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Modelling and Optimization of Flame Temperature in Preheated Air Combustion of Rotary Furnace using Regression Analysis

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ABSTRACT

This paper presents an interactive approach of regression analysis, being used as tool for optimizing the flame temperature of oil fired rotary furnace. The author has attempted to solve a crucial problem of enhancing a flame temperature in melting process in ferrous foundries. Based on experiments carried on a self designed and developed 200 kg rotary furnace in a foundry, the optimal process parameters for optimal Flame Temperature ^{0}C, selected are, time of melting of 200 kg charge (minutes), Melting Rate(kg/hr) and fuel consumption These parameters significantly effects the flame temperature therefore they must be controlled carefully. An attempt has been made to establish a correlation between flame temperature considered as an output parameter and time of melting of charge (minutes), Melting Rate(kg/hr) and fuel consumption considered as input parameters.

It is expected that this model of regression analysis may prove practically beneficial for industry by estimating the effect of input process parameters for predicting the flame temperature of furnace, prior to its actual operation, to solve the crucial issue of foundries. The high flame temperature leads to optimal fuel and energy consumption.

All measurements of time of melting of charge (minutes), Melting Rate(kg/hr) and fuel consumption were recorded. The multipass counterflow heat exchanger was used for optimizing process parameters. The results of regression analysis correlates with the experimental results

Keywords:*—Rotary furnace, Flame temperature, Preheated air combustion, melting rate.*

I. INTRODUCTION

The rotary furnace is a type of cylindrical furnace which continuously rotates on its axis to generate uniform heat transfer during melting process to create better quality casting. This cylindrical structure is supported on a rigid steel frame. The two cone shaped structures are welded at both ends. One accommodates the burner system and other the duct for exit of hot flue gases. Generally a recuperator is attached to this duct at exit for better waste heat utilization. The furnace is being run by furnace oil or light diesel oil but it can also be operated by natural gas, biofuels etc.

It has proven to be an ecofriendly and energy efficient furnace. The emission levels are within specified limits of CPCB (Central Pollution Control Board of India) and energy consumption under TERI (The Energy and Resources Institute) norms. It has found its applicability in small and medium scale foundries. One of its several advantages is producing better quality casting. Rotary furnace is shown in figure 1. The dimensions of self designed and developed rotary furnace are given in figure 2.

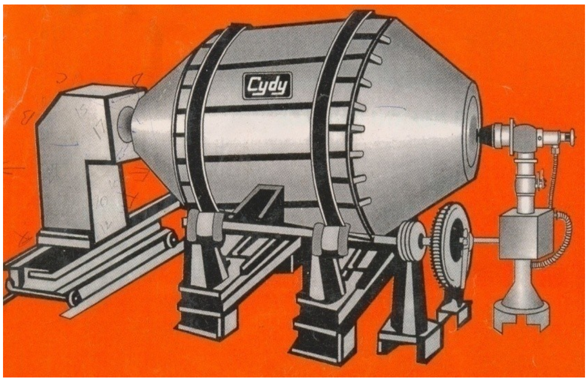

Figure 1: The oil fired rotary furnace

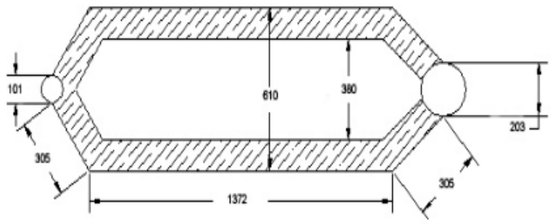

Figure 2: The dimensions of self designed and developed rotary furnace

II. Literature Review

Baker E.H.W. [1] described the working principles, characteristics, and operation of rotary furnace

Yutaka Suzukawa, Shunichi Sugiyama, Yoshimichi Hino, Munehiro IshiokaI, Sao Mori[2] 1997 designed and developed a combustion system . The temperature of preheated air was considerably increased which lead to increased flame temperature for better outputs

Ishii T., Zhang C., Sugiyama S. [3]1998, successfully carried out the modeling and optimisation of heat transfer employing highly preheated air and concluded that using regenerative burners with low no_x in conjunction with optimal air fuel ratio lead to improved performance

Katsuki Masashi, Hasegawa Toshiaki[4] 1998, achieved preheated air temperature above 1300^0K for efficient combustion which generated flames of very high temperature leading to energy and environmental conservations

Yuan Jianwei, Naruse Ichiro, [5]1998 concluded that the preheated air used for combustion should be slightly oxygen enriched and diluted as the air diluents have major effect on flame temperature and emissions of No_x

Choi Gyung-Min, Katsuki Masashi [6] 2001on basis of their experimental investigations declared that preheated air temperature for combustion should be more than of fuel ignition temperature

Gupta A.K. [7]2004, stated that properties of fuel with amount of oxygen enrichment are major factors affecting the flame temperature and emission level of furnace

Weber Roman, Smart John P., Kamp Willem vd [8] 2005, stated that preheated air combustion not only significantly affects the flame temperature during combustion but also reduces size and losses of furnace

Yang Weihong, Blasiak Wlodzimierz [9] 2005 applied eddy- break up model with RNG k-e turbulent model that it can accurately predict flame temperature

Jain R.K, Singh R [10]on basis of their experimental investigations concluded that for optimal flame temperature and energy/ fuel conservation, 10% excess air preheated up to 300ºC should be used.

Hasegawa T. Mochida S. and Gupta A. K. [11]2012 discussed the flame characteristics to conclude that optimal flame temperature leads to significant energy conservation, with reduced size and emission level

Abhilash E, Joseph MA [12] 2009-stressed upon employing modeling, and simulation for process design and parameters to predict them with greater accuracy in short time and for their experimental validation

Sanaye Sepehr, Hassan Hajabdollahi [13] 2009successfully applied genetic algorithm and ε-NTU method for modeling of rotary regenerator to predict the effectiveness and pressure drop, based on rotational speed, porosity and area of heat transfer .

Kumar Purshottam, Singh Ranjit [14] 2013 successfully used ANN for establishing the relations between melting time, fuel consumption etc with preheated air temperature, rpm and flame temperature

Singh Ranjit, Das Gurumukh, Jain R. K. [15]2008 effectively developed the numerical and regression technique to model and optimize the parameters of rotary furnace to conclude that in view of correlating results these techniques can successfully be applied for rotary furnace

The literature survey reveals that no author up till now has applied PSOM (Particle Swarm Optimization) technique to investigate Effect of preheated excess air on fuel consumption of oil Fired Rotary Furnace

III. Melting Operation

3.1 Experimentation Investigations of Effect of input parameters on flame temperature

The actual Experimentation for Investigations were performed on self designed rotary furnace of 200 kg installed in a cast iron foundry of Agra and observations recorded are tabulated in table 1

Table 1: Effect of time, fuel and melting rate on flame temperature

S.N.	Time (min.) [A]	Fuel (liters) [B]	Melting Rate kg/hr) [C]	Flame Temp°C
1	41.0	72.0	293.0	1510.0
2	40.0	70.0	300.0	1530.0
3	39.0	69.0	307.6	1540.0
4	38.0	68.0	315.7	1545.0
5	37.0	66.0	324.3	1550.0
6	37.0	64.0	324.3	1568.0
7	36.0	63.0	333.3	1570.0
8	35.0	61.0	342.8	1578.0
9	34.0	60.0	352.9	1580.0
10	34.0	59.0	352.9	1590.0
11	33.0	58.0	363.6	1620.0

The graphical presentation of above recorded observations as per table 1 of effect of time, fuel and melting rate on flame temperature is shown in figure 3.

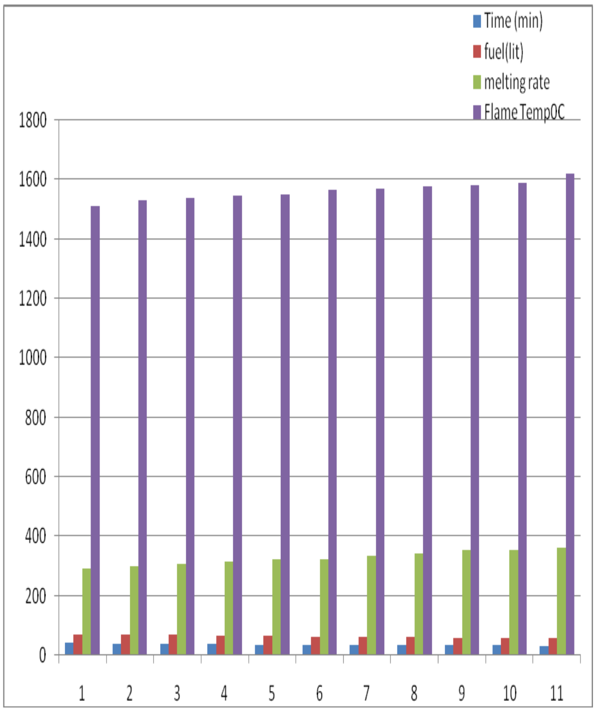

Figure 3: Effect of time, fuel and melting rate on flame temperature

IV. Modeling and optimization-Input Parameters

For modeling and optimization the following three parameters have been considered as input parameters

Time (min.), Fuel (liters) and Melting Rate (kg/hr) are input parameters

4.1 Output Parameters

The output parameters considered was **Flame Temp°C**

4.2 Regression Model

The following relationship has been developed between above mentioned input parameters and output parameter using the regression analysis employing Microsoft axle programme. The programme run is shown below

The intercept is 1352.473, and coefficients are 4.253606, 0.947538 and -3.99387 respectively

The equation formed is

Flame temperature =1352.473 +4.253606[A] - 3.92387 [B] + 0.947538[C] ---------(1)

Here A represents Time (min.), B Fuel (liters) and C Melting Rate (kg/hr)

V. Comparison of results

The modeled values of flame temperature were evaluated as per equation 1 and compared with actual experimental values as shown in table 3.

The diagrammatical presentation of variation is shown in figure 4

Table 2 – The regression analysis employing Microsoft axle programme

Summary Output

Regression Statistics	
Multiple R	0.97037
R Square	0.941618
Adjusted R Square	0.916597
Standard Error	8.888581
Observations	11

ANOVA

	df	SS	MS	F	Significance F
Regression	3	8919.861	2973.287	37.63327	0.000109
Residual	7	553.0481	79.00687		
Total	10	9472.909			

	Coeffi-cients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	1352.473	1244.256	1.086973	0.313054	-1589.73	4294.671	-1589.73	4294.671
[B]	4.253606	17.40787	0.24435	0.813968	-36.9095	45.41668	-36.9095	45.41668
[C]	0.947538	1.906228	0.497075	0.634366	-3.55998	5.455052	-3.55998	5.455052
E	-3.99387	4.228907	-0.94442	0.376402	-13.9936	6.005903	-13.9936	6.005903

Table 3: Comparison of Experimental and Modeled Values of flame temperature

S.N.	Time (min.)[A]	Fuel (liters)[B]	Melting Rate(kg/hr)[C]	Flame Temp°C Experimental	Flame Temp Modeled	%Variations
1	41.0	72.0	293.0	1510.0	1516.94108	+0.45757%
2	40.0	70.0	300.0	1530.0	1527.30795	-0.17626%
3	39.0	69.0	307.6	1540.0	1534.24866	-0.37346%
4	38.0	68.0	315.7	1545.0	1541.66462	-0.21588 %
5	37.0	66.0	324.3	1550.0	1553.54758	+0.22887%
6	37.0	64.0	324.3	1568.0	1561.53532	-0.41228%
7	36.0	63.0	333.3	1570.0	1569.80342	-0.012521%
8	35.0	61.0	342.8	1578.0	1581.92212	+0.24855%
9	34.0	60.0	352.9	1580.0	1591.21334	+0.70976%
10	34.0	59.0	352.9	1590.0	1595.20821	+0.32575%
11	33.0	58.0	363.6	1620.0	1605.06788	-0.921736%

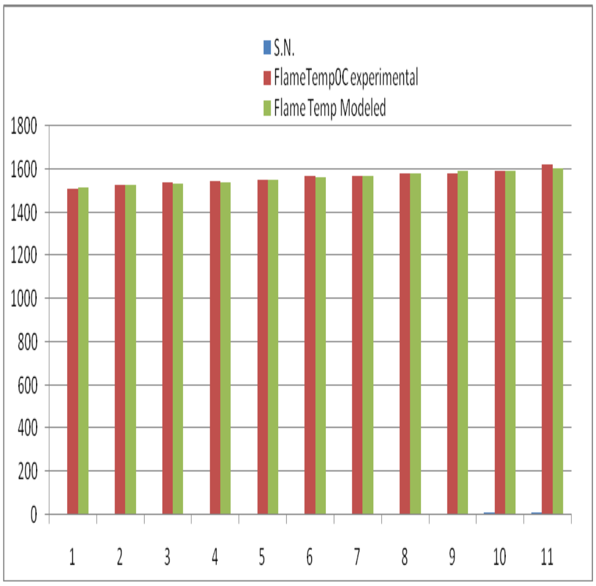

Figure 4: The diagrammatical presentation of variation

VI. Optimization of Flame Temperature

For optimization of fuel consumption the **regression technique** is used initially for settings of input parameters. The status after successive iterations is given in table 4 –

Table 4 : The status after successive iterations

Sn	Time	Melting rate	Fuel	Flame tem-perature
1	34.0	360.6	59	1613.92
2	33.0	364.0	58	1625.62
3	35.0	330.6	60	1560.50

It is clear from table 4 that input parameters for optimal flame temperature are as given in table 5:-

Table 5: The Input Parameters for Optimal Flame Temperature

Sn	Time	Melting rate	pFuel	Flame temperature
1	33.0	364.0	58.5	1625.62

This value is taken as the optimal value giving the final solution

VII. RESULTS AND DISCUSSION

These values of input parameters are considered as values for optimal fuel consumption and given in table 6.

Table 6: Values of input parameters for optimal flame temperature

Time (min.)	Melting Rate kg/hr)	Fuel liters	Flame Temp°C
33.0	364.0	585.	1625.62

The actual and optimized fuel consumption with %Error are given in table 7

VIII. CONCLUSIONS

It is very clear that under actual conditions of experimental investigations of time (min.)= **33.0,** fuel(liters)= 58.0 and melting rate(kg/hr) =363.6 the flame temp°c is =1620.0

The optimized value suggests that if experimental investigations are carried out at

Time (min.) =33.0, fuel(liters)= 58.5, melting rate(kg/hr)= 364.0 the flame temp°c shall be 1625.62°c. The percentage error is 0.34%

It is concluded that results of Modeling and optimization for flame temperature applying regression analysis correlates with experimental results, therefore regression analysis can be suitably applied for modeling and optimization of flame temperature The comparison of experimental flame temperature and modeled flame temperature is shown in Table 8.

The percentage error in modeling of experimental flame temperature is -0.921736% and in optimization is 0.34%. These variations are within acceptable limits.

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Table 7: The actual and optimized fuel consumption with %Error

Actual	Optimized	%Error						
Time (min.)	Fuel (liters)	Melting Rate(kg/hr)	Flame Temp°C	Time (min.)	Fuel (liters)	Melting Rate (kg/hr)	Flame Temp°C	Flame Temp°C
33.0	58.0	363.6	1620.0	33.0	58.5	364.0	1625.62	0.34%

Table 8: The comparison of experimental and modeled flame temperature

SN	Parameters	Flame Temp.	Time	Melting Rate	Fuel consumption	%Error Flame Temp.
1	Experiment 10	1590.0	34.0	352.9	59.0	
2	Experiment 11	1620.0	33.0	363.6	58.0	
3	Optimized	1625.62	33.0	364.0	58.5	0.34%
4	Modeled	1605.06788				-0.921736%

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