Study on Accretion Formation on DRI kiln during spong iron production

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Abstract---Today is an era of competition, and contrary to this the Iron and steel industries are also suffering from the same. One of the major challenges for sponge iron plant is the Accretion formation. Through this paper an attempt has been made to identify the root causes and broader the knowledge on Accretion formation. Accretion so called ring formation is the continuous production of thick layer of oxide and impurities on the inner portion of the DRI kiln during sponge iron production, the main reason behind this problem arises due to the softening of fluxing agents and impurities which amalgamate at specific temperature to form a low melting composition, thus they stick to the refractory wall of the kiln and due to the rotating motion of the kiln they stick thru ought the outskirt of the kiln. This accretion formation directly hampers the productivity, as they reduce the working volume of the kiln. the other impact includes irregularity in the temperature profile inside the kiln and mis measurements of the temperature sensors. This accretion formation also lead to the shutdown of the kiln in regular interval of two months, which badly effect the productivity and cost efficiency of the kiln. So the overall aim of this project was focused to understand the fundamental and aware the industrial society to re-search over the remedial factors, afterall spong iron industries are growing and becoming the major source of economy for the developing countries like india.

Index Terms—Accretion, DRI, Refractory,, sponge iron

1.INTRODUCTION

1.1 background of sponge iron production

Sponge iron, also known as "Direct Reduced Iron" (DRI) and its variant Hot Briquetted Iron (HBI) have emerged as prime feed stock which can replace steel scrap in EAF/IF as well as in other steel-making processes. in Indian scenario the sponge iron plants have grown drastically, and the driving force behind this are the increasing prices as well as scarcity of scrap for secondary steel making. the another reason lurk behind the scarcity and high cost of metallurgical coke for iron making through blast furnace route. The history of sponge iron production says that the need for development and commercialization of sponge iron manufacturing process arose in late 50's when Electric Arc Furnaces (EAFs) engaged in manufacturing steel started facing problems of availability of scrap of desired quality, the traditional source of their iron metallic's. The DRI processes soon became popular and since the inception of first DRI plant in 1957 in Mexico, there has been a continuous growth of this industry in last three decades. This is evident from the steep rise in world DRI production during the past three decades. India, entered the sponge iron industry only in 1980, when the coal based DRI plant of Sponge Iron India Limited (SIIL) was commissioned at Kothagudem, in Andhra Pradesh.[1]

Sponge iron is the resulting product (with a metallization degree greater than 82%) of solid state reduction of iron ores or agglomerates (generally of high grade), the principal constituents of which are metallic iron, residual iron oxides, carbon and impurities such as phosphorus, sulphur and gangue (principally silica and alumina). The final product can be in the form of fines, lumps, briquettes or pellets.

Sponge iron when briquetted in hot condition at elevated temperature is called hot briquetted iron (HBI).

Direct reduction processes available can be broadly classified under two major categories based on the type of reductant being used. Which are as follows:

1. Gas based processes

1.1 Fluidized Bed Technologies
1.1.1 Technologies using hydrogen as reductant
1.1.2 Technologies using carbon monoxide as reductant
1.1.3 Technologies using mixture of both hydrogen and carbon monoxide as reductant
1.2 Static bed technologies using mixed gas as reductant
1.3 Moving bed technologies using mixed gas as reductant

2. Solid based processes/ Coal Based Technologies

Out of the several technologies developed only a few were successfully commercialized; the plants based on the others like Purofer, Armco, Wiberg Sodefors, NSC, Plasma red and Usco were either closed down or dismantled for various reasons. The success of some of the technologies was limited to a few plants of small capacities only. The most

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successful technologies were the gas based static bed HYL-1 technology of Hojalata Y Lamina of S.A. (HYLSA), gas based moving bed technologies of Midrex Corporation of USA and HYL-III process of HYLSA. These contribute over 80% of world sponge iron production today. Out of the coal based technologies SL/RN technology of Lurgi GmbH, West Germany has been the most successful one. Little success has been achieved by other coal based technologies namely CODIR technology of Krupp Industriatechnik now Mannesmann Demag, W.G., DRC technology of Davy Mckee, USA; ACCAR technology of Allis Chalmers now Boliden Allis, USA and the TDR, the only indigenously developed technology of Tata Steel. Recently Jindal Strips have claimed to have developed indigenous coal based technology and that they are installing many sponge iron units based on the new technology. Besides this, Sponge Iron India Limited has absorbed the imported technology and are offering the same to the entrepreneurs.

The industry is gaining further importance due to proven utility of sponge iron in other steel manufacturing processes like L.D. Converters, Open Hearth Furnaces (OHFs), Blast Furnaces (BFs) & Basic Oxygen Furnaces (BOFs), Induction Furnaces (IFs) and Cupolas.

1.2 Rotary Kiln Operation

Generally in any sponge iron process, reduction is conducted in a refractory lined rotary kiln. The kiln of suitable size, generally inclined at 2.5 % slope rest on two-four support stations, depending on the kiln size. The transport rate of materials through the kiln can be controlled by varying its slope and speed of rotation. There are inlet and outlet cones at opposite ends of the kiln that are cooled by its individual fans. The kiln shell is provided with small sampling ports. The longitudinal positioning of the kiln on its riding rings is controlled by hydraulic systems. The coal and iron ore are metered into the high end of the inclined kiln. A portion of the coal is also injected pneumatically from the discharge end of the kiln. The burden first passes through a pre-heating zone where coal devolatilization takes place and iron ore is heated to pre-heating temperature for reduction. Temperature and process control in the kiln are carried out by installing suitable no. of air injection tubes made of heat-resistant steel spaced evenly along the kiln length and countercurrent to the flow of iron ore. Tips of the air tubes are equipped with special internal swirlers to improve uniformity of combustion. A central burner located at the kiln discharge end is used with LDO for heating the cold kiln. After initial heating, the fuel supply is turned off and the burner is used to inject air for coal combustion. The kiln temperatures are measured with fixed thermocouples and Quick Response Thermocouples (QRT) ports. Fixed thermocouples are located along the length of the kiln so that temperatures at various sections of the kiln can be monitored. Fixed thermocouples, at times may give erratic readings in case they get coated with ash, ore or accretion. In such cases QRT are used for monitoring the kiln temperatures.

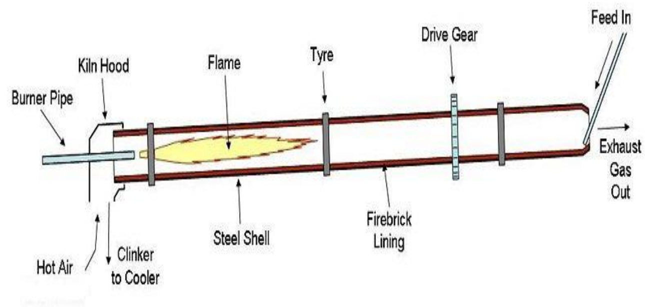

Figure 1.2.1 shows the layout of rotary kiln[8]

The product (DRI) is discharged from the kiln at about 1000°C. An enclosed chute at the kiln discharge end equipped with a lump separator and an access door for removing lumps transfers the hot DRI to a rotary cooler.

The cooler is a horizontal revolving cylinder of appropriate size. The DRI is cooled indirectly by water spray on the cooler upper surface. The cooling water is collected in troughs below the cooler and pumped to the cooling tower for recycling along with make-up water. Solids discharged to the cooler through an enclosed chute are cooled to about 100°C. Without air contact. A grizzly in the chute removes accretions that are large to plug up or damage the cooler discharge mechanisms. The product is screened to remove the plus 30mm DRI. The undersize — a mix of DRI, dolo char and coal ash are screened into +/- 3mm fractions. Each fraction passes through a magnetic separator. The non-magnetic portion of the plus 3mm fraction is mostly char and can be recycled to the kiln if desired. The nonmagnetic portion of — 3mm fraction mostly spent lime, ash and fine char is discarded. The magnetic portion of each fraction is DRI. The plus 3mm fraction can be used directly for steel making and the finer fraction can be briquetted / collected in bags. The kiln waste gases at about 850-900°C pass through a dust settling chamber where heavier dust particles settle down due to sudden decrease in velocity of gases. The flue gases then pass through an after burning chamber where un-burnt combustibles are burnt by blowing excess air. The temperature of the after burner chamber, at times, is controlled by water sprays. The burnt gases then pass through a down duct into a evaporation cooler where the temperature is brought down and through a pollution control equipment namely ESP / Bag filter/ scrubber where balance dust particles are separated. Then the gas is allowed to escape into the atmosphere through stack via induced draft fans (ID fan). In certain coal based large plant in India is equipped with waste heat recovery System (WHRB) the flue gases after the after burning chamber pass through an elbow duct to waste heat boiler where sensible heat of the gases is extracted. The gas is then let off into the atmosphere after passing through pollution control equipment like electrostatic precipitator, ID fan and stack.

The oxidation reaction of carbon during process is given as

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C+CO2 = 2CO
2CO+O2 = 2CO2
C+O2 = CO2
2C+O2 = 2CO
The reaction occurring during the reduction of iron ore are as follows
$3Fe_2O_3 + CO = 2Fe_3O_4 + CO_2$
$Fe_3O_4 + CO = 3FeO + CO_2$
$FeO + CO = Fe + CO_2$

1.3 Accretion in Rotary kiln

Material inside the kiln tumbles and slides, and a thin layer of dust invariably forms on the surface of the refractory lining. Some zones of the kiln may be specifically prone to particle accumulation and the combined effect of thermal and flow conditions results in the formation of cylindrical deposits, or *rings due to its rotating motion*. As the ring grows thicker, the available opening of the kiln is decreased, i.e. the working volume of the kiln decreased, resulting into the hindering the flow of lime product and flue gasses through the kiln. Rings are generally situated close to the reduction zone or burner and are caused by the very high temperature in this area, particularly when the refractory lining is overheated due to direct impingement of the burner flame. These are the most common and also the most troublesome type of rings. As they cannot be reached from outside the kiln and therefore bit impossible to remove during its service condition. In several cases, rings grow rapidly and cause the unscheduled shutdowns of the kiln. Depending on the severity of the problem, maintenance labor, make-up lime purchase, and lime mud disposal can lead to increase the cost of production. It has been observed that the 70% cause of kiln shut down is due to accretion formation only

1.3.1 Mechanism of accretion formation

There are several ways by which ring can form on the refractory wall such as [2][3]

- Formation of low melting eutectic composition product during reduction at specific temperature, this is followed by the softening of the complex product of oxides.
- A small amount of gangue present in the iron ore under special conditions fibrous precipitates grow, two fibrous iron become hooked to each other and finally crystallizes.

Several experiments were performed with CO or CO/CO2 ratio for reduction, on the basis of which three different types of sticking were recognized [4,5]:

- The first type of sticking starts under the presence of sulphur, which arrives in the process by reducing gas, coke and coal. some ore particles precipitate by the metallic iron with the fibrous shape on the grain surface and sticking is started by the contact of the needles that bond mechanically the grains together and appears at temperatures above 600°C. While the grains are temporally bounded the fibbers are growing and sintering. Under these conditions high number of agglomerations will be forming quickly. They offer favourable conditions for sticking. Good diffusion conditions and lower reduction velocity supported this kind of sticking.

- The second way of accretion formation is caused by the presence of higher quantity of fresh precipitated iron. This iron has got a high activity and due to this tendency it leads to a build-up of small surfaces. And If the quantity of freshly precipitated iron is high enough, it leads to sticking. Between the iron ore parts appears high adhesion energy and that carries out to agglomeration.

- The third type of accretion occurs after reduction degree of 33% that occurs in the presence of wustite. Which are often seen at temperatures above 850°C. The reason is the presence of a liquid phase within the overheated zone on the lining. This can be initiated by presence of gangue, because there is a build up of low melting eutectic phases (CaO-SiO2-FeO) that stick together in an iron ore particle. This type of sticking behavior of the ores was observed at temperatures above $810^{O}C$. When temperature increases, some complex compounds of the iron ore start to soften and melt. It could be induced the sticking of third kind [4].

The reaction exploited during the accretion formation is as below:

$FeO + SiO_2 + CaO + MgO = FeO.SiO_2.CaO.MgO$

The wustite produced after the reduction of Fe2O3, at high temperature react with the dolomite (Cao.MgO) , which results into the decreased in the melting temperature of the iron therefore it get soften and hence form a very complex compound as mentioned above. This complex compound are having low melting eutectic composition i.e. under the driving force of temperature they will stick together due to its soft behavior, this process will be continue thru ought the reduction zone and due to the circular rotating motion of the kiln the small sticked particles will starts to grow and acquire the shape of the ring.
From thermodynamic point of view the probability of the formation of different complex compound will be dependent on the temperature and composition.

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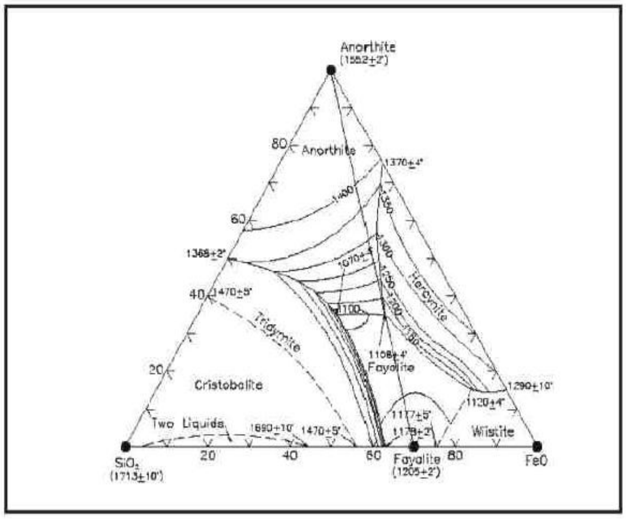

Figure 1.3.1 the ternary diagram between SiO2, FeO and Anorthite [6]

The stability of different phases and compound will be decided by the different composition present and the temperature meet at thar particular composition which ultimately form the low melting eutectic composition.

2. LITERATURE AND INDUSTRIAL SURVEY

There are several experiments done with tremendous observation although the accretion formation cannot be fully eradicated. According to K.K. Das et. al there are 6 phases being present in the accretion as revealed by the XRD analysis, they are as follws :[7]

Periclase : MgO
Iron Magnesium Silicate: $Mg_xFe_{2-x}SiO_4$
Iron: Fe
Fayalite : Fe_2SiO_4
Cristoballite : (SiO_2)
Anorthite : Cao.Al_2O_3.2SiO_2

The further observation reveals that the accretion contains MgO. thus the dolomite is the main origine which partially remain unreacted and the rest forms solid solution with Fayalite (F_2S). Although the Anorthite has been the only lime bearing compound in the accretion.

MgO Present in the accretion, forms solid solution with the fayalite , and the melting characteristics of the accretion in the Si Kiln would better explained by silica Anorthite Iron Magnesium silicate solid solution. As a result of this the melting point of the end member will be higher than that of the fayalite depending upon the exact composition of the solid solution.

The study of M Pisaroni et. al says that [8] the accretion formation could not be fully eradicate if related to its feed material rather overheating at specialized area can be related with the fluid dynamic inside the kiln by controlling the flow rate, they specially worked on the simulation of the fluid dynamics and find the better results to counteract the accretion formation in the rotary kiln.

A survey on different industries near by the Raigarh districts (Chhattisgarh) were done,the general elemental composition was found to be as follows[9]

Table 2.1 Final composition of Accretion formed [9]

Elements& Compounds	Iron (Fe) metallic	Iron(Fe) Total	SiO_2	Al_2O_3	Cao	MgO
% Composition	3.05	35.40	29.40	13.40	1.60	0.69

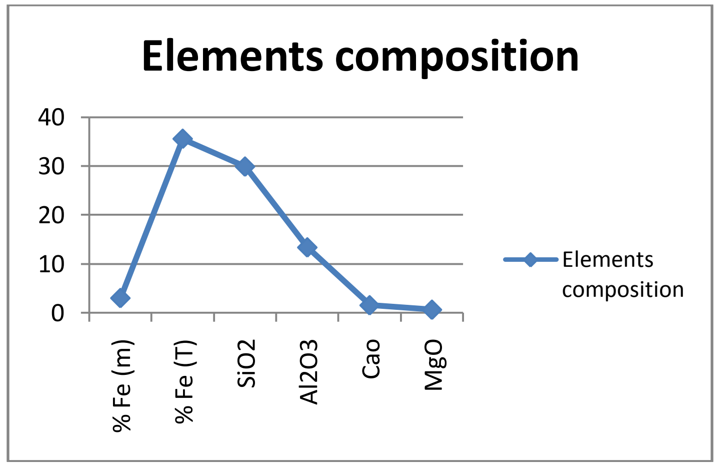

Figure 2.1 Final composition of Accretion

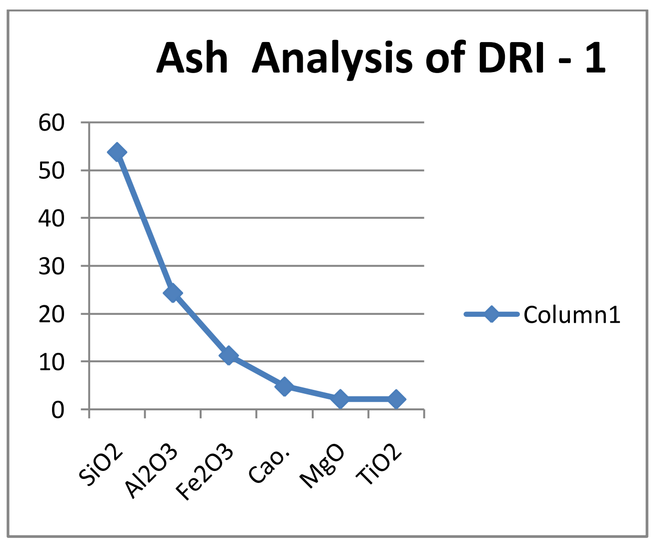

Figure2.2 shows the ash analysis of DRI-1 [9]

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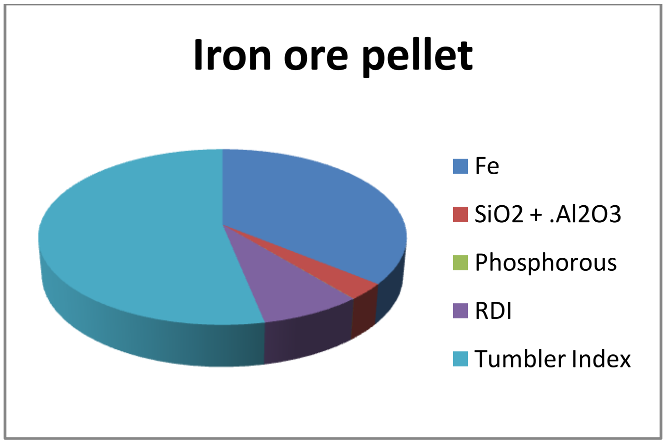

Figure 2.3 shows iron ore pellet main composition and physical test [9]

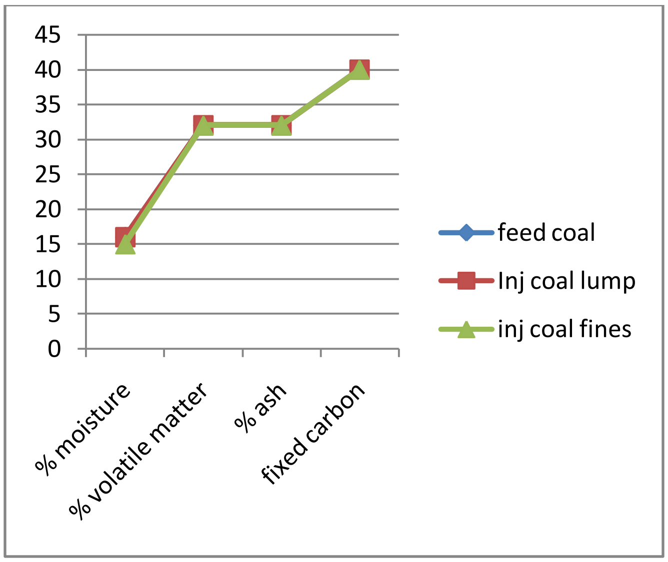

Figure 2.4 shows chemical characteristics of coal [9]

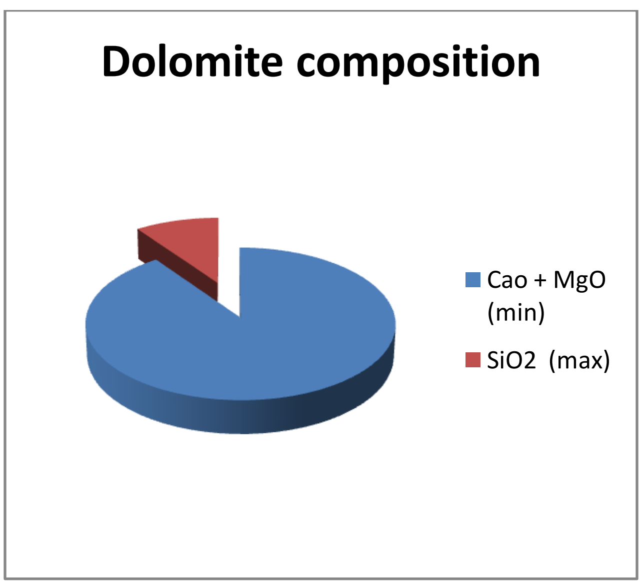

Figure 2.5 shows the Dolomite Composition [9]

These all the graphs showing the chemical and physical characteristics are very much relevant to the final Composition of the accretion formed on the refractory lining of the kiln as shown in table 2.1

3. EFFECT OF ACCRETION FORMATION ON

3.1 Productivity

The productivity is directly dependent on following factors
1. Characteristics of the raw material
2. Presence of inner working volume
3. Rate of production per day

Accretion formation will influence the second and third point as if severe ring formation inside of the kiln takes place then it need to be shutdown i.e. production for more than 5 to 6 days will be stopped, consequent to less production rate per month, which will definitely hamper the annual production rate.

3.2 kiln performance

Accretion formed on the inner lining of the kiln will reduce the working volume, which hinder the flow rate of reducing gas, and other solid fluids.This deaccelerate the penetration of CO gas inside the pellet to reduce and consequently the efficiency of the process will be badly hampered.
This kind of ring formation also leads to shutdown of the kiln which means no production during the repairement, this heavily effect the annual production.

3.3 cost of maintenance

During the shutdown so many modification and repairements in the kiln takes place but basically the main operation during that time is the breaking of accretion formed in the refractory lining. These maintenance are the summation of Labor cost + Energy cost + material purchasing cost + disposal cost. It has been estimated that in average worst condition of the kiln the repairing cost tends 150,000 euro.

4. PREVENTIVE MEASURES TO COUNTERACT THE ACCRETION FORMATION

Initially the formation of accretion cannot be fully eliminated but some preventive measures or modifications in the kiln can be done to reduce the formation of the same. at discharge end the metal to reducing gas ratio decreases in the kiln as during the subsequent reduction from charging to reduction zone the carbon present in the charge goes on decreasing thus at the end metallic iron would be more as compare to the reducing gas leading to the sintering of iron ore which result into excessive heating of the metal therefore more softening of the metal takes place

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consequeting into ring formation, thus to avoid it supplement addition of carbon can be done from the middle zone or from the discharge end of the kiln.

Modification in the refractory lining can be also a step to reduce the formation of accretion , a peer study by K.K. Das et.al [7] on refractory lining and accretion was conducted which states that the new refractory aggregate has been developed which gives a very loose texture at the interface of refractory and accretion. That castable refractory with modified matrix they have branded as ACCMON DRI. It has been well explained by them that how they resist the buildup of accretion on refractory even at a high temperature (1400^{o}C).[7]

5. CONCLUSION

1. it is concluded that formation of accretion can not be eliminated fully but can be reduced upto some extent.
2. ACCMON DRI refractory aggregate on study basis could be the the best replacement of the existing conventional andalisite based low cement castable refractory lining.
3. For industrial practice Thermal shock during time to time in the kiln can be given to reduce the adherence or stickness of the soften complex compound.
4. air to fuel ratio can be simulated to avoid the overheating of specific place thus softening of complex compound of wustite, silica , alumina and other oxides can be reduced upto much extent consequeting to the less formation of accretion.

6. FUTURE ASPECTS

1. Study on softening behavior of wustite with other oxides at deferent temperature and composition can be studied to get immense in depth idea regarding the accretion formation behavior.
2. Several computer simulations can be done to have correlation between input parameter and accretion behavior.

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