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Analysis of Experimental Innovative Melting Technique for Energy Efficiency in Ferrous Foundries

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Abstract

This paper presents the results of experimental investigations carried out by author on a 200 kg oil fired rotary furnace in a ferrous foundry for castings. Generally the rotary furnace is operated at 2 rpm. A series of experiments was conducted reducing rpm in steps from 2 rpm to 0.8 and optimal results were obtained at 1rpm. The specific fuel consumption for melting reduced from 0.415 liter/kg to 0.380 liter/kg (8.43%) and energy consumption from 4.110 kwh/kg to 3.763 kwh/kg(8.44%).

Further experiments were conducted by supplying only 75% of theoretically required oxygen enriched preheated air to furnace for combustion. The specific fuel consumption reduced to 0.260 liter/kg or 260 liter/tone and energy consumption reduced to 2.575kwh/kg or 257.5kwh/tone. Percentagewise it is 15.5% and 15.35% respectively.

Keywords:— oxygen, energy consumption, foundry industry, rpm

I. Introduction

The foundry industry is a "core industry" producing casting which is basic raw material to almost all sectors like auto mobiles, textile, machinery manufacturing, and machine tools apart from agro, pneumatics and railways etc. The machinery manufacturing industries may be, sugar mills, or paper mills etc. are regular buyers of foundry products.

The new manufacturing policy envisages the increase in the share of manufacturing in the GDP to 25% from current 15% & to create 100 Million additional jobs in next 10 years. Since all engineering & other sectors use metal castings in their manufacturing, the role of foundry industry to support manufacturing is very vital. It is not possible to achieve the above goal without the sustainable corresponding growth of the foundry sector

II. Literature Survey

G. L. Datta [1](2001) is of the opinion that approximately 10% of energy savings can be made in foundry industry by reviving current methods Barney L. Cape et al, [2] (2003) –stressed upon initial energy audit for energy saving. It can also control the waistage of energy. Malhan Rajinder[3] (2005) analyzed the foundry statistics and stressed upon to make Indian foundry industry globally competitive. Cardona Raman [4](2005) while explaining the scenario of Indian energy stressed upon non conventional sources of energy and also to search other inputs. TERI[5] (2005) in a report disclosed that energy consumption in Indian foundries is much above the desired limits. it also proposed to penalize the faulty units.

Panchal Subodh[6](2006) is very much hopeful about future growth on foundry industry. Arasu M. et al [7](2006) stressed upon to conserve the energy in melting by using advanced technology as it is the major portion of energy consumption in foundry. Jain R.K. Gupta B.D. et al [8](2007) expressed a major concern over deteriorating energy scenario in foundries. Baijya Nath, Pal Prosanto, and Panigrahy K.C [9](2007) advocated to upgrade rudimentary technologies and practices. Tiedje, Drivsholmetal [10] (2008) designed a new gating system for feeding molten material to moulds. Mukopadhayaya M.K. [11](2009) explained that rejection of castings leads to excess energy consumption and it should be controlled. Mukhopadhyay Gautam[12] (2009) dealt upon energy requirements of foundry industry and demonstrated an energy distribution tree to show the energy flow in various stages.

ASME Energy Assessment Guide[13] (2010) presented procedures to assess the energy requirements to actual work. John Reiety[14] (2010) urged to reduce use of fossil fuels in foundries and to avoid risk of temperature changes. Win rock International India, [15] (2010) recommended the use of different frequency devices for fans, pumps and compressors for energy savings.

Seweryn Jarza [16](2011), is of the opinion that Energy management should be done in foundries for optimizing energy consumption in furnaces, compressors, fans etc. Singh Saurabh Kumar, et al [17](2011) has advocated to use improved combustion equipments, reducing excess air, improving burners, and proper air supply to furnace etc. Mesbah, Khan G., Fartag Amir [18] (2011) strongly recommended the use of heat exchangers for waist heat utilization and for energy conservation in foundries. Visvanathan, [19] (2012) declared that for future growth of Indian foundry industry the technology should be upgraded. B.S. Govind, [20].(2012) wishes to introduce energy auditing and making employees aware of it. N. Ravi Shankar [21] (2013) described the procedure of energy auditing and reducing power consumption leading to huge cost savings.

Gajanan Patange, Mohan Khond [22] (2013) while explaining energy consumption in different operation informed that 70% of energy is consumed in melting. Even small saving in this sector important and melting should be upgraded. Kotecha J, [23](2013) found Divided Blast Cupola more economical and energy efficient than induction durance. TERI[24] (2014). (The Energy and Resources Institute) on basis of actual performance declared that Divided Blast Cupola is more energy efficient furnace for melting. Jagbir Singh[26] (2014) stressed upon energy management for sustainable development and making general masses aware of it.

DYL Chan [27], et al (2014)-made a detailed study of Taiwan industries and concluded that by upgrading technology 33% energy can be saved. MT Solnørdal, Thyholdta[28] (2017) analyzed the role of universities and research institutions in foundries and stressed upon cooperation with their competitors to improve energy efficiency. Emanuele Pagone, Konstantinos Salonitis, Mark Jolly[29] (2018) pointed out on energy and materials' efficiencies and flexible production. They validated it using data of five foundries melting different ferrous and non-ferrous alloys.

III. THE FOUNDRY INDUSTRY

India is the 2nd largest producer of castings worldwide. The production of industrial castings in million metric tones is given in figure 1

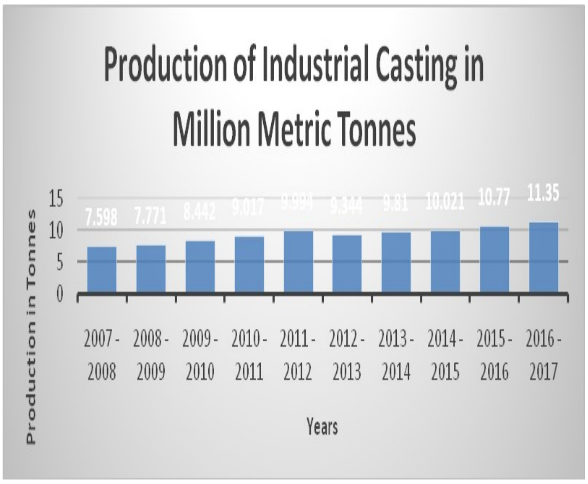

Figure 1- Production of Industrial Castings in India in Million Metric Tones

3.1 Exports Import trends:

The foundry industry is also earning considerable foreign exchange in form of exports. As per report the export is of approx. 2 billions USD. It is shown in figure 2

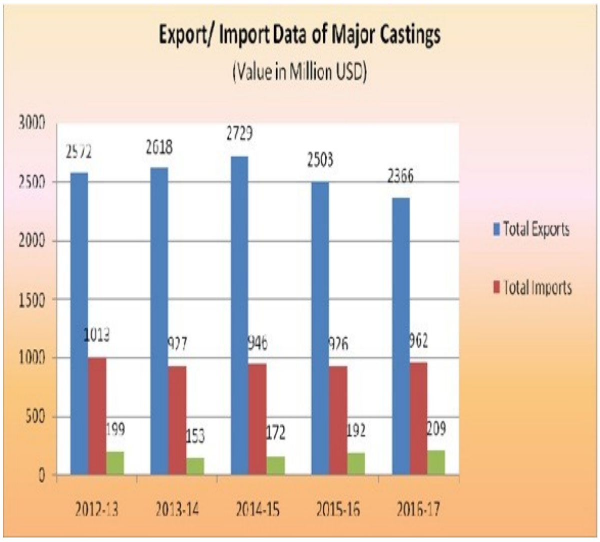

Figure 2 -The Exports_Import trends trend from india

3.2 Problems of Indian Foundry

The following are major Problems of Indian foundry-(1) Technical know-how for modernization (2) Energy consumption.

3.3 TERI Norms on Energy Consumption

TERI- The energy and resources institute, New Delhi) has laid following limits of energy consumption of furnaces being used in foundries. "Bureau of Energy Efficiency, reported that energy consumption in Indian foundries are to be reduced failing which they shall be closed down. The limits of energy consumption are given in table 1

Table 1: The Limits of Energy Consumption, as Laid Down by TERI in Melting the Charge

S. N	Description	Limits
1	Specific energy consumption in foundries with-	
(a)	oil fired furnaces>1 tone/hr	7000MJ(1805.55Kwh)/tone
(b)	oil fired furnaces<1 tone/hr	8000MJ(2221.60Kwh)/tone
(c)	electric furnaces	3400MJ(944.5 Kwh)/tone
(d)	coke fired furnaces	3400MJ(944.5 Kwh)/tone

3.4. Survey of Indian foundry clusters-

There are approximately five thousand foundries in India. Majority of them are small scale foundries. Some five lakhs of peoples are direcly or indirectly are involved in this sector. This sector is divided cluster wise. There are six major foundry clusters in India - Belgaum, Batala/ Jalandhar, Coimbatore, Kolhapur, Rajkot and Agra. Each cluster is famous for its particular type of castings.

Cupola is the main melting furnace used by majority of the foundries. Some foundries are also using induction furnaces. The survey of above foundry clusters was carried out. The main problem was excess energy consumption and use of obsolete technologies.

IV. Agra Foundries

Small foundries were established to support the machinery and spare parts requirement of local industries. Agra had over 100 foundries, but presently only about 80 of them are in operation. The foundry units are scattered both within and outside the city. The major concentrations of foundry units are in Rambagh, Nunhai and Foundry Nagar. Many foundry units in Agra have shifted to induction melting furnace which others are still using natural gas fired cupola furnaces.

Agra foundry units cater to the casting requirements of diesel generator-set, automotive, air compressor and other engineering sectors. Based on their average production levels, categorization of foundry industries in the cluster is given in the following table. The foundries employ close to 3,000 direct employees. The estimated annual turnover of the foundry cluster is nearly Rs 550 crore. Some of important products produced in the cluster. Of the foundry units operating in Agra cluster, about 35% production is accounted by cupola furnace-based units (50 foundries). The balance 65% production comes from induction furnace based units (30 foundries). The foundry units mostly use green sand moulding technique which some others use the cold box process for core making.

There are 30 units using induction furnace and 50 units using Cupola furnace. 0.70 Annual production is 0.70 lakh tone of induction furnace and 0.38 lakh tone of cupola furnace. Natural gas and electricity are the major sources of energy for the foundry industry.

V. Energy Consumption

The majority of energy consumption in foundries is in melting. The energy consumption in various processes in foundry is given in table 2.

Table 2- The Energy Consumption in Various Processes in Foundry

SN	Operation	Energy Consumption
1	Melting	70%
2	Moulding and core making	10%
3	Sand plant	6%
4	Lighting	5%
5	Compressor	5%
6	Other	4%

5.1 Energy Consumption in various furnaces:-

The energy consumption (Kwh/tone) in different Furnaces used in foundries is given in table 3.

5.2 Selection of optimal energy efficient furnace for foundries-

As per above table it is obvious that oil fired rotary furnace consumes maximum energy (Kwh/tone) for melting. Contrary to

Table 3 -Energy Consumption (kwh/tone) of Metal Produced in Various

Sn	Particulars	Coke fired Cupola	Oil fired Coke less cupola	Gas fired Coke less cupola	Electric Induction	Electric Plasma	Electric Arc	Oil fired Rotary	Crucible
1	Energy consumed	2272.5	715.0	963.0	1105.0	1205.0	1124.0	4163.0	1970.0

it the oil fired rotary furnace also have following advantages:—

(i) It produces the better quality of molten metal

(ii) the scrap easily available in market can be used

(iii) the rotation of furnace rotates leads to uniform heat transfer which yields better melting rate

(iv) the molten metal is having better fluidity

(v) rejection is minimum

(vi) easy to operate

(vii) It is technically feasible and economically viable

Although it consumes maximum energy (Kwh/tone) for melting but it can be reduced by further experimental investigations

VI. Experimental Investigations

A 200kg rotary furnace was self designed, developed, and installed at department of Mechanical engineering, faculty of engineering, Dayalbagh Educational Institute (D.E.I.), Dayalbagh, Agra and experimental investigations were carried out. Later on one more furnace was installed at foundry shop of M/s Harbhajan Singh Namdhari Enterprises, Industrial estate, Nunihai, Agra.

6.1 Experimental set up- Description of furnace:-

The cylindrical drum is main constituent of oil fired rotary furnace. The charging capacity of furnace decides length and diameter drum. This charging capacity generally is from 200 kg/hr to 2 ton/hr. A pair of roller supporting this drum are driven by electric geared motor. The cylindrical drum contains two cones each welded on each side and are of mild steel approx 7mm thick lined with refractory bricks and mortar for insulation. The burner is placed in one cone and can be fired by oil or natural gas while the duct for heat exchanger in the other. The top portion of drum is provided with tap hole, used for charging and emptying the drum. A covered oil tank containing LDO IS place approx. 7 meters above the burner and drum and connected through valves and pipe line. An oil pump is used to force the oil from oil tank to burner at suitable pressure. The plant lay out is shown in figure 3.

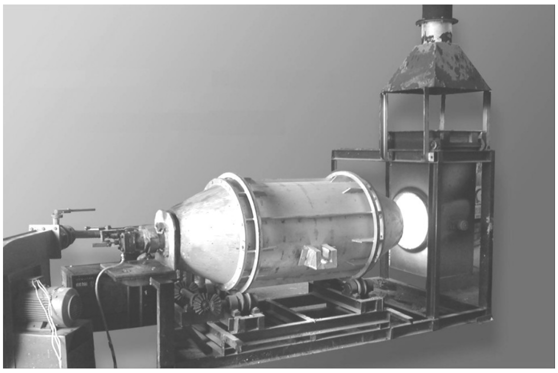

Figure 3: The Oil Fired Rotary Furnace

6. 2. Melting Operation-

The melting *Operation* consists of following steps:-

1. Preheating of furnace before charging
2. Preheating of oil
3. charging with pig iron and scrap from tap hole provided in top portion of drum
4. Rotation after preheating and charging
5. melting

During melting the temperature is measured and controlled by sophisticated devices. When temperature inside furnace reaches approximately 1300°C and flame color is whitish the furnace is stopped.

Tap hole is opened. Furnace is half rotated to lower down the tap hole and metal is transferred in preheated crucibles, inoculation is done, and then transferred to mould shop for pouring

6.3 Experimental investigation 1- Operating furnace under existing conditions at 2 rpm

The furnace was operated at 2 rpm. The recorded observation are given in table 4. (1 liter fuel= 9.9043 kWh)

Table 4: The Recorded Observations when Furnace Operated at 2 RPM

S N	Heat no	Rpm	Time min	Fuel liter	Sp.Fuel con-sumption(lit/kg)	Sp. Energy Consumption (kwh/kg)
1	1	2.0	50.0	92.0	0.460	4.556
2	2	2.0	47.0	90.0	0.450	4.457
3	3	2.0	46.0	87.0	0.435	4.308
4	4	2.0	46.0	86.0	0.430	4.259
5	5	2.0	45.0	83.0	0.415	4.110

The Effect of rotating furnace at 2 rpm on fuel/heat is shown in figure 4.

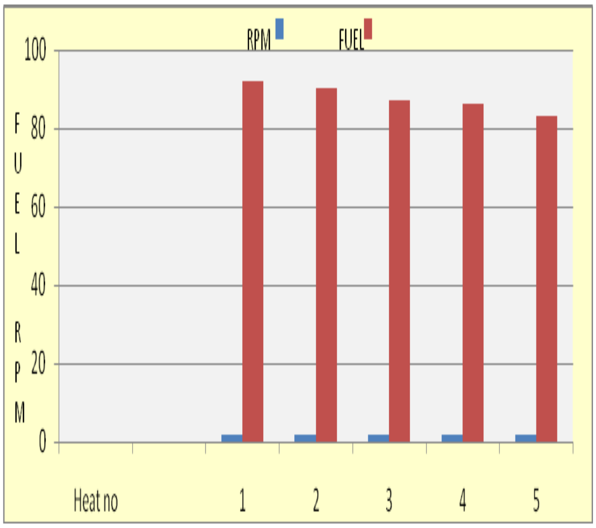

Figure 4: Effect of Rotating Furnace at 2 rpm on Fuel/ Heat

The Effect of rotating furnace at 2 rpm on sp. energy consumption (kwh/kg) is shown in figure 5.

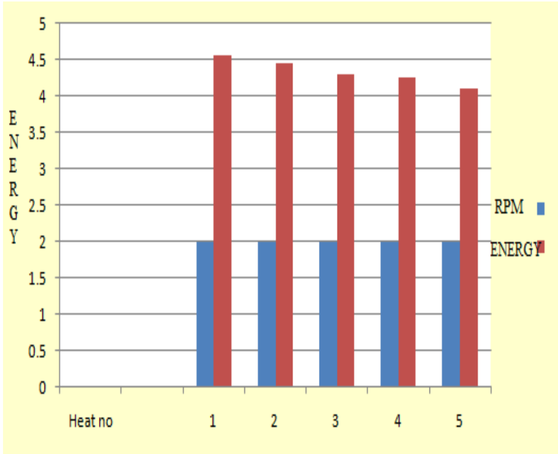

Figure 5 : The Effect of Rotating Furnace at 2 rpm on sp. Energy Consumption (kwh/kg)

Table 5: The Recorded Observations on Reducing rpm from 2 to 0.8

S. N	Rpm	Time (min)	Fuel (lit.)	Melt-ing rate kg/hr	Sp. Energy Kwh/ kg	Sp.Fuel (lit./kg)
1	2.0	50.00	92.0	240.0	4.556	0.460
2	2.0	47.00	88.0	255.0	4.3 57	0.440
3	2.0	45.00	83.0	266.0	4.110	0.415
4	1.6	48.00	88.0	250.0	4.3 57	0.440
5	1.6	45.00	83.0	266.0	4.110	0.415
6	1.6	43.00	80.0	279.0	3.961	0.400
7	1.4	42.00	83.0	286.0	4.110	0.415
8	1.4	40.00	80.0	300.0	3.961	0.400
9	1.4	39.0	78.0	308.0	3.8 62	0.390
10	1.2	40.00	80.0	300.0	3.961	0.400
11	1.2	38.00	78.0	316.0	3.8 62	0.390
12	1.2	37.00	77.0	324.0	3.8 13	0.385
13	1.0	38.00	79.0	316.0	3.912	0.395
14	1.0	36.00	77.0	333.0	3.8 13	0.385
15	1.0	35.00	76.0	343.0	3.763	0.380
16	0.8	42.00	79.0	286.0	3.912	0.395
17	0.8	40.00	78.0	300.0	3.8 62	0.39
18	0.8	38.00	77.0	316.0	3.8 13	0.385

6.4 Experimental investigation 2- Operating furnace at different rpms

The furnace was rotated at different rpms to study the effect of rpm on Time (min), Fuel (lit.), Melting rate kg/hr, Sp Energy Kwh/kg, and Sp.Fuel (lit./kg). The rpm was gradually reduced in steps from 2 to 0.8 and The recorded observations on reducing rpm from 2 to 0.8 are given in table 5

The Effect of reducing rpm from 2 to 0.8 on fuel consumption/ heat is shown given in figure 6 and on energy consumption/heat in figure 7.

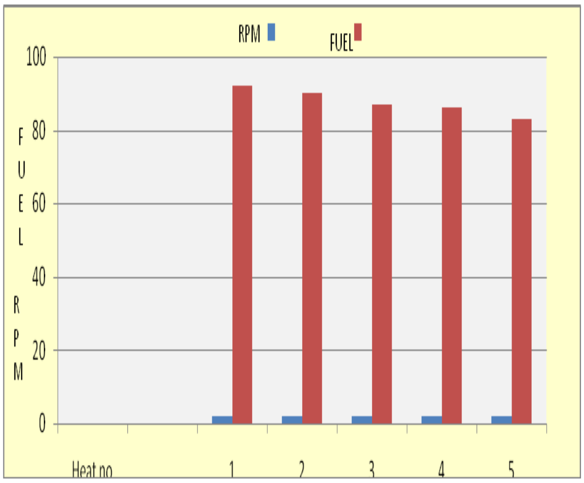

Figure 6- Effect of Reducing rpm on Fuel Consumption/ Heat

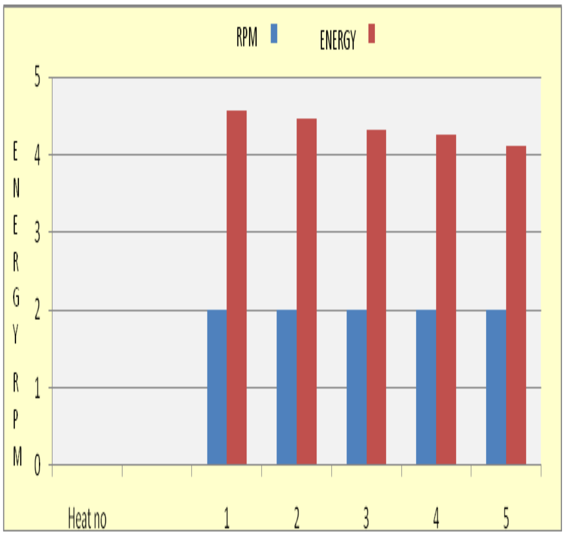

Figure 7- Effect of Reducing rpm on Specific Energy Consumption/ Heat

6.5 Experimental investigation 3- optimal oxygen enrichment of preheated air

It was concluded from earlier Experimental investigation that optimal rotational speed of furnace is 1 rpm. While rotating furnace at 1 rpm the optimally oxygen enriched preheated air was supplied to combustion chamber for combustion of fuel. The recorded observations on all other parameters are given in table 6.

Table 6: Effect of Optimally Oxygen Enriched Preheated and Rotating Furnace at 1 rpm on all other Parameters

Heat	Rpm	Pre-heated air temp 0C	Time min	Fuel liter	Melt-ing rate kg/ hr	Sp. fuel lit/kg	Oxy gen m3	Oxy gen %	Preheated air vol. m3	Preheated air vol. %	Energy Kwh/ kg	Energy. Kwh/ heat
1	1.0	410.0	33.0	56.0	363.0	0.280	39.0	6.9	459.0	75.3	2.773	155.2
2	1.0	418.0	32.0	56.0	375.0	0.280	39.0	6.9	459.0	75.3	2.773	155.2
3	1.0	428.0	32.0	55.0	375.0	0.280	38.5	6.9	451.0	75.4	2.773	152.1
4	1.0	449.0	31.5	54.0	385.0	0.270	38.0	6.9	443.0	75.4	2.674	149.7
5	1.0	454.0	31.0	53.0	387.0	0.265	37.0	6.9	434.5	75.3	2.624	139.0
6	1.0	458.0	30.5	52.0	393.0	0.260	36.6	6.9	426.7	75.4	2.575	133.9
7	1.0	460.0	30.5	52.0	393.4	0.260	36.5	6.9	426.5	75.4	2.575	133.9

The Effect of optimally oxygen enriched preheated and rotating furnace at 1 rpm on fuel/heat (air and oxygen are percentage wise) is shown in figure 8.

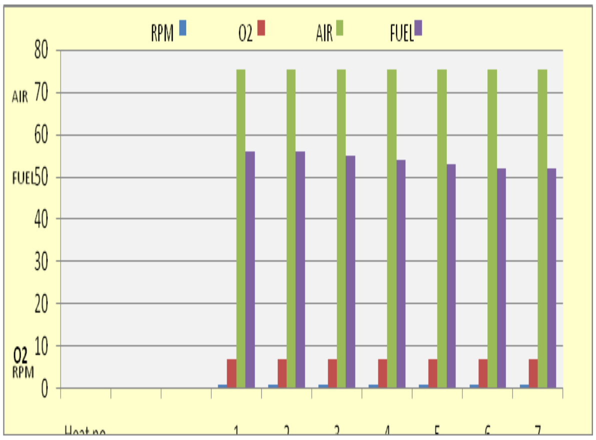

Figure 8 : Effect of Optimally Oxygen Enriched Preheated and Rotating Furnace at 1 rpm on Fuel/Heat (Air and Oxygen are Percentage Wise)

Effect of optimally oxygen enriched preheated and rotating furnace at 1 rpm on energy /heat (kwh/kg) with air and oxygen are percentage wise is shown in figure 9.

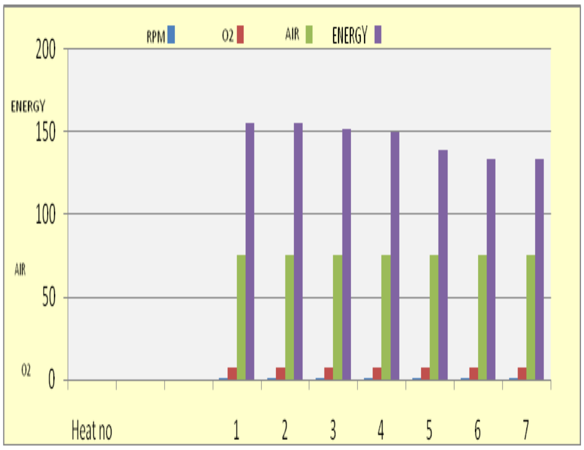

Figure 9: Effect of Optimally Oxygen Enriched Preheated and Rotating Furnace at 1 rpm on Energy / Heat (kwh/kg) with Air and Oxygen are Percentage wise

VII Analysis of Results

The results are based on series of experimental investigations. as per experimental investigation 1 when furnace was operated at 2 rpm the specific fuel consumed was 0.415 liter/kg or 415 liters/ tone and energy consumption was 4.110 kwh / kg or 4110.45 kwh/tone.

Later on in experimental investigation the furnace was rotated at 1 rpm the specific fuel reduced to 0.380 liter/kg or 380 liters/ tone and energy consumption also reduced to 3.763 kwh / kg or 3763 kwh/tone.

In continuation as per experimental investigation 3 While rotating furnace at 1 rpm the optimally oxygen enriched preheated air was supplied to combustion chamber for combustion of fuel. the specific fuel reduced to 0.380 liter/kg 0.260 liter/kg or 260liters/tone and energy consumption also reduced to 2.575 kwh / kg or 2.75 kwh/ tone. The percentage reductions are 37.3% in both cases.

VIII. Conclusions

It can be easily concluded that oil fired rotary furnace when operated at optimal rotational speed of 1 rpm and supplying the optimally oxygen enriched preheated air to combustion chamber for combustion of fuel is an innovative Melting Technique for Energy Efficiency in ferrous foundries.

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