Modeling of Experimentally verified Effect of Basic Input Parameters on Fuel Consumption of oil fired furnace using Machine Learning

Ratan Kumar Jain, Sanjay Jain

***Abstract*: The authors have attempted to create a model, based on actual experiments conducted on an oil fired Rotary Tilting Furnace of 200 kg melting capacity installed in a foundry unit of Agra. Multiple regression machine learning has been considered as a suitable and novel tool for Modeling of basic input process parameters of rotary tilting furnace. The basic process parameters in a rotary furnace considered are RPM (rotational speed per minute), Time of melting of one charge of 200 kgs (minute) ,melting rate of furnace (kg/hr) and fuel consumed for melting of one charge need to be controlled during whole process.**

In this paper the relation between input parameters such as rotational speed of the furnace, time, and melting rate have been attempted to be established with output parameter fuel consumption. This model of multiple regression machine learning may found its practical applicability in foundry industry to predict the fuel consumption of furnace before putting it in actual operation and accordingly the input parameters can be controlled for desired optimal fuel consumption. The methodology consists of experimental investigations, modeling of process parameters using machine learning, followed by result analysis. The fossil fuels may not last forever and till no other alternate fuels are developed for melting the foundry industry need to optimize it. The optimized results obtained by this model and computational technique are in line with the results of actual experiments.

Keywords* : *Oil fired furnace, furnace oil, multiple regression, Machine Learning, RPM.

I. INTRODUCTION

The oil fired furnace is constituted of a cylindrical central portion, used for melting of metal and supported on a rigid base. The metal is charged from a rectangular opening, located at top of this chamber. The furnace contains a ceramic lining insulation of silica and alumina bricks. The furnace oil is used as a fuel for melting the charged metal and is cheaply available in abundance in open market.

The oil was burned using RL/M series modulating burners which is more efficient than other burners and contains Fuel air ratio adjustments and provides high efficiency with low noise operation. The burner is accommodated at the centre of left cone which enables to spread the flame in centre of cylindrical portion leading to uniform distribution of heat to the metal to be melted. The right cone is used for exhaust of hot gases to heat exchanger through the ducts. The temperature sensor is used for temperature measurement. The change of flame color from yellow to white indicates the melting of metal. The temperature is again measured and on it's reaching to desired level the rotation of furnace is stopped by gear system and top door is opened for pouring the molten metal. The gear system is used to control the tilting of furnace. The metal is poured in ladles to be poured in earlier prepared moulds in nearby mould shop. The LDO is stored inside the overhead tank at a height of 6 meters approximately. The oil is forced in the burner using a pump in supply pipe line. The self designed and fabricated rotary furnace of 200 kg capacity is displayed in figure 1.

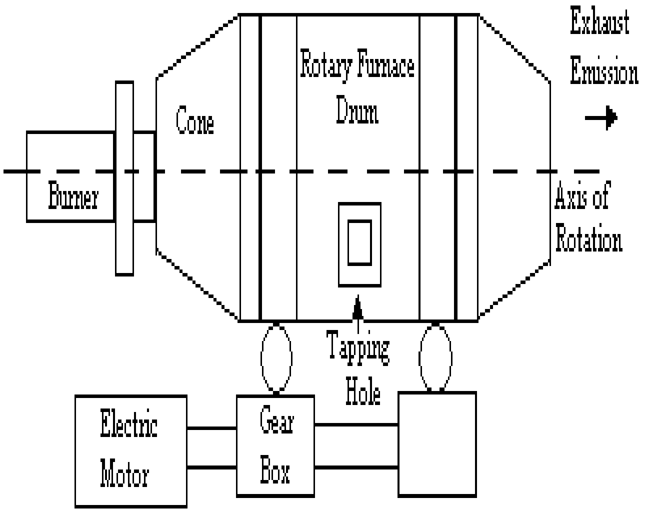

Fig. 1. The self designed and fabricated rotary furnace of 200 kg capacity

II. LITERATURE REVIEW

Peng–Fu Tan, Pierre Vix have successfully used waelz process to create a process model, with thermodynamic modeling to simulate the heat and mass transfer with heat balance in the kiln while modeling air injection into the slag presenting the optimized results[1].

Sanaye Sepehr, Hajabdollahi Hassan have employed genetic algorithm (NSGA-II) method for optimal design of rotary regenerator using ε-NTU method. The main design parameters considered were rpm, thickness, and diameter of matrix along with porosity..

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For optimal design they successfully achieved 'Pareto optimal solutions'. They also performed the sensitivity analysis of change in optimum effectiveness and pressure drop while changing design parameters [2].

Jain. R.K. have successfully carried out Modeling, and Optimization of experimentally verified input parameters for optimum specific fuel (energy) consumption of LDO fired Rotary furnace using feed forward and back propagation technique . further on carrying out simulation, an optimal and feasible set of input parameters was observed based on which the output, specific fuel and energy consumption were reduced to 0.2502 lit/kgand2.4781 kwh/kg respectively which is 3.769 % less than the actual experimental one[3].

Bo Zhou et al. have developed a mathematical melting model, for simulating the process of salt shell formation and aluminum melting, to investigate the influence of salt layer properties with the size of metal particles, and temperature of melt. they observed that results so obtained reasonably coincides with measured data and are hopeful of constructing an CFD based overall process model for rotary furnace on basis of this developed melting model[4].

A.R. Khoei et.al. have developed a numerical solution containing fluid flow and heat transfer for better understanding the processes of rotary furnace employing a finite element model which includes the simulation of RPM (rotation of furnace) and flow of energy inside the furnace. For prediction of evolution and temperature distribution inside the furnace the modeling and analysis of furnace under different flame temperature conditions was done using finite element modeling system ELFEN, which resulted in displaying the temperature distribution curves for different RPM and different flame conditions[5].

Bo Zhou et.al. developed a process model based on a CFD framework .He simulated the main processes viz combustion of natural gas, transfer of heat, and flow of fluid followed by radioactive mode of transfer of heat employing a commercial CFD code – ANSYS-CFX 5. On basis of developed process model they simulated and studied influence of the size distribution on melting behavior and approximately estimated some other parameters also including voidage, heat transfer coefficient around the solid particle, voidage coefficient Cvoid, rotation coefficient Crot, and wall temperature distribution functions[6].

B Zhou et.al. have simulated the Turbulent fluid flow, conjugated heat transfer, natural gas combustion, and radioactive heat transfer for the scrap melting process in a rotary furnace employing the CFD to develop the process model concluding that melting time can be reduced by controlling size and shape of feed, gas consumption can be reduced by reducing natural gas flow, and Pre-heating of the scrap feed may also produce better results[7].

R.K.Jain, Ranjit Singh have developed a non linear equation for basic input parameters of oil fired rotary parameters and solved it using excel solver. The so obtained results were compared with experimental one to conclude their acceptability[8]. Sylvester Olanrewaju Omole, Raymond Taiwo Oluyori have experimentally investigated the effect of using Recuperative System in Rotary Furnace to declare that they not only the efficiency of furnace employing the recuperating system was higher but also the rate of elemental loss was lesser than the furnace without it[9].

Mojtaba Rahimpour et.al. have employed CFD to investigate the effect of change of angle of burner to improve the performance of rotary furnace for melting aluminum. They developed a model for predicting the combustion of natural gas and oxygen, before mixing, under turbulent flow conditions, with furnace rotation, aluminum smelting and aluminum burn-off and concluded that on changing the burner angle from 0^{o} to 15 lead to better mixing of fuel and oxygen resulting in improved furnace performance and lower aluminum melting rate but simultaneously increasing burner angle more than 10^{o} resulted into overheating of refractory lining but to reduce furnace operation time by 35 minutes and increasing thermal efficiency from 65% to 74.7%. The burner angle should be changed from 0^{o} to 10^{o}[10].

V. Sai Varun et.al. have advocated the use of tilting rotary furnace as it besides reducing manufacturing time also reduces fuel consumption and heat is uniformly distributed over the charge[11]. Robert Dzur nak et.al have performed experimentation to optimize the burner nozzle diameter for aluminum melting process to conclude that suitably controlling the parameters of burner nozzle gives better results even at lower oxygen enrichment with enhanced rate of heat transfer which not only reduces the energy consumption but also the Co_2 emissions[12].

R. K. Jain, Nadeem Faisal applied PSOM (particle swarm optimization) technique for analyzing preheated air combustion of rotary furnace, using furnace oil as fuel, for validation experimentally verified result of using 10% excess air signifantly not only reduces fuel consumption but also increases melting rate and rate of heat transfer due to high flame temperature. The PSOM (particle swarm optimization) technique also verified the results of experimental investigations.[13].

III. Proposed Methodology

The operations of rotary furnace are completed using Preheating of oil and furnace, Charging, Rotation, Melting and Tapping-Inoculation- Pouring

A. Experimental Investigations

A 200 kg oil fired furnace was designed and fabricated in an industry of Agra having large foundry shop and manufacturing diesel engine parts to conduct several experimental investigations on fuel and energy combustion with a multipass counter flow heat exchanger. The experimental investigation on effect of RPM (Rotational speed) was conducted.

The rotation of furnace was carried out from 0.8 to 2.0 rpm, the melting time of 200 kg charge varied from 35 minutes to 50 minutes and fuel consumption varied from 76 to 92 liters under different RPM. The observations recorded are given in table I.

Table-I: Effect of rotational speed on fuel consumption, time and melting rate

S.NO.	RPM	Melting Time (minutes)	Rate of melting (kg/hr)	Fuel (liters)
1	2	50	240	92
2	2	47	255	88
3	2	45	266	83
4	1.6	48	250	88
5	1.6	45	266	83
6	1.6	43	279	80
7	1.4	42	286	83
8	1.4	40	300	80
9	1.4	39	308	78
10	1.2	40	300	80
11	1.2	38	316	78
12	1.2	37	324	77
13	1	38	316	79
14	1	36	333	77
15	1	35	343	76
16	0.8	42	286	79
17	0.8	40	300	78
18	0.8	38	316	77

B. Modeling

The above observations are based on practical operation of furnace of 200kg in a foundry industry manufacturing cylinder heads. The mathematical modeling is to be carried out in order to have generalized results. It is clear that fuel consumption depends upon (r.p.m., time of heat, melting rate,).

For optimal fuel conservation a mathematical model is to be developed and factors affecting it to be considered. For developing the model the critical input parameters includes RPM rotational speed of furnace, time for melting 200 kg charge in minutes and fuel consumption for melting 200 kg charge in liters**.**

We have used the multiple regression Machine learning approach to model experimentally investigated result of fuel consumption. The Non linear equation for the multiple regression model is

$$Y(Fuel) = -b0 + b1x1 + b2x2 + b3x3 \quad (1)$$

Where b_0= interceptor, b_1 = first coefficient, b_2= second coefficient, b_3= third coefficient x_1 = first variable(rpm), x_2 = second variable (time min), x_3 = third variable (Melting Rate (Kg/hr)).

We have trained the regression model using generated experimental result of fuel consumption. Data set consist of 100 experimental result generated from the real environment. We have divided the dataset in to training and test dataset. We have received the following outcome after training model:

Coefficients: [1.46678002 2.90964765 0.30079843]
Interceptor: [-129.55473446]
and the generated Non linear equation is:

$$Y[Fuel(liters)]=[-129.55473446]+[1.46678002][rpm]+[2.90964765]\,[time]+[0.30079843][MeltingRate] \quad (2)$$

IV. Result Analysis

The model is tested using the test dataset. The table 2 shows the modeled values as generated by the trained model and actual experimental values are compared as below:

Table-II: Result of Testing the Trained model

RPM	TIME minutes	Melting Rate kg/hr	Fuel experimental liters	Fuel modeled	% variations
2	50	240	92	91.126	-0.8043
2	47	255	88	86.911	-1.2375
2	45	266	83	84.402	+1.6891
1.6	48	250	88	87.7288	-0.3081
1.6	45	266	83	83.8148	+0.9816
1.6	43	279	80	81.9078	+2.3847
1.4	42	286	83	80.8112	-2.6371
1.4	40	300	80	79.2052	-0.9935
1.4	39	308	78	78.7032	+0.9015
1.2	40	300	80	78.9116	-1.3605
1.2	38	316	78	77.9076	-0.1184
1.2	37	324	77	77.4056	-0.5267
1	38	316	79	77.614	-1.7544
1	36	333	77	76.911	-0.1155
1	35	343	76	77.011	+1.3302
0.8	42	286	79	79.9304	+1.1777
0.8	40	300	78	78.3244	+0.4158
0.8	38	316	77	77.3204	+0.4161

The average percentage variation is=0.04% in the actual result and generated result by the model. Since variance score of the model is .98 therefore accuracy of the trained model is 98%. The plotted graph figure 2 shows the comparison between experimental result and the result generated by the regression model of fuel consumption in rotary furnace.

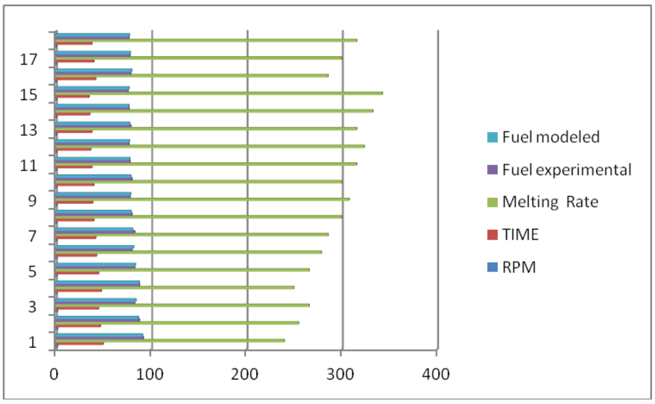

Fig. 2. The comparison between experimental result and the result generated by the regression model

Figure 3 shows the output values of modeled and experimental fuel and input values of melting rate, time and RPM rate, time and RPM.

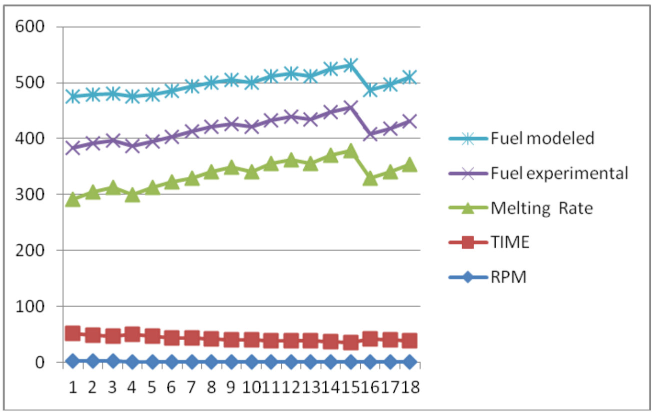

Fig. 3. Output values of modeled and experimental fuel and input values of melting rate, time and RPM

V. CONCLUSION

It is very clear as per above experimental investigations that for optimal fuel consumption the furnace must be rotated at 1RPM. The variation between developed and trained regression model results and actual experimental results is 0.04% with 98% accuracy of the trained model. At 1 rpm the average experimental absolute fuel consumption is 77.333 liters and average modeled is 77.178 .The absolute variation is -0.154 and percentage variation is -0.1995%.At 1 R.P.M we also observed average experimental melting rate of 330.66 kg/hr and average experimental time of one heat (melting 200 kgs) is 36.333 seconds. The results obtained by experiments conducted on rotary furnace coincide with the results of modeling by Multiple Regression modeling using machine learning.

Hence it is concluded that 1 rpm is the optimum rotational speed of rotary furnace at which it is most energy efficient and provides the maximum melting rate and further Multiple Regression modeling using machine learning can be used with sufficient accuracy for modeling any parameter.

It is strongly recommended that foundries should run the furnace at 1rpm only for optimal fuel consumption and melting rates. It shall lead to significant fuel/energy conservation and enhanced production

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