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Experimental Investigations and Statistical Analysis of Perceptive Sustainable Energy Efficient Furnace

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ABSTRACT

This technical paper is based upon actual experimental investigations carried out by author on 200kg capacity oil fired rotary furnace installed at foundry shop of namdhari enterprises Agra for reducing its fuel/energy consumption. Normally the furnace was being rotated at 2 rpm by workforce without having any technical reasoning behind it. During experimental investigations the furnace was rotated at different rpms and optimal rpm was found to be 1. Not only the results were surprisingly favorable but the performance of furnace was also significantly improved To validate these results the statistical analysis was carried out which also confirmed these results.

Keywords:— *Oil fired Rotary furnace, rpm, TERI, Energy Consumption*

I. INTRODUCTION

The Indian foundry industry manufacturers metal cast components for applications in Auto, Tractor, Railways, Machine tools, Sanitary, Pipe Fittings, Defence, Aerospace, Earth Moving, Textile, Cement, Electrical, Power machinery, Pumps / Valves, Wind turbile generators etc. Foundry Industry has a turnover of approx. USD 19 billion with export approx. USD 2.5 billion. However, Grey iron castings have the major share i.e. approx 68% of total castings produced. There are approx 5000 units out of which 90% can be classified as MSMEs.Approx 1500 units are having International Quality Accreditation. Several large foundries are modern & globally competitive. Govt. Focusing on “make in India”, “ease of doing business”, infrastructure & easing FDI norms to promote investments in manufacturing & new initiatives & cooperations in skill development. India to become fastest growing economy >7.5% Per year as per forecasts of leading International Institutions.

II. LITERATURE SURVEY

Baker EHW [1]1963 was the first person to explain the working of Rotary furnace**.** AFS [2] 1979 instead of any other fuel advised to use Pulverized coal for operation of Rotary furnace. Mike Yeoman [3]2000 is of the opinion that for future growth and survival of ferrous foundries the energy consumption must be reduced. Jain R.K., Singh R, [4] 2006, successfully utilized mathematical and numerical techniques for optimizing the basic parameters of oil fired Rotary furnace. Baijayanath**,** Prosantopal Panigrahy K.C.[5] 2007 advocated the use of latest technology for energy conservation in foundries. G.N. Pandey et al [6] 2007 suggested for fuel lean reburn system and supplying oxygen for complete combustion. Basu Navojit, Roy P.K.[7] 2007 concluded that gaseous fuels are more helpful to achieve net adiabatic flame temperature which leads to optimal radiation heat transfer and reduces energy consumption in melting. Jain R.K., Gupta B, D.[8] 2008 evaluated the effect of flame temperature on performance of rotary furnace. Jain R.K., Singh R [9]2008 used excel solver (Microsoft excel) for modeling rotary furnace parameters. M. Arasu, L. Rogers Jeffrey[10] 2009 detailed the major causes of energy consumption in foundries. EPRI Centre[11] 2010 on basis of experimental investigations confirmed that waste gases from the furnace carry 20% of sensible heat away. This sensible heat can be recovered by using suitable heat exchanger and preheating air, required for combustion of fuel, up to temperature of 370°C. It will reduce the energy consumption by 57 Kwh/ tone. DYL Chan, KH Yang, JD Lee, GB Hong [12] 2010 Performed on-site energy audits of 118 firms in the Taiwanese iron and steel industry during 2000–2008 and established a national database presenting information and energy. Mesbah, G.Khan, Amir Fartag[13] 2011, strongly believes that energy conservation can effectively be achieved only by utilizing effective heat exchangers, as they are important components for processes where energy conservation is achieved through enhanced heat transfer. Hak Young Kim, Seung Wook Beek[14] 2011 has used the fuel-lean re-burn system. It has maintained fuel lean conditions in the furnace, in oxygen-enhanced combustion, to replace additional air system, which reduces energy and emissions significantly. DYL Chan, et al [15] 2014-concluded after detailed study of Taiwan industries that the energy efficiency would be improved by 33% if bat (best available technology) were applied. The analysis results can serve as a benchmark for these industries and as a base case for stimulating changes aimed at more efficient energy utilization. José O. Valderrama et al [16]. 2014 have analyzed the use of artificial neural networks (ANNs) for the correlation and prediction of the melting temperature of ionic liquids (ILs) and concluded that the lack of knowledge on what are the properties that most affect melting are the main causes of the present incapability of accurately predicting the melting temperature of ionic liquids. Bala Divya Potnuru, et al 17 [2018] detailed the performance evaluation of furnace in a industry. The technique adopted is heat balance which is a means of determining the thermal efficiency of the furnace and comparing the relative values of heat losses. W.W. Levi [18]1947 much long back developed a relationship between carbon content in the feed and taped metal of furnace. Pehlke [19] 1963 was the first person to predict cupola performance in different conditions of operation using thermo chemical model developed by himself. Karunakar and Datta[20]2000 used artificial neural networks for controlling operation of cupola furnace. Gupta S.P. [21] (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[22] (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. Soti Ashish, Kaushal O.P[23] (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, cause and effect diagram, process capability analysis, and concluded that statistical methods worked another wonder in education sector also.

III. Production Statistics

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

Table 1- Production of Industrial Castings in Million Metric Tons

SN	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
7	2013-2014	9.810
8	2014-2015	10.021
9	2015-2016	10.770
10	2016-2017	11.35

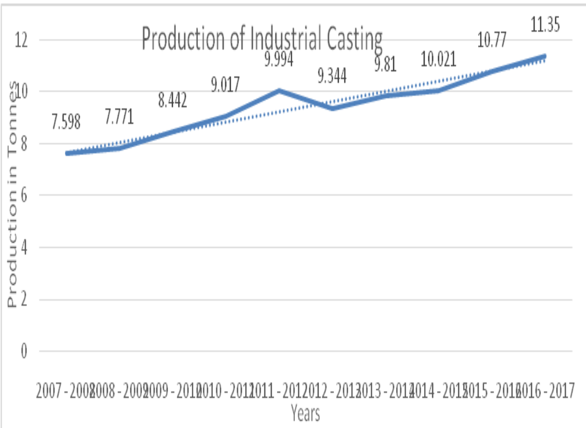

Figure 1: The Graphical Presentation of Production of Industrial Castings in Million Metric Tons

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. Exports Import Trends are given in table 2 and shown in figure 2.

Table 2: Exports Import Trends of Industrial Castings from India

SN	Year	Total exports million USD	Total imports million USD
1	2012-13	2572	1013
2	2013-14	2618	927
3	2014-15	2729	946
4	2015-16	2503	926
5	2016-17	2366	962

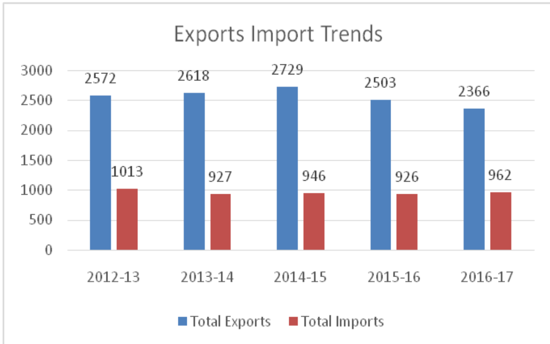

Figure 2: The Graphical Presentation of Exports Import Trends of Industrial Castings in Million Metric Tons

3.2 Problems of Indian Foundry Industry-

The major problems based upon survey conducted are :-

(1) Usage of old redumented technology

(2) Excess Energy consumption in melting by furnaces

IV. 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 3.

Table 3: The Limits of Energy Consumption as Imposed by TERI

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

4. 1 Energy consumption in various processes

The majority of energy consumption in foundries is in melting. The energy consumption in various processes in foundry is given in table 4.

Table 4: 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%

4.2 Energy Consumption in various furnaces:-

The energy consumption (Kwh/tone) in different Furnaces used for melting in foundries is given in table 5.

4.3 Identification of parameters and selection of sustainable Energy efficient furnace

The comparison of furnaces for optimal values of identified parameters is given in table 6.

Table 6: The Comparison of Various Furnaces for Optimal Values of Identified Parameters

SN	Parameters	Furnace Selected
1	Energy consumption kwh/tone	Cokeless cupola (LDO)
2	Emission level	Rotary
3	Melting rate (a) small size (b) medium	Rotary, Cokeless cupola, arc, Induction,
4	Capital and Installation cost	Rotary
5	Operating cost / tone of metal produced	Cokeless cupola, arc induction
6	Reliability and Safety	Rotary
7	Labor and technical personal (a) Labor requirement (b) Technical staff	 Rotary Rotary
8	Maintenance	Rotary

4.4 Selection of furnace based upon Identified parameters –

The rotary furnace is selected as it is having several distinct advantages over other furnaces. One major disadvantage is its high energy consumption which can be reduced after critical experimental investigations and analysis.

Table 5 -Energy Consumption (kwh/tone) of Metal Produced in Various Furnaces

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

4.5 The Rotary Furnace

The Rotary furnace, shown in figure 3, is very simple melting Unit, mainly consisting of a drum of required size having a cone on each side lined with refractory, firebricks and ramming mass having alumina as a constituent. The drum is placed on rollers so that it may either be locked or rotated slowly about its central axis. The rollers are driven by small electric motor. At one end of the drum a suitable burner is placed with appropriate blower system and combustion gases exit from the other end. One of the cones accommodates the burner whereas the other cone is used for exit of hot flue gases, and charging of materials, and it also accommodates the ducts for heat exchanger. The tap hole is located in the cylindrical wall half way between the ends. This tap hole is used for pouring the molten metal into ladles and also for charging of materials.

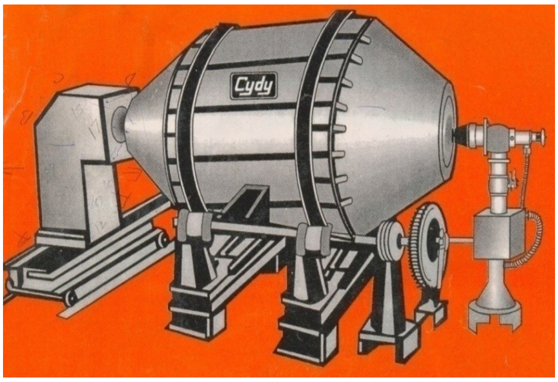

Figure 3 : The Rotary Furnace

V. 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.

5.1 Experimental Investigations Operating furnace under existing conditions of operation—

The furnace was operated at 2.0 rpm, as per existing conditions; the charge per heat is 200.0 kg. Observations recorded during the experiment are given in table 7.

5.1.1 Analysis of Results-

The effect of Operating furnace under existing conditions of operation is analyzed in following sections

5.1.2 Effect of Rotational Speed on Energy Consumption-

The total energy consumption consists of energy consumption in-

1. melting the charge
2. fuel consumption unit

Table 7: Observations Recorded During the Investigation 1 of Operating Furnace at 2.0 RPM

SN	Heat no	Rpm	Time min	Fuel lit.	Spec. Fuel (lit/kg)	Melting Rate (kg/hr)	Excess air m3	Excess air %	Flame temper. °C
1	1	2.0	50.0	92.0	0.460	240.0	1320.0	30.45	1310.0
2	2	2.0	47.0	90.0	0.450	255.3	1290.0	30.41	1314.0
3	3	2.0	46.0	87.0	0.435	260.8	1240.0	30.24	1325.0
4	4	2.0	46.0	86.0	0.430	266.0	1220.0	30.10	1334.0
5	5	2.0	45.0	83.0	0.415	266.0	1175.0	30.04	1350.0

3. plant and equipment
4. pollution control equipment
5. shot blasting machine.

The effect of rotational speed, 2.0 rpm, on energy consumption is given in table 8—

Table 8: The analysis of rotational speed, 2.0 rpm, on energy consumption (kwh/ tone)

SN	Particulars	Energy consumed	Total energy consumption kwh/tone
1	Fuel consumed in melting LDO=415Liter/ tone	415x9.9047=4110.450kwh/tone	4110.45kwh
2	Fuel combustion unit(SPT burner) (a) Oilfiltering-pump1hp (b) Heating element	0.746 kw 2.00kw=2.746kw for 266.00kg/hr	10.323 kwh
3	Plant& equipments a. Blower 7.5 hp b.Geared motor 2 hp	5.595 kwh 1.492kwh=7.087 kwhfor 266.00kg/hr =26.642 kwh/ tone	26.642kwh
4	Pollution Control Equipment: a. ID Fan 5 hp b. Motor 1 hp	3.73 kwh 0.746kwh=4.476 kwhfor266.00 kg/hr=16.827 kwh/tone	16.827 kwh
5	Shot Blasting M/c Capacity 3T/Hr.Motor 30H.P. = 22.38kwh	22.38/3 = 7.46 kwh/ tone	7.46 kwh
		Grand Total	4171.702 =4172.00

5.2 Experimental Investigations 2 – operating furnace at different rpms

To study the effect of rotational speed the investigations have been made between 0.8 to 2.0 rpm as described below. For each rotational speed several observations are taken as given in table 9 -

Table 9 : Observations Recorded During the Experimental Investigation 2 of Operating Furnace at Different RPMs

S.N	Rpm	Time (min)	Fuel (lit.)	Melting rate kg/hr
1	2.0	50.00	92.0	240.0
2	2.0	47.00	88.0	255.0
3	2.0	45.00	83.0	266.0
4	1.6	48.00	88.0	250.0
5	1.6	45.00	83.0	266.0
6	1.6	43.00	80.0	279.0
7	1.4	42.00	83.0	286.0
8	1.4	40.00	80.0	300.0
9	1.4	39.0	78.0	308.0
10	1.2	40.00	80.0	300.0
11	1.2	38.00	78.0	316.0
12	1.2	37.00	77.0	324.0
13	1.0	38.00	79.0	316.0
14	1.0	36.00	77.0	333.0
15	1.0	35.00	76.0	343.0
16	0.8	42.00	79.0	286.0
17	0.8	40.00	78.0	300.0
18	0.8	38.00	77.0	316.0

6.2.1 Analysis of results

The effect of Operating furnace under existing conditions of operation is analyzed in following sections

6.2.2 The effect of reducing rpm from 2.0 to 0.8 on energy consumption and performance of furnace is given in Table 10 -

Table 10 : The Improvement in Energy Consumption and Performance of Furnace by Changing RPM from 2.0 to 1.0

SN	Parameters	Absolute reduction		Percentage Reductions/ improvements
		2.0rpm	1.0 rpm	
1 (a)	Melting time (minutes)	45	35	22.22%
(b)	Minimum Fuel consumption (liters)	83	76	7.22%
(c)	Specific fuel consumption (lit/kg)	0.415	0.380	8.43%
(d)	Energy consumption in melting (kwh/ tone)	4110.45	3763.78	8.43 %
(e)	Melting losses	5%	3%	2%
2(a)	Melting rate (kg/hr)	266	343	28.94%
(b)	No. of heats per day(200 kg)	5	6	20%
3	Annual savings			
(a)	Annual energy consumption	--------	--------	1.247x10 5 kwh
(b)	Annual fuel (liters)			12.60kliters
(c)	Annual fuel cost			Rs.3.78 lakhs
4	Annual production(tones)	300	360	20%

VI. CONCLUSIONS

It is concluded from these Experimental Investigation that optimal rotational speed is 1.0 rpm. The rotational speed affects the melting rate and energy consumption. The optimal values of different parameters are obtained at 1.0 rpm. Energy consumption has reduced by 8.89%. The melting rate has improved by 28.94%. The detailed study of rotary furnace revealed that optimal rotational speed is 1.0 rpm. Hence optimal rotational speed selected is1.0 rpm

7.1. The Statistical Analysis of Results

To validate the results and analysis of above experimental investigations the statistical analysis of results (specific fuel consumption) is being made. The statistical /regression analysis has been carried out from 2, rpm to 0.8 rpm. The observations as given in table 9 (Observations recorded during the experimental investigation 2 of operating furnace at different rpms) are considered for this statistical /regression analysis

7.2 Effect of changing RPM on specific fuel consumption-

The graphical representation of effect of RPM on specific fuel consumption, as per observed values is shown in figure 4.

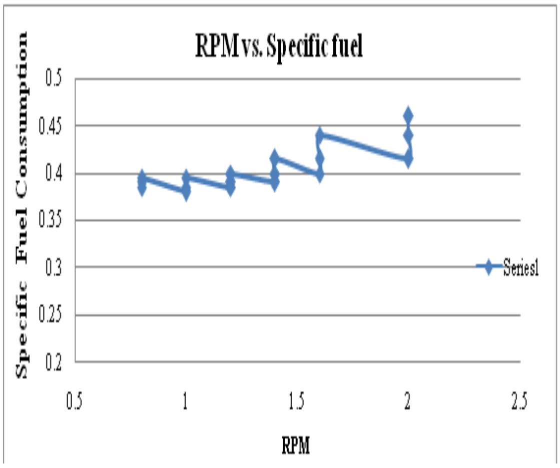

Figure 4: Effect of changing RPM on specific fuel consumption, as per observed values

7.3 Calculations

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

Table 11 : The Calculations of Rotational Speed (RPM) and Specific Fuel Consumption

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
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 $\hat{x}$ $\hat{Y}$

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

$(Y - 0.404) = b_{yx} (X - 1.50)$ -------------------------- (I.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-------------------------- (I. 2)

Specific fuel consumption = 0.0918484 0. (RPM) +0.266228

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

Table 12 : The Calculated Values, Observed Values, Variation, Percent Variation of Specific Fuel /RPM

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%
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% =0.0918484(2) =0.0918484(0.8)

IX. Results

The average variation is -0.0100752, the % variation is -4.821644%

The variation of observed values and calculated values of specific fuel consumption, and RPM are more clearly presented in figure 5, where red line represents observed values and green line the calculated values.

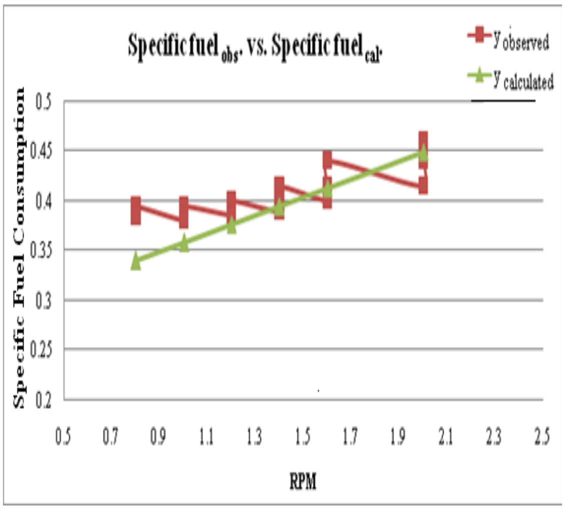

Figure 5: The Variation of Observed Values and Calculated Values of Specific Fuel

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

Table 13: The Prediction of Specific Fuel Consumption Based on RPM

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

From figure 5 and table 12, it is evident that variation between the calculated values and observed values 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.

IX. Conclusions

1. The optimal rotational speed is 1.0 rpm. It is very clear that rotational speed affects the fuel and, energy consumption. The optimal values of different parameters are obtained at 1.0 rpm. Energy consumption has reduced by 8.89%. Hence the optima l rotational speed is1.0 rpm

2. The statistical analysis reveals that variation between the calculated values and observed values of specific fuel consumption based on RPM is -4.821644%. It is within acceptable limits of ± 5%, hence the statistical/ regression analysis and regression equations are acceptable.

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