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# Experimentally Investigated Effect of Flame Temperature on Performance of Rotary Furnace

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ABSTRACT

***Energy consumption is major problem being faced by the almost all industries. The natural sources of energy coal, oil, gas etc. are depleting fast. As per the survey conducted and reports published by several national& international agencies the energy consumption in Indian ferrous foundries is much more above the required limits and has to be drastically reduced. This paper deals with the importance of an LDO fired rotary furnace for ferrous foundries .The experimental investigations revealed that by reducing the excess air to 10 % and using preheated air of 2000 C not only the fuel consumption was drastically reduced but also the melting rate was considerably increased.***

**Key Words –** Rotary furnace, SPM, Emission level, Excess Air percentage.

## 1. Introduction:

The rotary furnace (fig 1) consists of a horizontal cylindrical drum. The length and diameter of drum depends upon capacity of furnace, which varies from 200 kg/hr to 2 ton/hr. This drum is mounted on rollers, which are driven by electric geared motor. Two cones one on each side are welded to the drum. The drums and cones are made of MS plates` 5-7 mm thick and are lined with mortar and refractory bricks. One of the cone accomodates the burner which can be fired with L.D.O. or natural gas whereas the other cone accommodates the duct for heat exchanger. A tap hole is made approximately in centre of the drum. The charging of material is done through the tap hole and other cone whereas the pouring is done through tap hole.only A covered oil tank containing LDO is located at height of approx. 5-7 meters from burner end of the furnace which is connected to the burner through suitable diameter pipeline and control valves. A pump is installed to force the oil at desired pressure to the burner.

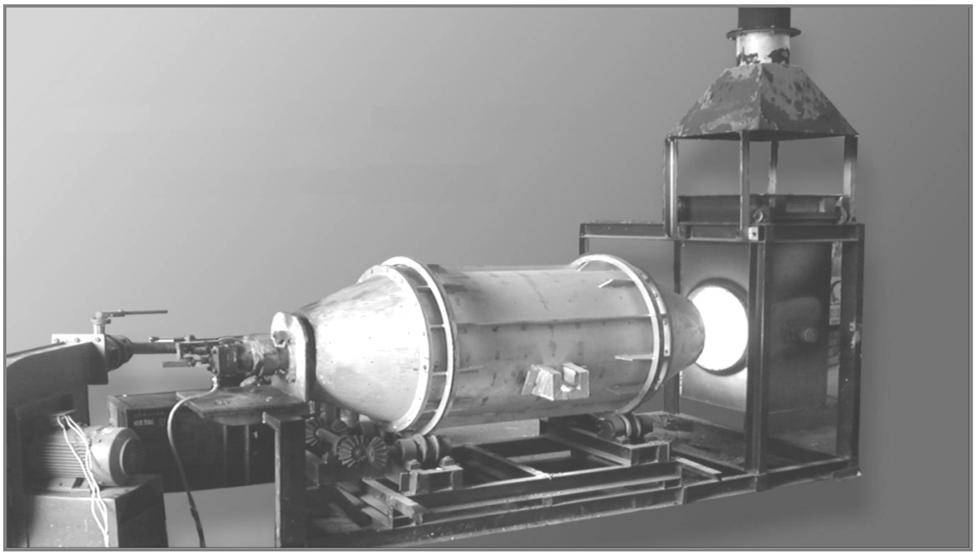


Fig 1- Rotary furnace

## 2. Literature review:

Baker EHW [1] explained the working of Rotary furnace. Singh R, Jain RK [2] concluded that optimum RPM for rotary furnace is 1.4. Jain RK, Singh R [3] on basis of survey confirmed that energy consumption is much more above limits as laid down by TERI. Baijya Nath, Pal Prosanto, Panigrahi K. C.[4]on basis of observations concluded that energy consumption in Indian ferrous foundries should be reduced. Singh Kamlesh Kumar[5] stressed upon to redeuce the rejection to control energy consumption. Arjunwadkar S.H. Pal Prosanto, et al [6].stressed upon energy savings by adopting modern advanced processes.Pandey G.N., Singh Rajesh & Sinha A.K, [7] advocated the uses of efficient energy saving techniques. 9. Singh Saurabh Kumar, Chandra Ayush, and Malik Kapil. [9] explained various new techniques for energy saving. Mesbah A., Khan G., and Far tag Amir[10] studied the effect of heat exchangers on energy conservation. Arasu M.et al [11] explained that 70% of energy is consumed in melting department. He concludes that a recording system of row material drawn, energy consumption in various departments and comprehensive scrap, is to be made in an Iron foundry to monitor the energy consumption. Journal of Cast Metals Association, U.S.A. California [12]reported that approx 70% of energy consumed in Iron Foundry are used for melting 7 holding, and any improvement effected in this area can bring considerable difference in energy consumption of iron Foundry. U.S. Department of Energy [13] has given the opinion that beyond 2000 only energy efficient Iron Foundries could survive. Aswani K.G.[14] concluded that to be energy efficient iron Foundries should monitor the furnace operation blast air pressure and correct distribution of air between the top and lower tuyere, along with load factor, power factor, further the equipment efficiencies should be checked regularly.Rudramoorthy R. Arasu M.[15] discussed the various parameters that influence the energy consumption & to find out their optimum conditions, and has made some recommendations about control over these variables when can bring out considerable difference in energy consumption. Cardona Raman [16]has described the “Present Indian Energy Scenario” and stressed that in view of depiction of fossil fuel, the “Non conventional sources of Energy” are to used and energy has to be conserved. The present situation can not be allowed to continue.Arasu M. et al [17]confirmed that appropriate melting techniques in arc furnace is important for survival of a foundry. Energy Conservation in Melting can be achieved by controlling melting techniques, and applying quick charging of raw material, appropriate power input, cut down of idling time, improvement of dust collecting efficiency etc. EPRI Centre [18]on basis experimental investigations confirmed that 20% of sensible heat is carried away by waste gases from the furnace. This sensible heat can be recovered by using suitable heat exchanger and preheating air, required for combustion of fuel, up to temperature of $370^0$C. It will reduce the energy consumption of 57 kwh/tone .Andrew Turner [19]Secretary General, World Foundry Organization (WFO) stressed upon improving the melting techniques in foundries by recovering & utilizing the waste heat from flue gases to preheat the air, scrap, cores and reduce the casting defects by employing suitable techniques.

## 3. Production processes

The process of melting the charge is carried in following steps:

1. Preheating of oil and furnace**-** The oil is preheated up to 70 ºC and forced at 1.5 kg/cm$^2$. To preheat the furnace and starting the combustion. A small volume of oil in form of stream jet, and primary air is forced inside the furnace. The droplets of oil come in contact with small volumes of primary air. At exit end of burner, initially drenched jute or warm cloth pieces are placed which are immediately ignited. As combustion proceeds, the volume of primary air is increased. When full ignition takes place, the secondary air at same pressure is started. The volumes of primary and secondary air are controlled by valves to avoid the danger of backfire.
2. Charging – After pre heating the furnace is charged.
3. Rotation**-** After sufficient pre heating and charging the furnace starts rotating.
4 Melting**-** The flame starts coming out of the exit end, which is initially yellowish in color. After approximately 1 hour, the color of flame changes to white indicating that metal has been thoroughly melted. The temperature of the molten metal is measured using pyrometer. If it is approximately 1250 to 1300ºC, the rotation of furnace is stopped.
5. Tapping**-** the tape hole is slightly lowered and opened and metal is transferred into ladles, which are pre heated prior to transfer of molten metal to avoid heat losses.
6. Inoculations**-** The Ferro silicon and ferro manganese are added in molten metal contained in the ladles.
7. Pouring **-** The ladles are then carried to moulds and pouring is completed.

## 4. Heat transfer studies:

The heat transfer in rotary furnace from flame to charged material takes place by conduction, convection and radiation. The flame generated inside the furnace is having sufficiently high temperature. Because of rotation of furnace its refractory lining gets heated. This refractory lining comes in contact with charge and heat transfer takes place by conduction. For optimum heat transfer the time of contact between refractory and charge must be maximum. The flame level is generally kept 15 mm to 25 mm above the charge level. Some heat transfer takes place by convection. The flame transfers heat to the refractory lining all around inside the furnace and charge under it by rotation. The flame is not in direct contact with

refractory lining or charge. The heat transfer to the charge mainly takes place by radiation and conduction but it is limited by slag cover when charge is in molten state. The heated refractory lining passes under the molten metal during rotation and heat transfer to the molten metal takes place by conduction. Some heat transfer also take place by convection. Due to the above reason the metal temperature and melting rate provided by the rotary furnace are much superior.
The heat transfer depends upon the temperature difference between refractory and metal temperature. The degree of heat transfer is quite high in initial stages of melting when charged material is relatively cold. The rate of heat transfer gradually reduces as refractory and metal temperature approaches closure to the flame temperature. The following factors are substantial for efficient heat transfer- 1.Available surface area of refractory, 2. Heat input, 3. Speed of furnace rotation, 4. Correct combustion condition, 5. Combustion volume.

## 5. Exhaust gases and heat exchangers

It was observed that exhaust gases leaving the exit cone of rotary furnace had a temperature of 800 to $900^0$ C. It contains enormous amount of heat. If it is allowed to go directly to the atmosphere not only a considerable amount of heat is lost but also the higher concentration of SPM, (Suspended particulate matters, including unburned carbon, sulfur, etc) $SO_2$, $CO_2$, $NO_x$, are being liberated to atmosphere which will damage the environment. Especially SPM and $SO_2$ are more dangerous therefore their concentration in the exhaust gases is to be minimized by reducing the temperature of exhaust gases. It is proper to use this heat energy of exhaust gases to preheat the incoming air required for combustion before supplying it to the burner. Several types of heat exchangers like parallel flow, counter flow, cross flow, are available in the market fabricated from MS, GI, Copper pipes etc. For optimum heat transfer, the LMTD (logarithmic mean temperature difference has to be maximum and heat losses from exchanger to atmosphere to be minimum. In view of above the counter flow type tubular heat exchanger is preferred with stainless steel tubing’s, provided with adequate insulation. The length of heat exchanger has to be minimum for optimum heat transfer from exhaust gases to incoming air and minimum heat losses by radiation.

## 6. Complete combustion of LDO & its effect on flame temperature

The flame temperature is an important parameter, which has to be optimized within safe metallurgical limits. It also depends upon complete combustion of fuel. LDO is a hydro carbonic fuel containing carbon, hydrogen sulfur and oxygen. The cetane number and its calorific value should be maximum. The calorific value of fuel is defined as energy liberated by complete combustion of unit mass or volume of fuel. The complete combustion of fuel is essential for optimum heat transfer and melting rate

### 6.1 Requirement of air for complete combustion

The exact amount of oxygen required theoretically for complete combustion of one kg of LDO can be determined from analysis of fuel. The amount of oxygen required for each of the constituent of fuel is calculated separately with help of chemical equation. Then these requirements are added to give the total amount of oxygen required. This oxygen for complete combustion of fuel has to be obtained from air which consists of oxygen, nitrogen, small amounts of carbon di oxide and traces of rare gases like neon, argon, etc .The composition of air for engineering calculations is taken as follows--

1. By weight Nitrogen= 77%, Oxygen 23%

2. By volume Nitrogen= 79% Oxygen= 21%

The theoretical or stoichiometric quantity of air is that quantity which is required for complete combustion of 1kg of fuel without any oxygen appearing in products of combustion.—

The light diesel oil (L.D.O.) is a mixture of Furnace oil and high speed Diesel. The theoretical air fuel ratio for LDO is 14.2 kg of air for 1 kg of LDO.

The density of air = 1.123 kg/$m^3$ .The volume of air required for combustion of 1 kg of LDO = 14.2/1.123 = 12.644 m3

The density of LDO = 860 kg/$m^3$, 1 liter of LDO = 0.86 kg LDO

Therefore for 1liter LDO air required theoretically=0.86x12.644 = 10.874$m^3$

### 6.2 Excess air:

For complete combustion of fuel we need air. As per theoretical basis there is minimum amount of air, which is required by fuel to burn completely but always air in excess is used because whole of the air supplied for combustion purpose does not come in contact with the fuel completely and as such a portion of fuel may be left unburnt. Therefore an additional extra amount of air in addition to the air required theoretically is to be supplied, for complete combustion of fuel. This additional amount of air is known as excess air.

**6.3 Effect of excess air on flame temperature---**

The role of excess air is more dominating **---**

(1) When burners are adjusted to operate with an excess of combustion air the products of incompletely burnt hydrocarbon fuels- carbon monoxide and hydrogen are minimized but measurable amount of residual oxygen remains.

(2) But contrary to it when operated with deficiency of combustion air the all available oxygen is consumed before complete burning of the fuel. Therefore, the resultant oxygen is minimized and considerable amount of unburned carbon monoxide and hydrogen remains.

Therefore for maximum flame temperature and melting rate the optimization of excess air and degree of air preheat is to be done. The most important is adiabatic flame temperature. To maintain the optimum flame temperature, the
To maintain the optimum flame temperature, the supply of excess air, and preheated air of required temperature is to be adjusted.

An optimum excess air has to be used because –

(1) More excess air will increase the combustion volume and reduce the adiabatic flame temperature

(2) No excess air will exceed the temperature beyond safe metallurgical limits which will reduce the life of refractory and furnace shell

**6.4 The Theoretical calculations-** Theoretical calculations of percentage excess air is shown in table.1—

Table.1 Excess air percentage in $m^3$ of air

| Sn | Excess Air percentage | Volume of air required |
|---|---|---|
| 1 | 0 | 10.874 $m^3$ |
| 2 | 10 | 11.961 $m^3$ |
| 4 | 20 | 13.049 $m^3$ |
| 5 | 30 | 14.136 $m^3$ |
| 6 | 40 | 15.224 $m^3$ |
| 7 | 50 | 16.311 $m^3$ |
| 8 | 60 | 17.399 $m^3$ |
| 9 | 70 | 18.486 $m^3$ |

## 7. Experimental investigations

The actual experimental investigations are required to evaluate the effect of excess air and preheated air on flame temperature.

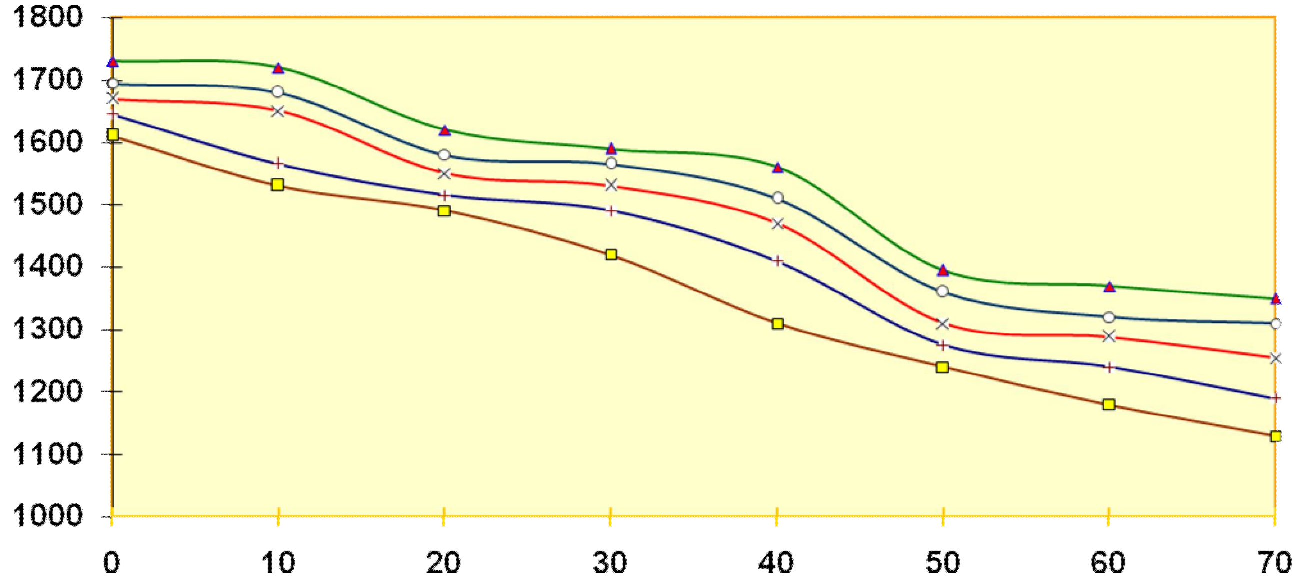
**7.1 Effect of excess air & preheated air on flame temperature**

Intensive studies and experimental investigations were carried out on effect of excess air and preheated air temperature on flame temperature and performance of rotary furnace by carrying out the actual experiments on 200 kg rotary furnace installed at foundry of M/s Harbhajan Singh Namdhari enterprises, Industrial estate Nunihai, Agra. The tubular heat exchanger of stainless steel tubes of 40 mm diameter with adequate insulations was used. The flame temperature as measured corresponding to 0 to 70 % excess air and 0 to 400c preheated air temperature is shown in table 2—

Table.2- Effect of excess air and preheated air on flame temperature

| S.N | Excess air % | FLAMETEMPERATURECORRESPONDING To Air Pre-Heat Temperature | | | | |
|---|---|---|---|---|---|---|
| | | 0°C | 100°C | 200°C | 300°C | 400°C |
| 1. | 0 | 610 | 1645 | 1670 | 1695 | 1730 |
| 2. | 10 | 1530 | 1565 | 1650 | 1680 | 1720 |
| 3. | 20 | 1490 | 1515 | 1550 | 1580 | 1620 |
| 4. | 30 | 1420 | 1490 | 1530 | 1565 | 1590 |
| 5. | 40 | 1310 | 1410 | 1470 | 1510 | 1560 |
| 6. | 50 | 1240 | 1275 | 1310 | 1360 | 1395 |
| 7. | 60 | 1180 | 1240 | 1288 | 1320 | 1370 |
| 8. | 70 | 1130 | 1190 | 1255 | 1310 | 1350 |

The graphical representation of effect of excess air and pre-heated air on flame temperature is shown in figure 2




Excess air %-------------------------->

Figure 2- Graphical representation of effect of excess air and pre-heated air

| | | | | | |
|---|---|---|---|---|---|
| FLAME TEMPERATURE | 0° C – أ | $100^0$C – + | 200° C – x | 300° C – o | 400° C – Δ |

This investigation reveals that with same temperature of preheated air, increasing the excess air reduces the flame temperature, while decreasing the excess air increases the flame temperature. It is due to the fact that increment of excess air increases the combustion volume which ultimately results in reduced flame temperature. The reason of increasing the excess air is to provide the additional oxygen required for complete combustion

**7.2 Effect of reducing excess air on flame temperature-**

In view of above observations of increasing the flame temperature and increasing the preheated air temperature by reducing the excess air, the experimental investigations were carried out at 1 rpm with --- (1) Excess air 20% and (2) preheated air temperature 2000C--to study the effect of flame temperature on melting rate, melting time, and specific fuel consumption. The observations are tabulated in table 3—

Table 3-Effect of flame temperature on melting rate & fuel consumption

| Sn | Flame Temp.(°C) | Rpm | Time (min.) | Fuel (litters) | Melting Rate(kg/hr) | Specific Fuel(litter/kg) |
|---|---|---|---|---|---|---|
| 1 | 1510 | 1 | 38 | 79 | 316 | 0.3947 |
| 2 | 1520 | 1 | 36 | 78 | 333 | 0.390 |
| 3 | 1529 | 1 | 36 | 77 | 333 | 0.385 |
| 4 | 1544 | 1 | 35 | 76 | 343 | 0.379 |

The graphical representation of effect of flame temperature on melting rate, fuel consumption and time is shown in following figures 3, 4, & 5

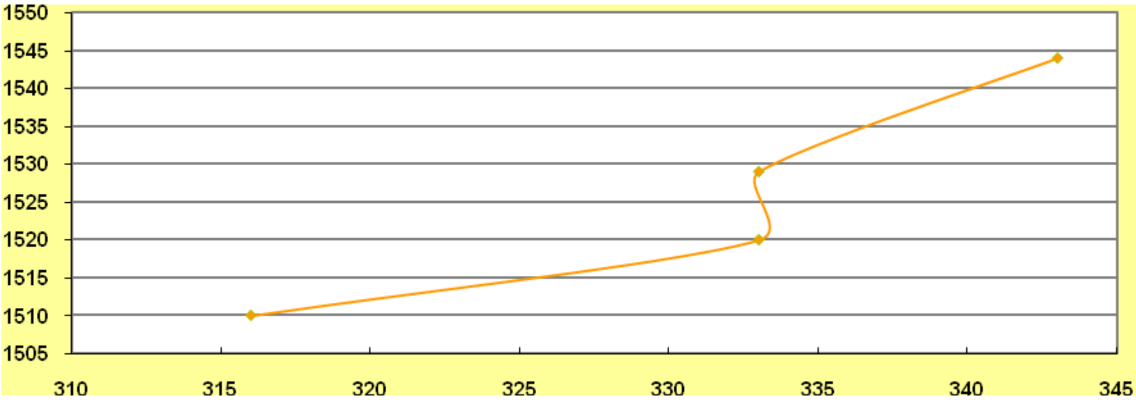



Fig.3-- Flame Temperature Vs Melting Rate

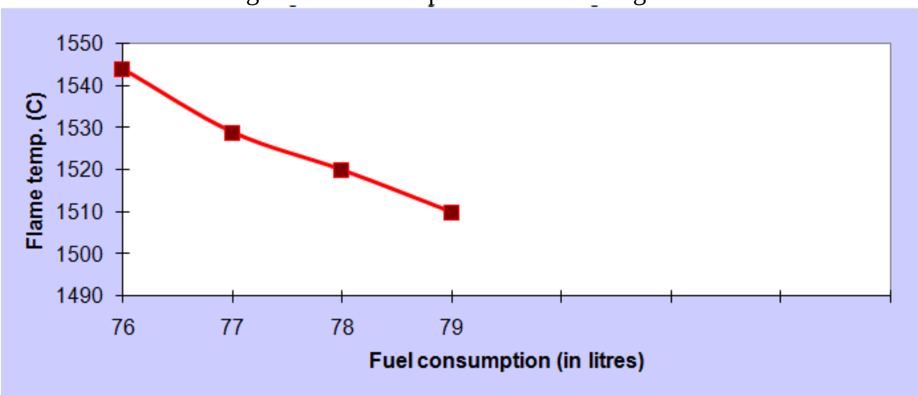



Fig.4 -- Flame Temperature Vs fuel consumption

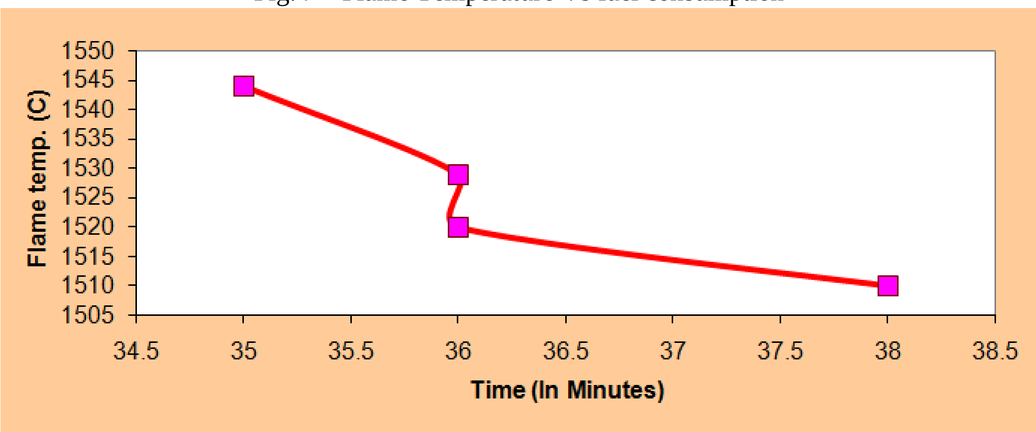



Fig. 5 Flame Temperature Vs Time (in minutes)

It is very clear that rise in flame temperature from 1510 to 1544 °C not only increases the melting rate from 316 kg/hr to 343 kg/hr but also reduces the fuel consumption from 0.395liter/kg to 0.3800 liter/kg of metal produced.
Further another set of Experimental investigations were carried out using only 10% excess air and same preheated air of 200**°C** temp .with same heat exchanger. The observations are tabulated in table.4—

Table 4- Effect of 10% excess air, temp 200□C, on flame temperature, melting rate & specific fuel consumption

| Sn | Flame Temp (°C) | Rpm | Time (min.) | Fuel (liters) | MeltingRate (kg/hr) | Spcific Fuel (litre/kg) |
|---|---|---|---|---|---|---|
| 1 | 1622 | 1.0 | 34 | 68 | 352.00 | 0.340 |
| 2 | 1630 | 1.0 | 33 | 68 | 363.60 | 0.340 |
| 3 | 1642 | 1.0 | 33 | 66 | 363.60 | 0.330 |
| 4 | 1657 | 1.0 | 32 | 64 | 375.00 | 0.320 |
| 5 | 1677 | 1.0 | 31 | 62 | 387.06 | 0.310 |

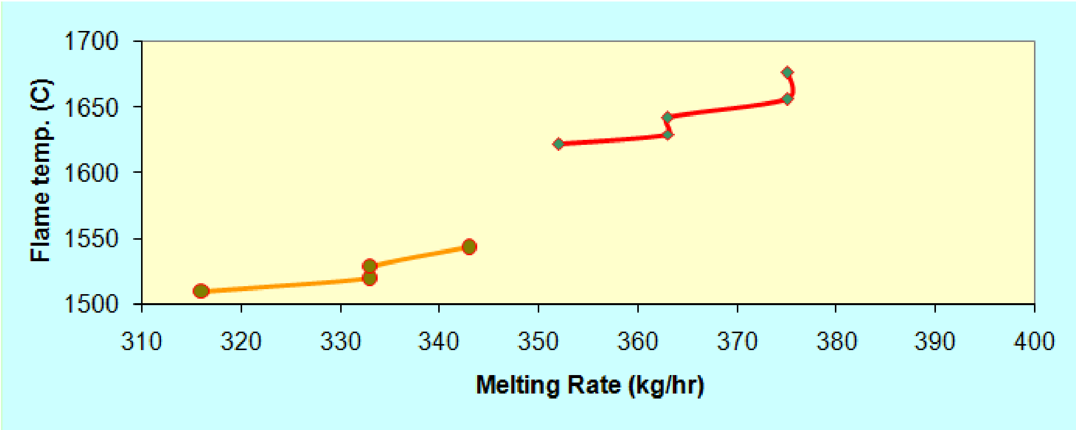
**8. Results:** The results of above experimental investigations are summarized in the table 5-

Table 5-Results of experimental investigations

| SN | PARAMETERS | EXCESS AIR 20% | EXCESS AIR 10% | PERCENTAGE |
|---|---|---|---|---|
| 1 | **INCREMENTS** | | | |
| | (A)FLAME TEMPERATURE | $1544^0$C | $1677^0$C | 8.61% |
| | (B)MELTING RATE | 343KG/HR | 387.06KG/HR | 12.82% |
| | (C) PRODUCTION | 5.7142KG/MI | 6.4516KG/MI | 12.90% |
| | (D)*ANNUAL PRODUCTION | | | 0.7374X186X25X12=41.146TONE |
| 2 | **REDUCTIONS** | | | |
| | (A)MELTING TIME | 35 MINUTES | 31 MINUTES | 11.42% |
| | (B)FUEL CONSUMPTION | 76 LITERS | 62 LITERS | 18.42% |
| | (C)SPECIFIC FUEL CONSUMP. | 0.379LIT/KG | 0.310 LIT/KG | 18.20% |
| | (C)ENERGY CONSUMPTION | 4031.629KW | 3129.51KW | 22.37% |
| 3 | **ANNUAL SAVINGS** | | | |
| | (A)FUEL COST | RS40.932LACS | RS33.48LACS | RS7.452LACS |
| | (B)FUEL QUANTITY | 136440 LITERS | 111600 LITERS | 24840 LITERS |
| | (C) ENERGY CONSUMPTION | | | 1000KW/TX360T=$3.6x10^5$KW |

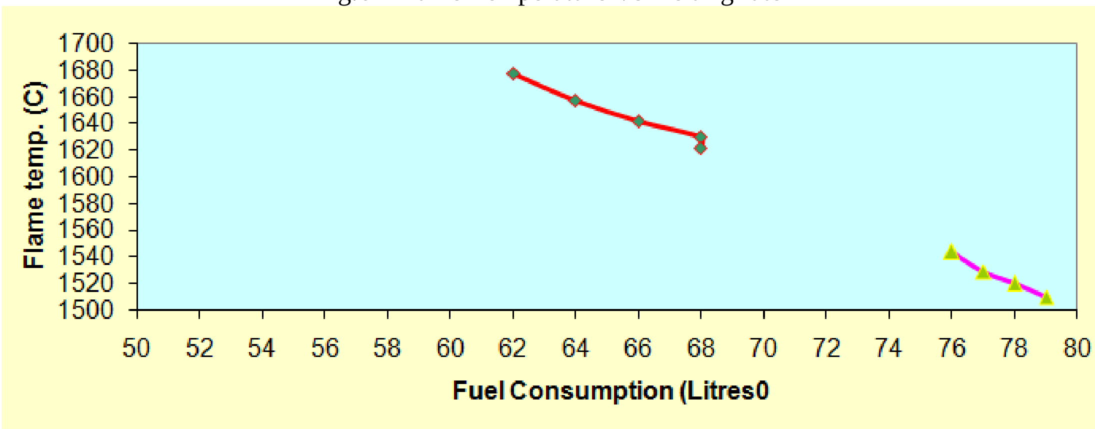
[*Increments in annual production has been calculated assuming 31 minutes of melting time per heat,x6 heats per day=186 minutes per day=186x25x12=55800 minutes@ 0.7374kg/min=41.146 tones]

The comparative graphical representation of effect of reducing excess air from 20% to 10% on flame temperature and its subsequent effect on melting rate, fuel consumption, and melting time is shown in figures 6,7,and 8:



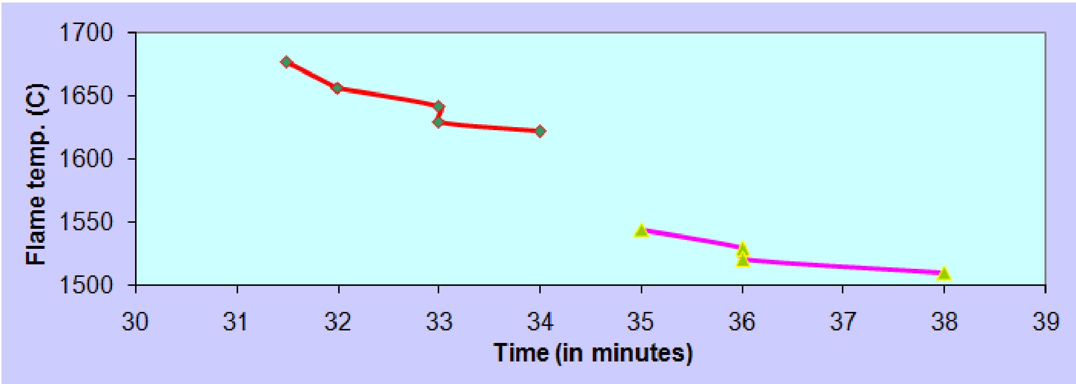

◊ - 10 % Excess Air ● – 20 % Excess Air

Fig.6 - Flame Temperature Vs melting rate




Δ - 20 % Excess Air ◊ - 10 % Excess Air

Fig7 - Flame Temperature Vs fuel consumption




Δ - 20 % Excess Air ◊ - 10 % Excess Air

Fig.8 - Flame Temperature Vs Melting Time (minutes)

## 9. Conclusions:

Several castings have been produced using the rotary furnace and the effect of air preheating and excess air has been studied. It has been found that for optimum Flame temperature we can have 10% of excess air at a preheat temperature of 2000C.Reducing excess air reduces the combustion volume which ultimately increases the flame temperature. This increased flame temperature not only drastically reduced the fuel consumption and emission levels but also significantly increased the melting rate and quality of castings produced.

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