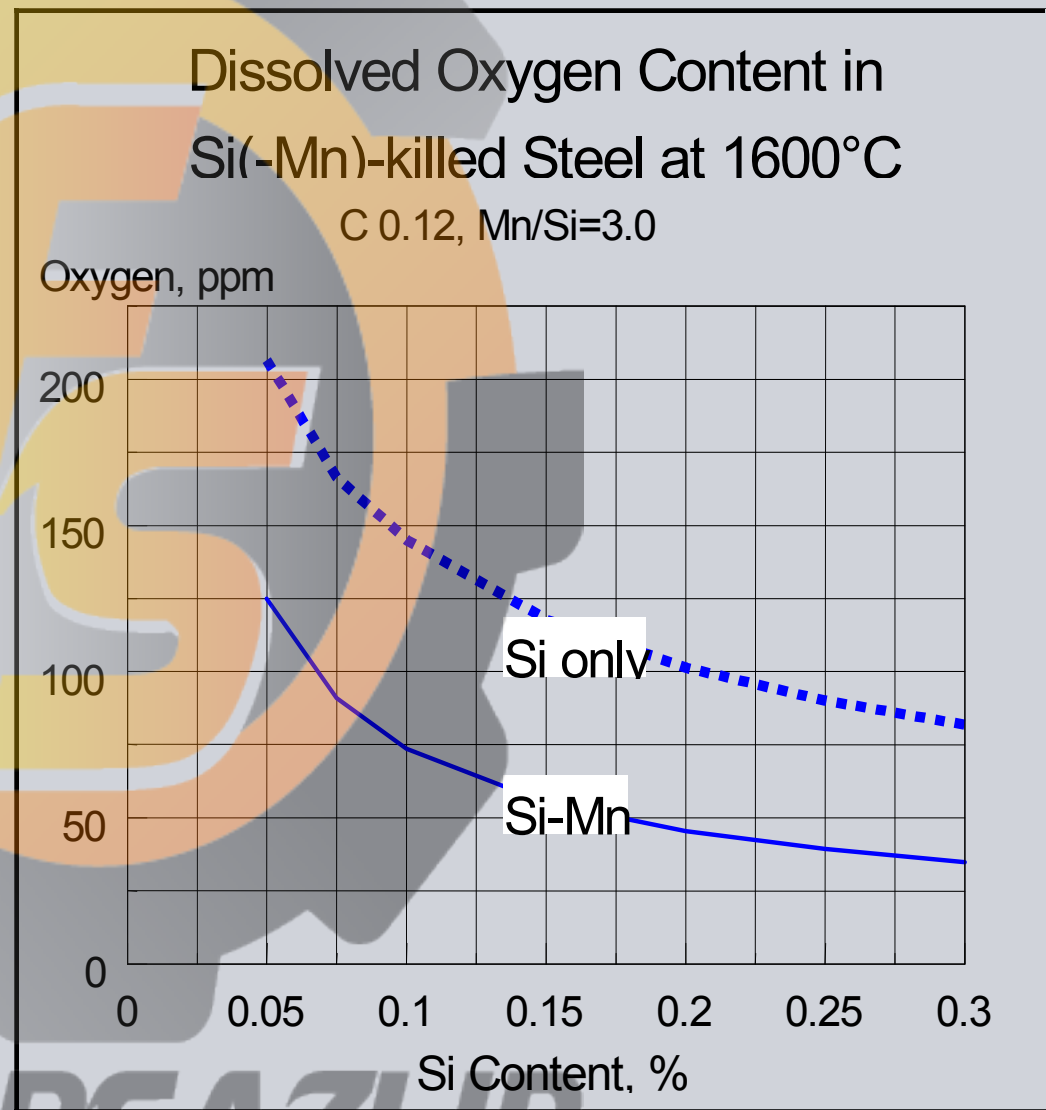
The precipitation deoxidation in itself does not reduce the oxygen content but just transforms the dissolved oxygen into oxidic oxygen. Next, the oxidic oxygen particles must be removed from the metal bath by flotation.



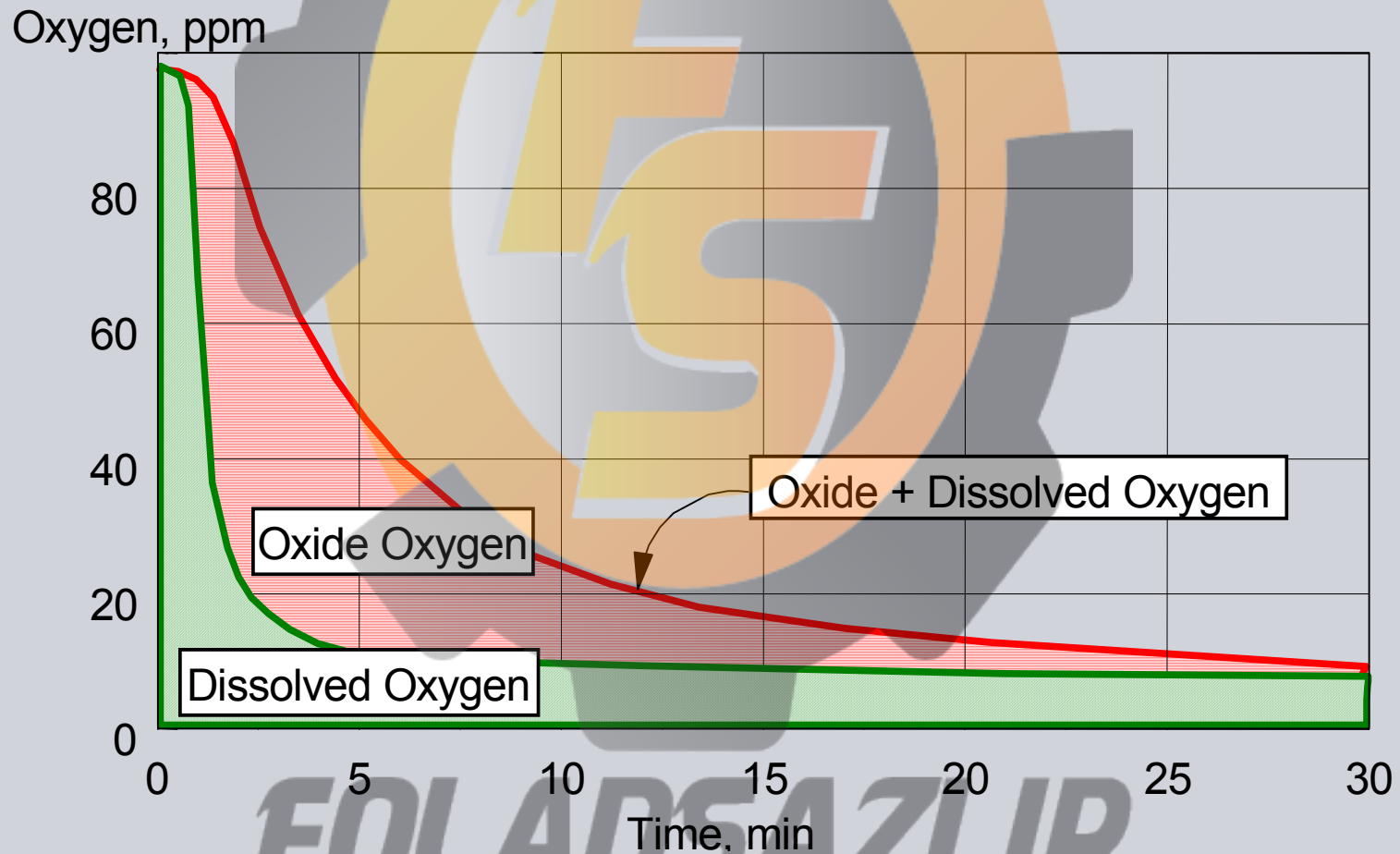
## Fundamental of ladle furnace technology

### Si and Si-Mn deoxidation

One normally aims at an Mn/Si ratio after deoxidation of  $>3$ . This ensures that the manganese formed silicate is liquid at steelmaking temperatures.



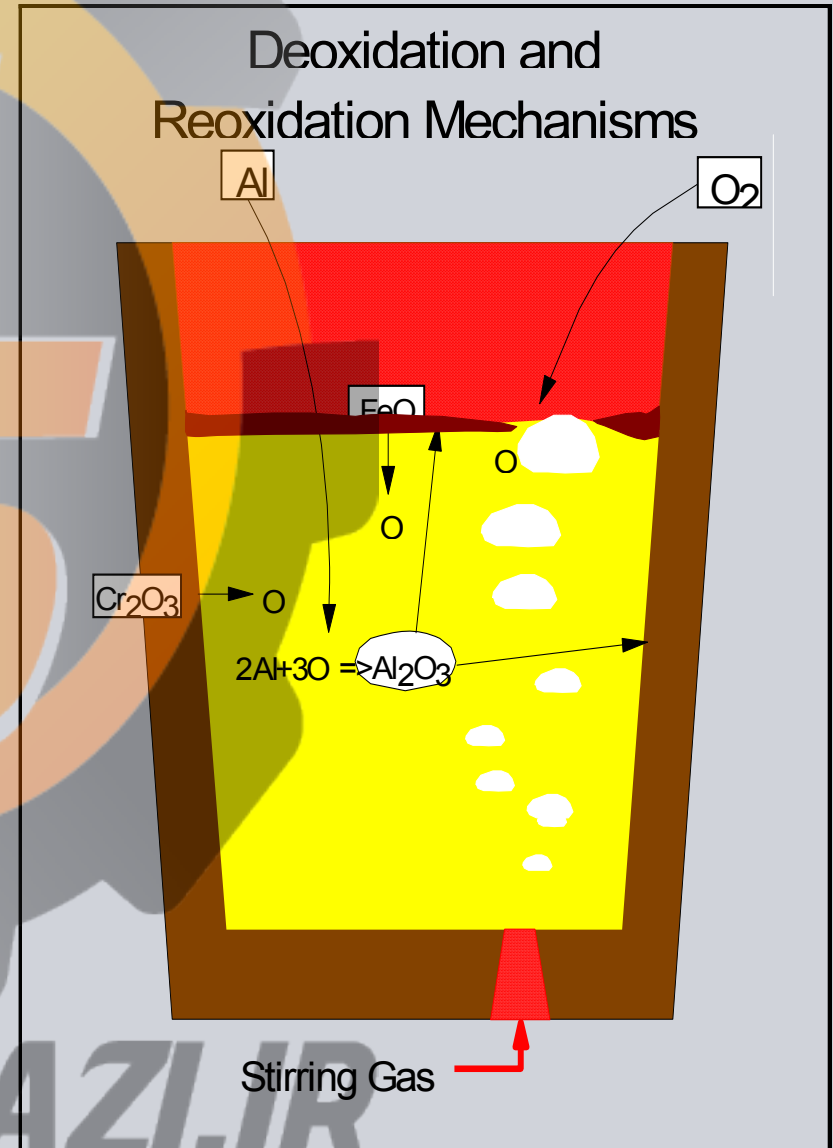
Precipitation Deoxidation  
Floatation of Inclusions  
*Addition of Deoxidiser at Time = 0*



## Fundamental of ladle furnace technology

The metal bath is always exposed to reoxidation, which generates new precipitates.

Such reoxidation is caused by FeO, MnO and Cr<sub>2</sub>O<sub>3</sub> in the top slag refractories. It is also caused by direct oxidation with atmospheric oxygen





## Fundamental of ladle furnace technology

### SLAG IN THE LADLE FURNACE

Slag is a desired product of refining, new refining slag is prepared at the LF furnace with a function of:

- thermal insulation layer
- protect layer from the atmosphere
- refining purpose
- inclusion removal



## Fundamental of ladle furnace technology

### FUNDAMENTAL PROCESS REQUIREMENTS:

Primary slag (coming from EAF and BOF during tapping) must be avoided in order to:

- minimize the phosphorus reversion into the steel
- minimize the amount of oxygen entering the ladle.
- minimize the ladle refractory lining wear
- increases (FeO + MnO) in the ladle
- increases Al Consumption
- Reduces Steel Cleanliness
- Reduces Desulphurisation

**FOLADSAZI.IR**

## Slag Control

- Control Slag on tapping

EBT

Slag Stoppers

- Slag Modifiers

Al – CaO

CaC<sub>2</sub> – CaO

**FOLADSAZI.IR**

# Fundamental of ladle furnace technology

## What is Clean Steel ?

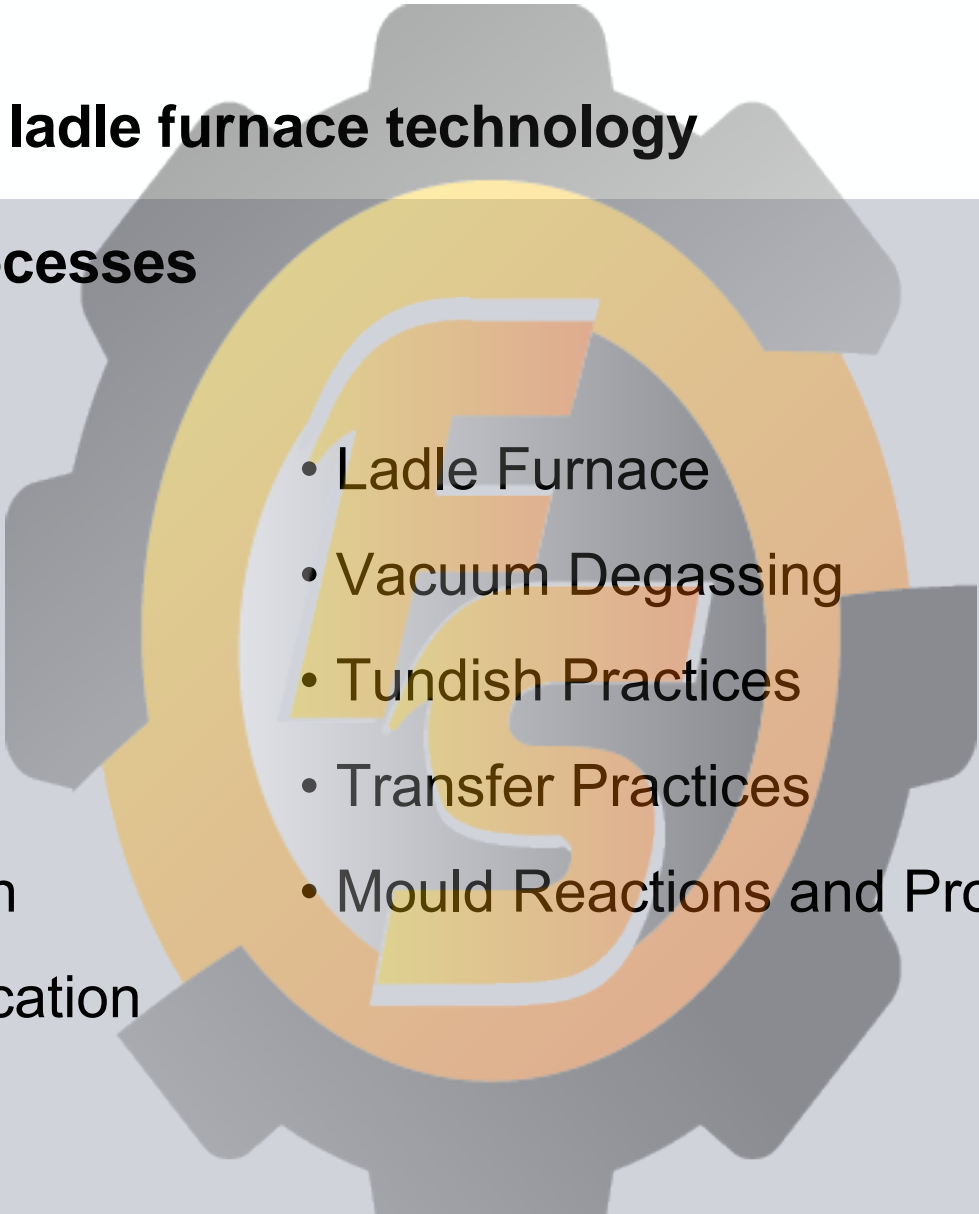
„Clean Steel is steel for which the composition and inclusions are closely controlled to improve properties or production of steel.” In particular, we are concerned with one or more of the following:

1. Low Oxygen or oxides
2. Oxide Shape Control
3. Low Sulphur
4. Sulphide Shape Control
5. Low Hydrogen
6. Low Nitrogen
7. Low Phosphorous
8. Tight control of alloying elements, such as Al, Mn, Si, etc.

**FOLADSAZI.IR**

# Fundamental of ladle furnace technology

## Clean Steel Processes

- 
- Tapping
  - Slag Control
  - Deoxidation
  - Gas Bubbling
  - Desulphurisation
  - Inclusion Modification
  - Ladle Furnace
  - Vacuum Degassing
  - Tundish Practices
  - Transfer Practices
  - Mould Reactions and Processes

Note, clean steel is not made in the primary furnace

**FOLADSAZI.IR**

## Fundamental of ladle furnace technology

After tapping into the ladle ,the steel is normally pre-deoxidized but it still contains a high oxygen content ,and the oxygen potential of the slag is very high. In order to prevent the primary furnace slag from entering the ladle furnace there are three possible ways to deslag:

1. DESLAGGING OF THE PRIMARY FURNACE BEFORE TAPPING.
2. DESLAGGING OF THE LADLE BEFORE STARTING TREATMENT..
3. RELADLING.

The method used mostly today is to deslag before treatment, this can be done by tilting the ladle, simply running off via a slag spout, or by the most popular method of using a slag rake



# Fundamental of ladle furnace technology

## CHEMICAL COMPOSITION.

Refining slag are composed of the main constituents from the CaO-SiO<sub>2</sub>-Al<sub>2</sub>O<sub>3</sub> - MgO system.

CaO comes from the added lime and the slag should normally be saturated with it.

SiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> come from the primary furnace slag, deoxidation products and, to some extent from the refractory wear, Al<sub>2</sub>O<sub>3</sub> is also an important flux in many synthetic slag.

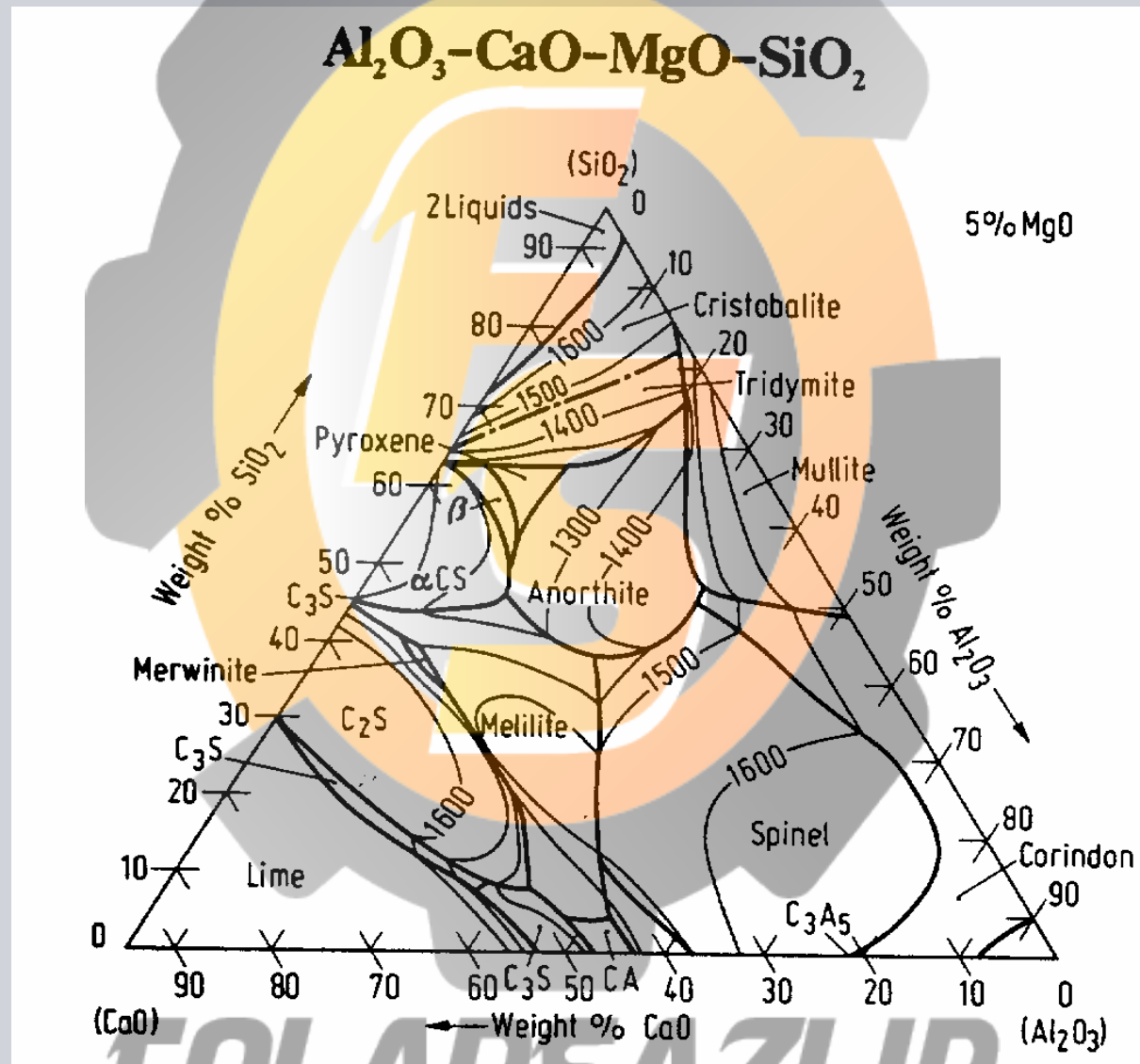
The MgO content normally comes from the dissolution of MgO in the ladle and roof refractory.

Al killed

Si killed

CaO	56-62%	CaO	56-62%
SiO <sub>2</sub>	6-10%	SiO <sub>2</sub>	15-20%
Al <sub>2</sub> O <sub>3</sub>	20-25%	Al <sub>2</sub> O <sub>3</sub>	5-8%
FeO+MnO+Cr <sub>2</sub> O <sub>3</sub>	<2%	FeO+MnO+Cr <sub>2</sub> O <sub>3</sub>	<2
MgO	6-8%	MgO	6-8%
S	0.3-2.0%	S	0.3-1%

# Fundamental of ladle furnace technology



# Fundamental of ladle furnace technology

## Ladle Slag Mass Balance

Component	Amount (kg/tonne)					Percentage
	Steelmaking	Ladle Addition	Reactions	Refractory	Total	
CaO	1,29	4,5	0	0,50	6,29	59
SiO <sub>2</sub>	0,60	0	0	0	0,60	6
MgO	0,21	0	0	0,50	0,71	7
Al <sub>2</sub> O <sub>3</sub>	0,12	0	2,83	0	2,95	28

10,55 kg/tonne (Total)

1,00 kg/tonne (Dolomite refractory)

## Fundamental of ladle furnace technology

### HEAT CAPACITY

The heat capacity for the aforementioned slags is 0.41kWh/(tonne,K) and practically independent of temperature within the 1500 - 1700 °C range.

### DENSITY

The density of refining slags can be calculated with fair precision on the basis of empirical models. Densities for the two aforementioned slags are in the 2.7 to 2.8 kg/dm<sup>3</sup> range for temperatures within the 1500 to 1700°C.

## Fundamental of ladle furnace technology

### SLAG BASICITY

The single most important numerical index which summarizes the composition of a slag and serves as a single parameter with which its chemical character can be correlated, is the BASICITY INDEX.

The simplest and most widespread definition is the one by Herty in the 1920,s called V -RATIO and defined as :

$$\text{V-ratio} = (\text{WT-\% Ca O}) / (\text{WT-\% SiO}_2) [1,8-3,5]$$

The V-ratio ignores the effects of the other basic (FeO,MnO, MgO) and acid (Fe<sub>2</sub>O<sub>3</sub>,Al<sub>2</sub>O<sub>3</sub>,P<sub>2</sub>O<sub>5</sub>).

## Fundamental of ladle furnace technology

Removal of S from steel into the slag is conventionally illustrate by the reaction



To achieve a good desulphurisation it is first of all necessary that three fundamental conditions be satisfied.

1. Basic Slag.
2. High Temperature (60-80deg greater than delta T sl).
3. De -oxidation of the bath(aO2 less than 40ppm).

The stirring of the bath and the reactivity of the slag are important to speed up the formation of Ca Sulphide.

**FOLADSAZI.IR**



# Fundamental of ladle furnace technology

Desulphurisation is mathematically represented by the formula

$$S_{\text{final}} = S_{\text{initial}} * e^{-k_s * (A/V) * t}$$

A = bath area m<sup>2</sup>

V = metal volume m<sup>3</sup>

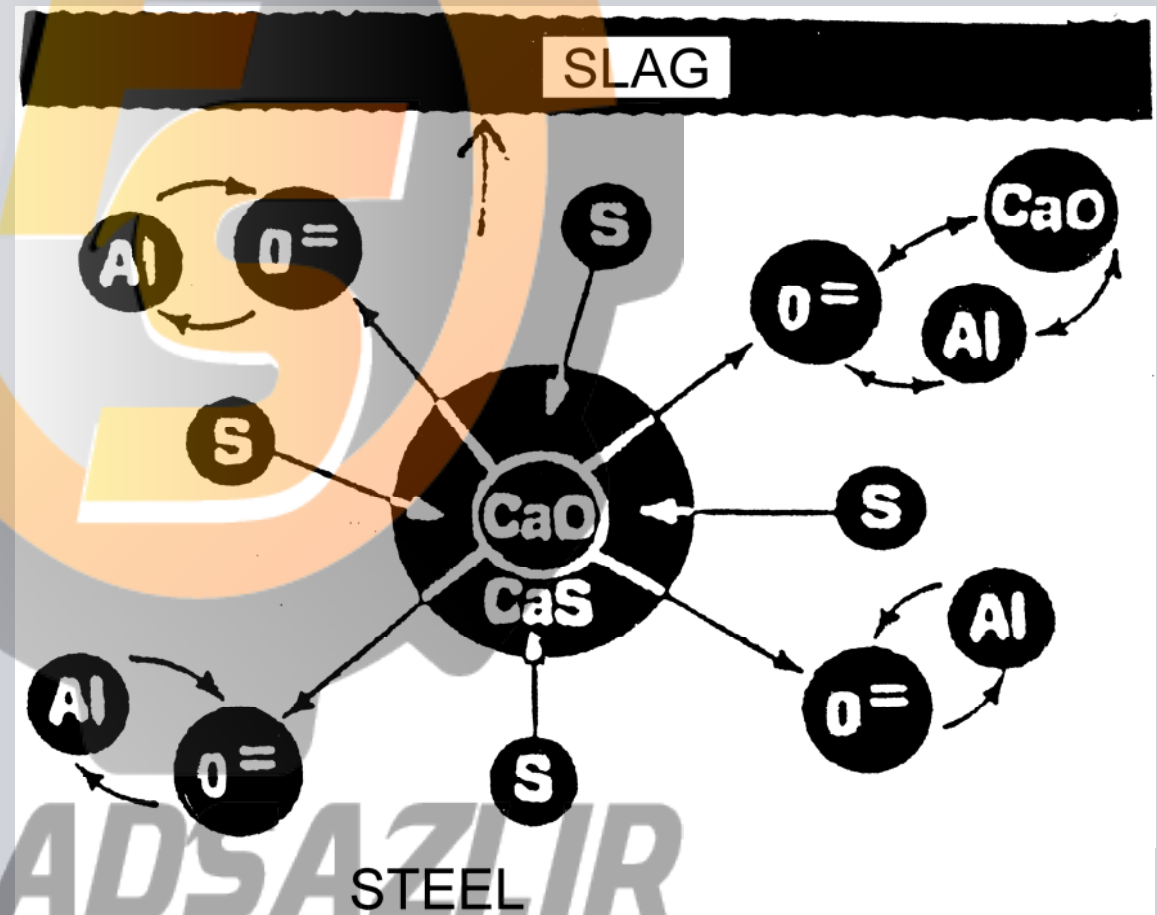
K<sub>s</sub> = deS rate constant m/min

t = process time

K<sub>s</sub> in the LF = 0.08

(0.8-1.2 NI/ton min)

K<sub>s</sub> in the VD = 0.20



# Fundamental of ladle furnace technology

## Ladle Desulphurisation

- Mature, well understood process

- Desulphurisation equilibrium

depends on

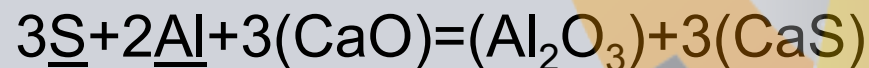
Sulphide capacity of slag

Oxygen activity (Al or Si)

Slag Weight

Desulphurisation is, therefore, favoured by

- Basic Reaction



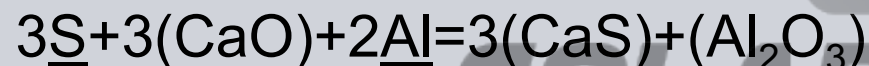
- High basicity

- High level of Al or Si, Al is generally more effective.

- Kinetics

Equilibrium sulphur

Stirring energy



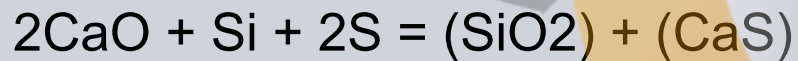
# Fundamental of ladle furnace technology

## Ladle Desulphurisation



- High CaO and Al
- Optimum slag
- (S)/[S] as high as 500

However, kinetics are not fast enough for simple ladle, Ladle furnace is required for optimum results.



$$(\text{S})/[\text{S}] \sim 50$$

Desulphurisation is limited

$$L_S = \frac{(\%S) \text{ (slag)}}{[\%S] \text{ (metal)}}$$

The higher  $L_S$ , the more effective is desulphurisation

**FOLADSAZI.IR**

# Fundamental of ladle furnace technology

## Process Kinetics

The rate of desulphurisation is controlled by liquid phase mass transfer and favoured by:

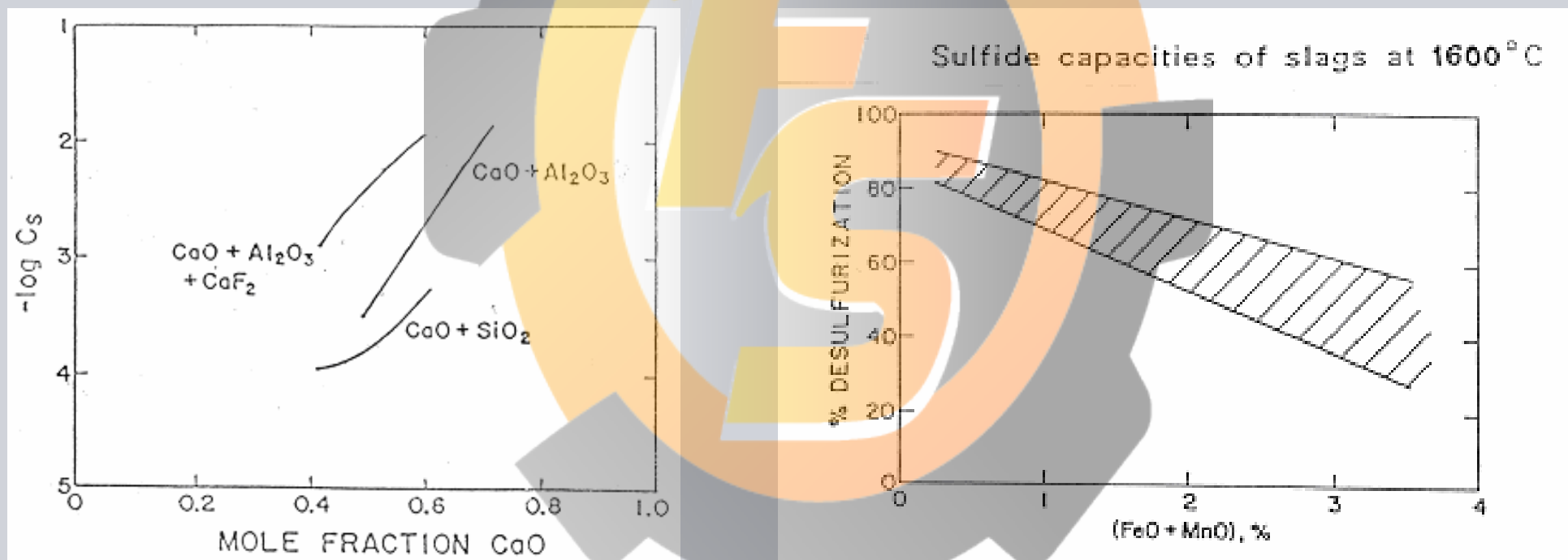
- Stirring
- Fluid Slag ( $\text{CaF}_2$ )
- Low [%S]
- High  $L_s$
- High  $W_s$

Example shown in the next two figure.

**FOLADSAZI.IR**

# Fundamental of ladle furnace technology

## Effect of FeO and MnO on Desulphurisation

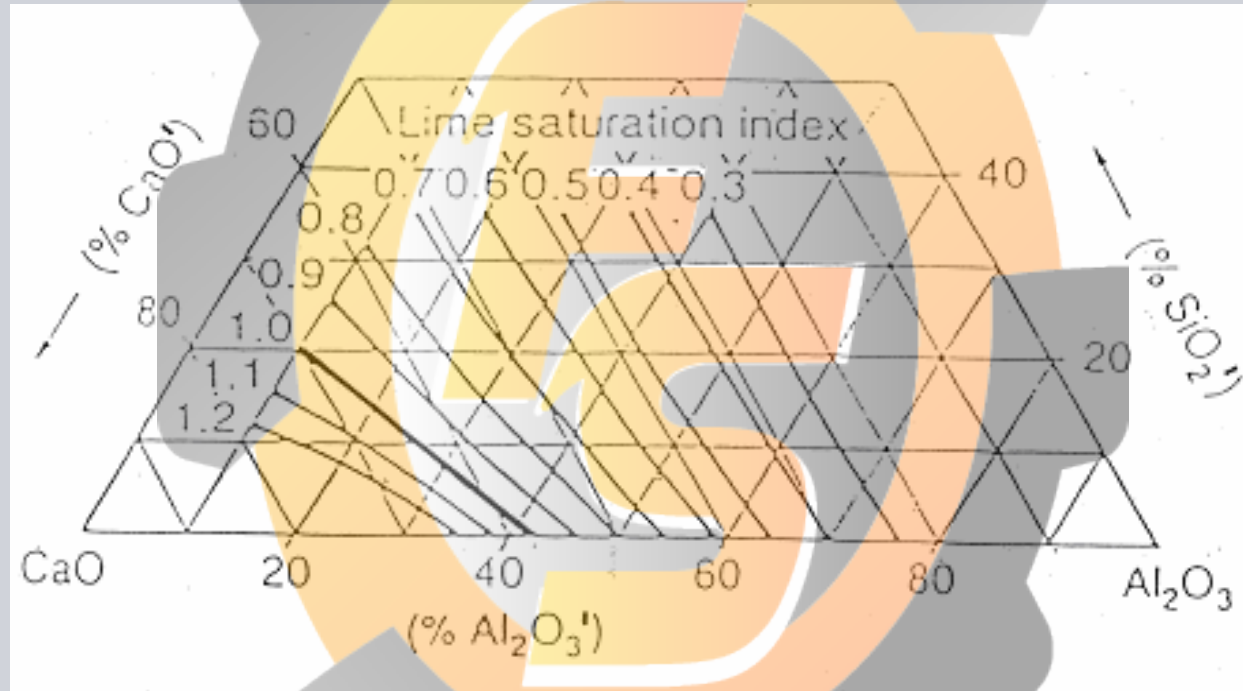


**FOLADSAZI.IR**



# Fundamental of ladle furnace technology

## Lime Saturation index



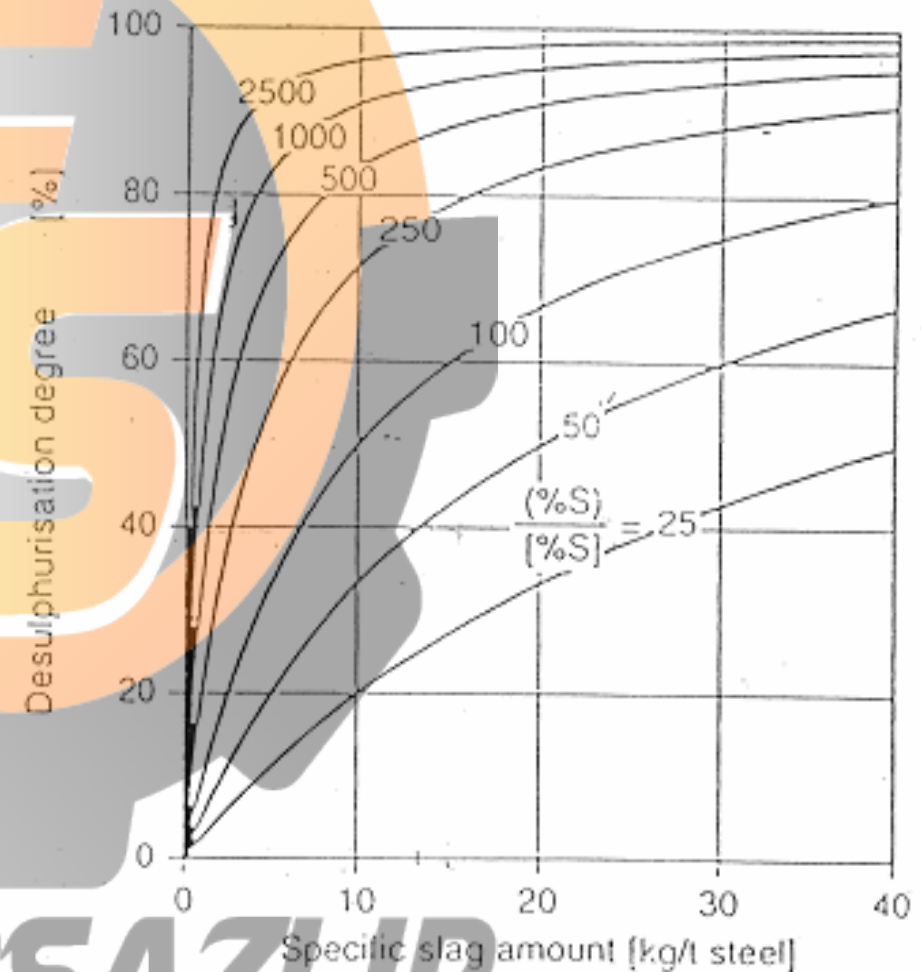
Ladle Slag formation and lime saturation index in the system  
 $\text{CaO} - \text{Al}_2\text{O}_3 - \text{SiO}_2$

**FOLADSAZI.IR**

# Fundamental of ladle furnace technology

## Desulphurisation versus Slag Amount

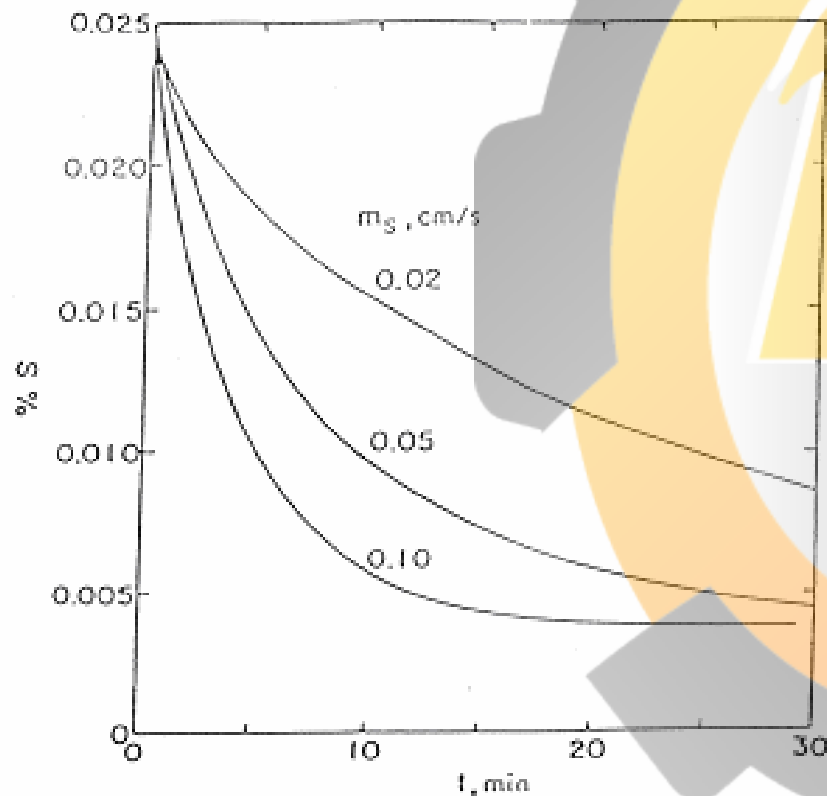
Desulphurisation degree for different Sulphur distributions as a function of specific slag amount



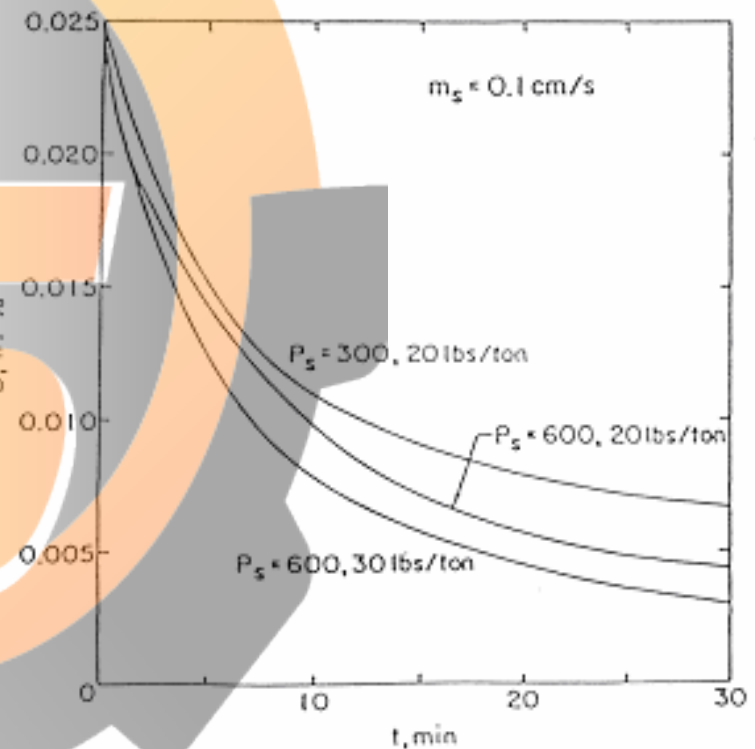
**FOLADSAZI.IR**

# Fundamental of ladle furnace technology

## Desulphurisation



Effect of stirring on desulphurisation  
(Figure 10)



Effect of (S)/[S] and  $W_s$  on  
desulphurisation  
(Figure 11)

# Fundamental of ladle furnace technology

## Kinetics

The rate of desulphurisation is controlled by liquid phase mass transfer and favoured by:

- Stirring
- Fluid slag (CaF<sub>2</sub>)
- Low [%S]

High LS  
High WS

Examples shown in Figures (10-11)

Percentage  
Desulphurisation

$$\frac{[\%S]_i - [\%S]_f}{[\%S]_i} \times 100$$

Stirring  
(SCFM)

Time  
(minutes)

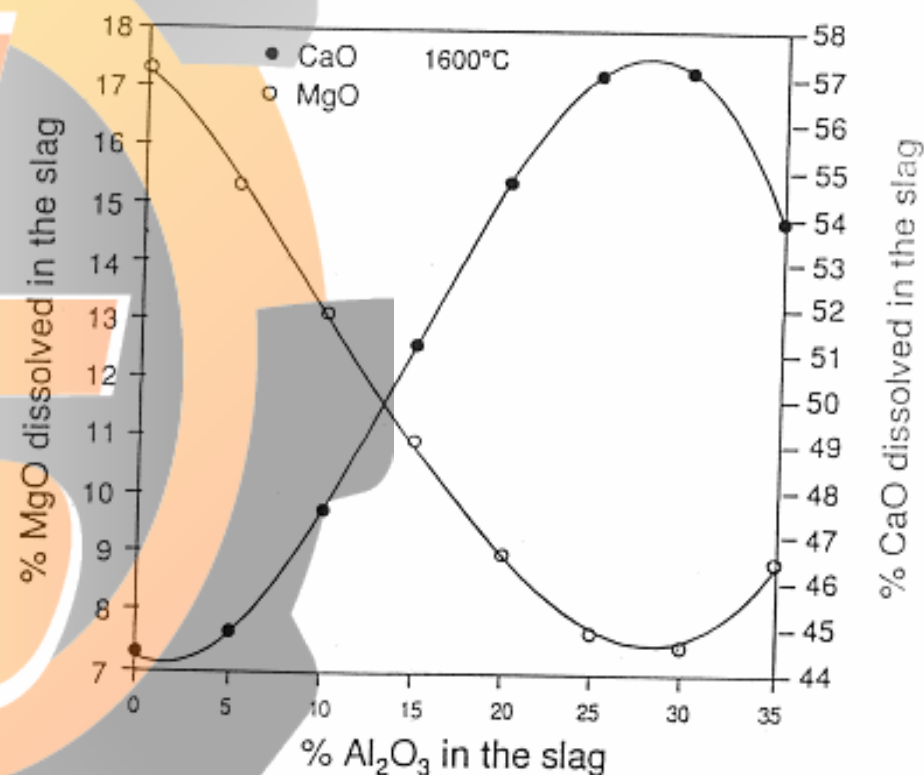
70%	10	10
85%	10	20
70%	30	5
95%	30	15

FOLADSAZI.IR

# Fundamental of ladle furnace technology

## Optimum Slag at 1600°C

%Al <sub>2</sub> O <sub>3</sub>	%MgO	%CaO	%SiO <sub>2</sub>	C/S ratio	Opt.Bas (Λ)	-log C <sub>s</sub>
0	17,32	44,31	38,37	1,15	0,696	3,042
5	15,19	44,79	34,92	1,28	0,700	2,982
10	13,11	47,45	29,44	1,61	0,715	2,763
15	10,92	51,13	22,95	2,23	0,737	2,458
20	8,99	54,69	16,32	3,35	0,759	2,132
25	7,68	57,05	7,68	5,56	0,778	1,856
30	7,47	57,15	5,38	10,62	0,789	1,702
35	8,92	53,88	2,20	24,49	0,786	1,742





# Fundamental of ladle furnace technology

## Desulphurisation efficiency

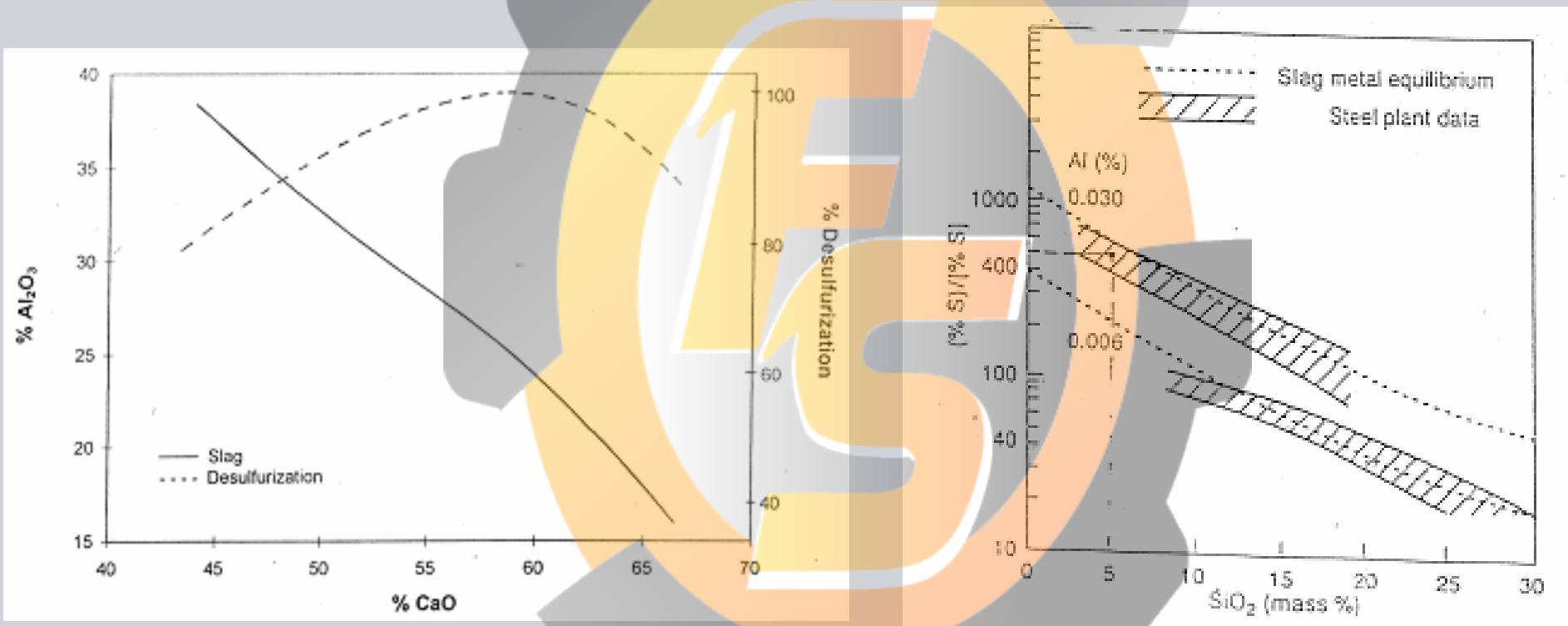


Fig. 2 - Plot of %CaO versus %Al<sub>2</sub>O<sub>3</sub> in the slags and the desulfurising efficiency of the slags

Fig. 3 – Slag/steel sulphur distribution ratios after desulphurisation with lime-saturated CaO – MgO – Al<sub>2</sub>O<sub>3</sub> – SiO<sub>2</sub> slags at 1600 ± 15°C with steels containing residual 0,006% Al and 0,03% Al are compared with the equilibrium values.

**FOLADSAZI.IR**

# Fundamental of ladle furnace technology

## Slag Color

Since slags cannot be analysed as quickly as steel, it is necessary to adapt the slag conditions according to other information, which is given by the appearance of the slag. The slag have to be cooled prior the appearance can be analysed.

The colour of the slag can be black, brown, grey, green, yellow or white with a lot of nuances in between. The slag colour changes from black to white with the rate of slag reduction.

**Black:**  $\text{FeO} + \text{MnO} > 5\%$  to be reduced either by Al,  $\text{CaC}_2$  or FeSi.

**Dark to green:**  $\text{FeO} + \text{MnO} = 4\%$  to be reduced either by Al,  $\text{CaC}_2$  or FeSi.

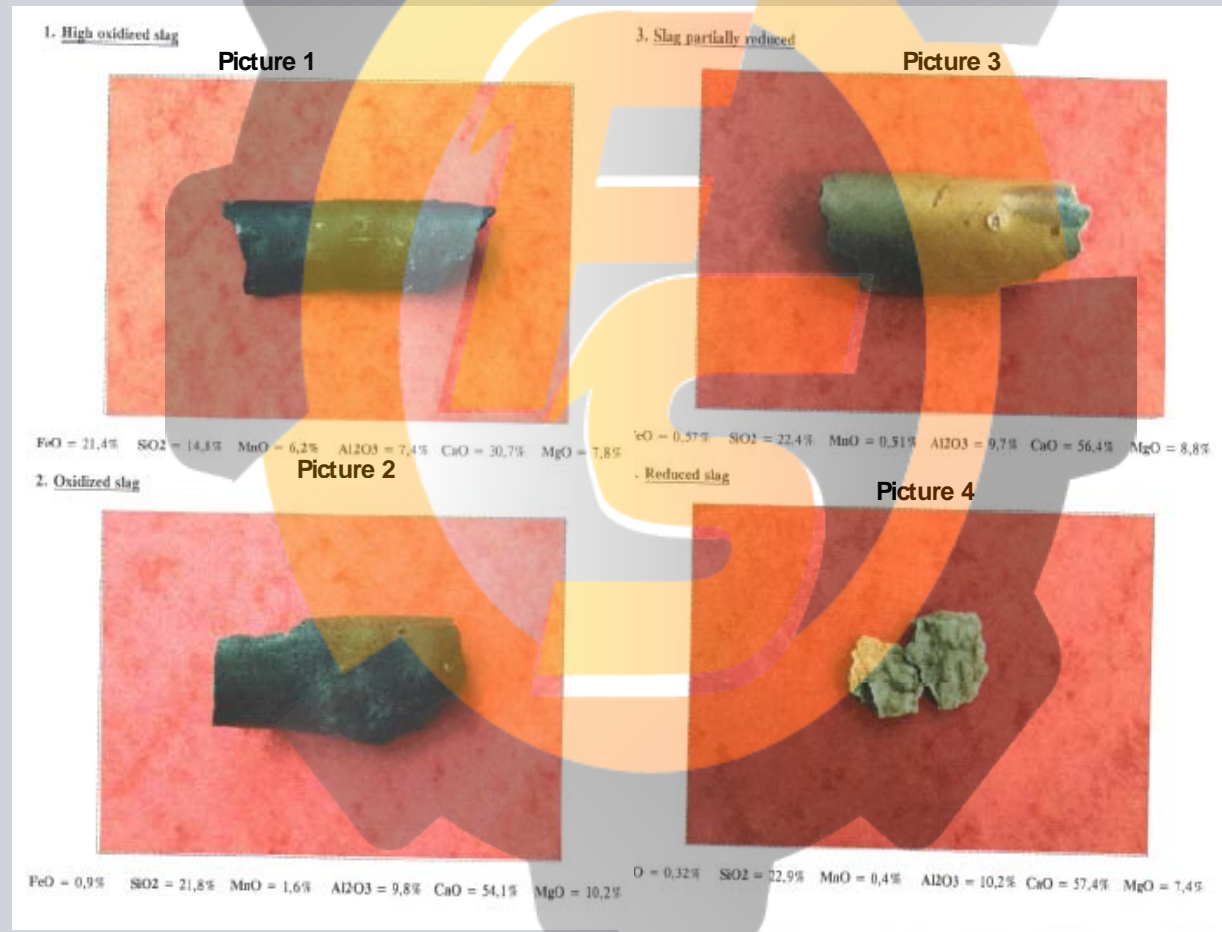
**Dark to grey:**  $\text{FeO} + \text{MnO} = 3\%$  to be reduced either by Al,  $\text{CaC}_2$  or FeSi.

**White to yellow:**  $\text{FeO} + \text{MnO} < 2\%$ .

This slag is well reduced. The yellow colour indicates that desulphurisation has taken place. This slag should disintegrated to powder when cooled down.

**FOLADSAZI.IR**

## LADLE SLAG REFERENCE PICTURES



Ladle Slag Colours {typical}

**FOLADSAZI.IR**

# Fundamental of ladle furnace technology

## Slag Surfaces

The slag surface can be glassy, smooth or brittle, depending on the different components in the slag.

**Glassy and thin:** This indicates that the  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$  or  $\text{CaF}_2$  content are too high. Lime should be added in this case, not more than 1,0 kg/t steel at a time. After dissolving it should be tested once more.

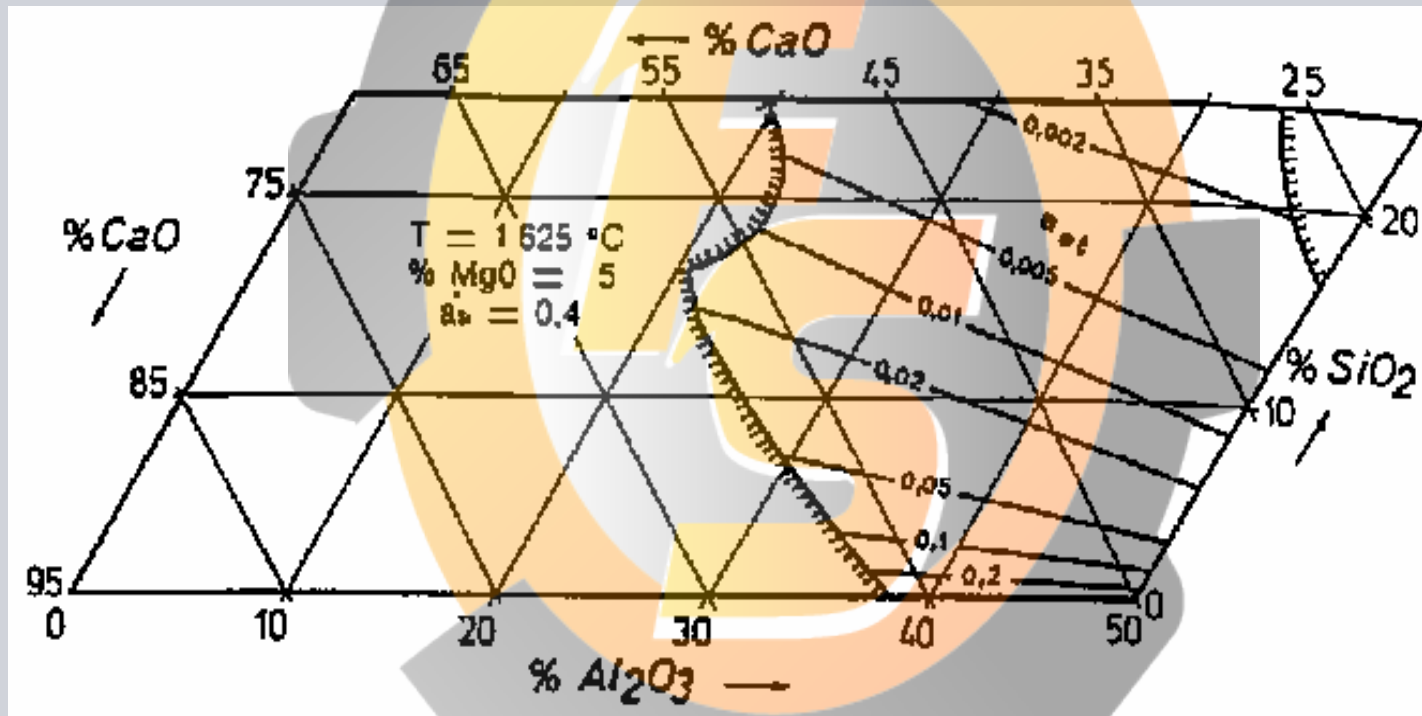
**Smooth and thick:** This slag should normally disintegrate to powder when cold. Slag condition seems ideal. In case it does not disintegrate, the  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$  or  $\text{CaF}_2$  may be high. Desulphurisation may cause problems in this case. More lime shall be added, as indicated above.

**Rough and thick:** The amount of lime is too high. In case undissolved lime particles are found,  $\text{Al}_2\text{O}_3$  or  $\text{CaF}_2$  shall be added. Not more than 0,5 kg/t at a time should be added and dissolved prior new test.

The above mentioned can only be a rough indication, how to react on different situations.

## Fundamental of ladle furnace technology

**CaO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub>-5%MgO with Si-0,4%**

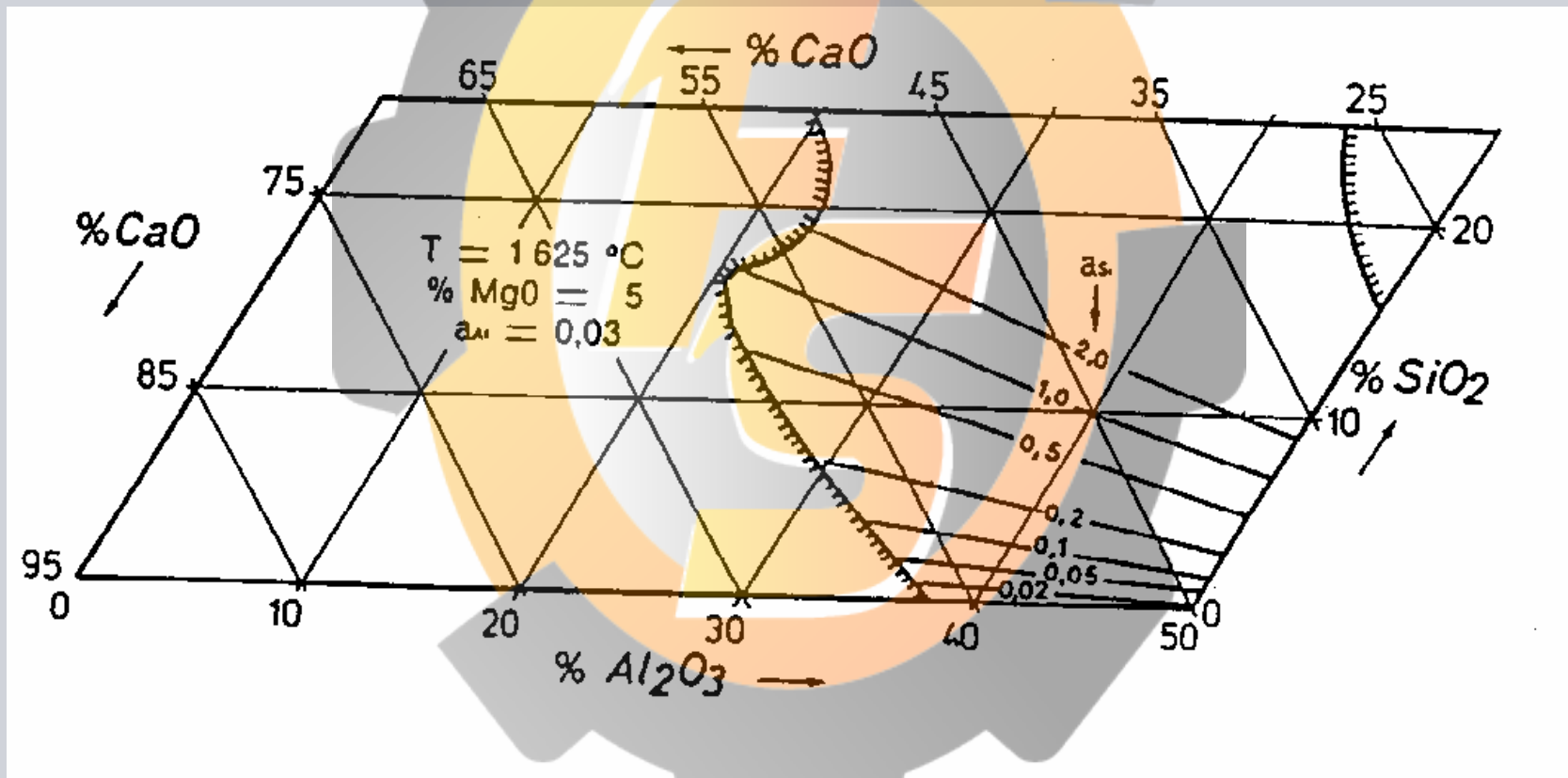


Al content in the metal in equilibrium with CaO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> and 5% MgO slag with a Si activity = 0,4%.

**FOLADSAZI.IR**

## Fundamental of ladle furnace technology

**CaO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub>-5%MgO with Al 0,03%**

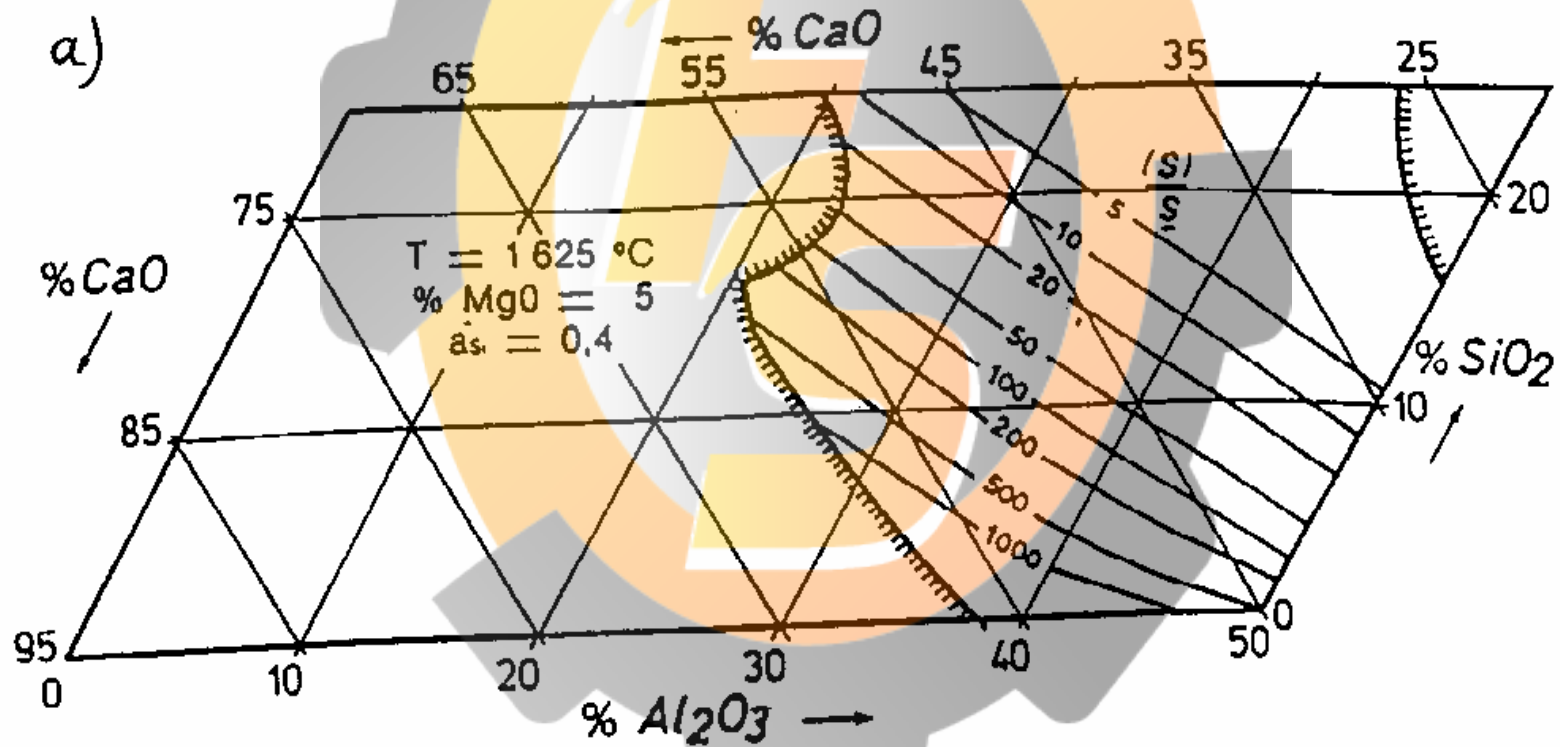


Si activity in the metal in equilibrium with CaO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> and 5% MgO slag with a Al activity = 0,03 (0,03% Al).



# Fundamental of ladle furnace technology

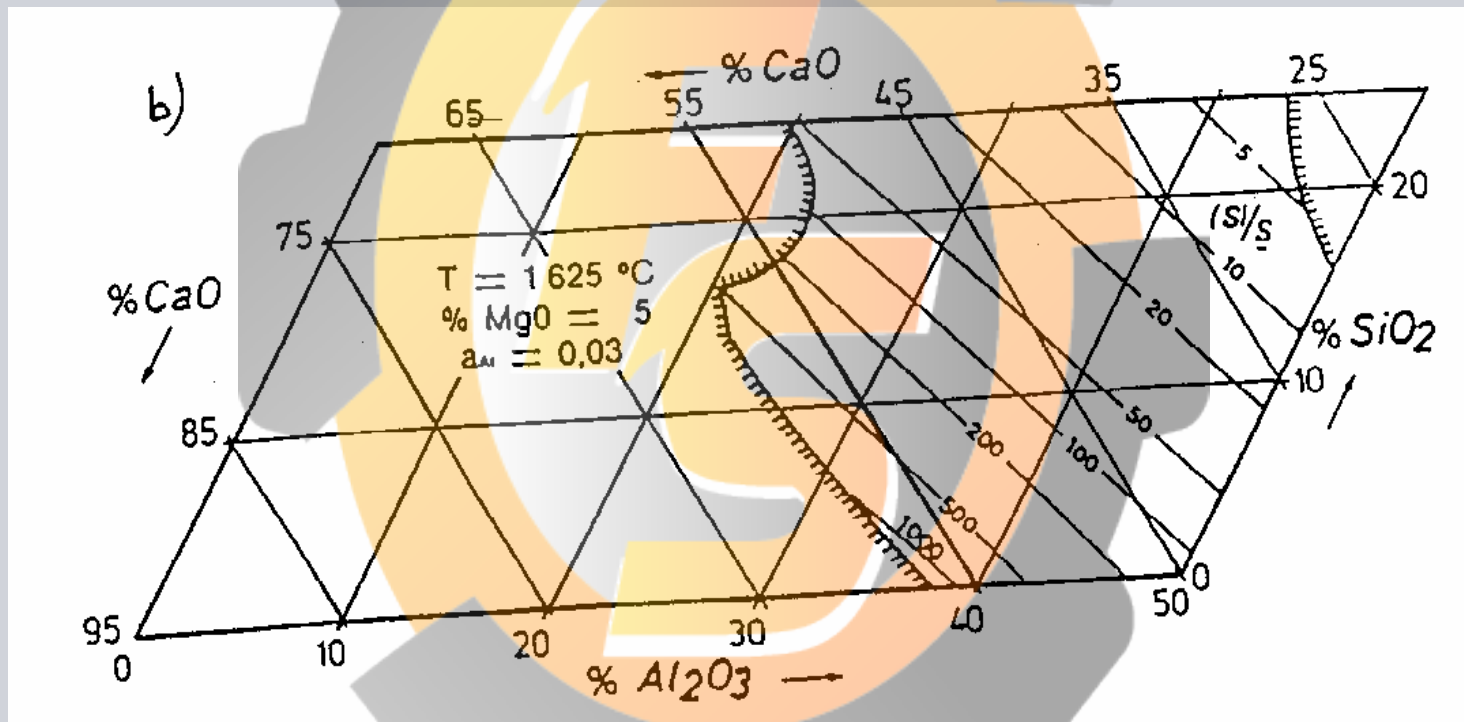
## $L_s$ for Si-killed Steel



**FOLADSAZI.IR**

# Fundamental of ladle furnace technology

## $L_s$ for Al-killed Steel



Sulphur partition ratio for a steel with

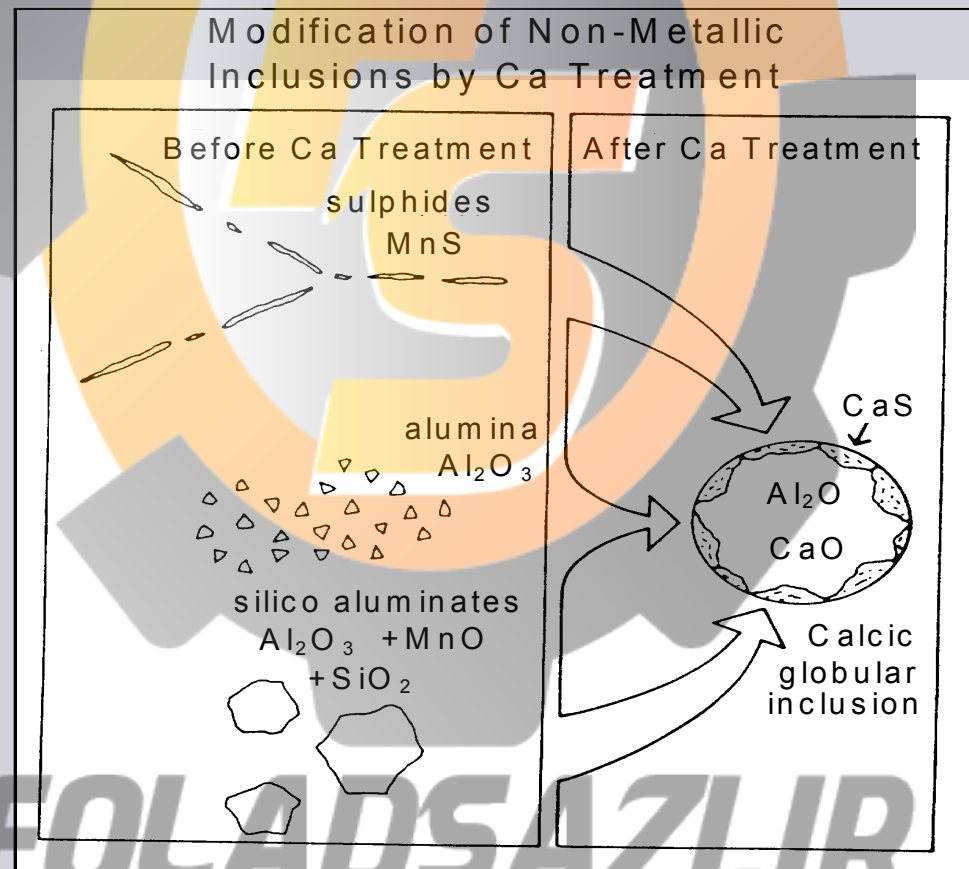
- a Si activity of 0,4
- an Al activity of 0,03 (0,03% Al)

In equilibrium with  $\text{CaO}-\text{Al}_2\text{O}_3-\text{SiO}_2$  and 5%  $\text{MgO}$  slag

## Fundamental of ladle furnace technology

### CALCIUM TREATED STEELS

The aim of calcium treatment is in most cases to improve castability, by modifying the sharp edged, solid  $\text{Al}_2\text{O}_3$  particles into spherical liquid calcium aluminates.



# Fundamental of ladle furnace technology

## Calcium Reaction

1. Reacts with oxygen (O) , Steel must be deoxidised
2. Reacts with sulphur or  $Al_2O_3$  inclusions  
 If sulphur is high sulphur first
 

%Al	%S
0,01	0,015
0,03	0,010
0,05	0,006

$$CaS + Al_2O_3 = (CaO - Al_2O_3) + \underline{S} + \underline{Al}$$
3. If sulphur is low during solidification Ca prevents MnS formation  
 $S \rightarrow (CaO - Al_2O_3) \text{ into solution } Ca + S = CaS$
4. For re-sulfurised steel
  - Remove as much  $Al_2O_3$  as possible
  - Add Ca
  - Add wire just prior to casting

**FOLADSAZI.IR**

# Fundamental of ladle furnace technology

## Oxide Shape Control

- Liquid ( $\text{MnO} - \text{SiO}_2$ ) Ca may help
- Liquid ( $\text{CaO} - \text{Al}_2\text{O}_3$ )

Ca Reacts

Oxygen

Sulphur

Inclusion

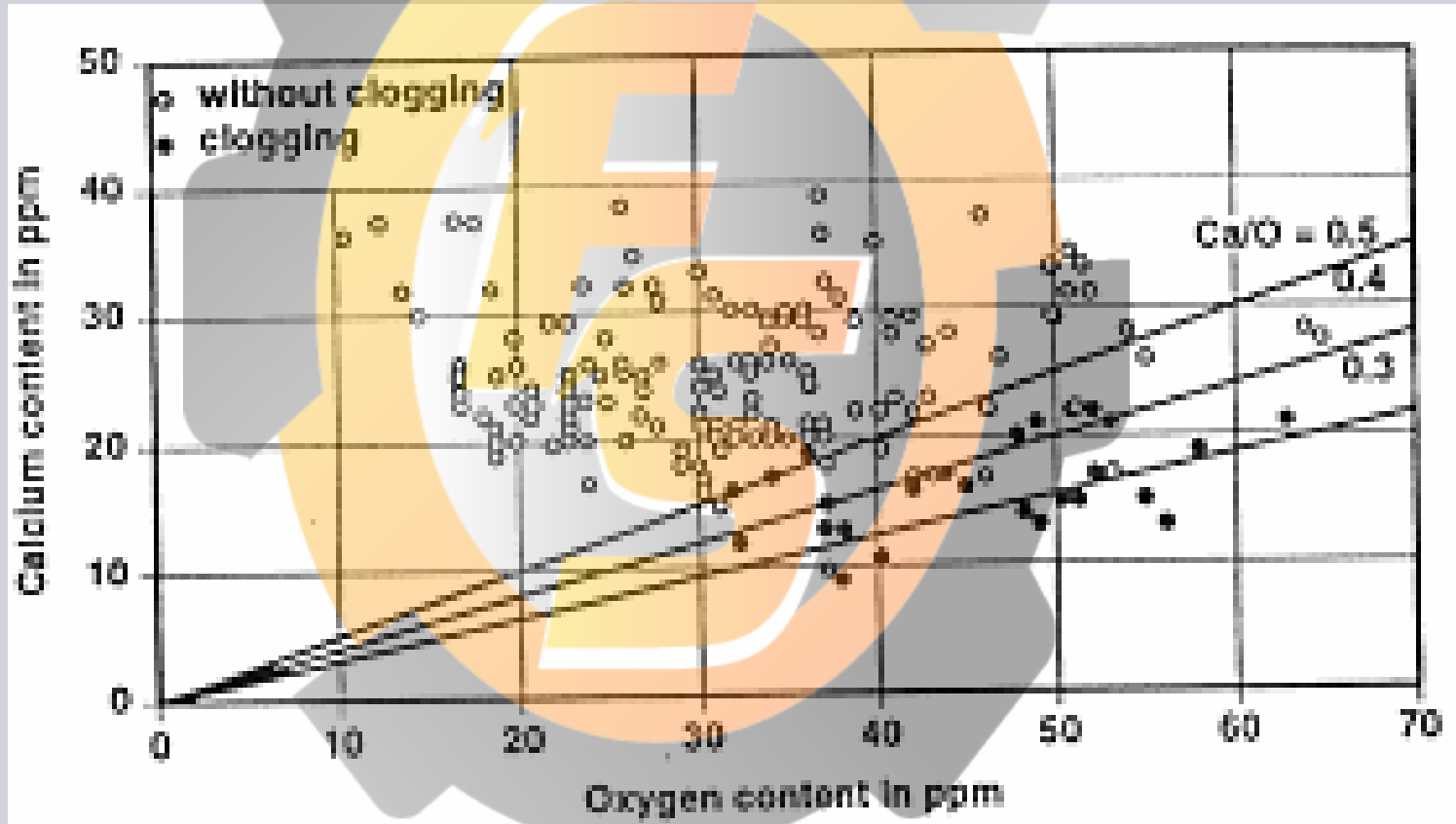


Al and S must be below curve

**FOLADSAZI.IR**

# Fundamental of ladle furnace technology

## Clogging behaviour



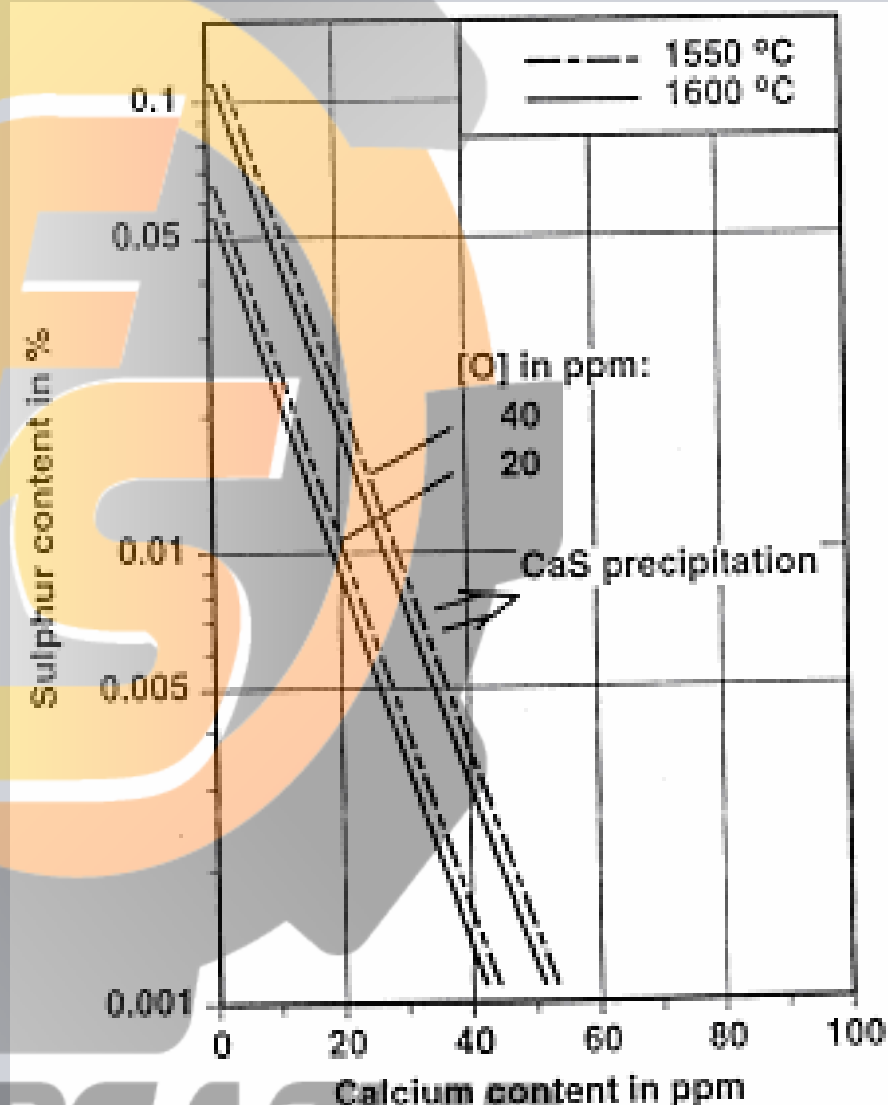
Clogging behaviour dependent on the oxygen and calcium of the steel for Fe – Ca – Al treated heats



## Fundamental of ladle furnace technology

### CaS precipitation

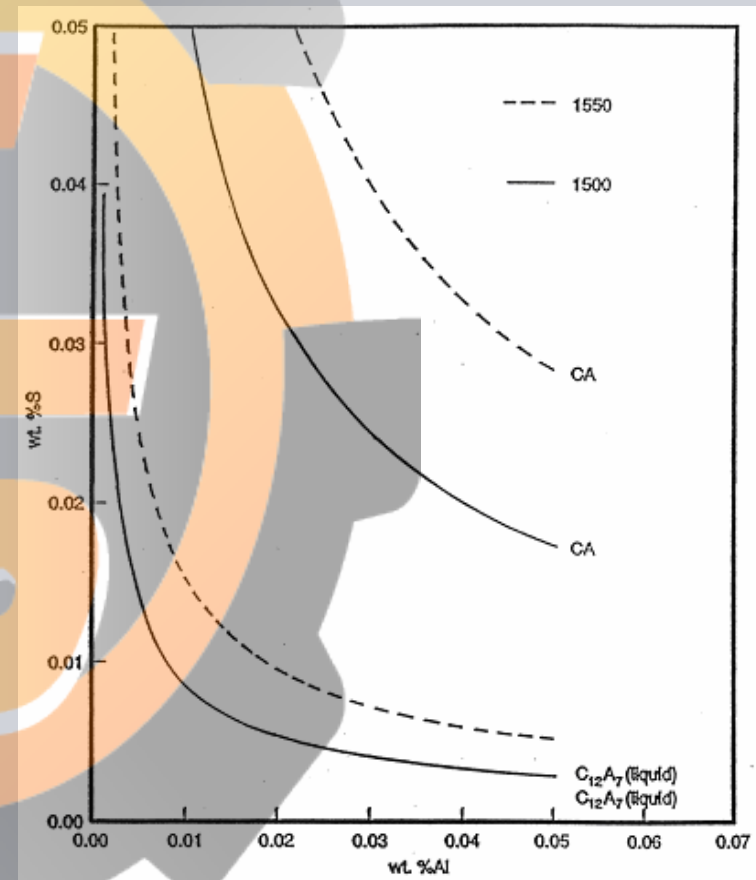
CaS precipitation dependent on calcium, oxygen sulphur content.



**FOLADSAZI.IR**

## Fundamental of ladle furnace technology

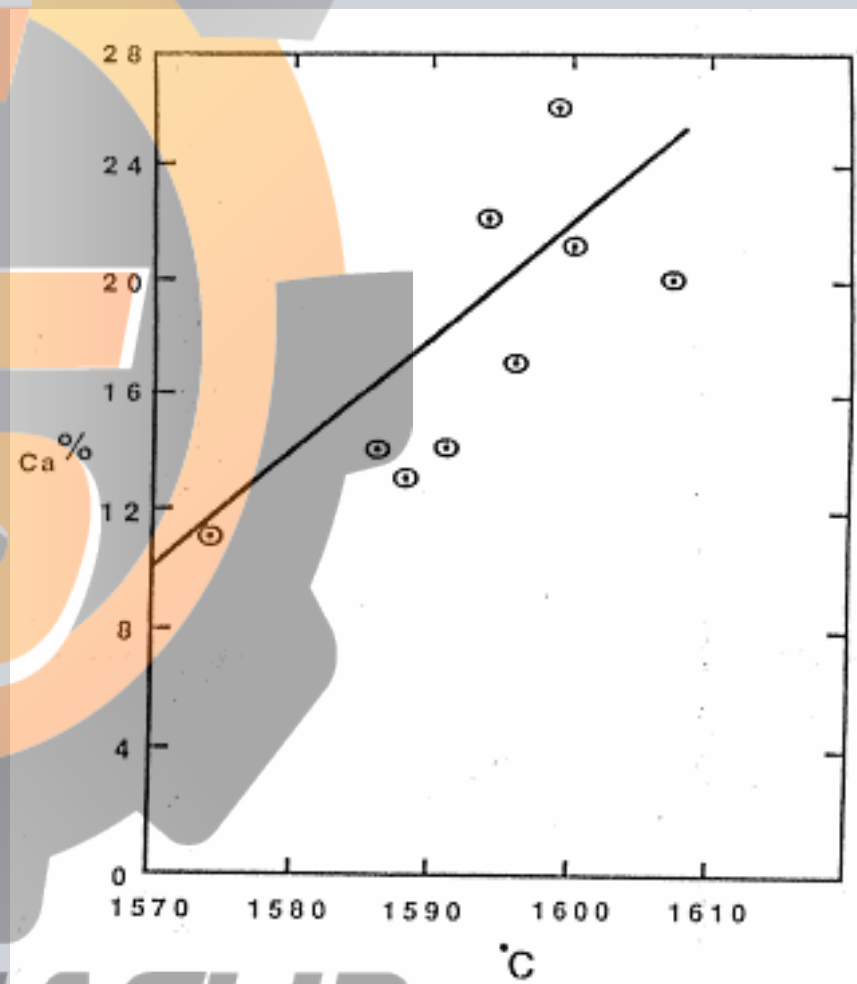
### Equilibrium for CaS and $C_{12}A_7$



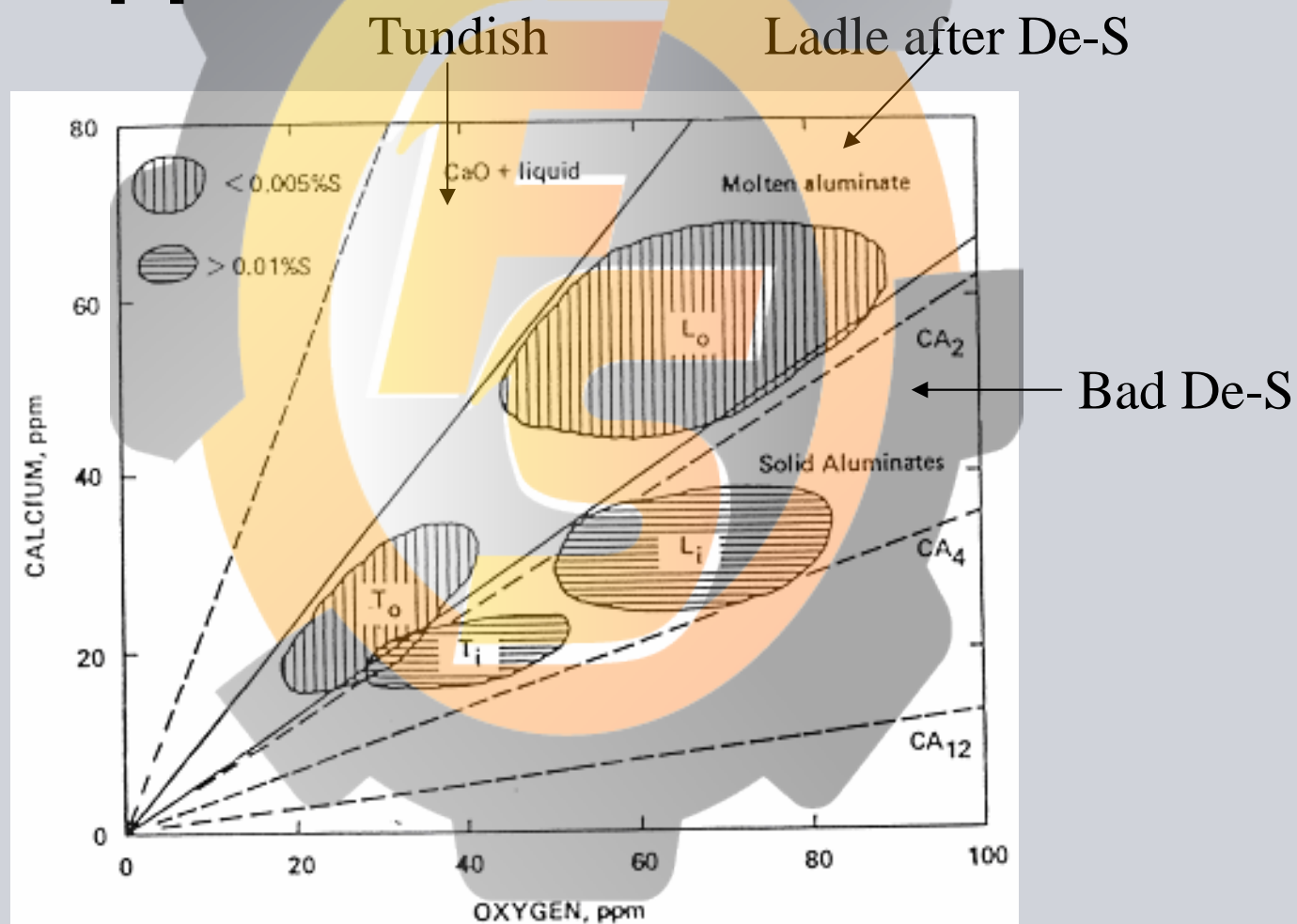
Univariant equilibrium for CaS ( $a_{CaS} = 0,74$ ) and  $C_{12}A_7$  or CA as a function of %Al and %S at 1550 and 1500°C

## Calcium Retention Efficiency

Calcium retention efficiency in the steel after wire feeding of CaSi (~30%Ca) at an average rate of about 180 m/min (~10kg Ca/min) into (123 ± 5), tonnes heats (~0,5 kg Ca/tonne total added). This figure shows the observed calcium retention efficiency in (123 ± 5) tonne heats as determined from the known quantity of calcium added and the calcium content of a sample taken after the calcium addition. Although the data show some scatter, there is a clear trend showing that the retention efficiency increases with increasing bath temperature, the net effect of a bath temperature increase is an increase in calcium retention efficiency, presumably because of faster reaction rates between calcium and the reactive constituents present in the steel.



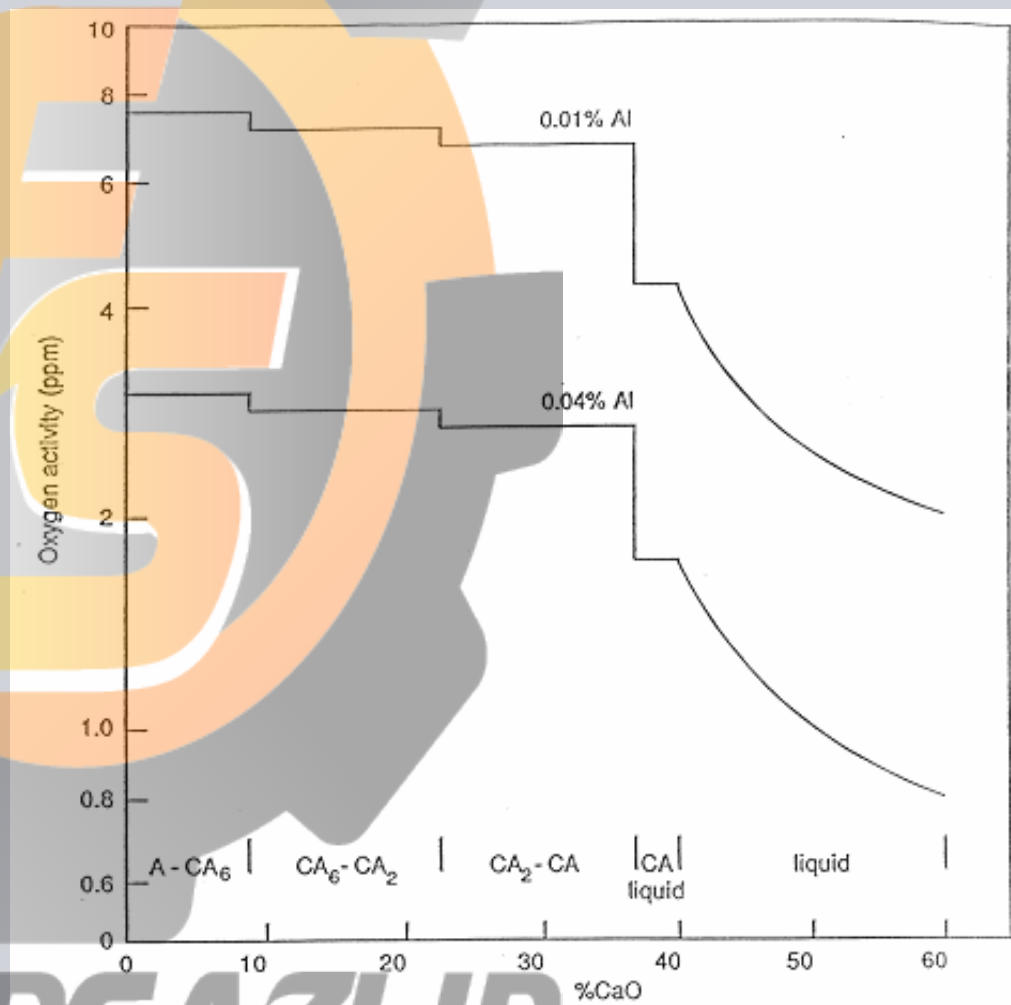
## Calcium and Tot. [O] content in Ca treated steels



**FOLADSAZI.IR**

## Oxygen Activities after Ca-treatment

Oxygen activity in Iron containing 0,01% Al and 0,04% Al in equilibrium with calcium aluminates at 1600°C.



**FOLADSAZI.IR**

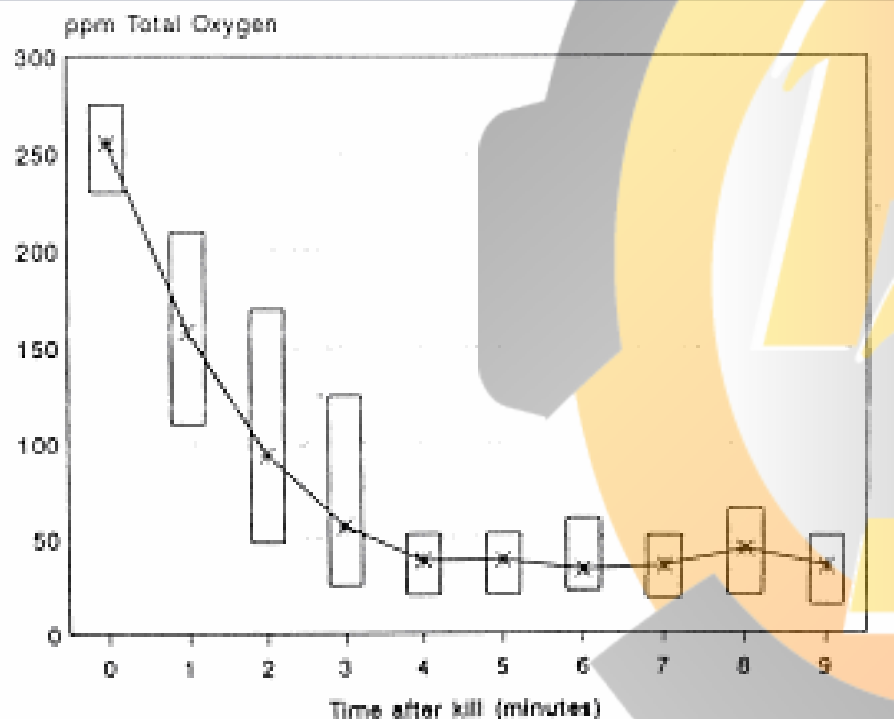
## Inclusion removal

- Low flow for removal
  - 5 SCFM for 200 tonnes
  - 5 – 6 minutes
- For cooling higher flows can be used but should finish with gentle stir.
- Plugs are best.
- Lance can be used but more difficult to control and usually higher cost.
- Large inclusions float out easily.
- Gas helps make larger inclusions, provides fluid flow and inclusions attach to bubbles.

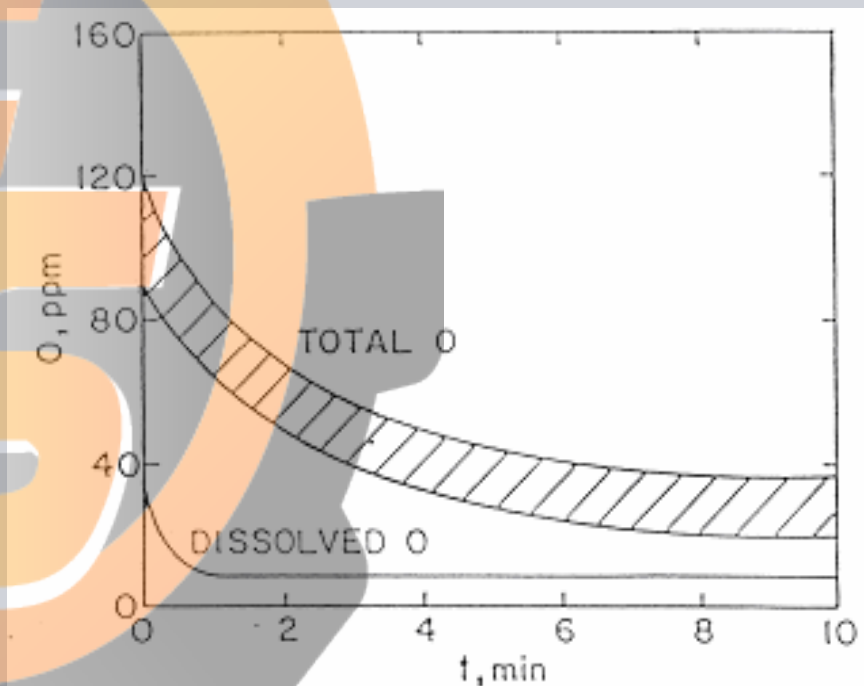
FOLADSAZI.IR



## Total Oxygen



Total oxygen of LCAK heats during stirring after final aluminium deoxidation addition.

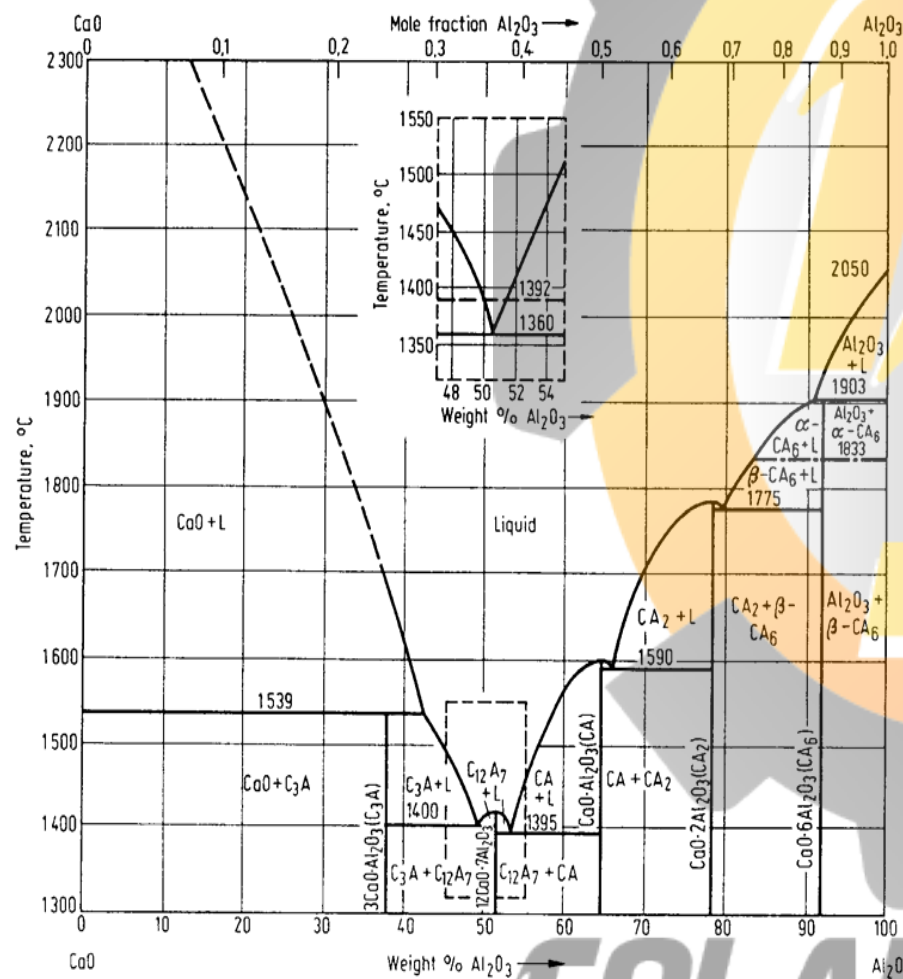


Rate of alumina inclusion removal with Ar bubbling.

**FOLADSAZI.IR**

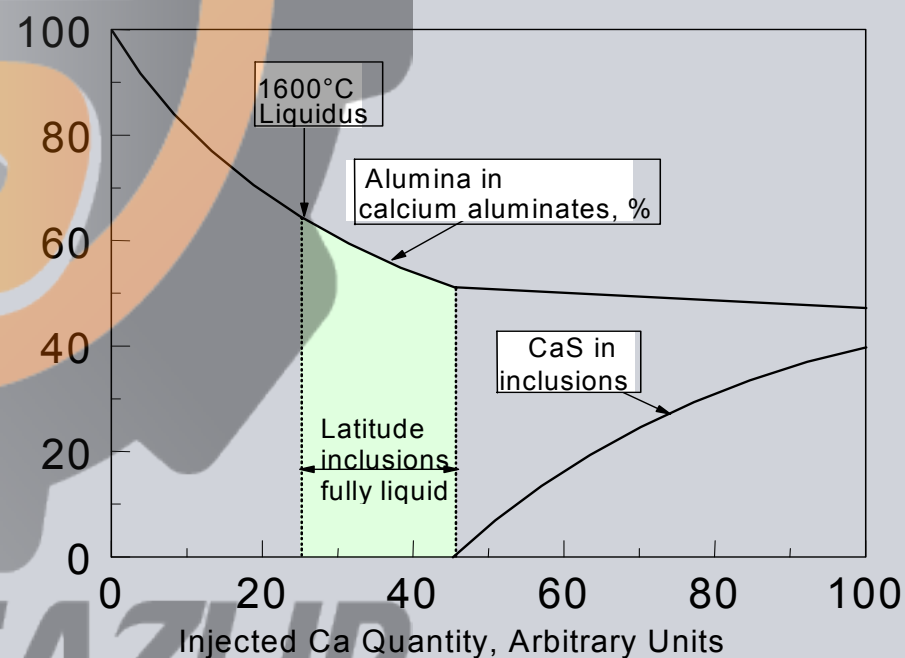
# Fundamental of ladle furnace technology

## $\text{Al}_2\text{O}_3\text{-CaO}$



**Changes in Inclusion Composition  
During Injection of Ca at 1600 $^{\circ}\text{C}$**   
Steel: 0.1C, 0.2Si, 0.45Mn, 0.03 Al, 0.02 S

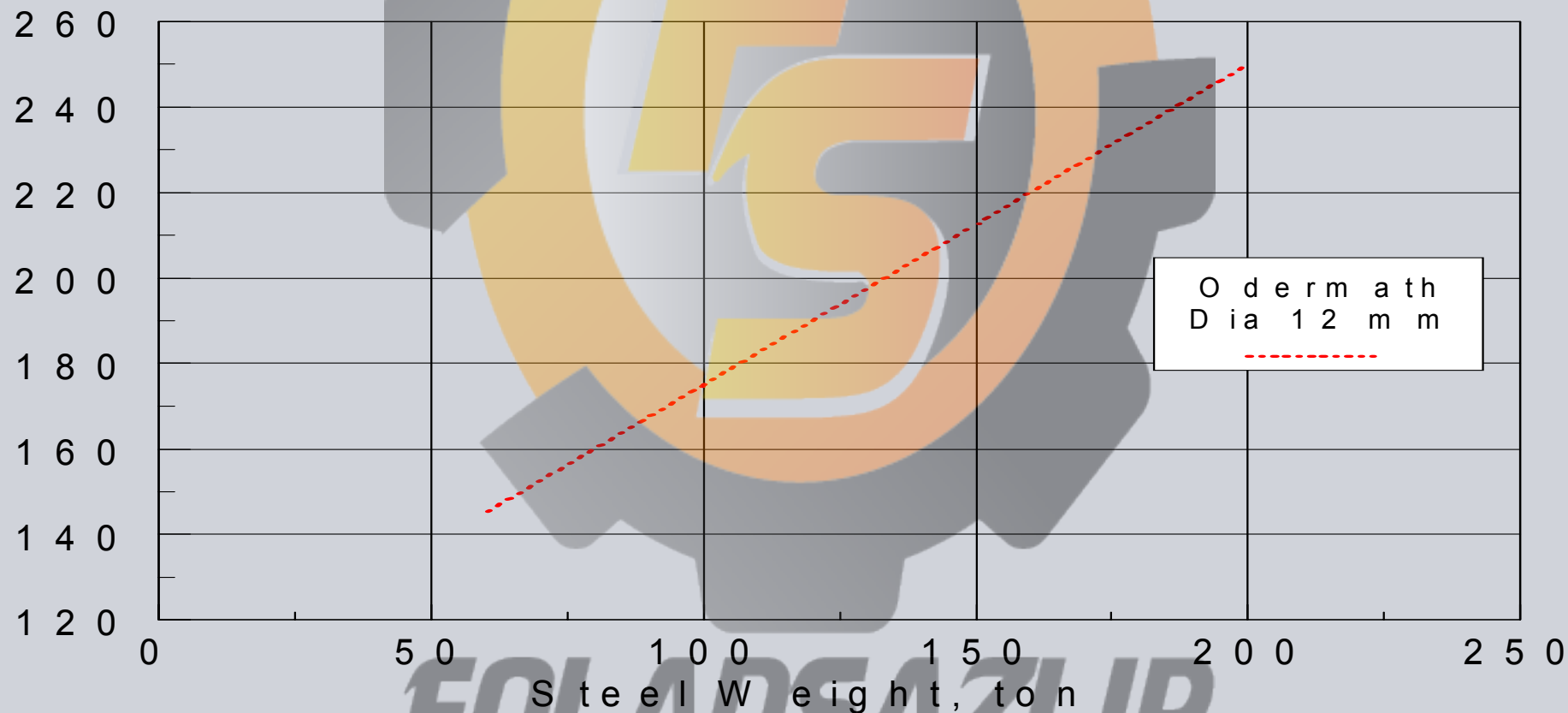
%  $\text{Al}_2\text{O}_3$  in Aluminates, %  $\text{CaS}$  in Inclusions



# Fundamental of ladle furnace technology

CaSi Wire Feedrate as Function of Steel Weight  
for 12 mm Wire Diameter

Feedrate, m / m in





**End**

**Fundamental of ladle  
furnace technology**

***FOLADSAZI.IR***