1. The flow sensor data (Columns 2-4) were converted to mass flow (kg/h) using the provided calibration equation, and the flow rates are plotted below:



1. Looking at the data, there is a clear change in the cold water flow rate at point 1708. Only the stationary phase is considered, so the data is divided into two sections: Section A (1-1500) and Section B (1800-2800). The mean and variance are shown below:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  | **Cold Water** | **Hot Water** | **Total Water** |
| **Section  A** | **Mean** | 298.2 | 314.4 | 596.0 |
| **Variance** | 5.2 | 11.8 | 201.9 |
| **Section  B** | **Mean** | 283.4 | 316.3 | 600.0 |
| **Variance** | 4.9 | 13.9 | 129.9 |

1. Outliers were determined using the mean and variance (outlier = mean ± 3\*sqrt(variance)). These outliers were replaced by the mean value. The plots of flow rate without outliers is shown below:



1. During steady state, the mass flow should be in balance (. This theoretical value is compared with the measured sensor values:

The errors were calculated and shown on the histogram below:



Section B has a normal noise distribution (mean is -0.368), indicating there is only noise error and negligible bias.

The mean of errors in Section A is at 16.4; therefore, there is a bias of 16.4 for a sensor during the stationary phase. Only the cold water flow was changed, which suggests that the bias is in the cold water flow sensor.

1. The temperature data is plotted below. There is a change in hot water temperature so the limits of the stationary phase were changed; the two sections are: Section A (1-777) and Section B (1800-2800).



The mean and variance of the temperatures were calculated and shown on the table below:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  | **T1** | **T2** | **T4** | **T5** |
| **Section  A** | **Mean** | 17.4 | 44.7 | 38.4 | 31.7 |
| **Variance** | 12.6 | 82.5 | 61.1 | 41.6 |
| **Section  B** | **Mean** | 17.8 | 50.9 | 43.1 | 35.1 |
| **Variance** | 0.1 | 0.1 | 0.8 | 0.2 |

The outliers (mean ± 3\*sqrt(variance)) were removed and the sections are plotted below.



The energy balance () was used to determine determined at steady state temperature of the total stream. This theoretical value was compared to the reading of the total stream sensors (T4 and T5). Part d) showed that the total flow sensor for Section A was not reliable; therefore, the sum of the hot and cold streams was used for calculations.



The deviation from the energy balance (was determined for sensors T4 and T5.





The means of errors are shown in the table below. There is negligible bias for sensor T4, while senor T4 showed an average bias of -7.61.

|  |  |  |  |
| --- | --- | --- | --- |
|  | | **T4** | **T5** |
| **Mean** | **Section A** | -7.22 | -0.28 |
| **Section B** | -7.91 | 0.17 |

**Matlab Code:**

%matrix of flow rates

FlowRates(:,1) = 1.256 +178.032\*sqrt(Data\_3(:,2)); %Cold Water

FlowRates(:,2) = 1.444+181.574\*sqrt(Data\_3(:,3)); %Hot Water

FlowRates(:,3) = -2.319 + 355.822\*sqrt(Data\_3(:,4)); %Total Water

%plot raw data

figure

plot([FlowRates(:,1) FlowRates(:,2) FlowRates(:,3)])

title('Raw Flow Rates')

ylabel('Mass Flow(kg/h)')

set(legend('FlowCold','FlowHot','FlowTot'),'Location','SouthEast');

%step at 1708, separate data

aFlowRates = FlowRates(1:1500, :); %reduce data to 1500

bFlowRates = FlowRates(1800:2800, :); %reduce data to 1000

%Results (mean, Variance)

FlowMean(1,:) = mean(aFlowRates); %flow mean part a

FlowMean(2,:) = var(aFlowRates); %flow variance part a

FlowMean(3,:) = mean(bFlowRates); %flow mean part b

FlowMean(4,:) = var(bFlowRates); %flow variance part b

%find and replace outliers

for i= 1:1:3

FlowOutliers = find(aFlowRates(:,i)<FlowMean(1,i)-3\*sqrt(FlowMean(2,i)) | aFlowRates(:,i)>FlowMean(1,i)+3\*sqrt(FlowMean(2,i)));

aFlowRates(FlowOutliers,i) = FlowMean(1,i);

end

for i= 1:1:3

FlowOutliers = find(bFlowRates(:,i)<FlowMean(3,i)-3\*sqrt(FlowMean(4,i)) | bFlowRates(:,i)>FlowMean(3,i)+3\*sqrt(FlowMean(4,i)));

bFlowRates(FlowOutliers,i) = FlowMean(3,i);

end

%Results without Outlier (mean, Variance)

NewFlowMean(1,:) = mean(aFlowRates); %flow mean part a

NewFlowMean(2,:) = var(aFlowRates); %flow variance part a

NewFlowMean(3,:) = mean(bFlowRates); %flow mean part b

NewFlowMean(4,:) = var(bFlowRates); %flow variance part b

%plot flow without outlier

figure

subplot(1, 2, 1)

plot(aFlowRates)

title('Clean Flow Rates for Section A')

ylabel('Mass Flow(kg/h)')

set(legend('FlowCold','FlowHot','FlowTot'),'Location','East');

subplot(1, 2, 2)

plot(bFlowRates)

title('Clean Flow Rates for Section B')

ylabel('Mass Flow(kg/h)')

set(legend('FlowCold','FlowHot','FlowTot'),'Location','East');

%mass balance

aMassBalance(:,1) = aFlowRates(:,1) + aFlowRates(:,2);

aMassBalance(:,2) = aFlowRates(:,3);

aMassBalance(:,3) = aMassBalance(:,1) - aMassBalance(:,2);

bMassBalance(:,1) = bFlowRates(:,1) + bFlowRates(:,2);

bMassBalance(:,2) = bFlowRates(:,3);

bMassBalance(:,3) = bMassBalance(:,1) - bMassBalance(:,2);

%data plot

figure

subplot(1, 2, 1)

plot(aMassBalance(:,1:2))

title('Clean Flow Rates for Section A')

ylabel('Mass Flow(kg/h)')

set(legend('Theoretical Flow','FlowTot'),'Location','SouthEast');

subplot(1, 2, 2)

plot(bMassBalance(:,1:2))

title('Clean Flow Rates for Section B')

ylabel('Mass Flow(kg/h)')

set(legend('Theoretical Flow','FlowTot'),'Location','SouthEast');

%histogram plot

figure

subplot(1, 2, 1)

hist(aMassBalance(:,3))

title('Frequency of Error for Section A Mass Balance')

subplot(1, 2, 2)

hist(bMassBalance(:,3))

title('Frequency of Error for Section B Mass Balance')

%error in Section A (1 = section A; 2 = section B)

ErrorMass(1)=mean(aMassBalance(:,3));

ErrorMass(2)=mean(bMassBalance(:,3));

%Temperatures

Temp = Data\_3(:,5:1:8);

%plot raw data

figure

plot(Temp)

ylabel('Temp(\circC)')

set(legend('T1','T2','T4','T5'),'Location','SouthEast');

%same data range as flow

aTempEnd = 777;

aTemp = Temp(1:aTempEnd, :);

bTemp = Temp(1800:2800, :);

%plot temperature data

figure

subplot(1, 2, 1)

plot(aTemp)

title('Raw Temperature for Section A')

ylabel('Temp(\circC)')

set(legend('T1','T2','T4','T5'),'Location','SouthEast');

subplot(1, 2, 2)

plot(bTemp)

title('Raw Temperature for Section B')

ylabel('Temp(\circC)')

set(legend('T1','T2','T4','T5'),'Location','SouthEast');

%Results (mean, Variance)

TempMean(1,:) = mean(aTemp); %flow mean part a

TempMean(2,:) = var(aTemp); %flow variance part a

TempMean(3,:) = mean(bTemp); %flow mean part b

TempMean(4,:) = var(bTemp); %flow variance part b

%find and replace outliers

for i= 1:1:4

TempOutliers = find(aTemp(:,i)<TempMean(1,i)-3\*sqrt(TempMean(2,i)) | aTemp(:,i)>TempMean(1,i)+3\*sqrt(TempMean(2,i)));

aTemp(TempOutliers,i) = TempMean(1,i);

end

for i= 1:1:4

TempOutliers = find(bTemp(:,i)<TempMean(3,i)-3\*sqrt(TempMean(4,i)) | bTemp(:,i)>TempMean(3,i)+3\*sqrt(TempMean(4,i)));

bTemp(TempOutliers,i) = TempMean(3,i);

end

%plot temperature data

figure

subplot(1, 2, 1)

plot(aTemp)

title('Clean Temperature Data for Section A')

ylabel('Temp(\circC)')

set(legend('T1','T2','T4','T5'),'Location','SouthEast');

subplot(1, 2, 2)

plot(bTemp)

title('Clean Temperature Data for Section B')

ylabel('Temp(\circC)')

set(legend('T1','T2','T4','T5'),'Location','SouthEast');

%Results without Outlier (mean, Variance)

NewTempMean(1,:) = mean(aTemp); %flow mean part a

NewTempMean(2,:) = var(aTemp); %flow variance part a

NewTempMean(3,:) = mean(bTemp); %flow mean part b

NewTempMean(4,:) = var(bTemp); %flow variance part b

%Temperature sensor vs theory (col 1 = theory temp; col 2 = T4; col 4 = T5)

aEnergyBalance(:,1) = (aFlowRates(1:aTempEnd, 1).\*aTemp(:,1) + aFlowRates(1:aTempEnd, 2).\*aTemp(:,2))./(aFlowRates(1:aTempEnd, 1) + aFlowRates(1:aTempEnd, 2));

aEnergyBalance(:,2) = aTemp(:,3);

aEnergyBalance(:,4) = aTemp(:,4);

bEnergyBalance(:,1) = (bFlowRates(:, 1).\*bTemp(:,1) + bFlowRates(:, 2).\*bTemp(:,2))./bFlowRates(:, 3);

bEnergyBalance(:,2) = bTemp(:,3);

bEnergyBalance(:,4) = bTemp(:,4);

%plot temperature data

figure

subplot(1, 2, 1)

plot([aEnergyBalance(:,2) aEnergyBalance(:,4) aEnergyBalance(:,1)])

title('Clean Temperature for Section A Mixed Section')

ylabel('Temp(\circC)')

set(legend('T4','T5','Theoretical Temp'),'Location','SouthEast');

subplot(1, 2, 2)

plot([bEnergyBalance(:,2) bEnergyBalance(:,4) bEnergyBalance(:,1)])

title('Clean Temperature for Section B Mixed Section')

ylabel('Temp(\circC)')

set(legend('T4','T5','Theoretical Temp'),'Location','SouthEast');

%deviation from theory

for i = 1:1:1500

aEnergyBalance(:,3) = aEnergyBalance(:,1) - aEnergyBalance(:,2);

aEnergyBalance(:,5) = aEnergyBalance(:,1) - aEnergyBalance(:,4);

end

for i = 1:1:1001

bEnergyBalance(:,3) = bEnergyBalance(:,1) - bEnergyBalance(:,2);

bEnergyBalance(:,5) = bEnergyBalance(:,1) - bEnergyBalance(:,4);

end

%stat of temperatures (row 1 mean, row 2 var; col 1 = part a, col2 = part b

EnergyBalanceMean(1,:) = [mean(aEnergyBalance(:,3)) mean(aEnergyBalance(:,5)) mean(bEnergyBalance(:,3)) mean(bEnergyBalance(:,5))];

EnergyBalanceMean(2,:) = [var(aEnergyBalance(:,3)) var(aEnergyBalance(:,5)) var(bEnergyBalance(:,3)) var(bEnergyBalance(:,5))];

%error for each section

figure

subplot(1, 2, 1)

hist(aEnergyBalance(:,3))

title('Frequency of Error for Section A Sensor T4')

ylabel('Temp(\circC)')

subplot(1, 2, 2)

hist(bEnergyBalance(:,3))

title('Frequency of Error for Section B Sensor T4')

ylabel('Temp(\circC)')

figure

subplot(1, 2, 1)

hist(aEnergyBalance(:,5))

title('Frequency of Error for Section A Sensor T5')

ylabel('Temp(\circC)')

subplot(1, 2, 2)

hist(bEnergyBalance(:,5))

title('Frequency of Error for Section B Sensor T5')

ylabel('Temp(\circC)')

ErrorEnergyBalance(1,:) = [mean(aEnergyBalance(:,3)) mean(bEnergyBalance(:,3))];

ErrorEnergyBalance(2,:) = [mean(aEnergyBalance(:,5)) mean(bEnergyBalance(:,5))];