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Behavior of an indigenously fabricated transferred arc plasma furnace for smelting studies

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Abstract

The utilization of industrial solid waste for metal recovery requires high-temperature tools due to the presence of silica and alumina, which is reducible at high temperature. In a plasma arc furnace, transferred arc plasma furnace (TAP) can meet all requirements, but the disadvantage of this technology is the high cost. For performing experiments in the laboratory, the TAP was fabricated indigenously in a laboratory based on the different inputs provided in the literature for the furnace design and fabrication. The observed parameters such as arc length, energy consumption, graphite electrode consumption, noise level as well as lining erosion were characterized for this fabricated furnace. The nitrogen plasma increased by around 200 K (200 °C) melt temperature and noise levels decreased by ~10 dB compared to a normal arc. Hydrogen plasma offered 100 K (100 °C) higher melt temperature with ~5 dB higher sound level than nitrogen plasma. Nitrogen plasma arc melting showed lower electrode and energy consumption than normal arc melting, whereas hydrogen plasma showed lower energy consumption and higher electrode consumption in comparison to nitrogen plasma. The higher plasma arc temperature resulted in a shorter meltdown time than normal arc with smoother arcing. Hydrogen plasma permitted more heats, reduced meltdown time, and lower energy consumption, but with increased graphite consumption and crucible wear. The present study showed that the fabricated arc plasma is better than the normal arc furnace with respect to temperature generation, energy consumption, and environmental friendliness. Therefore, it could be used effectively for smelting-reduction studies.

Keywords: smelting, transferred arc plasma, furnace characterization, hydrogen and nitrogen plasma, hollow electrode, graphite and magnesite lining

(Some figures may appear in colour only in the online journal)

1. Introduction

Industrial waste contains mainly stable oxides such as silica and alumina, which need a lot of energy and high temperature for their reduction in the presence of reducing agents [1]. Plasma is a known tool for the generation of enormous heat energy, with temperatures ranging from 5000–8000 K (4727 °C–7727 °C), which is useful for melting refractory metals and alloys [2–5]. Increasing attention is being paid to applications of plasma smelting for mineral processing and plasma spray coating for the surface modification of metals,

which is gaining popularity [6–17]. The amount of heat generation in plasma arc depends on the types of current, current density, the ionization behavior of different gases, types of plasma, etc [18]. Both AC and DC current could be used to form a normal arc as well as plasma arc [18–20]. Many researchers have studied the heat distribution in different arc systems and showed that 72% of the total heat of DC arc is transferred to the melt, whereas only 65% is transferred in the case of AC arc. DC plasma provides the convenience, safety and more heat input to the metals. Therefore, it is widely used in laboratory experiments

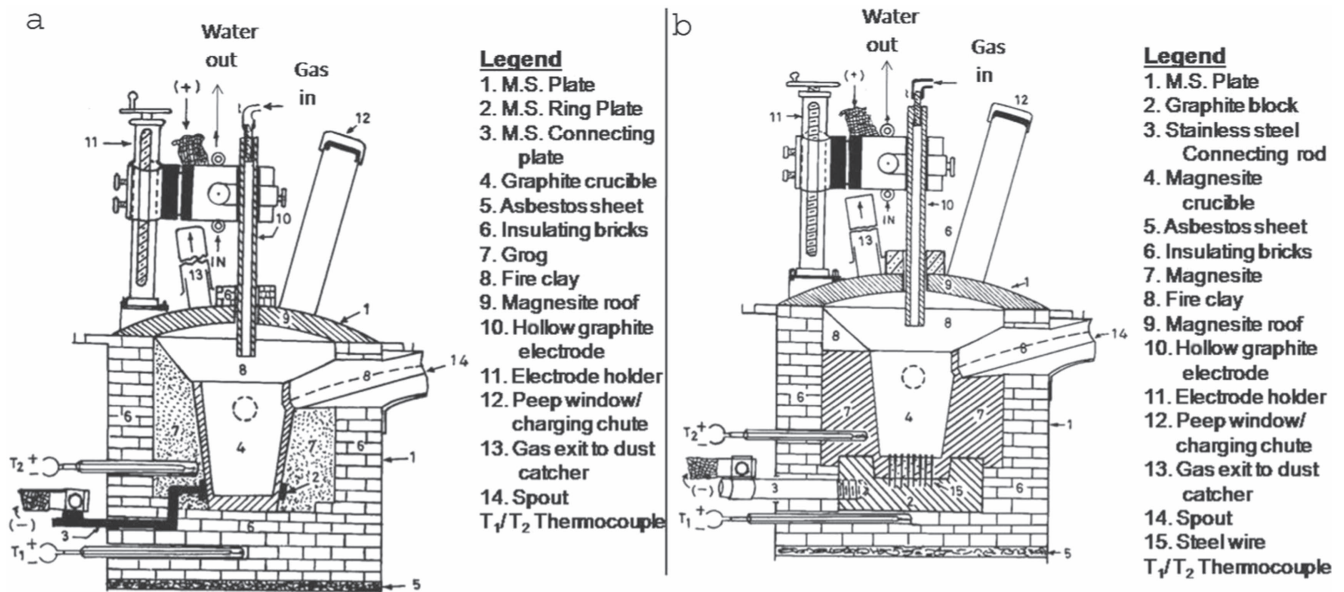


Figure 1. Cross-section view of a plasma arc furnace with magnesite lining.

[21, 22]. The selection of plasma-producing gas is based on the need and its chemical effect on the work piece and electrodes [23]. Oxygen is used for oxidizing, argon and nitrogen for providing inactive (inert) atmosphere and hydrogen maintains a reducing atmosphere around the melt [4, 24].

Besides the use of nitrogen plasma for creating an inert atmosphere around the melt, it is also used for producing nitrogen-bearing austenitic stainless steel. Nitrogen gas is cheaper and more readily available than nickel and therefore in the nitrogen plasma process nickel is partially or fully substituted by nitrogen [25, 26]. In the case of smelting-reduction studies, nitrogen plasma is generally used to minimize the re-oxidation of metals [27]. Steel makers widely utilize electrically generated gas plasma in which arc is present between the graphite electrode and charge material, known as transferred arc plasma [28, 29]. The transferred arc gives higher current compared to non-transferred arc, but maximum power for both the arcs is similar. The main difference between the two arc systems is the energy density of the plasma gas generated in the respective arc. In the transferred arc, the energy density is 30 times higher than the non-transferred arc. Therefore, in the case of transferred arc plasma, the heat transfer to the metal is tremendously high. For that reason, metal and alloy melting are commonly performed by the transferred arc plasma melting [23]. Initially, only DC furnaces generated arc, but nowadays, a three-phase AC plasma furnace is feasible [19, 30, 31]. In 1991, Takuma developed a DC plasma furnace used for melting the residue and conducted necessary melting tests from 1993. The output production of that bench-scale furnace having 300 kW capacity was 7.2 ton/day. In 1998, they started a new demonstration plant with 1710 kW output and 25 ton/day output to conduct tests [18, 29]. No information about the transferred arc plasma for smelting-reduction studies in laboratory scale is yet found elsewhere in the literature.

Hence, the main objective of our work is to observe the behavior of an indigenously fabricated laboratory-scale transferred arc plasma furnace with respect to operational parameters such as meltdown time, arc length, energy consumption, sound levels, electrode consumption, lining life, etc, in a smelting study to establish the suitability of its use.

2. Experimental

2.1. Fabricated furnace for study

It may be pointed out that this unit was fabricated based on the available information from the literature and work experience. This design was accepted after three consecutive upgrades in the design, depending upon the problem faced during melting trials.

The furnace body, having a cylindrical shape of diameter 0.300 m (300 mm) and height 0.280 m (280 mm), was fabricated with mild steel sheet of thickness 0.003 m (3 mm). The top of the furnace was provided with a swinging lid, made of 0.005 m (5 mm) thick steel plate, which could be easily lifted up and closed as required during the melting operation. The inside of the mild steel roof was lined with magnesite to protect it from direct heating. Provision was made for charging, gas for the exit, and an electrode holder assembly.

A graphite block of 0.12 m (120 mm) diameter and 0.08 m (80 mm) height was used for providing electrical connection to the charge through the bottom of the crucible. It was connected by a stainless steel rod 0.025 m (25 mm) long screwed into it without any cooling system for providing (-ve) power. In the present study, magnesite lining was used. For preparing the magnesite lining, around 20–25 steel nails, 0.003 m (3 mm) in diameter and 0.035 m (35 mm) long were fixed on the top of the graphite block embedded in the refractory lining for making an electrical connection between

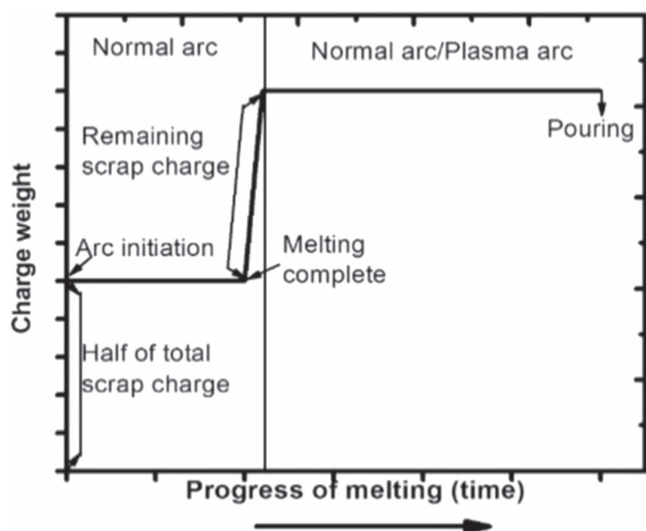


Figure 2. Flow chart of scrap-melting procedure.

the melt and graphite block, as shown in figure 1. A gas purification train was fabricated with a mixing and flow control system to pass the desired plasma gas (nitrogen/hydrogen).

2.2. Melting operation

The crucible of the furnace was first tested for its proper functioning using both normal as well as plasma arc (H_2/N_2) for melting 2 kg mild steel (MS) scrap charge. Initially, 0.5 kg (500 g) of MS scrap was charged in the crucible with the furnace power switched on. The melting was initiated by striking the normal arc without plasma gas with the use of a solid graphite electrode. The additional charge was made gradually through the charging chute after melting the previous charge, and this was continued till all the steel scrap was molten. After ensuring the complete melting of the charge, nearly 2 kg of the first heat was discarded as a wash heat to make the magnesite-lined crucible superheated for a smooth running after further melting, as shown in figure 2.

A fresh heat was prepared after complete melting of the scrap, and then the solid electrode was replaced by a hollow one. The arc was struck again by the hollow electrode, which was connected to the particular ionizing gas through the gas purification train. Before starting the plasma gas through the hollow electrode, the temperature of the melt was measured and one sample was collected. The gas started to pass at a constant flow rate through the electrode hole up to the arc zone where it was ionized, resulting in increased arc zone temperature.

3. Results and discussions

The behavior of the fabricated furnace under normal arc and different plasma (N_2/H_2) conditions using a magnesite crucible were studied, and the results are described in the following sections.

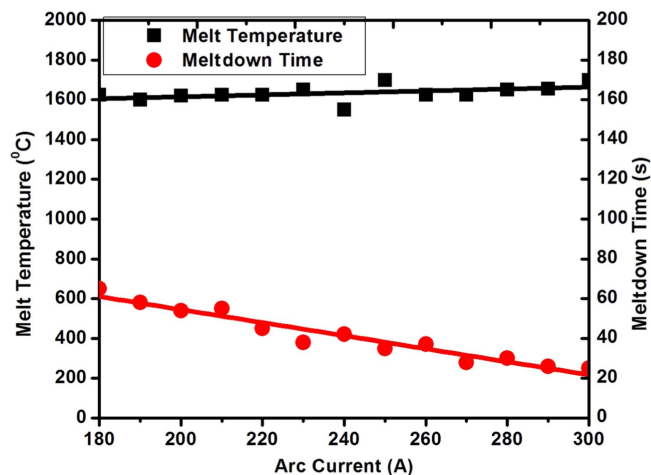


Figure 3. Effect of arc current on the melt temperature and meltdown time under normal arc.

3.1. Melt temperature and meltdown time

Temperature is an important parameter, which controls the meltdown time and gas/metal reactions occur while exposed under plasma arc. Factors affecting temperature are dependent on the type of arc and current. Therefore, the furnace was first operated at the normal arc, and the effect of the arc current on the melt temperature was noted. In the second phase, nitrogen and hydrogen gas were passed separately to get the plasma, while in the third phase, the arc current was changed, but a fixed plasma gas flow rate of the nitrogen/hydrogen gases was maintained. The effect of the different plasma gases on the melt temperature is illustrated in the following subsections.

3.1.1. Effect of arc current on the melt temperature and meltdown time under normal arc. The arc current was increased from 188 to 278 A, which increased the melt temperature from 1898 to 1973 K (1625°C to 1700°C), as shown in figure 3. The increasing current provided high energy to the system, which resulted in increased melt temperature and decreased meltdown time from 65 to 25 min. This confirmed the healthy functioning of the furnace system.

3.1.2. Effect of plasma gas on the melt temperature. Steel scrap was melted under normal arc (~ 230 A) and the temperature was recorded for 300 s of normal arc exposure to observe the influence of nitrogen and hydrogen gas. A hollow electrode replaced the solid electrode, and nitrogen/hydrogen gas (flow rate $\sim 16 \times 10^{-6} \text{ m s}^{-1}$) passed through electrode for 300 s. In the meantime, the temperature was recorded continuously by using a radiation pyrometer at an interval of 10 s. Plasma-forming gases (i.e. nitrogen/hydrogen) after reaching a high temperature in the arc zone get dissociated into atoms followed by ions, which liberated an enormous amount of heat around the arc. Consequently, the temperature of the arc zone increased tremendously in the case of the plasma compared to the normal arc, resulting in more melt temperature. Higher melt temperature was noted in the case of hydrogen plasma than nitrogen plasma due to the

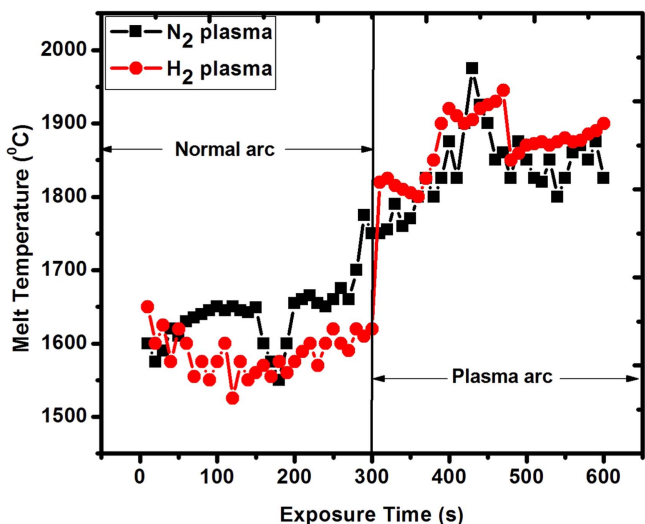


Figure 4. Effect of plasma gas on the melt temperature when exposed to different plasma.

combined effect of the ionization and combustion of hydrogen gas. The plasma showed an increase of the average melt temperature of 300 °C for hydrogen and 200 °C for nitrogen, as shown in figure 4.

3.1.3. Effect of plasma arc current on the melt temperature.

As the gas–metal reactions are sensitive to the melt temperature, the effect of arc current in regulating the melt temperature was an important parameter for the present study. Several melts of 2 kg each were made with different arc current (200–280 A), while the flow rate of nitrogen/hydrogen ($8.33 \times 10^{-6} \text{ m}^3 \text{ s}^{-1}$) was kept constant during the 300 s exposure time. The melt temperature was found to have increased linearly with the plasma arc current, as shown in figure 5. Hydrogen plasma generated more heat than nitrogen plasma, resulting in increased melt temperature. This trend served as a guideline for obtaining the required temperature inside the chamber of the plasma furnace.

3.1.4. Effect of heat number on the melt temperature and meltdown time under normal arc. The heat produced by normal, as well as plasma arc, played different roles in the melting chamber. Generated heat was utilized for superheating the crucible refractories, melting the charge materials, superheating the melt as well as compensating for the heat loss through radiation, conduction and off gas.

Consequently, the temperature requirement was higher in the initial stage of melting. As the furnace refractories were gradually superheated, the need for thermal energy was reduced for further continuous melting. An increase in heat number decreased the meltdown time. In the first heat, it took more time to compare to the next heats for further continuous melting. The meltdown time for achieving $\sim 1823 \text{ K}$ ($1550 \text{ }^\circ\text{C}$) temperature for continuous melting of different heats, are shown in figure 6. It was observed that in the normal arc melting, the meltdown time was reduced for the same quantity of scrap melting from 35 min for the first heat,

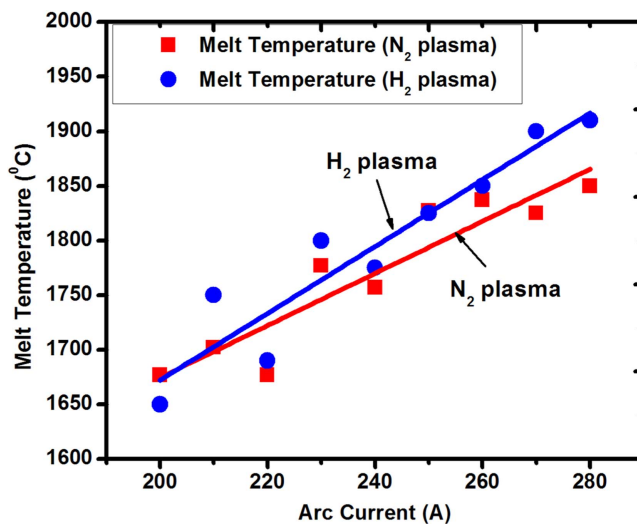


Figure 5. Effect of arc current on the melt temperature when exposed to different plasma.

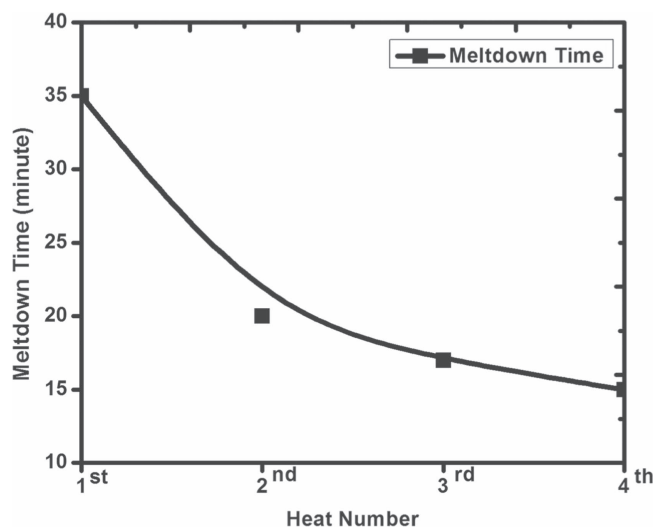


Figure 6. Effect of number of heats per campaign on melt temperature and meltdown time under normal arc.

which was decreased to 20 min for the second, 17 min for the third and 15 min for the fourth. This indicates that 20 min melting time was reduced by using the furnace for continuous operation.

3.2. Arc length

The length of the arc in free arcing condition decides the area of arc impingement on the melt surface. A longer arc length will give a wider plasma impingement area above the melt. This area is significant for the gas–metal reaction occurring during melting/smelting-reduction studies. A longer arc length is desired for smelting studies to have a higher retention time for the particles in the plasma flame. Furthermore, a shorter arc length offers concentrated heat in a narrow zone whereas a longer arc length provides even heat distribution over a wider area. Thus, depending upon the need, the flame length is adjusted. The arc length was measured by the scale

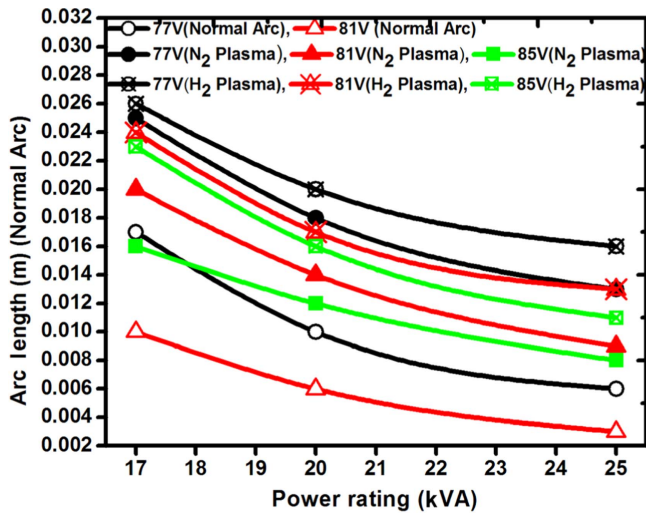


Figure 7. Variation in arc length with power rating under normal and plasma arcs.

fitted on the electrode holder (figure 1, parts number 11). For the measurement, first the electrode was just touched over the melt/charge surface to do short-circuiting, which was indicated by the energy meter. After short-circuiting, the electrode was moved gradually in an upward direction up to the height where arc breaking took place. The distance measured on the fitted scale between the short-circuiting points to the arc breaking represents the arc length.

The present study was done to know the effect of current and gas flow rate on arc length. These observations are described in the following subsections.

3.2.1. Effect of power rating and arc voltage on arc length. To study the above parameter, 2 kg steel scrap was first melted in the crucible using normal arc without plasma gas. Subsequently, at a given arc voltage, the arcing was freely allowed at a certain power rating without using plasma gas (i.e. normal arc) and the length of the arc was measured. This arc length was measured at different power ratings and voltages. The experiment was repeated with a gas flow rate ($8.33 \times 10^{-6} \text{ m}^3 \text{ s}^{-1}$) through the electrode for generating plasma arc. These observations are shown in figure 7. It could be noted that the arc length was longer in the case of the plasma gas compared to normal arc at all levels of power rating. Furthermore, longer arc length was also obtained in the case of lower arc voltage (77 V) and power rating ($\sim 17 \text{ kVA}$).

The falling trend is characteristic of increasing arc conductance with increasing current caused either by an increase of the electrical conductivity (i.e. high temperature) or the arc diameter or both [32]. The diameter of a graphite electrode is constant and therefore the conductance is varied with an increase in temperature. The conductance of N_2 plasma arc is more than normal arc due to increased temperature. In the case of hydrogen Plasma, this value is again increased, as shown in figure 8. Calculated values of conductance are given in table 1.

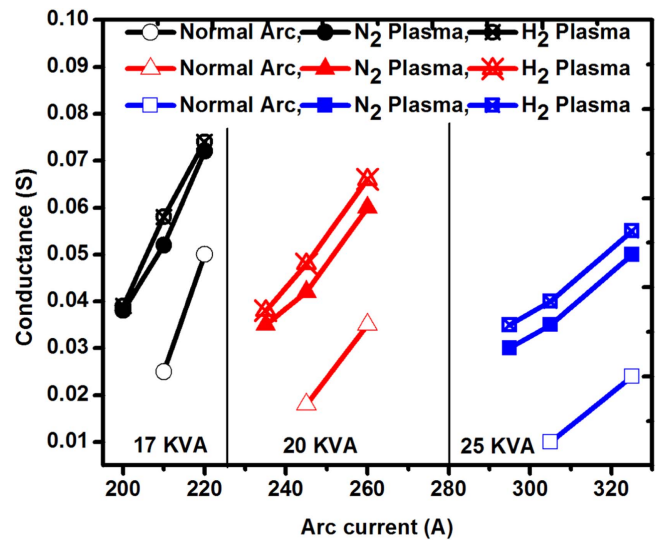


Figure 8. Variation in arc conductivity with current under normal and plasma arc.

3.2.2. Effect of gas flow rate on plasma arc length and conductance. In the previous section 3.2.1, it was shown that longer arc length with better conductance could be obtained by flowing nitrogen as a plasma gas. This study was repeated in the same manner as mentioned by keeping the arc voltage at 85 V and power rating at $\sim 17 \text{ kVA}$.

A change in the arc length was noted with increased gas flow rate, as shown in figure 9. The arc conductance values were calculated and plotted to indicate that higher gas flow rate ($8.33 \times 10^{-6} - 33 \times 10^{-6} \text{ m}^3 \text{ s}^{-1}$), resulted in a longer flame (0.020 to 0.040 m) with better conductance (0.047 to $0.094 \Omega^{-1} \text{ m}^{-1}$).

3.3. Energy consumption

The total energy consumption in the arc melting process depends on the efficiency of heat transfer to the melt. Any saving on electrical power will obviously be a major factor in promoting the use of plasma arc. The energy consumption in the present study was noted directly from the energy meter.

3.3.1. Energy consumption for melting. Three separate melts (2 kg scrap) were prepared under normal arc as well as nitrogen and hydrogen plasma arc, respectively. The meltdown time, energy consumption, electrode consumption, and power fluctuations were noted (table 2). It can be seen that normal arc melting takes more time (35 min) with more energy consumption (28.8 MJ) compared to the nitrogen plasma. In the case of hydrogen plasma, it takes the least time for melting (20 min), and also consumes less energy (19.5 MJ). This may be due to the high flame temperature and better heat transfer from the longer and wider plasma flame. It may be pointed out that nearly 2412 MJ/ton of energy consumption was observed during industrial practice using a 3-ton plasma arc furnace [30, 33].

3.3.2. Energy consumption during melt heating. Once the charge was completely melted down, the arc energy was

Table 1. Calculated values of conductance.

Arc voltage	77 V				81 V			85 V		
	Power rating (kVA)	Arc length (m)	Arc current (A)	Conductance per unit area	Arc length (m)	Arc current (A)	Conductance per unit area	Arc length (m)	Arc current (A)	Conductance per unit area
Normal arc	17	0.017	221	0.049	0.010	210	0.026	—	—	—
	20	0.010	260	0.034	0.006	247	0.018	—	—	—
	25	0.006	325	0.025	0.003	309	0.011	—	—	—
N ₂ plasma	17	0.025	221	0.072	0.020	210	0.052	0.016	200	0.038
	20	0.018	260	0.061	0.014	247	0.043	0.012	235	0.033
	25	0.013	325	0.055	0.009	309	0.034	0.008	294	0.028
H ₂ Plasma	17	0.026	221	0.075	0.024	210	0.062	0.023	200	0.054
	20	0.020	260	0.067	0.017	247	0.052	0.016	235	0.044
	25	0.016	325	0.067	0.013	309	0.050	0.011	294	0.038

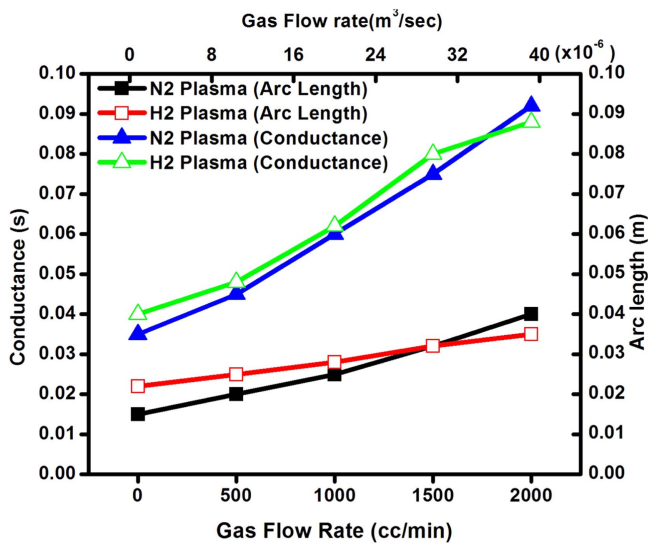


Figure 9. Effect of gas flow rate on arc length and its conductance.

consumed for superheating the melt. It can be noted from figure 4 that higher melt temperature was obtained in the case of plasma arc compared to normal arc. The melt temperature was further increased with continuing arc current.

The energy consumption for 5 min arc exposure in different melts at different arc current for normal and nitrogen plasma arc is shown in figure 10. The lower energy consumption for plasma arc in comparison to normal arc at all current levels was distinctly observed. Plasma technology was found to be an attractive tool, which could be utilized in the study of the smelting reduction of oxides.

3.4. Sound level

The noise is a well-known cause of nuisance and annoyance for a long exposure time. Recently, it has been recognized that a higher level of noise encountered in many working environments can result in loss of hearing among those who

are exposed to it for a prolonged period. The effect of noise on human beings has been reported by Wills [34].

In the present investigation, some effort was made to note the relative sound level of the laboratory plasma arc unit during melting under normal arc and while switching over to a different plasma arc. The effect of arc current on sound level was also noted with normal and plasma arc. These are described briefly in the following two subsections. A sound meter (software version 1.0 pro) was used for recording the noise level within a one-meter radius of the furnace.

3.4.1. Effect of arc type on sound level during melting. To observe the effect of arc type on the sound level during melting, 2 kg scrap charge was first melted under normal arc. The values of arc current, power rating, and average sound levels were noted during melting, as shown in figure 11. From the figure, it may be noted that at the beginning stage of the melting, the sound level is nearly 90 dB, which gradually reduces to 70 dB after the complete melting of the charge.

During the initial stage of scrap melting, the flickering of arc gradually decreased, resulting in a reduction in sound level. After complete melting of the scrap, the arc becomes stable, resulting in a lower noise level and stable power rating with a decrease in current. When plasma gas was introduced through the hollow electrode, a substantial reduction in the sound level was observed followed by power rating as well as arc current. This was due to the very smooth and intense flame produced in the plasma, which experienced a better path for current flow through the ionized gases.

In the case of hydrogen plasma, the sound level was slightly higher than nitrogen plasma, although it experienced a smoother arcing. This may be due to the generation of a ‘hissing’ sound produced during the combustion of flammable hydrogen gas (table 3).

3.4.2. Effect of arc current on sound level for different arc environment. It was noted in previous sections that arc current is an important parameter for arc furnace operation. A

Table 2. Comparison of melting under normal and different plasma arc.

Parameters	Normal arc	Nitrogen plasma	Hydrogen plasma
Charge weight (kg)	2	2	2
Scrap meltdown time (s)	35	25	20
Energy consumption for total melting (MJ)	28.8	21.6	19.5
Electrode consumption (kg)	0.018	0.012	0.010
Power fluctuation	High	Low	Low

Table 3. Comparison of arc current, power rating and noise level in different arc exposure.

Parameters	Normal arc (after complete melting)	Nitrogen plasma exposure	Hydrogen plasma exposure
Arc current (A)	245	200	195
Power rating (kVA)	20	16.5	16
Sound level (dB)	68 ± 8	58 ± 5	62 ± 4

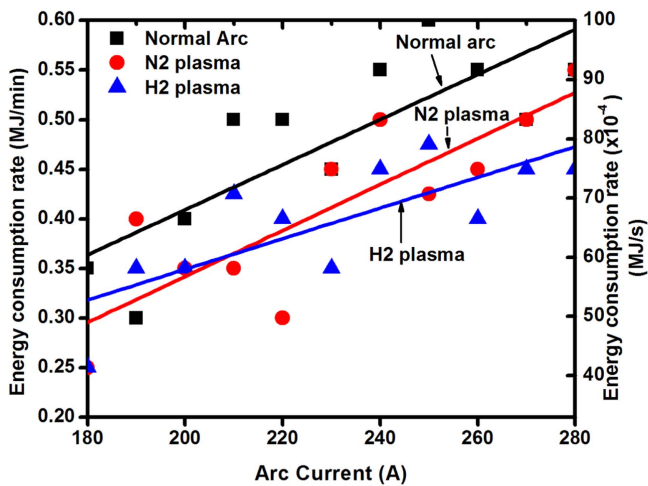


Figure 10. Effect of arc current on energy consumption rate under normal and plasma.

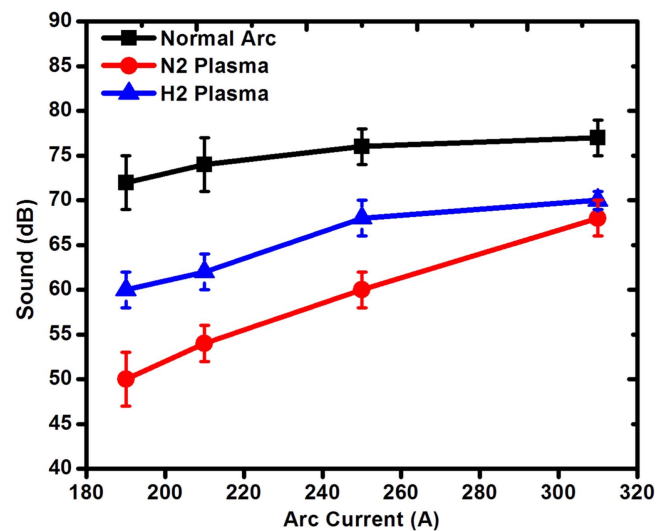


Figure 12. Effect of arc current on sound level, while exposing arc to liquid melt.

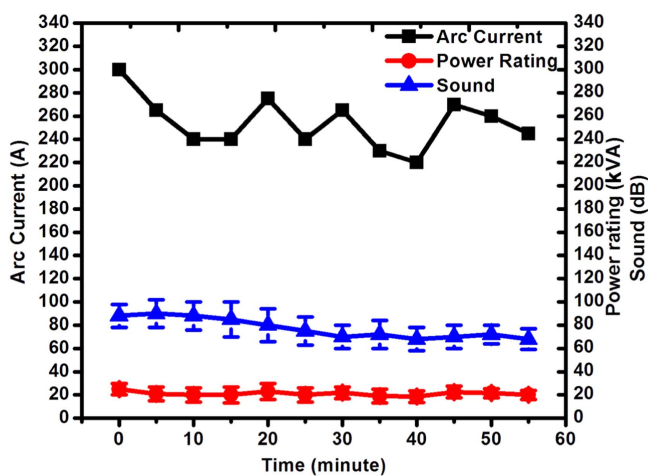


Figure 11. Variations of sound level, arc current and power rating during melting under normal arc.

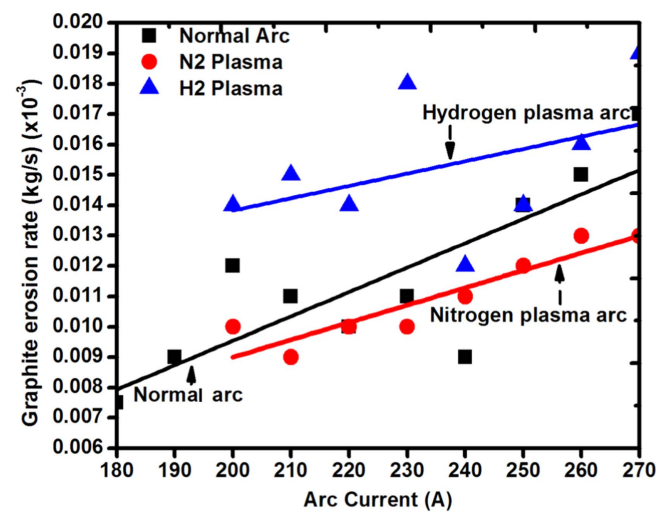


Figure 13. Graphite electrode erosion as a function of arc current.

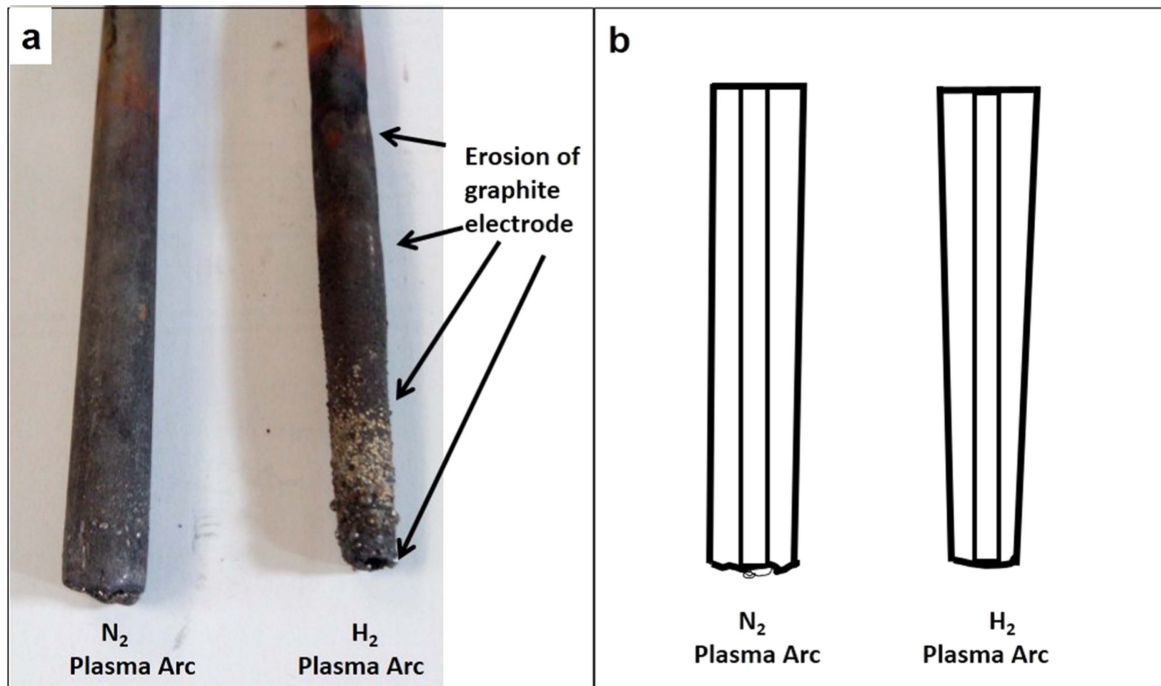


Figure 14. Erosion trends of the graphite electrode in different arc plasma condition. (a) Photograph of electrodes. (b) Sketch of electrodes.

Table 4. Rate of lining erosion as well as the number of heat sustainability in different arc exposure.

Parameters	Normal arc	Nitrogen plasma arc	Hydrogen plasma arc
Maximum number of heats done	—	7	6
Number of heats under consideration	4	7	6
Time of total heat (min)	220	300	280
Total erosion			
Volume (m ³) × 10 ⁻⁵	765	873	957
Weight (kg)	0.186	0.522	0.783
Rate of erosion			
kg/heat	0.047	0.075	0.131
kg/hr	0.051	0.104	0.168

few more experiments were conducted with 2 kg steel scrap charge in the molten stage using different arc currents for both normal and plasma arc to observe this effect on the sound level. The observations are shown in figure 12.

From the figure, it could be noted that with an increase in arc current, the sound level increases for all types of arc condition. The increased current level, however, caused an increased noise level due to the discharge of ions and their movement. As mentioned above, due to the hissing sound of hydrogen burning, the average noise level value in the case of hydrogen plasma is always higher.

3.5. Electrode consumption

The consumption of the graphite electrode not only reflects the total cost of the melting but adds the carbon in the metal. Lower electrode consumption is always preferable, due to its higher cost. In the present study, the electrode consumption during melting was observed for both the normal and plasma arc conditions. Eschenbach *et al* reported that the

consumption of the graphite electrode increased with increasing electrode current [31].

In the present work, a drilled graphite electrode was used for generating plasma arc. The electrode consumption was observed by measuring the change in weight for a certain known exposure time, during the melting of 2 kg steel using normal and plasma arc, respectively. The graphite erosion rate (kg/s) trends with different arcing conditions are shown in figure 13.

It was also observed that the erosion rate of the graphite electrode used in nitrogen plasma arc is slightly lower than normal arc. This occurred due to the smooth arcing and inert atmosphere inside the melting chamber during nitrogen plasma arc, which prevents the oxidation of the graphite electrode. An interesting feature observed in the case of hydrogen plasma was the increased electrode consumption rate compared to nitrogen plasma and normal arc. This may be due to the formation of the methane (CH₄) gas produced by hydrogen plasma reacting with the carbon of the graphite. Due to this reaction, the graphite electrode inside the furnace chamber was eroded to a needle-like shape whereas, in the

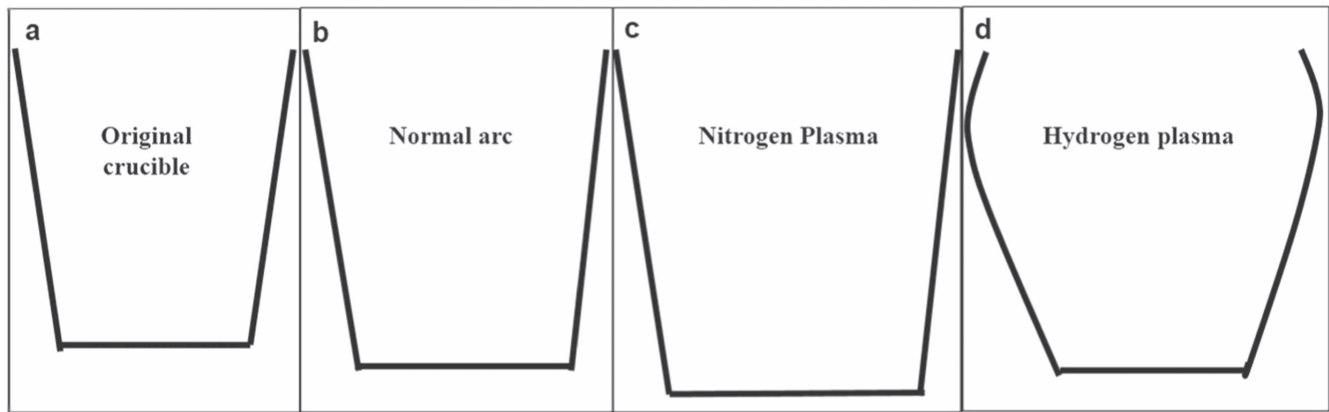


Figure 15. Erosion patterns of the magnesite crucible in different arcing condition. (a) Original crucible pattern. (b) Crucible erosion pattern after normal arc exposure. (c) Crucible erosion pattern after nitrogen plasma arc exposure. (d) Crucible erosion pattern after hydrogen plasma arc exposure.

case of nitrogen plasma, erosion at the tip of the graphite electrode was observed due to the generation of heat only (figure 14).

3.6. Lining life

The wear life of the lining is essential because of its cost addition and the fact that it also influences the quality of the melt. In the present unit, the maximum number of heats were sustained by the magnesite crucible, and in the case of nitrogen plasma melting this was seven. But in the case of hydrogen plasma, only six heats were sustained.

In the case of normal arc melting, this type of calculation was not done, but the erosion rate (i.e. kg/heat) was determined for a crucible having three types of arc exposure, as listed in table 4.

The erosion of the lining happened due to the generation of intense heat inside the furnace and chemical reactions at the interface between the metal-lining material and gas-lining material. It clearly demonstrates that the erosion rate was least in the case of normal arc compared to plasma arc. Hydrogen plasma produces more heat and also creates a reducing atmosphere, resulting in a higher erosion rate of the refractory lining. Figure 15 shows the (a) original crucible dimension without erosion, (b) erosion pattern of the crucible after normal arc exposure, (c) erosion pattern of the crucible after nitrogen plasma exposure, (d) erosion pattern of the crucible after hydrogen plasma exposure. Normal arc and nitrogen plasma eroded the lining uniformly throughout the area, as shown in figures 15(b) and (c). In the case of hydrogen plasma, the arc zone area above the liquid metal eroded very fast. This may be due to the reduction of the magnesite lining in the presence of hydrogen gas at a very high temperature of the arc zone, as shown in figure 15(d).

4. Conclusions

The major observations noted, based on the experimental studies, are summarized as follows:

1. The plasma arc furnace, designed and fabricated from local resources was found suitable to melt 2 kg steel, and its attachment for various functions offered trouble-free operation.
2. The higher plasma arc temperature resulted in shorter meltdown time than normal arc with smoother arcing. Nearly 200 K (200 °C) increased melt temperature was observed with nitrogen plasma arc compared to normal arc. Hydrogen plasma offered 100 K (100 °C) higher melt temperature than nitrogen plasma, and therefore decreases the maximum meltdown time.
3. Nitrogen plasma produces ~10 dB lower sound levels than normal arc, whereas hydrogen plasma reduces the sound level by only ~5 dB.
4. Lower energy consumption was noted with nitrogen plasma arc melting than normal arc melting. However, lower energy consumption was observed in the case of hydrogen plasma in comparison to normal arc as well as nitrogen plasma.
5. Lower electrode consumption and lining erosion were noted with nitrogen plasma arc melting than normal arc melting. However, higher electrode consumption and lining erosion were observed in the case of hydrogen plasma in comparison to nitrogen plasma.

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