Controller design and evaluation of their effectiveness [1-5]

References:

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3. Seborg D.E., Mellichamp D. A., Edgar T.F, Doyle F.J., 2011, Process Dynamics and Control , John Wiley and Sons ISBN: 978-0-470-64610-6

4. Seborg D.E., Mellichamp D. A., Edgar T.F, Doyle F.J., ÇEVİRENLER: Tapan N.A., Erdoğan S. 3. baskıdan çeviriden 1.basım, 2012, Proses Dinamiği ve Kontrolu, Nobel Akademik Yayıncılık ISBN: 978-605-133-298-7

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Unsteady state:

$$q + wC(T_i - T_o) - wC(T - T_o) = \rho CV \frac{dT}{dt}$$

Steady state:

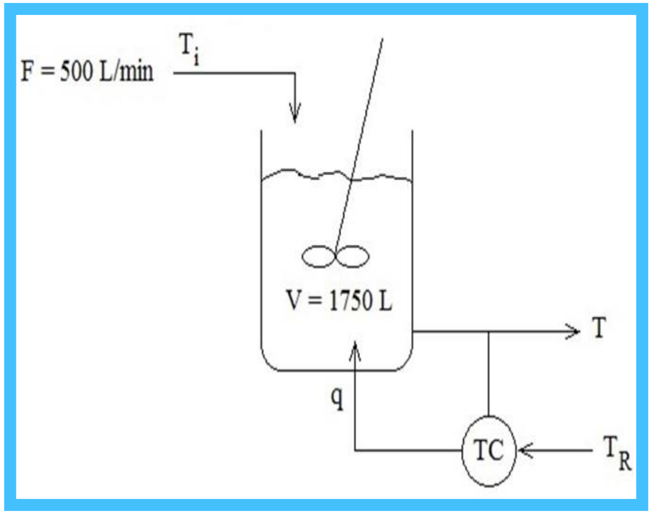
$$q_s + wC(T_{is} - T_o) - wC(T_s - T_o) = 0$$

Subtracting steady state equation from unsteady state equation

$$q - q_s + wC[(T_i - T_{is}) - (T - T_s)] = \rho CV \frac{d(T - T_s)}{dt}$$

Deviation variables:

$$T_i - T_{is} = T_i^{'}$$
$$q_i - q_s = Q$$
$$T - T_s = T^{'}$$



Rearranging the equation using deviation variables

$$Q + wC(T_i' - T') = \rho CV \frac{dT'}{dt}$$

$$Q + wCT_i' = wCT' + \rho CV \frac{dT'}{dt}$$

$$\frac{1}{wC} Q + T_i' = T' + \frac{\rho V}{w} \frac{dT'}{dt}$$

Taking the Laplace transform of both sides

$$\frac{1}{wC} Q(s) + T_i'(s) = T'(s) + \frac{\rho V}{w} sT'(s)$$

$$T'(s)\left[1 + \frac{\rho V}{w} s\right] = \frac{1}{wC} Q(s) + T_i'(s) \quad ; \quad \tau = \frac{\rho V}{w}$$

$$T'(s)[\tau s + 1] = \frac{1}{wC} Q(s) + T_i'(s)$$

$$T'(s) = \frac{1/wC}{\tau s + 1} Q(s) + \frac{1}{\tau s + 1} T_i'(s) \quad ; \quad \frac{1}{wC} : heater\ gain$$

$$\tau = \frac{\rho V}{w} = \frac{V}{w/\rho} = \frac{V}{F} = \frac{1750\ L}{500\ L/min} = 3.5\ min$$

$$\frac{1}{wC} = \frac{1}{\left(500\,\frac{L}{min}\right)\left(\frac{1\,kg}{1L}\right)\left(\frac{1\,min}{60\,s}\right)\left(4.184\,\frac{kJ}{kg^oC}\right)} = \frac{1}{34.87}\frac{^oC}{kW} = 0.028\frac{^oC}{kW}$$

$$T'(s) = \left(\frac{1}{3.5s+1}\right)\left(\frac{1}{34.87}\right)Q(s) + \left(\frac{1}{3.5s+1}\right)T_i'(s)$$

Measuring element transfer function:

$$\frac{T_m'(s)}{T'(s)} = \frac{1}{\tau_m s + 1}$$

$$T'(s) = \frac{1}{s}$$

$$T_m'(s) = \frac{1}{s}\left(\frac{1}{\tau_m s + 1}\right) = \frac{A}{s} + \frac{B}{\tau_m s + 1}$$

$$A = \left[\frac{s}{s(\tau_m s + 1)}\right]_{s=0} = 1$$

$$B = \left[\frac{(\tau_m s + 1)}{s(\tau_m s + 1)}\right]_{s=-1/\tau_m} = -\tau_m$$

$$T_m'(s) = \frac{1}{s} - \frac{\tau_m}{\tau_m s + 1} = \frac{1}{s} - \frac{1}{(s + \frac{1}{\tau_m})}$$

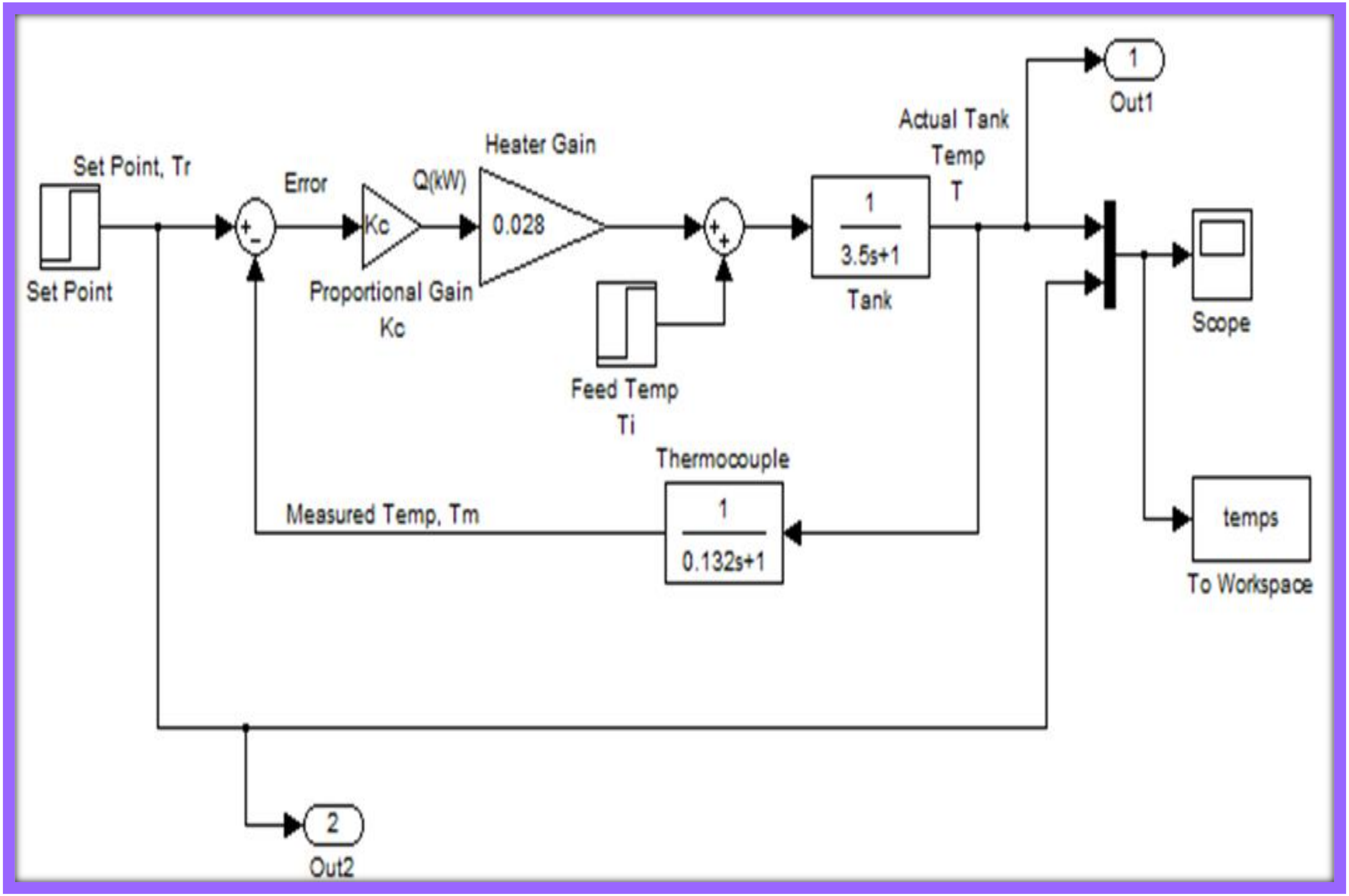
$$T_m'(t) = 1 - e^{-t/\tau_m}$$

$$0.85 = 1 - e^{-15/\tau_m}$$

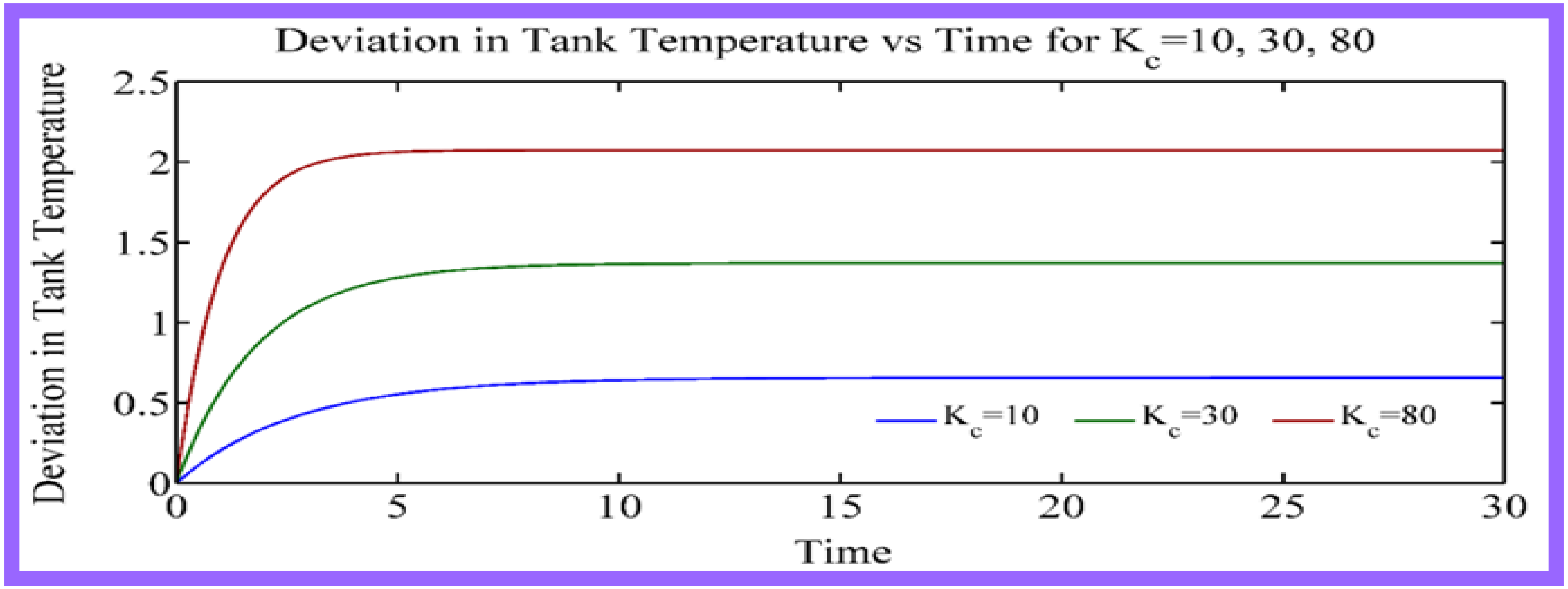
$$\tau_m = 7.91\,s = 0.132\,min$$

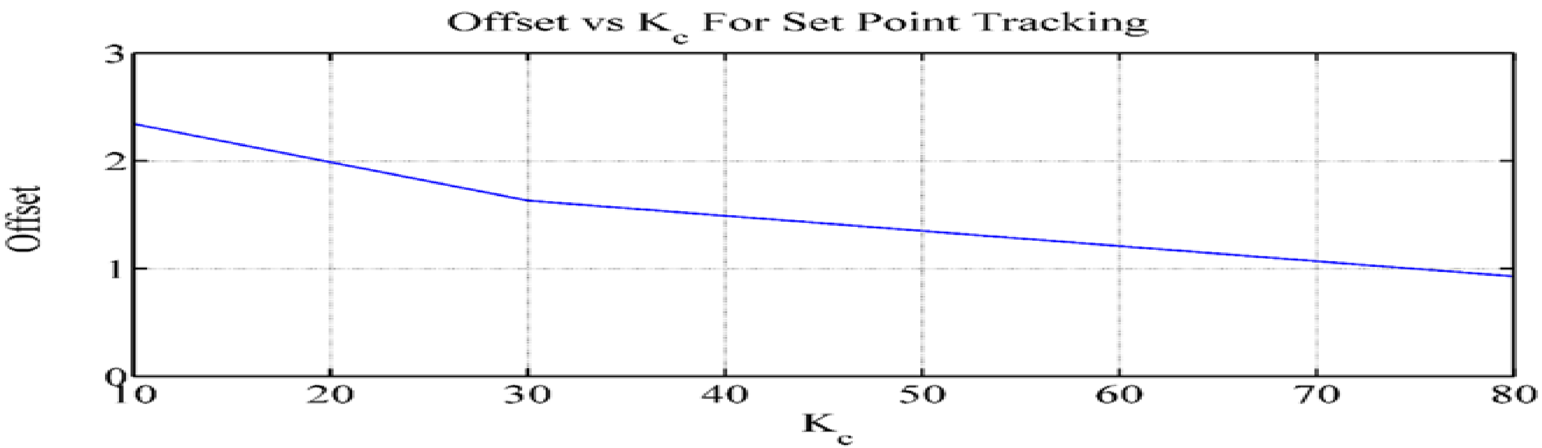
$$\frac{T_m'(s)}{T'(s)} = \frac{1}{0.132\,s + 1}$$

Simulink Model



```
clear all
clc
Kcplot(3,1)=0.0;
offset(3,1)=0.0;
for i=1:3
     z=[10,30,80];
     Kc=z(1,i);
     [t,x,y]=sim('hw_part_c',30);
     plot(t,y(:,1))
     hold on
     [norow,nocol]=size(y);
     offset(i,1)=y(norow,2)-y(norow,1);
     Kcplot(i,1)=Kc;
end
grid
title('Deviation in Tank Temperature vs time for Kc=10,30,80');
hold off
figure;
plot(Kcplot,offset);
title('Offset vs Kc For Set Point Tracking');
```





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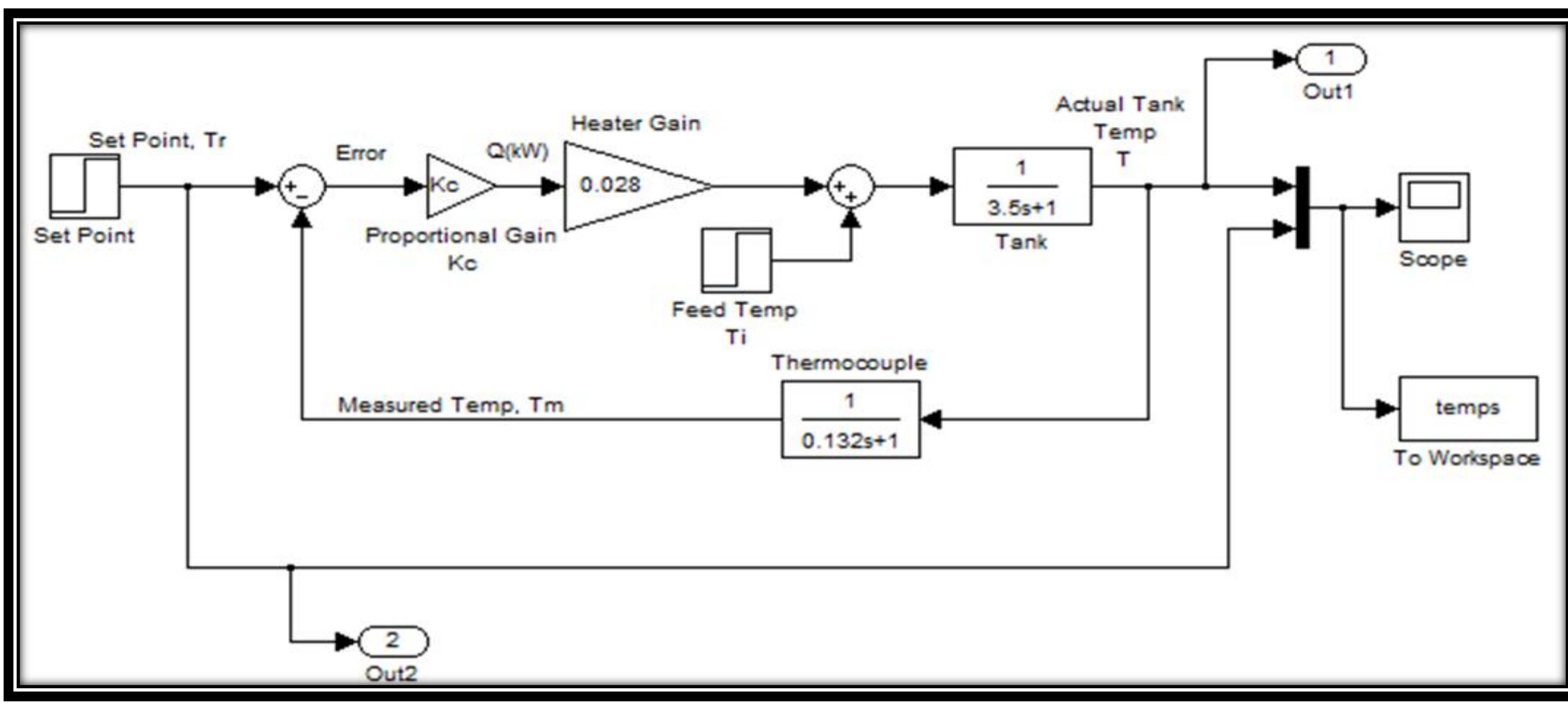
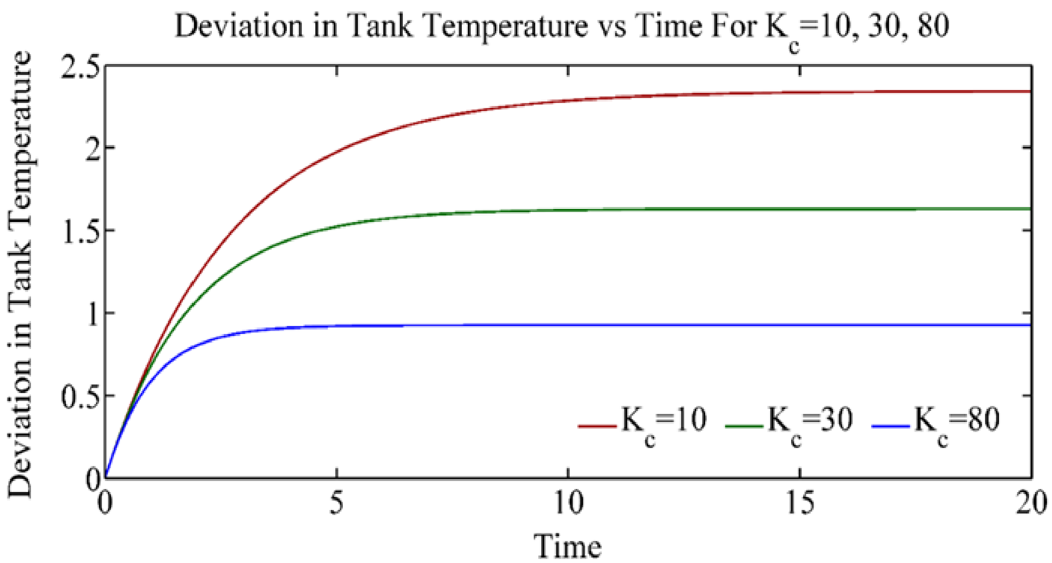
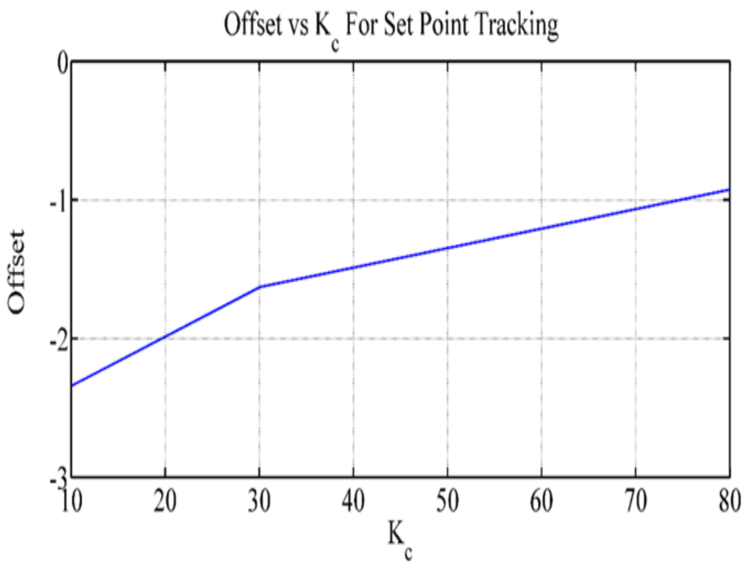


```
clear all
clc
Kcplot(3,1)=0.0;
offset(3,1)=0.0;
for i=1:3
    z=[10,30,80];
    Kc=z(1,i);
    [t,x,y]=sim('hw_part_d',20);
    plot(t,y(:,1))
    hold on
    [norow,nocol]=size(y);
    offset(i,1)=y(norow,2)-y(norow,1);
    Kcplot(i,1)=Kc;
end
grid
title('Deviation in Tank Temperature vs Time For Kc=10,30,80');
hold off
figure;
plot(Kcplot,offset);
title('Offset vs Kc For Set Point Tracking');
```





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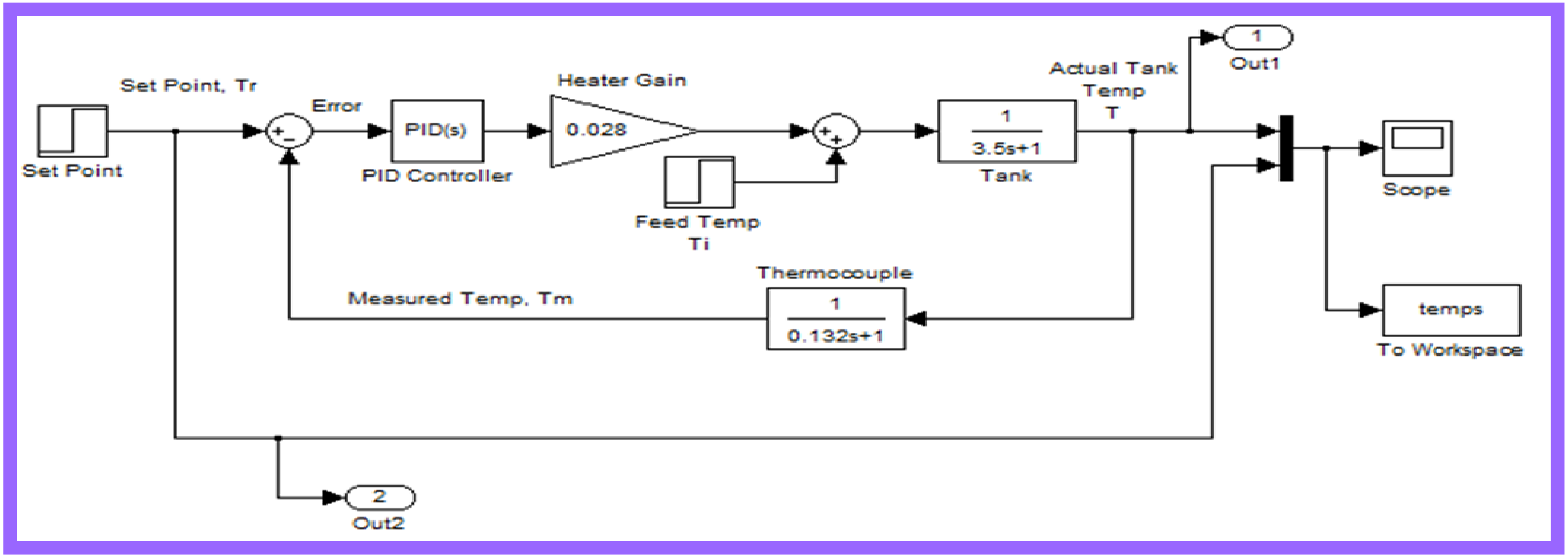
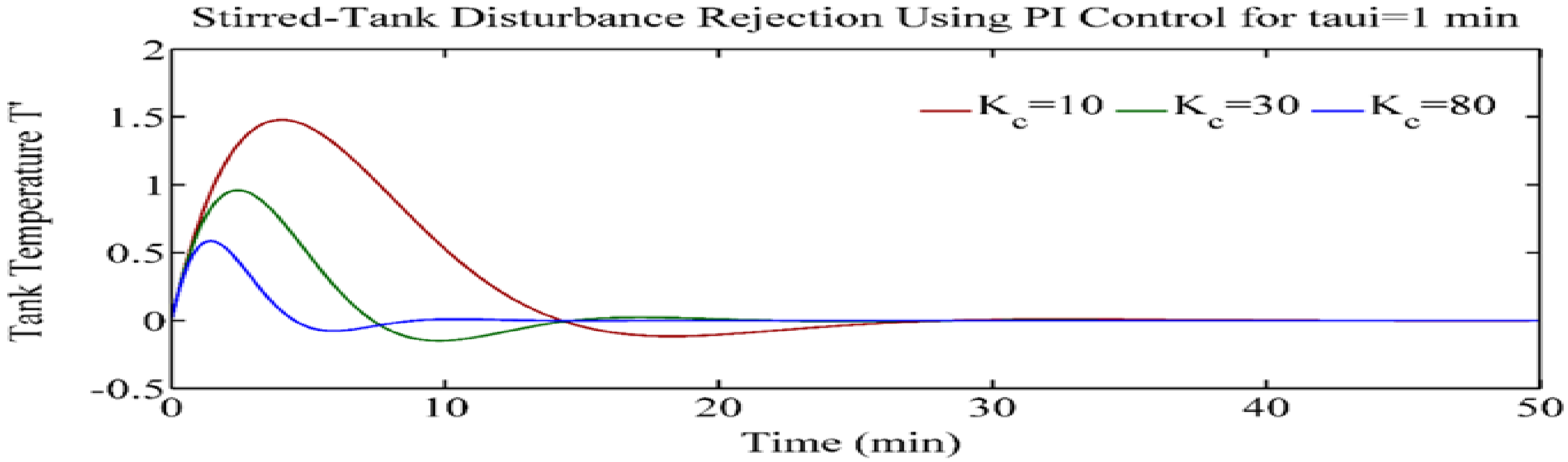
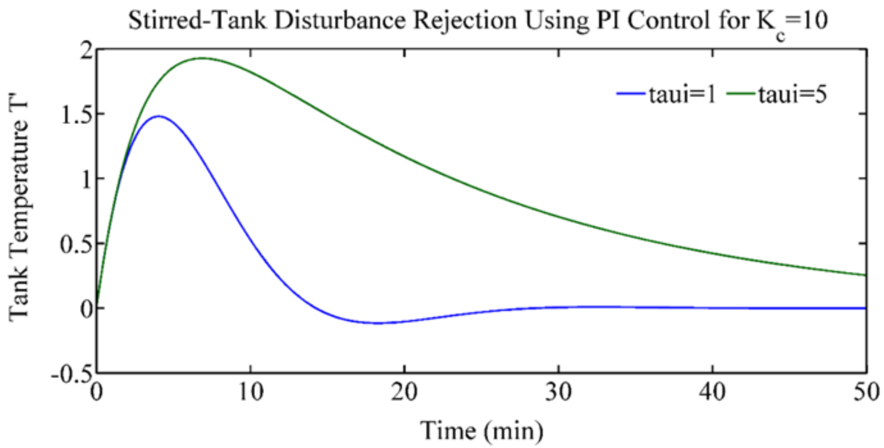


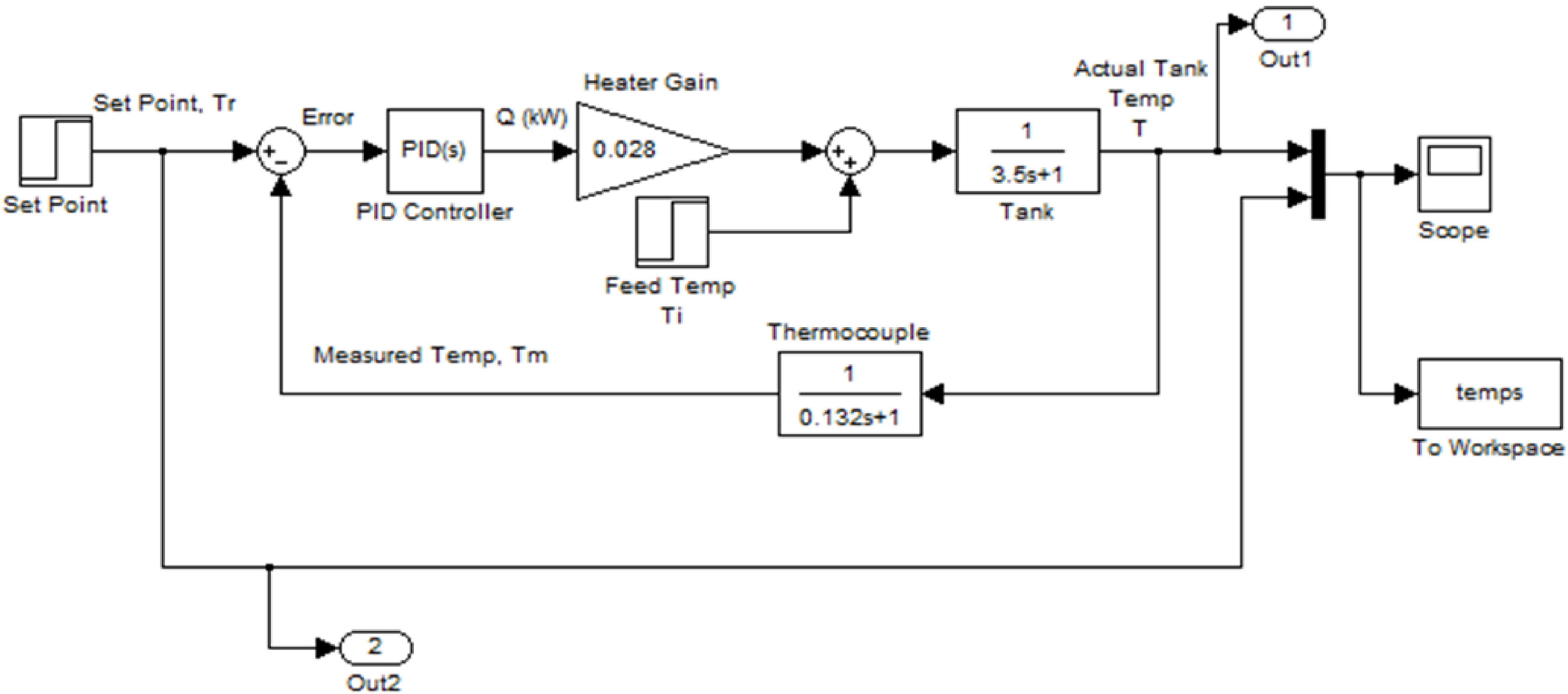

```
clear all
clc
h(1,:)='g-';
h(2,:)='r-';
h(3,:)='b:';
h(4,:)='--';
h(5,:)='k-';
taui=1;
for i=1:3
    z=[10,30,80];
    Kc=z(1,i);
    [t,x,y]=sim('hw_part_e',50);
    plot(t,y(:,1),h(i,:))
    hold on
end
grid
hold off
```



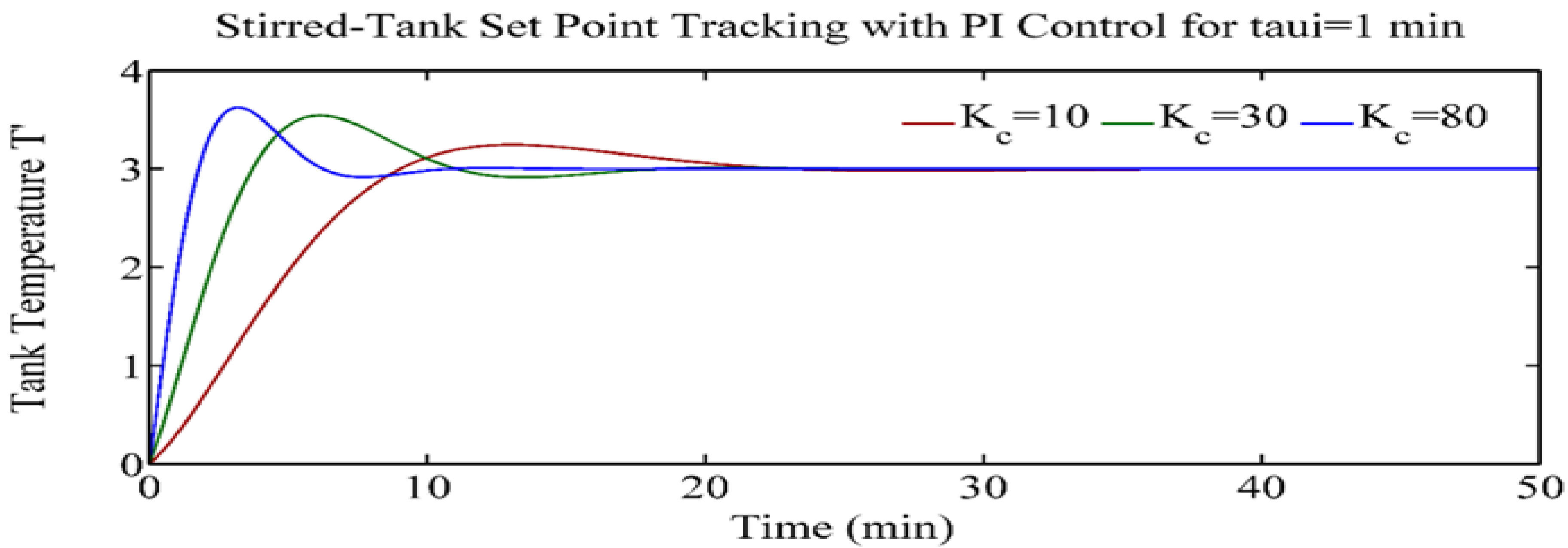

```
clear all
clc
h(1,:)='g-';
h(2,:)='r-';
h(3,:)='b:';
h(4,:)='--';
h(5,:)='k-';
Kc=10;
for i=1:2
    z=[1,5];
    taui=z(1,i);
    [t,x,y]=sim('hw_part_e',50);
    plot(t,y(:,1),h(i,:))
    hold on
end
grid
hold off
```



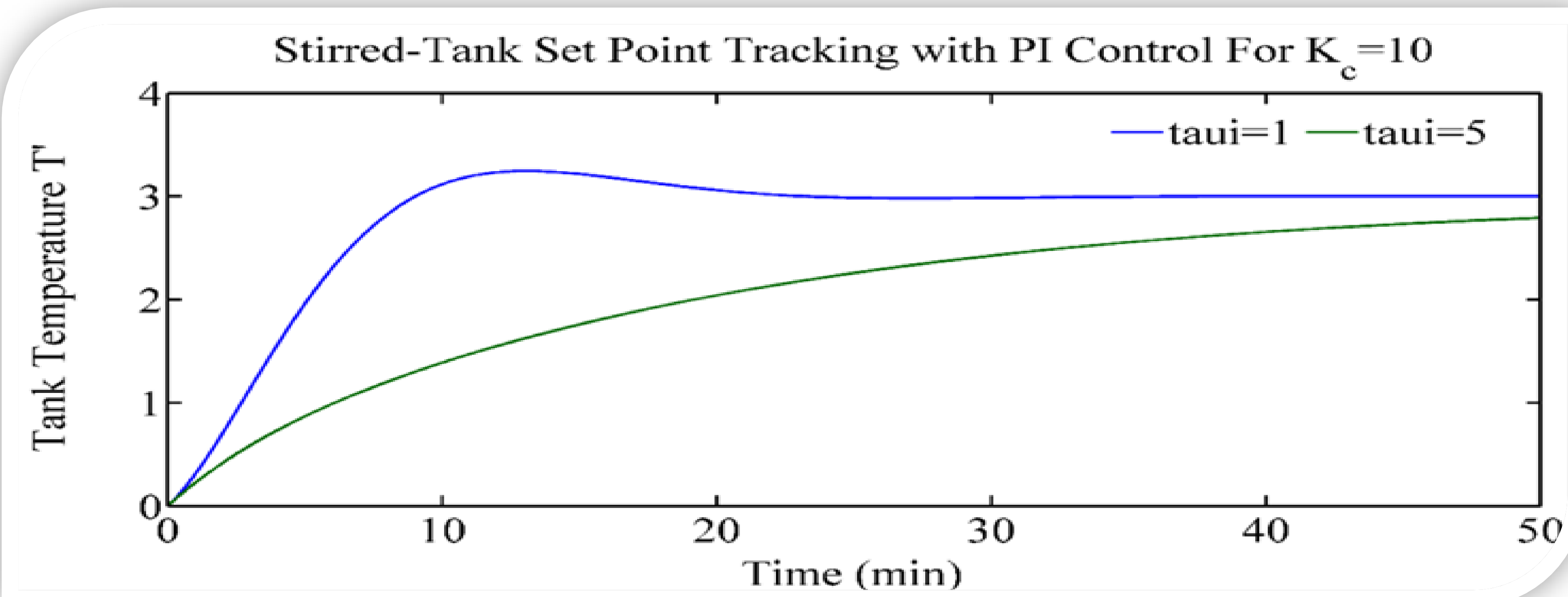
Simulink Model



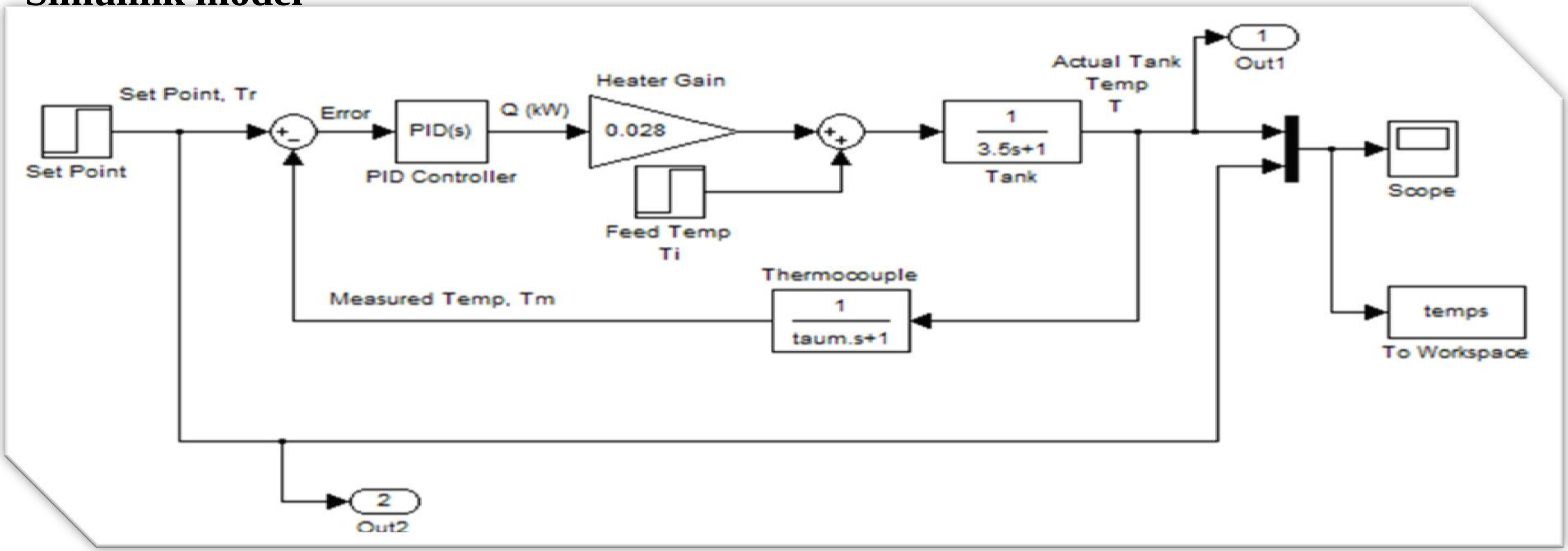
```
clear all
clc
h(1,:)='g-';
h(2,:)='r-';
h(3,:)='b:';
h(4,:)='--';
h(5,:)='k-';
taui=1;
for i=1:3
    z=[10,30,80];
    Kc=z(1,i);
    [t,x,y]=sim('hw_part_f',50);
    plot(t,y(:,1),h(i,:))
    hold on
end
grid
hold off
```



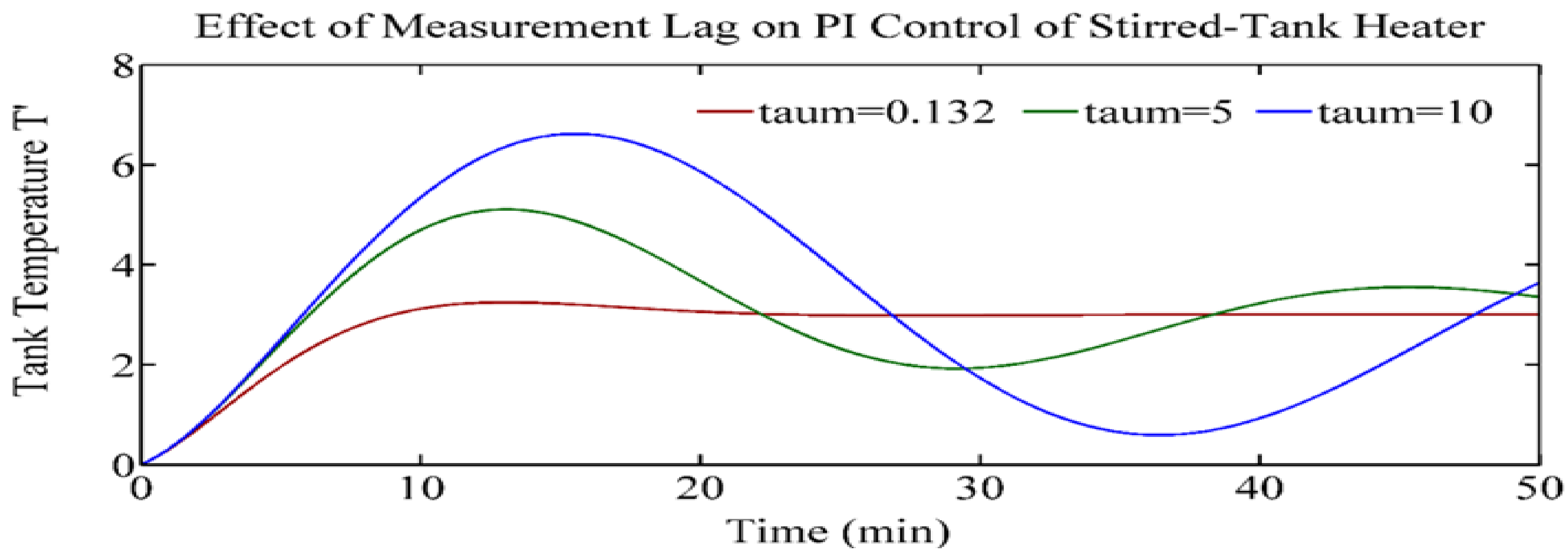
```
clear all
clc
h(1,:)='g-';
h(2,:)='r-';
h(3,:)='b:';
h(4,:)='--';
h(5,:)='k-';
Kc=10;
for i=1:2
    z=[1,5];
    taui=z(1,i);
    [t,x,y]=sim('hw_part_f',50);
    plot(t,y(:,1),h(i,:))
    hold on
end
grid
hold off
```



Simulink model




```
clear all
clc
h(1,:)='g-';
h(2,:)='r-';
h(3,:)='b:';
h(4,:)='--';
h(5,:)='k-';
for i=1:3
    z=[0.132,5,10];
    taum=z(1,i);
    [t,x,y]=sim('hw_part_g',50);
    plot(t,y(:,1),h(i,:))
    hold on
end
grid
hold off
```



the proportional gain K_c ↑ : the process more narrowly approaches the desired set point,

the system does a better trade at rejecting the disturbance

for a fixed value of τ_I ,

the proportional gain K_c ↑ : the response maximum deviation increases,

the response less oscillatory

For a fixed value of Kc,

the integral time τ_I ↓ : the maximum deviation decreases