Optimizing Process Parameters of Fuel Consumption of Rotary Furnace - An Interactive regression analysis and python approach

Ratan Kumar Jain and Jai Kumar Sharma
Department of Mechanical Engineering, ITM University, Gwalior (India)
Jaikumarsharma94@gmail.com
ORCID ID :- https://orcid.org/0000-0002-1065-3115

Abstract

An interactive approach of regression analysis, and python being used as the tool for optimizing the fuel consumption of an industrial tilting rotary furnace, operating with additional amount of stoichiometric air has been presented in this paper. The author has made an attempt of optimizing fuel consumption in ferrous foundries in view of energy conservation. The experimentations were carried out on a 200 kg oil fired industrial tilting rotary furnace installed in a medium scale cast iron foundry at Agra manufacturing cylinder heads and engines. On basis of experimental investigations, it was found that crucial operating parameters like preheated excess air significantly affects the melting time, melting rate, and the fuel consumption The author has tried to establish the mathematical relationship between fuel consumption and all other input parameters utilizing regression analysis and python. It is believed that this modeled relationship may prove beneficial for industrial foundries to predict the fuel consumption of a furnace operating under a specific set of input parameters without actually operating the furnace thus saving time and energy The results of regression analysis and python correlates with the experimental results.

Key Words –Industrial Furnace, fuel consumption, regression analysis, python, preheated excess air

1.0 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 is more advantageous than any other industrial furnace having robust structure and better operational procedure [1] .

Over the past few decades, to improve the performance and efficiency of different industrial furnaces the modeling of processes is being carried out besides utilizing proper burners and optimal air fuel ratio aimed to reduce emission levels of nitrogen oxides [2]. The efforts are being continuously made to achieve the optimal fuel consumption and it has been observed that comparative temperatures of fuel ignition and preheated air is the significant factor [3]. A step ahead for reducing fuel consumption the idea of additionally providing the oxygen with air instead of extracting it from excess preheated air was successfully carried out to conclude that it not only significantly reduced the fuel consumption but also the combustion temperature enhanced [4]. The characteristics of flame helps in the fuel conservation and reducing the size of furnace and emission levels [5],

Sanaye Sepehr, Hassan Hajabdollahi [6] are being credited for generating a model of rotary furnace using Genetic algorithm for predicting the effectiveness and pressure drop considering the rpm, surface area of heat transfer, and porosity [6].

Kumar Purshottam, Singh Ranjit [7] 2013 on basis of their experimental investigations, of flame temperature and rpm developed a relationship between them applying ANN to conclude that experimentally verified results corelate with modeled relationship.

The FEM (ELFEN) technique was successfully utilized by A. R. Khoei et.al [8] for simulation of RPM and heat transfer of an industrial furnace and obtaining different temperature distribution curves depicting furnace performance.

The credit of utilizing feed forward method of ANN with two intermediate layers to develop a model for optimizing energy consumption of an oil-fired industrial furnace goes to Jain R. K, Chaturvedi DK [9}. The extensive experimental investigations on burner design with oxygen enriched preheated air combustion were carried out by Róbert Dzurnáket.al.[10] to conclude that it led to significant reduction of melting time and Co_2

emissions. The rotary furnace has been extensively preferred due to its unique advantages of uniform heat transfer, Melting rate and optimal fuel consumption V. Sai Varun et.al [11]

Based on literature survey it is clear that no attempt has been made by any author to utilize the python and regression analysis to establish mathematical relationship between fuel consumption and all other input parameters utilizing regression analysis and python

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.

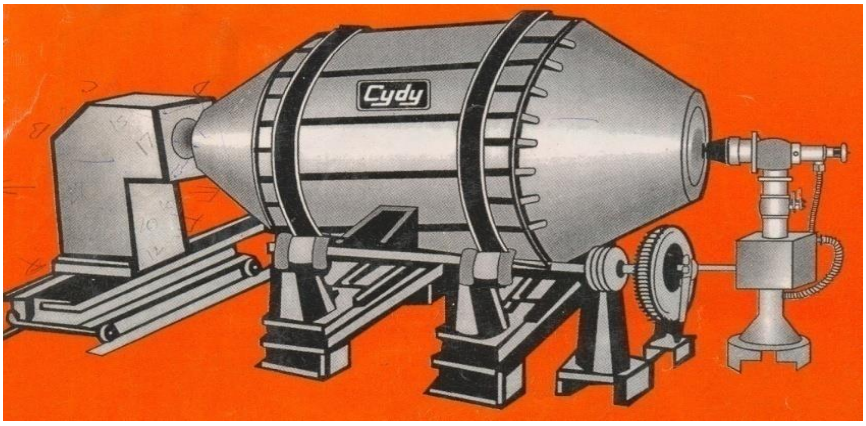

Figure 1.

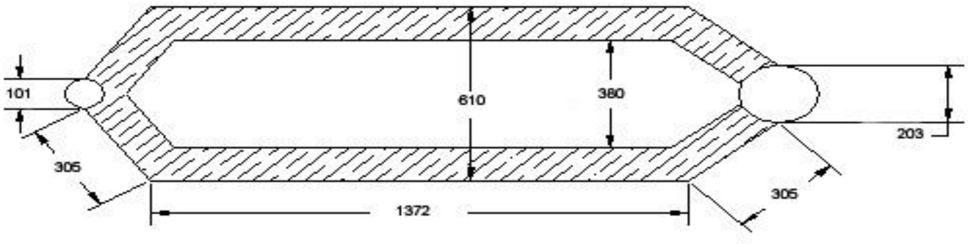

Figure 2

2.0 Melting Operation:

For melting the charge following sequence of steps was carried out--1. Preheating of oil and furnace 2. Charging 3. Rotation 4. Melting 5. Tapping 6. Inoculation 7. Pouring. During melting the change of flame color from yellow to white indicates thorough melting of charge and molten metal has achieved a temperature of 1250 to 1300ºC

2.1 Experimentation Investigations -Effect of 20.0% preheated excess air

The experimental investigations as carried out on a 200 kg oil fired industrial tilting rotary furnace in a cast iron foundry are depicted in table 1

Heat no	Flame Temp °C	Rpm	Time min.	**Fuel liters**	Melting rate kg/hr	Specific fuel cons. liter/kg	Preheated excess air.m^3	Preheated excess air %	Preheated excess air temp.°C
1	1510.0	1.0	41.0	**72.0**	293.0	0.360	995.0	30.1	304.0
2	1530.0	1.0	40.0	**70.0**	300.0	0.350	970.0	25.5	316.0

3	1540.0	1.0	39.0	**69.0**	307.6	0.345	930.0	20.3	320.0
4	1545.0	1.0	38.0	**68.0**	315.7	0.340	905.0	20.1	329.0
5	1550.0	1.0	37.0	**66.0**	324,3	0.330	870.0	20.2	332.0
6	1568.0	1.0	37.0	**64.0**	324.3	0.320	835.0	19.9	340.0
7	1570.0	1.0	36.0	**63.0**	333.3	0.315	822.0	20.0	348.0
8	1578.0	1.0	35.0	**61.0**	342.8	0.305	795.0	19.9	370.0
9	1580.0	1.0	34.0	**60.0**	352.9	0.300	788.0	20.1	378.0
10	1590.0	1.0	34.0	**59.0**	352.9	0.295	785.0	20.0	385.0
11	1620.0	1.0	33.0	**58.0**	363.6	0.290	760.0	20.0	402.0

Table 1--

2.2 The graphical representation effect of 20.0% preheated excess air on fuel consumption, flame temperature, Time), melting rate is shown in figure 3,4,5,6, respectively

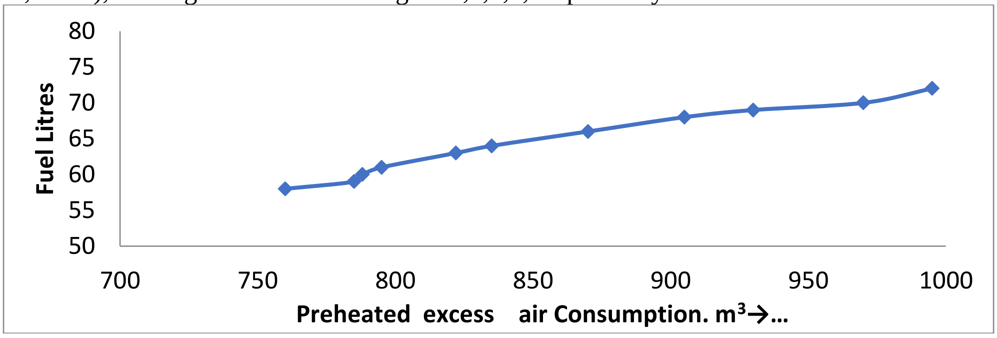

Figure 3

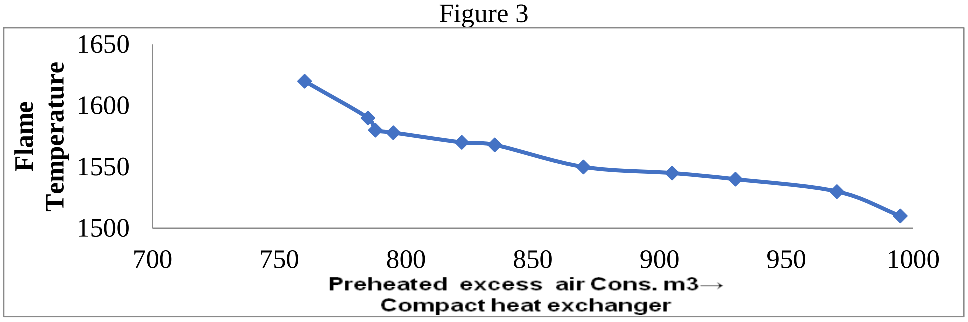

Figure 4

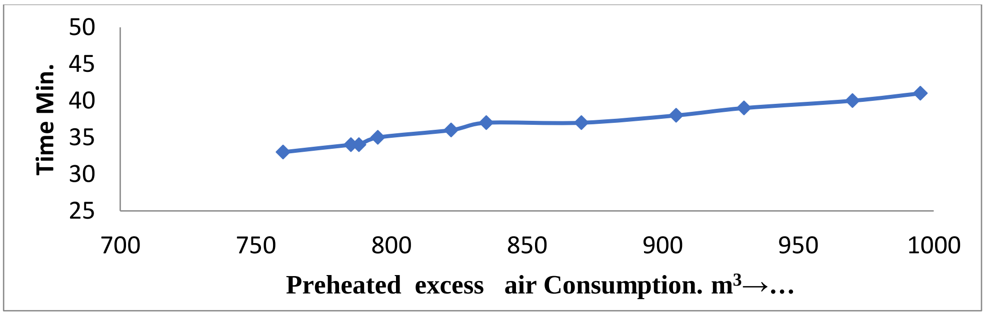

Figure 5

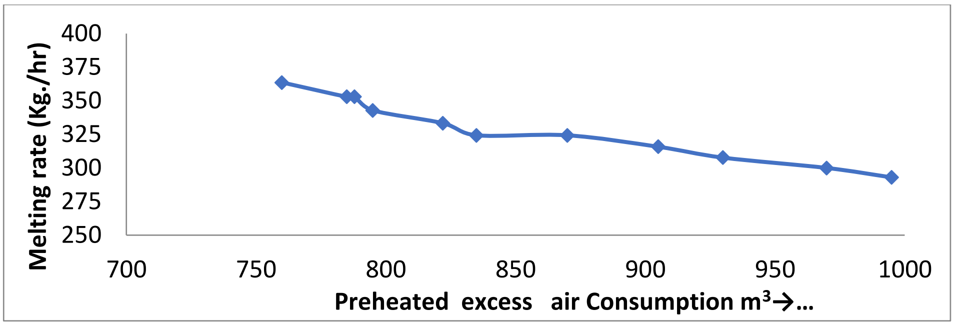

Figure 6

3.0 The Model development

For developing the relationship, the Flame temperature, Time (min.), Melting Rate(kg/hr.) and preheated excess air m^3 are considered as input parameters and fuel consumption as output parameter MATLAB regression analysis has been applied to find the modelled values of fuel consumption The output is fuel (Liters) experimental and input are **Flame Temp (°C)**, **Time min**, melting rate, and preheated excess air m3 are as shown in table 2.

sn	Flame Temp(°C)	Time min	Melting rate kg/hr	Preheated excess air m^3	Fuel Litters exp
1	1510	41	293	995	72
2	1530	40	300	970	70
3	1540	39	307.6	930	69
4	1545	38	315.7	905	68
5	1550	37	324.3	870	66
6	1568	37	324.3	835	64
7	1570	36	333.3	822	63
8	1578	35	342.8	795	61
9	1580	34	352.9	788	60
10	1590	34	352.9	785	59
11	1620	33	363.6	760	58

Table 2

The relationship as given in equation (1) has been developed between fuel as output parameter and all other as input parameters utilizing the mat lab regression analysis. c0, c1, c2, c3, c4 are the corresponding constants evaluated from regression analysis

Fuel =c0+c1*(flame temp) +c2*(time)+c3*(melting rate) +c4*(preheated excess air) --(1)

The values of constants as evaluated are given in table 3

1	**c0**	235.1454
2	**c1**	-0.0016
3	**c2**	-2.5969
4	**c3**	-0.3408
5	**c4**	0.0455

Table 3

4. Comparison of results using (1) Mat Lab Regression analysis-

The modeled values of were evaluated as per equation (1) and compared with actual experimental values as shown in table 4.

sn	Flame Temp(°C)	Time min	Melting rate kg/hr	Preheated excess air m^3	Fuel Litters exp	Fuel Litters modelled	% Variation	Average% variation
1	1510	41	293	995	72	71.6746	-0.45194	**-0.05479%**
2	1530	40	300	970	70	70.7164	+1.02342	
3	1540	39	307.6	930	69	68.8872	-0.16347	
4	1545	38	315.7	905	68	67.5781	-0.62044	
5	1550	37	324.3	870	66	65.6437	-0.53984	
6	1568	37	324.3	835	64	64.0224	+0.03500	
7	1570	36	333.3	822	63	62.9574	-0.06761	
8	1578	35	342.8	795	61	61.0754	+0.12360	
9	1580	34	352.9	788	60	59.9085	-0.40666	
10	1590	34	352.9	785	59	59.756	+1.28135	
11	1620	33	363.6	760	58	57.5208	-0.82620	

Table 4--

The average percent variation is **= -0.05479%**

The diagrammatical presentation of variation is shown in figure 7

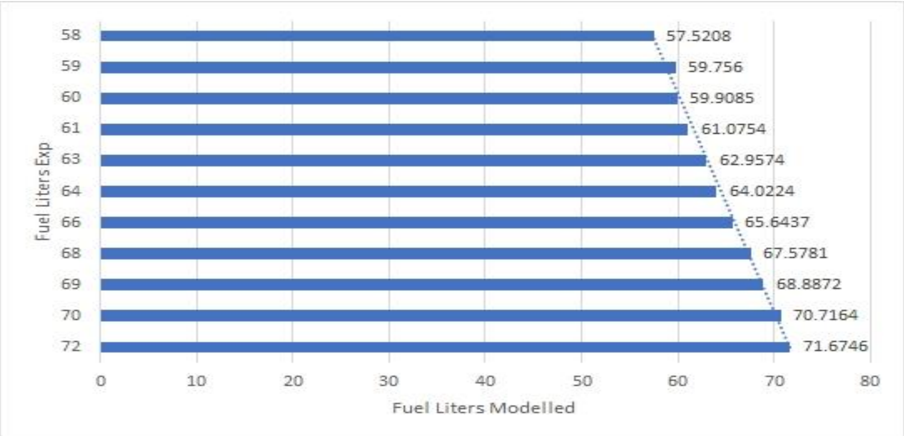

figure 7

Python regression analysis has also been applied to find the modelled values of fuel consumption fuel=b0+b1*(flame temp) +b2*(time)+b3*(melting rate) +b4*(preheated excess air) given in figure 8 fuel on y axis and samples on x axis. The python analysis as shown above resulted in the relationship given in equation 2. The values of constants are given in table 5

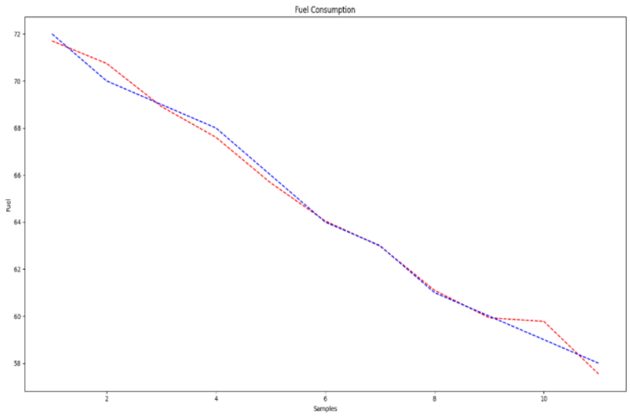

figure 8

fuel=b0+b1*(flame temp) +b2*(time)+b3*(melting rate) +b4*(preheated excess air) -	(2)

1	b0	235.14540003171606
2	b1	-0.00158907278
3	b2	-2.59692563
4	b3	-0.340834258
5	b4=	0.0455217790

Table 5

5.0 Comparison of results using python-

The modeled values of flame temperature were evaluated as per equation (1) and compared with actual experimental values as shown in table 6

sn	Flame Temp(°C)	Time min	Melting rate kg/hr	Preheated excess air m^3	Fuel Litters exp	Fuel Litters modelled	% Variation	Average% variation
1	1510	41	293	995	72	71.70168164	-0.4143311	**-0.094346%**
2	1530	40	300	970	70	70.74294154	+1.061345	
3	1540	39	307.6	930	69	68.91276492	-0.0872351	
4	1545	38	315.7	905	68	67.60294323	-0.5839073	
5	1550	37	324.3	870	66	65.66748661	-0.5038909	
6	1568	37	324.3	835	64	64.04562104	+0.07128281	
7	1570	36	333.3	822	63	62.98007708	-0.03162381	
8	1578	35	342.8	795	61	61.09727664	+0.1594669	
9	1580	34	352.9	788	60	59.92994567	-0.11675667	
10	1590	34	352.9	785	59	59.77748961	+0.19789266	
11	1620	33	363.6	760	**58**	**57.54177202**	-0.79005138	

Table 6

The average percent variation is **= -0.094346%**

The diagrammatical presentation of variation is shown in figure 9

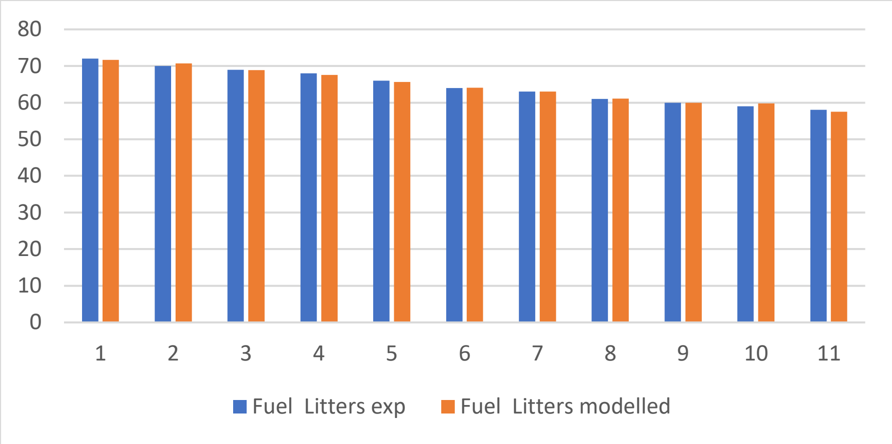

figure 9

the comparison of modeled value and experimental value of fuel consumption utilizing regression analysis (with all other as input parameters) is depicted in table 7

SN	**Flame Temp(°C)**	**Time min**	**Melting rate kg/hr**	**Preheated excess air m^3**	**Fuel Litters exp**	**Fuel Litters modelled**	**% Variation**
11	1620	33	363.6	760	58	57.5208	-0.82620

Table 7

the comparison of modeled value and experimental value of fuel consumption utilizing Python analysis (with all other as input parameters) is depicted in table 8

SN	**Flame Temp(°C)**	**Time min**	**Melting rate kg/hr**	**Preheated excess air m^3**	**Fuel Litters exp**	**Fuel Litters modelled**	**% Variation**
11	1620	33	363.6	760	58	**57.54177202**	-0.79004828

Table 8

6.0 Results and Discussion-The Comparison of actual and optimized fuel consumption with both technique including %Error is given in table 9

sn	Technique	Flame Temp(°C)	Time min	Melting rate kg/hr	Preheated excess air m^3	Fuel Litters exp	Fuel Litters modelled	% Variation
1	Python	1620	33	363.6	760	58	57.54177202	-0.79004828
2	Regression	1620	33	363.6	760	58	57.5208	-0.82620

Table 9

The diagrammatical presentation of variation of experimental and modeled value of fuel consumption using python and regression analysis are shown in figure 10

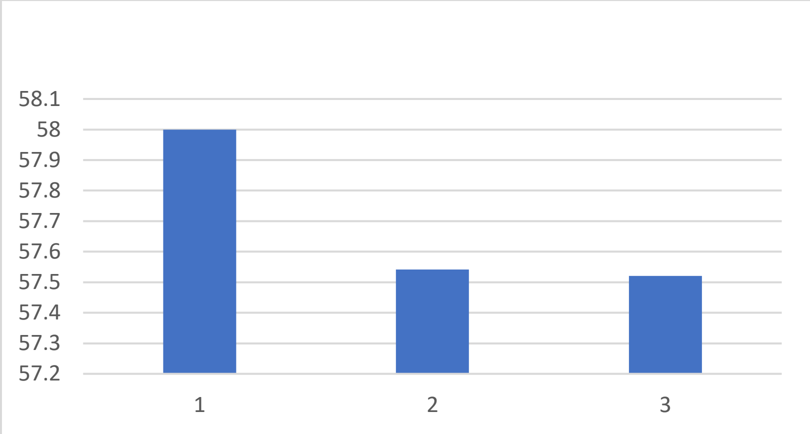

figure 10

as per above analysis it is clear that if furnace is operated with basic input process parameters as shown in table 10 the actual fuel consumption shall be 57.5208 as compared to experimental 58.0 liters shown in table 10

sn	**Flame Temp(°C)**	**Time min**	**Melting rate kg/hr**	**Preheated excess air m^3**	**Fuel Litters exp**	**Fuel Litters modeled**
11	1620	33	363.6	760	58	57.5208

table 10

7. CONCLUSIONS

It is very clear that while applying regression and python the result of both corelates with the experimental result therefore regression analysis and python both can be suitably applied for modeling and optimization of fuel consumption. The final comparison of both above techniques is given in table 11.

sn	Technique	Experimental fuel consumption	Modeled fuel consumption	Percentage error
1	Regression	**58**	**57.5208**	**-0.82620**
2	Python	**58**	**57.54177202**	**-0.7900**

Table11

On comparison the Percentage error is slightly lower in regression analysis hence it is marginally better as given in table11.

Compliance with ethical standards

Conflict of interest: On behalf of all authors, the corresponding author states that there is no conflict of interest.

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