Electric Arc Furnace

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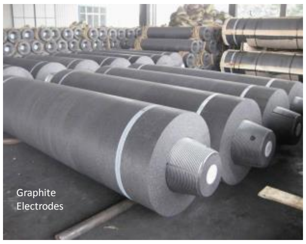
What is an EAF?

- AC or DC powered furnace which uses graphite electrodes to melt scrap iron and steel.



Graphite Electrodes

A Brief History

- The Heroult company in France introduced the EAF in 1899.
- In the 1950s EAFs were small and usually located in a back comer of the melt shop.

A Brief History

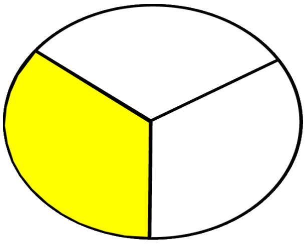
- From 1965 to 1969 several primary EAF fume control systems were installed in the United States.
- The hot gases at the fourth hole caused considerable problems in the duct work. This problem with the original designs was later solved by using water-cooled ducts to reduce the temperature of the gases.

What Happens In EAF?

- Recycled steel scrap is melted and converted into high quality steel by using high-power electric arcs.
- Almost any type of metal can be used as the raw material in EAF.

EAF in Steel Production

- Almost a third of the world's steel production today is done by EAF.

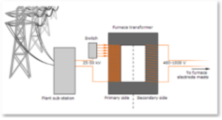


Economical Aspects

- The recovery of metal scraps benefits both the natural resources of the world and the economical growth.
- Moreover, using recycled products enables EAF to produce a variety of materials.

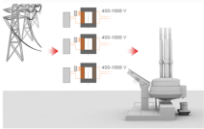
Electrical Power System

The modern steel plant receives low current, high voltage power from the generators of the electrical utility company. The **purpose of the steel plant primary transformer** is to step-down this voltage. The transformer thus provides high current, low voltage power for the EAF furnace. Large furnaces with transformers rated at 100MVA or higher is not uncommon. There are usually two stages to this process. The transformer first steps-down the voltage from high to medium levels. There are different standards for a "medium-level voltage" in different countries; usually between **30 to 33 kV for Europe and Japan**, but **for the USA it is usually 34.5 kV**. Finally, a heavy duty furnace transformer powers the EAF. This special furnace transformer is designed to allow the electric arc to operate within the desired current and voltage range.



Other electrical systems around the EAF are the **delta closure, the power cables, the current conduction arm, and the electrode holders.** The power cables provide a connection between the delta closure and the current conducting arm. It is usually made of **copper** wires, with a rubber water jacket around the outside for water-cooling the cables. The power cable is connected with the current conducting arm, usually made of copper clad steel or aluminum alloys.

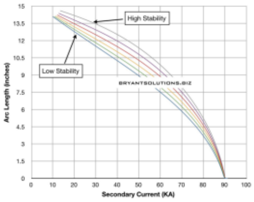
- There are 3 phases used and 3 electrodes will be needed. Each of these 3 phases is connected to one of the graphite electrodes.



- Why graphite electrodes?

- They are durable at high temperatures and they have a good electrical conductivity. When the electrode is near the scrap, an ore is created and an electrical circuit is formed. To melt this scrap, there will be energy need and these arc provide the heat energy.

- It is important to note that the variance in arc length is highly dependent on the EAF transformer tap voltage. Lower voltage systems (~500v) will display less variance in absolute terms than higher voltage systems (~1000v).



Movement of Electrodes

- Vertical movement of the electrodes is obtained by adjusting the electrode arm positions.
- This phenomena controlled by the feedback from the electrical system.
- By controlling the electrical performance, we reach the predefine set point at an optimum power input.
- Electrode have an upper limit in maximum current alloved and this changes the secondary voltage parameters. The secondary voltage and arc of the lenght are directly proportional to each other.

Furnace Operations

- Furnace charging
- Melting
- Refining
- De-slagging
- Tapping
- Furnace turn-around

Furnace Charging

- Before the melting and heating operations start, the first step is charging into the scrap. The roof and electrods are raised and are swung to the side of the furnace allow the scrap charging to the bottom. When bucket of the furnace is full of the scrap, the roof and electrodes are lowered to strike an arc on the scrap.
- At this time electrical power is switched on and the furnace is transforming electiricity to the heat the scraps. When the scraps start to melt, more volume is made available inside the furnace
- At this time the electricity is switched off and another basket will be loaded in to the furnace. The power is on again and melting of the second basket starts.

Melting

- Melting is accomplished by supllying chemical or electrical energy to the furnace interior.
- The graphide electrodes are moved downwards.
- Electrical energy is supllyed by graphite electrodes.
- Chemical energy is supplyed by lanced oxygen directly to aluminum, silicon, manganese, phosphorus, carbon and iron. All of reactions with oxygen are exothermic.
- After first charge has been melted; second charge is added into furnace.

Refining

- Refining operations in the electric arc furnace have traditionally involved the removal of phosphorus, sulfur, aluminum, silicon, manganese and carbon from the steel.
- Refining reactions are all dependent on the availability of oxygen.
- Higher level of P and S in the furnace charge than what is required in the in steel as per the specification, are to be removed.
- P retention in the slag depends on the bath temperature, slag basicity and FeO levels in the slag.
- Removal of S in the EAF is difficult especially in the modern practice where the oxidation level of the bath is quite high.
- At the end of refining, bath temperature measurement and bath sample are taken. If the temperature is too low, power can be applied to the bath. Low temperature is not a big issue in modern steel melting shops where temperature adjustment is carried out in the ladle furnace.

De-Slagging

- Some of the undesirable materials within the bath are oxidized and enter the slag phase. De-slagging operations are carried out to remove these impurities from the furnace.
- It is advantageous to remove as much phosphorus into the slag as early in the heat as possible
- During slag foaming operations, carbon may be injected into the slag where it will reduce FeO to metallic iron and in the process produce carbon monoxide which helps foam the slag. If the high phosphorus slag has not been removed prior to this operation, phosphorus reversion will occur. During slag foaming, slag may overflow the sill level in the EAF and flow out of the slag door.

•The following table shows the typical constituents of an EAF slag:

Component	Source	Composition Range
CaO	Charged	40 - 60 %
SiO_2	Oxidation product	5 - 15 %
FeO	Oxidation product	10 - 30 %
MgO	Charged as dolomite	3 - 8 %
CaF_2	Charged - slag fluidizer	
MnO	Oxidation product	2 - 5%
S	Absorbed from steel	
P	Oxidation product	

Tapping

- Once the desired steel composition and temperature are achieved in the furnace, the tap-hole is opened, the furnace is tilted, and the steel pours into a ladle for transfer to the next batch operation.
- De-oxidizers may be added to the steel to lower the oxygen content prior to further processing.
- This is commonly referred to as "blocking the heat" or "killing the steel".

Tapping

- Common de-oxidizers ===> > Al or Si (in the form of ferrosilicon or silicomanganese)
- Most carbon steel operations aim for minimal slag carry-over.
- For ladle furnace operations, a calcium aluminate slag is a good choice for sulfur control.

Tapping

- Slag forming compounds ===>> ladle at tap, a slag cover is formed prior to transfer to the ladle furnace.
- If the slag cover is insufficient ===>> more slag materials may be added.

Furnace Turn-around

- What is the furnace turn-around ?
- Period following completion of tapping until the furnace is recharged for the next heat.
- How it works ?
- Electrodes and roof are raised and the furnace lining is inspected for refractory damage.

Furnace Turn-around

- In most modern furnaces, the increased use of water-cooled panels has reduced the amount of patching or "fettling" required between heats.
- Furnace turn-around time is generally the largest dead time period in the tap-to-tap cycle.

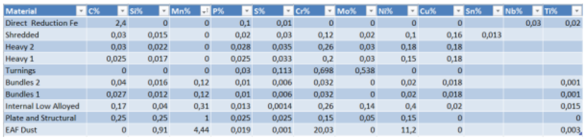
SIMULATION
Steel University

1-Engineering Steel is chosen.
2-Target composition →

Target steel grade:
Engineering Steel

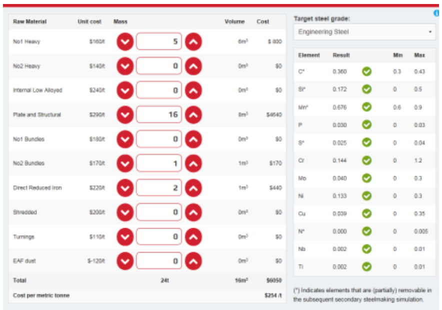
Element	Result		Min	Max
C*	0.000	✗	0.3	0.43
Si*	0.000	✓	0	0.5
Mn*	0.000	✗	0.6	0.9
P	0.000	✓	0	0.03
S*	0.000	✓	0	0.04
Cr	0.000	✓	0	1.2
Mo	0.000	✓	0	0.3
Ni	0.000	✓	0	0.3
Cu	0.000	✓	0	0.35
N*	0.000	✓	0	0.005
Nb	0.000	✓	0	0.01
Ti	0.000	✓	0	0.01

Raw Material's Composition



Material	C%	Si%	Mn%	P%	S%	Cr%	Mo%	Ni%	Cu%	Sn%	Nb%	Ti%
Direct Reduction Fe	2,4	0	0	0,1	0,01	0	0	0	0		0,03	0,02
Shredded	0,03	0,015	0	0,02	0,03	0,12	0,02	0,1	0,16	0,013		
Heavy 2	0,03	0,022	0	0,028	0,035	0,26	0,03	0,18	0,18			
Heavy 1	0,025	0,017	0	0,025	0,033	0,2	0,03	0,15	0,18			
Turnings	0	0	0	0,03	0,113	0,698	0,538	0	0			
Bundles 2	0,04	0,016	0,12	0,01	0,006	0,032	0	0,02	0,018			0,001
Bundles 1	0,027	0,012	0,12	0,01	0,006	0,032	0	0,02	0,018			0,001
Internal Low Alloyed	0,17	0,04	0,31	0,013	0,0014	0,26	0,14	0,4	0,02			0,015
Plate and Structural	0,25	0,25	1	0,025	0,025	0,15	0,05	0,15	0			0
EAF Dust	0	0,91	4,44	0,019	0,001	20,03	0	11,2	0			0,003

1st Trial



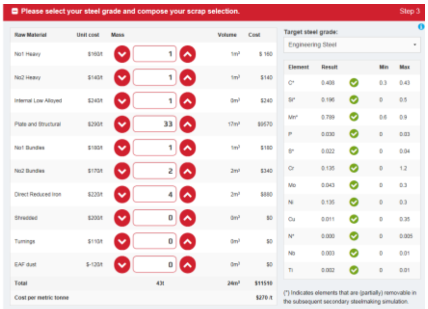
Raw Material	Unit cost	Mass	Volume	Cost
No1 Heavy	$160/t	5	6m³	$ 800
No2 Heavy	$140/t	0	0m³	$0
Internal Low Alloyed	$240/t	0	0m³	$0
Plate and Structural	$290/t	16	8m³	$4640
No1 Bundles	$180/t	0	0m³	$0
No2 Bundles	$170/t	1	1m³	$170
Direct Reduced Iron	$220/t	2	1m³	$440
Shredded	$200/t	0	0m³	$0
Turnings	$110/t	0	0m³	$0
EAF dust	$-120/t	0	0m³	$0
Total		**24t**	**16m³**	**$6050**
Cost per metric tonne				**$254 /t**

Target steel grade:
Engineering Steel

Element	Result		Min	Max
C*	0.360	✓	0.3	0.43
Si*	0.172	✓	0	0.5
Mn*	0.676	✓	0.6	0.9
P	0.030	✓	0	0.03
S*	0.025	✓	0	0.04
Cr	0.144	✓	0	1.2
Mo	0.040	✓	0	0.3
Ni	0.133	✓	0	0.3
Cu	0.039	✓	0	0.35
N*	0.000	✓	0	0.005
Nb	0.002	✓	0	0.01
Ti	0.002	✓	0	0.01

(*) Indicates elements that are (partially) removable in the subsequent secondary steelmaking simulation.

2nd Trial



Please select your steel grade and compose your scrap selection. Step 3

Raw Material	Unit cost	Mass	Volume	Cost
No1 Heavy	$160/t	1	1m³	$ 160
No2 Heavy	$140/t	1	1m³	$140
Internal Low Alloyed	$240/t	1	0m³	$240
Plate and Structural	$290/t	33	17m³	$9570
No1 Bundles	$180/t	1	1m³	$180
No2 Bundles	$170/t	2	2m³	$340
Direct Reduced Iron	$220/t	4	2m³	$880
Shredded	$200/t	0	0m³	$0
Turnings	$110/t	0	0m³	$0
EAF dust	$-120/t	0	0m³	$0
Total		**43t**	**24m³**	**$11510**
Cost per metric tonne				**$270 /t**

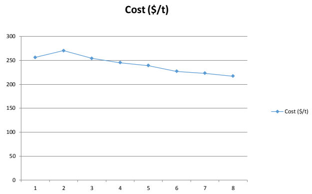
Target steel grade:
Engineering Steel

Element	Result		Min	Max
C*	0.408	✓	0.3	0.43
Si*	0.196	✓	0	0.5
Mn*	0.789	✓	0.6	0.9
P	0.030	✓	0	0.03
S*	0.022	✓	0	0.04
Cr	0.135	✓	0	1.2
Mo	0.043	✓	0	0.3
Ni	0.135	✓	0	0.3
Cu	0.011	✓	0	0.35
N*	0.000	✓	0	0.005
Nb	0.003	✓	0	0.01
Ti	0.002	✓	0	0.01

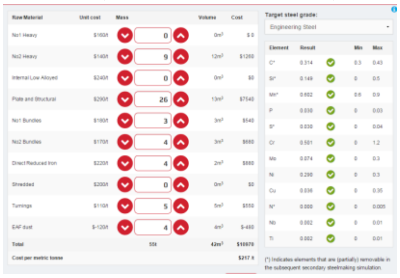
(*) Indicates elements that are (partially) removable in the subsequent secondary steelmaking simulation.

What did we change?

Cheap materials are used instead of expensive ones like ‘’plate and structural’’.



After 9 trials, the minimum cost was found as $217/t



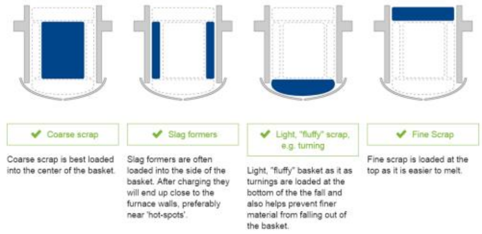
Raw Material	Unit cost	Mass	Volume	Cost
No1 Heavy	$160/t	0	0m³	$ 0
No2 Heavy	$140/t	9	12m³	$1260
Internal Low Alloyed	$240/t	0	0m³	$0
Plate and Structural	$290/t	26	13m³	$7540
No1 Bundles	$180/t	3	3m³	$540
No2 Bundles	$170/t	4	3m³	$680
Direct Reduced Iron	$220/t	4	2m³	$880
Shredded	$200/t	0	0m³	$0
Turnings	$110/t	5	5m³	$550
EAF dust	$-120/t	4	4m³	$-480
Total		55t	**42m³**	**$10970**
Cost per metric tonne				**$217 /t**

Target steel grade: Engineering Steel

Element	Result		Min	Max
C*	0.314	✓	0.3	0.43
Si*	0.149	✓	0	0.5
Mn*	0.602	✓	0.6	0.9
P	0.030	✓	0	0.03
S*	0.030	✓	0	0.04
Cr	0.501	✓	0	1.2
Mo	0.074	✓	0	0.3
Ni	0.290	✓	0	0.3
Cu	0.036	✓	0	0.35
N*	0.000	✓	0	0.005
Nb	0.002	✓	0	0.01
Ti	0.002	✓	0	0.01

(*) Indicates elements that are (partially) removable in the subsequent secondary steelmaking simulation.

Scrap Bins



Coarse scrap is best loaded into the center of the basket.

Slag formers are often loaded into the side of the basket. After charging they will end up close to the furnace walls, preferably near 'hot-spots'.

Light, "fluffy" basket as it as turnings are loaded at the bottom of the the fall and also helps prevent finer material from falling out of the basket.

Fine scrap is loaded at the top as it is easier to melt.

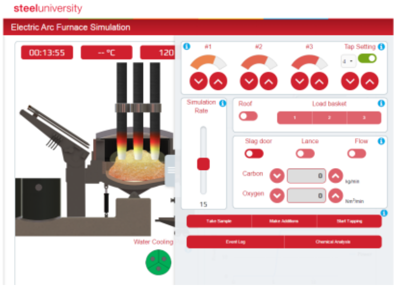
Scrap Bins

Scrap baskets

Transfer mass /t: 11

Total mass: 55t
Total cost: $10970

Melting & Slagging



-Electrodes should not be broken
so speed is important.

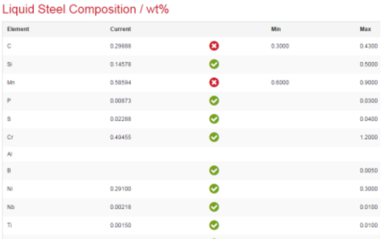
-Sample is taken for control
before slagging.

-For slagging, air(30 kg/min) and
C(50 Nm^3/min) is blown.

Additives

- We need C and Mn

- To reach target composition,
we added 10 kg Ferro-manganese
as additivies



Liquid Steel Composition / wt%

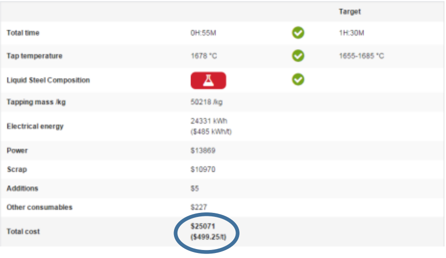
Element	Current		Min	Max
C	0.29888	✗	0.3000	0.4300
Si	0.14578	✓		0.5000
Mn	0.58594	✗	0.6000	0.9000
P	0.00873	✓		0.0300
S	0.02288	✓		0.0400
Cr	0.49455	✓		1.2000
Al				
B		✓		0.0050
Ni	0.29100	✓		0.3000
Nb	0.00218	✓		0.0100
Ti	0.00150	✓		0.0100

Final Composition

Liquid Steel Composition / wt%

Element	Current		Min	Max
C	0.30047	✓	0.3000	0.4300
Si	0.14731	✓		0.5000
Mn	0.60493	✓	0.6000	0.9000
P	0.00464	✓		0.0300
S	0.02266	✓		0.0400
Cr	0.49735	✓		1.2000
Al				
B		✓		0.0050
Ni	0.28970	✓		0.3000
Nb	0.00215	✓		0.0100
Ti	0.00150	✓		0.0100
V	0.00146	✓		0.0100
Mo	0.07411	✓		0.3000

Conclusion



			Target
Total time	0H:55M	✓	1H:30M
Tap temperature	1678 °C	✓	1655-1685 °C
Liquid Steel Composition	⚗	✓	
Tapping mass /kg	50218 /kg		
Electrical energy	24331 kWh ($485 kWh/t)		
Power	$13869		
Scrap	$10970		
Additions	$5		
Other consumables	$227		
Total cost	**$25071 ($499.25/t)**		

THANK YOU