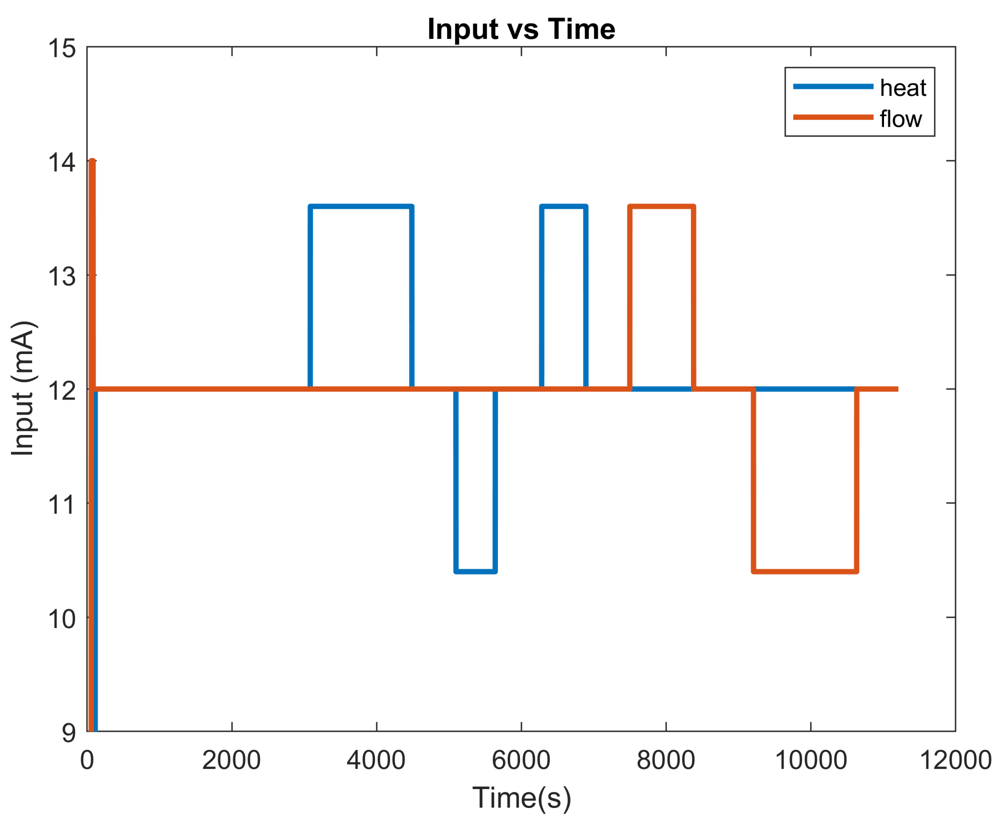
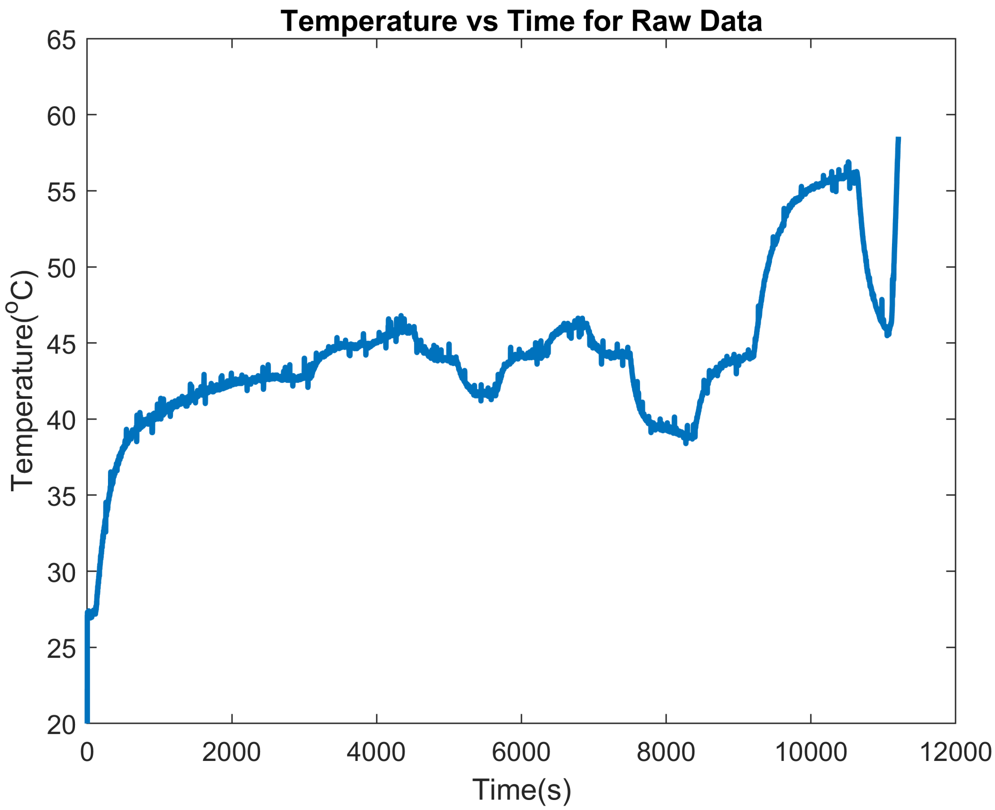
```
clear
clc
%%% Loading Data
data = load('B6A_OPENLOOP.txt');
n = 11078;  % number of rows of data
time = data(1:n,1);
temp = data(1:n,2);
heat = data(1:n,3);
flow = data(1:n,4);
dU = 1.6;
U=12;

plot(time,heat,LineWidth=2)
hold on
plot(time,flow,LineWidth=2)
hold off
legend('heat','flow')
ylim([9,15])
xlabel("Time(s)")
ylabel("Input (mA)")
title("Input vs Time")
```




```
plot(time,temp,LineWidth=2)
xlabel("Time(s)")
ylim([20,65])
```

```
ylabel("Temperature(^oC)")
title("Temperature vs Time for Raw Data")
```



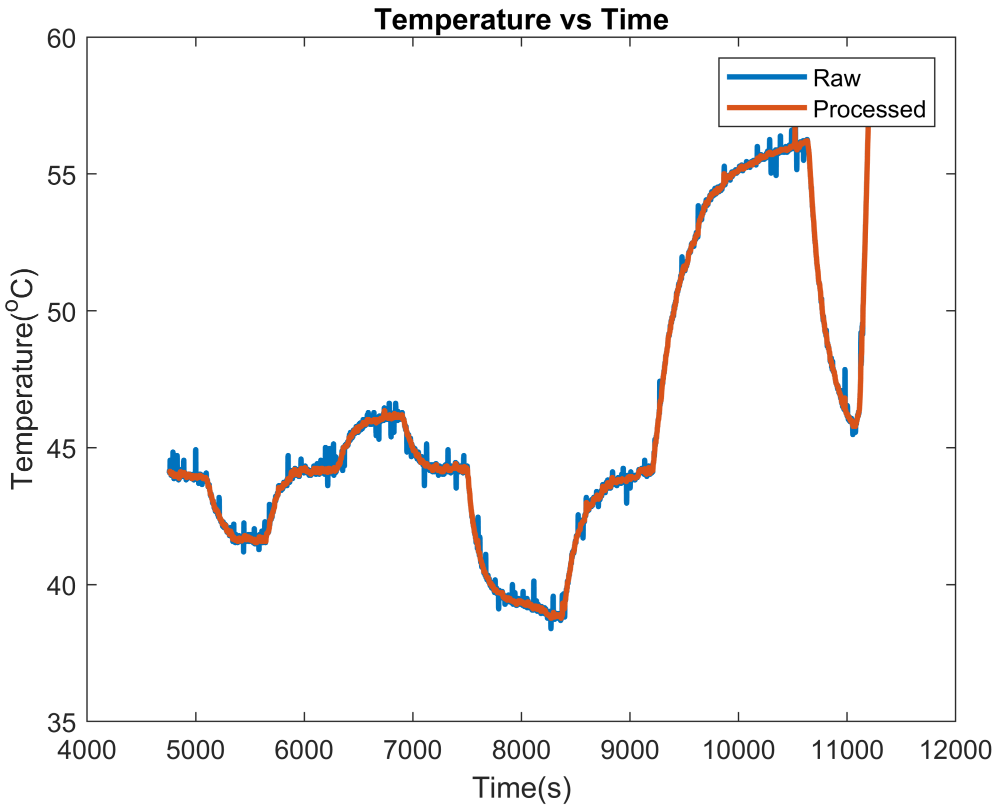
Our Initial Setting up values were errorneous, so slicing the initial part.

```
a = 4700;
time = data(a:n,1);
temp = data(a:n,2);
heat = data(a:n,3);
flow = data(a:n,4);

plot(time,temp,LineWidth=2)
hold on
xlabel("Time(s)")
%ylim([20,65])
ylabel("Temperature(^oC)")
title("Temperature vs Time")
```

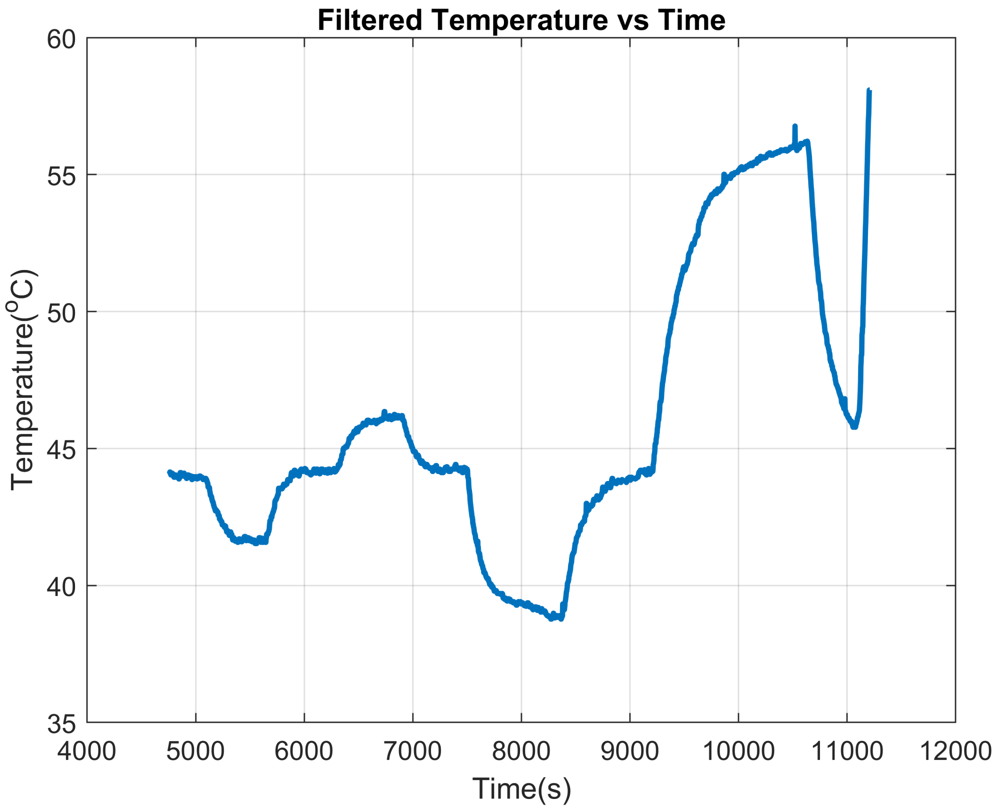
Sharp Spikes in the data is due to the noise in the measurement. Removing the error

```
% requires signal processing toolbox
temp_filtered = medfilt1(temp,10);
temp_filtered(1) =  temp_filtered(2);
plot(time,temp_filtered,LineWidth=2)
hold off
```

```
legend('Raw','Processed')
```

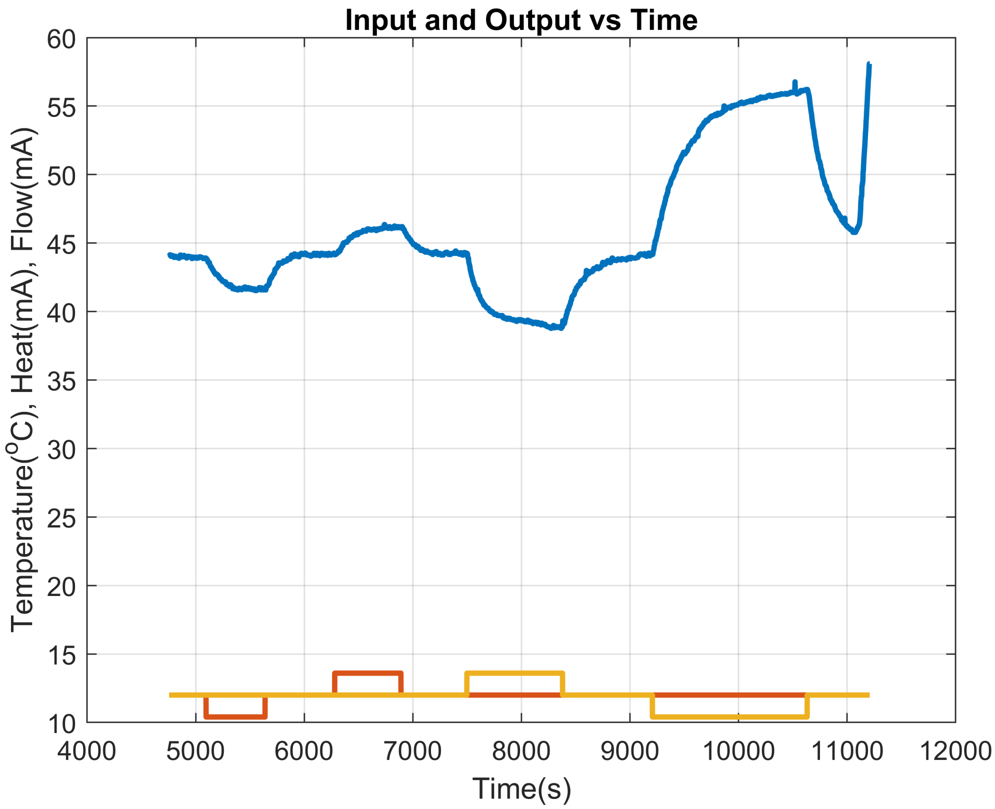



```
plot(time,temp_filtered,LineWidth=2)
title("Filtered Temperature vs Time")
grid on
xlabel("Time(s)")
ylabel("Temperature(^oC)")
```



A plot with input and output together

```
plot(time,temp_filtered,LineWidth=2)
hold on
title("Input and Output vs Time")
grid on
xlabel("Time(s)")
ylabel("Temperature(^oC), Heat(mA), Flow(mA)")
plot(time,heat,LineWidth=2)
plot(time,flow,LineWidth=2)
hold off
```



Determining the Steady State Values

```
SS_U1 = find(heat==U-dU,1);
temp_SS_U1 = mean(temp_filtered(SS_U1-50:SS_U1-1)) %steady-state temp
```

```
temp_SS_U1 = 43.9090
```

```
heat_SS_U1 = mean(heat(SS_U1-50:SS_U1-1)) %steady-state heat current
```

```
heat_SS_U1 = 12
```

For Changing Manipulated Variable (Heater)

```
SS_U_N_H = find(heat==U & time>5500,1);
temp_SS_U_N_H = mean(temp_filtered(SS_U_N_H-50:SS_U_N_H-1)) %steady-state temp
```

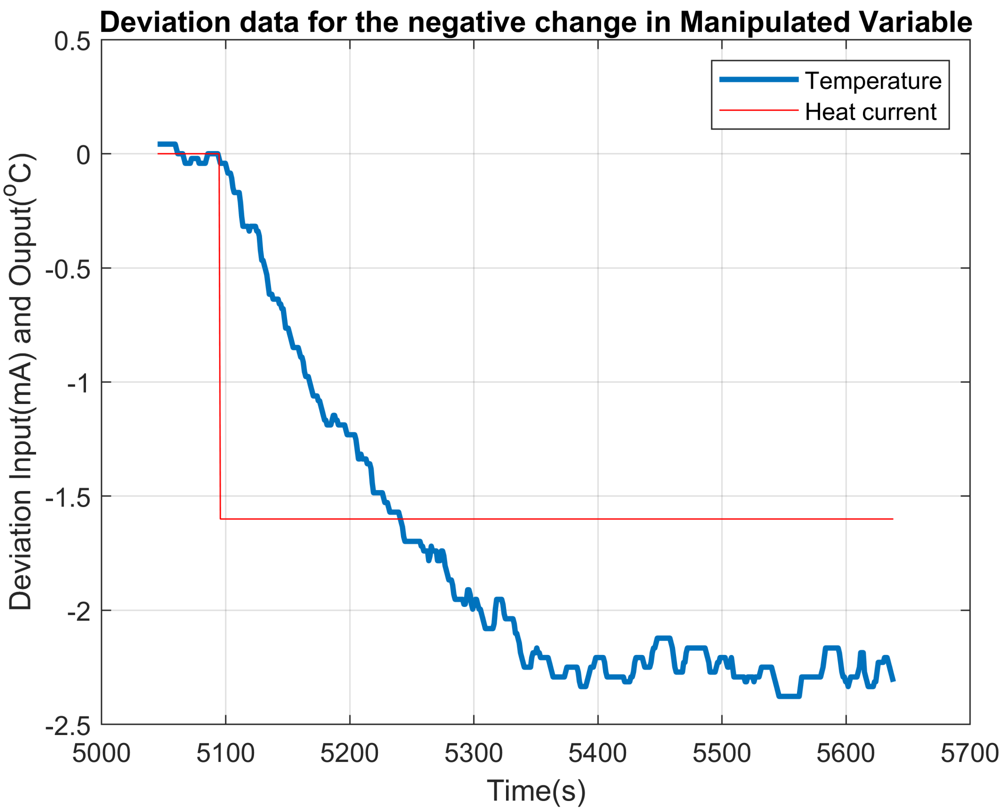
```
temp_SS_U_N_H = 41.6507
```

```
heat_SS_U_N_H = mean(heat(SS_U_N_H-50:SS_U_N_H-1)) %steady-state heat
```

```
heat_SS_U_N_H = 10.4000
```

PLOTTING for negative input change (Manipulated)

```
plot(time(SS_U1-50: SS_U_N_H-1),temp_filtered(SS_U1 - 50:SS_U_N_H-1)- temp_SS_U1,LineWidth=2)
hold on
plot(time(SS_U1-50: SS_U_N_H-1),heat(SS_U1-50:SS_U_N_H-1)- heat_SS_U1,"r")
hold off
title("Deviation data for the negative change in Manipulated Variable")
legend("Temperature","Heat current")
xlabel("Time(s)")
ylabel("Deviation Input(mA) and Ouput(^oC)")
grid on
```



Method : Calculating K and tau

```
% Graphical
K_N_H = (temp_SS_U_N_H-temp_SS_U1)/(heat_SS_U_N_H-heat_SS_U1)
```

```
K_N_H = 1.4114
```

```
yc = 0.633*(temp_SS_U_N_H-temp_SS_U1);

if(yc<=0)
 n_c = find(temp_filtered - temp_SS_U1 - yc <= 0,1);
else
 n_c = find(temp_filtered-temp_SS_U1 - yc >= 0,1);
end
t_c = time(n_c);
% t(find(heater-heater_s,1))
% t(idx_s)
```

```
tau_N_H= t_c-time(SS_U1)
```

```
tau_N_H = 122.4530
```

```
% Optimization Method
%del_N_H_heat = heat(SS_U1:SS_U_N_H)-heat_SS_U_N_H;
del_N_H_temp = temp_filtered(SS_U1:SS_U_N_H)-temp_SS_U1;
t_NH = time(SS_U1:SS_U_N_H)-time(SS_U1);

f = @(x)sum(((x(1).*(-dU).*(1-exp(-t_NH/x(2)))) - del_N_H_temp).^2);

x0=[K_N_H,tau_N_H];
[x,~] = fminunc(f,x0);
```

```
Local minimum found.

Optimization completed because the size of the gradient is less than
the value of the optimality tolerance.

<stopping criteria details>
```

```
K_N_H_opt = x(1)
```

```
K_N_H_opt = 1.4837
```

```
tau_N_H_opt = x(2)
```

```
tau_N_H_opt = 124.5298
```

```
SS_U2 = find(heat==U+dU,1);
temp_SS_U2 = mean(temp_filtered(SS_U2-50:SS_U2-1)) %steady-state temp
```

```
temp_SS_U2 = 44.1837
```

```
heat_SS_U2 = mean(heat(SS_U2-50:SS_U2-1)) %steady-state heat current
```

```
heat_SS_U2 = 12
```

```
SS_U_P_H = find(heat==U & time>6500,1);
temp_SS_U_P_H = mean(temp_filtered(SS_U_P_H-50:SS_U_P_H-1)) %steady-state temp
```

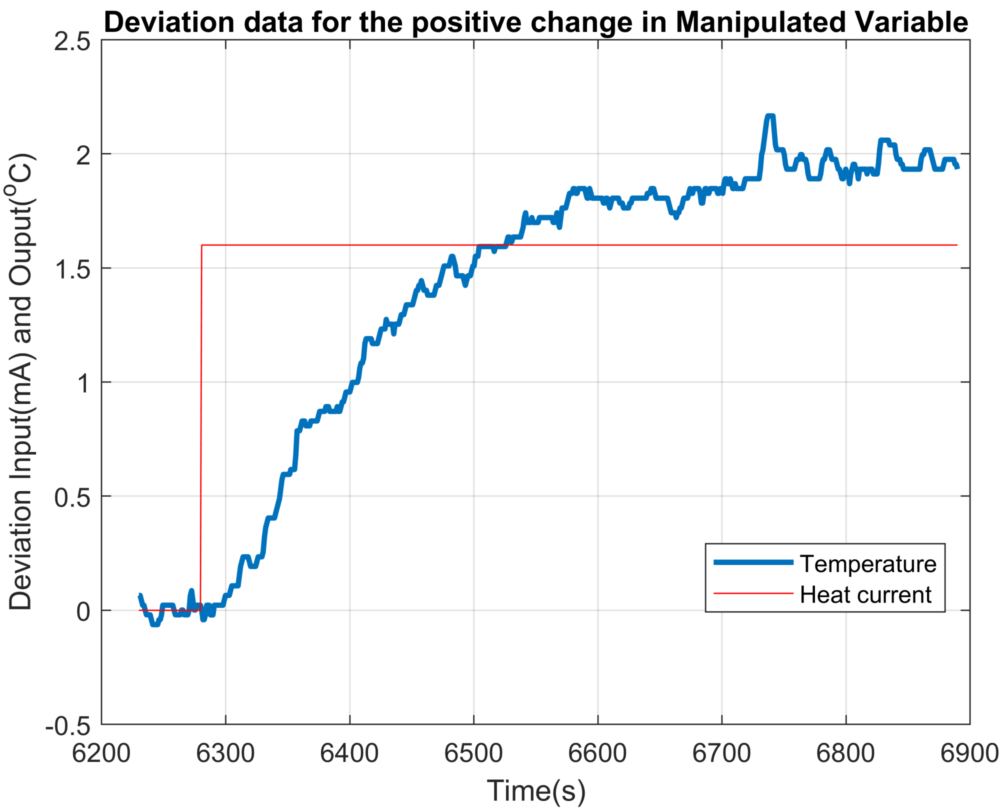
```
temp_SS_U_P_H = 46.1434
```

```
heat_SS_U_P_H = mean(heat(SS_U_P_H-50:SS_U_P_H-1)) %steady-state heat
```

```
heat_SS_U_P_H = 13.6000
```

PLOTTING for positive input change (Manipulated)

```
plot(time(SS_U2-50: SS_U_P_H-1),temp_filtered(SS_U2 - 50:SS_U_P_H-1)- temp_SS_U2,LineWidth=2)
hold on
plot(time(SS_U2-50: SS_U_P_H-1),heat(SS_U2-50:SS_U_P_H-1)- heat_SS_U2,"r")
hold off
title("Deviation data for the positive change in Manipulated Variable")
legend("Temperature","Heat current",Location="best" )
xlabel("Time(s)")
ylabel("Deviation Input(mA) and Ouput(^oC)")
grid on
```



Method : Calculating K and tau

```
% Graphical
K_P_H = (temp_SS_U_P_H-temp_SS_U2)/(heat_SS_U_P_H-heat_SS_U2)
```

```
K_P_H = 1.2248
```

```
yc = 0.633*(temp_SS_U_P_H-temp_SS_U2);

if(yc<=0)
 n_c = find(temp_filtered - temp_SS_U2 - yc <= 0,1);
else
 n_c = find(temp_filtered-temp_SS_U2 - yc >= 0,1);
end
t_c = time(n_c);
% t(find(heater-heater_s,1))
% t(idx_s)
```

```
tau_P_H= t_c-time(SS_U2)
```

```
tau_P_H = 148.7650
```

```
% Optimization Method
%del_P_H_heat = heat(SS_U2:SS_U_P_H)-heat_SS_U_P_H;
del_P_H_temp = temp_filtered(SS_U2:SS_U_P_H)-temp_SS_U2;
t_PH = time(SS_U2:SS_U_P_H)-time(SS_U2);

f = @(x)sum(((x(1).*(dU).*(1-exp(-t_PH/x(2)))) - del_P_H_temp).^2);

x0=[K_P_H,tau_P_H];
[x,~] = fminunc(f,x0);
```

```
Local minimum found.

Optimization completed because the size of the gradient is less than
the value of the optimality tolerance.

<stopping criteria details>
```

```
K_P_H_opt = x(1)
```

```
K_P_H_opt = 1.2970
```

```
tau_P_H_opt = x(2)
```

```
tau_P_H_opt = 172.4255
```

```
SS_U3 = find(flow==U+dU,1);
temp_SS_U3 = mean(temp_filtered(SS_U3-50:SS_U3-1)) %steady-state temp
```

```
temp_SS_U3 = 44.2291
```

```
heat_SS_U3 = mean(heat(SS_U3-50:SS_U3-1)) %steady-state heat current
```

```
heat_SS_U3 = 12
```

```
flow_SS_U3 = mean(flow(SS_U3-50:SS_U3-1)) %steady-state flow
```

```
flow_SS_U3 = 12
```

Now For Disturbance (Flow)

```
SS_U_P_F = find(flow==U & time>8000,1);
temp_SS_U_P_F = mean(temp_filtered(SS_U_P_F-50:SS_U_P_F-1)) %steady-state temp
```

```
temp_SS_U_P_F = 38.8510
```

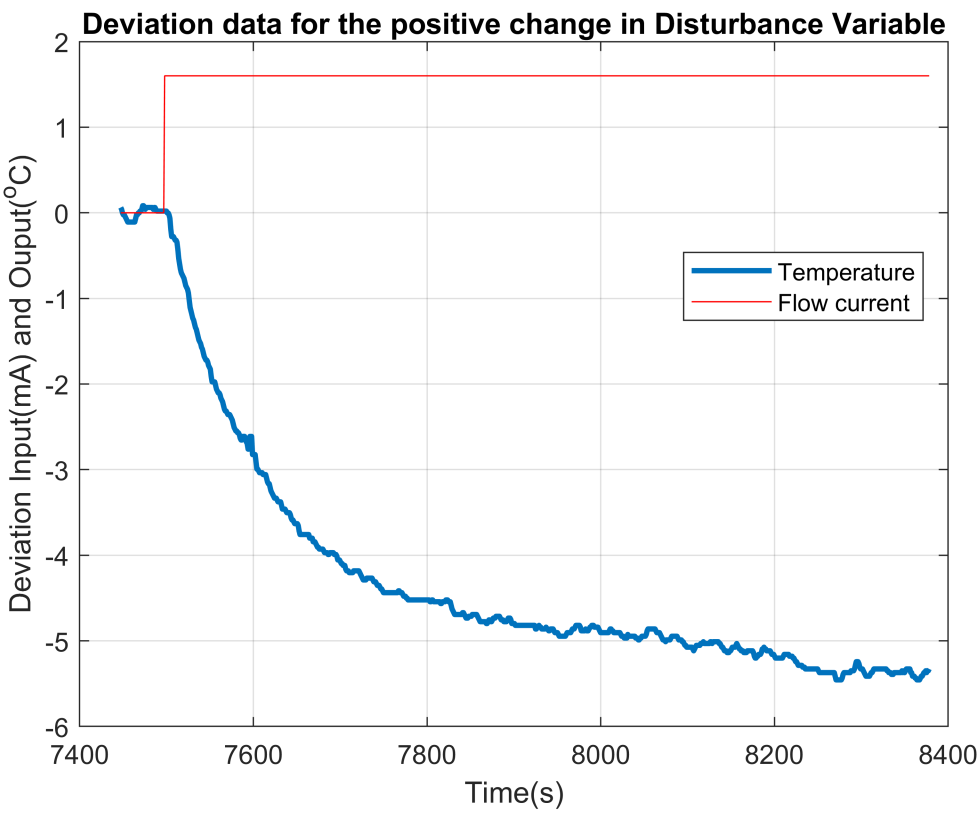
```
flow_SS_U_P_F = mean(flow(SS_U_P_F-50:SS_U_P_F-1)) %steady-state flow
```

```
flow_SS_U_P_F = 13.6000
```

```
```

PLOTTING for positive input change (Disturbance)

```
plot(time(SS_U3-50: SS_U_P_F-1),temp_filtered(SS_U3 - 50:SS_U_P_F-1)- temp_SS_U3,LineWidth=2)
hold on
plot(time(SS_U3-50: SS_U_P_F-1),flow(SS_U3-50:SS_U_P_F-1)- flow_SS_U3,"r")
hold off
title("Deviation data for the positive change in Disturbance Variable")
legend("Temperature","Flow current",Location="best" )
xlabel("Time(s)")
ylabel("Deviation Input(mA) and Ouput(^oC)")
grid on
```



Method : Calculating K and tau

```
% Graphical
K_P_F = (temp_SS_U_P_F-temp_SS_U3)/(flow_SS_U_P_F-flow_SS_U3)
```

```
K_P_F = -3.3613
```

```
yc = 0.633*(temp_SS_U_P_F-temp_SS_U3);

if(yc<=0)
 n_c = find(temp_filtered - temp_SS_U3 - yc <= 0,1);
else
 n_c = find(temp_filtered-temp_SS_U3 - yc >= 0,1);
```

```
end
t_c = time(n_c);
% t(find(heater-heater_s,1))
% t(idx_s)
tau_P_F= t_c-time(SS_U3)
```

```
tau_P_F = 134.5620
```

```
% Optimization Method
%del_P_F_heat = heat(SS_U3:SS_U_P_F)-heat_SS_U_P_F;
del_P_F_temp = temp_filtered(SS_U3:SS_U_P_F)-temp_SS_U3;
t_PF = time(SS_U3:SS_U_P_F)-time(SS_U3);

f = @(x)sum(((x(1).*(dU).*(1-exp(-t_PF/x(2)))) - del_P_F_temp).^2);

x0=[K_P_F,tau_P_F];
[x,~] = fminunc(f,x0);
```

```
Local minimum found.

Optimization completed because the size of the gradient is less than
the value of the optimality tolerance.

<stopping criteria details>
```

```
K_P_F_opt = x(1)
```

```
K_P_F_opt = -3.2205
```

```
tau_P_F_opt = x(2)
```

```
tau_P_F_opt = 130.4005
```

```
SS_U4 = find(flow==U-dU,1);
temp_SS_U4 = mean(temp_filtered(SS_U4-50:SS_U4-1)) %steady-state temp
```

```
temp_SS_U4 = 44.1567
```

```
flow_SS_U4 = mean(flow(SS_U4-50:SS_U4-1)) %steady-state flow
```

```
flow_SS_U4 = 12
```

```
SS_U_N_F = find(flow==U & time>9500,1);
temp_SS_U_N_F = mean(temp_filtered(SS_U_N_F-50:SS_U_N_F-1)) %steady-state temp
```

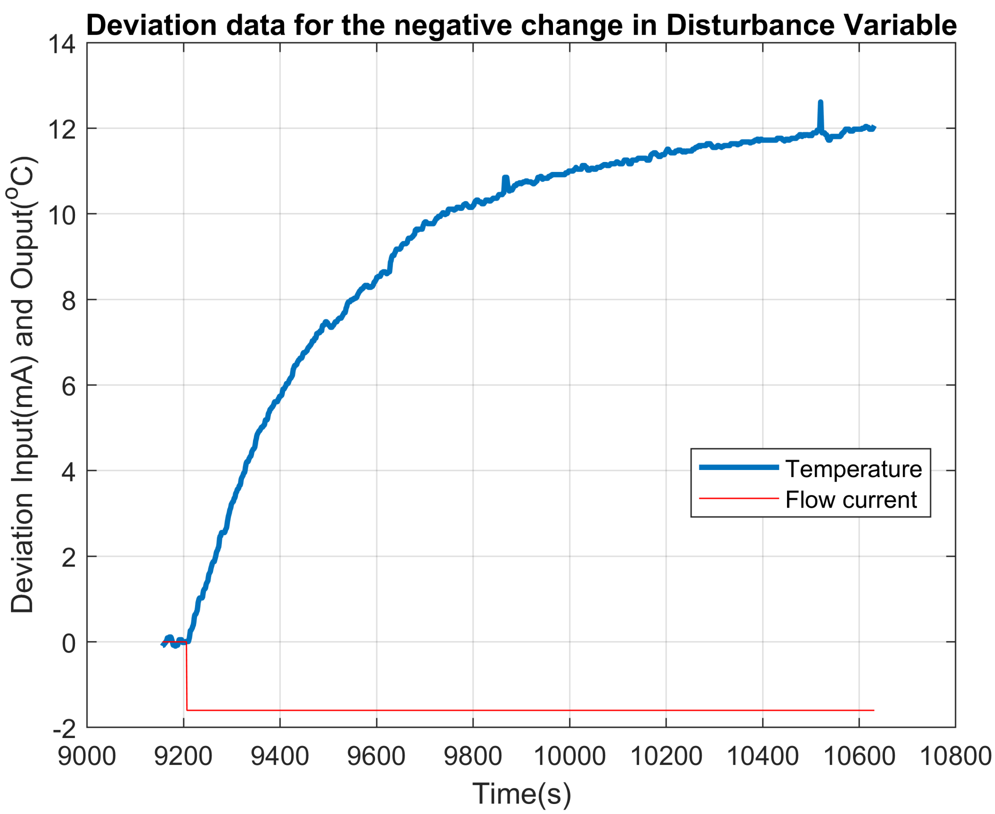
```
temp_SS_U_N_F = 56.1430
```

```
flow_SS_U_N_F = mean(flow(SS_U_N_F-50:SS_U_N_F-1)) %steady-state flow
```

```
flow_SS_U_N_F = 10.4000
```

PLOT for negative deviation in Disturbance

```
plot(time(SS_U4-50: SS_U_N_F-1),temp_filtered(SS_U4 - 50:SS_U_N_F-1)- temp_SS_U4,LineWidth=2)
hold on
plot(time(SS_U4-50: SS_U_N_F-1),flow(SS_U4-50:SS_U_N_F-1)- flow_SS_U4,"r")
hold off
title("Deviation data for the negative change in Disturbance Variable")
legend("Temperature","Flow current",Location="best" )
xlabel("Time(s)")
ylabel("Deviation Input(mA) and Ouput(^oC)")
grid
```



Method : Calculating K and tau

```
% Graphical
K_N_F = (temp_SS_U_N_F-temp_SS_U4)/(flow_SS_U_N_F-flow_SS_U4)
```

```
K_N_F = -7.4914
```

```
yc = 0.633*(temp_SS_U_N_F-temp_SS_U4);
```

```
if(yc<=0)
 n_c = find(temp_filtered - temp_SS_U4 - yc <= 0,1);
else
 n_c = find(temp_filtered-temp_SS_U4 - yc >= 0,1);
end
t_c = time(n_c);
% t(find(heater-heater_s,1))
% t(idx_s)
tau_N_F= t_c-time(SS_U4)
```

```
tau_N_F = 321.7030
```

```
% Optimization Method
%del_N_F_heat = heat(SS_U4:SS_U_N_F)-heat_SS_U_N_F;
del_N_F_temp = temp_filtered(SS_U4:SS_U_N_F)-temp_SS_U4;
t_NF = time(SS_U4:SS_U_N_F)-time(SS_U4);

f = @(x)sum(((x(1).*(-dU).*(1-exp(-t_NF/x(2)))) - del_N_F_temp).^2);

x0=[K_N_F,tau_N_F];
[x,~] = fminunc(f,x0);
```

```
Local minimum found.

Optimization completed because the size of the gradient is less than
the value of the optimality tolerance.

<stopping criteria details>
```

```
K_N_F_opt = x(1)
```

```
K_N_F_opt = -7.4475
```

```
tau_N_F_opt = x(2)
```

```
tau_N_F_opt = 301.4070
```

The Final Steady State after resetting the Disturbance was not obtained due to shutting off of the air supply to valve due to external factors.

But an assumption based on prior steady state values is taken as.

```
SS_U5 = mean([temp_SS_U1,temp_SS_U4,temp_SS_U2,temp_SS_U3])
```

```
SS_U5 = 44.1196
```

Controller Response

```
K_p = 0.5*(K_P_H_opt+K_N_H_opt)
```

```
K_p = 1.3903
```

```
tau_p = 0.5*(tau_P_H_opt+tau_N_H_opt)
```

```
tau_p = 148.4777
```

```

K_d = 0.5*(K_P_F_opt+K_N_F_opt)
```

```
K_d = -5.3340
```

```
tau_d = 0.5*(tau_P_F_opt+tau_N_F_opt)
```

```
tau_d = 215.9037
```

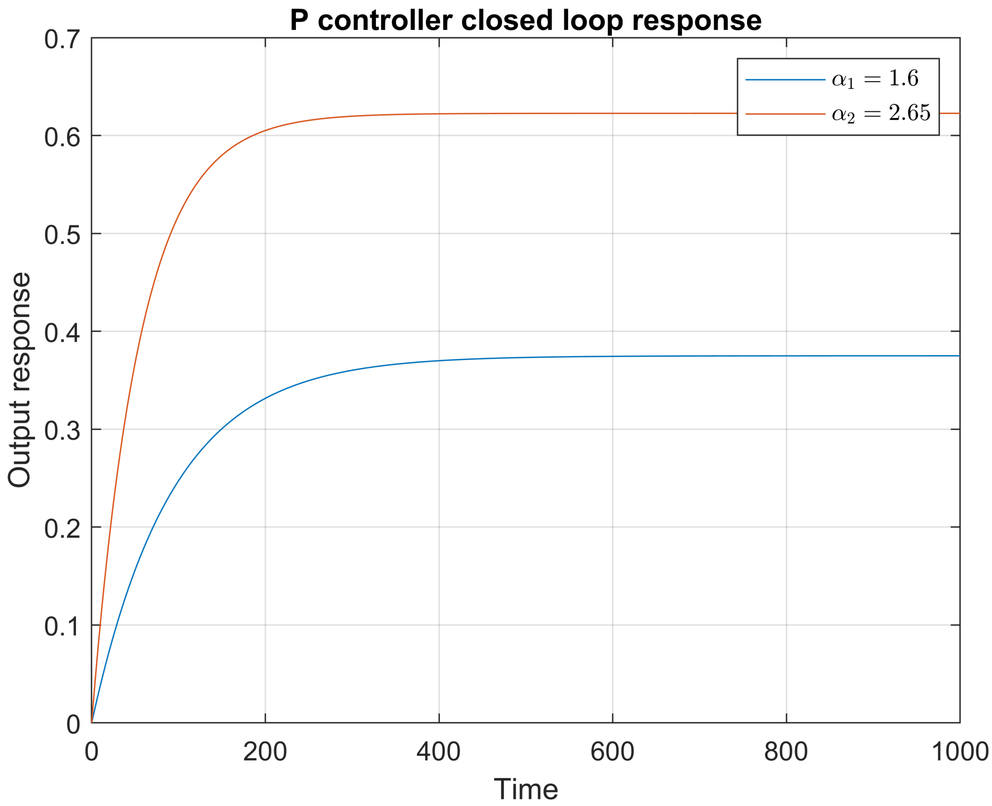
```

% TODO
alpha1 = 1.6
```

```
alpha1 = 1.6000
```

```
alpha2 = 2.65
```

```
alpha2 = 2.6500
```

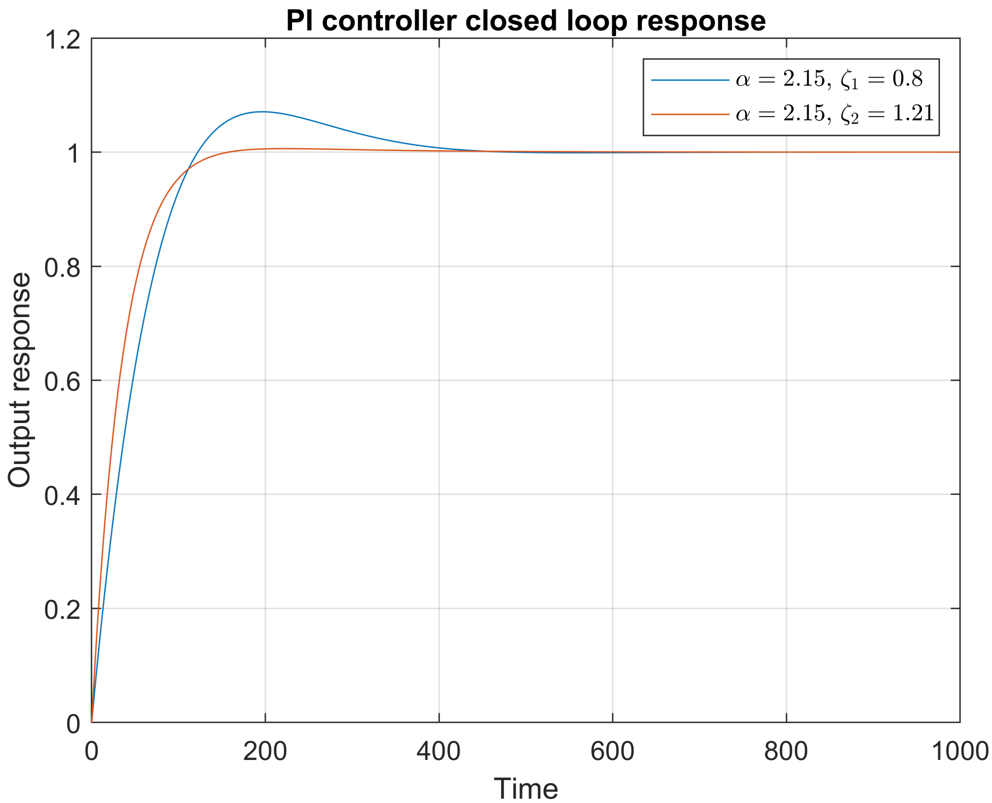
```
K_c1 = (alpha1-1)/K_p;
K_c2 = (alpha2-1)/K_p;


syms t s
H1 = K_c1*K_p*(1/s)/(tau_p*s+ 1+ K_c1*K_p);
H2 = K_c2*K_p*(1/s)/(tau_p*s+ 1+ K_c2*K_p);
h1=matlabFunction(ilaplace(H1));
h2=matlabFunction(ilaplace(H2));
t = 0:1.003:1000;

plot(t, h1(t))
hold on
plot(t,h2(t))
hold off
grid
title('P controller closed loop response')
leg1 = legend('$\alpha_1 = 1.6$', '$\alpha_2 = 2.65$');
set(leg1,'Interpreter','latex');
xlabel('Time')
ylabel('Output response')
```



PI Controller

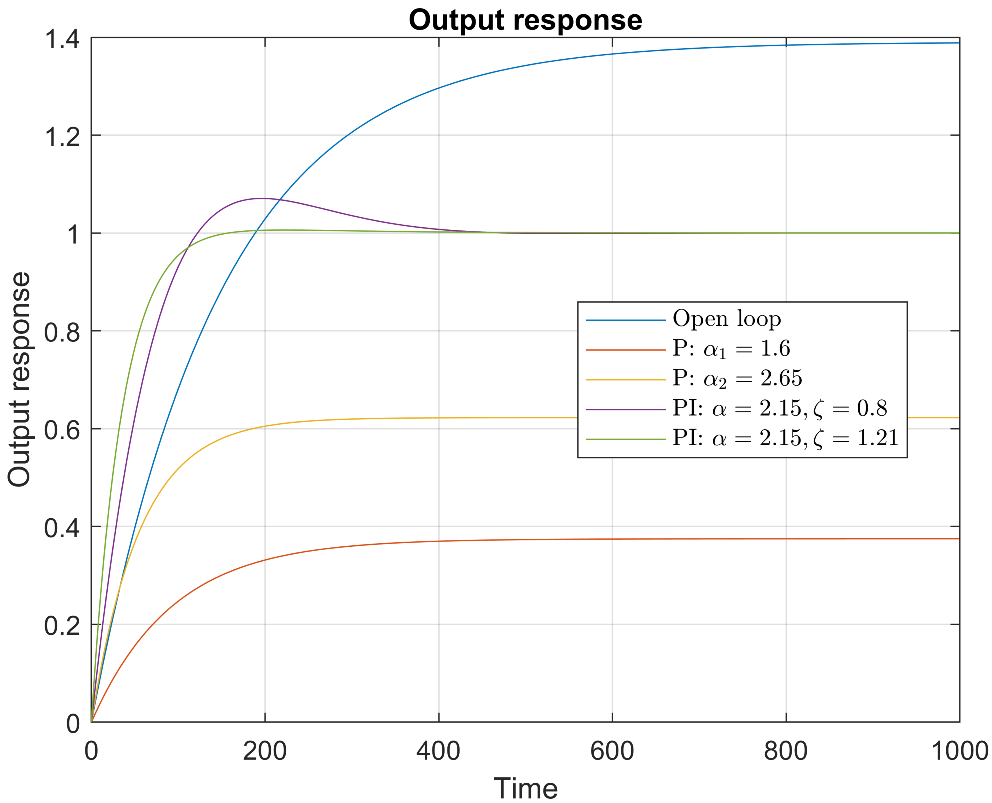
```
alpha_PI = 2.15;

%TODO
zeta_1 = 0.8; %(underdamped)
zeta_2 = 1.21; %(overdamped)

K_PI_c1 = (2*alpha_PI*zeta_1 - 1)/K_p;
K_PI_c2 = (2*alpha_PI*zeta_2 - 1)/K_p;

tau_i_1= (2*alpha_PI*zeta_1 - 1)*tau_p/(alpha_PI^2);
tau_i_2= (2*alpha_PI*zeta_2 - 1)*tau_p/(alpha_PI^2);

syms t3 s
t3 = 0:1.031:1000;
H_PI_1 = (tau_i_1*s + 1)*(1/s)/ ((tau_p*tau_i_1*s^2/(K_PI_c1*K_p))+(tau_i_1*s/(K_PI_c1*K_p/(1+K
H_PI_2 = (tau_i_2*s + 1)*(1/s)/ ((tau_p*tau_i_2*s^2/(K_PI_c2*K_p))+(tau_i_2*s/(K_PI_c2*K_p/(1+K
h1_PI=matlabFunction(ilaplace(H_PI_1));
h2_PI=matlabFunction(ilaplace(H_PI_2));
plot(t3,h1_PI(t3))
hold on
plot(t3,h2_PI(t3))
hold off
```

```
grid
title('PI controller closed loop response')
legend('$\alpha = 2.15$, $\zeta_1 = 0.8$', '$\alpha = 2.15$, $\zeta_2=1.21$','Interpreter','lat
xlabel('Time')
ylabel('Output response')
```



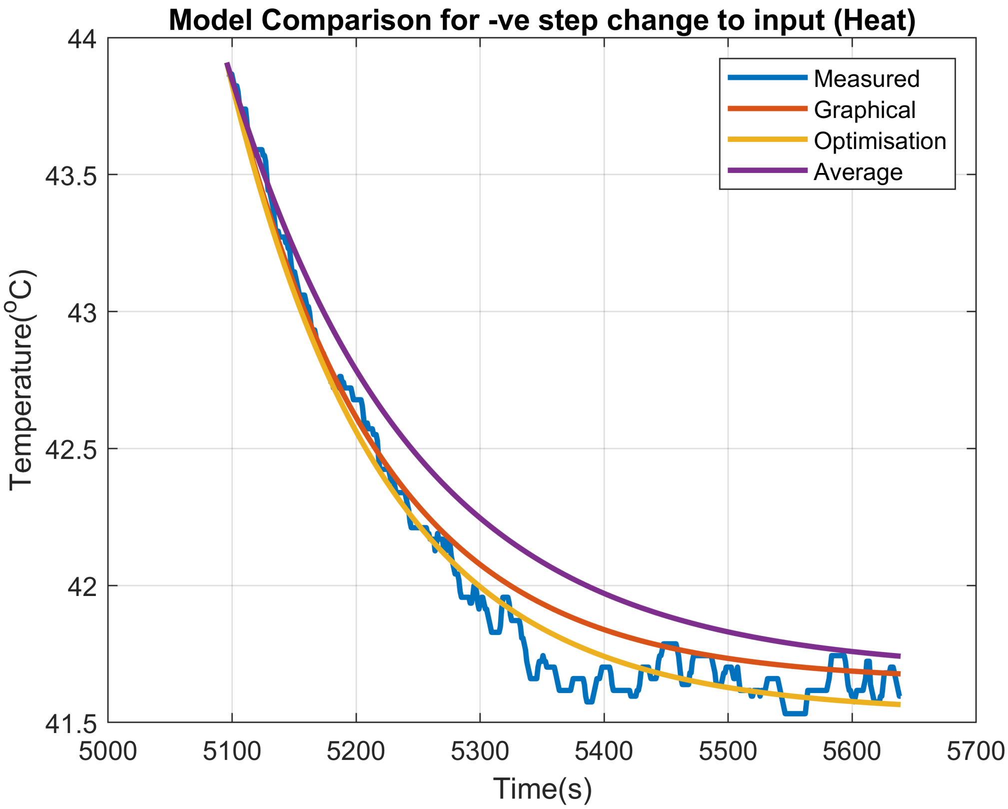
OPEN LOOP RESPONSES

```
syms t4 s
t4 = 0:1.031:1000;
hh_open = K_p*(1/s)/(tau_p*s + 1); %open loop response
h_open=matlabFunction(ilaplace(hh_open));
figure(3)
plot(t4,h_open(t4),t4,h1(t4),t4,h2(t4),t4,h1_PI(t4),t4,h2_PI(t4))
grid()
title('Output response')
legend('Open loop', 'P: $\alpha_1 = 1.6$', 'P: $\alpha_2 = 2.65$','PI: $\alpha = 2.15, \zeta =
xlabel('Time')
ylabel('Output response')
```

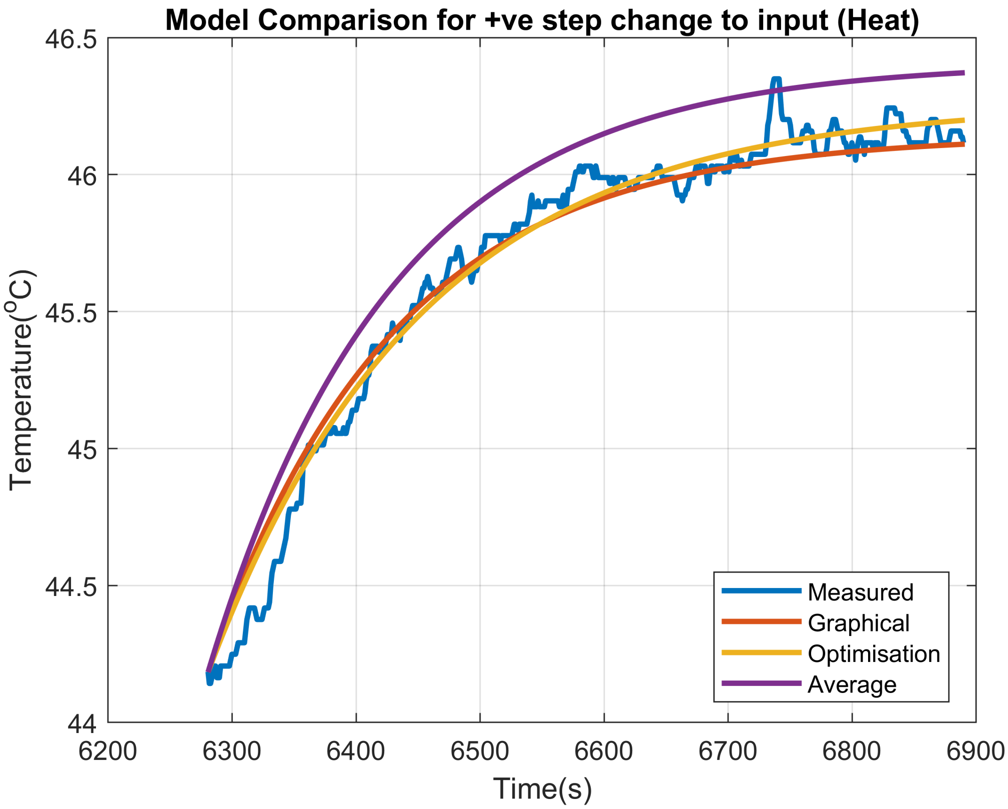


COMPARISON

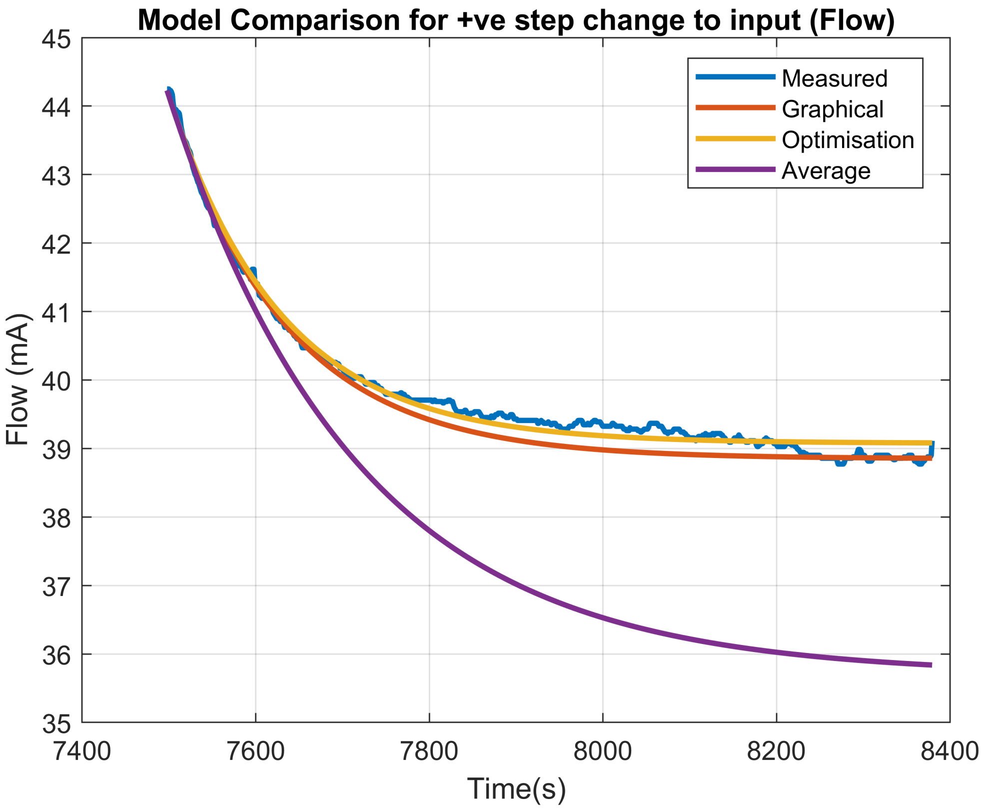
```
% For NEGATIVE MANIPULATED
graph =temp_SS_U1+ K_N_H.*(-dU).*(1-exp(-t_NH/tau_N_H));
opt = temp_SS_U1+K_N_H_opt.*(-dU).*(1-exp(-t_NH/tau_N_H_opt));
avg = temp_SS_U1+K_p.*(-dU).*(1-exp(-t_NH/tau_p));
t_plot = time(SS_U1:SS_U_N_H);
plot(t_plot,temp_filtered(SS_U1 :SS_U_N_H),LineWidth=2)
hold on
plot(t_plot,graph,LineWidth=2)
plot(t_plot,opt,LineWidth=2)
plot(t_plot,avg,LineWidth=2)
hold off
title("Model Comparison for -ve step change to input (Heat)")
ylabel("Temperature(^oC)")
xlabel("Time(s)")
legend("Measured","Graphical","Optimisation","Average")
grid
```



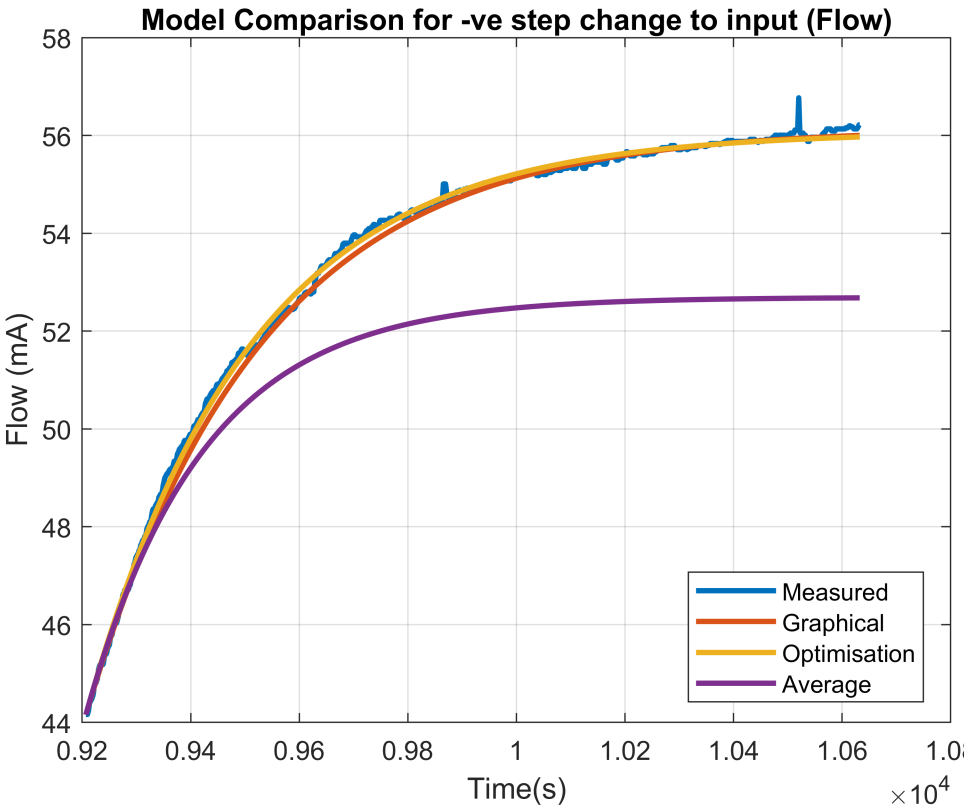

```
% For Positive MANIPULATED
graph =temp_SS_U2+ K_P_H.*(dU).*(1-exp(-t_PH/tau_P_H));
opt = temp_SS_U2+K_P_H_opt.*(dU).*(1-exp(-t_PH/tau_P_H_opt));
avg = temp_SS_U2+K_p.*(dU).*(1-exp(-t_PH/tau_p));
t_plot = time(SS_U2:SS_U_P_H);
plot(t_plot,temp_filtered(SS_U2 :SS_U_P_H),LineWidth=2)
hold on
plot(t_plot,graph,LineWidth=2)
plot(t_plot,opt,LineWidth=2)
plot(t_plot,avg,LineWidth=2)
hold off
title("Model Comparison for +ve step change to input (Heat)")
ylabel("Temperature(^oC)")
xlabel("Time(s)")
legend("Measured","Graphical","Optimisation","Average",Location="best")
grid
```




```
% For Positive Disturbance
graph =temp_SS_U3+ K_P_F.*(dU).*(1-exp(-t_PF/tau_P_F));
opt = temp_SS_U3+K_P_F_opt.*(dU).*(1-exp(-t_PF/tau_P_F_opt));
avg = temp_SS_U3+K_d.*(dU).*(1-exp(-t_PF/tau_d));
t_plot = time(SS_U3:SS_U_P_F);
plot(t_plot,temp_filtered(SS_U3 :SS_U_P_F),LineWidth=2)
hold on
plot(t_plot,graph,LineWidth=2)
plot(t_plot,opt,LineWidth=2)
plot(t_plot,avg,LineWidth=2)
hold off
title("Model Comparison for +ve step change to input (Flow)")
ylabel("Flow (mA)")
xlabel("Time(s)")
legend("Measured","Graphical","Optimisation","Average",Location="best")
grid
```




```
% For Negative Disturbance
graph =temp_SS_U4+ K_N_F.*(-dU).*(1-exp(-t_NF/tau_N_F));
opt = temp_SS_U4+K_N_F_opt.*(-dU).*(1-exp(-t_NF/tau_N_F_opt));
avg = temp_SS_U4+K_d.*(-dU).*(1-exp(-t_NF/tau_d));
t_plot = time(SS_U4:SS_U_N_F);
plot(t_plot,temp_filtered(SS_U4 :SS_U_N_F),LineWidth=2)
hold on
plot(t_plot,graph,LineWidth=2)
plot(t_plot,opt,LineWidth=2)
plot(t_plot,avg,LineWidth=2)
hold off
title("Model Comparison for -ve step change to input (Flow)")
ylabel("Flow (mA)")
xlabel("Time(s)")
legend("Measured","Graphical","Optimisation","Average",Location="best")
grid
```


Model Comparison for -ve step change to input (Flow)
Flow (mA)
58
56
54
52
50
48
46
44
0.92
0.94
0.96
0.98
1
1.02
1.04
1.06
1.08
Time(s)
$\times 10^4$
Measured
Graphical
Optimisation
Average