Analysis of Variance and Significance of Innovative Melting Techniques for Energy Conservation in Ferrous Foundries

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Abstract--

The natural sources of energy coal, oil, gas etc. are depleting fast. Energy consumption is major problem being faced by the Indian ferrous foundries. "Bureau of Energy Efficiency, "The Energy Research Institute," Govt. of India New Delhi & other International agencies has reported that energy consumption in Indian ferrous foundries is much more above the required limits and has to be drastically reduced.

This paper deals with Experimental Investigations of oxygen enrichment of preheated air in LDO-fired rotary furnace, for optimal specific fuel and energy consumption. The author conducted experimental investigation on oxygen enrichment of preheated air in a self designed and developed 200 kg rotary furnace in an industry. Initially when furnace was operated under existing conditions, at 2 rpm, the fuel consumption is 0.415 liter/kg or 415 liters/tone and energy consumption is 4.11045 Kwh / kg or 4110.45 Kwh/tone.

In view of reducing the energy consumption, furnace was operated with 6.9% oxygen enrichment of 75.3%-75.4% of theoretically required air at 1 rpm. The fuel consumption reduced to 0.260 liter/kg or 260 liter/tone and energy consumption reduced to 2.575Kwh/kg or 2575.0 Kwh/tone. The percentage reductions are 37.349 %and 37.354% respectively.

Further the furnace was operated with 7.7-8.4% oxygen enrichment of 61.1-64.9% of theoretically required air at 1 rpm. The fuel consumption reduced to 0.208 liter/kg or 208 liter/tone and energy consumption reduced to 2.060kwh/kg or 2060.0 Kwh/tone. The percentage reductions are 49.87% and 49.88% respectively.

The statistical analysis of variance and significance has been carried out to verify the experimentally investigated results to generalize them for any size of furnace. The deviations and variations are within acceptable limits of ±5%.The test of significance rejected the prevailing hypothesis that reducing rpm or increasing oxygen enrichment does not reduces the fuel and energy consumption.

2. Literature survey --

Datta G. L. [1](2001) submitted that in India the energy saving potential varies from industry to industry, ranging from 10% to 0%. A recent study carried out by Administrative Staff College (ASC) Hyderabad India indicates that only few companies maintained records of energy use.

Malhan Rajinder[2](2005) presented the statistics on the foundry industry and suggest measured for Indian foundry to be globally competitive. **Cardona Raman [3](2005)** 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. **TERI[4] (2005) (**The energy and resources institute, New Delhi) expressed its deep concern on excess energy being consumed in Indian ferrous foundries and laid down the limits. Further proposed to penalize the units consuming excess energy.

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Panchal Subodh[5] **(2006)** presented an overview of the upsurge of foundry industry in new century and is very much optimistic about growth of Indian foundry. **Arasu M. et al** [6]**(2006)** 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.

Jain R.K. Gupta B.D.et al [7]**(2007)** presented an overview of energy consideration in ferrous foundries. They are of opinion that keeping in view the present Indian scenario, the techniques for energy conservation must be adopted because energy saved is equal to energy produced, further adding new energy input may be a remote future possibility but immediate need is to save the energy. **Baijya Nath, Pal Prosanto, and Panigrahy K.C** [8]**(2007)** experienced that Indian foundry needs optimization of energy consumption. Most of the units are crippled with usages of rudimentary technologies and unsound operational practices, which are to be upgraded. **Basu Navojit, Chaudhuri Bimal, RoyP.K.**[9] **(2007)** has explained the importance of updating the technology of using gaseous fuels in foundries to curb energy consumption. **Singh Kamlesh Kumar** [10] **(2007)** advocated to use newer and cleaner technology to control the casting rejection and leading to energy conservation. **Pandey G.N., Singh Rajesh, and Sinha A.K.**[11] **(2007)** felt that area of melting has got a lion's share of power consumption and experimentally investigated that oxygen at 8 kg/cm^2 reduces melting time and energy consumption.

Tiedje, Drivsholmetal[12] **(2008)** has preferred to use the modern gating system for savings in energy consumption and use of modern tools for gating design and feeding to optimize production.

MukopadhayayaM.K.[13] **(2009)** stressed upon to control rejections in castings for energy conservation. **ASME Energy Assessment Guide**[14] **(2010)** gives the basic guidance in fulfilling the requirements of the energy assessments standards. The energy assessment standards established procedures for assessing an entire system for energy inputs to work performed. The standards are intended to assist the plant personnel in identifying the energy saving.

Win rock International India, [15]**(2010)** on basis of investigations recommended to install Variable Frequency Drives (VFDs) for ID/FD(Induced draft/Forced draft) fans, oil circulation pumps and doubling machines. A minimum saving of 20% can be realized by installing Variable Frequency Drives (VFDs)**.**

Singh Saurabh Kumar, Chandra Ayush, Malik Kapil [16] **(2011)** has advocated the energy conservation in furnaces by adopting certain techniques like check against infiltration of air, using sealed doors, monitoring $O_2/CO_2/CO$ and controlling excess air, improving burner design, combustion control and proper instrumentation. They are of opinion that combustion chamber should have slight positive pressure, the load should match with furnace capacity, heat exchangers to be used, and flame should not touch the stock. **Mesbah, Khan G., Fartag Amir** [17] **(2011)** strongly believes that energy conservation can effectively be achieved only utilizing effective heat exchangers as they are an important components for processes where energy conservation is achieved through enhanced heat transfer.

Visvanathan, [18] **(2012)** vice president of COINDIA, Coimbatore emphasized the importance of energy efficiency on the changing global scenario and up gradation of technology as well as processes.

Modern Casting Staff. [19]**(20013)** reported that India is third largest producer of industrial castings, after china and USA with total annual production of 9.344 million metric tons. **Gajanan Patange, Mohan Khond** [20] **(2013)** revealed that the two thirds of the energy consumed in a foundry is used for metal casting and holding operation. Considerable energy saving can be achieved by proper attention to this process with proper energy management. **Kotecha J,** [21] **(2013)** preferred to use Divided Blast Cupola over the induction durance as it is not only economical but also energy efficient furnace. **TERI**[22] **(2014).**(The Energy and Resources Institute) Based on the first demonstration of Divided Blast Cupola in the Howrah foundry cluster in 1998 confirmed that divided blast cupola (DBC) is an energy efficient coke-based melting furnace. The DBC typically saves 20–30% of the coke consumed by a conventional cupola, thereby reducing fuel expenses and increasing profits.

Thirumalavan S., Jayavel S. 23 (2014) explained that need for energy is accelerating exponentially and natural sources are depleting fast, the renewable sources are critical to meet increasing demand for energy. They studied an innovative reactor system to produce biodiesel. This reactor is of continuous flow type in which the thorough mixing of reactants takes place simultaneously under isothermal conditions. It has produced excellent results.**TERI**[24] **(2014)** Explained that In general, the melting process consumes the maximum amount of energy in a foundry. Hence, foundries can cut costs by reducing energy (fuel) consumption during the melting process. This can be done by replacing the conventional cupola with the energy efficient divided blast cupola (DBC), or by reducing heat losses in the induction furnace. **Gupta S.P.** [25] **(2004*)*** have described in detail the statistical methods viz. measurement of central values, Median, Mean deviation, Standard deviation, and applied it in all fields of engineering and management.

Jhunjhunwala Bharat[26]**(2008)** have explained various statistical methods viz. correlation and regression analysis, and the students t distribution, as applied in industry for testing the significance of hypothesis and analysis of results. **Ray M, Sharma G.C.**[27] **(2008)** have narrated measures of dispersion, correlation and regression, and elementary theory of testing a hypothesis with errors and critical region.

Ashish, Kaushal O.P[29] **(2009*)*** have successfully applied statistical methods for analysis of results of students of first year B. Tech of R. K. Goyal institute of engineering and technology, Ghaziabad of different subjects, using regression analysis.

Schneider M., Serghini A.et al [28] **(2010)** has described the physical modeling and simulation of core shooting binder hardening and binder degradation during casting using statistical methods. The production of corresponding core has become a limiting factor. **Soti**

3. The foundry industry

The ferrous foundry industry is one of the largest and most ancient methods of production. It plays an important role in industrial development of any country. India is the third largest producer of industrial castings after china and USA. The foundry industry statistics are given in table 1(Editorial staff. Modern castings USA (2013)-

S N	Year	Production of industrial castings in million metric tones
1	2007-2008	7.598
2	2008-2009	7,771,
3	2009-2010	8.442
4	2010-2011	9.017
5	2011-2012	9.994.
6	2012-2013	9.344

Table 1 Production of industrial castings in India

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3.1 *Export orientation-*

The foundry industry is also an export oriented industry. The export of industrial castings from India is given in table 2 (Panchal Subodh, Ramamurthy N, 2006)

Sn	Year	Million metric tones	Rs. In crores
1	2007-2008	2.1280	9363.63
2	2008-2009	1.7893	12183.81
3	2009-2010	1.9203	8727.27
4	2010-2011	2.000	11128.18
5	2011-2012	2.106	11717.97
6	2012-2013	2.201	12349.6 7

Table 2 -The exports of industrial casting from India

3.2 *Major Problems being faced by Indian Foundry Industry*

The following problems are being faced by Indian Foundry Industry -

(1)Restriction by Central Pollution Control Board (2) Restriction by TERI on Energy consumption (3) Technology up gradation

3.3 *Restriction by* TERI on Energy consumption

As per the survey conducted and reports published by **TERI,** "Bureau of Energy Efficiency, the energy consumption in Indian ferrous foundries is much above the required limits and has to be drastically reduced .The limits of energy consumption, as laid down by TERI are given in table 4-

S.N	Description	TERI limits
1	Average specific energy consumption in foundries	
	(a)using electric furnaces	3400MJ(944.5 Kwh)/tone
	(b)using coke fired furnaces	3400MJ(944.5 Kwh)/tone
	(c)using oil fired furnaces>1	7000MJ(1805.55Kwh)/tone
	tone/hr<1 tone/hr	8000MJ(2221.60Kwh)/tone

Table 3- the limits of energy consumption, as laid down by TERI in melting the charge

3.4. *Survey of leading foundries-*

The survey of several leading foundries of India including foundry clusters of Rajkot, Belgaum, Agra, Jalandhar, Pune, Surat etc has been conducted. The problem being faced is of the excess energy consumption in majority of abovementioned foundries.

4. Survey of Agra Foundries-

The survey was conducted in some of the major medium and small scale foundries of Agra, using coke fired cupola (melting rate>3Mt/hr) and relevant data were collected. The same have been used for analysis of technical and economic feasibility of various options.

5. Energy consumption

The distribution of energy consumption in various processes in foundry (energy input 100%) is given in table 4-

SN	Operation	%Energy consumption
1	Transmission losses	3.47 %

2	Melting furnace	78.76%
3	Auxiliary	4.49%
4	Environmental control	5.33 %
5	Utilities	2.97%
6	Molding	2.80 %
7	Finishing	2.18%

Table 4- The distribution of energy consumption in various processes in foundry

5.1 Energy Consumption in various furnaces:-

On basis of survey conducted in various leading foundries the energy consumption (Kwh/tone of metal produced) in different Furnaces is given in table 7

Sn	Para meter	Cupola	Cokeless cupola		Induction	Plasma	Arc	Rotary	Crucible
			Oil	Gas					
1	Energy consumed.	2272.0	714.0	962.0	1103.0	1203.0	1123.0	4162.0	1968.0

Table 5 -Energy consumption (Kwh/tone) of metal produced in various furnaces

6. Selection of furnace for foundries

The energy consumption in rotary furnace is maximum. But it is having following distinct advantages, as compared to other furnaces

(1) Graded and ductile iron can be produced. (2) The molten metal temperature achievable is higher than of other furnaces. (3) The quality of metal produced is better.(4) It can be easily operated on a stand by generator in case of power failure.(5) Low quality contaminated scrap can be used.(6) Due to rotation the uniform heat transfer takes place inside the furnace which gives the better melting rate.(7) Fluidity of molten metal and precision of operation can be controlled.(8) It is economically viable

The major disadvantage is the Energy consumption is more than the other furnaces. Hence if energy consumption is reduced by further investigations then it can be the most suitable furnace. Few experimental investigations have been carried out to achieve the optimal values for energy consumption in rotary furnace.

7. Experimental Investigations-

The experimental investigations were carried out to see the effect of identified parameters on the performance of rotary furnace. For this purpose a 200.0 kg rotary furnace was designed and fabricated. The designed rotary furnace was installed at foundry shop of M/s Harbhajan Singh Namdhari Enterprises, Industrial estate, Nunihai, Agra. Few experiments have also been conducted on another 200.0 kg rotary furnace installed at foundry shop of the department of Mechanical engineering, faculty of engineering, Dayalbagh Educational Institute (D.E.I.), Dayalbagh, Agra.

7.1 Experimental set up- Description of furnace:-

The rotary furnace consists of a horizontal cylindrical drum, the length and diameter of drum depends upon capacity of furnace, which varies from 200.0 kg/hr to 5.0tone/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 7.0 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

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tank containing LDO is located at height of approximately 7.0 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. The plant lay out is shown in fig.1

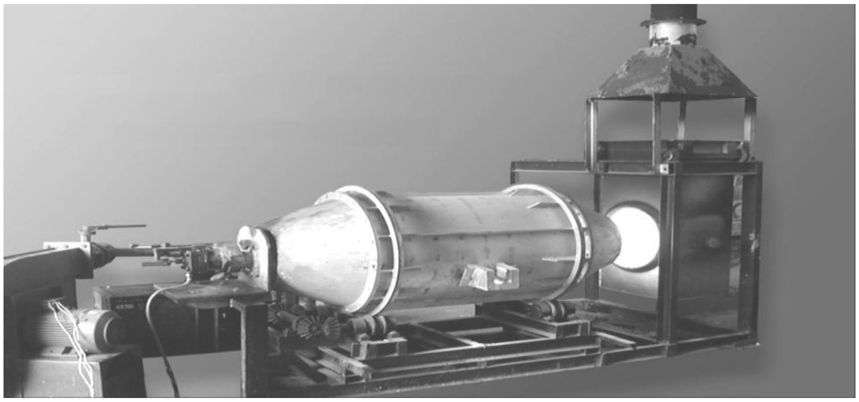

Fig.1-The oil fired rotary furnace

7. 2 Melting Operation-

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

(I) Preheating of oil and furnace-The oil is preheated up to 70ºC and forced at 1.5 kg/cm^2 to preheat the furnace and starting the combustion. (II) Charging–After pre heating, the furnace is charged. (III) Rotation-After sufficient pre heating and charging, the furnace is rotated at desired speed. (IV)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.(V) Tapping-The tape hole is slightly lowered ,opened and metal is transferred into ladles, which are pre heated prior to the transfer of molten metal to avoid heat losses.(VI) Inoculation-The Ferro silicon and Ferro manganese approx. 600 grams per heat are added in molten metal contained in the ladles. (VII) Pouring –The ladles are then carried to moulds and pouring is completed.

7.3 Operating furnace under existing conditions of operation at 2 rpm

The furnace was operated at 2.0 rpm, as per existing conditions; the charge per heat is 200.0 kg. In first heat, as furnace 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 table 8 (1 liter fuel= 9.9043 kWh)

S N	Heat no	Rpm	Time min	Fuel liter	Sp. Fuel (lit/kg)	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

Table 6- Effect of operating furnace at 2 rpm on fuel and energy consumption/heat

7.4 Operating furnace at different rotational speeds (rpms)

To study the effect of rotational speed on energy consumption, the investigations have been made between 0.8 to 2.0 rpm as described below. The rotational speed is changed from 2.0 rpm to 1.6 rpm and then in steps of 0.2 rpm. Experiments have been conducted at different rotational speeds varying from 0.8 to 2.0 rpm. It was difficult to rotate the furnace below 0.8 rpm. For each rotational speed several observations are taken as given in table 7 –

S.N	Rpm	Time (min)	Fuel (lit.)	Melting rate kg/hr	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

Table 7- Effect of operating furnace at different rotational speeds rpm on Sp. Fuel and Sp. energy

7.5 *Operating furnace with oxygen enrichment of preheated air using compact heat exchanger*

Numbers of experiments are conducted, rotating furnace at optimal rotational speed 1.0 rpm, with 6.9% oxygen enrichment of 75.3-75.4% of theoretically required air, and using compact heat exchanger, preheating LDO to 70^0C. The effect of above on flame temperature, time, fuel, melting rate, and specific fuel consumption are given in table 8-

Heat	Rpm	Preheated air temp ^{0}C	Time min	Fuel liter	Melting rate kg/hr	Sp. fuel lit/kg	Oxygen m^3	Oxygen %	Preheated air vol. m^3	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

Table 8- Effect of 6.9% oxygen enrichment of 75.3-75.4% of theoretically required air preheated up to 460.0^{0}C, at optimal rotational speed of 1.0 rpm, on energy consumption/heat

7.6 *Operating furnace with increasing oxygen enrichment and reducing preheated air using compact heat exchanger*

Again the experiments were conducted with 7.7-8.4% oxygen enrichment of 61.1-64.9% of theoretically required air, and using compact heat exchanger, preheating LDO to 70^{0}C and air up till 476^{0}C. The effect of above on flame temperature, time, fuel, melting rate, and specific fuel consumption are given in table 11-

Heat no	Rpm	Preheated air temp ^{0}C	Flame temp ^{0}C	Time Min.	Fuel liters	Melting rate kg/hr	Specific fuel cons. lit/kg	Oxygen cons m^3	Oxygen cons %	Preheated air cons m^3	Preheated air cons %	Energy Kwh/ heat
1	1	424.0	1745.0	32.0	48.0	375.00	0.240	49.3	8.3	319.0	61.1	475.40
2	1	430.0	1752.0	32.0	47.0	375.00	0.235	49.0	8.4	319.0	62.4	465.50
3	1	437.0	1755.0	32.0	46.5	375.00	0.232	48.0	8.3	317.0	62.6	460.54
4	1	448.0	1762.0	31.5	45.8	380.95	0.229	46.8	8.2	313.0	62.8	453.61
5	1	465.0	1770.0.	31.0	45.0	387.00	0.225	46.0	8.1	310.0	63.3	445.69
6	1	470.0	1772.0	30.5	44.6	393.44	0.223	45.0	8.1	309.0	63.3	441.73
7	1	472.0	1773.0	30.5	43.8	393.44	0.219	45.0	8.3	302.0	63.4	433.80
8	1	474.0	1776.0	30.4	42.9	394.73	0.214	43.0	8.1	297.0	63.6	424.89
9	1	475.0	1778.0	30.1	42.0	398.67	0.210	41.5	8.0	295.0	64.5	415.98
10	1	476.0	1778.0	30.1	41.6	398.67	0.208	40.0	7.7	294.0	64.9	412.01

Table 9-Effect of 7.7-8.4% oxygen enrichment of 61.1 -64.9% of theoretically required air preheated up to 476^{0}C,using compact heat exchanger,rotating furnace at optimal rotational speed of 1.0 rpm, on specific fuel, specific energy, flame temperature, time, fuel, and melting rate

8. Statistical analysis of variance and significance

8.1 Effect of rotational speed (RPM) on specific fuel consumption

The statistical analysis of results (specific fuel consumption) is being made. The observations as given in table 7 are reproduced for ready references for analysis as table 10

S.N	Rpm	Time (min)	Fuel (lit.)	Melting rate kg/hr	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

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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

Table 10- Table 7 reproduced for ready references

The graphical representation of effect of RPM on specific fuel consumption, as per observed values table 12 is shown in fig 2-

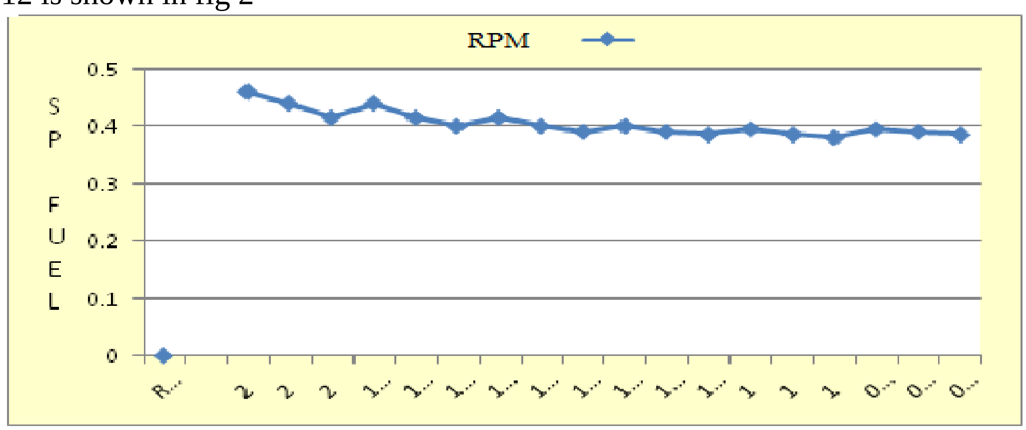

Fig 2- Effect of RPM on specific fuel consumption

Calculations -The calculations of rotational speed (RPM) and specific fuel consumption are given in table 11-

Sn	**X**	**x=x-x'**	**x^2**	**Y**	**Y =Y-y'**	**y^2**	**xy**
1	2.0	0.5	0.25	0.460	0.056	0.003136	0.028
2	2.0	0.5	0.25	0.440	0.036	0.001296	0.018
3	2.0	0.5	0.25	0.415	0.011	0.000121	0.0055
4	1.6	0.1	0.01	0.440	0.036	0.001296	0.0036

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5	1.6	0.1	0.01	0.415	0.011	0.000121	0.0011
6	1.6	0.1	0.01	0.400	0.036	0.000016	0.0036
7	1.4	-0.1	0.01	0.415	0.011	0.000121	-0.0011
8	1.4	-0.1	0.01	0.400	0.036	0.000016	-0.0036
9	1.4	-0.1	0.01	0.390	-0.414	0.000196	0.0414
10	1.2	-0.3	0.09	0.400	0.036	0.000016	-0.0108
11	1.2	-0.3	0.09	0.390	-0.414	0.000196	0.1242
12	1.2	-0.3	0.09	0.385	-0.019	0.000361	0.0057
13	1.0	-0.5	0.25	0.395	-0.009	0.000081	0.0045
14	1.0	-0.5	0.25	0.385	-0.019	0.000361	0.0095
15	1.0	-0.5	0.25	0.380	-0.024	0.000576	0.012
16	0.8	-0.7	0.49	0.395	-0.009	0.000081	0.0063
17	0.8	-0.7	0.49	0.390	-0.414	0.000196	0.2898
18	0.8	-0.7	0.49	0.385	-0.019	0.000361	0.0133
	$\hat{x}$=1.50			$\hat{Y}$=0.404			
Σ	27	0	3.3	7.28	0.008	0.00854	0.3031

Table 11 -The calculations of rotational speed (RPM) and specific fuel consumption

Equation of Y on X. Y=specific fuel X=RPM

$(Y - \hat{y}) = b_{yx} (X - \hat{x})$

$\hat{y}$=0.404, $\hat{x}$ = 1.50

$(Y - 0.404) = byx (X - 1.50)$ -------------------------- (1)

Where $b_{yx} = r\frac{\sigma y}{\sigma x} = \frac{\Sigma xy}{\Sigma x^2} = \frac{0.30310}{3.3000} = 0.0918484$

Putting it in (1) $Y - 0.404 = 0.0918484 (X - 1.50)$

On Solving **Y= 0.0918484 X +0.266228**-------------------------- (2)

Specific fuel consumption = 0. 0918484 (RPM) +0.266228

The calculated values, observed values, variation and % variation of specific fuel based on RPM are given in table 12 –

SN	X	Y calculated	Y observed	variation	% variation
1	2.0	Y= 0.0918484(2)+0.266228= 0.4499248	0.460	-0.0100752	-2.23931%
2	2.0	Y= 0.0918484(2)+0.266228= 0.4499248	0.440	0.0099248	+1.98798%
3	2.0	Y= 0.0918484(2)+0.266228= 0.4499248	0.415	0.034924	+7.762199%
4	1.6	Y= 0.0918484(1.6)+0.266228 =0.413185	0.440	-0.026814	-6.489721%
5	1.6	Y= 0.0918484(1.6)+0.266228 =0.413185	0.415	-0.0018135	-0.439272%
6	1.6	Y= 0.0918484(1.6)+0.266228 =0.413185	0.400	-0.013185	-3.191061%
7	1.4	Y= 0.0918484(1.4)+0.266228 =0.394815	0.415	-0.020184	-5.112323%
8	1.4	Y= 0.0918484(1.4)+0.266228 =0.394815	0.400	-0.005185	-1.313273%
9	1.4	Y= 0.0918484(1.4)+0.266228 =0.394815	0.390	0.004815	+1.219558%
10	1.2	Y= 0.0918484(1.2)+0.266228 =0.376446	0.400	-0.023554	-6.256939%

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11	1.2	Y= 0.0918484(1.2)+0.266228 =0.376446	0.390	-0.013554	-3.600503%
12	1.2	Y= 0.0918484(1.2)+0.266228 =0.376446	0.385	-0.008554	-2.272304%
13	1.0	Y= 0.0918484(1.0)+0.266228 =0.358076	0.395	-0.036923	-10.31166%
14	1.0	Y= 0.0918484(1.0)+0.266228 =0.358076	0.385	-0.026924	-7.519074%
15	1.0	Y= 0.0918484(1.0)+0.266228 =0.358076	0.380	-0.021924	-6.122722%
16	0.8	Y= 0.0918484(0.8)+0.266228 =0.339758	0.395	-0.055241	-13.81861%
17	0.8	Y= 0.0918484(0.8)+0.266228 =0.339758	0.390	-0.050242	-14.78758%
18	0.8	Y= 0.0918484(0.8)+0.266228 =0.339758	0.385	-0.045242	-13.31594%

Table 12-The calculated values, observed values, variation, % variation of specific fuel /rpm

The variation of observed values and calculated values of specific fuel consumption, based on RPM are presented in figure3, where blue line represents calculated values and red line the actual values of specific fuel(lit/kg)

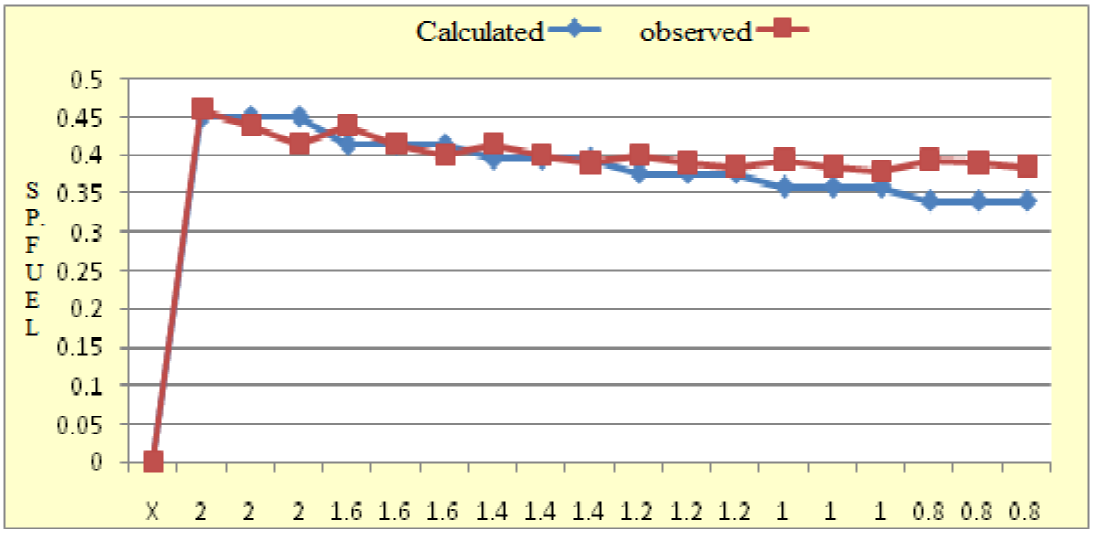

Fig 3- The variation of observed values and calculated values of specific fuel

The prediction of specific fuel consumption based on RPM is given in table13–

Table 13- The prediction of specific fuel consumption based on RPM

8.1.1 Calculations of Deviation & variance of Effect of rotational speed (RPM) on specific fuel consumption

The observations taken during experiment, at 2.0 rpm and 1.0 rpm are given in table 14(part of table 7reproduced)

Sn	rpm	Time (min)	Fuel (lit.)	Specific Fuel lit/kg.	Melting rate kg/hr
1	2.0	50.00	92.0	0.460	240.0
2	2.0	47.00	88.0	0.440	255.0
3	2.0	45.00	83.0	0.415	266.0
4	1.0	38.00	79.0	0.395	316.0
5	1.0	36.00	77.0	0.385	333.0
6	1.0	35.00	76.0	0.380	343.0

S.N	Predictor	Regression coefficient	Regression Equation
1	Specific fuel consumption	b_{yx} = 0.0918484	Y= 0.0918484 X + 0.266228 Specific fuel consumption = 0.0918484 (RPM)+0.266228

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Table 14-Effect of rotational speed (rpm) (2-1) on specific fuel consumption

At 2.0 rpm –No. of observations=3

1. Median n is odd=3+1=4/2= 2nd term =0.440
2. Mean $\hat{x}=\frac{\Sigma x}{N}=\frac{0.460+0.440+0.415}{3}=\frac{1.315}{3}=0.438333$
3. Standard Deviation $\sigma=\sqrt{\frac{\Sigma x^2}{n}-\bar{X}^2}$

Calculations of Standard Deviation σ

$\bar{X}^2=(0.43833)^2=0.192136111$, and $\Sigma x^2=[0.46^2+0.44^2+0.415^2]=0.57745$

$\frac{\Sigma x^2}{n}=\frac{0.5774}{3}=0.19248333$

Standard Deviation $\sigma=\sqrt{\frac{\Sigma x^2}{n}-\bar{X}^2}=\sqrt{0.1924833-0.192136111}=0.018633902$

4. Variance $\sigma^2=(0.018633902)^2=0.000347219$
5. Coefficient of variance=0.018633902x100/0.438333=4.2510835 %
6. Mean deviation=[0.020+0.000+0.025]/3=0.045/3=0.015

The Deviations, variations etc. are compiled in table 15-

1	2	3	4	5	6
Median	Mean	Standard deviation	Mean deviation	Variance	Coefficient of variance%
0.440	0.438333	0.018633902	0.015	0.000347219	4.2510835

Table 15- Deviations and variation of table 5.15, page 144-2.0 rpm

At 1.0 rpm – No. of observations=3

1. Median n is odd=3+1=4/2=2nd term = 0.385
2. Mean $\hat{x}=\frac{\Sigma x}{N}=\frac{0.395+0.385+0.380}{3}=\frac{1.16}{3}=0.38666666$
3. Calculations of Standard Deviation σ

$\bar{X}^2=(0.38666666)^2=0.1495111111$ and $\Sigma x^2=[0.395^2+0.385^2+0.380^2]=0.44865$

$\frac{\Sigma x^2}{n}=\frac{0.44864}{3}=0.14955$

Standard Deviation $\sigma=\sqrt{\frac{\Sigma x^2}{n}-\bar{X}^2}=\sqrt{0.14955-0.1495111111}=0.006236096$

4. Variation $\sigma^2=[0.14955-0.1495111111]=0.0000388889$[
5. Coefficient of variance=0.006236096x100/0.38666666=1.61278347%
6. Mean deviation==[0.01+0.00+0.005]/3=0.015/3=0.015

The Deviations, variations etc are compiled in table 16-

1	2	3	4	5	6
Median	Mean	Standard deviation	Mean deviation	variance	Coefficient of variation
0.385	0.38666666	0.006236096	0.015	0.0000388889[	1.61278347%

Table 16- Deviations and variation of table 5.15 -1.0 rpm

8.1.2 The *comparisons of all Deviations and variation at rotational speed2 rpm and 1 rpm*

The comparisons of all Deviations and variation at 2 rpm and 1 rpm are given in table 17-

sn	parameter	2 rpm	1 rpm	Absolute variation	Percentage variation
1	Median	0.440	0.385	0.055	5.5
2	Mean	0.438333	0.38666666	0.05166634	5.16
3	Standard deviation	0.018633902	0.006236096	0.012397806	1.2397806
4	Mean deviation	0.015	0.015	0.000	0.000
5	variance	0.000347219	0.0000388889	0.0003083301	0.03083
6	%Coefficient of variation	4.2510835%	1.61278347%	2.63830003%	2.63830003%

Table 17- Comparison of Deviations and variation at 2.0 rpm and 1.0 rpm

8. 1.3 -The graphical comparison

The graphical comparison of all Deviations and variation at 2 rpm and 1 rpm is given in figure4

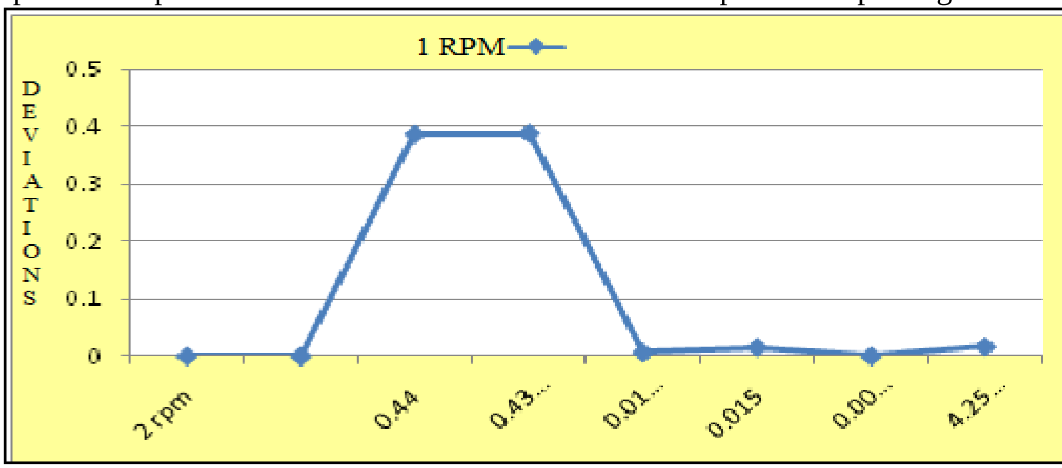

Figure 4 -Comparisons of all Deviations and variation at 2 rpm and 1 rpm respectively

8.1.4 Test of significance

All industries using rotary furnace for melting iron are rotating it at 2.0 rpm. The general opinion among all other furnace operators and industry experts is that "reducing the rpm does not reduce the specific fuel consumption"

The average specific fuel consumption reduced from 0.460 lit/kg at 2 rpm to 0.385 lit/kg at 1.0/0.8 rpm. We take the two samples. Sample size n_1 and n_2 from the same population (experimental investigations) and we use the t test. The test of significance is carried out using Students t-distribution.

According to this the hypothesis is that "reducing the rpm from 2.0 to 1.0, does not reduce the specific fuel consumption" i, e, $H_0 : \mu < \mu_0$. The t test is being applied. The hypothesis is tested in following sections.

"t" in t-distribution refers to i, e, - $\mathbf{t} = \frac{(\bar{X}-\bar{Y})}{s\sqrt{\frac{1}{n_1}+\frac{1}{n_2}}}$ ---------------------------------- (I.3)

(a) At 2.0 rpm

n_1=no. of observations =3, s_1=*0.018633902* $(s_1)^2$= *0.000347222333*, $\bar{X} = 0.43833$

(b)At 1.0 rpm

n_2= no. of observations =3, s_2=0.006236096, $(s_2)^2$=0.0000388889, $\bar{Y} = 0.38666$

$S^2 = \frac{[n_1 s_1^2] + [n2 \quad s_2^2]}{n_1+n_2-2} = \frac{[3\times0.000347222333]+[3\times0.0000388889]}{3+3-2} = \frac{0.001158333699}{4}$ =0.00028958342
S=0.01701715

,- $t = \frac{(\bar{X}-\bar{Y})}{s\sqrt{\frac{1}{n_1}+\frac{1}{n_2}}} = \frac{(0.438333-0.38666666)}{0.01701715\sqrt{2/3}} = \frac{(0.05166634)}{0.01701715X0.81649658}$ = 3.718489

Tabulated value for 4 degrees of freedom of 5% level of significance =2.132
The t calculated is, 3.718489. It is greater than tabulated value of t= 2.132. The difference is significant. We apply a right tail test (figure5) and lie in region of rejection

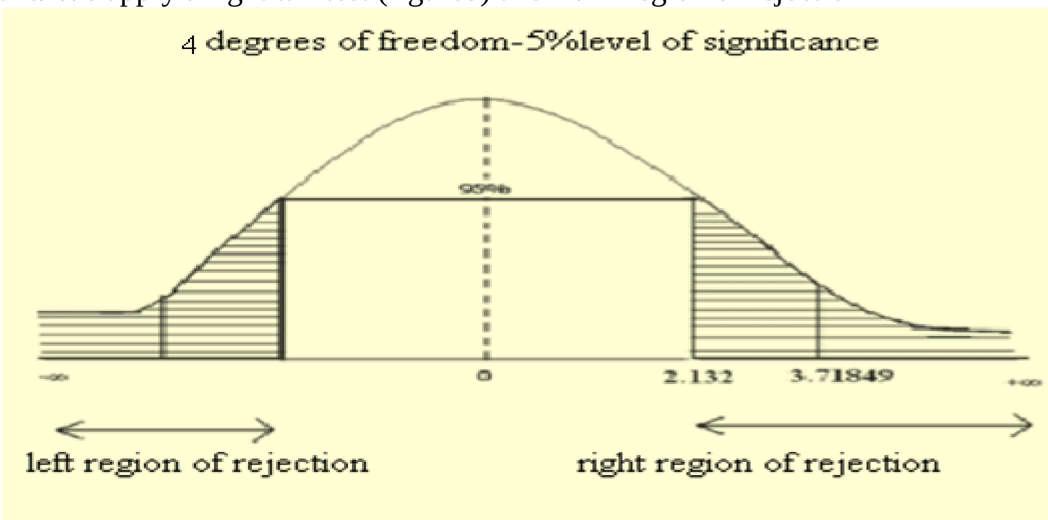

Figure 5-- Test of significance of reducing RPM from 2 to 1

Results:

It is evident that average variation is -0.0100752 and variation between the calculated values and an observed value of specific fuel consumption based on RPM is -4.821644%. It is within acceptable limits of ± 5%, hence the regression analysis and regression equations are acceptable.

The standard deviation and coefficient of variation at 2 rpm are 0.018633902 and 0.000347219, whereas at 1 rpm are 0.006236096 and 0.0000388889 respectively.

For test of hypothesis, for 4 degrees of freedom and 5% level of significance, the t calculated is 3.718489 which is greater than tabulated value of t(2.132).A right tail test is applied (figure5). We lie in region of rejection. Hence prevailing hypothesis, is rejected

8.2 Effect of Oxygen consumption (m^3) on specific fuel consumption-

The graphical representation of effect of oxygen consumption (m^3) on specific fuel consumption as per observed values (table) is shown in fig 6

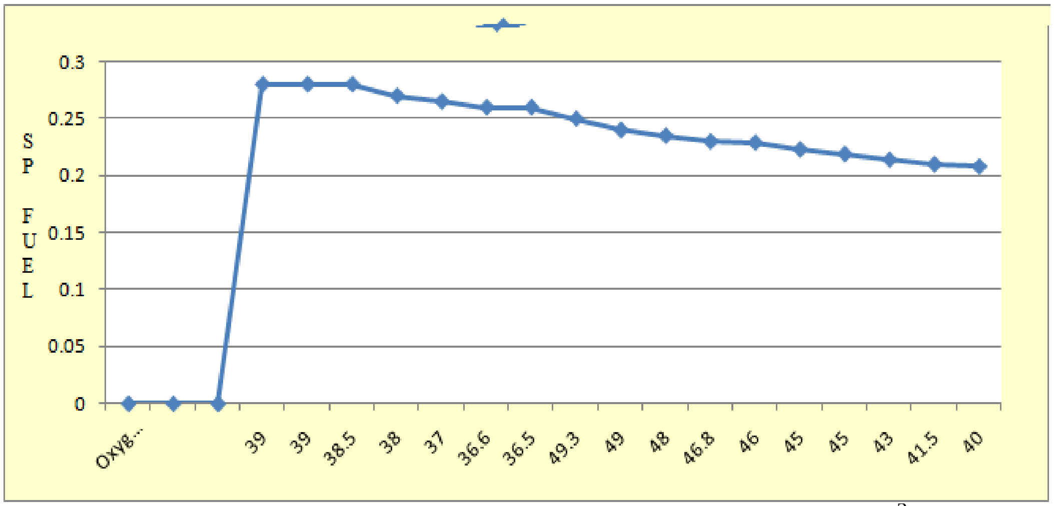

Fig 6-The graphical representation of effect of oxygen consumption (m^3) on specific fuel consumption

Calculations- The calculations of oxygen and specific fuel consumption are given in Table18
Y= specific fuel consumption, X= oxygen consumption

Sn	X	$x=X-\bar{x}$	x^2	Y	$y= Y -\bar{y}$	y2	xy
1	49.3	3.94	15.5236	0.240	0.0165	0.00027225000	0.06501
2	49	3.64	13.2496	0.235	0.0115	0.00013225000	0.04186
3	48	2.64	6.9696	0.232	0.0085	0.00007225000	0.02244
4	46.8	1.44	2.0736	0.229	0.0055	0.00003025000	0.00792
5	46	0.64	0.4096	0.225	0.0015	0.00000225000	0.00096
6	45	-0.36	0.1296	0.223	0.0005	0.00000025000	0.00018
7	45	-0.36	0.1296	0.219	0.0045	0.00002025000	0.00162
8	43	-2.36	5.5696	0.214	0.0095	0.00009025000	0.02242
9	41.5	-3.86	14.8996	0.21	0.0135	0.00018225000	0.05211
10	40	-5.36	28.7296	0.208	0.0155	0.00024025000	0.08308
∑	453.6	0.00	87.684	2.235	-5.6E-17	0.00104250000	0.2976

Table18– The calculations of oxygen and specific fuel consumption. $\bar{x}$=45.36, $\bar{y}$=0.2235
Regression equation of specific fuel consumption vs. oxygen consumption.
X is oxygen, Y is specific fuel. Equation of Y on X

$(Y - \hat{y}) = b_{yx} (X - \hat{x})$ $\hat{y}$=0.2235, $\hat{x}$ = 45.36

$Y - 0.2235 = b_{yx} (X - 45.36)$ ------------------- (I.20)

Where $b_{yx} = r\frac{\sigma y}{\sigma x} = \frac{\Sigma xy}{\Sigma x^2} = \frac{0.2976}{87.684} = 0.003394$, Putting it in (1)

$Y - 0.2235 = 0.003394 (X - 45.36)$

On Solving **Y=0.003394 X+0.069548**---------- (I.21)

Or **Specific fuel consumption = 0.003394 (oxygen consumption) +0.069548**

The calculated values, observed values, variation and % variation of specific fuel based on oxygen consumption are given in table 19-

Sn	X	Y observed	Y calculated	Variation	% Variation
1	49.3	0.240	Y=0.003394(49.3)+0.069548= 0.236872	– 0.003128	– 1.320%
2	49.0	0.235	Y=0.003394(49)+0.069548 = 0.235854	+.000854	+0.3621%
3	48.0	0.232	Y = 0.003394(48) +0.069548 = 0.23246	+0.00046	+0.19788%
4	46.8	0.229	Y 0.003394(46.8) +0.069548 = 0.22838	– 0.006128	– 0.2683%
5	46.0	0.225	Y = 0.003394(46) +0.069548 = 0.22567	+0.000672	+ 0.29777%
6	45.0	0.223	Y = 0.003394(45) +0.069548 = 0.222278	–0.000722	–0.324818%
7	45.0	0.219	Y = 0.003394 (45) +0.069548 = 0.222278	0.0003278	+0.01474%
8	43.0	0.214	Y = 0.003394 (43) +0.069548 = 0.21549	0.00149	++0.69144%
9	41.5	0.21	Y = 0.003394(41.5) +0.069548 = 0.210399	0.000399	0.189639%
10	40	0.208	Y = 0.003394(40) +0.069548 = 0.205308	–0.002692	–1.3100%

Table 19-The calculated values, observed values, variation, % variation of specific fuel based on oxygen consumption

The variation of observed values and calculated values of specific fuel, based on oxygen consumption, are more clearly presented in figure 7 where blue line represents its observed values and red line the calculated values-

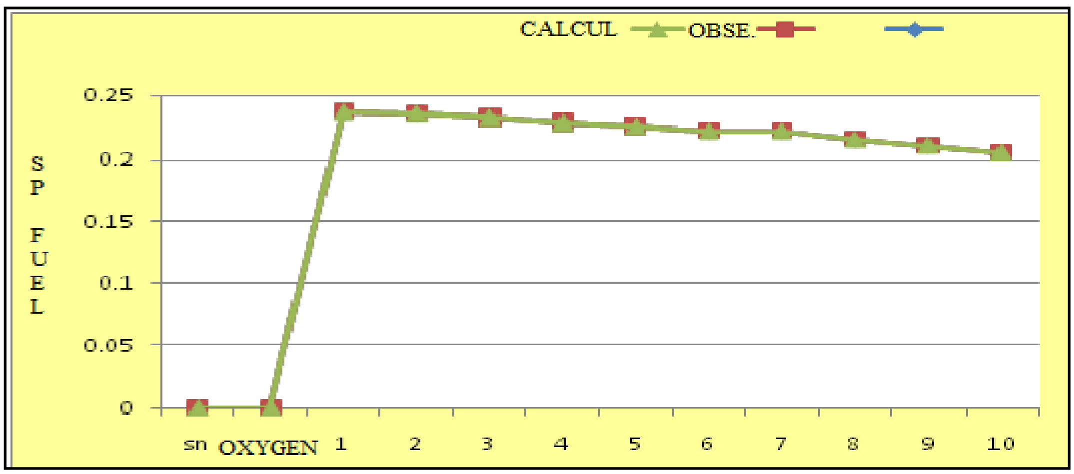

Fig 7--The observed and calculated values of spec. fuel based on oxygen consumption,

The prediction of specific fuel consumption based on oxygen consumption is given in table 20-

Sn	Predictor	Regression coefficient	Regression Equation
1	Specific fuel consumption	b_{yx} = 0.003394	Y= 0.003394X +0.069548 Specific fuel=0.003394(oxygen consumption +0.069548

Table 20- The prediction of specific fuel consumption based on oxygen consumption

8.2.1 Effect of 6.9% oxygen enrichment of 75.3-75.4 % of theoretically required air

The table is reproduced for ready references as table 21—

Heat	charge	Rpm	Preheated air temp ^{0}C	Flame temp ^{0}C	Time min	Fuel liter	Melting rate kg/hr	Specific fuel cons lit/kg	Oxygen cons m^3	Oxy Gen cons%	Preheated air cons. m^3	Preheated air air cons %
1	200.0	1.0	410.0	1710.0	33.0	56.0	363.0	0.280	39.0	6.9	459.0	75.3
2	200.0	1.0	418.0	1722.0	32.0	56.0	375.0	0.280	39.0	6.9	459.0	75.3
3	200.0	1.0	428.0	1730.0	32.0	55.0	375.0	0.280	38.5	6.9	451.0	75.4
4	200.0	1.0	449.0	1746.0	31.5	54.0	385.0	0.270	38.0	6.9	443.0	75.4
5	200.0	1.0	454.0	1752.0	31.0	53.0	387.0	0.265	37.0	6.9	434.5	75.3
6	200.0	1.0	458.0	1754.0	30.5	52.0	393.0	0.260	36.6	6.9	426.7	75.4
7	200.0	1.0	460.0	1755.0	30.5	52.0	393.4	0.260	36.5	6.9	426.5	75.4

Table 21--Effect of 6.9% oxygen enrichment of 75.3-75.4% of theoretically required air preheated up to 460.0^{0}C, using compact heat exchanger, rotating furnace at optimal rotational speed of 1.0 rpm, on flame temperature, time, fuel, melting rate, and specific fuel consumption.

8.2.1 Calculations of Deviation &Variance of Effect of 6.9% oxygen enrichment of 75.3-75.4 % of theoretically required air

1. Median, 2. Mean 3.Standard Deviation, 3. Variance 4. Coefficient of variation

1. Median n is odd n =7 $\left(\frac{n^{th}+1}{2}\right)^{th}=\left(\frac{7+1}{2}\right)=4^{th}$ term = 0.270

2. Mean $\bar{X} = \frac{\Sigma x}{N} = \frac{1.895}{7}$ =0.270714285, $\bar{X}^2$=0.073286224,

3. Standard Deviation $\sigma = \sqrt{\frac{\Sigma x^2}{n} - \bar{X}^2}$

Calculations of Standard Deviation σ

Σx = [0.280x3+0.270+0.265+0.260x2] =1.895 ,

Σx^2 = [0.280^2x3+0.270^2+0.265^2+0.260^2x2] = [0.2352+0.0729+0.070225+0.1352] =0.513525

$\frac{\Sigma x^2}{n}$= 0.075932142

Standard Deviation $\sigma = \sqrt{\frac{\Sigma x^2}{n} - \bar{X}^2} = \sqrt{0.075932142 - 0.073286224}$ = 0.051438495

4. Mean deviation $=\frac{1}{n}\sum|X-A| = \frac{1}{n}\sum|D|$ variations of items from medians are given in table 22 (ΣD = 0.055, n=7,)

Sn	1	2	3	4	5	6	7
deviation	0.01	0.01	0.01	0.00	0.005	0.01	0.01

Table 22-Variations from median

Mean deviation $=\frac{0.055}{7}$ = 0.007857

5. Variance $\sigma^2 = \left[\frac{\Sigma x^2}{n} - \left(\frac{\Sigma x}{n}\right)^2\right] = [0.075932142 - 0.073286224]$=0.002645918

Coefficient of Variance- CV=$\left[\frac{\sigma}{\bar{x}}\right] x\,100$= [$\frac{0.051438495}{0.270714285}$] x 100= 19.0010272%

Out of the two series for which the Coefficient of Variance is greater is said to be more variable or less consistent

The deviations and variations are compiled in table 23-

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1	2	3	4	5	6
Median	Mean	Standard deviation	Mean deviation	variance	Coefficient .of variation
0.270	0.270714285	0.051438495	0.007857	0.002645918	19.0010272%

Table 23- The deviations and variations of Effect of 6.9% oxygen enrichment of 75.3-75.4 % of theoretically required air

8.2.2 Effect of 7.7-8.4% oxygen enrichment of 61.1-64.9% of theoretically required air

. The observations taken during experiment are reproduced in table24 -

Heat no	Charge kg	Rpm	Preheated air temp ^{0}C	Flame Temp ^{0}C	Time Min.	Fuel liter	Melting rate kg/hr	Specific fuel cons. lit/kg	Oxygen cons m^3	Oxygen cons %	Preheated air cons m^3	Preheated air cons %
1	200.0	1.0	424.0	1745.0	32.0	48.0	375.00	0.240	49.3	8.3	319.0	61.1
2	200.0	1.0	430.0	1752.0	32.0	47.0	375.00	0.235	49.0	8.4	319.0	62.4
3	200.0	1.0	437.0	1755.0	32.0	46.5	375.00	0.232	48.0	8.3	317.0	62.6
4	200.0	1.0	448.0	1762.0	31.5	45.8	380.95	0.229	46.8	8.2	313.0	62.8
5	200.0	1.0	465.0	1770.0.	31.0	45.0	387.00	0.225	46.0	8.1	310.0	63.3
6	200.0	1.0	470.0	1772.0	30.5	44.6	393.44	0.223	45.0	8.1	309.0	63.3
7	200.0	1.0	472.0	1773.0	30.5	43.8	393.44	0.219	45.0	8.3	302.0	63.4
8	200.0	1.0	474.0	1776.0	30.4	42.9	394.73	0.214	43.0	8.1	297.0	63.6
9	200.0	1.0	475.0	1778.0	30.1	42.0	398.67	0.210	41.5	8.0	295.0	64.5
10	200.0	1.0	476.0	1778.0	30.1	41.6	398.67	0.208	40.0	7.7	294.0	64.9

Table 24 Effect of 7.7-8.4% oxygen enrichment of 61.1 -64.9% of theoretically required air preheated up to 476^{0}C,using compact heat exchanger,rotating furnace at optimal rotational speed of 1.0 rpm, on flame temperature, time, fuel, melting rate, and specific fuel consumption

8.2.3 Calculations of Deviation & Variance of Effect of 7.7-8.4% oxygen enrichment of 61.1-64.9% of theoretically required air

1. Median, 2. Mean 3.Standard Deviation, 3. Variance 4. Coefficient of variation

1. Median *n* is even n = 10 $\frac{n^{th}}{2}$term = 5th term

$$\text{Median} = \frac{\left(\frac{n^{th}}{2}term\right)+\left(\frac{n^{th}}{2}+1\right)^{th} term}{2} = \frac{5^{th}+6^{th}\,term}{2} = \frac{0.225+0.223}{2} = \frac{0.448}{2} = 0.224$$

2. Mean $== \frac{\Sigma x}{N} = \frac{2.235}{10} = 0.2235 = \hat{x}$, $\bar{X}^2 = 0.04995225$, $\Sigma x = 2.235$

3. Standard Deviation $\sigma = \sqrt{\frac{\Sigma x^2}{n} - \bar{X}^2}$ $\bar{X}^2$ =0.04995225, $\Sigma \mathbf{x}^2$ =0.500565

Calculations of Standard Deviation σ

$\hat{X}$=[0.24+0.235+0.232+0.229+0.225+0.233+0.219+0.214+0.210+0.208]/10=0.2235.n=10

Σx^2=[0.24^2+0.235^2+0.232^2+0.229^2+0.225^2+0.233^2+0.219^2+0.214^2+0.210^2+0.208^2]=0.500565

Standard Deviation $\sigma = \sqrt{\frac{\Sigma x^2}{n} - \bar{X}^2} = \sqrt{\frac{0.500565}{10} - 0.04995225} = 0.010210288$

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4. Mean deviation $=\frac{1}{n}\sum|X-A| = \frac{1}{n}\sum|D|$ variations of items from medians are given in table 25

Sn	1	2	3	4	5	6	7	8	9	10
deviation	0.016	0.011	0.008	0.005	0.001	0.001	0.005	0.010	0.014	0.016

Table 25- Variations from median

$\Sigma D = 0.087$, n=10 Mean deviation $=\frac{0.087}{10} = 0.0087$

5. Variance $\sigma^2 = \left[\frac{\Sigma x^2}{n} - \left(\frac{\Sigma x}{n}\right)^2\right] = [0.0500565 - 0.04995225]=0.00010425$

6. Coefficient of Variance- CV$=\left[\frac{\sigma}{\hat{x}}\right] x100=$ [$\frac{0.010210288}{0.2235}$] x100= 4.56836152%

-The deviations and variations are compiled in table 26

1	2	3	4	5	6
Median	Mean	Standard deviation	Mean deviation	variance	%Coefficient of variation
0.224	0.2235	0.010210288	0.0087	0.00010425	4.56836152

Table 26- The deviations and variations of table 5.27

8.2.4 The comparisons of all Deviations and variation oxygen enrichment 6.9% and 7.8%

The comparisons of all Deviations and variation at 2 rpm and 1 rpm are given in table 27

sn	parameter	***6.9***	***7.7—8.4***	Absolute variation	Percentage variation
1	Median	0.270	0.224	0.046	4.66
2	Mean	0.270714285	0.2235	0.047214285	4.7214285
3	Standard deviation	0.051438495	0.010210288	0.041228207	4.1228207
4	Mean deviation	0.007857	0.0087	-0.000843	-0.0843
5	variance	0.002645918	0.00010425	0.006054082	0.6054082
6	Coefficient of variation	19.0010272	4.56836152	14.43266568	14.43266568

Table 27- comparisons of all Deviations and variation oxygen enrichment 6.9% and 7.8%

The comparisons of all Deviations and variation oxygen enrichment 6.9% and 7.8% is shown in figure 8.The 6.9% oxygen has been taken on x axis

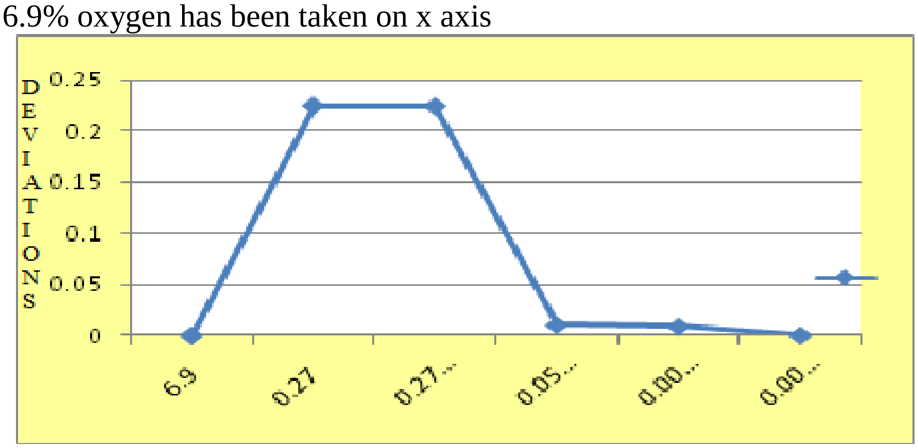

Fig 8- comparisons of all Deviations and variation oxygen enrichment 6.9% and 7.8%

8.2.5 Test of Significance

We take the two samples (sample size n_1 and n_2) from the same population (experimental investigation) and we use the t test. Among the furnace operators, and industrial experts the existing opinion is that **"Increasing the oxygen enrichment and reducing the air volume does not reduces the specific fuel consumption".** According to this the hypothesis is that **"Increasing the oxygen enrichment and reducing the air volume does not reduces the specific fuel consumption"** i,e, $H_0\ \mu < \mu_0$.

"t" in t-distribution refers,- $\mathbf{t} = \frac{(\bar{X}-\bar{Y})}{s\sqrt{\frac{1}{n_1}+\frac{1}{n_2}}}$

(a)Table 8(6.9%oxygen enrichment of, 75% of theoretically required air)

n_1=no. of observations=7, standard deviation S_1=0.051438495, $\bar{X} = 0.270714285$

$(S_1)^2$ =0.002645918857

(b)Table 9(7.7-8.4% oxygen enrichment of 61.1 -64.9% of theoretically required air)

n_2==no. of observations=10, standard deviation, S_2=0.010210288,$\bar{Y} = 0.2235$,

$(S_2)^2$ =0.00010425

$$S^2 = \frac{[n_1 s_1^2] + [n2\ \ s_2^2]}{n_1+n_2-2} = \frac{[7\times0.002645918857]+[10\times0.00010425]}{7+10-2} = \frac{0.0195639332}{15} = 0.001304262133$$

S=0.036114569

$$t = \frac{(\bar{X}-\bar{Y})}{s\sqrt{\frac{1}{n_1}+\frac{1}{n_2}}} = \frac{(0.270714285-0.2235)}{0.036114569\sqrt{\frac{1}{7}+\frac{1}{10}}} = \frac{(0.047214285)}{0.036114569\text{x}0.49280538} = 2.652$$

Tabulated value for 15 degrees of freedom of 5% level of significance = 1.753

The test of significance with tabulated and calculated values of t are shown in figure 9

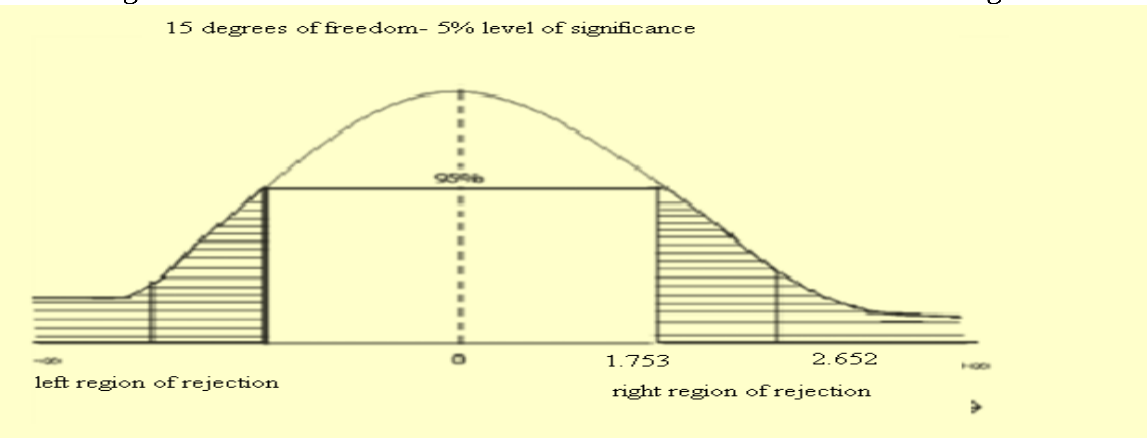

Fig. 9-test of significance of increasing oxygen enrichment

Results:

The average variation= +0.0003717, the average % variation= –0.14695%. The Standard. Deviation is 0.051438495 and variance is 0.002645918. The variation between calculated values and observed values of Spec. fuel based on oxygen consumption is -0.14695%. It is within acceptable range of ± 5%, hence the regression analysis and regression equations, are acceptable.

For test of significance, t calculated is 2.652 which is greater than tabulated value of t=1.753 (fig 9). The difference is significant. We lie in right region of rejection. Therefore

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"Increasing the oxygen and reducing the air volume effectively reduces the specific fuel consumption"

9. Results and discussions

Initially furnace was operated under existing conditions of operation without oxygen enrichment of preheated air, the fuel consumption is 0.415 liter/kg or 415 liters/tone and energy consumption is 4.110 kwh / kg or 4110.45 kwh/tone and

In view of reducing the energy consumption, furnace was operated with 6.9% oxygen enrichment of 75.3%-75.4% of theoretically required air. The fuel consumption reduced to 0.260 liter/kg or 260 liter/tone and energy consumption reduced to 2.575kwh/kg or 2575.0 kwh/tone. The percentage reductions are 37.349 %and 37.354% respectively.

Further the furnace was operated with 7.7-8.4% oxygen enrichment of 61.1-64.9% of theoretically required air. The fuel consumption reduced to 0.208 liter/kg or 208 liter/tone and energy consumption reduced to 2.060kwh/kg or 2060.0 kwh/tone. The percentage reductions are 49.87%and49.88% respectively.

To generalize the results for any larger size furnace the statistical analysis was carried out. The standard deviation and coefficient of variation at 2 rpm are 0.018633902 and 0.000347219, whereas at 1 rpm are 0.006236096 and 0.0000388889 respectively. Further the test of significance was also carried out. The t calculated is, 3.718489. It is greater than tabulated value of t= 2.132. The difference is significant. We apply a right tail test (figure 12) and lie in region of rejection. Hence the deviations and variations are positive and within specified limit of ±5% hence are acceptable further reducing the RPM from 2 to 1, effectively reduces the specific fuel consumption".

The Standard. Deviation and coefficient of variation of 6.9% oxygen enrichment of 75.3-75.4 % of theoretically required air are 0.051438495 and 0.002645918 respectively and for 7.7-8.4% oxygen enrichment of 61.1-64.9% air is 0.010210288 and 0.00010425 respectively. Further the test of significance was also carried out. The t calculated is, 2.652. It is greater than tabulated value of t which is 1.753. The difference is significant. We apply a right tail test and lie in region of rejection.

10. Conclusions

It is concluded that when operated under standard conditions, optimal rotational speed 1.0 rpm, with 6.9% oxygen enrichment of 75.3-75.4% of theoretically required air, preheated up to 460 ^{0}C (using compact heat exchanger), preheating LDO to 70^{0}C, it is an energy efficient furnace for ferrous foundries. Under these operating conditions not only the fuel and energy consumption are significantly reduced but also the performance of furnace is improved. Hence it is recommended for ferrous foundries

The deviations and variations at 2 rpm and 1 rpm are positive and within specified limit of ±5% hence are acceptable. All deviations and variations at 6.9% oxygen enrichment of 75.3-75.4 % of theoretically required air and for 7.7-8.4% oxygen enrichment of 61.1-64.9% air are also within specified limit of ±5%, hence are also acceptable.

For rpm The test of significance indicates that t calculated is, 3.718489 which is greater than tabulated value of t= 2.132. It is concluded that –"reducing the rpm from 2 to 1 reduces the specific fuel consumption"

Hence the hypothesis –**"reducing the rpm and does not reduce the specific fuel consumption"** is **REJECTED.** This test of significance resembles with results of experimental investigations.

For oxygen enrichment the test of significance indicates that t calculated is, 2.652. It is greater than tabulated value of t which is 1.753. The difference is significant It is concluded that –"Increasing the oxygen and reducing the air volume effectively reduces the specific fuel consumption"

Hence the hypothesis –**"Increasing the oxygen and reducing the air volume does not reduce the specific fuel consumption"** is **REJECTED.** This test of significance resembles with results of experimental investigations.

The statistical analysis enumerates the variability of results of experimental investigations.

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12. Remarks

The above experimental investigations were carried out on a 200.0 kg rotary furnace. When operated with 6.9% oxygen enrichment of 75.3%-75.4% of theoretically required air the average specific fuel consumption was 0.260 liter/kg and energy consumption was 2.575kwh/kg 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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