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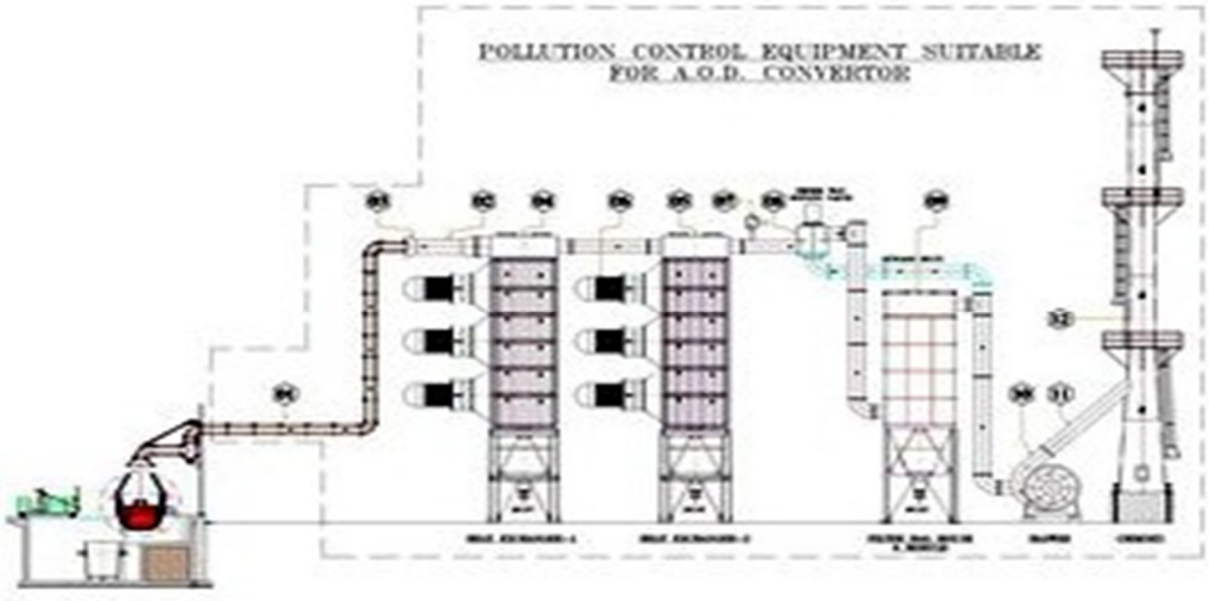
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An Excursion of a Technocrat, when Business is not Stable and Product Development is a Survival

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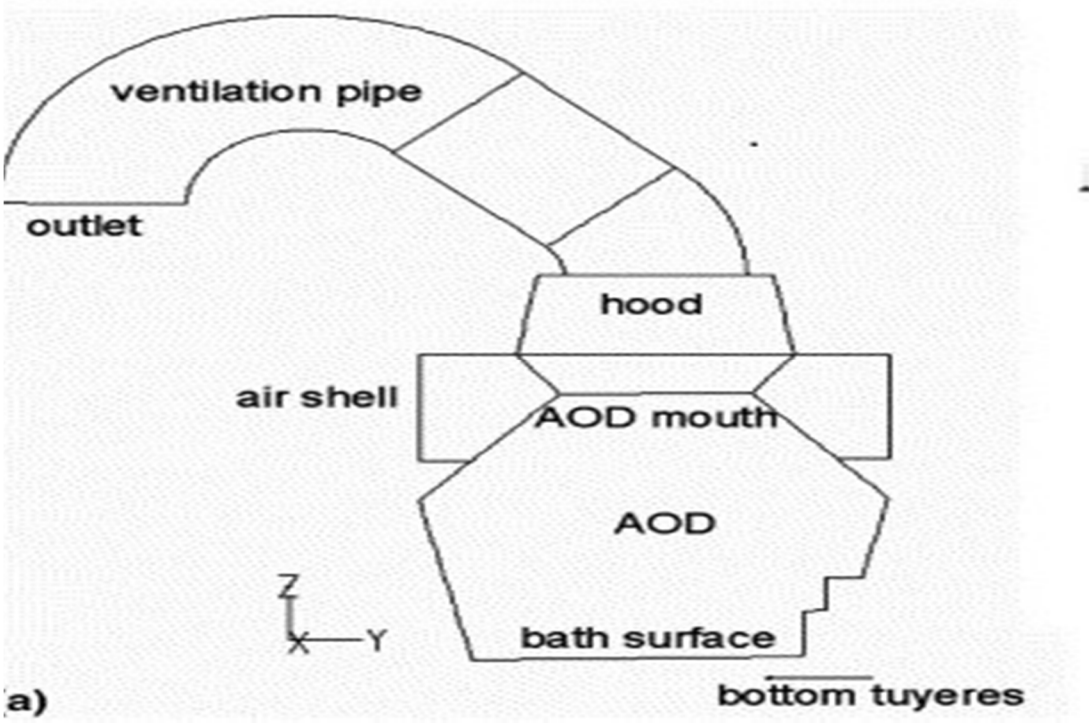
Abstract: ***When business was not very stable due to one reason or another, but the equipments were lied idle, a huge burden of salaries & wages, Electricity bills really put me in deeper thoughts , if the salaries/wages can be managed by developing a new product which can be a silent support to the management but above all its an act towards mankind when the decisions can be blunt so an idea emerged, along with 30MT & 25MT AOD Converter, there were five nos. of SAF adjacent to the SS plant where different bulk Ferro Alloys (HCFeCr, HCFeMn, HCSiMn, MCSiMn) were the products but the execution of the idea right from SS to unique Ferro Alloys was extremely tough job when there was no technical inputs, no research facilities, no support and above all no motivation! Except only 'permission' from the owner was the only guiding force, otherwise more than 600 people direct employment and subsequent indirect employment would be at stake. With the technical knowledge of SS in AOD Converter development of MCFeMn could be possible and marketability with proper economization was real challenge. It was done successfully with lot many derivatives and eventually customers delight were possible to draw.***
Product Development from bulk Ferro Alloys to niche Ferro Alloys (HCFeMn to MCFeMn)
Keywords: AOD Converter, SAF, Ferro Alloys, HCFeMn, MCFeMn

I. SCHEMATIC DIAGRAM OF AN AOD CONVERTER ALONG WITH POLLUTION SYSTEM



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II. AN OVERVIEW

As stated in the abstract, a shop studded with equipments suitable for SS billet/bloom making/shaping was a difficult task for the people who never handled Ferro Alloys even in the grass root level, sampling in the liquefied state was different than hot metal or stainless steel. A new experience indeed, because of viscosity, behavior of metal, compositional aspects and above all to make it marketable were the objectives. We split the entire task in the following order,

1) *Transfer of the hot Metal*: SS shop and FA shop were situated in 'L' shape, so it was not very difficult task to imagine transferring the hot metal from one shop to another. We first tried to transfer with the help of CI slag box/CI ladle but because of the behavioral science of HCFeMn it became reddish in color which can be a cause of metal penetration along with accidents, we switched over to refractory lined ladle which can accommodate hot metal along with slag, but again to transfer it took nearly 25 min. and the problem of jamming in the knuckle areas forced me to make few researches on insulation and heat conservation.
2) *Deslagging and weighment*: Despite of it was an R & D work of an Indian steel mill, but still the economization was very vital so ladle deslagging were practiced in ladle hanging condition though it was risky in the safety point of view but up to certain extent it's were possible to understand how much metal is getting transferred to evaluate the yield & recovery.
3) *Suitable blowing size*: The AOD were of 30 MT & 25 MT capacities so to make a justice to the blowing practices and refractory consumption per ton it becomes necessary to take hot metal of HCFeMn from minimum two SAF and maximum four SAF to smoothen the AOD Converter process. But there were times that only 20%-50% of the hot metal got transferred due to the abnormal tapping, tap hole mal-functioning , ladle jamming, metal spillages during deslagging and pouring etc. multiple nos. of steps been designed in the aforesaid situations.
4) *Avoidance of boiling*: It was indispensible failure in higher temperature inside of AOD, metal becomes susceptible to boiling and metal tries to come out from the converter which can be very dangerous in relation to safety and even to the equipments. In other words, temperature control with a proper slag volume and compatibility can become helpful in avoidance of sudden metal coming out from the vessel.

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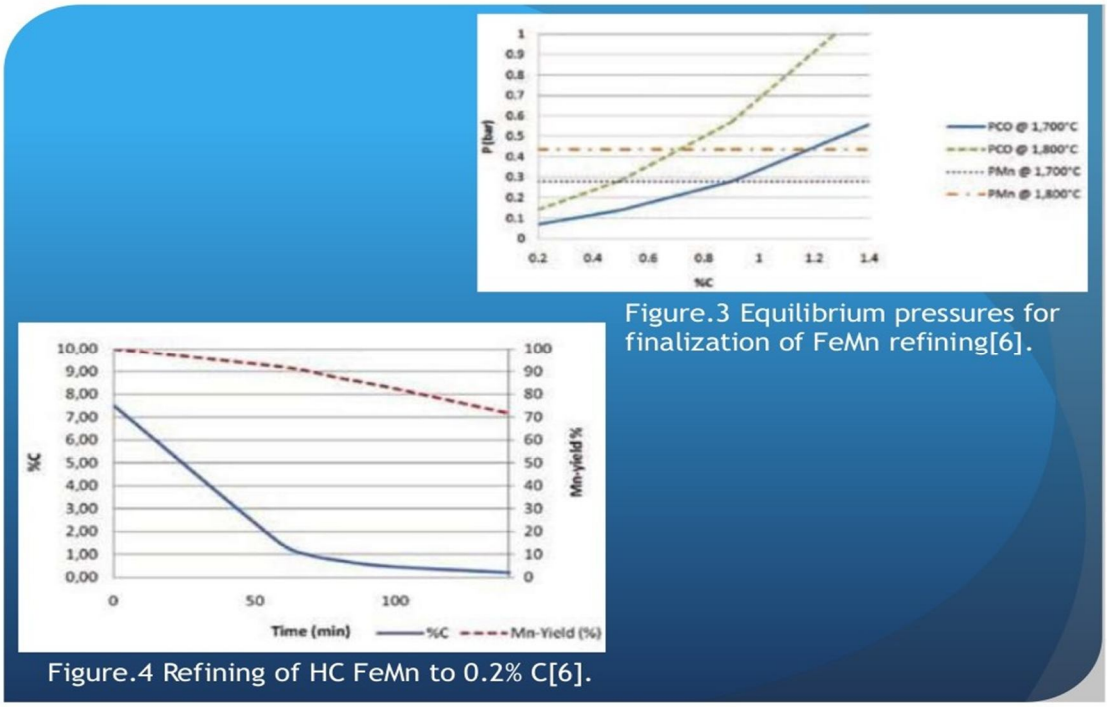


Figure.3 Equilibrium pressures for finalization of FeMn refining[6].

Figure.4 Refining of HC FeMn to 0.2% C[6].

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Thermodynamics of Manganese Oxide Reduction

$2MnO_2 \rightarrow Mn_2O_3 + ½\ O_2$
$3Mn_2O_3 \rightarrow 2Mn_3O_4 + ½O_2$
$Mn_3O_4 \rightarrow 3MnO + ½O_2$

$3Mn_2O_3 + C \rightarrow 2Mn_3O_4 + CO$
$3Mn_2O_3 + CO \rightarrow 2Mn_3O_4 + CO_2$

$Mn_3O_4 + C \rightarrow 3MnO + CO$
$Mn_3O_4 + CO \rightarrow 3MnO + CO_2$

$MnO+CO \rightarrow Mn+CO_2$
(Due to high partial pressure requirement of carbon monoxide, the reduction of MnO by carbon monoxide does not occur.)

$MnO + \frac{10}{7} C \rightarrow \frac{1}{7} Mn_7C_3 + CO$

$MnO + \frac{10}{7} Fe_3C \rightarrow \frac{1}{7} Mn_7C_3 + \frac{30}{7} Fe + CO$

Mn_7C_3 reacts with excess MnO to form liquid manganese metal.

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5) *Betterment in Yield & Recovery*: it's are bit complicated to manage and maintain. In the temperature ranges of greater than 1650^0C, the susceptibilities of %Mn oxidation and evaporation take places and as result, the reduction slag can have a higher %MnO and the evaporation losses can be high could be 5-6%, that Mn is irreversible, up to certain extent the %MnO from the reduction slag can be reduced with the help of proper slag compositions and temperature control.

Besides of slag and temperature management, there could be three distinct areas where metal can be recovered,

a) The de-siliconisation slag and reduction slag will be powdered and will be CaO saturated so once the slag will be air cooled rather than water quenched that slag can be screened with the help of suitable screen, and depending upon practices minimum of 1% to maximum of 2.5%can be recovered from the slag (of the entire inputs as metallic in AOD).

b) The second most important area where metal can be recovered i.e. the casting area and its sand mixed, which can be jigged and approx. .8-1.3% of metal can be obtained.

c) The third area is AOD mouth jams and spillages those jams can be pulverized and suitable metal quantity can be availed.

d) Fourth area is the CI circular pans in which the metal can be cast either with sand lining inside of the pans or some other process, all the four areas the associated products can be jigged/screened and nearly 4-5% of metal recovery can be possible which may not be prime metal but at the end of the day this metal can be accumulated and a contribution in yield & recovery can be possible.

It was an opportunity that with the existing Ferro Alloys shop there were screening and jigging facilities so realization was not very difficult task.

6) *Deslagging from AOD:* It's a tricky act to perform not alike of SS because the slag can contain a very high level of %MnO and as result the slag can be viscous and sometimes crusty. As typical practices hot metal (HCFeMn bears 1-1.5% of %Si) if we want to carried out the process with metal 'Si', followed by SiO_2 that will be coming to the slag and an extra requirement of Lime will be required to form C_2S (Di-Calcium Silicate) which might form an obstacle to obtain a proper slag kinetics as well as CRE (Carbon Removal Efficiency). So it is mandatory to deslag in the initial stage i.e. de-siliconisation. After the reduction/refinement gets over, the slag should be drained out, the characteristic of the reduction slag, should be free flow, with moderate temperature and should content optimized percentage of MnO otherwise slag will not become free flow and fluid. Interestingly without a proper slag, the slag may contain higher %MnO and as a result it is an indirect losses to yield and recovery. Designing of slag (De-siliconisation, De- Carburization, Reduction) will be different and a thorough knowledge (know-how & show-how) are required.

Some experimental act can be done, e.g. the aforesaid example is designing of slag for De-Carburization at different steps of De-Carb, and the CRE is different and with different 'Mn' content the CRE can be affected greatly because of slag permeability which is directly proportional to the chemical spec. of slag and the working temperature.

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Ellingham diagram for the Mn-O-C system at 1 atm total pressure [5] with dissociation/carbothermic reactions

Dissociation of manganese oxides: (1) >450-500°C **$4MnO_2$**=$2Mn_2O + (0_2)$ (2) >900-950°C**$6Mn_2O_3$**=$4MnO4+(O)$
1172°C $2MnO4 =6MnO +(O_i)$

Carbothermic reactions:

(3) Mn_3O_4 +C=3(MnO) +(CO)

(4) 14MnO + 20C=2[Mn_7C_3] + 14(CO)

(4) MnO+ C [Mn] +(CO)

(4) MnO + C (Mn) (CO)

Fe_2O3 +C 2 (FeO)
+(CO

FeO + C [Fe]
+(CO}

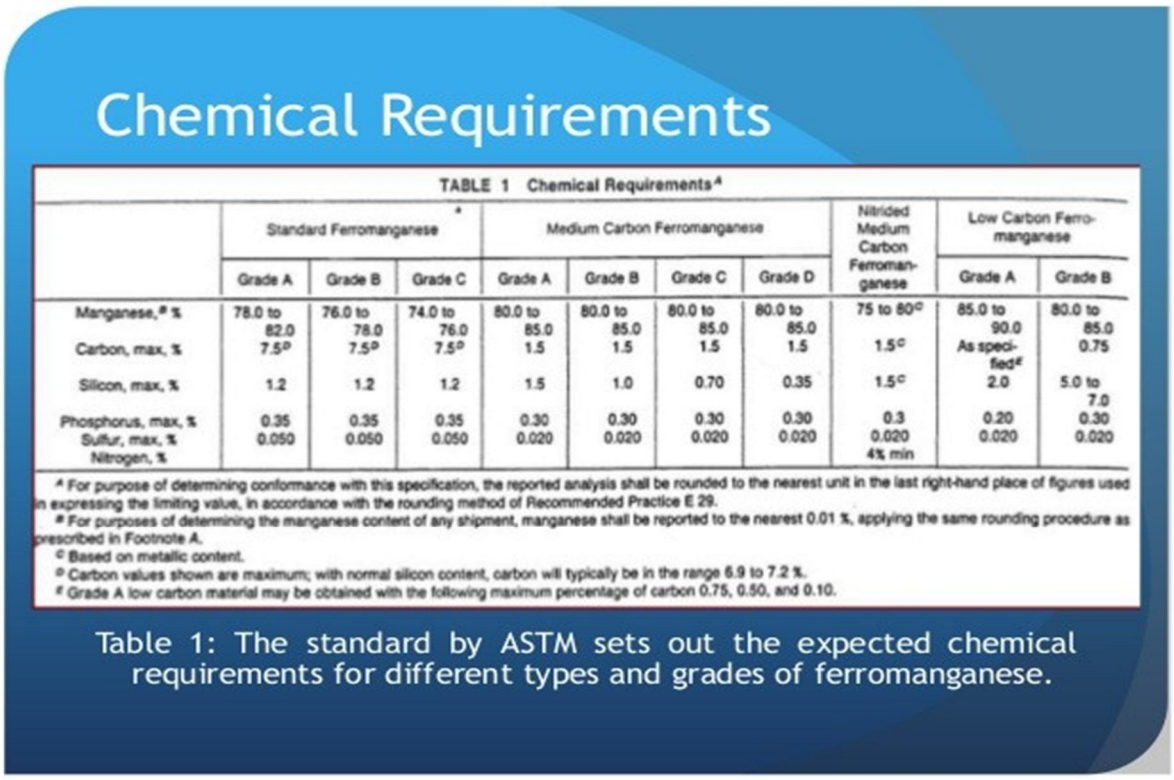
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Same as De-Carburization slag, reduction slag also act very interestingly. In the end of de- carburization let's say requirement of %C in the final metal is 1.5%, then a lesser quantity of FeSi is required, in another situation if the final %C required is .50% then it is assumed that higher percentage of 'Mn' will be getting oxidized. Requirement of increase quantity of reductant will be there. Slag designing will be most important in that regard, as of increased reductant will form additional SiO_2 and subsequent C_2S formation as well as spinel (MgO-MnO, MgO-FeO) will be equally important. The cost of slag transfer->pulverization (for the undissolved solid particles)-> screening(usually by 3 deck system but other procedure can be evaluated)-> non-prime metal remelting cost to convert to prime metal let's consider 'X'. Selling of the slag to the cement manufacturer without metal pieces and lime-saturated. And designing of a second category reduction slag in which, the slag will not become powdered after cooling down, it will remain solid based on the design and the metal as well as metallic oxides will be entrapped in the slag itself, this slag also can have high percentage of %MnO which may not be reduced. This slag transferring cost-> to make it sizable to charge in the SAF->extra reductant and extra power to smelt-> can be considered as'Y'. The cost 'X' and cost 'Y' can be compared, and judicious decision can be taken which is cost effective! In cost 'Y' the metal and the metal oxides will have a scope to reduce in the SAF, and the cost of lot of activities can be avoided. It is the choice of the head of operation which is easy to perform and at what cost?

7) *Tapping in Ladle*: It is typically observed that certain quantity of slag will always gets transferred during tapping for the benefits of thermal insulation, in case if usage of external insulation even in the recommended temperature whence ready for casting either by cyphonic system with the help of ladle slide-gate and controlled rate of casing, or by toppling of the ladle certain quantity of the ladle slag gets deposited in the bottom and knuckle areas of the ladle, during cleaning these slag never gets drained out even by O2 lancing, and after couple of heats ladle have to be kept as non-circulated ladle to allow it to air-cooled. In case of basic slag and with proper chemistry sticked over slag will get powdered and can be cleaned in lieu of reusage of the ladle after reheating.
8) *Casting of Metal*: Metal casting once its transferred to the ladle the required temperature for the specific grades are unique, depending upon %C, %Mn, %Si the solidus temperature should get varied and with an appropriate temperature which is usually varies from 1530^0C-1570^0C, In few of the grades it goes to very low temperature even. The structure of the metal becomes extremely good, and the luster on the metal surfaces are attractive. In high temperature casting it has been experienced on CI pan metal penetration or even puncture. So the entire practices to study carefully, then a correct decision can be taken. It has been heard, that metal casting machine are equipped in some of the MCFeMn manufacturing plant, then also temperature management are extremely important phenomena.
9) *Gases Entrapment/Requirement*: In the beginning when we started the process the perception was that the Ferro Alloy what we have manufactured that may not be an invention but in India nobody is making right then and every grade can be nitrogenated (N2 enriched), in PPM language as high as 8000PPM as reported. But eventually it becomes a requirement of the HRC followed by CRC manufacturer of the automobile grades of steel that restricted concentration of N2 is the necessity to overcome the 'work hardening issue'; So again worked on N2 interstitial absorption/evolvement even with restricted to very close ranges within 100PPM variation could be possible. As low as 300PPM of N2 has been ever achieved, by the help of 'Ar' at different stages with different concentration. Still it s a virtue of learning with so many adversities these R & D work needs much more time and patience for to understand the interstitial restriction of the Ferro Alloys which is again unlike to SS. With the help of CO_2 , the expensive gas for De-nitrogenation of 'Ar' can be substituted, The CO2 is much cheaper than 'Ar', and as per today's market status 'Ar' is 2.5 times expensive than CO2. It is obvious that the specific gravity of 'Ar' is than other inert gases but the specific gravity of CO2 is also comparable to 'Ar' so removal of N2 PPM were successfully done and cost/T can be optimized up to certain extent. But it is my assumption the requirement of H2 and O2 ppm will be also a requirement of the CRC makers, because these will affect the rolling and after rolling behavior of the automobile grades of steel.
10) *Casting Process Improvement*: In the initial day's metal cast in sand bed and the yield found erratic, no gases control especially N2 PPM, because of air pockets in sand bed. We switched over to CI rectangular pans/ MS pot cladded with castable and sand/ slag pots lined with carbon paste and finally to CI Circular pans lined with sand mixed with sodium silicate found no change in chemical composition or gases PPM.That were continued as standard practices. But for a bulk production and uniform casting result one need to switch over to metal casting machine, through which the yield, recovery, quality and cost can be optimized.
11) *Ladle Management*: It is experienced that with four SAF (rated as 6.5-8MVA) running, nos. of heats could be 12-13 from AOD with 22-25MT of sizes and four ladles with compatible lining will be good to mark a control on refractory cost/T and consumption/T. The shop was tried to manage with one AOD Converter in SS and another AOD Converter with MCFeMn and it was succeeded. But thermal discipline of the ladle along with slag management in the ladle participated an important role to cater the task successfully.

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12) *Chemistry Derivative Management*: Chemistry as derived by the customer was the bible for us, and we put all our efforts to manage the chemical spec. within the ranges same as SS/CA Steel with a view that a slight variation can hamper the properties, as well as cost/T, 70 grade MCFeMn had a restriction of 69.8-70.2, usually it finished within the ranges. Maximum benefits we obtained in %Si controlling, it was directly proportional to the cost/T. In higher grade making unless high grade of Mn-ore is available, higher grades like 75%/78%/80%/82% were not possible to make but with the introduction of Mn-metal (@99.5%) this were possible to do.



13) *Economics*: The aforesaid all the check-points actually led to optimize the cost/T. Right from chemistry control to consumption control. Performances are inversely proportional, e.g. AOD refractory life, ladle life, metal yield, elemental recovery etc. But most important is process step and metallurgical SOP formation so that operation and its results can be stereotyped. Another important area is realization of metal pieces from different sources as discussed previously which can improve the yield and simultaneously can optimize the cost/T.
14) *Customer Joy followed by Delight*: For the beginning without any ideas we made all the grades as nitrogenated, and eventually it was experienced that the chemical derivatives as well as physical derivatives were possible to attain, so good quantity of orders received from TATA, ESSAR, JSW etc. Equally it was possible to make cost competitive in compare to import sources, so the inclination was switched over to us.

III. CHEMISTRY AND RAW MATERIALS

The transfer chemistry can be %C=7-8%, %Mn=67-82%,%Si=1-2%, rest will be %Fe. The desired finish chemistry can be %C=.4-2.5, %Mn=70-82, %Si=.5-1.5 and rest %Fe, N2 PPM can be demanded by the customer within very low ranges to very high ranges (500-6000PPM). The process metallurgy associated with it are blowing of O2,N2,Ar and occasionally compressed air will be the main gas resources which can elevate the bath temperature and can fine-tune the chemical spec. as desired by the customer.Raw material can be as follows, FeMn (HC) liquid,

FeMn (HC) solid
SiMn (HC)/SiMn (MC)/FeSi
Lime/Cal Dolomite/Flour Spar/Mn-Ore etc.etc.

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IV. BY PRODUCT & ASSOCIATED PRODUCT

The byproduct & associated products could be AOD slag (20%-25% of the processing metal weight) which can have a potential to utilize to develop SAW (sub merge arc welding) fluxes as well as pavement tiles. Pollution dust can be briquetted and utilized in SAF/AOD converter in the philosophy of waste utilization. The type of pollution control system what we intend to conceive is not going to increase the pollution load in the environment. FeMn (MC) production is the exercise of the extension of the brand and we are very committed towards the society and the environment ever before, so we are keeping the promises towards the mother earth at all the time.

V. CONCLUSION

The objective to produce this product is in Ferro-alloys market especially in Indian scenario, since last 3-4 years steel industries are doing bad to worse due to low priced steel import from China and with the available technologies the cost optimization plan/execution is not at all feasible with the international players, same story is happening in Ferro-alloys industry. Mainly the raw material prices are going upwards in Ferro alloys industry due to one reason or another but finished-product may not get the taste to raise the prices due to heavy competition and bulk Ferro alloys producers which really disturbs the demand-supply graph as per our national FA market. An innovative product which can be considered as niche- product in the bulk FA market and the usage is essentially to be in the automobile grade steel sector, agro-chemicals industries, welding electrodes industries etc.

Especially in this very competitive Ferro alloys market we need to survive with an innovative product which may not be copied at ease and the potential of this product is very deep-routed as of the cost potential is there and the bulk production with successful SQC may not be possible through other process/production routes.

VI. ABBREVIATIONS

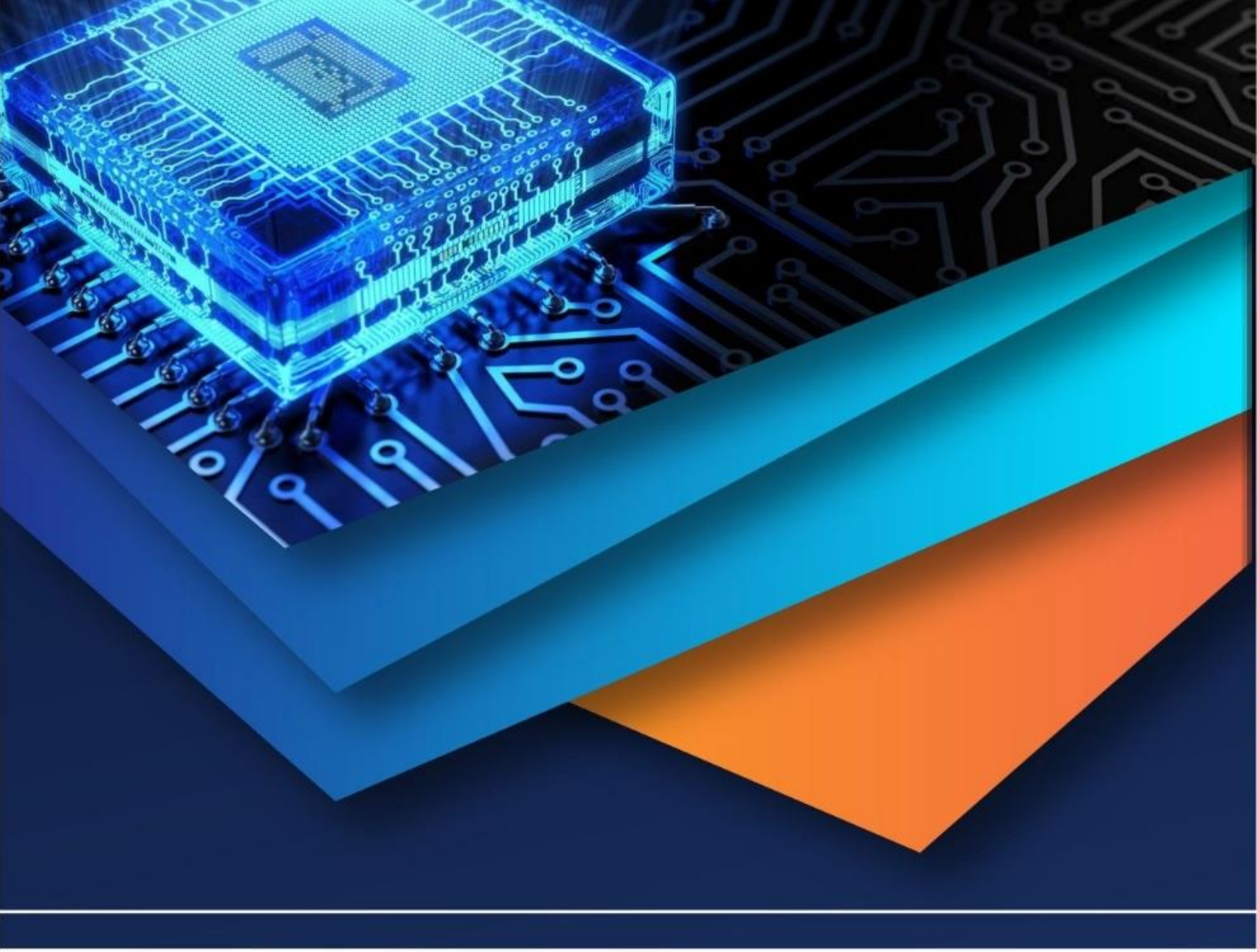
AOD- Argon Oxygen Converter SAF-Sub Merge Arc Furnace, SS-Stainless Steel,
HCFeCr- High Carbon Ferro Chrome HCFeMn- High Carbon Ferro Manganese HCSiMn- High Carbon Silico Manganese,MCSiMn-Medium Carbon Silico Manganese,

MCFeMn-Medium Carbon Ferro Manganese SQC-statistical quality control
N2-nitrogen
SAF- sub merge arc furnace O2-oxygen
Ar-argon

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