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PERFORMANCE ENHANCEMENT OF A ROTARY FURNACE: A HARBINGER TO POLLUTION FREE CASTINGS

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ABSTRACT

The Iron foundries have been playing a vital role in the industrial development of India. The major problems being faced by iron foundries are restrictions on energy consumption by TERI and emission levels due to which majority of coal fired ferrous foundries in Agra have been closed by an order of the Hon'ble Supreme court of India. The present state of foundries in Agra reveals that extensive research is necessary to develop an ecofriendly and energy efficient furnace for Ferrous Foundries. Therefore, A 200 Kg capacity Rotary Furnace, have been designed and developed in DEI and studied for its technical feasibility, economic efficiency, energy consumption and emission levels.

Experiments conducted with heat exchanger and different fuels and their combination improved the energy consumption and pollutants but still not within the limits of TERI and CPCB. So, a modified heat exchanger has been designed. Experiments are conducted with the changed nozzles, modified heat exchanger and using jatropha and LDO mixed fuel. The furnace parameters are optimized experimentally and found that using Reillo burners, modified heat exchanger, new refractory lining of the furnace rotating at 1RPM using 10% excess air and 410 degrees air preheat, CPCB limits and TERI limits are fully satisfied. Also Quality of the casting is found excellent. Hence, Rotary Furnace with the above modifications will be a boon for the foundry industry of Agra and India at large.

Keywords—Bio fuel; Heat losses; Iron foundries; Rotary furnace

I. INTRODUCTION

The iron foundries have been playing a vital role in the industrial development of India. It is a core industry manufacturing castings which is basic raw material to almost all industrial sectors. The major problems being faced by iron foundries are restrictions on emission levels laid down by CPCB(Central Pollution Control Board) due to which majority of ferrous foundries using coal fired cupola furnace have been closed by an order of the Hon'ble Supreme court of India, and limits of energy consumption laid down by TERI. Bandopadhya[1] provided a set of strategies and necessary gas cleaning system required for bringing down the level of pollution to the desired level and recommended urgent anti-pollution measures in Cupolas. He suggested that a suitable scrubber, cyclone or bag filter may be put along with a dry/wet arrester to reduce the particulate emission level.

Bandopadhya[2] also emphasized the problems and strategies of environmental pollution in CI foundries.Bandopadhya et al.[3] emphasized energy, environment and resource management in Indian mineral industries.Banerjee[4] emphasized that besides gasses and fumes, noise also poses serious problems.Datta et al.[5] advocated the installation of medium frequency coreless induction melting furnace.Landge[6] recommended the use of high energy venturi scrabbling system.

Maiti[7] suggested deletion and monitoring techniques on the basis of fundamental principles involved, mode of operation, accuracy of measurement etc. for environmental pollution from foundries.

Mohammad et. al.[8] emphasized the installation of Induction furnace for melting as they have lower emission values.

Panigrahi[9] suggested the use of dry spark arrester, wet spark arrester, cyclones, bag filter, tower wet dust catcher with venture pipe and waste water treatment.

Parthasarathy et al. [10] recommended the use of ESP (Electro-static Precipitators), bag filters, wet collectors and cyclones for the control of air pollution in the foundries.Raizada[11] suggested a water cooling system for induction furnace.Selby [12] discussed the advantages of rotary furnace.Tiwari[13] stressed the need to install electric furnace to get rid of cupola emission.

PurshottamKumar[14]emphasized on using a Rotary furnace to avoid the additional cost of pollution control equipment for producing castings in pollution free environment using different fuels and combustion equipment. The results indicated that present combustion equipment used gives improvement in pollution contents almost to the level of CPCB norms but energy requirements are still high as per the TERI norms.

The literature surveyed and present state of foundries in India reveals that extensive research work is necessary to develop an ecofriendly and energy efficient furnace for Ferrous Foundries.A 200 kg rotary furnace with a heat exchanger was designed, fabricated and used for investigations by the Faculty of Engineering, DEI, Dayalbagh. Rotary furnace made of 7 mm thick MS plates lined with mortar and refractory bricks have been used to study the emission level and energy consumption.

Under existing conditions of operation, existing combustion equipment using L.D.O. (light diesel oil) as fuel, the total energy consumption was 4172.00 kwh/tonne. The energy consumption as per TERI norms is only 2084. Kwh/tonne. The energy consumption of the furnace with the existing condition is very high.Experiments conducted by Purshottam Kumar with heat exchanger and different fuels and their combination (LDO with 10%bio-fuel) improved the energy consumption and pollutants but still not within the limits of TERI and CPCB. So, a Modified heat exchanger is designed and new lining of the furnace is used for further experiments. Blends of LDO and bio-fuels in varying percentage are used for reducing the pollution levels below the CPCB norms. The effect of rotational speed of furnace, percentage of excess air, preheat air and different types of burners using optimal blend of LDO with bio-fuel, are considered for evaluating the performance of the furnace. Energy requirement and emission level for the castings using modified compact heat exchangers, have been experimentally investigated.

II.DEVELOPMENTS IN DESIGN OF COMPACT HEAT EXCHANGER

It was observed during experimental investigations that reducing (excess air) i.e.combustion volume and supplying oxygen additionally the specific fuel consumption is reduced.In view of this development, design of compact cross flow heat exchanger is carried out . The following datas are considered

Approximate volume of air =450.0m^3,approximate time of one heat =40.0 minutes, oxygen consumption inone heat =38.5 m^3, Atmospheric air temperature at inlet of exchanger =27.0^{0}C, Air temperature at exit from exchanger=500.0^{0}C,

TABLE I. THE DESIGN DATA OF COMPACT CROSS FLOW HEAT EXCHANGER FOR IMPROVED PERFORMANCE FOR THE DESIGNED FURNACE

Features/Description	Values	Features/Description	Values
Type	Compact(cross flow)	Surface to volume ratio	753.87m^2/m^3
Temperature of cold air at inlet of exchanger	27^{0}C	fouling factor R_f	0.0004
Temperature of cold air at outlet of exchanger	500^{0}C	Efficiency of counter flow heat exchanger	46.11%
Temperature of hot gases at inlet of exchanger	1100^{0}C	No of copper plates fitted as fins	533
Temperature of hot gases at outlet of exchanger	732.60^{0}C	No. of baffle plates	2
Logarithmic mean temperature difference	651.45^{0}C	Dimension of one fin	0.80mx0.70mx
Overall heat transfer coefficient	30.00 w/m$^{2\,0}$C	Thickness of one fin	1.0mm
Diameter of each tube	0.04 m	Spacing between fins	2.75 mm
Length of each tube	2.00 m	Dimensions of chamber at top and bottom	2.40mx0.80mx0.20m
Material of tube	Copper	Cylindrical duct Diameter for inlet /exit of fresh air	8.0 cm
Material of shell (25% Ni,20%Cr)	Ni Cr steel	Cylindrical duct Length for inlet and exit of fresh air	0.80m(Exchanger width)
No. of tubes/ arrangement	28(4x7)	Diameter of duct for inlet &exit of flue gases	16.0 cms
Total length/width/thickness (heat exchanger)	2.40mx0.80mx0.90m	Length of duct for inlet of flue gases	20.0 cms
Shape of heat exchanger	Box type	Height of duct for exit of flue gases	50.0 cms
Mass flow rate of air at inlet	0.276kg/sec	Temperature ratio P	0.440
Mass flow rate of hot gases at inlet	0.32456 kg/sec	Capacity ratio R	0.776
Surface area of one tube	0 2512 m^2	Correction factor F	0.97
Total surface area for heat transfer.	566.6897m^2	Shape of heat exchanger	Box type
Total volume for heat transfer.	0.7517 m^3	Dimensions of heat exchanger	2.40m x 0.80m x 0.90m

TABLE II. COMPARISION OF COMPACT (CROSS FLOW) AND MULTIPASS (COUNTER FLOW) HEAT EXCHANGER

S.No	Compact (cross) flow	Multipass counter flow
1	The maximum temperature of air from exit of exchanger is 500^0C	The maximum temperature of air from exit of exchanger is 350^0C
2	The efficiency is 46.11%	The efficiency is 30.11%
3	The area density β is 753.87 m^2/m^3.The rate of heat transfer is better with 533 fins	The area density β is 100.14m^2/m^3. The rate of heat transfer is poor
4	Suitable for heat transfer between air to gas	Suitable for heat transfer between liquid to liquid (or a liquid and gas).
5	The refractory brick lining is better leading to reduced heat losses	The refractory brick lining is poor leading to more heat losses

By modifying the heat exchanger the area density is increased to a very high value and efficiency is also increased from 45.36% to 46.11% and number of fins is increased from 500 to 533.45.36% was the efficiency and 500 fins were used in the heat exchanger used by PurshottamKumar.

III.EXPERIMENTAL EVALUATIONS

TheExperimental Investigations have been carried out-

(1) To reduce the energy consumption of furnace by-

(a) Improving the heat transfer mechanism

(b) Reducing heat losses

(2)To reduce the emission levels of SPM, SO_2, CO_2, CO etc. and make furnace more eco-friendly.

(3)To optimize the input parameters to achieve the above.

Equipment for further Experimental Investigations -

Burners- Till now the burners used were Self proportionating type or circular with number of holes on the periphery. These burners were having increased energy consumption and fuel consumption. So for reducing fuel consumption and energy consumption, the burner is changed and the experiments are conducted with the new burner.

TABLE III. FUEL CONSUMPTION FOR DIFFERENT BURNERS WITH 10% AND 20% BLENDINGS OF LDO & BIOFUEL AT DIFFERENT ROTATIONAL SPEED

Type of Burner	Fuel Consumption		Fuel Consumption		Fuel Consumption		Fuel Consumption		Fuel Consumption		Fuel Consumption	
	10%	20%	10%	20%	10%	20%	10%	20%	10%	20%	10%	20%
Rotational speed	2	2	1.6	1.6	1.4	1.4	1.2	1.2	1	1	0.8	0.8
Circular	89	91	89	92	87	90	85	88	85	87	85	88

Circular	86	88	85	87	84	86	82	85	84	85	85	85
Circular	87	89	87	87	85	85	83	85	80	83	82	84
SPT Type	110	115	110	112	108	110	106	108	104	105	105	106
SPT Type	104	108	108	109	106	108	104	106	105	105	104	106
SPT Type	107	107	106	108	105	108	104	106	102	104	102	105
Riello Burner	82	88	82	85	80	84	76	82	74	80	75	82
Riello Burner	80	86	79	82	78	82	76	80	72	76	74	79
Riello Burner	80	85	80	80	76	81	77	79	72	74	72	78

It has been found that at 1RPM rotation of the furnace with 10% blending of LDO with bio-fuel, Reillo burners of the type RL/M70-190 gives the minimum fuel consumption. This burner in comparison to the other two is also having sturdy structure, easy to operate and maintain, ensures study performance and long life and is suitable for furnaces for ferrous casting.

Hence,for reducing the fuel consumption the prevailing Circular ring burners and SPT types of burners are replaced by the burner of series RL/M70-190 manufactured by Riello burners. Experimental evaluations by Purshottam Kumar also reveal that minimum fuel consumption was obtained at 1 RPM with blending of 10% bio-fuel with LDO. Hence, in the further evaluations 1RPM rotational speed and 10% blending is used.

Refractory lining (1) was used by Purshottam Kumar in his experimental evaluations with the following specifications

(a) Installation of Ceramic fiber blanket of thickness 25.0 mm to reinforce the insulation and further reduce the heat losses from exchanger.

(b) The brick lining was done using alumina bricks of AL2O3 up to thickness of 60mm.

(c) The ramming with ramming mass consisting of 25% quartz and 75% fire clay up to thickness of 40.0 was done.

For present experimental evaluation, the following changes in refractory brick lining (2) are carried out to reduce the heat losses from furnace shell and increase furnace life.

a. Aluminum paint coating: The outer surface of furnace shell which remains exposed to atmosphere is painted with metallic aluminum paint of thickness 1mm. as aluminum paint has lowest emissivity among all available paintswhich drastically reduces the heat losses from furnace shell, and increases the utilization of heat inside the furnace and thus reduces the energy consumption.

b. Ceramic fibre blanket—These blankets have Excellent thermal stability, High resistance to burning, Low thermal conductivity.(0.09w/m0k), Low heat storage, Low shrinkage, and Convenience in installing

c. High alumina brick lining—Instead of rammed monolithic silica brick lining, the high alumina brick lining (70% Al_2O_3+2.5%Fe_2O_3) which gives an excellent operational life is used with the following technical specifications.

TABLE IV. TECHNICAL SPECIFICATIONS OF HIGH ALUMINA BRICKS

SN	Parameters	Particulars
1	Type	High alumina
2	Raw material base	Calcinated bauxite
3	Maximum service temperature	1500 ^{0}C
4	Reversible thermal expansion	0.65 at1000 ^{0}C
5	Chemical composition (a) Al_2O_3 (b) SiO_2 (c) Fe_2O_3 (d)TiO_2 (e) CaO	 70% 19.30% 2.5% 3.75% 1.40%
6	Bulk density	2.65-2.66 g/cc
7	Apparent porosity	21%-23%
8	Cold crushing strength	600-680 kg/cm^2
9	Thermal conductivity (k) (a) At 400^{0}C (b) At 600^{0}C (c) At 800^{0}C	 1.39 kcal/m/hr/^{0}C 1.42 kcal/m/hr/0C 1.45 kcal/m/hr/0C

d. Special ramming mass- After few heats the ramming mass is repaired and patching is done. The special ramming mass consists of 70%Al_2O_3+1.0 %Fe_2O_3 and balance fire clay

For this new lining (2) the heat losses occur from inner surface to outermost surface as shown in figure 1.

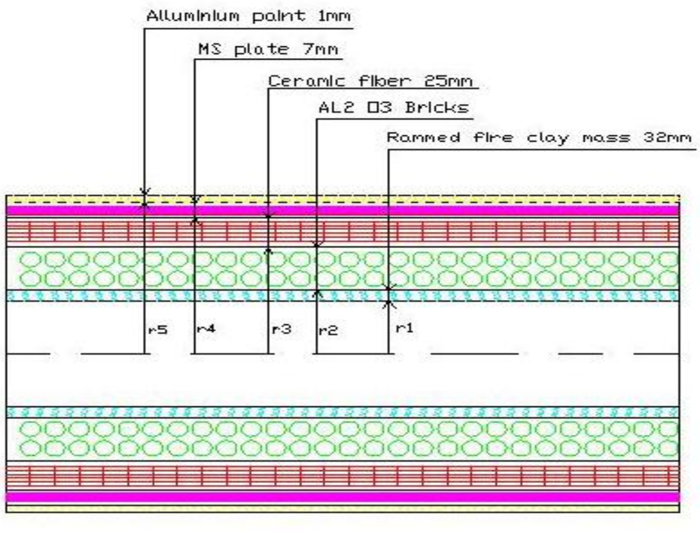

Fig. 1. Front view of layout of lining 2

Heat losses from furnace shell with lining (2)- The heat lossesfrom furnace shell depends uponresistance to heat flow.The comparison of heat losses from furnace shell with two different linings--(1) Without aluminum paint, monolithic silicabrick lining andrammed silica mass, and (2) With aluminum paint**,**ceramic fiber blanket, high alumina brick lining, and rammed fire clay mass, withproper installation,is shown in table V.

TABLE V. COMPARISON OF HEAT LOSSES (KW/M^2) FROM FURNACE SHELL WITH TWO DIFFERENT LININGS

S.N	Temperature^{0}C	Heat losses lining (1) without aluminum paint, silica lining & rammed silica mass.	Heat losses Lining (2) with aluminum paint, ceramic fiber blanket high alumina brick lining, rammed fireclay mass.	Percentage (%) reduction in heat losses
1	50^{0}C	5.87	3.37	42.58
2	100^{0}C	5.48	3.15	42.51
3	150^{0}C	5.40	3.15	41.66
4	200^{0}C	4.95	2.82	43.00
5	250^{0}C	4.78	2.72	43.09
6	300^{0}C	4.62	2.67	42.20

The average percentage reduction in heat losses is 42.50%-

The graphical representation ofComparison of heat losses from furnace shell with lining 1(without aluminum paint) andwith lining 2(with aluminum paint) is shown in fig 2.

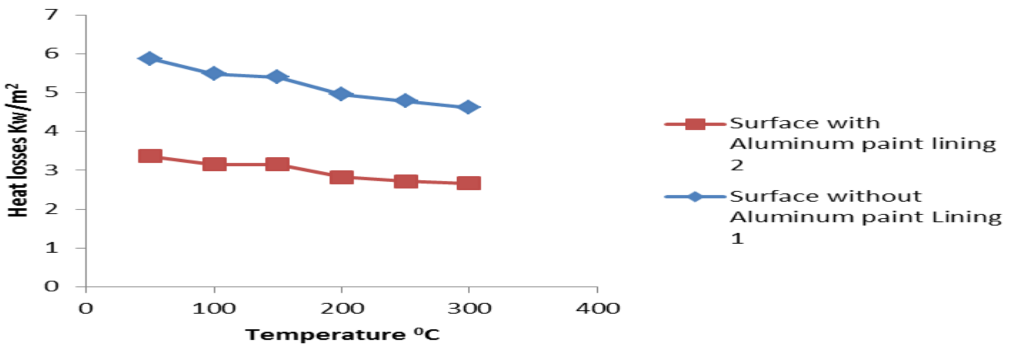

Fig. 2.Graphical representation of comparative heat losses from furnace shell with two different linings

3.1 Further Experimental Investigations

After replacing the combustion equipment and refractory brick linings as explained in preceding sections, the following experimental investigations are carried out to see the effect of identified parameters on the performance of rotary furnace.

(1) Effect of rotational Speed on energy consumption and performance of Furnace.

(2) Effect of rotational speed on Emission level.

(3) Effect of 20% excess air on flame temperature, melting rate, & specific fuel consumption.

(4) Effect of 10% excess air flame temperature, melting rate, & specific fuel consumption.

3.1.1 Effect of Rotational Speed on energy consumption and performance of Furnace-

The rotation of furnace is very important input parameter. If rotation is high the time of contact between charge and heated refractory will be very less consequently, the rate of heat transfer between the charge and refractory will be very low. To study the effect of rotational speed the investigations have been made between 0.8 to 2.0 rpm.

TABLE VI. EFFECT OF ROTATIONAL SPEED ON FUEL CONSUMPTION MELTING RATE & EMISSION LEVEL WITH 10% BLENDING OF BIO-FUEL AND LDO

S.N	Rpm	Time (min)	Fuel (lit.)	Melting rate kg/hr	Pollution Level(mg/m^3)			
					SOx	SPM	CO_2	CO
1	2.0	48.00	90.0	250.00	88.0	40.0	4.1	4.2
2	2.0	47.00	88.0	255.40	84.0	40.0	4.0	4.2
3	2.0	46.00	85.0	260.86	85.0	40.0	4.0	4.0
4	1.6	45.00	86.0	266.50	86.0	38.0	3.95	4.1
5	1.6	45.00	83.0	266.60	85.0	38.0	4.0	4.2
6	1.6	42.00	80.0	285.70	85.0	38.0	4.0	4.0
7	1.4	40.00	80.0	300.00	87.0	36.0	4.0	4.0
8	1.4	40.00	80.0	300.00	84.0	36.0	4.0	4.0
9	1.4	40.00	79.0	300.00	85.0	36.0	3.95	4.0
10	1.2	39.00	80.0	307.69	86.0	35.0	4.0	4.1
11	1.2	39.00	78.0	307.69	85.0	35.0	4.0	4.0
12	1.2	39.00	77.0	307.69	87.0	35.0	4.0	4.1
13	1.0	38.00	76.0	315.78	87.0	35.0	3.95	3.90
14	1.0	36.00	77.0	333.30	87.0	35.0	3.95	3.90
15	1.0	35.00	76.0	342.00	87.0	35.0	3.90	3.90
16	0.8	42.00	79.0	285.70	89.0	35.0	3.90	3.90
17	0.8	40.00	78.0	300.00	88.0	35.0	3.90	3.90
18	0.8	38.00	77.0	315.78	88.0	35.0	3.90	3.90

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The computation of results of Experimental investigations (1)-Effect of rotational speedon annual energy savings, fuel cost, and annual production are calculated below -

(i)The effect of rpm on annual energy saving--

At 2.0 rpm specific fuel consumption is 0.425 liter/kg

At 1.0 rpm specific fuel consumption is 0.38 liter/kg

Saving in fuel consumed in liters/kg = (0.425-0.380) =0.045 liters/kg.

For one heat of 200.0 kg = 200x0.045litres =9.0 liters/heat

6 heats per day (at1 rpm) =9x6= 54.0litres/day.

Assuming 25 days /month=25x54.0=1350 liters/month.

The annual saving= 12x1350.0litres=16200 liters =16.2 kliters

The annual saving in energy consumption=16.2kliters x9.9047 Kwh/liter =16045614 Kwh==1.604x10^5 Kwh

Reducing rpm from 2.0 to1.0, the annual energy savings

=1.604x10^5 Kwh

(ii) The effect of rpm on fuel cost—

(a) The present L.D.O. cost = Rs 40.00/ litre.and cost of jatropha is Rs75.00/litre.Taking combination of LDO and 10% jatropha,the approximate cost of the fuel is considered as Rs50/litre

(b) The annual savings= 16200 litre x Rs 50/litre =Rs 8.10 Lakhs.

(iii)The effect of rpm on annual production-

(a) At 2.0 rpm-No. of heats/day =5, production /heat =200 kg, per day=1000 kg,

Per annum =300x1000kg= 300 tonnes

(b) At 1.0 rpm -No. of heats =6, production /heat =200.0 kg, per day =1200.0 kg, per annum=300x1200kg= 360.0 tonnes

The results of above experimental investigations of reducing rpm from 2.0 to 0.8 are studied and then the optimal values are obtained for energy consumption and emission level of pollutants. These values are obtained at 1.0 rpm. The improvement in performance of furnace by changing rpm from 2.0 to 1.0 is shown in table VII.

SN	Parameters	Absolute reduction		Percentage Reductions/ improvements
		2.0rpm	1.0 rpm	
1	(a)Melting time(minutes)	46	35	23.91%
	(b)Minimum Fuel consumption(liters)	85	76	10.58%
	(c)Specific fuel consumption(lit/kg)	0.425	0.380	10.58%
	(d)Energy consumption in melting (kwh/tonne)	4110.45	3763.78	8.43 %
	(e) Melting losses	6%	4%	2%

	(f) Emission levels- (mg/m3) 1.SOx 2 SPM 3 CO_2 4 CO	 90 40 4.00 4.00	 88 35 3.90 3.90	 0.02% 2.22% 12.50% 12.50%
2	(a)Melting rate(kg/hr) (b)No. of heats per day(200 kg)	260.86 5	342 6	31.10% 20%
3	Annual savings (a)Annual energy consumption (b)Annual fuel (liters) (c)Annual fuel cost			 $1.6x10^5$ kwh 16.2 k liters Rs.8.10 lakhs
4	Annual production(tonnes)	300	360	20%

TABLE VII. IMPROVEMENT IN PERFORMANCE OF FURNACE BY CHANGING RPM FROM 2.0 TO 1.0

During operation of furnace under existing conditions it was observed that (i) The atmospheric air is directly being supplied to burner (without preheating) for combustion of oil which leads to its incomplete combustion.
(ii) The 30% excess air was supplied which leads to higher combustion volume and increases the air fuel ratio.These both factors increase the oil consumption, resulting into more energy consumption.
Excess air- Minimum amount of air, which is required for complete combustion of fuel, is calculated theoretically, but always excess air 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 amount of air is required to be supplied for complete combustion of fuel.

Effect of excess air on performance of furnace--The role of excess air is more dominating as explained in the following section.

For maximum flame temperature and melting rate the optimization of excess air and preheat is required. To maintain the optimum flame temperature, the supply of excess air and its preheating is to be adjusted. An optimum excess air has to be used because more excess air will increase the combustion volume and reduce the flame temperature and exact amount of air will exceed the temperature beyond safe metallurgical limits which will reduce the life of refractory and furnace shell.

3.1.2 Experimental investigations —Effect of 20.0% excess air on flame temperature, time, fuel, melting rate, & specific fuel consumption.

Again experiments were repeatedby reducingexcess air to 20%,with compact heat exchanger, rotating furnace at optimal rotational speed 1.0 rpm**,** preheating LDO up till 70.0^0C. The observations taken during experiment are given in table VIII.

TABLE VIII. EFFECT OF 20% EXCESS AIR ON FLAME TEMERATURE, TIME, FUEL, MELTING RATE & SPECIFIC FUEL CONSUMPTION

Heat No	Flame Temp°C	RPM	Time min.	Fuel liters	Melting rate (kg/hr)	Specific fuel cons liter/kg	Preheated excess air cons.m^3	Preheated excess air %	Preheated excess air temp.°C
1	1510.0	1.0	42.00	74.0	285.7	0.370	995.0	30.1	304.0
2	1530.0	1.0	40.00	72.0	300.3	0.360	970.0	25.5	316.0
3	1540.0	1.0	40.00	69.0	300.3	0.345	930.0	20.3	320.0
4	1545.0	1.0	39.00	68.0	307.6	0.340	905.0	20.1	329.0
5	1550.0	1.0	37.00	66.0	324.3	0.330	870.0	20.2	332.0
6	1568.0	1.0	38.00	64.0	315.7	0.33	835.0	19.9	340.0
7	1570.0	1.0	36.00	63.0	333.3	0.315	822.0	20.0	348.0
8	1578.0	1.0	35.00	61.0	344.82	0.305	795.0	19.9	370.0
9	1580.0	1.0	35.00	60.0	344.82	0.300	788.0	20.1	378.0
10	1590.0	1.0	34.00	59.0	353.35	0.295	785.0	20.0	385.0
11	1620.0	1.0	33.00	59.0	363.6	0.295	760.0	20.0	402.0

The above results are graphically represented in figures 3, 4, 5 & 6.

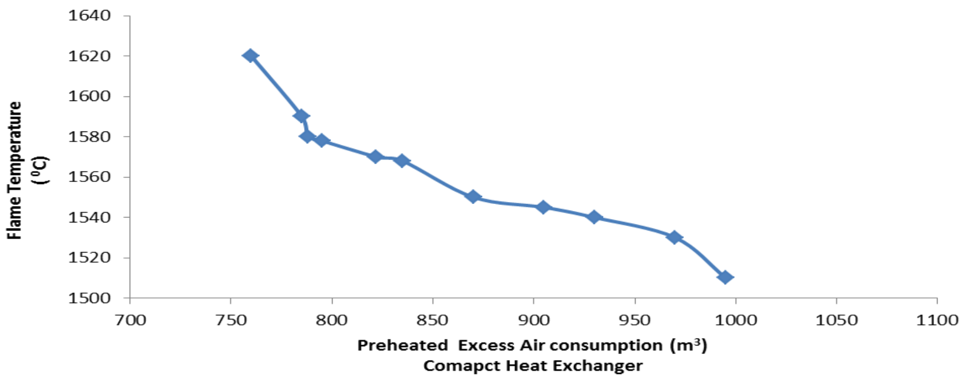

Fig. 3. Effect on flame temperature^{0}C

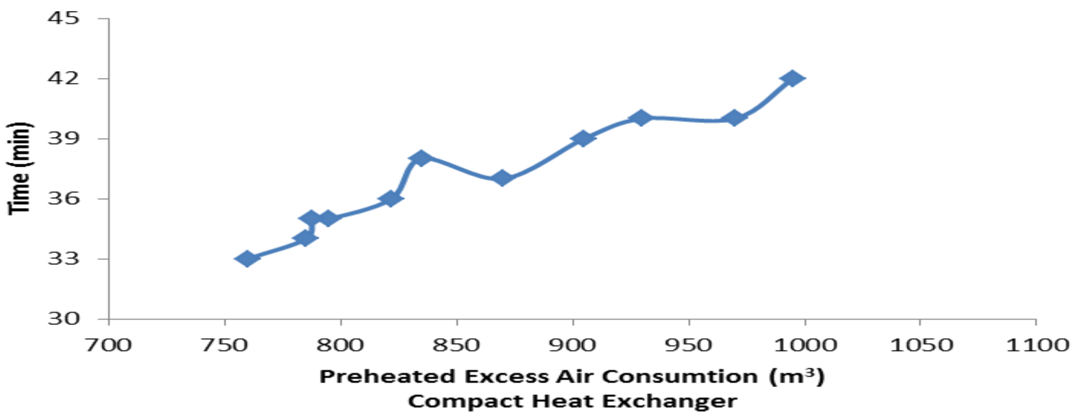

Fig. 4. Effect on time (min.)

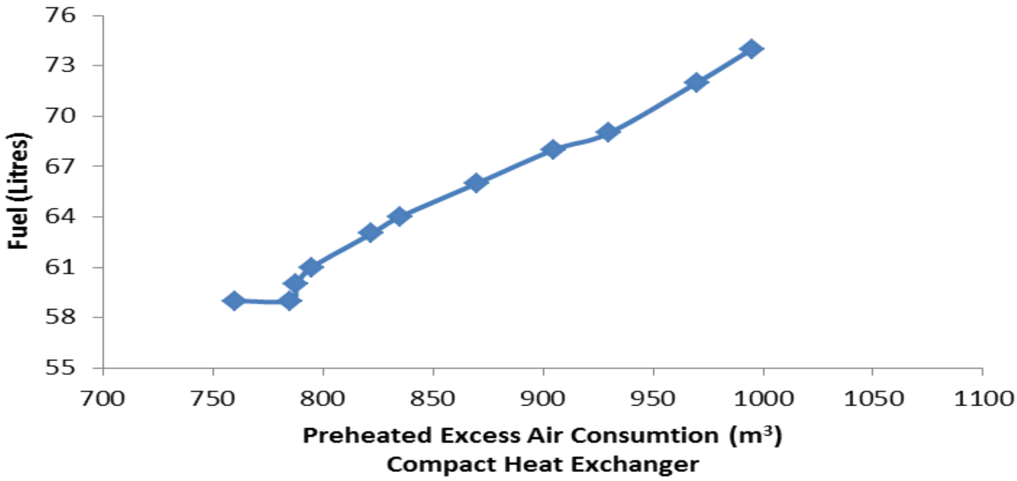

Fig. 5. Effect on fuel (liters)

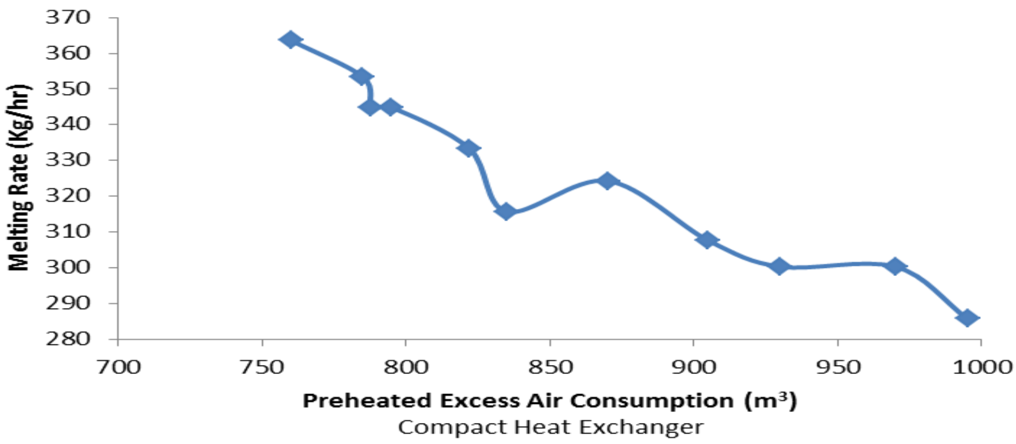

Fig. 6. Effect on melting rate (kg/hr)

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Figs 3,4,5 & 6 --The graphical representation of Effect of 20.0% excess air rotating furnace at optimal speed of 1.0 rpm, on flame temperature, time, fuel and melting rate.

Effect of 10.0% excess air on flame temperature,time, fuel, melting rate, and specific fuel consumption-
Experiments wererepeated reducing excess air to 10.0%, under similar conditions. The observations taken during experiment are given in table IX.

TABLE IX. EFFECT OF 10% EXCESS AIR ON FLAME TEMERATURE, TIME, FUEL, MELTING RATE & SPECIFIC FUEL CONSUMPTION

S.No	**FlameTem p^{0}C.**	Rp m	Time min.	Fuel liters For 200 L	Melting rate kg/hr	Specific fuelcons liter/kg	**Preheatedair cons. (m^3)**	Preheated air%	Preheated air temp.°C
1	**1642.0**	1.0	34.00	59.0	353.35	0.295	**810.0**	11.4	386.0
2	**1656.0**	1.0	33.00	58.0	363.63	0.285	**790.0**	11.3	395 .0
3	**1666.0**	1.0	33.00	58.0	363.63	0.282	**755.0**	10,0	396.0
4	**1678.0**	1.0	32.50	57.0	369.68	0.285	**725.0**	10.6	397.0
5	**1684.0**	1.0	32.00	57.0	375.23	0.285	**690.0**	10.1	403.0
6	**1693.0**	1.0	32.00	56.0	375.23	0.280	**680.0**	10.1	408.0
7	**1695.0**	1.0	31.00	56.0	387.50	0.280	**670.0**	10.0	412.0

The above results are graphically represented in the form of curves in the figure 7, 8, 9 & 10.

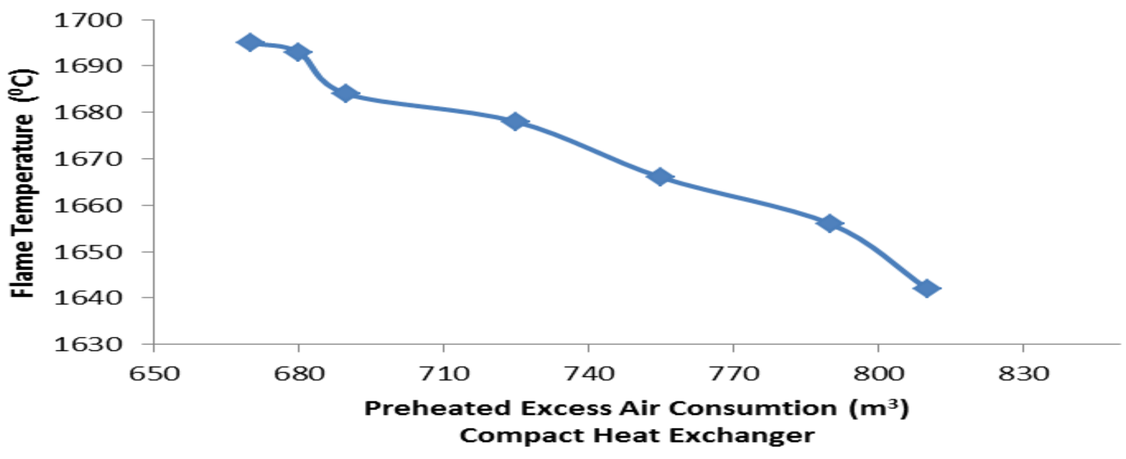

Fig. 7. Effect on Flame temperature

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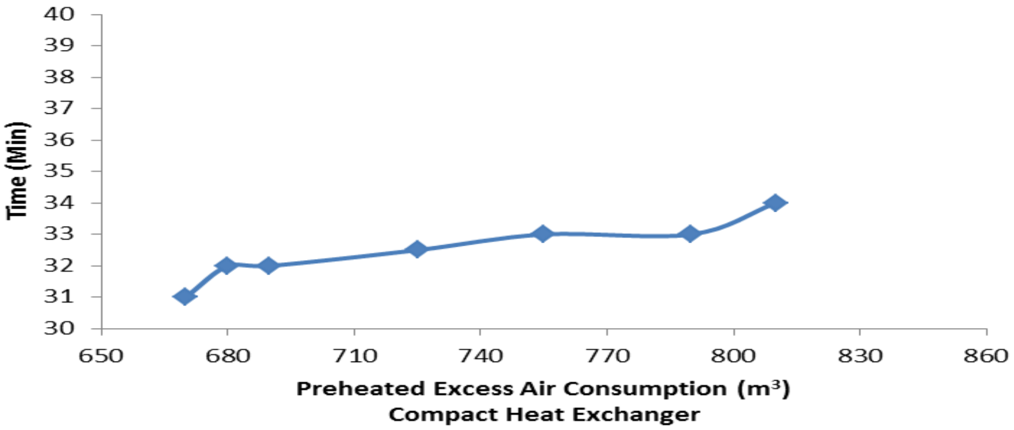

Fig. 8. Effect on Time (min)

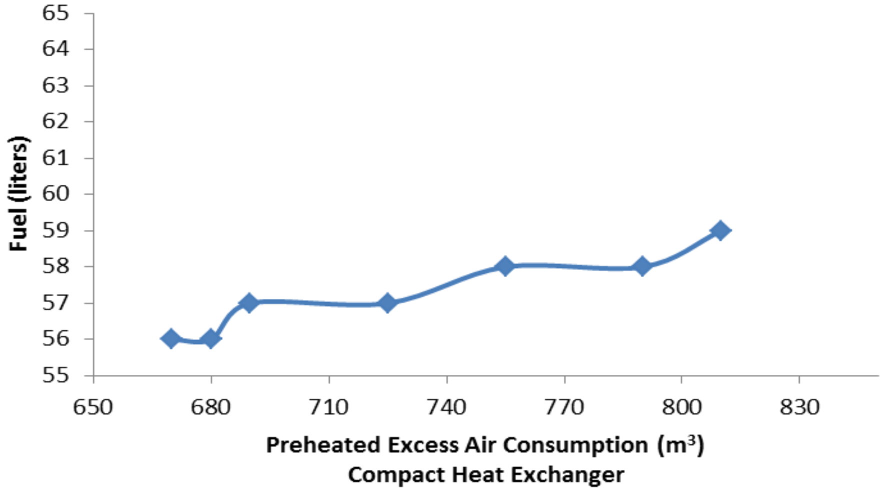

Fig. 9. Effect on fuel consumption (Litres)

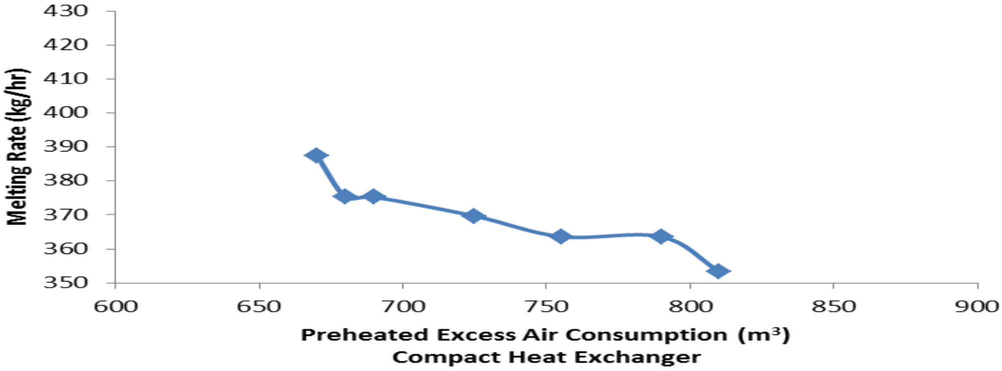

Fig. 10. Effect on melting rate (kg/hr)

Figs.7,8,9 & 10--Effect of 10.0% excess air at optimal rotational speed 1.0 rpm on flame temperature, time, fuel, andmelting rate.

It is very clear thatusing compact heat exchanger and gradually reducing excess air**,**not only increases the flame temperature from 1510.0 to 1695.0°C, and melting rate from 285.70 kg/hr to 387.50 kg/hr but also reduces the fuel consumption to 0.280 litre/kg of molten metal produced.

Energy consumption-the effect of reducing excess air initially to 20.0% and then to 10.0%,rotating furnace at optimal rotational speed 1.0 rpmonmelting rate and fuel consumption are shown in table and on energy consumption in table X.

TABLE X. MELTING RATE & FUEL CONSUMPTION UNDER DIFFERENT CONDITIONS OF EXCESS AIR

S.No	Parameter	20.0%-excess air with compact heat exchanger, rotational speed of 1.0 rpm,	10.0%-excess air with compact heat exchanger, rotational speed of 1.0 rpm,
1	Melting rate kg/hr.	363.6	387.0
2	Fuel used in melting (Litres/tone)	290.0	280.0

And on energy consumptions (kwh/tonne) is shown in table XI.

TABLE XI. ENERGY CONSUMPTION UNDER DIFFERENT CONDITIONS OF EXCESS AIR

S.No	Parameter	20.0%-excess air	10.0%-excess air
1	Melting only	2872.36	2773.31
2	Fuel combustion unit (Reillo burner)	5.128	4.818
3	Plant & Equipment	22.566	21.199
4	Pollution controlequipment	12.309	11.563
5	Shot blasting m/c	7.460	7.460
	Total energy consumption kwh	2919.81 (2920.00)	2818.348 (2819.00)

Comparison of energy consumptions—When furnace wasrotated at optimal rotational speed 1.0rpm,withexcess air 10.0%,preheated up to 412.0^{0}C,using compact heat exchanger, in melting only, the energy consumption is reduced to 2773.31kwh/tonne and total energy consumption to 2819.00 kwh/tonne

IV. CONCLUSION

(1) The new Refractory brick lining (2) isfound significant for rotary furnace to reduce the energy consumption, maximum utilization of heat inside the furnace, reducing heat losses, and increasing life of furnace.

(2) It is concluded from this Experimental Investigation that using modified heat exchanger with changed lining(2) and LDO with 10%bio-fuel,optimal rotational speed is 1.0 rpm. It is very clear that rotational speed affects the melting rate, energy consumption and emission level of pollutants. During operation of furnace under existing conditions it is also observed that

(a) All the pollutants are within the range of CPCB norms

(b) Only 10.0% excess air, preheated up to 410^{0}C,is to be supplied for complete combustion of fuel.

(c) With above input parameters the energy consumption in melting is reduced to 2774.00 Kwh/tonne and total energy consumption to 2819.00Kwh/tonne.

(3) It is concluded that reducing rotation of furnace from 2 to 1rpm the annual saving in fuel cost of Rs. 8.10 lakhs is obtained which is a significant amount. Also annual change in rpm has significant effect on annual production.

(4) It is also clear that using compact heat exchanger and gradually reducing excess air, not only increases the flame temperature from 1510.0 to 1695.0°C, and melting rate from 285.70 kg/hr to 387.50 kg/hr but also reduces the fuel consumption to 0.280 litre/kg of molten metal produced.

Hence, it can be concluded that a Rotary furnace with the suggested modifications can be used as furnace for melting iron in an eco-friendly environment using energy within the limits of TERI. Hence, Rotary Furnace with the above modifications will be a boon for the foundry industry of Agra and India at large.

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Dr. Ashok Yadav is an Associate Professor in Mechanical Engineering Department with more than 12 years of experience. He teaches Refrigeration and Air Conditioning, Heat Transfer, IC Engines, Automobile Engineering, Applied Thermodynamics and Renewable Energy Sources. His research interest includes alternate renewable fuels (Bio-diesels) for CI Engines, Life cycle analysis (LCA), Solar Energy and Energy Management. He has authored more than 16 research papers which have been published in archival journals of high repute like Journal of Power and Energy, IMechE (London), National Journals, International and National conferences. He is also member of several professional bodies like Institution of Engineers (India) and ISHRAE, Indian Society of Heating, Refrigeration and Air conditioning Engineers.