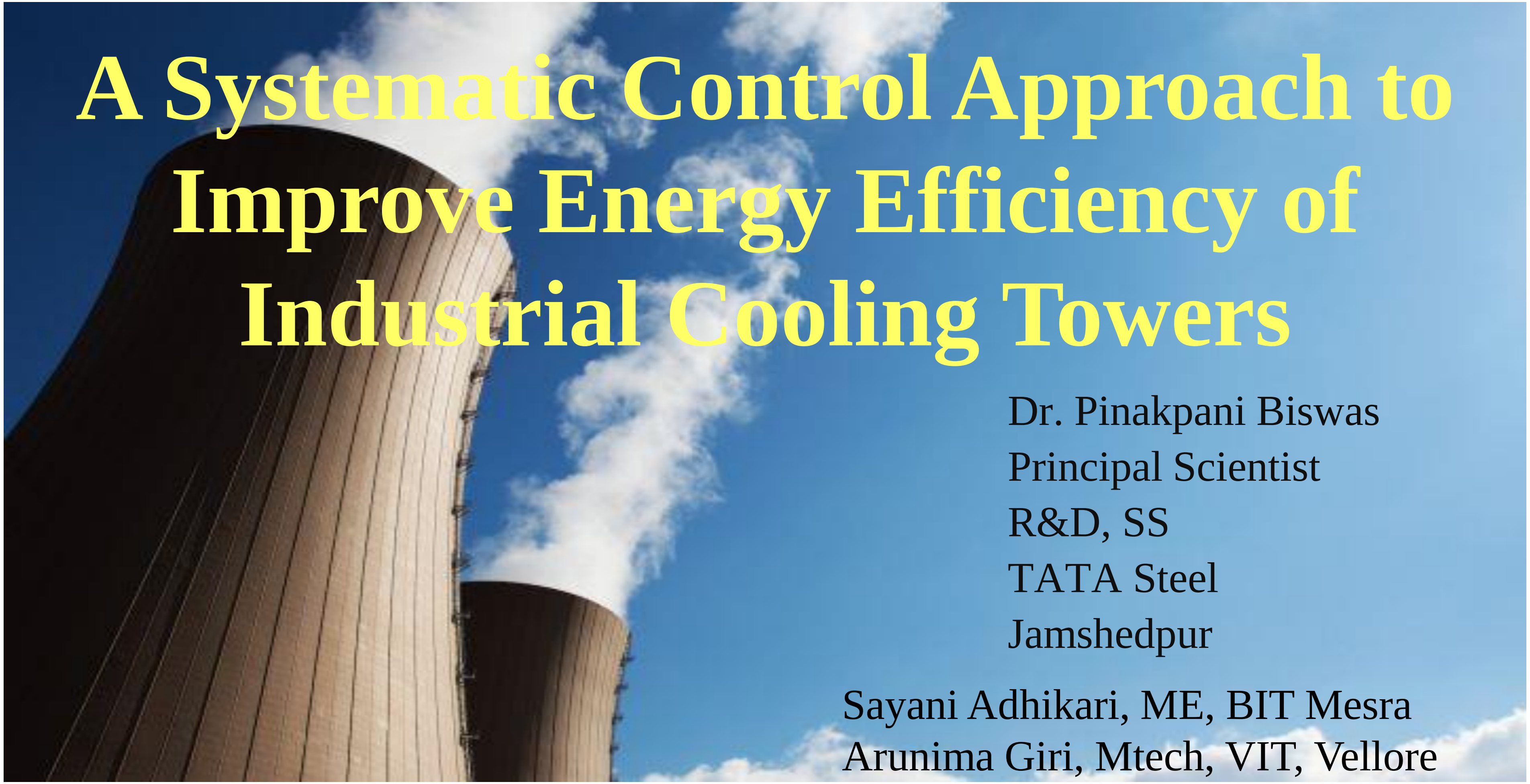


A Systematic Control Approach to Improve Energy Efficiency of Industrial Cooling Towers

Dr. Pinakpani Biswas
Principal Scientist
R&D, SS
TATA Steel
Jamshedpur

Sayani Adhikari, ME, BIT Mesra
Arunima Giri, Mtech, VIT, Vellore

Agenda

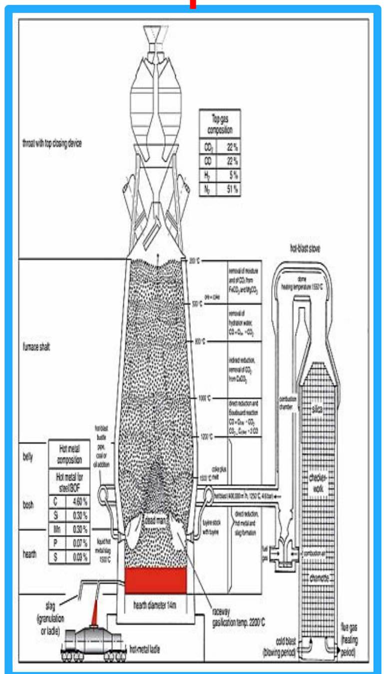
- Brief Introduction
- Key Challenges
- Solution Overview
- Objectives & Assumptions
- Approach
- Model Development
- Tools Used
- Optimization Flowchart
- Results and Discussion
- Conclusion
- Future Scope of work

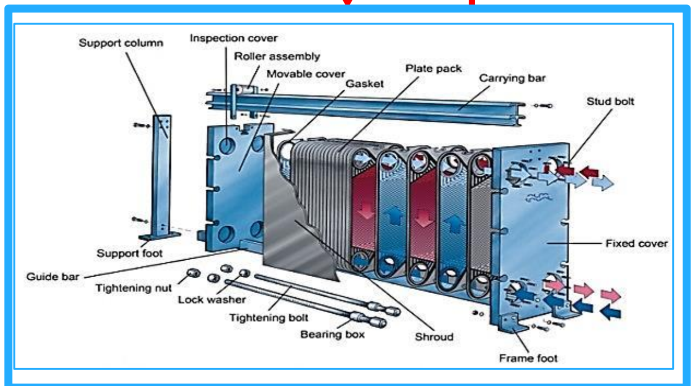
Brief Introduction

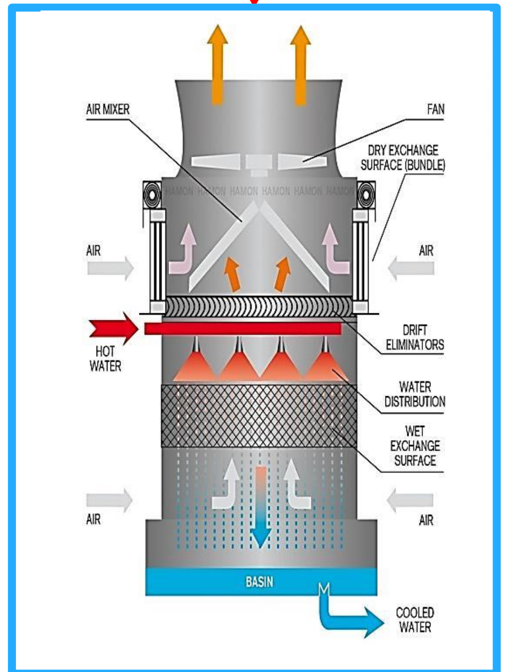
A device used to COOL hot water stream based on evaporative cooling

Hot stream(DM Water)

Warm Process Water







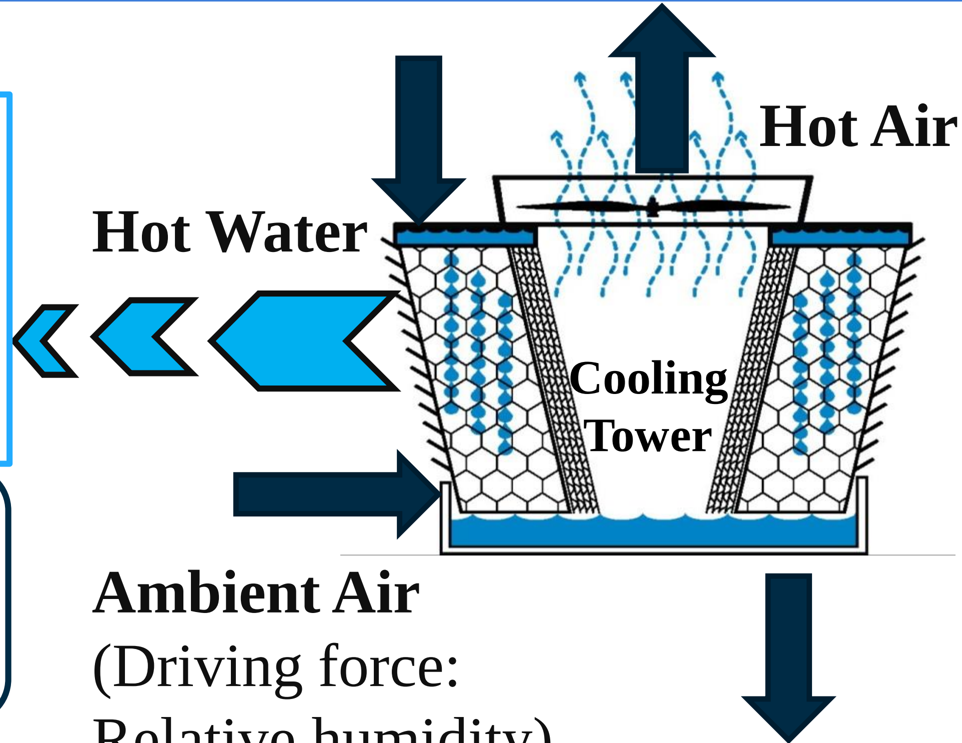
Cold stream(DM Water)

Cold Process Water

Key Challenges

CT Objective
To decrease hot water temperature by 4-8 degrees (TATA Steel Jamshedpur)

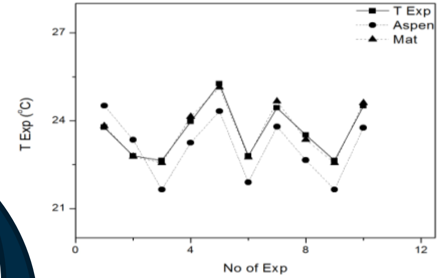
Cooling tower is an energy intensive process



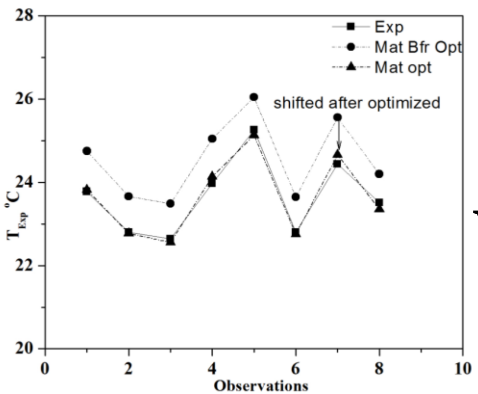
- **Tuning cooling tower parameters for optimized operation**
- **Optimizing Energy Consumption**

Solution Overview

MATLAB/Simulink Simulation



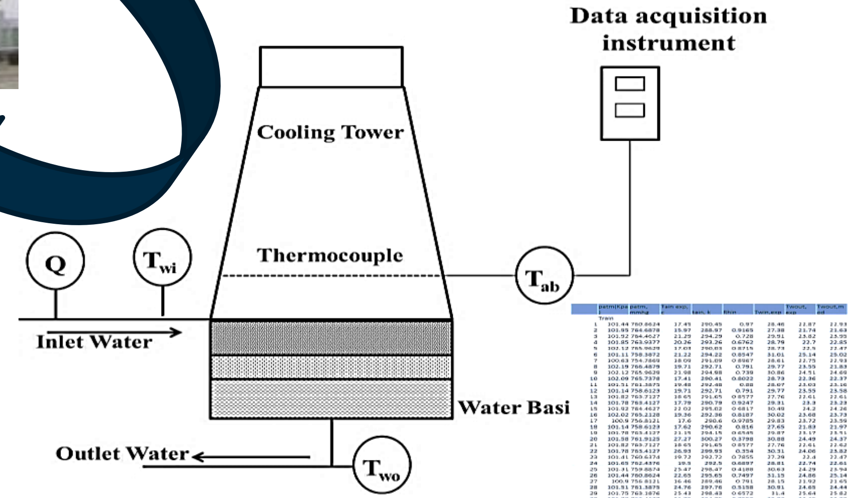
Implementation



Validation

Monitor Operation/ Collect data

MATLAB Program



Optimization: E value obtained

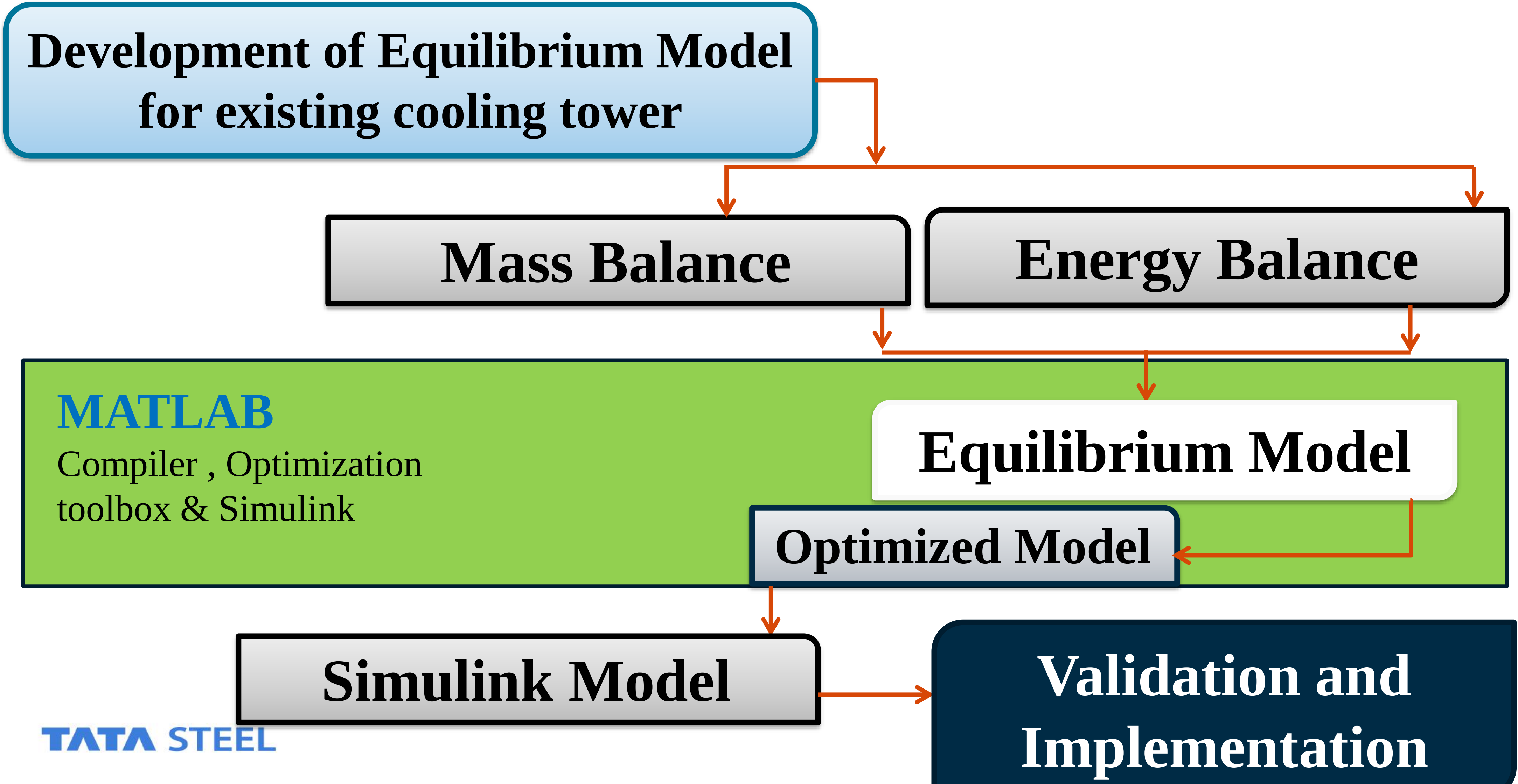
Objectives

- Tune the model parameters to decrease energy consumption

Assumptions

- Stage efficiency was assumed to be equal for all stages for basic simulation purpose which later on to be optimized with the help of available data
- Vapor liquid equilibrium

Approach



TATA STEEL

Model Development

Mass balance for 2 stages

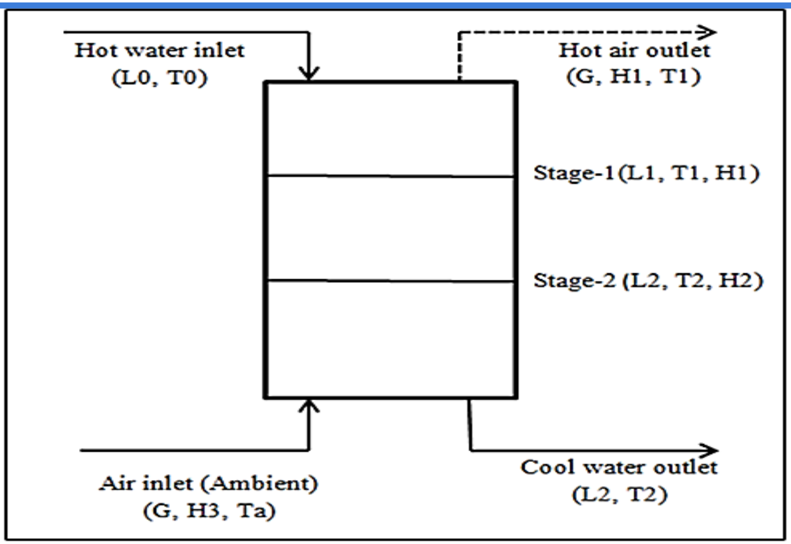
Mass of water in = Mass of water out

Stage-1

$$L_o + GH_2 = L_1 + GH_1 \Rightarrow L_1 = L_o + G(H_2 - H_1)$$

Stage-2

$$L_1 + GH_3 = L_2 + GH_2 \Rightarrow L_2 = L_1 + G(H_3 - H_2)$$



Energy balance for 2 stages

Sensible heat of inlet air + sensible heat of inlet water
+ sensible heat of inlet water vapour + latent heat of inlet water vapour
= sensible heat of exit air + sensible heat of exit water
+ sensible heat of exit water vapour + latent heat of exit water vapour

Stage-1

$$(G \times C_{pa} \times T_2) + (L_0 \times C_{pw} \times T_0) + (G \times H_2 \times C_{pv} \times T_2) + (G \times H_2 \times \lambda)$$
$$= (G \times C_{pa} \times T_1) + (L_1 \times C_{pw} \times T_1) + (G \times H_1 \times C_{pv} \times T_1) + (G \times H_1 \times \lambda)$$

Stage-2

$$(G \times C_{pa} \times T_a) + (L_1 \times C_{pw} \times T_1) + (G \times H_3 \times C_{pv} \times T_a) + (G \times H_3 \times \lambda)$$
$$= (G \times C_{pa} \times T_2) + (L_2 \times C_{pw} \times T_2) + (G \times H_2 \times C_{pv} \times T_2) + (G \times H_2 \times \lambda)$$

Model Development(Contd.)

- Unknowns: L_2, L_1, T_2, T_1, H_2, H_1 (No of unknowns is 6)
- No of equations: 4
- Degrees of freedom=2
- To eliminate one set of unknowns in order to make the number of unknowns and number of equations equal murphy efficiency equation is used

$$E_n = \frac{Y_n - Y_{(n+1)}}{YS_n - Y_{(n+1)}}$$

- Equations obtained for '2' stages are

$$Y_1 = E_1(YS_1 - Y_2) + Y_2$$

$$Y_2 = E_2(YS_2 - Y_3) + Y_3$$

- H_1 and H_2 can be calculated from Y_1 and Y_2

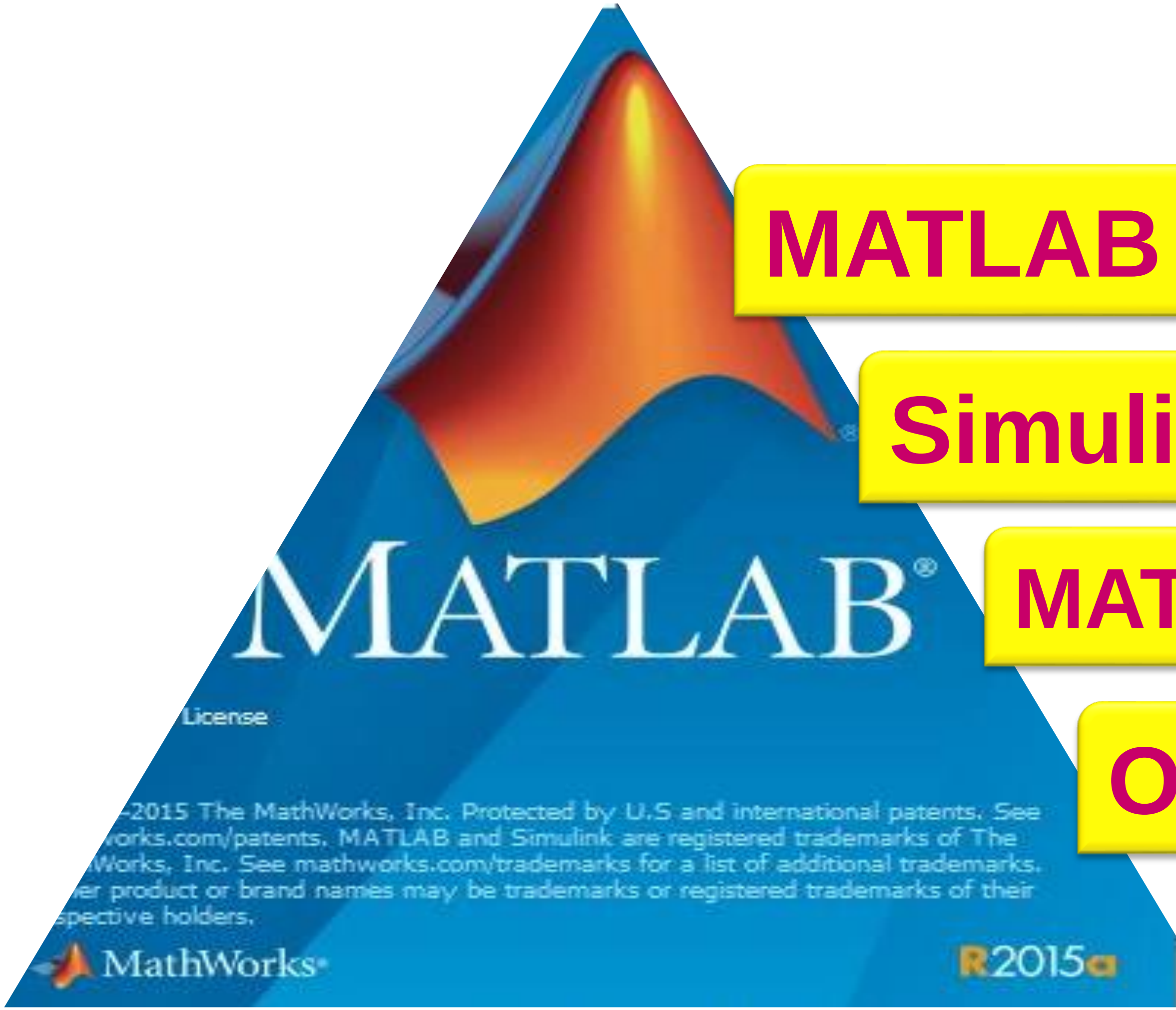
$$H_1 = \frac{Y_1}{1 - Y_1} * \frac{M_{H_2O}}{M_{Air}}$$

$$H_2 = \frac{Y_2}{1 - Y_2} * \frac{M_{H_2O}}{M_{Air}}$$

TATA STEEL

- Degrees of freedom after variable substitution: No. of variables 4 and No. of equations 4. This implies D.O.F=0

Tools Used



- MATLAB R2016b
- Simulink
- MATLAB Compiler
- Optimization toolbox

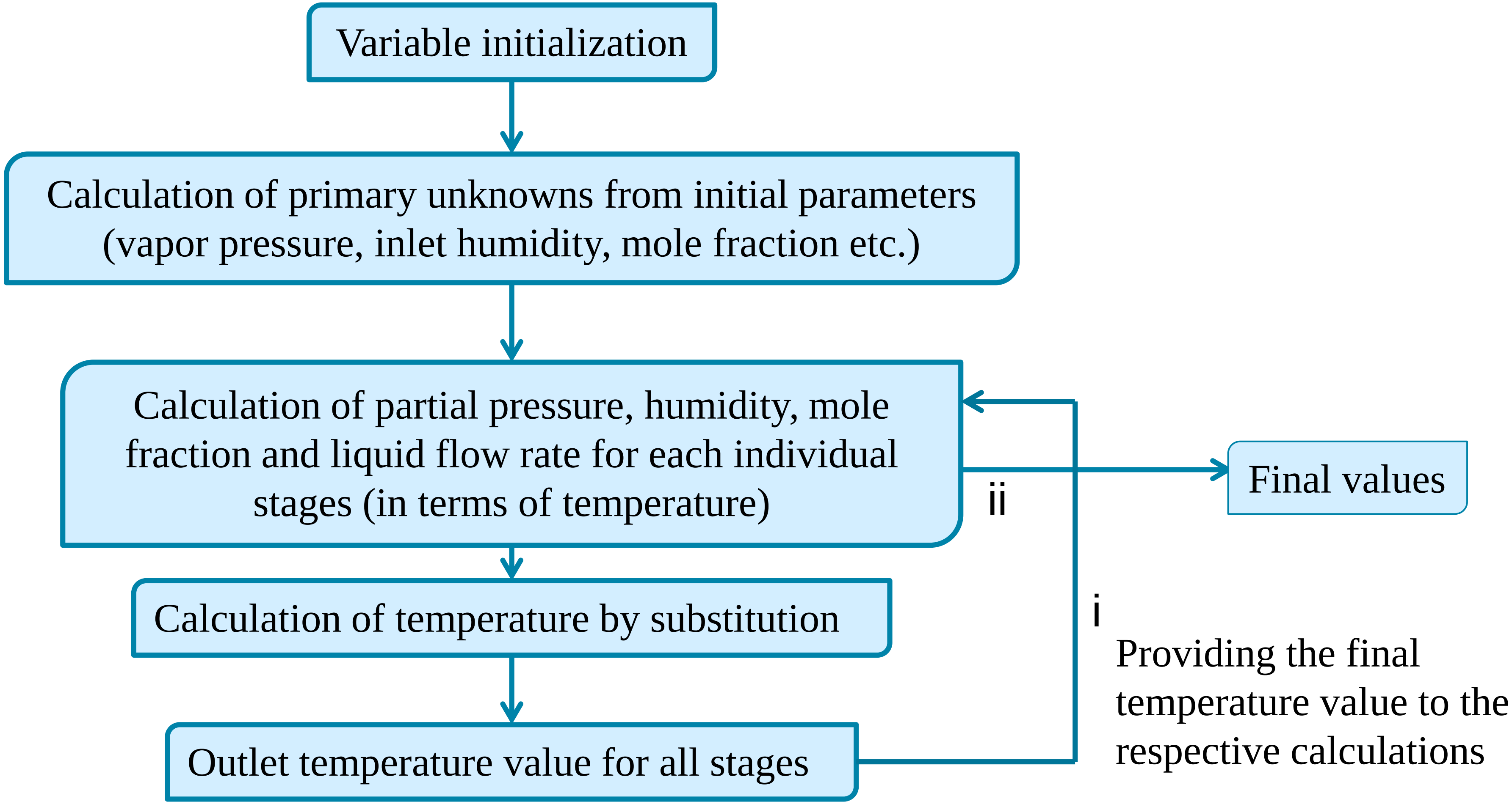
Coding

calc_opt.m | cmpN.m | it1.m | OPT1.m | HUM.m | HUMm.m | RH.m | RH1.m | DBT.m | VAP.m

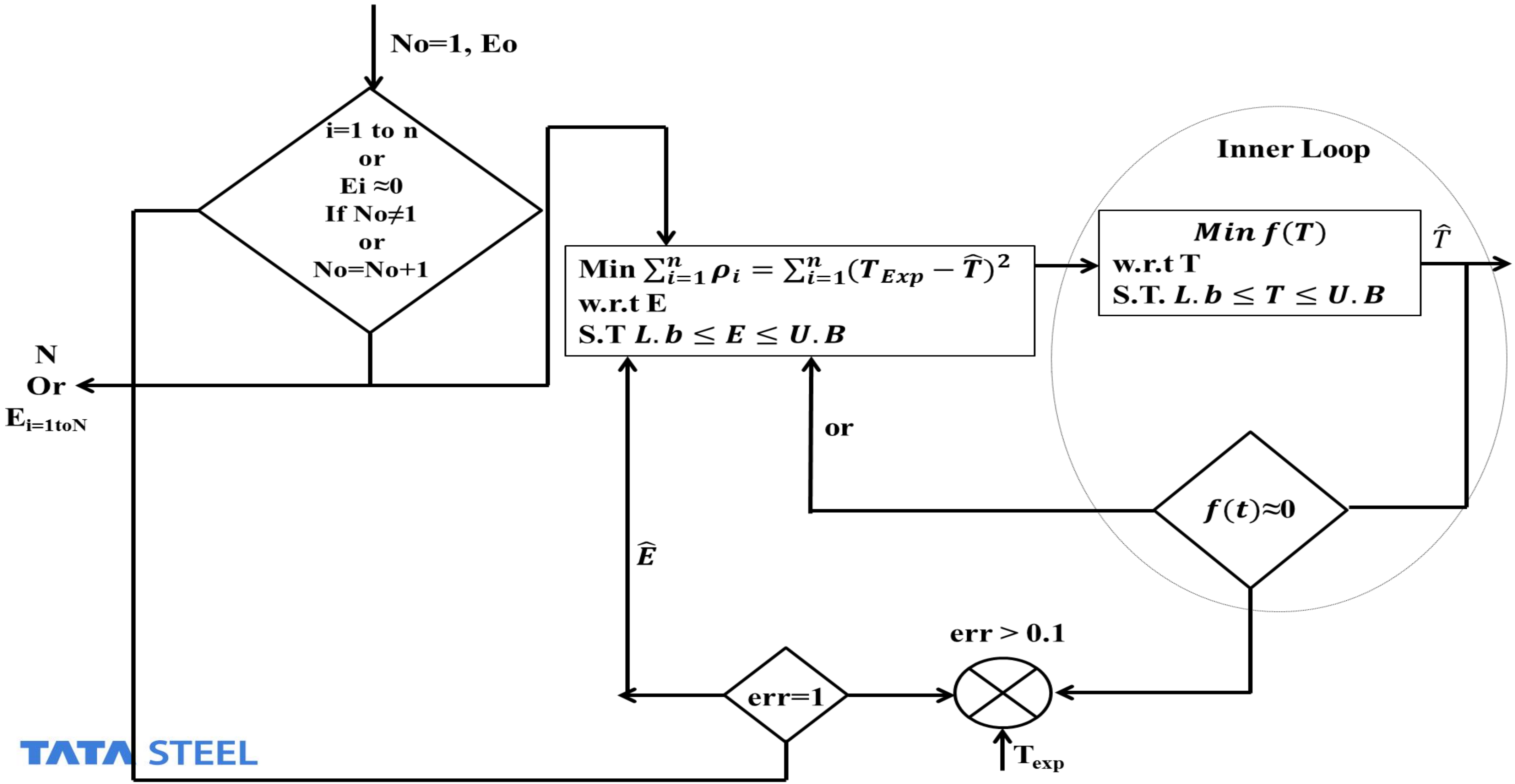
```
pao(1)=(Mair*P*H(1))/(Mair*H(1)+MH2O);
for i=2:n
pao(i)=(Mair*P*H(i))/(Mair*H(i)+MH2O); %output partial pressure
end
disp('partial pressure')
disp(pao)
pavo(1)=(exp(11.96481-(3984.923/((T(1)+273)-39.724))))*750;
 for i=2:n
    pavo(i)=(exp(11.96481-(3984.923/((T(i)+273)-39.724))))*750; %vapour pressure of each stage
end
disp('output vapour pressure:')
disp(pavo)

RHs(1)=(pao(1)/pavo(1));
for i=2:n
RHs(i)=(pao(i)/pavo(i)); %stage Relative humidity
end
disp('Relative humidity of each stage:')
disp(RHs)
e(1)=L0*cpw*t0+g*cpa*T(2)+g*H(2)*cpv*T(2)+g*H(2)*hv-g*cpa*T(1)-L(1)*cpw*T(1)-g*H(1)*cpv*T(1)-g*H(1)*hv;
for i=2:n
   e(i)=L(i-1)*cpw*T(i-1)+g*cpa*T(i+1)+g*H(i+1)*cpv*T(i+1)+g*H(i+1)*hv-g*cpa*T(i)-L(i)*cpw*T(i)-g*H(i)*cpv*T(i)-g*H(i)*hv;
end
% loss=g*(H(1)-H(n+1))
% loss1=L0-L(n)
f=[e];
```

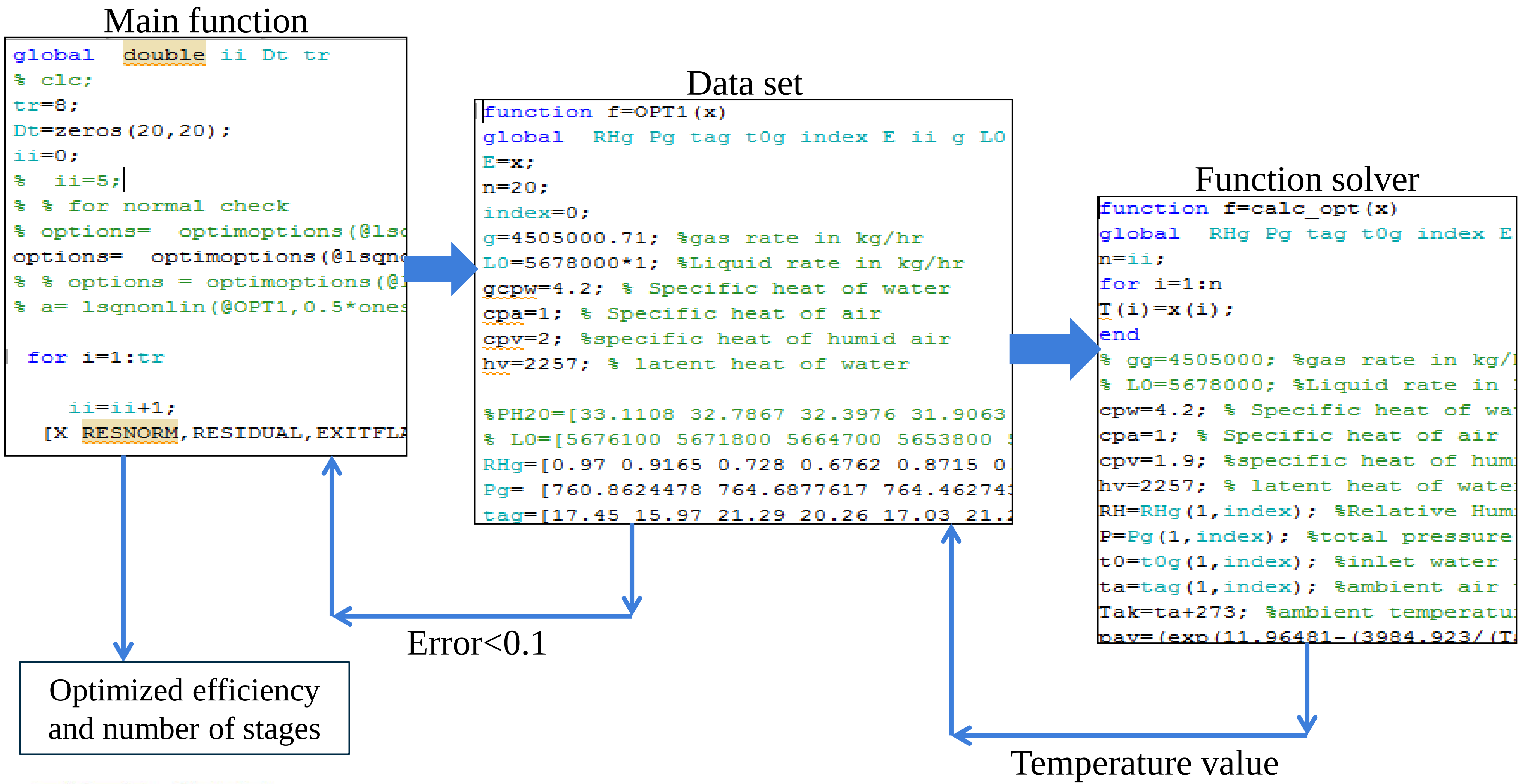
Steps involved in solving the Code



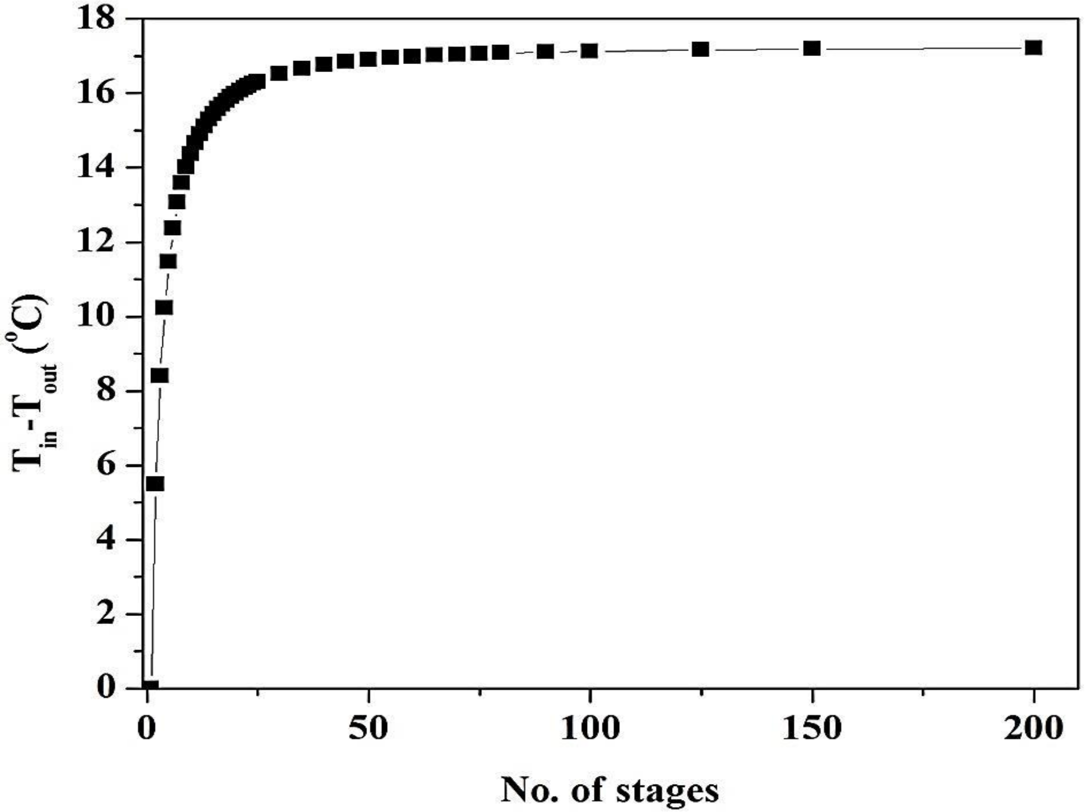
Optimization Flowchart

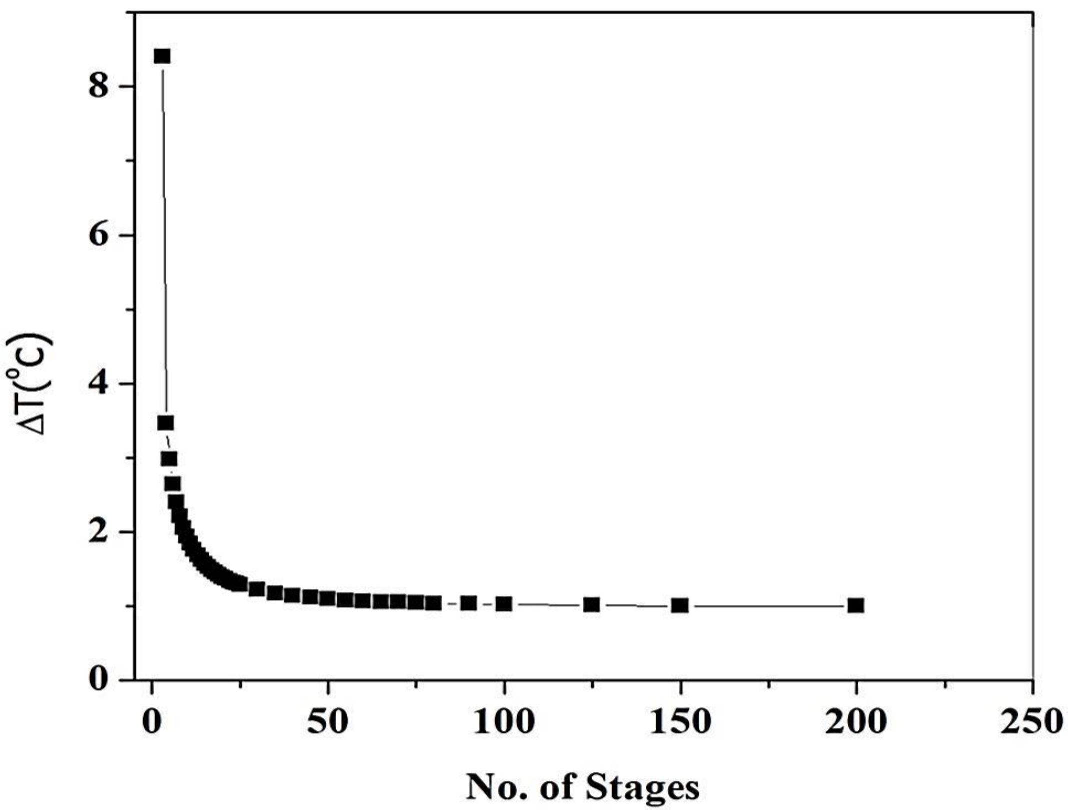


Optimization Process

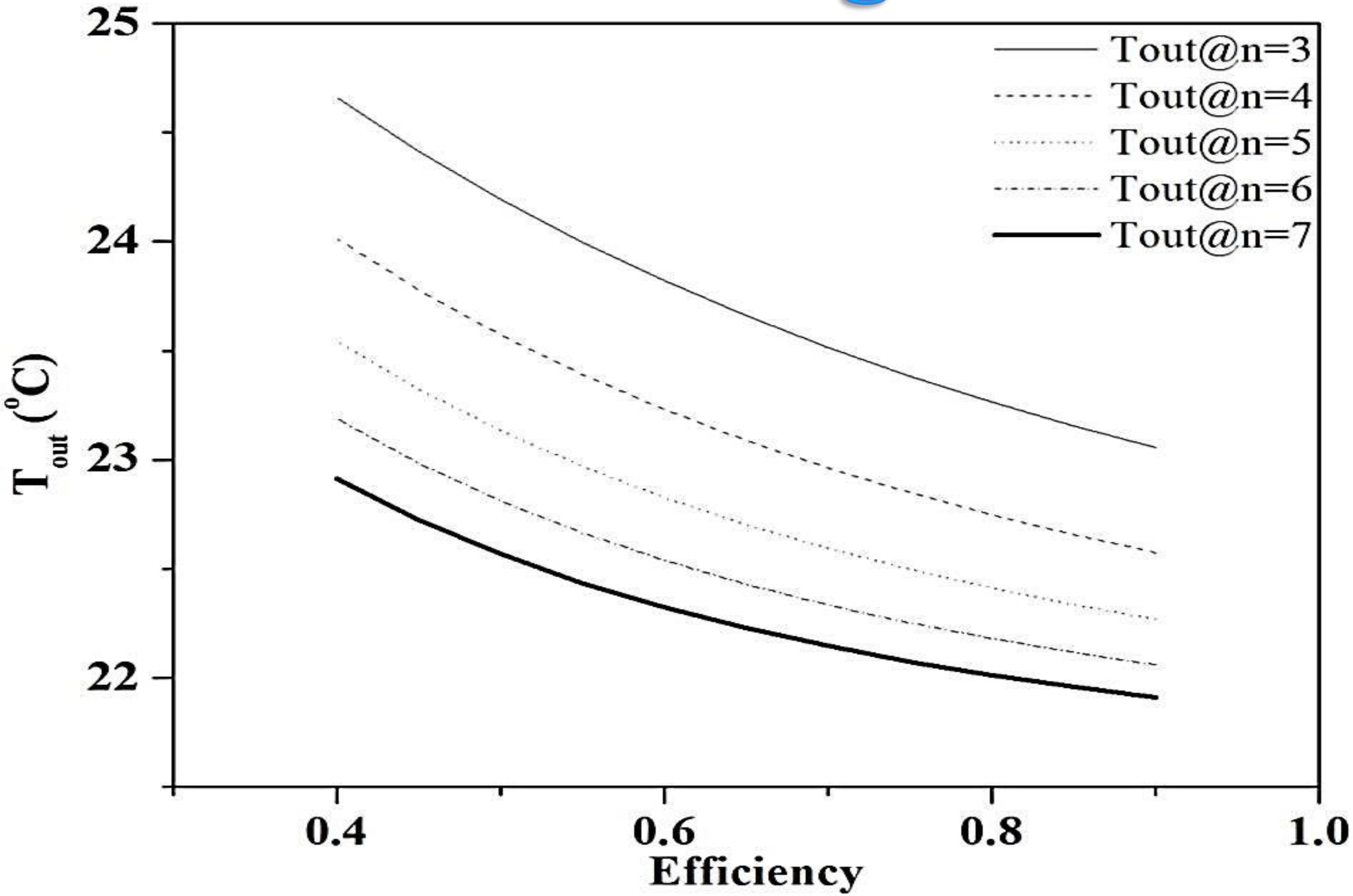


Effect of No. of Stages on Cooling Tower Outlet Temperature

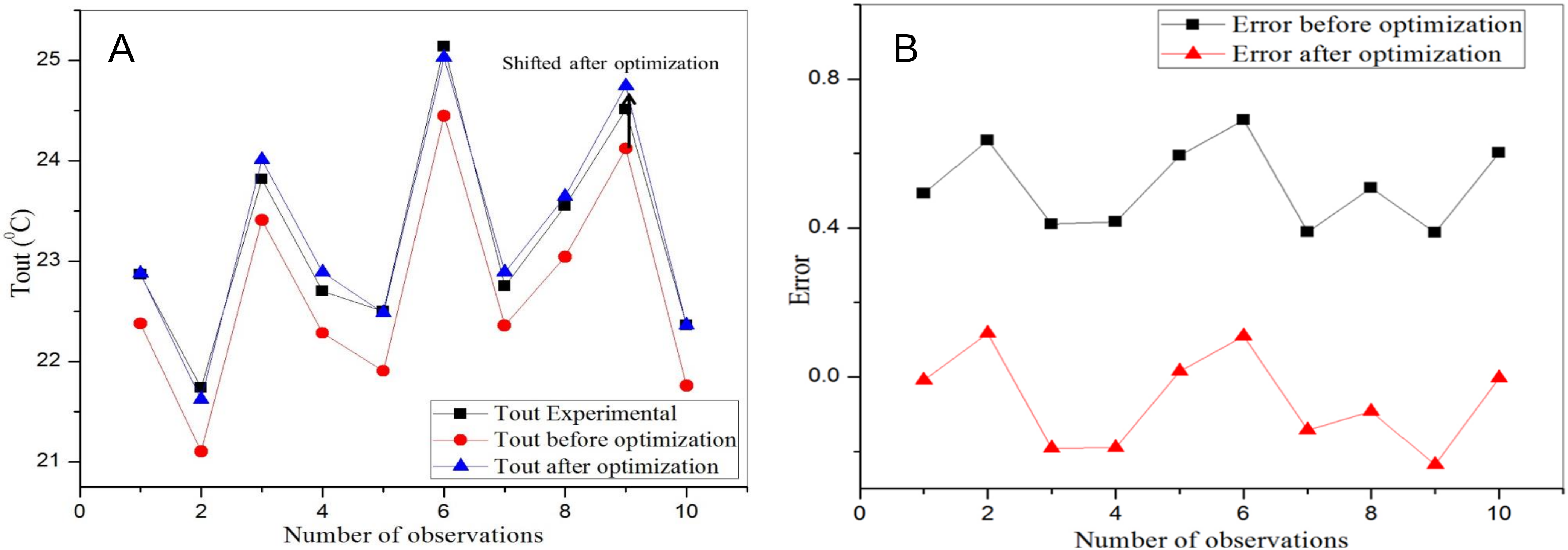




Effect of Murphree Efficiency on Number of Stages

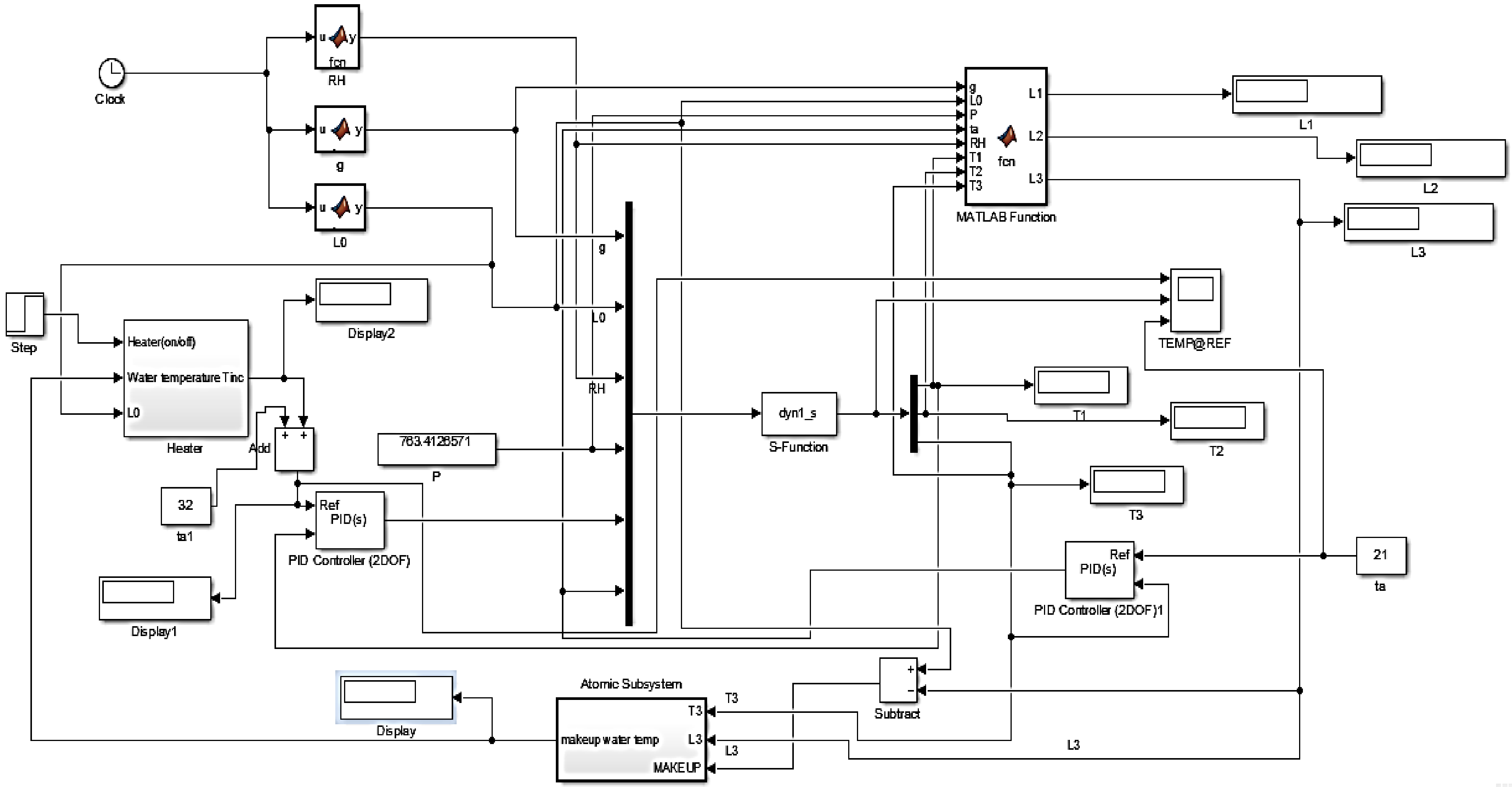


Comparison of experimental data with optimized data

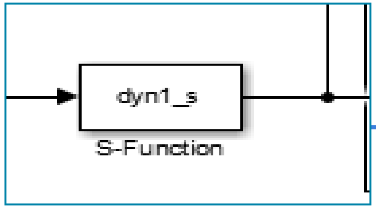


A: Comparison of initial MATLAB model with optimized model validated with experimental data. B: Error Comparison before optimization and after optimization

Control Strategy



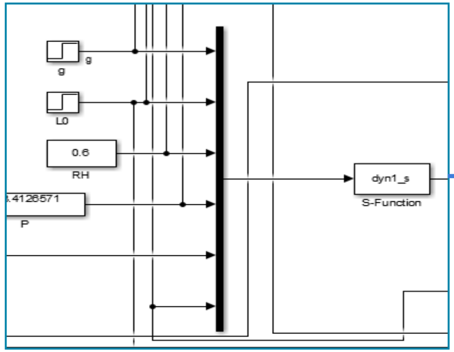
Control Strategy (Contd.)



S-Function block

Used to solve differential equations with initial conditions

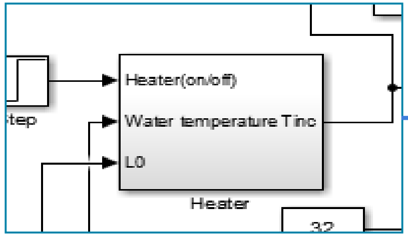
Conditions: flag=0 initialization, flag=1 derivatives
Flag=3 output, flag=2 discrete, flag=9 termination



Temperature calculation module

Input to the module: gas and liquid flow rate, relative humidity, partial pressure, ambient air temperature, inlet liquid temperature

Output of the module: stage temperatures, liquid flow rate at each stage



Heater

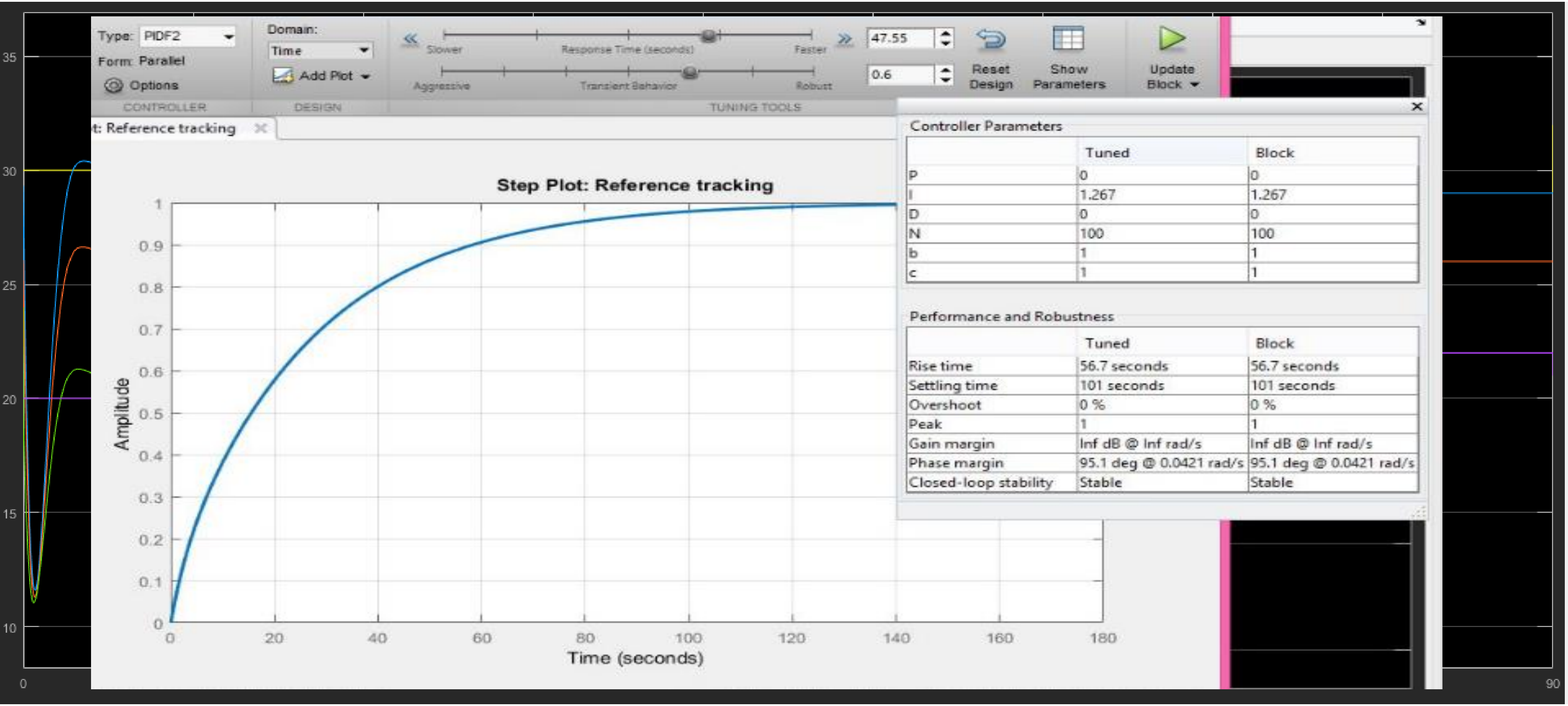
Input: water temperature, flowrate, constant heat supply

Output: heat gain (increase in temperature due to heat supply)

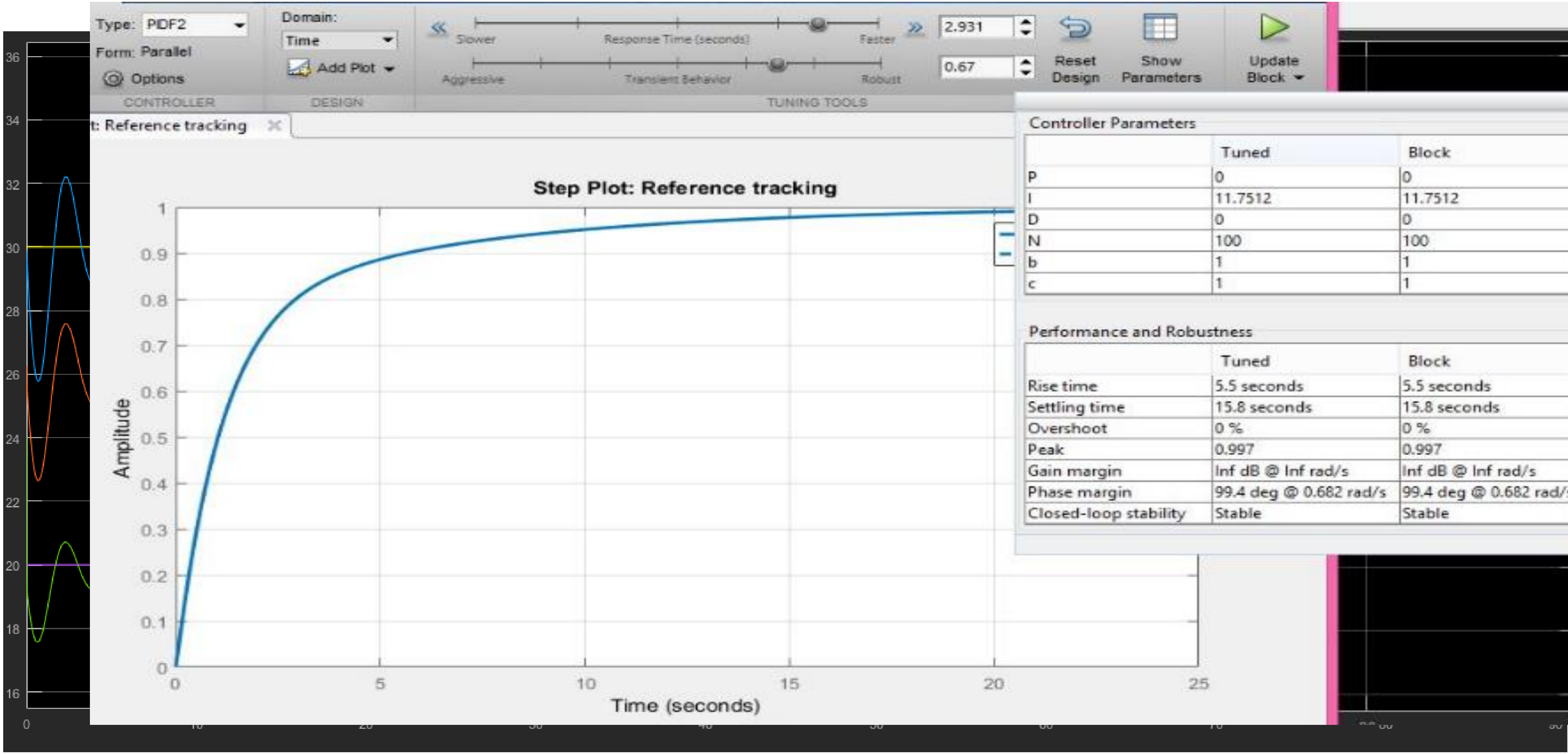
TATA STEEL

PID Controller tuning

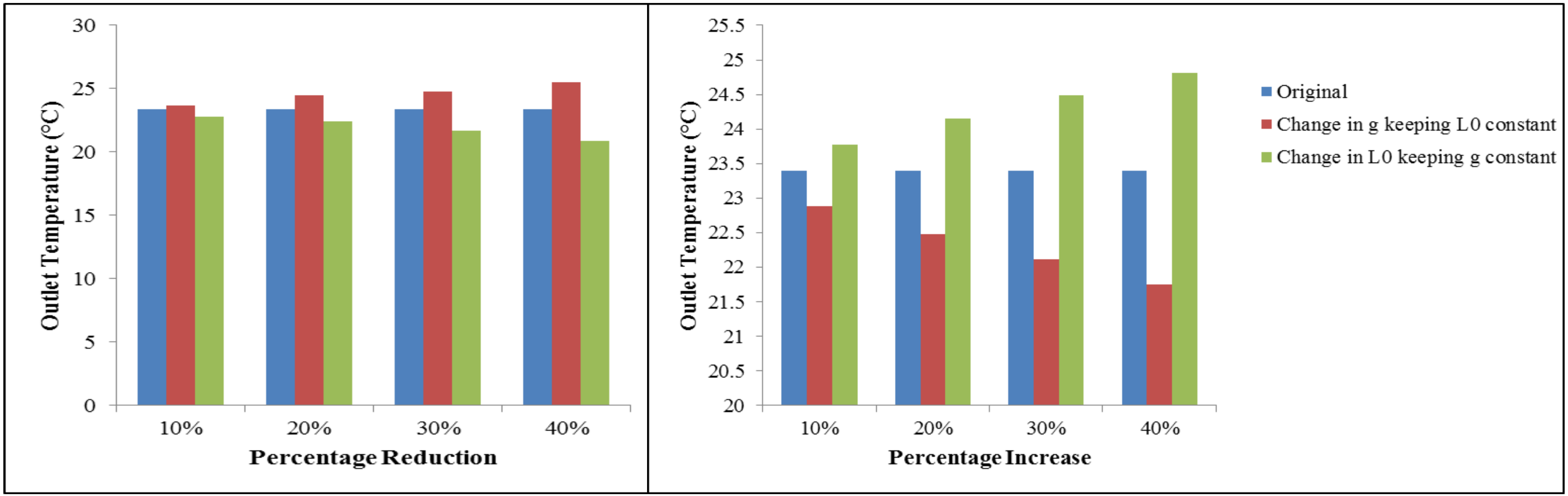
-Controllers were tuned by auto tuning method and by adjusting time and robustness



PID Controller tuning(Contd.)

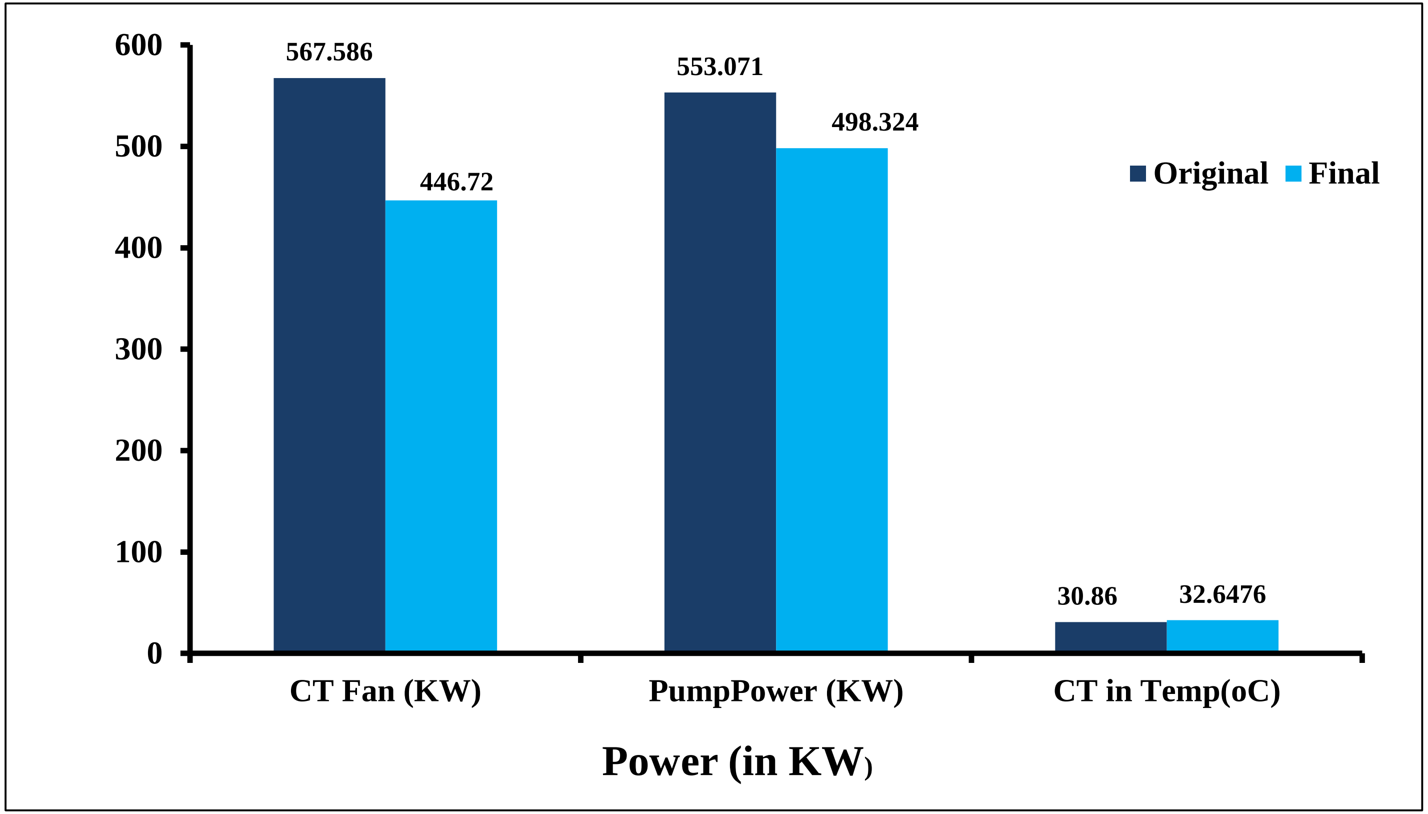


Effect of change in liquid flow rate and gas flow rate on outlet temperature



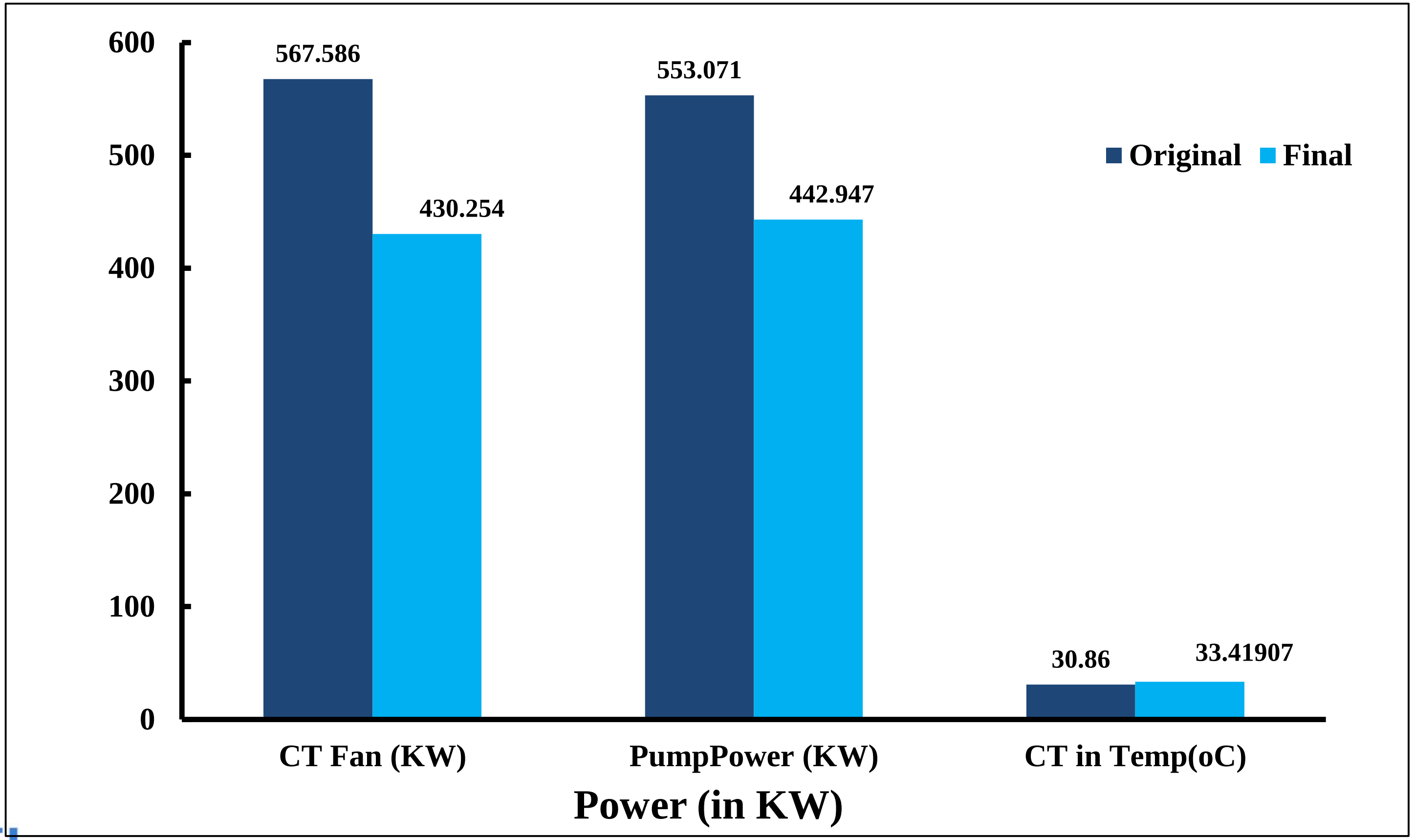
Effect of change in liquid flow rate on power consumption

10% reduction in liquid flowrate



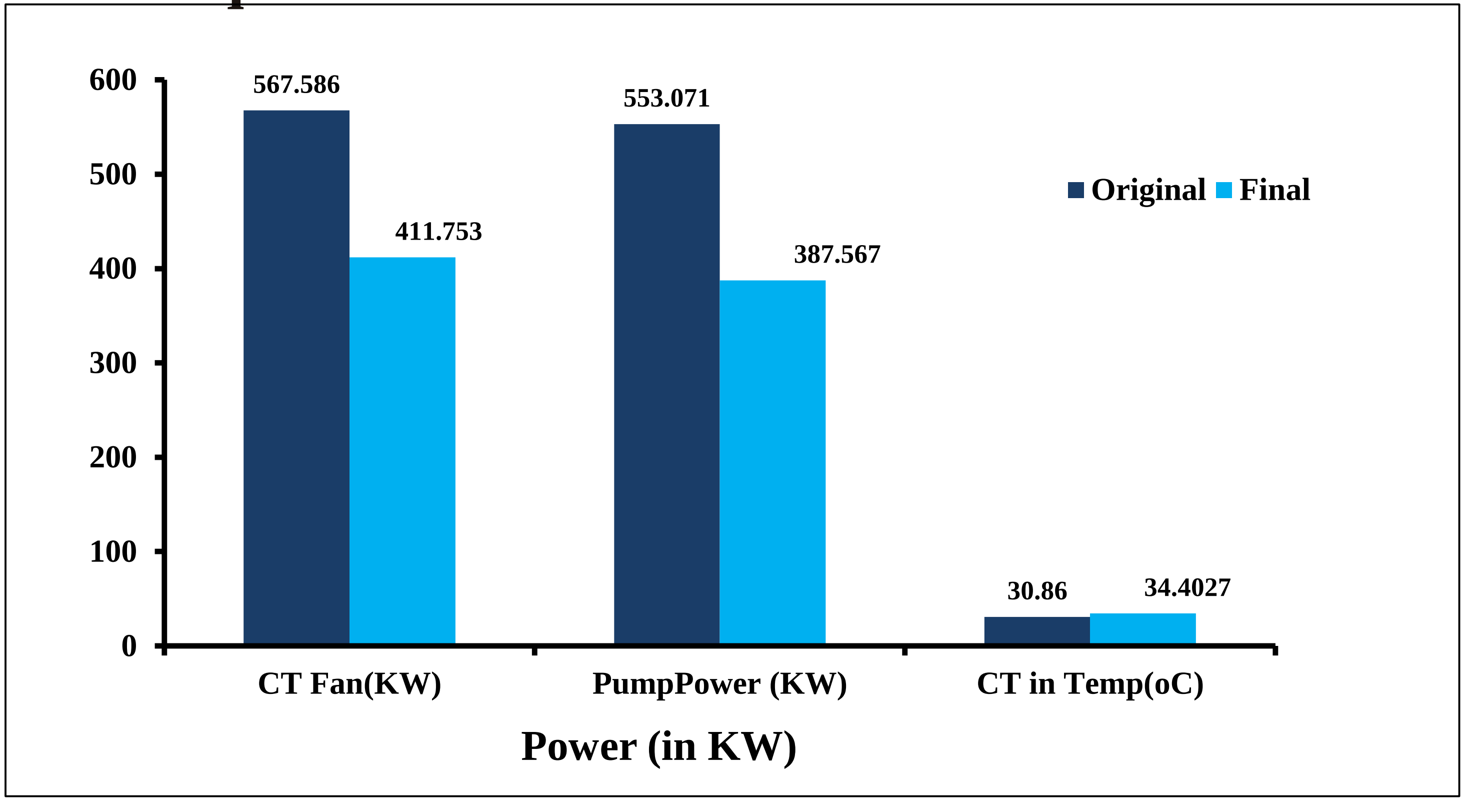
Effect of change in liquid flow rate on power consumption(Contd.)

20% reduction in liquid flowrate



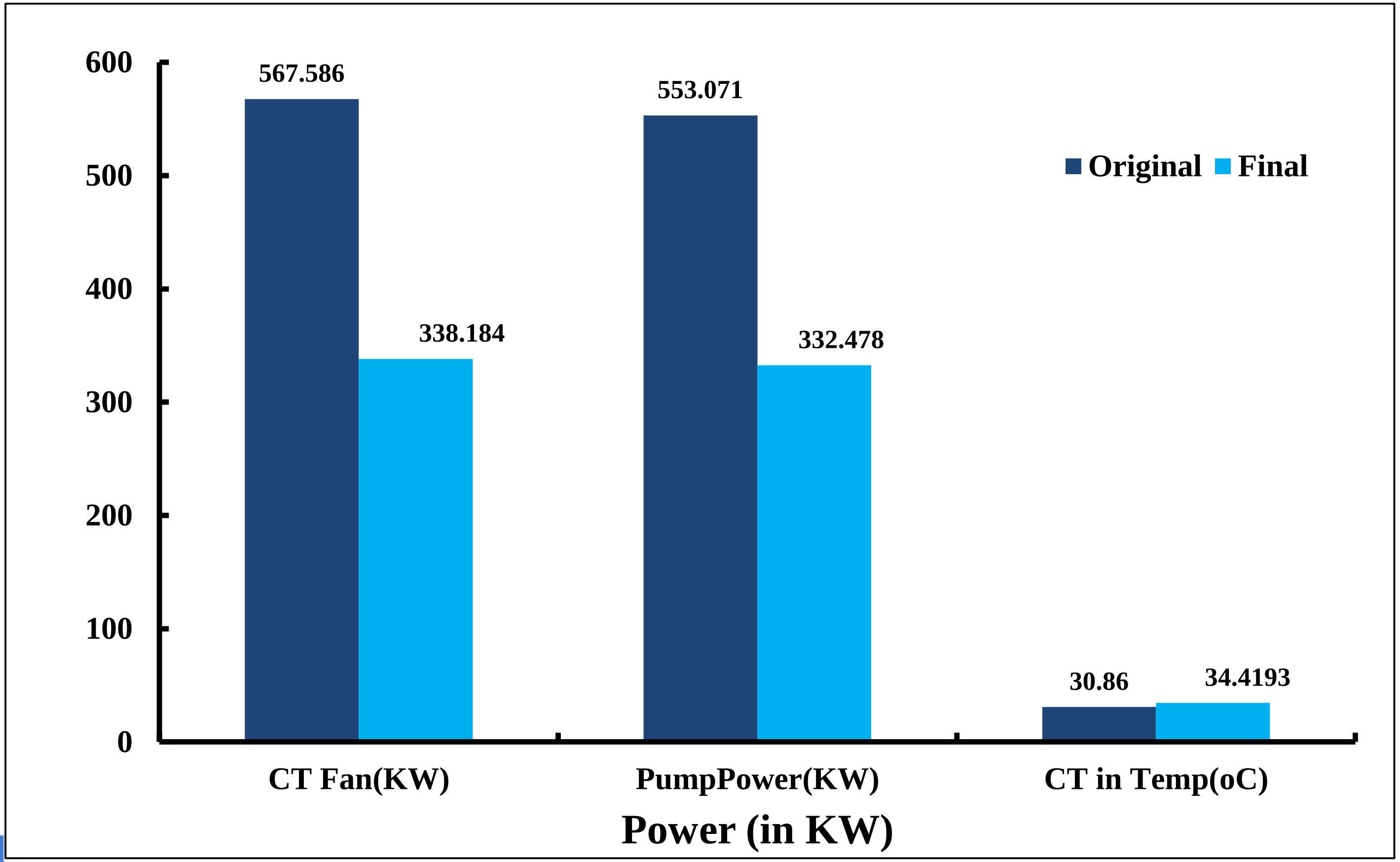
Effect of change in liquid flow rate on power consumption(Contd.)

30% reduction in liquid flow rate



Effect of change in liquid flow rate on power consumption(Contd.)

40% reduction in liquid flow rate



Conclusion

- Cooling tower outlet temperature was predicted by mathematical model created
- Created model was optimized dynamically
- Improved efficiency and optimized number of stages were obtained
- Three stages with 60 % efficiency
- Cooling tower can be operated by decreasing the water flowrate up to 30 % without affecting the overall performance

Conclusion

1. Data collection
2. Development of mathematical model
3. Model creation in Matlab
4. Validation of Matlab result using collected data
5. Matlab model optimization
6. Optimized number of stages=3, efficiency= 60%
7. Performance evaluation at reduced flowrate

Future Scope of Work

Control Application based on MIMO system

Model predictive control, robust control

Thank You!