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Optimum Geometry for Two Trapezoidal Corrugated of Surface for the Cylindrical Combustion Chamber

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***Abstract-* The temperature of surface is effect by the radiation heat flux especially in combustion chamber. The radiation heat flux depends the geometry of combustion chamber. Corrugate surface is one of the technical has impression on the radiation heat flux. The effect of trapezoidal dimension (high and width of trapezoidal), which lay out the corrugate surface of cylindrical combustion chamber, on the average radiation heat flux are studied. Objective function, average radiation heat flux, was calculated using neural network technical. Genetic algorithm will be exploitation incur optimum value of design victor. The results demonstrate the optimum value of design vector (high and width of trapezoidal) are 29.944 and 709.36625 mm respectively.**

Key word: Radiation, heat transfer, fluent, optimization

INTRODUCTION

Most energy production over the world depends the combustion process. The combustion chamber is the important device in the combustion system. The geometry of combustion chamber has effect on the combustion efficiency. Therefore many researchers are interested to study the combustion chamber geometry. The main goal of combustion chamber is convert the chemical energy of the fuel into heat energy, but heat can be transferred by three ways conduction, convection and radiation. At high temperature radiation has bigger effects on heat transfer especially in combustion chambers. Radiation is affected by the geometry of combustion chamber. Man Young et al [1] were developed a theoretical model to calculate the raditive heat transfer in an axisymmetric enclosure with absorbing, emitting, and scattering medium by using the different methods. Sumit Kumar [2] solve the radiation heat in square and rectangular enclosures, three dimensional heat generation. The problem was solved by using FLUENT software. The parameters has been studied including isothermal absorbing emitting, purely scattering medium and diffuse gray surface. Temperature profile was defined using the user defined function (UDF) in C programming language. John C. Chai and et al [3] produce a theoretical model radiative transfer in irregular geometries using finite volume method (FVM). The case study is symbolize enclosed by black or reflecting walls. P.J. Coelho [4] build a numerical simulation of radiative heat transfer from non-gray gases in three-dimensional enclosures. In that simulation a several gas radiative property model were used. His model known the correlated k – distribution (CK). The results explain the CK model is accurate as evaluated method but needs large time for engineering applications. P.J. Coelho and et al [8] are studied the radiation in enclosures containing obstacles of very small thickness using finite volume method. The study included comparison with other method zone method calculations and the Monte – Carlo method. Their results show their method and finite volume method are economical. Gleyzer Martins and et al [9] evaluated optimum geometry of radiative heat transfer of corrugate surface. The model was solved by using finite volume technical. Two methods of optimization simulated annealing and the simplex method were used. Two cases are studied a theoretical furnace and combustion chamber. Both cases has constant temperature profile with gray gas and cold walls of furnace, while non – gray gas for combustion chamber.

From the review above, one can be study the optimum geometry surface of combustion chamber for non-constant temperature profile and other type of corrugation geometry. Therefore this work will represent extended study for evaluated optimum geometry of combustion chamber surface. Real combustion (Methane – air) will be taken, and two trapezoidal (one inverse the other) represent the corrugation of the surface will be studied.

i. GOVERING EQUATIONS

Temperature distribution, mass conservation of species, intensity radiation and gases velocities are governed by conservation equations. The partial differential equations for the system are:

1) Mass conservation

$$\frac{\partial\rho}{\partial t} + \nabla.(\rho\vec{v}) = 0 \quad \ldots\ldots(1)$$

2) Momentum equation

$$\frac{\partial}{\partial t}(\rho\vec{v}) + \nabla.(\rho\vec{v}\vec{v}) = -\nabla P + \nabla.\bar{\bar{\tau}} + \rho\vec{g} + \vec{F} \quad \ldots\ldots(2)$$

3) Energy conservation:

$$\frac{\partial}{\partial t}(\rho e) + \nabla.\left(\vec{v}(\rho e + P)\right) = \nabla.(\lambda \nabla T) + S_h \quad \dots\dots\dots (3)$$

$$e = h - \frac{P}{\rho} + \frac{v^2}{2} \quad \dots (4)$$

4) Radiation intensity conservation

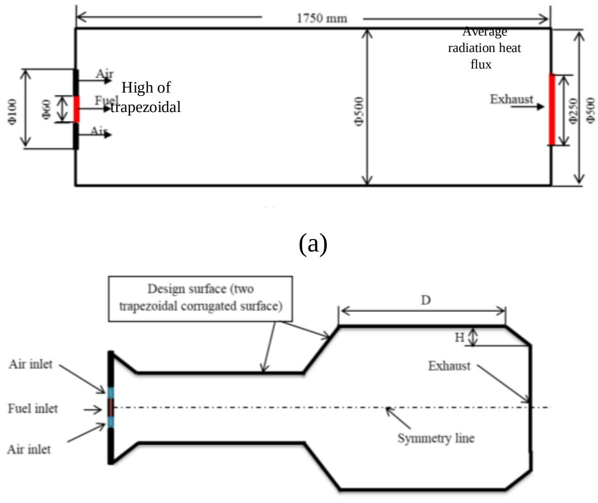
$$\frac{dI(\vec{r},\vec{s})}{ds} + (a + \sigma_x) I(\vec{r},\vec{s}) = an^2 \frac{\sigma T^4}{\pi} + \frac{\sigma_s}{4\pi} \int I(\vec{r},\vec{s}')\, \Phi(\vec{s},\vec{s}')\, d\Omega' \quad \dots\dots (5)$$

ii. CHOOSING a RADIATION MODEL

Fluent code has five radiation models: Discrete Transfer (DTRM), P-1, Rosseland, Surface-to-Surface (S2S) and Discrete Ordinates (DO). The DO model was used in this project due to it using for wide large of optical thicknesses and solving problems ranging from surface to surface radiation to participating radiation in combustion problems as cited in reference [6].

iii. MODEL DESCRIPTION

A cylindrical combustion chamber, which including two trapezoidal corrugated surface, was modeled and solved by FLUENT. The geometry of this model was shown in figure (1, a). The length of combustion chamber (longitudinal of cylinder) was corrugated in to two trapezoidal shape. In this research, the optimum value of this trapezoidal corrugate dimensions (H and D as shown in figure 1, b) will be calculated. The design surface (length of the combustion chamber) was taken as diffusion surface with absorption coefficient 0.5 m-1 and reflective index 0.5. The velocity of fuel and air were fixed in this research by value 0.5 m/s and 3 m/s respectively.



(a)

(b)

Figure (1) cylindrical combustion chamber

i. OPTIMUM CORRUGATED SURFACES

For optimization, the surfaces of the combustion chamber were substituted by corrugated surfaces. The corrugated surface, which including only two trapezoidal corrugate, was modeled as trapezoidal shape as shown in above (fig. 1, b). The dimension of this trapezoidal are length (D) and high (H). The parameters for geometric optimization of radiation heat transfer of the corrugated surface are the two as design variables: the length (D) and high (H) of the trapezoidal. The objective function was the maximizing and defined as the average radiation heat flux on the corrugated surface as following:

F(min.)=average (q_r'') …………. (6)

With subjected to the following conditions:

$$0 \le H \le 45\text{mm} \quad , \quad 0 \le D \le 775\text{mm} \quad \dots\dots(7)$$

ii. FORMULATION THE EQUATION OF OBJECTED FUNCTION

The average radiation heat flux on the corrugated surface was calculated using fluent code. The empirical equation of average radiation heat flux on the corrugated surface as a function of the trapezoidal shape geometry (D and H) was formulated by using the artificial neural network (ANN) model. The ANN model is a single output (Average incident radiation heat flux as output) with two input parameters (Length D and high H of trapezoidal), one hidden layer, which has 23 nodes as shown in figure below.

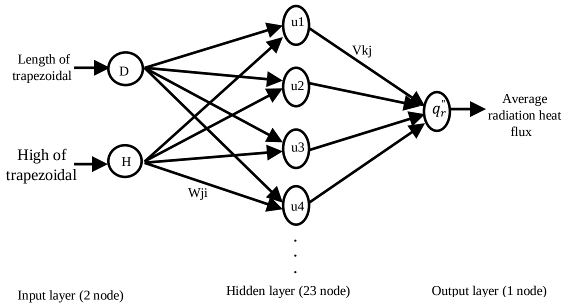


Figure (2) the artificial neural network

The artificial neural network (ANN) model which has a Tan sigmoid as activation function with pure line as output transfer function. The correlation coefficient of ANN was 0.999998. The output form hidden layer node can be write as:

$$\left.\begin{aligned} h_1 &= \frac{\exp(u_1) - \exp(-u_1)}{\exp(u_1) + \exp(-u_1)} \\ h_2 &= \frac{\exp(u_2) - \exp(-u_2)}{\exp(u_2) + \exp(-u_2)} \\ &\vdots \\ h_{23} &= \frac{\exp(u_{23}) - \exp(-u_{23})}{\exp(u_{23}) + \exp(-u_{23})} \end{aligned}\right\} \quad \dots .(8)$$

Where:

$$\left.\begin{array}{c} u_1 = w_{11} * D + w_{21} * H + b_1 \\ u_2 = w_{12} * D + w_{22} * H + b_2 \\ u_3 = w_{13} * D + w_{23} * H + b_3 \\ \vdots \\ u_{23} = w_{123} * D + w_{223} * H + b_{23} \end{array}\right\} \quad \dots\dots(9)$$

The output of the output layer can be expressed as:

$$q_r^{"} = \left(\sum_{i=1}^{23}(h_i * V_i)\right) + B \quad \dots\dots(10)$$

Where w_{ij} are the weights of the hidden layer, b_1, b_2... b_{23} are thresholds of the hidden layer, V_i the weights of the output layer and B the thresholds of the output layer.

i. OPTIMIZATION METHOD

The Genetic algorithms (GA) method was used to determine the optimum values of the design vector. GA are search algorithms that are based on concepts of natural selection and natural genetics.

The genetic algorithm programming starting generated random population of chromosomes. The steps of evaluated fitness function can be shown in chart below as cited in reference [7]:

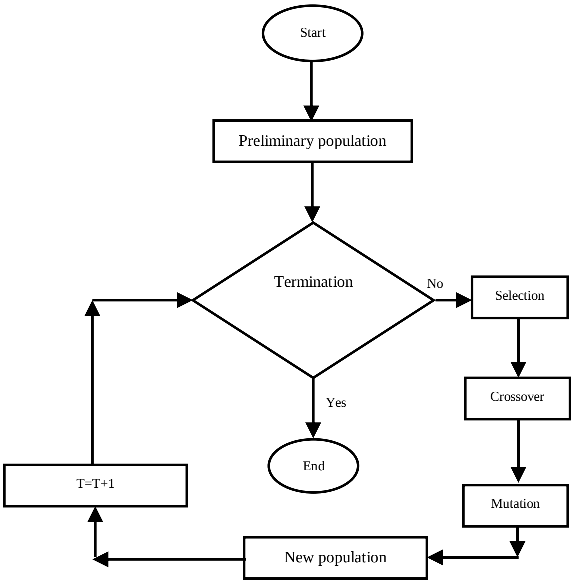


Figure (3) the genetic algorithm flowchart.

i. RESULTS AND DISCUSSIONS

The procedure to evaluate the results has three techniques. First, to get the data represent objective function including the independent variable from software (FLUENT code). Secondly technique is evaluated the objective function by using Neural network technique. Finally, by using the genetic algorithm, the optimum value of objective function was calculated. To dependence this procedure a case study was taken. This case represented as calculate the optimum value of enclosure geometry produce the uniform heat flux distribution over design surface that studied by K. J. Daun and et al [8]. Figure (4) consists of heated surface at constant heat flux (1 W/m^2). Two adiabatic reflector surface and the design surface. The objective work is to find the enclosure geometry that products a target heat flux (-1W/m^2) over the design surface. The objective function was minimizing and defined as:

$$F(\Phi) = \frac{1}{N}\sum_{j=1}^{N}\left[q_{sj}(\Phi) - q_{sj}^{target}\right]^2 \quad \dots\dots(11)$$

Where $q_{sj}^{target} = -1\ W/m^2$, N number of nodes

The value of the two optimum variables (Φ1 and Φ2) were Φ^*(0.0034, 0.8547) and the objective function is 2.26×10^{-4} as cited in reference [8]. Here the optimum values are (0.00329, 0.8597) and the objective function value is (1.248×10^{-4}) respectively.

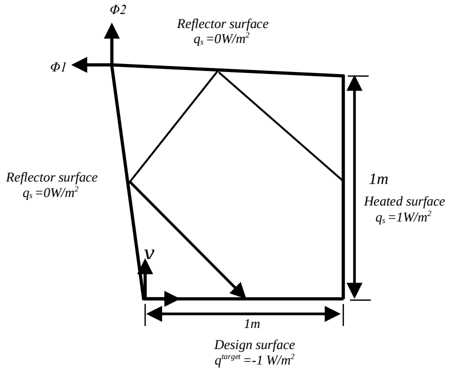


Figure (4) enclosure design problem [8].

Figure (5) shows the radiation heat flux at the cylindrical surface of the combustion chamber without corrugation and optimum value of the trapezoidal corrugate. The edges of the trapezoidal caused high discontinue in the distribution of the heat flux.

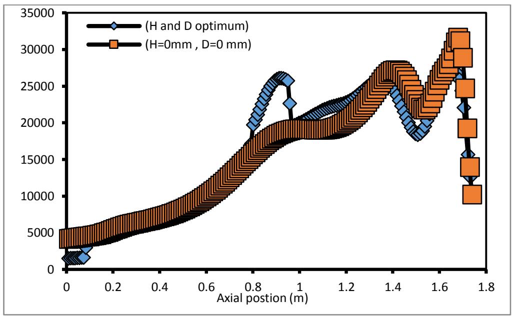


Figure (5) Heat flux of the design surface without and with optimum value of corrugation.

Figure (6) shows the relation between average temperature and radiation heat flux of the corrugated surface. From this figure one can see a linear proportional average temperature with radiation heat flux. In this figure, reducing average surface temperature while average surface radiation heat flux. This phenomena can be represent surface cooling. For this case the reducing in average surface temperature was about 50 C^o.

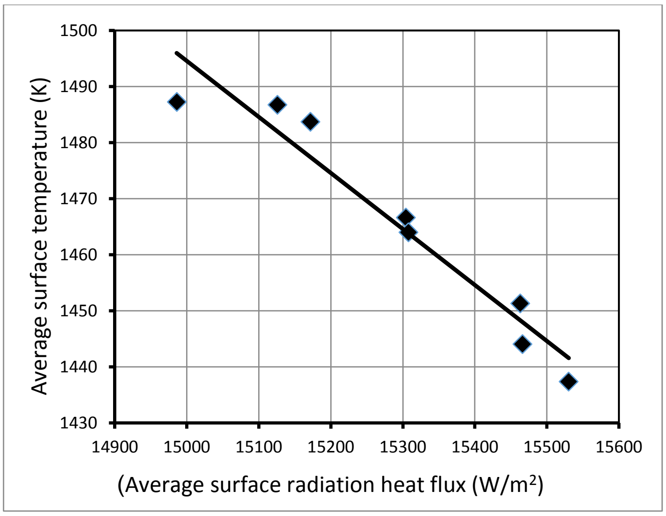


Figure (6) Relationship between average surface temperature and radiation heat flux at constant width of trapezoidal (D=600mm).

The results of the optimization method are shown in Table 1, where the objective function is the average radiation heat flux at the cylindrical corrugated surface.

Table 1. Results of the optimization

Design variables results		Average Radiation Heat Flux (W/m^2)
D*(mm)	H*(mm)	
709.36625	29.944	15823.993

CONCLUSIONS

The surface temperature of combustion chamber has sensitive radiation heat flux along this surface. In other hand, radiation heat flux depends on its geometry. From these results, the producer of calculate optimum design vector was effectiveness.

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