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Innovative Melting Techniques for Sustainable Energy Conservation in Iron Foundries

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Abstract:

This paper is aimed to study the energy consumption in Indian Ferrous Foundries and to investigate measures for energy conservation. 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 LDO fired rotary furnace. The author conducted a series of experimental investigations on the self-designed and developed ,rotary furnaces, installed at S.Harbhajan Singh Namdhari Enterprises industrial estate, Nunihai, Agra for production of cylinder heads and auto parts, and at Faculty of Engineering, Dayalbagh Educational Institute (DEI), Dayalbagh, Agra (a self-deemed university.) These experimental investigations on the rotary furnaces produced excellent results, which are accrued here in. The experimental investigations revealed that by oxygen enrichment of the preheated air, the specific fuel consumption reduced by 49.87% and energy consumption by 47.14%.

***Keywords*-- Rotary furnace, oxygen enrichment, preheated air, energy consumption, TERI (the energy research institute of India).**

I. I. INTRODUCTION

The rotary furnace consists of a horizontal cylindrical drum. The length and diameter of drum depends upon capacity of furnace,

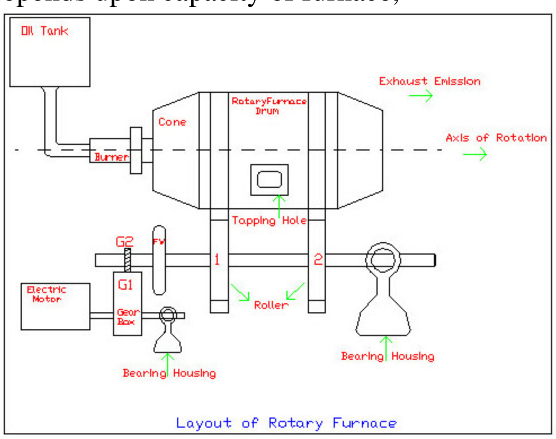


Fig 1 layout of rotary furnace

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 is 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 cones accommodates 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 and 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. Layout of furnace is shown in fig 1. Baker EHW [1] explained the working of Rotary furnace. Baijayanath, Pal Prosanto Panigrahy K.C. [2] explained that most of the units are crippled with usage of rudimentary techniques. The Indian foundry industry needs optimization of energy consumption. Pandey G.N., Singh Rajesh, Sinha A.K [3] emphasized upon to supply oxygen at 8kg/cm2 pressure as it reduces melting time and emission levels. Singh Kamlesh Kumar [4] advocates the use of newer and cleaner technology for environmental and energy conservation. Aswani K. G [5] has explained that 70-80% of energy in foundry is consumed in melting alone. The furnace operation needs attention of skilled operators to minimize rejection and energy losses. Arjunwadkar S.H, Pal Prosanto, [6] stressed upon to use energy efficient melting techniques. TERI New Delhi [7] reports have shown that energy consumption in Indian ferrous foundries is much more above the required limit Basu Navojit, Chaudhuri Bimal, Roy P.K. [8] concludes that with judicious applications and implications of correct energy auditing and monitoring techniques, it is possible to achieve energy conservation in Indian foundries. EPRI Centre [9] on basis of experimental investigations confirmed that waste gases from the furnace carry 20% of sensible heat away. 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 by 57 Kwh/tone. Andrew Turner[10] 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. Mesbah, G.Khan, Amir Fartag [11] strongly believes that energy conservation can effectively be achieved only by utilizing effective heat exchangers, as they are important components for processes where energy conservation is achieved through enhanced heat transfer. Hak Young Kim, Seung Wook Beek [12] has used the fuel-lean re-burn system.It has maintained fuel lean conditions in the furnace, in oxygen-enhanced combustion, to replace additional air system, which reduces energy and emissions significantly. Dr. B. K. Basak [13] developed high efficiency regenerative oil burners to utilize energy lost as sensible heat through the gas especially in high temperature applications like metal melting in hot brick chamber. Saurabh Kumar Singh, Ayush Chandra, Kapil Malik[14]has advocated the energy conservation in furnaces by, check against infiltration of air, using proper sealings etc.

II. MELTING OPERATION

The process of melting the charge is carried in following steps: (1) Preheating of oil and furnace (2) Charging (3) Melting (4) Tapping (5) Inoculation (6) Pouring.

III. EXPERIMENTAL INVESTIGATIONS

1. Experimental Investigation 1

A. ***Operating furnace under existing conditions of operation—***

The furnace was operated without oxygen enrichment and preheating of air as per existing conditions. The charge per heat is 200.0 kg. In first heat, as furnace was started from room temperature, more air was required, the flame temperature, preheated air temperature, and melting rate were less, but time and fuel consumption were more. In subsequent heats, the air was reduced, flame temperature, preheated air temperature and melting rate increased whereas the time and fuel consumption decreased. Observations taken during the experiment are given in table1 (1literLDO=9.9047Kwh/litre).

B. ***Graphical representation-***

The graphical representation of energy consumption without oxygen enrichment of preheated air is shown in figure2.

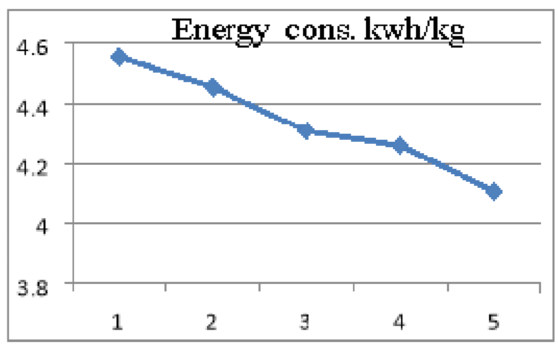


Figure2 Energy consumption under existing conditions of operation

III. TOTAL ENERGY CONSUMPTION- *Effect of operating furnace without oxygen enrichment of air on total energy consumption-*

The total energy consumption consists of energy consumption in-

(1) Melting the charge
(2) Fuel consumption unit
(3) Plant and equipment

(4) Pollution control equipment
(5) Shot blasting machine.

SN	Heat no	Rpm	Time min	Fuel liter.	Specific Fuel(l	Melting rate(kg/hr)	Excess air m^3	Excess air %	Flame temp.^{0}C	Energy kwh/kg
1	1	2.0	50.00	92.0	0.460	240.0	1320.0	30.45	1310.0	4.556
2	2	2.0	47.00	90.0	0.450	255.3	1290.0	30.41	1314.0	4.457
3	3	2.0	46.00	87.0	0.435	260.8	1240.0	30.24	1325.0	4.308
4	4	2.0	46.00	86.0	0.430	266.0	1220.0	30.10	1334.0	4.259
5	5	2.0	45.00	83.0	0.415	266.0	1175.0	30.04	1350.0	4.110

Table I- Energy consumption of furnace without oxygen enrichment of preheated air

S	Particulars	Energy consumed	Total energy consumption
1	Fuel consumed in melting LDO=415Liter/tone	415x9.9047=4110.450kwh/tone	4110.45Kwh
2	Fuel combustion unit (a)Oilfilteringpump1hp (b) Heating element	0.746 Kw 2.00kw=2.746kwfor 266.00kg/hr	10.323 Kwh
3	Plant& equipments a. Blower 7.5 hp b. Geared motor 2 hp	5.595 Kw 1.492 Kw =7.087Kwh for266.00kg/hr=For1tonne=26.642	26.642Kwh
4	Pollution Control Equipment: a. ID Fan 5 hp b. Motor 1 hp	3.73 Kw 0.746kw=4.476kwhfor266.00kg/hr=16.827 Kwh/tone	16.827 Kwh
5	Shot Blasting M/c Capacity 3tones/hr.Motor30H.P.=22.38kwh	22.38/3 = 7.46 Kwh/ tone	7.46 Kwh
		Grand Total	4171.702(4172.00)Kwh

Table II- Total Energy consumption (Kwh/ tone) when furnace operated without oxygen enrichment of preheated air

2. Experimental Investigation 2

A. Effect of 20% excess air with compact heat exchanger, rotating furnace at optimal rotational speed temperature, energy consumption Again experiment was carried by further reducing excess air to 20%, with compact heat exchanger rotating furnace at optimal rotational speed 1.0 rpm, preheating LDO up till 70^{0}c.

The observations taken during experiment are given in table iii

B. ***Graphical representation-***

The graphical representation of energy consumption (20% excess air with compact heat exchanger) is Shown in figure 3

Heat no	Flame Temp °C	Rpm	Time min.	Fuel liters	Melting rate kg/hr	Specific fuel cons. liter/kg	Preheated excess air.m^3	Preheated excess air %	Preheated Excess air temp.°C	Specific energy cons. kwh/kg
1	1510.0	1.0	41.0	72.0	293.0	0.360	995.0	30.1	304.0	3.5656
2	1530.0	1.0	40.0	70.0	300.0	0.350	970.0	25.5	316.0	3.4666
3	1540.0	1.0	39.0	69.0	307.6	0.345	930.0	20.3	320.0	3.4171
4	1545.0	1.0	38.0	68.0	315.7	0.340	905.0	20.1	329.0	3.3675
5	1550.0	1.0	37.0	66.0	324,3	0.330	870.0	20.2	332.0	3.2685
6	1568.0	1.0	37.0	64.0	324.3	0.320	835.0	19.9	340.0	3.1695.
7	1570.0	1.0	36.0	63.0	333.3	0.315	822.0	20.0	348.0	3.1199
8	1578.0	1.0	35.0	61.0	342.8	0.305	795.0	19.9	370.0	3.0209
9	1580.0	1.0	34.0	60.0	352.9	0.300	788.0	20.1	378.0	2.9714
10	1590.0	1.0	34.0	59.0	352.9	0.295	785.0	20.0	385.0	2.9218
11	1620.0	1.0	33.0	58.0	363.6	0.290	760.0	20.0	402.0	2.8723

Table III Effect of 20.0% excess air with compact heat exchanger, rotating furnace at optimal rotational speed of 1.0 rpm, on energy consumption

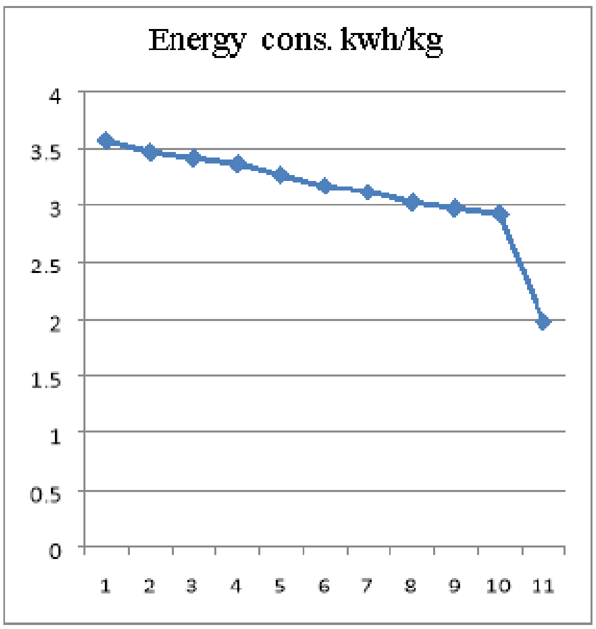


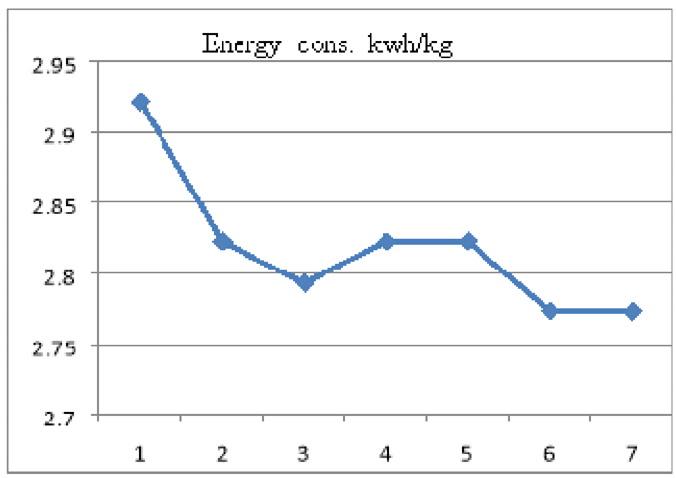
Fig.3 Energy consumption 20% excess air with compact heat exchanger

3. Experimental Investigation 3

A.Effect of 10% excess air with compact heat exchanger, rotating furnace at optimal rotational speed on energy consumption

Again, experiment was carried by further reducing excess air to 10%, with same compact heat exchanger. The observations taken during experiment are given in table IV.

Fig 4. Energy consumption 10%excess air with heat compact heat exchanger



S N	Flame Temp ^{0}C.	Rpm	Time min.	Fuel liters	Melting rate kg/hr	Specific fuel cons liter/kg	Preheated excess air m^3	Preheated excess air%	Preheated excess air temp.°C	Specific energy cons. kwh/kg
1	1644.0	1.0	34.0	59.0	352.9	0.295	810.0	11.4	384.0	2.9218
2	1656.0	1.0	33.0	58.0	370.0	0.285	790.0	11.3	392 .0	2.8228
3	1666.0	1.0	33.0	58.0	373.0	0.282	755.0	10,0	396.0	2.7931
4	1678.0	1.0	32.5	57.0	378.0	0.285	725.0	10.6	398.0	2.8228
5	1684.0	1.0	32.0	57.0	382.0	0.285	690.0	10.1	405.0	2.8228
6	1693.0	1.0	32.0	56.0	375.0	0.280	680.0	10.1	407.0	2.7733
7	1707.0	1.0	31.0	56.0	387.0	0.280	670.0	10.0	412.0	2.7733

Table IV Effect of 10.0% excess air with compact heat exchanger, rotating furnace at optimal rotational speed of 1.0 rpm, on energy consumption

4. Experimental Investigation 4

A. **Effect of oxygen enrichment of preheated air on energy consumption of furnace-**

If the combustion volume is, more than more fuel and time shall be required for reaching to a certain temperature. Hence, it is thought to optimize the combustion volume by reducing the amount of preheated air and supplying oxygen externally. Several experiments were conducted, gradually reducing air to its theoretical requirement and even lesser in steps of 5.0 to 10.0% and supplying oxygen externally in steps of 1.0 to 2.0 %and its effect on flame temperature, time, fuel, melting rate, and fuel consumption was studied. The effect was significant only when air was reduced to 75.0% of its theoretical requirement and approx 7.0% oxygen was supplied externally.

B. **Effect of 6.9% oxygen enrichment of preheated air on energy consumption**

Numbers of experiments were conducted, with 6.9 oxygen enrichment of 75.3-75.4% of theoretically required air, the effect of above on energy consumption and performance of furnace is shown in table V

Table v- Effect of 6.9% oxygen enrichment of preheated air on energy consumption

C ***Total energy consumption-***

Effect of operating furnace with 6.9-% oxygen enrichment of Preheated air on total energy consumption is given in table VI-

D. **The graphical presentations-** The graphical presentations of effect of 6.9% oxygen enrichment of reheated air on energy consumption of furnace is shown in fig V.

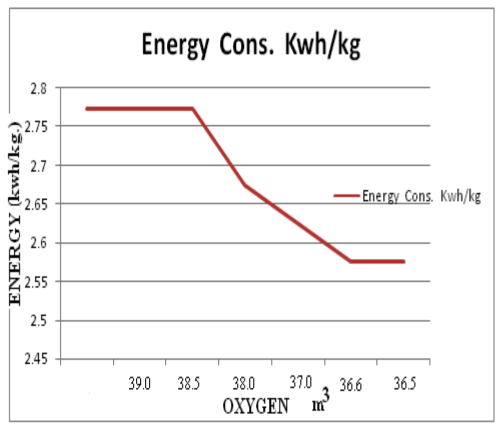


Fig V - Effect of 6.9 % oxygen enrichment on energy Consumption (kwh/kg)

Heat no	Rpm	Preheated air temp °C	Flame temp °C	Time min	Fuel liter	Melting rate kg/hr	Specific fuel consume lit/kg	Specific Energy consume Kwh/kg	Oxygen cons.m3	Oxygen cons %	Preheated air cons.m3	Preheated air cons %
1	1.0	410.0	1710.0	33.00	56.0	363.0	0.280	2.773	39.0	6.9	459.0	75.3
2	1.0	418.0	1722.0	32.00	56.0	375.0	0.280	2.773	39.0	6.9	459.0	75.3
3	1.0	428.0	1730.0	32.00	55.0	375.0	0.280	2.773	38.5	6.9	451.0	75.4
4	1.0	449.0	1746.0	31.50	54.0	385.0	0.270	2.674	38.0	6.9	443.0	75.4
5	1.0	454.0	1752.0	31.00	53.0	387.0	0.265	2.624	37.0	6.9	434.5	75.3
6	1.0	458.0	1754.0	30.50	52.0	393.0	0.260	2.575	36.6	6.9	426.7	75.4
7	1.0	460.0	1755.0	30.50	52.0	393.4	0.260	2.575	36.5	6.9	426.5	75.4

S. N	Particulars	Energy Consumed	Total Energy consumption /tone
1	Fuel consumed in melting LDO=260 Liter/tone, Oxygen=36.50/200 m^3/kg=182.5 m^3/tone	260x9.9047=2575.22 Kwh =182.5x0.5 =91.25 Kwh	2575.22 Kwh 91.25Kwh =2666.47 Kwh
2	Fuel combustion unit a.2.5 hp (Reillo burner)	=1.865 Kwh for 393.44 kg/hr=	4.740 Kwh
3	Plant & equipments a. Blower 7.5 HP b. Geared motor 2 HP c. Fan- heat exchanger 1HP atmosphere side and0.5HP furnace side	5.595 Kwh 1.492Kwh 1.119Kwh= 8.206 Kwh for 393.44 kg/hr=20.857Kwh/tone	20.857Kwh
4	Pollution Control Equipment: a. ID Fan 5 HP b. Motor 1 HP For 393.44 Kg melt/hr For 1 tone	3.73 Kwh 0.746kwh= 4.476kwh 4.476kwh =11.376kwh/	11.376Kwh
5	Shot Blasting M/c Capacity 1 Tone/hr. Motor 30 H.P=22.38kwh	22.38/3 = 7.46 Kwh/ tone	7.46 Kwh
		Grand Total	2710.90=2711.00Kwh/tone

Table VI - Total Energy consumption (Kwh/tone) when furnace operated with 6.9-% oxygen enrichment of air preheated air on total energy consumption is given in table VI

5. Experimental Investigation 5

To further reduce the energy consumption, it is proper to increase the oxygen enrichment of preheated air. The oxygen enrichment was increased in steps of 0.4-0.6% and Air was reduced in steps of 3.0-4.0%. The effect was more significant when oxygen enrichment was increased to 7.4 -8.4%

B .Total energy consumption-Effect of 7.4-8.4% oxygen enrichment on total energy consumption is given in table VII

*A. Effect of 7.7-8.4% oxygen enrichment of preheated air on energy consumption*Again the experiment was repeated further reducing volume of air to (60 -65)% of its theoretical requirement and increasing additional oxygen supply to 7.5%- 8.5 %,. Several experiments were conducted, operating furnace in different conditions in different consecutive heats. In later heats the flame temperature, preheated air temperature increases whereas the time and fuel consumption decreases. The observations taken during experiment are given in table VI.

B. Total energy consumption-Effect of7.4 -8.4 % oxygen enrichment on total energy consumption is given in table VI

C. The graphical representations the graphical presentations of effect of 7.5 -8.5 % oxygenenrichment of preheated air on energy consumption is shown in fig 5.

Heat no	Rpm	Preheated air temp ^0C	Flame temp ^0C	Time Min.	Melting rate kg/hr	Fuel liters	Specific fuel cons lit/kg.	Energy Cons. Kwh/kg	Oxy gen cons.m^3	Oxy gen cons %	Preheated air cons m^3	Preheated air cons %
1	1	424.0	1745.0	32.0	375.00	48.0	0.240	2.377	49.3	8.3	319.0	61.1
2	1	430.0	1752.0	32.0	375.00	47.0	0.235	2.327	49.0	8.4	319.0	62.4
3	1	437.0	1755.0	32.0	375.00	46.5	0.232	2.297	48.0	8.3	317.0	62.6
4	1	448.0	1762.0	31.5	380.95	45.8	0.229	2.268	46.8	8.2	313.0	62.8
5	1	465.0	1770.0	31.0	387.00	45.0	0.225	2.228	46.0	8.1	310.0	63.3
6	1	470.0	1772.0	30.5	393.44	44.6	0.223	2.208	45.0	8.1	309.0	63.3
7	1	472.0	1773.0	30.5	393.44	43.8	0.219	2.169	45.0	8.3	302.0	63.4
8	1	474.0	1776.0	30.4	394.73	42.9	0.214	2.119	43.0	8.1	297.0	63.6
9	1	475.0	1778.0	30.1	398.67	42.0	0.210	2.079	41.5	8.0	295.0	64.5
10	1	476.0	1778.0	30.1	398.67	41.6	0.208	2.060	40.0	7.7	294.0	64.9

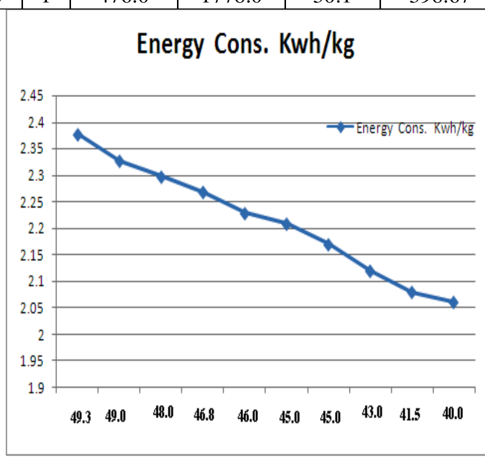


Fig 6 effect of 7.5 -8.5 % oxygenenrichment of preheated air on energy consumption

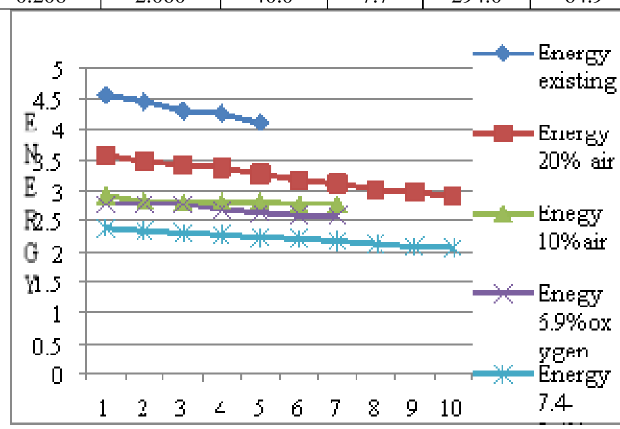


Table VI Effect of7.4-8.4% oxygen enrichment on Total energy consumption

6. COMPARISON OF ENERGY CONSUMPTION-

The Comparison of Energy Consumption, as per experimental investigations is shown in figure 5

Table VII Effect of7.4-8.4% oxygen enrichment on Total energy consumption

Fig.7-The Comparison of Energy Consumption, as per experimental investigations

SN	Particulars	Energy Consumed	Total Energy Consumption
1	Fuel consumed in melting (7.4 8.4% oxygen enrichment of 61.11-64.99% of theoretically required air, preheated up to 476.0^{0}c, using compact heat exchanger).LDO=208.0liters/tone. Oxygen=40.18/200m^3/kg=200.9m^3/tone	208x9.9047=2060.17Kwh 200.9x0.5=100.45 Kwh	2060.17Kwh 100.45Kwh =2160.62 Kwh
2	Fuel combustion unit a.2.5 hp(Reillo burner)	=1.865 Kwh for 398 kg	4.685Kwh
3	Plant& equipments a. Blower 7.5 HP b Geared motor 2 HP c Pump heat exchanger 1HP atmosphere side Pump heat exchanger 0.5HP furnace side	5.595 Kwh 1.492kwh 1.119Kwh=8.206 Kwh for398 kg/ hr=20.618 Kwh/tone	20.618Kwh
4	Pollution Control Equipment: a. ID Fan 5 HP b. Motor 1 HP For 398.67 Kg melt/hr For 1 tone	3.73 Kwh 0.746 Kwh 4.476kwh for 398.67 kg/hr =11.227 Kwh/tone	11.227 Kwh
4	Shot Blasting M/c Capacity 1 T/Hr. Motor 30 H.P. = 22.38kwh	22.38/3 = 7.46 Kwh/	7.46 Kwh
		Grand Total	2204.625=2205.00Kwh/tone

V. RESULTS

A.Effect of oxygen enrichment of preheated air on energy consumption the results of above experimental investigations and effect of oxygen enrichment of preheated air on energy consumption of rotary furnace are given in table VII

VI. CONCLUSION

On basis of above experimental investigations the following conclusions are drawn-

1. with 7.7-8.4% oxygen enrichment of preheated air,

(a) The fuel consumption per heat (for melting charge of 200 kg) reduced from 83.0 liters to 43.5liters i.e. by 47.59%,

(b) The specific fuel consumption has reduced from 0.415liter/kg to 0.208liter i.e. by 49.87 % (c) The

Particulars	With out oxygen enrichment	With 20% excess air	With 10% excess air	With 6.9% oxygen enrichment	With7.7-8.4% oxygen enrichment	%Savings compared to with out oxygen enrichment
Reduction						
(a)Fuel/ heat liters	83.0	58.0	56.0	52.0	43.5	47.59 %
(b)Spec. fuel. liter/kg	0.415	0.290	0.280	0.260	0.208	49.87%
(c)Energy Kwh /tone	4172.0	2872.3	2773.3	2711.0	2205.0	47.14%
(d)Annual production tones	360.0	360.0	360.0	420.0	420.0	16.66%
(d)Annual Energy consumption Kwh	4172.0 x360= 1.501x 10^6	2872.3 x360= 1.03 x 10^6	2773.3 x360= 0.998x 10^6	2711.0 x420= 1.138x 10^6	2205.0 x420= 0.926 x10^6	0.575x10^6

Table VIII- Effect of oxygen enrichment of preheated air on energy consumption

Energy consumption/tone reduced from 4172.00. Kwh/t to 2205.00 Kwh/t i.e. by 47.14 %,

(d) Annual Energy consumption reduced from $1.501x10^6$ Kwh to 0.926 $x10^6$ i.e. by $0.575x10^6$ Kwh or 38.30%

2. The energy consumption is 2.82% lower than the TERI norms.

It is clear that 7.7-8.4% oxygen enrichment of preheated air, significantly reduces the fuel and energy consumption.

VII. REMARKS

The above experimental investigations were carried out on a 200.0 kg rotary furnace. When operated with 7.7-8.4% oxygen enrichment of preheated air, the average specific fuel consumption was 0.208 liter/kg and energy consumption was 2.060 Kwh/kg. This may further be reduced significantly for larger size rotary furnace (up to 5.0 tones/hr) as heat losses also are significantly reduced for larger size furnaces.

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IX. BIOGRAPHY

The author Ratan Kumar Jain was born at Agra, India on 11th October 1949.He got his B.E. (Hons.) in Mechanical Engineering in 1972 from B.I.T.S. Pilani (Rajasthan) India, M.E. (Thermal Engg.) from Dr.B.R. Ambedkar University, Agra (U.P) in 2005, Ph.D. (Equiv.) in 2009 and Ph.D. (Mech.) in 2011 from U.P. Technical University Lucknow (U.P.) India.He has 40 years of industrial and academic experience in large multinational companies/colleges in India and abroad. Supreme Court of India, ordered closure of approximately 500 foundries, using coke fired cupola furnace, due to higher emission levels and energy consumption.

He designed and developed a Rotary furnace with L.D.O. (light diesel oil) as fuel. Series of experimental investigations were carried out for energy and environmental conservation in ferrous foundries, over a span of 7 years. The results are accrued herein.
He is a member of institute of Indian foundry men, Kolkata (India) and affiliating member of World Foundry Organization Birmingham (U.K.).At present working as Professor&Head, Deptt. Of Mechanical Engineering, ITM University, Gwalior
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