**TP 78**

# An Interactive Genetic Algorithm and Machine Learning approach for validating the effect of preheated air combustion on fuel consumption of oil-fired industrial furnace

By
DR. R. K. Jain
Professor, Department of Mechanical Engineering
ITM University, Gwalior-474001
Dr. Sanjay Jain
Associate Professor, Department of computer science and applications
ITM University, Gwalior-474001

Abstract

This paper presents an interactive approach of Genetic Algorithm and Machine Learning being used as tool for optimizing the Fuel Consumption of oil-fired rotary furnace operating with 20% preheated excess air.

The author has attempted to solve a crucial problem of optimizing fuel consumption in ferrous foundries.

Based on experiments carried on a self-designed and developed 200 kg rotary furnace in a foundry, it was found that crucial operating parameters like preheated excess air not only affects the flame temperature and melting rate but also significantly the fuel consumption

An attempt has been made to establish a correlation between fuel consumption as output parameter and all others as input parameters

It is expected that this model may prove practically beneficial for industry by estimating the effect of input process parameters for predicting the fuel consumption

The results of Genetic Algorithm and Machine approach 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 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.

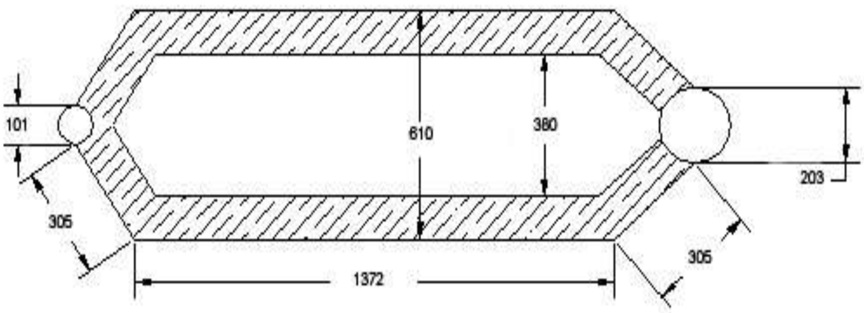


Figure 2

Rotary furnace is one of the suitable furnaces for the production of irons. However, conventional furnaces for producing ductile iron are: induction furnaces of different types, electric arc furnace and cupola furnace. Due to difficulty in operating air furnaces producing a low carbon, malleable cast iron and as a result of wasteful in fuel, rotary furnace was designed [1]. Rotary furnaces have cylindrical barrel which revolves completely at the rate of about one revolution per minute. Their capacity ranges from few kilograms to several tonnes, there is a single burner at one end of the barrel; they are fired by oil or pulverized coal. High temperature flame melts and superheats the charge in the furnace barrel. The waste gases that pass out at the other end of the barrel can be directed through a series of recuperation tubes on their way to the chimney [1]. This can be use to pre heat the incoming cold air in order to increase the efficiency of the furnace [1].

## 2.0 Literature Review

Baker E.H.W. [1] was the first one to study the tilting rotary furnace and explained its several advantages over other prevailing furnaces

Ishii T., Zhang C., Sugiyama S [2]1998, utilized regenerative burners with low NOx for investigations of effect of high temperature pre heated air with an optimal air fuel ratio leads to the efficient heat transfer

Gyung-Min, Katsuki Masashi [3] 2001 conducted several experiments to conclude that for efficient combustion the temperature of preheated air should be more than that of fuel ignition

Gupta A.K. [4]2004 while working on effect of flame temperature on emission levels of furnace found that the fuel properties and percentage of oxygen enrichment are the significant factors to be considered.

Hasegawa T. Mochida S. and Gupta A. K. [5]2012 stressed upon maintaining the optimal flame temperature for significant energy conservation , reduced size of furnace, and emission levels

Sanaye Sepehr, Hassan Hajabdollahi [6] 2009 predicted the effectiveness and pressure drop of an oil fired rotary furnace based on its RPM, porosity and heat transfer by modeling, employing the genetic algorithm and ε-NTU method

Kumar Purshottam, Singh Ranjit [7] 2013 developed a mathematical relationship between the fuel consumption based on melting time , preheated air temperature, rpm and flame temperature utilizing ANN to conclude that the modeled results are in correlation with results of experimental investigations conducted on a 200 kg oil fired rotary furnace

A.R. Khoei et.al [8] 2003 used self-developed ELFEN of finite elements method. he simulated the rpm and heat transfer of furnace to predict the performance of furnace under different conditions of flame temperature, rpm and temperature conditions

Jain R.K, Chaturvedi DK[9] 2011 employed feed forward method of ANN (artificial neural network)containing two intermediate layers. They successfully developed a model for modeling and optimizing energy consumption of rotary furnace

RóbertDzurnáket.al.[10] 2019Found during experimentation that modified burner design and combustion with 25% oxygen enrichment of preheated air significantly reduced the CO2emissions and melting time by 23.66%. He advocated for optimal burner design and oxygen enrichment of preheated air.

V. Sai Varun et.al[11]2018. 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

The literature survey reveals that no author up till now has applied genetic and machine learning technique to investigate Effect of preheated excess air on fuel consumption of oil Fired Rotary Furnace

**3.0 Melting Operation:**

The process of melting the charge is carried in following steps:

**1. Preheating of oil and furnace-**

**2.Charging** – After preheating the furnace is charged.

**3. Rotation-** After sufficient pre heating and charging the furnace starts rotating.

**4. Melting-** The flame starts coming out of the exit end, which is initially yellowish in color. After approximately 30-40 minutes,

the color of flame changes to white indicating that metal has been thoroughly melted. The temperature of the molten metal is measured using pyrometer. If it is approximately 1250 to 1300ºC, the rotation of furnace is stopped.

**5. Tapping-** the tape hole is slightly lowered and opened and metal is transferred into ladles, which are pre heated prior to transfer of molten metal to avoid heat losses.

**6. Inoculation-** The Ferro silicon and Ferro manganese are added in molten metal contained in the ladles.

**7. Pouring -** The ladles are then carried to molds and pouring is completed.

**3.1 Experimentation Investigations -Effect of 20.0% preheated excess air**

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—

| Heat no | Flame Temp °C | Time min. | Preheated excess air.$m^3$ | Melting rate kg/hr | Preheated excess air temp.°C | Preheated excess air % | **Fuel liters** |
|---|---|---|---|---|---|---|---|
| 1 | 1510.0 | 41.0 | 995.0 | 293.0 | 304.0 | 30.1 | **72.0** |
| 2 | 1530.0 | 40.0 | 970.0 | 300.0 | 316.0 | 25.5 | **70.0** |
| 3 | 1540.0 | 39.0 | 930.0 | 307.6 | 320.0 | 20.3 | **69.0** |
| 4 | 1545.0 | 38.0 | 905.0 | 315.7 | 329.0 | 20.1 | **68.0** |
| 5 | 1550.0 | 37.0 | 870.0 | 324,3 | 332.0 | 20.2 | **66.0** |
| 6 | 1568.0 | 37.0 | 835.0 | 324.3 | 340.0 | 19.9 | **64.0** |
| 7 | 1570.0 | 36.0 | 822.0 | 333.3 | 348.0 | 20.0 | **63.0** |
| 8 | 1578.0 | 35.0 | 795.0 | 342.8 | 370.0 | 19.9 | **61.0** |
| 9 | 1580.0 | 34.0 | 788.0 | 352.9 | 378.0 | 20.1 | **60.0** |
| 10 | 1590.0 | 34.0 | 785.0 | 352.9 | 385.0 | 20.0 | **59.0** |
| 11 | 1620.0 | 33.0 | 760.0 | 363.6 | 402.0 | 20.0 | **58.0** |

Table 1-- Experimentation Investigations -Effect of 20.0% preheated excess air

**3.2 The graphical representations—Effect of 20.0% preheated excess air on fuel consumption, flame temperature, Time), melting rate is shown in** figure 3,4,5,6, respectively

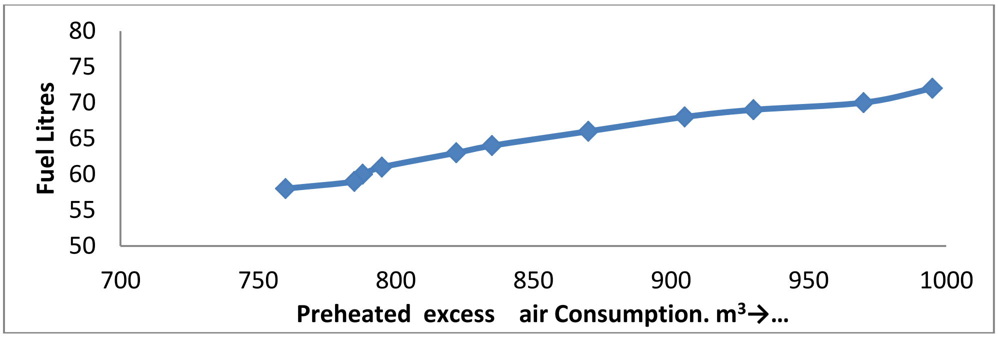


figure 3

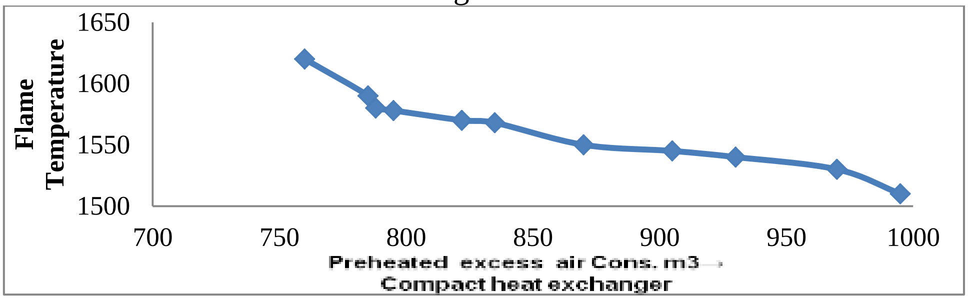


figure 4

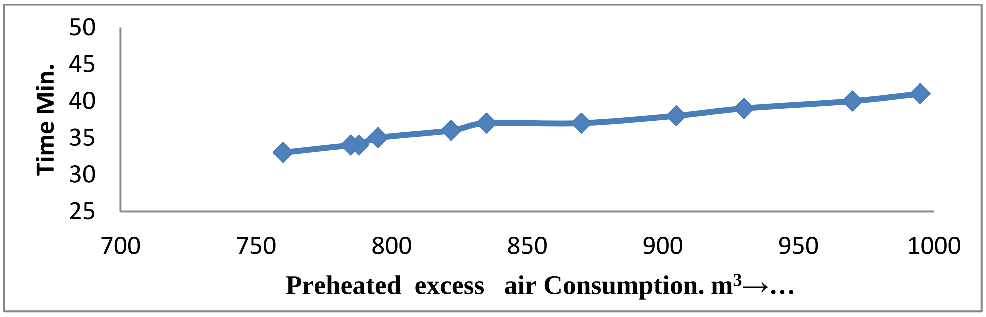


figure 5

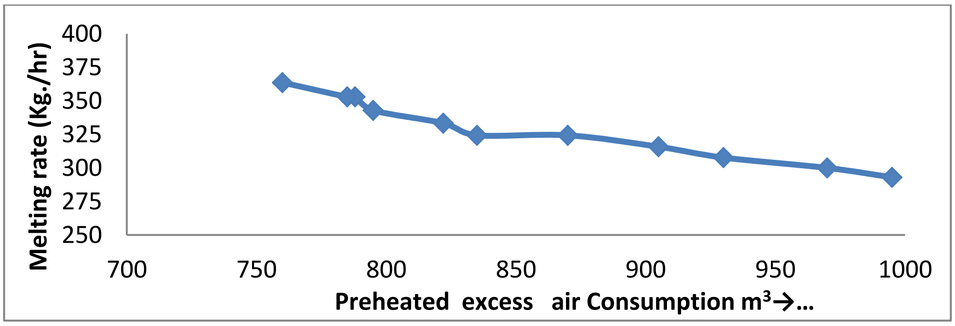


figure 6

## 4.0 Modeling and optimization----Input Parameters

For modeling and optimization, the following four parameters have been considered as input parameters---- Flame temperature, Time (min.), Melting Rate(kg/hr.) and preheated excess air $m^3$ and Fuel Consumption the output parameter

**Optimization of fuel consumption –**

## (1) Using Machine Learning approach —

**Design of Multiple Regression Model for estimating the Fuel Consumption in Rotary Furnace:**

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

$$Y = b0 + b1x1 + b2x2 + b3x3 + b4x4 + b5x5 + b6x6$$

Where b0= interceptor, b1… b6 are derivatives of coefficients and x1 = Flame_Temp, x2 = time min, x3= Preheated excess(air.m3), x4 = Melting Rate (Kg/hr.), x5= Preheated excess air(%),x6= Preheated excess air temp.(°C)

We have trained the regression model using generated experimental result of fuel consumption. Data set consist of around 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: [-1.06740705 18.27282782 1.70794968 16.43971962 -1.52771278 -1.76079121 ]
Interceptor: [64.50000000000003] and the generated multiple linear regression equation is:

***Y*[*Fuel*(*liters*)] =[64.50000000000003]-[1.06740705] [FlameTemp]+[18.27282782][Time Min.]+[1.70794968][Preheated excess air $m^3$]+[16.43971962][Melting Rate kg/hr.] – [1.52771278][Preheated excess air %]-[1.76079121][ Preheated excess air temp° C]** ---------------------------------------------------------------------------- (2)

The model is tested using the training and test dataset. We have achieved 99.7 % training accuracy and 97.6% testing accuracy of the proposed machine learning algorithm. The modeled values as generated by the trained model and actual experimental values are compared in table 2—

| Heat no | Flame Temp | Time _Min | Preheated Excess Air $m^3$ | Melting Rate kg/hr. | Preheated Excess _air_temp.°C | Preheated Excess air_% | **Actual Fuel liters** | **Predicted Fuel liters** |
|---|---|---|---|---|---|---|---|---|
| 1 | 1510 | 41 | 995 | 293 | 304 | 30.1 | **72** | **71.82** |
| 2 | 1530 | 40 | 970 | 300 | 316 | 25.5 | **70** | **70.32** |
| 3 | 1540 | 39 | 930 | 307.6 | 320 | 20.3 | **69** | **69.97** |
| 4 | 1545 | 38 | 905 | 315.7 | 329 | 20.1 | **68** | **67.74** |
| 5 | 1550 | 37 | 870 | 324.3 | 332 | 20.2 | **66** | **65.8** |
| 6 | 1568 | 37 | 835 | 324.3 | 340 | 19.9 | **64** | **64.22** |
| 7 | 1570 | 36 | 822 | 333.3 | 348 | 20 | **63** | **62.87** |
| 8 | 1578 | 35 | 795 | 342.8 | 370 | 19.9 | **61** | **60.8** |
| 9 | 1580 | 34 | 788 | 352.9 | 378 | 20.1 | **60** | **60.31** |
| 10 | 1590 | 34 | 785 | 352.9 | 385 | 20 | **59** | **59.62** |
| 11 | 1620 | 33 | 760 | 363.6 | 402 | 20 | **58** | **57.89** |

Table-2: Result of Testing the Trained model using Machine Learning

The plotted graph Figure 7 shows the comparison between experimental result and the result generated by the regression model of fuel consumption in rotary furnace. Figure 8 shows the actual vs predicted fuel consumption of testing and training data sets.

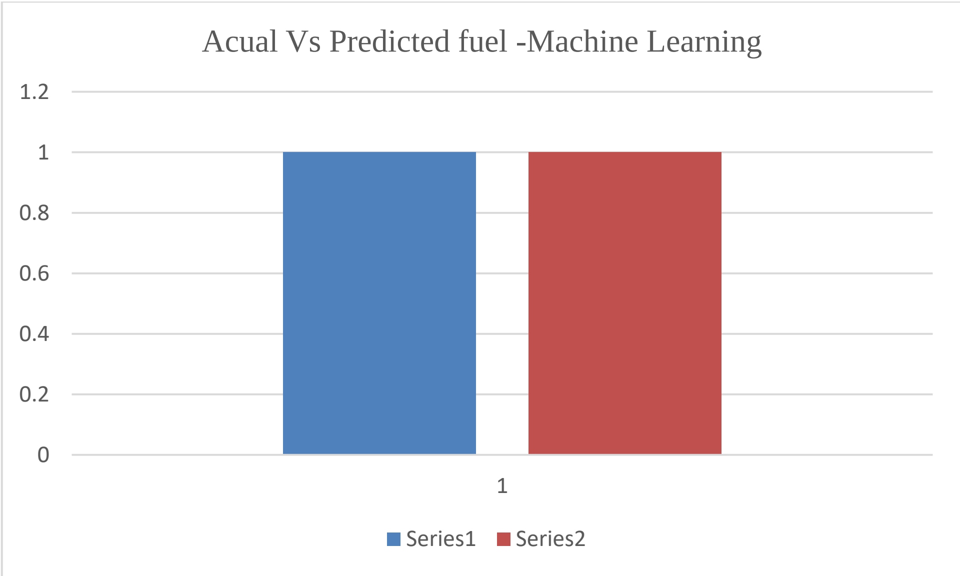


Figure 7: comparison between experimental result and the result generated by Using Machine Learning approach

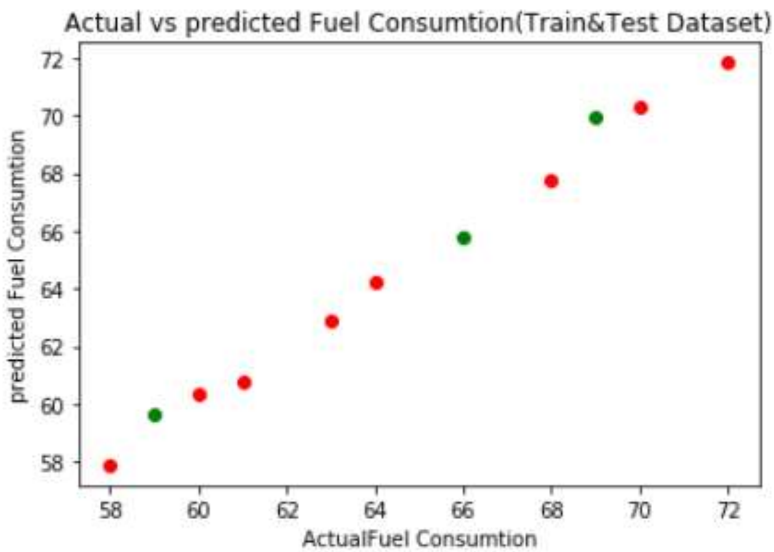


Figure 8 -the actual vs predicted fuel consumption of testing and training data sets.

**(2 ) Using genetic algorithm approach —**

For optimization of fuel consumption, a genetic algorithm approach is used for solving linear regression

Linear regression can be analytically solved by matrix calculus. However, it is a problem in which we can be approximately correct,

In any regression problem, we have some elements:

**Inputs:** these are the variables used in predicting outputs.

**Outputs:** these are the variables we wish to predict.

**Parameters:** values that define relationships between inputs and outputs. We try to predict these with as much accuracy as possible.

We have used the **Using genetic algorithm approach to** model experimentally investigated result of fuel consumption. The Linear equation for the multiple regression model Using genetic algorithm approach is

EA1=c0+c1*(flame_temp) +c2*(time)+c3*(melting rate) +c4*(preheated excess air)

**Fuel=c0+c1*(flame temp) +c2*(time)+c3*(melting rate) +c4*(preheated excess air $m^3$)**

Where --c0=-0.8703112155966014, c1=0.012878392328843025, c2=1.1326878830457192, c3=-0.039523963795492945, c4=0.01892841192534156]

Ysimulated=[71.7017,70.7429,68.9128,67.6029,65.6675,64.0456,62.9801,61.0973,59.9299,59.7775,57.5418].The tabular comparison is given in table 3----

| Heat no | Flame Temp | Time _Min | Preheated Excess Air $m^3$ | Melting Rate kg/hr. | Actual Fuel liters | Predicted Fuel liters |
|---|---|---|---|---|---|---|
| 1 | 1510 | 41 | 995 | 293 | 72 | **72.26951287946628,** |
| 2 | 1530 | 40 | 970 | 300 | 70 | 70.64451479829543, |
| 3 | 1540 | 39 | 930 | 307.6 | 69 | 68.58309223667872, |
| 4 | 1545 | 38 | 905 | 315.7 | 68 | 66.72144191040019, |
| 5 | 1550 | 37 | 870 | 324.3 | 66 | 64.65074548297049, |
| 6 | 1568 | 37 | 835 | 324.3 | 64 | 64.22006212750271, |
| 7 | 1570 | 36 | 822 | 333.3 | 63 | 62.5113459999258, |
| 8 | 1578 | 35 | 795 | 342.8 | 61 | 60.59514047746942, |
| 9 | 1580 | 34 | 788 | 352.9 | 60 | 58.95651846126952, |
| 10 | 1590 | 34 | 785 | 352.9 | 59 | 59.02851714878192, |
| 11 | 1620 | 33 | 760 | 363.6 | 58 | 57.386064324856186 |

Table 3- Result of Testing the Trained model using genetic algorithm

figure 9 shows the Actual vs Predicted fuel using Genetic Algorithm

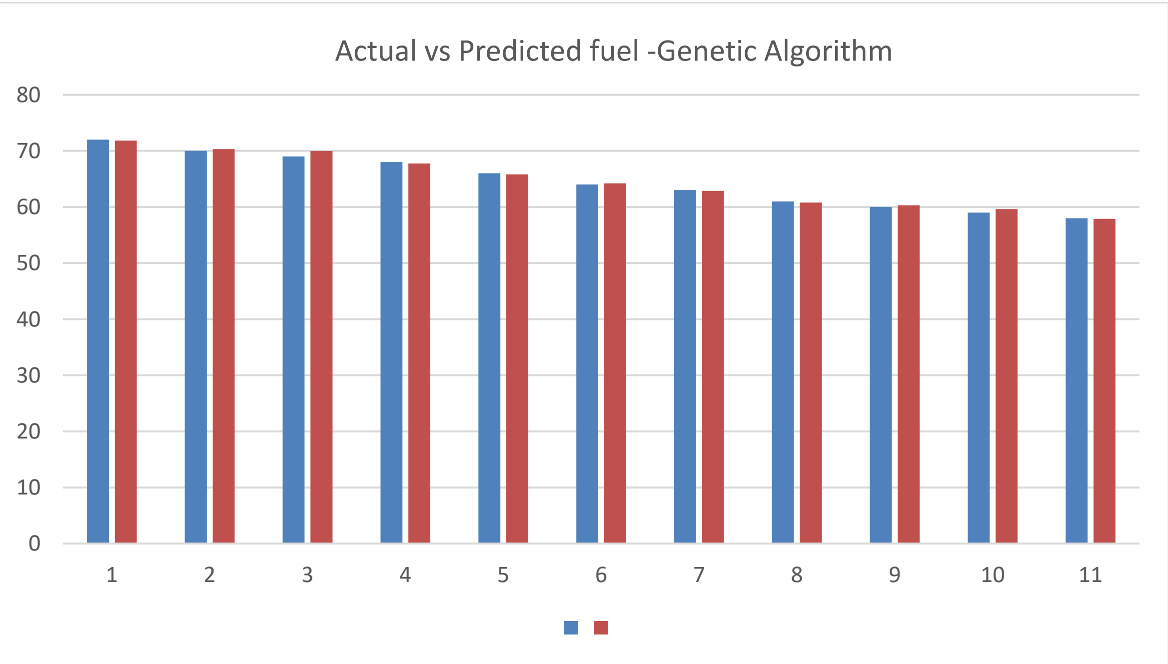


Figure 9: Comparison between Actual vs Predicted fuel using Genetic Algorithm

## 4. Comparison of results using machine learning and genetic algorithm

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

| sn | | Machine learning | | Genetic algorithm | |
|---|---|---|---|---|---|
| | Actual Fuel liters | Predicted Fuel liters | % Variations | Predicted Fuel liters | % Variations |
| 1 | 72 | 71.82 | -0.25000 | 72.26951287946628, | +0.9652778 |
| 2 | 70 | 70.32 | +0.45714 | 70.64451479829543, | +0.9207349 |
| 3 | 69 | 69.97 | +1.40579 | 68.58309223667872, | -0.604214 |
| 4 | 68 | 67.74 | - 0.38235 | 66.72144191040019, | -1.880233 |
| 5 | 66 | 65.8 | - 0.30303 | 64.65074548297049, | -2.696028 |
| 6 | 64 | 64.22 | +0.34375 | 64.22006212750271, | +0.343847 |
| 7 | 63 | 62.87 | -0.20634 | 62.5113459999258, | -0.775641 |
| 8 | 61 | 60.8 | -0.32786 | 60.59514047746942, | -0.006637 |
| 9 | 60 | 60.31 | +0.51666 | 58.95651846126952, | -1.739142 |
| 10 | 59 | 59.62 | +1.05084 | 59.02851714878192, | +0.0483339 |
| 11 | 58 | 57.89 | -0.18965 | 57.386064324856186 | -1.05851207 |
| | Average% variation | | **+0.19226816%** | Average% variation | **-0.05479%** |

Table 4 -Comparison of results using machine learning and genetic algorithm

Figure 10 shows the comparison of Actual vs Predicted fuel using Machine learning & Genetic Algorithm

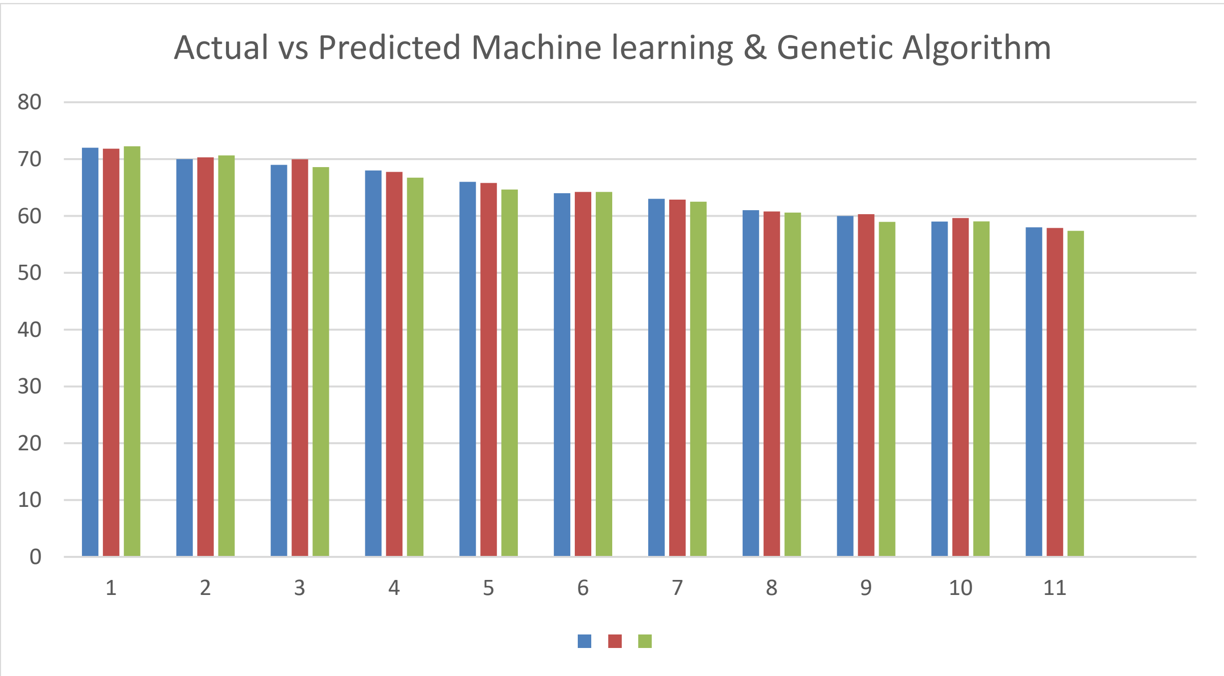


Figure 10 : comparison between experimental result and the result generated by Using Geneti c Algorithm &machine learning approach

**6.0 Results and Discussions**

The Comparison of actual and predicted fuel consumption using machine learning and genetic algorithm the both techniques including %Error is given in Table 5

| sn | technique | Flame Temp(°C) | Time min | Preheated Excess Air $m^3$ | Melting Rate kg/hr. | Actual Fuel liters | Modeled Fuel liters | % Variation |
|---|---|---|---|---|---|---|---|---|
| **1** | Machine learning | 1620 | 33 | 760 | 363.6 | 58 | 57.8900000000 | **-0.189655%** |
| **2** | Genetic algorithm | 1620 | 33 | 760 | 363.6 | 58 | 57.386064324856186 | **-1.0585172** |

Table 5- The Comparison of actual and predicted fuel consumption using machine learning and genetic algorithm

The diagrammatical presentation of variation of experimental and modeled value of fuel consumption using Machine learning and Genetic algorithm is shown in figure 11

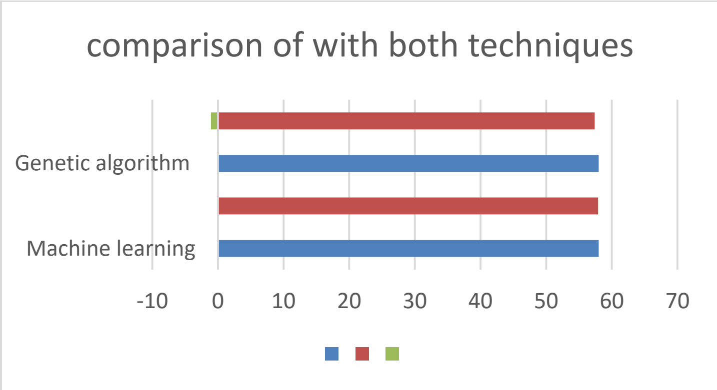


Figure 11--comparison of actual and modelled with Machine learning and Genetic algorithm both techniques

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.

The optimal input parameters and predicted fuel consumption is shown in table 6

| **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 6- The optimal input parameters and predicted fuel consumption

The diagrammatical presentation shown in figure 12

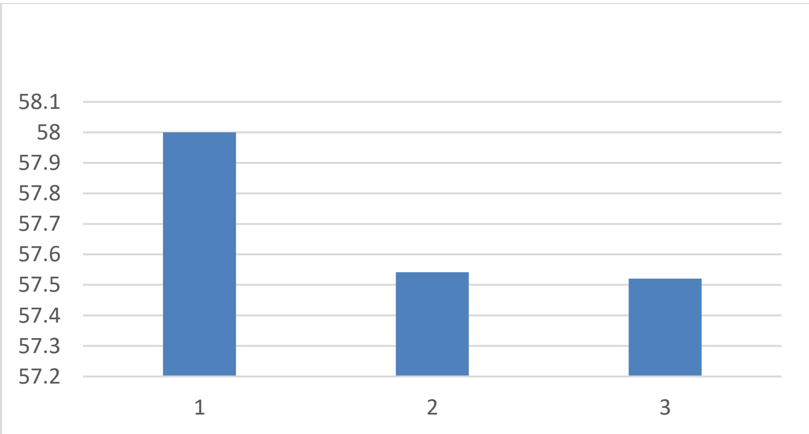


figure 12 -The optimal input parameters and predicted fuel consumption

**7. CONCLUSIONS**

It is very clear that while applying genetic and machine learning 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 7

| sn | Technique | Experimental fuel consumption | Modeled fuel consumption | Percentage error |
|---|---|---|---|---|
| 1 | Genetic algorithm | **58** | 57.386064324856186 | **-1.0585172** |
| 2 | Machine learning | **58** | 57.8900000000 | **-0.189655%** |

Table7-the comparison of Genetic algorithm and Machine learning

Hence it is concluded that both Genetic algorithm and Machine learning can very well be applied for modeling the fuel consumption of oil-fired rotary furnace as they correlate with actual experimental results. they are useful for industry for predicting the fuel consumption for any range of data without actually installing the furnace. Marginally the genetic algorithm is slightly better

REFERENCES:

[1] Baker EHW – "Rotary furnace" Modern Workshop Technology, part - 1, Clever Hummer Press Ltd., London-2nd Edition.

[2] T. Ishii, C. Zhang S. Sugiyama "Numerical Simulations of Highly Preheated Air Combustion in an Industrial Furnace" J. Energy Resource. Technol. Dec 1998, 120 (4): 276-284 (9 pages) https:// doi.org/10.1115/1.2795048 Published Online: December 1, 1998

[3] Gyung-Min Choi Masashi Katsuki 2001 "Advanced low NOx combustion using highly preheated air" Energy Conversion and Management, Volume 42, Issue 5, March 2001, Pages 639-652

[4] A. K. Gupta "Thermal Characteristics of Gaseous Fuel Flames Using High Temperature Air" J. Eng. Gas Turbines Power. Jan 2004, 126(1): 9-19 (11 pages) https:// doi.org/10.1115/1.1610009 Published Online: March 2, 2004

[5] T. Hasegawa S. Mochida and A. K. Gupta "Development of Advanced Industrial Furnace Using Highly Preheated Combustion Air" Published Online: 23 May 2012https:// doi.org/10.2514/2.5943 Journal of Propulsion and Power Vol. 18 No 2 March 2002 ARC

[6] Sepehr Sanaye Hassan Hajabdollahi 2009 " Multi-objective optimization of rotary regenerator using genetic algorithm" International Journal of Thermal Sciences Elsevier Volume 48, Issue 10, October 2009, Pages 1967-1977

[7] Purshottam Kumar, Ranjit Singh January 2013 "Optimizing Process Parameters of Rotary Furnace using Bio-fuels: An Interactive ANN approach". International Journal of Computer Applications 62(1):25-31 DOI: 10.5120/10046-4631

[8] A.R. Khoei I. Masters D.T. Gethin, 2003 "Numerical modelling of the rotary furnace in aluminum recycling processes" Journal of Materials Processing Technology 139 (2003) 567–572.

[9] Jain R. K, Chaturvedi DK [2011]"Modelling, Optimization and simulation of Rotary Furnace using Artificial Neural Network" IJEST (International Journal of Engineering, Science, and Technology) SINGAPORE (impact factor 1.83) ISSN: 0975-5462 Vol. 3 No. 4 April 2011.Pp 2609-2621

[10] Róbert Dzurnák et.al. (2019) "Influence of Burner Nozzle Parameters Analysis on the Aluminum Melting Process", Applied Sciences MDPI 18 April 2019 Appl. Sci. 2019, 9, 1614; doi: 10.3390/app9081614 www.mdpi.com/journal/applsci

[11] Varun V. Sai, Tejesh P. Prashanth B.N. Design and Development of Tilting Rotary Furnace. In: IOP Conf. Series, Materials Science and Engineering 310, 1 February 2018. DOI: 10.1088/1757-899X/310/1/012084