

# EFFECT OF LOW METALLIC DRI ON ELECTRIC ARC FURNACE PRODUCTIVITY AND IT'S PERFORMANCE

**\*Dr Rachappa Kadli, M.Tech., Ph.D. Deputy General Manager, Department-SMS-3 JSW Steel Ltd. Thoranagallu, Ballari.**

## **ABSTRACT:**

*Low metallic DRI has a direct influence on the operational behavior and productivity of Electric Arc Furnaces. When the metallic iron content in DRI drops, the material carries a higher fraction of unreduced iron oxides and gangue. This shifts more of the reduction work to the furnace itself and raises the thermal load required during melting. As a result, the EAF consumes more electrical and chemical energy to reach target temperatures, which extends power-on time and increases energy intensity per ton of steel produced. The inconsistent thermal response caused by low metallization also affects the stability of the slag layer. Higher FeO levels in slag reduce foaming quality, weaken arc shielding, and increase heat loss. These conditions force operators to use more oxygen and carbon to manage slag composition, but the extra additions rarely restore full efficiency.*

*Low metallic DRI also reduces yield. More iron becomes trapped in slag or is lost during reduction reactions that do not complete efficiently in the bath. The greater slag volume produced from increased gangue makes separation of metal droplets slower and less effective, which further lowers metallic recovery. With longer melting times, irregular bath temperatures, increased refractory wear, and reduced utilization of burners and oxygen lances, the furnace struggles to maintain stable, high-rate operation. Tap-to-tap cycles become longer, feeding sequences become more difficult to control, and throughput drops. Plants relying on continuous charging systems feel this effect strongly because temperature fluctuations disrupt steady-state melting conditions.*

*The combined impact of higher energy demand, reduced yield, slower cycle times, and greater process variability makes low metallic DRI one of the most significant raw material factors affecting EAF performance. Even skilled operational adjustments can only partially offset these fundamental limitations.*

**Keywords:** DRI, Metallization, EAF Productivity, FeO, Slag Foaming, Energy Consumption.

## **INTRODUCTION:**

Metallic DRI refers to direct reduced iron that contains a high percentage of metallic iron rather than iron oxide. It is produced by reducing iron ore in a solid state using reducing gases, usually hydrogen and carbon monoxide. Metallization is the ratio of metallic iron to total iron in the product. When metallization is

high, most of the iron exists in metallic form and melts easily in the furnace. When it is low, the DRI contains more iron oxides, which require additional energy and chemical reactions inside the furnace to complete reduction. Metallic DRI is valued because it provides a clean, predictable source of iron with low tramp elements and supports high-quality steelmaking when its metallization is maintained at an optimal level.

An Electric Arc Furnace is a steelmaking unit that melts metallic charge materials using electric arcs generated between graphite electrodes and the metal bath. Unlike blast furnaces, EAFs rely on electricity and chemical energy from oxygen and carbon to melt and refine scrap, DRI, or other iron units. The furnace operates in cycles that include charging, melting, refining, slag control, and tapping. EAFs offer flexibility, fast start-stop capability, and the ability to handle a wide range of metallic inputs. Their performance depends heavily on the quality of the feed materials, energy balance, slag behavior, and the stability of arc conditions. Because of their ability to efficiently produce various steel grades, EAFs play a central role in modern steelmaking, particularly in plants seeking lower emissions and energy-efficient operations.

### **OBJECTIVE OF THE STUDY:**

This study examines how low-metallic DRI affects electric arc furnace productivity, energy use, slag behavior, and overall melting performance.

### **RESEARCH METHODOLOGY:**

This study is purely based on secondary data sources such as articles, research papers, books, journals and other sources.

#### **1. Influence of Low Metallic DRI on EAF Energy Consumption and Power-On Time**

Low metallic DRI changes the energy balance inside an EAF in a way that operators immediately feel on the furnace's power-on time and total electrical load. DRI that has a lower metallic iron percentage carries more oxygen locked in the gangue and unreduced iron oxides. This shifts the process toward increased electrical energy use because the furnace must supply the heat needed to finish the direct reduction that the shaft furnace did not fully accomplish upstream. Once low-metallic DRI enters the bath, unreduced iron oxides react with carbon in the melt, but this reaction is endothermic and pulls heat from the steel bath. That means the electrode system must compensate, which shows up directly as higher specific energy consumption per ton of liquid steel. Lower metallization also reduces the efficiency of chemical energy input. When oxygen is injected for decarburization or foamy slag practice, some of that oxygen ends up reducing iron oxides instead of contributing to oxidation of carbon or generating heat at the slag-metal interface. In furnaces that rely heavily on chemical energy through burners and oxygen lances, this diversion weakens the contribution of those systems and forces operators to keep electrodes online longer. Over time, this leads to higher electrode wear and greater reliance on electrical energy, neither of which is desirable for productivity.

The bath temperature tends to drop periodically during DRI feeding when metallization is low. Operators often must pause feeding or adjust the feed rate to avoid quenching the bath. This pacing alone extends the heat time. EAFs producing high-quality steel grades often chase tight temperature windows, and low metallic DRI makes these windows harder to maintain because the furnace spends more time climbing back to target temperature after each cooling dip. In a well-optimized melt practice, tapping is scheduled promptly once chemistry and temperature targets are reached, but low metallic DRI keeps operators waiting longer for consistent bath conditions. Slag formation is another factor that ties into energy efficiency. Low metallization results in a slag that contains more FeO. Higher FeO levels in slag increase its oxidizing potential, and an oxidizing slag interferes with efficient carbon-oxygen reactions in the foam. The poorer the foam, the weaker the shield around the arc and the more electrical energy escapes as radiation. That lost energy must be replaced by increased electrode power, again stretching power-on time and weakening productivity.

The additional unreduced oxides also raise the sensible heat demand on the furnace. Energy that would normally go into melting scrap or superheating liquid steel gets diverted into reducing iron oxide and heating gangue that does not provide metallurgical value. This means that DRI with lower metallic iron is essentially forcing the furnace to do upstream reduction work that should have been completed before the material arrived at the melt shop. Over a campaign, an EAF running on low metallic DRI consistently shows longer tap-to-tap cycles. Even improvements in oxygen practice, burner settings, and foamy slag control only partially compensate because the thermodynamic penalty is inherent to the raw material. Plants that operate continuous charging systems feel this effect strongly because feed rate and bath stability depend heavily on predictable thermal behavior. In short, low metallic DRI imposes additional thermal and chemical loads that push energy consumption upward and stretch the active melting portion of the cycle.

## **2. Impact of Low Metallic DRI on Slag Chemistry, Foaming Behavior, and Arc Stability**

The metallization level of DRI plays a central role in shaping slag chemistry inside an EAF. When metallization drops, more FeO enters the slag system because a larger fraction of the iron is still in oxide form. A slag with elevated FeO is more oxidizing and shifts the entire chemical environment of the furnace. This causes several operational challenges that show up in productivity numbers, particularly those tied to arc stability, heat transfer, and slag foaming. Slag foaming is one of the most important features for EAF efficiency. A stable foam shields the arc, allowing the furnace to operate at higher voltages without causing excessive radiation loss or arc flare-ups. When the FeO content rises because of low metallic DRI, carbon injected into the slag reacts aggressively with FeO to form CO, but the reaction becomes erratic rather than controlled. Instead of forming a thick, stable foam, the slag can become overoxidized. High FeO reduces the viscosity and stability of the foam and causes it to collapse more frequently. These collapses expose the arc, reduce thermal efficiency, and increase radiation to the furnace walls and roof panels.

The unstable slag condition also interferes with efficient use of carbon injectors and burners. Operators rely on predictable slag reactions to maintain a good foam height. With low metallic DRI, carbon must work harder to reduce excess iron oxide, and that reduces the available carbon for consistent foaming. Because of this, carbon injection rates may increase, but the furnace still struggles to maintain an ideal foam layer. This leads to additional oxygen and carbon adjustments that create a constant cycle of correction rather than smooth operation. An overoxidized slag also attacks furnace refractories more aggressively. FeO acts as a solvent that eats into the working lining, particularly the slag line. As refractory wear increases, operators may lower power input to avoid damage during certain parts of the heat, slowing overall melting and reducing energy efficiency. More frequent maintenance stops or patching work also remove furnace time from production. Although these effects are not instant, they accumulate across weeks and months, creating a measurable decrease in shop output.

Arc stability depends heavily on the combined behavior of slag and the metallic bath. Low metallic DRI reduces the predictability of how the bath responds to incoming energy. Fluctuation in slag thickness and foaming makes it harder for an EAF to maintain consistent arc length and impedance. The arc may wander, strike the slag inconsistently, or generate more flare. These variations force operators to maintain more conservative power settings, lowering kWh input per minute and slowing melt progress. Burner efficiency drops when FeO is high because the heat transfer between flame and slag becomes less effective. The oxidizing slag absorbs heat but does not release it efficiently into the bath. This creates a thermal barrier rather than a facilitator, undermining attempts to compensate for lower metallization through burner enrichment or oxygen lancing.

Slag volume also increases because low metallic DRI introduces more gangue relative to metallic iron. A higher slag volume reduces the freeboard inside the furnace and limits the amount of DRI or scrap that can be introduced quickly. The furnace becomes constrained not only chemically but physically. Managing a larger, more fluid slag requires more corrections, more additives, and tighter control of the process to prevent overflow or unmanageable foam surges. The combined effects unstable foam, oxidizing reactions, increased refractory wear, unstable arc conditions, and reduced burner transfer efficiency feed directly into longer tap-to-tap times. Even if operators tune their practices well, the slag chemistry introduced by low metallic DRI consistently drags down furnace performance by disrupting the delicate balance required for stable high-power operations.

### **3. Effect on Yield, Metallic Recovery, and Overall Melt Efficiency**

Low metallic DRI affects the yield of liquid steel by introducing more unreduced iron oxides and higher levels of impurities that reduce the percentage of charged iron that ultimately becomes part of the tapped heat. Yield in an EAF depends on how much metallic iron survives oxidation, slag formation, and the complex reactions that occur during melting and refining. When metallization drops, a larger fraction of the charged iron ends up

in the slag or becomes trapped in slag droplets that never fully separate into the bath. Iron oxide reduction depends on carbon availability and temperature. Low metallic DRI forces the furnace to spend more time reducing FeO in the slag and FeO contained in the DRI itself. Not all of this iron is recovered. FeO dissolved in slag increases slag viscosity and interferes with separation of metallic droplets. Some metallic iron becomes entrained in slag as small droplets that either do not settle or partially reoxidize before they can merge with the bath. This creates a steady but often hidden loss of metallics that directly lowers yield per ton of DRI charged.

Slag volume increases as the gangue level rises. More gangue material requires more fluxes to reach the right fluidity and basicity. These additional additions increase slag weight and dilute the metallic phase. A larger slag mass traps more iron droplets and extends the time needed for separation. The longer the furnace runs to recover this trapped metal, the more thermal losses accumulate. At some point, operators choose to tap rather than continue refining because running the furnace longer becomes less economical than accepting a small yield loss. Plants that push for high productivity often tap earlier, which amplifies yield loss even more when metallization is low. Metallic recovery is also influenced by carbon content in the DRI. Low metallic DRI frequently carries lower carbon levels because the reduction reactions did not reach completion. Without sufficient carbon in the pellet or lump, the bath relies heavily on injected carbon. This injected carbon first reduces excess FeO instead of contributing to efficient slag foaming or helping recover iron droplets. Lower in-situ carbon also slows carburization of the bath, which can create challenges when producing grades that require specific carbon levels. This forces additional carburization steps that add time but do not add productivity.

The temperature profile inside the furnace also affects metallic recovery. When low metallic DRI continuously cools the bath, metal droplets may not stay hot enough to coalesce easily. A cooler bath suspends more metallic fines rather than absorbing them. These fines eventually exit the furnace as part of the slag, especially during tapping when slag carryover can increase if the slag is thick or hard to control. Mills often install slag detection systems to minimize this, but even the best systems cannot completely prevent metallic losses when slag chemistry is unfavorable. In plants where hot DRI is used, low metallization still harms recovery because the thermal benefit of hot charging cannot compensate fully for the additional reduction load. Hot DRI may enter at high temperature, but the furnace still must handle the chemical burden of unreduced oxides. This means reduced yield despite the incoming thermal energy. The combined influence of increased FeO, higher slag volumes, unstable droplet separation, lower inherent carbon, and reduced bath temperature all work together to reduce overall melt efficiency. The furnace must run longer for the same tonnage of liquid steel, yet still produces less liquid steel per unit of DRI charged. Yield loss compounds over time and becomes one of the most expensive hidden costs associated with low metallic DRI.

#### 4. Influence on EAF Process Control, Oxygen Practice, and Carbon Management

EAF steelmaking relies on a carefully balanced combination of electrical energy, chemical energy, oxygen injection, carbon input, and slag chemistry. Low metallic DRI disrupts this balance and forces operators to shift process parameters more aggressively. These adjustments create operational complexity, slow down melting, and increase variability across heats. Oxygen practice is one of the areas most affected. When metallization drops, the furnace must deal with more iron oxide. Operators inject oxygen for decarburization, oxidation of unwanted elements, and promotion of slag foaming, but the extra FeO in the system causes some of that oxygen to behave differently. Instead of focusing on decarburizing the bath or reacting efficiently at the slag–metal boundary, the injected oxygen may simply push the FeO content higher. This produces an aggressive slag that demands even more carbon injection to compensate. As a result, oxygen use becomes less targeted and more of a balancing act between oxidation and reduction.

Carbon management becomes more complicated. Operators typically inject carbon to promote foaming and reduce FeO. With low-metallic DRI, carbon must work double duty, first reducing oxides in the DRI itself and then reducing FeO in slag. This reduces carbon available for maintaining a stable foam. The furnace may require higher carbon injection rates, but increasing carbon does not always improve the situation because the slag chemistry may not support stable foaming. Inefficient utilization of carbon leads to more off-gas CO variability, which affects downstream off-gas analysis and makes heat-by-heat control harder. Process control systems rely on predictable behavior to optimize energy input and adjust lancing, charging, and burner operations. Low metallic DRI increases fluctuation in bath temperature, slag height, and furnace impedance. The furnace may repeatedly shift between hot and cold periods during DRI feeding. Such fluctuations can confuse automated control systems, forcing operators to intervene manually. Manual control is slower and less consistent than optimized automatic practice, which impacts heat times.

An oxidizing furnace atmosphere caused by excess FeO also affects the recovery of valuable elements such as chromium in alloy steels. Low metallic DRI makes the slag more hostile to alloy recovery. This means additional alloy additions later in the heat or after tapping to correct chemistry deviations, adding cost and process time. Burner systems also work harder with low metallic DRI. Operators often increase burner time to compensate for cooling from unreduced oxides. But burner efficiency drops in oxidizing slag conditions, meaning more fuel is required for the same heat input. The off-gas temperature may rise, pushing the heat load on the off-gas system and reducing the efficiency of heat recovery systems where they exist.

Foamy slag practice becomes inconsistent when slag repeatedly dips below or rises above ideal viscosity. Many EAF shops rely heavily on good foaming to shield the arc and allow high-voltage operation. Without stable foam, the furnace must operate at lower voltage settings, which reduces the arc's energy density and slows melting. The added variability makes the furnace harder to run at steady high productivity. Operators must frequently adjust oxygen flow, change carbon injector settings, alter DRI feed rates, and modify burner

timing. These reactive adjustments interrupt the normal flow of operations and make it difficult to maintain optimal tap-to-tap cycle times.

## 5. Effect on EAF Throughput, Cycle Time, and Overall Productivity Metrics

Low metallic DRI influences nearly every metric used to measure EAF productivity. When metallization is low, the furnace spends more time melting, more time correcting slag chemistry, and more time recovering temperature lost during feeding. The tap-to-tap cycle becomes longer not because of one large cause, but because a series of small delays accumulate into a meaningful productivity loss. Cycle time is heavily dependent on stable feeding. Continuous charging systems, especially those feeding hot DRI or cold DRI on a fixed schedule, rely on predictable bath reactions. Low metallic DRI cools the bath more than high-metallization material. Operators slow the feed rate to avoid quenching the bath. Even a short reduction in feed rate adds minutes to the cycle, and across many heats per day, these minutes turn into hours of lost furnace availability. Furnace throughput depends on how quickly each heat can progress from charging to tapping. With low-metallic DRI, the melting phase takes longer because the furnace must supply additional energy to complete reduction of iron oxides. The refining stage may also lengthen because slag chemistry needs more time and more adjustments before it reaches target conditions. Each additional correction adds to the cycle.

Higher FeO levels in slag also push operators to use more fluxes and carbon. These additions are necessary but create handling time, mixing time, and reaction time. More flux means more material to melt and heat, which further extends the tap-to-tap cycle. Lower yield means the furnace may need to charge more DRI or scrap to reach the same liquid steel tonnage. Charging more material increases the overall cycle time and reduces the number of heats that can be completed in a shift. Over time, the shop produces fewer tons per electrode set, fewer tons per tap, and fewer tons per furnace campaign.

Productivity metrics such as tons per hour, tons per kWh, and tons per electrode all decrease when metallization drops. The furnace operates longer to produce the same amount of steel. Energy intensity rises, electrodes wear faster, and oxygen consumption grows. These increased inputs show up as reduced efficiency and higher operating costs per ton. Maintenance cycles may tighten because of faster refractory wear caused by oxidizing slag. Each maintenance stop removes furnace availability from production time. Even minor patching work reduces throughput on a daily or weekly basis. Off-gas systems and environmental controls can also feel the effect. Erratic carbon oxidation from unstable slag conditions produces fluctuating CO and CO<sub>2</sub> levels. Off-gas systems may need more adjustment, and plants with energy recovery equipment may see reduced recovery efficiency when process conditions are unstable. Plants that measure productivity through KPI dashboards usually observe increases in tap-to-tap time, delays in scrap or DRI charging sequences, and higher variability in bath temperature readings. Variability is often more damaging than the average shift in numbers because it complicates planning, makes scheduling less reliable, and reduces the ability to run consistent campaigns for specific steel grades. Across a full production schedule, these small inefficiencies

accumulate into fewer heats per day, higher conversion cost per ton, and reduced competitiveness. The furnace becomes less predictable, less efficient, and less capable of maintaining high-intensity operations.

## CONCLUSION

Low metallic DRI substantially undermines the productivity and performance of electric arc furnaces by imposing a heavier chemical and thermal burden on the melting process. Because a greater fraction of iron is still in oxide form, the furnace must expend more energy to complete reduction, leading to elevated electrical consumption and extended power-on times. The resulting slag becomes highly oxidizing, with elevated FeO content that destabilizes foam, weakens arc shielding, and increases refractory wear. These slag-chemistry issues in turn demand more carbon and oxygen injections, complicating process control and increasing operational variability. Metallic recovery suffers too: unreduced iron oxides and gangue raise slag volume and trap iron in droplets that fail to coalesce efficiently, driving yield losses. The cycle time per heat lengthens, reducing throughput while increasing maintenance burden due to refractory degradation. Slower, less predictable operations also diminish the return on electrode and energy usage. Even when operators make process adjustments, the fundamental thermodynamic penalties associated with low metallization remain. In sum, low metallic DRI delivers a clear productivity disadvantage for EAF shops. To maximize performance, steels mills must prioritize high-metallization DRI, rigorous slag management, and optimized chemical energy practices.

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