International Journal of Engineering and Information Systems (IJEAIS)
ISSN: 2643-640X
Vol. 6 Issue 5, May - 2022, Pages: 17-22

Numerical Approach for Estimating the Length of Boiler Tube for a Small Scale Solid Waste Fired Steam Boiler

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Abstract— *The design calculation of any mechanical system often appears tedious, time consuming and demand enormous mathematical skill if it is intended to be solved using analytical method. This paper presents the Design Calculation of a small scale solid waste fired steam boiler using Numerical Method. This method provides an approach for solving physical or mathematical equation using a computer software by creating a specific algorithm. Matrix Laboratory (MATLAB) software was used to implement the algorithm created, detailing the design of the economizer, evaporator and the super heater. MATLAB Code was developed for estimating the length of tube required to produce steam for a given design parameters specifying temperature, pressure and steam flowrate. Initial design values were entered and computation was done for the following parameters: heat transfer coefficient, flue gas mass velocity, resistance to heat transfer, log mean temperature difference, convective boiling heat transfer coefficient and nucleate boiling suppression factor. The result of the computation reveals that for a specified temperature of 150°C and a pressure of 5 bar with a mass flow rate of 1.5 kg/, the total length of the economizer, evaporator and superheater required is 82.3 m.*

Keywords—MATLAB, Economizer, Evaporator, Super heater, Convection, Temperature, Pressure and Flow rate.

1. INTRODUCTION

The numeric method used in this work employs the Matrix Laboratory (MATLAB), which is a programming language for technical computing that integrates visualization and numeric computation. Numerical methods are algorithms for computing numeric data. They're used to produce 'approximate' solutions to problems, and they're used when addressing a problem analytically becomes impossible or extremely difficult. MATLAB provides an interactive system whose essential data component is an array that does not demand dimensioning. The accurate design of a boiler is very important in order to produce steam at the specified temperature, pressure and flow rate. However, this may be very difficult to do when applying analytical approach. Hence, this work aims at the design calculation of a small scale solid waste fired steam boiler using numerical method. This method provides an easy way to solve a problem quickly in comparizm with analytical solution, it also provides a fast approximation solution for mathematical problems. The application of MATLAT in this work is limited to a small scale steam boiler fired by solid waste for generating steam for a given specification. Waini (et al, 2019) applied numerical method to investigate 'Heat transfer and hybrid nanofluid flow over a nonlinear permeable stretching/shrinking surface' According to the findings, 'dual solutions exist for a specific range of stretching/shrinking and suction parameters.' With increasing copper (Cu) nanoparticle volume fractions for the upper branch, the skin friction coefficient increases and the local Nusselt number decreases on the decreasing sheet. Patil (et al, 2019) carried out 'The variations of different dimensionless parameters have been depicted on velocity, temperature, and species concentration profiles for NaCl and Sucrose aqueous solutions through graphical representations for unsteady mixed convection triple diffusive transport phenomena,' according to the findings'. Takuya and Koichi (2021) applied the numerical method to carry out their work on extended overstressed model and its implicit stress implication algorithm: formulations, experiments and simulations, in this work the model developed possesses the fundamental structure capable of defining monotonic/cyclic loading behavior at a broad rate of deformation from quasi-static to impact loading. Experiments were carried out with spheroidal graphite cast iron under various loading circumstances, and it was determined that the experimental results may be accurately predicted using the subloading – overstress model.

2. METHODOLOGY

The methodology employed in executing the objectives is centred on two stages, namely – 1) the development of a flow chart detailing the steps for computing the length of the boiler tube and 2) the application of MATLAB code.

2.1 The Development of a Flow Chart

The flow chart in figure 2.1 was developed to capture all the essential stages that are involved in the estimation of the length of the boiler tube in which steam is produced.

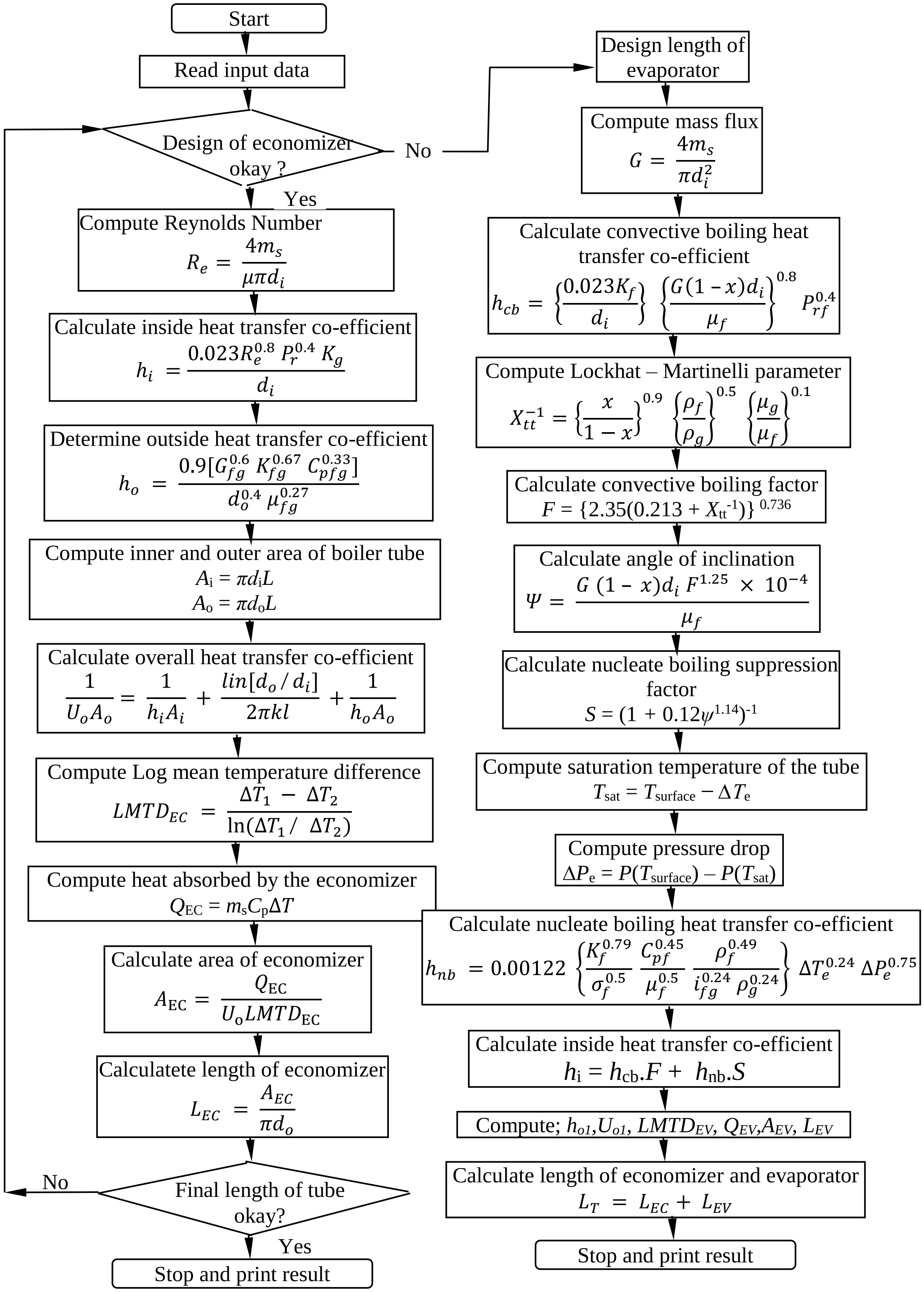

Figure 2.1: Flow chart for estimating the length of boiler tube

2.2 Application of MATLAB Code for Estimating the Length of Boiler Tube

MATLAB is a programming language that allows matrix manipulations, plotting of functions and data, implementation of algorithms, and interfacing with programs written in other languages. In this work an algorithm was created to calculate the length of the boiler tube required to produce steam at the designed parameters of 150°C and 5 bar, the algorithm was then implemented with a MATLAB software. The code implemented here follows the sequence shown in the flow chart of Figure 2.1.

%MATLAB Code for Estimating the Length of Boiler Tube

%Initial Values

ΔT=112; % Change in temperature of water in economizer tube (°C)
ΔT_1=551.6; % Temp. difference between the flue gas and water at outlet of evaporator (°C)
ΔT_2=135.3; % Temp. difference between the flue gas and water at inlet of evaporator (°C)
ΔT_3=135.3; % Temp. difference between the flue gas and water at outlet of Economizer (°C)
ΔT_4=162; % Temp. difference between the flue gas and water at inlet of economizer (°C)
ΔT_e=20 % Excess temperature (°C)
C_{fg}=1.0626; % Specific heat capacity on water-side (kJ/kg.°C)
C_p=4.186; % Specific heat capacity of water (kJ/kg.°C)
C_{pf}=4.56; % specfic heat capacity of saturated water at 212.4 °C (kJ/kg.°C)
C_{pfg1}=1.162; % Specific heat capacity on the flue gas-side(kJ/kg.°C)
d_i=0.017; % Inner diameter of tube(m)
d_o=0.019; % Outer diameter of tube(m)
G_{fg}=0.233; % Flue gas mass velocity (kg/m^2.s)
h_{fg}=2.257; % Change in enthalpy of steam (kJ/kg)
i_f=1889.56; % Latent heat of vapourization of water at 212.4°C
K=0.401; % Thermal conductivity of mild steel tube(kW/m^2.°C)
K_f=665*10^-6; % Thermal conductivity of saturation water (kW/m^2.°C) at 264.15°C
K_{fg}=3.156*10^-3; % Thermal conductivity on water-side (kW/m^2.°C)
K_{fg1}=0.004425; % Thermal conductivity on the flue gas-side (kW/m^2.°C)
K_g=688*10^-6; % Thermal conductivity of saturation water (kW/m^2.°C) at 129.4°C
L=1; % Assumed length of boiler tube (m)
m_s=0.006337; % Mass flow rate of the flue gas (kg/s)
m_{st}=0.2; % Mass flow rate of steam (kg/s)
Pr=1.32; % Prandlt number of sat. water at 129.4°C
p_{rf}=0.88; % Prandlt number of sat. water at 264.15°C
P_{sat}=4.8; % Saturation pressure at T_{sat} (bar)
$P_{surface}$=7.9; % Saturated pressure at $T_{surface}$ (bar)
$T_{surface}$=170; % Temperature of tube inner surface (°C)
x=0.25; % Dryness fraction
N_w=15; % Number of tubes along each wall
m_g=418.3; % mass flowrate of the flue gas (kg/hr)
S_t=0.003; % Lateral distance (m)
x=0.25; % Dryness fraction
x=0.25; % Dryness fraction

μ=21323*10^-8; % Kinematic viscosity of sat. water(kg/m.s)at 129.4oC
μ_f=126.33*10^-6; % Kinematic viscosity of saturated fluid (kg/m.s)at 264.15°C
μ_{fg}=1.079*10^-5; % Kinematic viscosity on water-side (kg/m.s)
μ_{fg1}=1.40*10^-4; % Kinematic viscosity on the flue gas-side
μ_g=16.07; % Kinematic viscosity of sat. vapour(kg/m.s)at 264.15°C
ρ_f=850.28; % Density of saturated fluid at 264.15°C
ρ_{fg}=1.387; % Density of flue gas (kg/m^3)
ρ_g=9.91; % Density of saturated vapour at 264.15°C
σ_f=34.97*10^-3; % Surface tension of water at 212.4°C (N/m)

% DESIGN OF ECONOMIZER LENGTH

% calculating Reynold's number
$R_e=4*m_s/(\mu*\pi*d_i)$

% computing inside heat transfer coefficient
$h_i=K_g*(0.023*R_e\wedge 0.8*P_r\wedge 0.4)/d_i$

%Calculating flue gas mass velocity
$G_{fg}=12*m_g/(N_w*L*)(St - do)$

%Calculating outside heat transfer coefficient
$h_o=0.9*((G_{fg}\wedge 0.6*K_{fg}\wedge 0.67*C_{fg}\wedge 0.33)/(d_o\wedge 0.4*\mu_{fg}\wedge 0.27))$

% Calculating inner Area
$A_o= \pi*d_o*L$

% Calculating Outside Area
$A_i= \pi*d_i*L$

% computing total resistance to heat transfer
$U_o=1/(A_o*(1/(h_i*A_i)+\log(d_o/d_i)/(2*\pi*K*L)+1/(h_o*A_o)))$

% computing log mean temperature difference for economizer
$LMTD_{EC}=(\Delta T_1-\Delta T_2)/\log(\Delta T_1/\Delta T_2)$

% Calculating heat transfer to the economizer
$Q_{EC}=m_{st}*C_p*\Delta T$

% calculating Area of economizer
$A_{EC}=Q_{EC}/(U_o*LMTD_{EC})$

%calculating Length of economizer
$L_{EC}=A_{EC}/(\pi*d_o)$

%DESIGN OF EVAPORATOR LENGTH

%Calculatng mass flux
$G=4*M_s/(\pi*d_i\wedge 2)$

%Computing convective boiling heat transfer co-efficient
$h_{cb}=(0.023*K_f/d_i)*((G*(1-x)*d_i/\mu_f)\wedge 0.8)*p_{rf}\wedge 0.4$

% Calculating Lockhat-Martineli parameter
$Xtt^{-1}=((x/(1-x))\wedge 0.9)*((\rho_f/\rho_g)\wedge 0.5)*(\mu_g/\mu_f)\wedge 0.1$

% Computing convective boiling factor
$F=(2.35*(0.213+Xtt^{-1}))\wedge 0.736$

% Computing angle of inclination
$\Psi=(G*(1-x)*d_i*(F\wedge 1.25)*10\wedge -4/\mu_f)$

% Computing nucleate boiling suppression factor
$S=(1+0.12*\Psi\wedge 1.14)\wedge -1$

% Calculating saturated temperature of the tube
$T_{sat}=T_{surface}-\Delta T_e$
% Calculating pressure drop
$\Delta p_e=P(T_{surface})-P(T_{sat})$

%Computing nucleate boiling heat transfer co-efficient
$h_{nb}=0.00122*(K_f$^0.79*C_{pf}^0.45*ρ_f^0.49)*(ΔT_e^0.24*Δp_e^0.75)/(σ_f^0.5*μ_f^0.24*ρ_g^0.24)

% Computing inside heat transfer co-efficient`
$h_1=h_{cb}*F+h_{nb}*S$

%Calculating Outside film coefficient
$h_{o1}=0.00579*0.9*((G_{fg}$^0.6*$K_{fg1}$^0.67*$C_{pfg1}$^0.33)/($d_o$^0.4*$\mu_{fg1}$^0.27))

% computing overall heat transfer co-efficient
$Uo_1=1/(A_o*(1/(h_{i1}*A_i)+\log(d_o/d_i)/(2*\pi*K*L)+1/(h_{o1}*A_o)))$

% computing $LMTD_{EV}$
$LMTD_{EV}=(\Delta T_3-\Delta T_4)/\log(\Delta T_3/\Delta T_4)$

% Calculating heat absorbed by the evaporator
$Q_{EV}=m_{st}*h_{fg}$

% calculating Area of evaporator
$A_{EV}=Q_{EV}/(U_o*LMTD_{EV})$

%calculating Length of evaporator
$L_{EV}=A_{EV}/(\pi*d_o)$

% Computing length of economizer and evaporator
$L_{CV}=L_{EC}+L_{EV}$

3.0 RESULTS AND DISCUSSION

The algorithm detailing the computation of the following parameters – heat transfer coefficient, flue gas mass velocity, resistance to heat transfer, log mean temperature difference, convective boiling heat transfer coefficient and nucleate boiling suppression factor – was drawn to create easy execution of MATLAB code. The algorithm gives the computer a specific set of instructions, which allows the computer determine the total length of boiler tube required to produce steam for a specific design condition. The result of the computation reveals that for a specified temperature of 150°C and a pressure of 5 bar with a mass flow rate of 1.5 kg/, the total length of the economizer, evaporator and superheater required is 82.3 m. Numerical approaches may solve much more complex, common, and difficult issues and jobs in a short amount of time, and a numerical solution can optimize basic parameters based on the requirements. Inasmuch as analytical methods can only answer two or three unknown variables, numerical methods can accomplish much more precisely. Numerical techniques are a branch of mathematics that is used to resolve problems. Whether the equations are linear or nonlinear, efficient and robust numerical methods are required to solve a system of algebraic equations.

4.0 CONCLUSION

In comparison to analytic answers, numerical approaches allow you to solve issues rapidly and easily. There are various methods available to reduce the solution of what can be fairly difficult analytical math to basic algebra, whether the goal is integration or the solution of complex differential equations. Manipulation of data is crucial and it doesn't matter which programming language is applied; the key is to comprehend programming concepts such as loops, variables, and so on. In this way, even for designing, the ability to create variables and examine a large number of outputs that can only be done numerically to select the best result is critical.

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