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Modeling and Optimization of Experimentally Verified Effect of Preheated Excess Air on Fuel consumption of Rotary Furnace using PSO (Particle Swarm Optimization) Technique

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Abstract: ***The energy consumption in ferrous foundries has been reported as a serious concern. The prevailing natural sources may not last long. By the time of availability of new resources we have to optimize the usage of prevailing resources to avoid serious conditions later on. The authors have attempted to analyze the effect of aspects of combustion of furnace oils in an oil fired rotary furnace with highly preheated air, and to verify the experimental results using PSOM (Particle Swarm Optimization) technique. The authors conducted a series of experiments on an oil fired rotary furnace of 200 kg capacity installed in a leading ferrous foundry. Detailed in measurements of temperature, and heat transfer, flame temperature, fuel consumption etc has been performed. During experimentation furnace was supplied with 10% excess air, preheated using multipass counter flow heat exchanger. The experimental investigations revealed that using 10% excess air drastically reduces the fuel consumption, increase melting rate, and the heat transfer rates due to enhanced flame temperature. The PSOM (Particle Swarm Optimization) technique also verified the experimental results.***

Keywords : ***Rotary furnace, Excess Air percentage, Preheated air combustion Energy saving Thermal efficiency .***

I. INTRODUCTION

A horizontal cylindrical drum supported by two cones, one welded on each end, constitutes the rotary furnace. The rotary furnace may vary in capacity from 200kg to 2 tons per hour of melting. The dimensions of drums and cones are decided by melting capacity of furnace. The supporting rollers mount the furnace. An electric geared motor is used to derive the rollers. The mild steel plates of approximately 6-8 mm are used to fabricate the furnace. The insulation of drums and cones was done using mortar and silica bricks

The burner is place in the left cone and it can be fired with light diesel oil, furnace oil, bio-fuel or natural gas. The right side cone contains the ducts for exit of hot gases which are connected to a heat exchanger. The furnace is charged through a tap hole which is placed in drums centre and it can also be used for pouring of molten metal . An oil tank of designed capacity is placed above the burner end at height of approximately 8 meters and is covered. This drum is connected to burnaer using pipe line and control valves. The length and diameter of pipe line is calculated accordingly. The oil at required pressure is forced to the furnace wit aid of suitable pump.

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II. LITERATURE REVIEW

Baker EHW [1] described the importance and operation of Rotary furnace, YutakaSuzukawaShunichiSugiyamaYoshimichiHinoMunehiroIshiokaIsaoMori[2] 1997 designed and developed a combustion system based on regeneration using a ceramic honeycomb for storage of heat for regeneration, which significantly increased the temperature of preheated air till 1600^0K. It was concluded that heating potential of flue gas can be increased by using highly preheated air which reduces the fuel consumption but simultaneously also increases NO_x emission. For reducing NO_x emission a newly developed low NOx regenerative burner was suggested.

T. Ishii , C. Zhang S. Sugiyama [3] 1998, attempted for simulation of turbulent flow and heat transfer in an industrial furnace, utilizing highly preheated air for combustion, with aid of numerical techniques using k-ε model and wall function.They concluded that the low NO_x emission along with significant efficiency for heating is attainable if regenerative burners with low NO_x in addition to optimal air/fuel injection velocity ratio are employed

MasashiKatsuki[1] ToshiakiHasegawa[2][4]1998, has confirmed that using advanced design and materials, the preheated air of temperature above 1300^0 K can be achieved for efficient combustion. This generates high nitric oxide emissions but additionally the advantage is of generating flames of higher temperature which can be used for special applications simultaneously achieving energy and environmental conservation Jianwei Yuan Ichiro Naruse [5] 1998 found that for effective NO_x emission control and improving uniformity of temperature the preheated air used for combustion in a regenerative furnace should be diluted. While carrying out simulation for furnace the nitrogen, helium, flue gas, carbon dioxide were used as air diluents and it was observed that these air diluents significantly, affected the emissions of NOx and flame temperature with same oxygen concentration and temperature of preheated air Gyung-Min Choi Masashi Katsuki[6] 2001 on basis of their study, stated that for better and sustainable combustion, the auto-ignition temperature of the fuel, should be lower than the temperature of preheated air being used.

A.K. Gupta[7]2004, Advocated the waste heat utilization, with a process of returning back the waste heat of flue gases, and make them to reenter again in the furnace using a regenerator. It was concluded that nature and characteristic of fuel, oxygen content and temperature of preheated air not only affected the flame temperature for energy savings but also reduced the emitting pollutants like CO_2 and CO and size of furnace

Roman Weber, John P.Smart, Willem vdKamp[8] 2005, after experimental investigations concluded that preheated air combustion is an effective technology for ecofriendly combustion of larger variety of fuels and it is an important parameter affecting the design of industrial furnaces

Weihong Yang, Wlodzimierz Blasiak [9] 2005 created an atmosphere of highly preheated with low oxygen concentration and forced a jet of propane in its cross stream. They applied Eddy- Break up model, PDF /mixture fraction combustion model, and RNG k-e turbulent model for prediction of results and concluded that of all Eddy- Break up model gave better results for field and flame temperature prediction

Jain RK, Singh R [10] carried out Experimental investigations on 200 kg rotary furnace and declared that flame temperature is a significant parameter for energy conservation. The optimal flame temperature can be achieved with preheated air temperature of 300 ºC and excess air 10 percent within safe metallurgical limits.

T. Hasegawa S. Mochida and A. K. Gupta [11]2012 detailed the methodology for furnace designing and process optimization of flame characteristic for combustion using high temperature air and concluded that these optimized parameters can lead to energy saving of 30% along with reduction in pollutants and furnace size by 25-30%

E Abhilash, MA Joseph [12] 2009- Are of the view that simulation is an essential tool in modern foundries and cast shops for mould and process design, process control, and process optimization. The concepts of modeling and simulation of casting process is essential to enrich the knowledge of foundry engineers and researchers to readily simulate a casting process model with greater accuracy in lesser time depending mainly on the thermo-physical properties of materials involved in that model. Modeling and its experimental validation should be encouraged, so that the successful model can be applied for the benefit of foundry industries.

Sepehr Sanaye Hassan Hajabdollahi [13] 2009 successfully modeled a **regenerator applying** genetic **algorithm (**NSGA-II) method. He used ε-NTU method for estimating the effectiveness and pressure drop of rotary regenerator and the design parameters considered were Heat Transfer Area, Rotational Speed and Porosity etc

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

Ranjit Singh,Gurumukh Das,Ratan Kumar Jain[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

The melting operation is carried out as below---1. Oil and furnace are preheated. The oil preheated up to 60 ^{0}C is forced to furnace using a suitable pump.2. Charging - the furnace is charged through the tap hole in centre 3. Rotation-next the furnace is rotated after its sufficient charging and preheating .4. Melting- approximately after 1 hour of rotation the color of flame, coming from exit end, changes from yellow to white which indicates the thorough melting of metal. A pyrometer is used for temperature measurement and upon its reaching approximately 1300 ^{0}C the furnace is stopped 5. Tapping- to tap the molten metal the centered tap hole is placed on top of earlier preheated ladles to avoid heat losses6. Inoculation- the molten metal after being transferred to ladles is inoculated by adding Ferro silicon and Ferro manganese.7. inoculation and Pouring and –before pouring the molten metal to ladles chemicals are added and then it is transferred to ladles to be finally poured in the moulds in molding shop

IV. EXCESS AIR

The stoichiometrically calculated theoretical amount of air is required for combustion for fuel LDO which contains elements such as Carbon, Sulfur, Phosphorous, Hydrogen etc.,. The additional excess air is always supplied to the furnace to account for various losses during combustion. This additional air is known as excess air

V. EXPERIMENTATION FOR INVESTIGATIONS OF EFFECT OF PREHEATED EXCESS AIR ON FUEL CONSUMPTION-

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 I- Effect of Preheated Excess Air on fuel consumption

S.No.	Flame Temp (°C) [A]	Time (min.) [B]	Melting Rate (kg/hr) [C]	Preheated Excess Air (m^3) [D]	Fuel (liters)
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

The graphical presentation of above recorded observations of fuel consumption is shown in fig 1

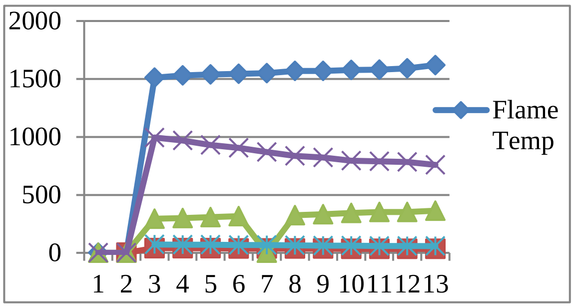

Fig.1- Effect of Preheated Excess Air on fuel consumption

It can be observed that on increasing the excess air the flame temperature reduces which results in increased fuel consumption and contrary to it reducing excess air the flame temperature is increased leading to reduced fuel consumption.

VI. MODELING AND OPTIMIZATION----INPUT PARAMETERS

For modeling and optimization the following four parameters have been considered as input parameters---- *Flame Temperature* (ºC), *Time* (min.), *Melting Rate*(kg/hr) and *Preheated Excess Air* (m^3).as per experimentations the fuel consumption is mainly affected by these parameters

VII. OUTPUT PARAMETERS

The output parameters considered was Fuel Consumption

VIII. REGRESSION MODEL

The following relationship has been developed between above mentioned input parameters and fuel consumption using the Minitab 16 as given in equation (1)

Fuel Consumption = 0.000251A + 0.011510B + 0.008012C − 0.252000D + 0.058006 (1)

Here A represents Flame Temperature (ºC), B Time (min.), C Melting Rate (kg/hr) and D Preheated Excess Air (m^3)

IX. PARTICLE SWARM OPTIMIZATION TECHNIQUE

Equations for particle swarm optimization (PSO) is given below in Eqns. 2 and 3

$$V_{i+1} = wV_i + c_1 r_1 (pBest_i - X_i) + c_2 r_2 (gBest_i - X_i) \quad (2)$$

$$X_{i+1} = X_i + V_{i+1} \quad (3)$$

The r_1 and r_2 are generate randomly having range of (0 to 1). c_1 and c_2 are constants which represents the weight age of acceleration terms representing the confidence of particles in swam. they are also known as cognitive and social parameters and determines the magnitude of tension in system under consideration denoting the changes

The chart for Implementation of PSO in process is given in figure 2

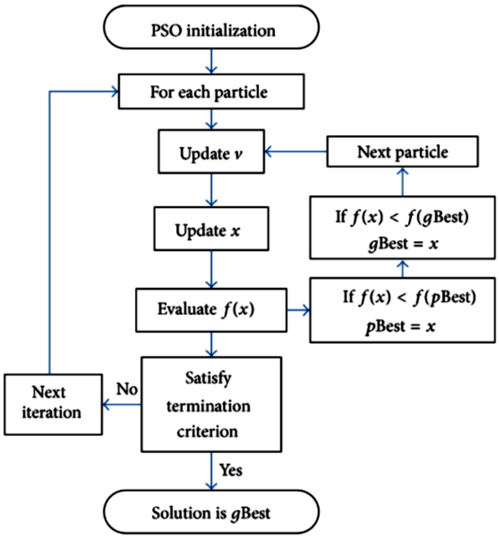

Figure 2 PSO flowchart

The algorithm for PSO implementation is shown in Figure 3—

Initialize the PSO parameters;
while (not terminated)
$\{ \ t = t + 1$
for i = 1:N // for eachparticle
$\{$
$v_i(t+1) = wv_i(t) + c_1 rand_1(Pbest_i - x_i(t)) + c_2 rand_2(Gbest_i - x_i(t));$
$x_i(t+1) = x_i(t) + v_i(t+1);$
$Fitness\ i(t) = f(x_i(t));$
if needed, update $Pbest_i$ *and* $Gbest_i$*;*
}// end for i
}// end for while

Figure 3 : PSO Algorithm

The part of the code for PSO is shown in Figure 4--

```
% handling boundary violations
for i=1:n
    for j=1:m
        if x(i,j)<LB(j)
            x(i,j)=LB(j);
        elseif x(i,j)>UB(j)
            x(i,j)=UB(j);
        end
    end
end

% evaluating fitness
for i=1:n
    f(i,1)=ofun(x(i,:));
end

% updating pbest and fitness
for i=1:n
    if f(i,1)<f0(i,1)
        pbest(i,:)=x(i,:);
        f0(i,1)=f(i,1);
    end
end

[fmin,index]=min(f0);   % finding out the best particle
ffmin(ite,run)=fmin;    % storing best fitness
ffite(run)=ite;         % storing iteration count

% updating gbest and best fitness
if fmin<fmin0
    gbest=pbest(index,:);
    fmin0=fmin;
end
```

Figure 4: A part of the PSO code

X. OPTIMIZATION OF FUEL CONSUMPTION USING PSO

For optimization of fuel consumption the PSO technique is used initially for settings of PSO parameters followed by determination of performance of the PSO algorithm. On the basis of works done by Hu and Eberhart the values of parameters have been chosen as w = 0.5+ (rand/2). c_1 and c_2 are constants and selected equal as 1.49445. The population size has been taken as 11 particles and iterations as 100.Further the initialization of the random position and velocity vectors is performed. For deriving the fitness values the function as given in eqn. 4 is used –

$$MinF(x) = -w_1 f_1 + w_2 f_2 \qquad (4)$$

f1 has been taken as normalized value of fuel consumption and f_2 of excess air consumption. The inertia weight for f1 fuel consumption is considered as 0.99 and for f_2 excess air is 0.01 to minimize the fuel consumption.. The initial values of parameters is given in table 2—

Table 2-. Initial Population and Fitness Value

Particle	A	B	C	D	Fuel	Fitness Value
1	1510.0	41.0	293.0	995.0	72.0	0.6834
2	1530.0	40.0	300.0	970.0	70.0	0.5058
3	1540.0	39.0	307.6	930.0	69.0	0.5642

The third step in PSO technique is to evaluate **the values of p best and g best**. The fitness values are determined and the lowest one is the value of g best. For modeling purposes **the values of p best and g best** are taken as same for first iteration. Next equation 2 and equation 3 are applied to find the change in position. The position of particles after first iteration has been change has changed and is given in table 3

Table 3.The position of particles after first iteration

Particle	A	B	C	D
1	103.92	2.82	20.09	68.47
2	95.62	2.4	17.98	58.18
3	0.5	0.5	0.05	0.5

The particles gains new position after first iteration and this is given in table 4

Table 4. New position of particles after the first iteration

Particle	A	B	C	D	Fuel	Fitness Value
1	1613.92	43.82	313.09	1063.47	71.95	0.765
2	1625.62	42.40	317.98	1028.18	69.45	0.654
3	1540.50	39.50	307.65	930.50	68.15	0.721

It is clear from table 2 that the minimum fitness value has been occupied by particle 2.The position of particle 2 denotes the value of p best for each parameter, but this value is higher than of g best which indicates that obtained value of g best is not optimal. This process is repeated for further 100 iterations which ultimately give final value of g best. This value is taken as the optimal value giving the final solution

XI. RESULTS AND DISCUSSION

The above mentioned steps of PSO are repeated till **the** optimized value of fuel consumption is achieved. The final values of corresponding dimensions of the particle obtained are, G best $_A$ = 1610, G best $_B$ = 34, G best $_C$ = 361.6, G best $_D$ = 780 . These values of input parameters are considered as values for optimal fuel consumption and given in table 5 .

Table 5. Values of input parameters for optimal fuel consumption

Flame Temp(°C)[A]	Time(min.) [B]	Melting Rate (kg/hr)[C]	Preheated Excess Air(m^3)[D]
1610	34	361.6	780.

For these Values of input parameters the actual and optimized fuel consumption with %Error are given in table 6

Table 6. The actual and optimized fuel consumption with %Error

Flame Temp (°C).	Time (min.)	Melting Rate(kg/hr)	Preheated Excess Air(m^3)	Fuel Consumption		
				Actual	Optimized	%Error
1610	34	361.6	780	58.35	58.1	0.43%

XII. CONCLUSIONS

It is very clear that under conditions of Flame Temp.=1610 (°C), Time=34(min.)Melting Rate=361.6(kg/hr) and Preheated Excess Air= 780(m^3) the optimized Fuel Consumption is 58.10 liters. The experimental investigations were carried out at 1590.0 ^{0}C and 1620.0 ^{0}C flame temperature which gave fuel consumption of 59.0 liters and 58.0 liters respectively. The optimized value suggests that if experimental investigations are carried out at 1610^{0}C flame temperature, 34 minutes time with melting rate of 361.6 kg/hr and Preheated Excess Air of 780(m^3) we get the best fuel consumption of fuel consumption of 58.10 liters.It is concluded that results of Modeling and optimization for fuel consumption applying PSO, correlates with experimental results, therefore PSO can be suitably applied for modeling and optimization of fuel consumption
The comparison of experimental fuel consumption and modeled fuel consumption is shown in Table 7--

Table 7. Comparison of experimental fuel consumption and modeled fuel consumption

sn	Parameters	Flame Temp^{0}c	Time min	Melting Rate kghr	Preheated Excess Air	Fuel consumption liters
1	Experiment 10	1590	34	352.9	785	59
2	Experiment 11	1620	33	363.6	760	58
3	Modeled	1610	34	361.6	780	58.1

REFERENCES

1. Baker EHW – "Rotary furnace" Modern Workshop Technology, part -1, Clever Hummer Press Ltd., London-2nd Edition
2. Yutaka Suzukawa, Shunichi Sugiyama, Yoshimichi, Hino Munehiro, IshiokaIsao, Mori 1997"Heat transfer improvement and NO_x reduction by highly preheated air combustion" Energy Conversion and Management, Volume 38, Issues 10–13, July–September 1997,Pages 061-1071

3. T. Ishii , C. Zhang S. Sugiyama "Numerical Simulations of Highly Preheated Air Combustion in an Industrial Furnace" *J. Energy Resour. Technol*. Dec 1998, 120(4):276-284.
4. MasashiKatsuki[1]ToshiakiHasegawa[2] 1998, "The science and technology of combustion in highly preheated air" Symposium (International) on Combustion Volume 27, Issue 2, 1998, Pages 3135-3146 Science Direct Elsevier
5. Jianwei Yuan Ichiro Naruse1998 'Effects of Air Dilution on Highly Preheated Air Combustion in a Regenerative Furnace" *Energy Fuels* 199913199-104 Publication Date: November 19, 1998 https://doi.org/10.1021/ef980127y Energy and Fuels ACS Publication
6. Gyung-Min Choi Masashi Katsuki 2001 **"Advanced low NO_x combustion using highly preheated air** "Energy, Volume 42, Issue 5, March 2001, Pages 639-652
7. A. K. Gupta "Thermal Characteristics of Gaseous Fuel Flames Using High Temperature Air" *J. Eng. Gas Turbines Power* Jan 2004, 126(1): 9-19.
8. Roman Weber[a] John P.Smart[a] Willem vd Kamp[b] 2005 "On the (MILD) combustion of gaseous, liquid and solid fuels in high temperature preheated air" Proceedings of the Combustion Institute Volume 30, Issue 2, January 2005, Pages 2623-2629 Science Direct Elsevier
9. Weihong Yang, Wlodzimierz Blasiak "Numerical study of fuel temperature influence on single gas jet combustion in highly preheated and oxygen deficient air" Energy--Volume 30, Issues 2–4, February–March 2005, Pages 385-398
10. Singh R, Jain R.K., Patvardhan C, Kumar A ""Effect of air preheating & excess air on performance LDO fired Rotary furnace" Indian foundry journal, Vol. 46, No.11, 2006, p.p. 26-32
11. T. Hasegawa S. Mochida and A. K. Gupta"Development of Advanced Industrial Furnace Using Highly Preheated Combustion Air' Published Online: 23 May 2012
12. **E Abhilash, MA Joseph [12] 2009**-Modeling and Simulation of Casting Process: an Overview Indian Foundry Journal, 2009Indian Foundry Journal, Vol. 55, No.10, 2009, pp 28-37.
13. Sepehr Sanaye Hassan Hajabdollahi [13] 2009 "Multi-objective optimization of rotary regenerator using genetic algorithm"International Journal of Thermal Sciences ElsevierVolume 48, Issue 10, October 2009, Pages 1967-1977 ""Author links Sepehr Sanaye Hassan Hajabdollahi
14. Purshottam Kumar, Ranjit Singh January 2013International Journal of Computer Applications 62(1):25-31
15. Ranjit Singh,Gurumukh Das,Ratan Kumar Jain"Modeling and Optimization of Rotary Furnace Parameters using Regression and Numerical Techniques" World Foundry Congress At: Chennai trade centre, Chennai, India, February 2008

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