

Heat Exchanger Analysis

April 1, 2019

```
In [2]: import pandas as pd
df = pd.read_csv('RunSix.csv')
df
```

```
Out [2]:
```

	Time	CoCIN	CoCOUT	CoHIN	CoHOUT	ConCIN	ConCOUT	ConHIN	\
0	1.001	7.193	22.686	38.841	28.076	7.232	23.847	38.705	
1	2.001	7.193	22.655	38.810	28.014	7.201	23.847	38.642	
2	3.001	7.193	22.592	38.747	27.951	7.201	23.784	38.579	
3	4.001	7.193	22.561	38.716	27.920	7.201	23.721	38.485	
4	5.002	7.224	22.498	38.653	27.857	7.232	23.658	38.422	
5	6.002	7.193	22.466	38.621	27.763	7.232	23.564	38.390	
6	7.002	7.224	22.372	38.527	27.701	7.201	23.501	38.296	
7	8.002	7.224	22.340	38.496	27.669	7.232	23.406	38.233	
8	9.002	7.193	22.309	38.433	27.607	7.232	23.406	38.107	
9	10.002	7.193	22.278	38.370	27.544	7.264	23.344	37.981	
10	11.003	7.224	22.215	38.307	27.544	7.201	23.312	37.887	
11	12.003	7.193	22.183	38.213	27.576	7.232	23.281	37.761	
12	13.003	7.193	22.152	38.150	27.576	7.232	23.281	37.667	
13	14.003	7.224	22.120	38.055	27.513	7.232	23.281	37.572	
14	15.003	7.224	22.089	37.961	27.450	7.201	23.249	37.415	
15	16.003	7.224	22.026	37.867	27.357	7.232	23.218	37.320	
16	17.003	7.224	21.963	37.741	27.294	7.232	23.155	37.226	
17	18.003	7.224	21.963	37.615	27.263	7.232	23.092	37.100	
18	19.003	7.224	21.869	37.521	27.200	7.232	23.029	37.006	
19	20.003	7.224	21.869	37.427	27.138	7.232	22.966	36.880	
20	21.003	7.224	21.806	37.332	27.106	7.232	22.934	36.785	
21	22.003	7.224	21.774	37.175	27.106	7.232	22.840	36.660	
22	23.003	7.224	21.711	37.049	27.138	7.232	22.808	36.534	
23	24.003	7.224	21.680	36.924	27.075	7.232	22.745	36.439	
24	25.003	7.224	21.648	36.798	26.981	7.232	22.682	36.345	
25	26.003	7.224	21.586	36.735	26.919	7.232	22.619	36.282	
26	27.003	7.224	21.554	36.609	26.887	7.232	22.556	36.156	
27	28.003	7.224	21.523	36.483	26.887	7.232	22.525	36.062	
28	29.003	7.224	21.491	36.389	26.825	7.264	22.493	35.999	
29	30.003	7.193	21.428	36.326	26.793	7.232	22.399	35.904	
...	
10634	10635.674	6.344	17.276	37.835	28.671	6.414	17.456	37.730	

10635	10636.674	6.375	17.276	37.804	28.671	6.414	17.456	37.730
10636	10637.674	6.344	17.276	37.835	28.639	6.414	17.456	37.730
10637	10638.674	6.375	17.276	37.804	28.702	6.414	17.456	37.730
10638	10639.674	6.375	17.245	37.804	28.702	6.414	17.424	37.761
10639	10640.674	6.375	17.245	37.835	28.671	6.445	17.456	37.761
10640	10641.674	6.344	17.245	37.835	28.608	6.414	17.456	37.730
10641	10642.674	6.375	17.245	37.804	28.577	6.414	17.424	37.730
10642	10643.674	6.344	17.245	37.804	28.546	6.414	17.424	37.761
10643	10644.674	6.344	17.245	37.835	28.514	6.414	17.456	37.761
10644	10645.674	6.375	17.245	37.835	28.546	6.382	17.456	37.761
10645	10646.674	6.375	17.245	37.804	28.577	6.414	17.424	37.761
10646	10647.675	6.344	17.245	37.835	28.639	6.414	17.424	37.761
10647	10648.675	6.375	17.245	37.835	28.608	6.414	17.424	37.761
10648	10649.675	6.344	17.214	37.835	28.608	6.414	17.424	37.761
10649	10650.675	6.375	17.214	37.835	28.608	6.414	17.424	37.761
10650	10651.675	6.375	17.245	37.804	28.671	6.414	17.424	37.761
10651	10652.675	6.344	17.214	37.804	28.671	6.414	17.424	37.730
10652	10653.675	6.375	17.214	37.804	28.671	6.414	17.424	37.761
10653	10654.675	6.375	17.214	37.835	28.702	6.414	17.424	37.761
10654	10655.675	6.375	17.214	37.835	28.702	6.414	17.424	37.698
10655	10656.675	6.344	17.182	37.804	28.702	6.382	17.456	37.730
10656	10657.675	6.344	17.214	37.741	28.608	6.414	17.519	37.730
10657	10658.675	6.375	17.182	37.772	28.577	6.414	17.487	37.698
10658	10659.675	6.375	17.214	37.772	28.546	6.414	17.456	37.761
10659	10660.675	6.344	17.182	37.804	28.608	6.445	17.487	37.761
10660	10661.675	6.375	17.214	37.804	28.639	6.414	17.487	37.761
10661	10662.675	6.375	17.182	37.835	28.639	6.382	17.487	37.761
10662	10663.675	6.375	17.182	37.835	28.639	6.414	17.550	37.730
10663	10664.675	6.375	17.214	37.772	28.546	6.414	17.550	37.698

	ConHOUT	SiCIN	SiCOUT	SiHIN	SiHOUT	MPCIN	MPCOUT	MPHIN \
0	23.533	7.575	14.406	37.481	29.546	7.436	24.488	37.692
1	23.470	7.607	14.406	37.450	29.515	7.436	24.425	37.630
2	23.407	7.481	14.438	37.418	29.452	7.404	24.394	37.567
3	23.345	7.575	14.469	37.355	29.421	7.404	24.331	37.504
4	23.282	7.575	14.438	37.292	29.390	7.436	24.300	37.379
5	23.251	7.544	14.501	37.229	29.327	7.404	24.237	37.285
6	23.188	7.607	14.501	37.198	29.296	7.436	24.206	37.191
7	23.157	7.575	14.532	37.135	29.264	7.404	24.175	37.066
8	23.094	7.607	14.532	37.104	29.202	7.373	24.175	37.003
9	23.063	7.575	14.532	37.041	29.170	7.436	24.143	36.877
10	23.031	7.575	14.564	36.946	29.139	7.404	24.112	36.752
11	22.969	7.575	14.564	36.883	29.108	7.436	24.049	36.658
12	22.844	7.607	14.564	36.820	29.076	7.404	24.049	36.533
13	22.781	7.607	14.595	36.757	29.014	7.404	23.987	36.439
14	22.718	7.607	14.595	36.663	29.045	7.436	23.924	36.345
15	22.656	7.607	14.627	36.568	28.982	7.404	23.893	36.219
16	22.562	7.607	14.627	36.474	28.951	7.436	23.830	36.125

17	22.499	7.575	14.627	36.411	28.920	7.467	23.799	36.000
18	22.436	7.575	14.658	36.317	28.888	7.404	23.767	35.906
19	22.342	7.575	14.690	36.222	28.857	7.436	23.704	35.812
20	22.217	7.575	14.658	36.159	28.826	7.404	23.642	35.749
21	22.154	7.575	14.690	36.033	28.795	7.436	23.610	35.655
22	22.092	7.575	14.690	35.970	28.732	7.404	23.548	35.593
23	22.029	7.575	14.690	35.876	28.701	7.436	23.516	35.499
24	21.967	7.607	14.721	35.813	28.669	7.436	23.454	35.405
25	21.935	7.575	14.721	35.719	28.638	7.436	23.422	35.311
26	21.873	7.607	14.721	35.593	28.607	7.436	23.360	35.279
27	21.779	7.607	14.753	35.561	28.544	7.436	23.360	35.248
28	21.747	7.607	14.753	35.467	28.513	7.404	23.297	35.154
29	21.716	7.607	14.784	35.372	28.450	7.404	23.266	35.060
...
10634	27.698	6.631	12.863	36.726	33.492	6.528	20.257	37.097
10635	27.698	6.662	12.895	36.726	33.492	6.528	20.257	37.066
10636	27.667	6.599	12.895	36.726	33.492	6.528	20.289	37.034
10637	27.698	6.599	12.863	36.726	33.492	6.559	20.257	37.066
10638	27.730	6.631	12.863	36.726	33.492	6.528	20.226	37.097
10639	27.604	6.631	12.895	36.726	33.461	6.528	20.195	37.034
10640	27.604	6.631	12.863	36.726	33.461	6.528	20.163	37.066
10641	27.667	6.631	12.863	36.726	33.461	6.528	20.226	37.066
10642	27.698	6.662	12.863	36.726	33.524	6.559	20.226	37.066
10643	27.636	6.662	12.895	36.757	33.492	6.496	20.226	37.066
10644	27.636	6.631	12.863	36.726	33.492	6.528	20.226	37.066
10645	27.636	6.631	12.895	36.726	33.524	6.528	20.257	37.097
10646	27.698	6.631	12.895	36.726	33.492	6.559	20.226	37.097
10647	27.698	6.631	12.863	36.726	33.492	6.559	20.257	37.066
10648	27.667	6.631	12.895	36.726	33.524	6.559	20.226	37.066
10649	27.667	6.631	12.895	36.726	33.492	6.496	20.226	37.066
10650	27.636	6.662	12.863	36.726	33.492	6.559	20.226	37.066
10651	27.479	6.662	12.895	36.726	33.492	6.559	20.195	37.097
10652	27.416	6.631	12.863	36.694	33.492	6.559	20.163	37.097
10653	27.479	6.631	12.895	36.726	33.461	6.528	20.195	37.066
10654	27.573	6.662	12.895	36.694	33.461	6.559	20.195	37.034
10655	27.667	6.662	12.895	36.694	33.461	6.559	20.163	37.034
10656	27.636	6.631	12.895	36.694	33.461	6.559	20.163	37.034
10657	27.667	6.662	12.895	36.694	33.461	6.528	20.132	37.034
10658	27.667	6.662	12.895	36.694	33.430	6.528	20.132	37.034
10659	27.698	6.631	12.895	36.726	33.461	6.528	20.163	37.066
10660	27.698	6.662	12.895	36.726	33.461	6.559	20.132	37.066
10661	27.604	6.662	12.895	36.726	33.492	6.496	20.195	37.066
10662	27.604	6.631	12.895	36.726	33.461	6.528	20.132	37.066
10663	27.667	6.631	12.895	36.694	33.461	6.528	20.163	37.034

	MPHOUT	BEND 1	BEND 3
0	26.141	0.561	0.533
1	26.079	0.561	0.533

2	25.985	0.561	0.532
3	25.923	0.562	0.531
4	25.861	0.561	0.531
5	25.798	0.562	0.530
6	25.674	0.562	0.530
7	25.580	0.562	0.530
8	25.518	0.561	0.528
9	25.424	0.561	0.528
10	25.362	0.561	0.527
11	25.299	0.562	0.527
12	25.237	0.561	0.527
13	25.144	0.562	0.526
14	25.081	0.561	0.525
15	25.019	0.561	0.525
16	24.894	0.561	0.524
17	24.863	0.561	0.524
18	24.801	0.561	0.523
19	24.738	0.561	0.522
20	24.645	0.561	0.522
21	24.614	0.561	0.521
22	24.551	0.561	0.521
23	24.489	0.561	0.520
24	24.396	0.561	0.519
25	24.333	0.561	0.519
26	24.240	0.561	0.519
27	24.177	0.561	0.518
28	24.115	0.560	0.517
29	24.053	0.560	0.516
...
10634	26.827	0.576	0.545
10635	26.858	0.575	0.545
10636	26.858	0.575	0.545
10637	26.858	0.575	0.545
10638	26.827	0.576	0.545
10639	26.827	0.576	0.545
10640	26.827	0.576	0.545
10641	26.858	0.576	0.545
10642	26.827	0.575	0.545
10643	26.827	0.576	0.545
10644	26.827	0.575	0.545
10645	26.827	0.576	0.545
10646	26.827	0.576	0.545
10647	26.796	0.576	0.545
10648	26.827	0.576	0.545
10649	26.827	0.576	0.545
10650	26.858	0.576	0.545
10651	26.827	0.576	0.545
10652	26.858	0.576	0.545

10653	26.827	0.576	0.545
10654	26.827	0.576	0.545
10655	26.827	0.576	0.545
10656	26.827	0.576	0.545
10657	26.827	0.576	0.545
10658	26.796	0.576	0.545
10659	26.827	0.576	0.545
10660	26.827	0.576	0.545
10661	26.827	0.576	0.545
10662	26.827	0.577	0.545
10663	26.827	0.577	0.544

[10664 rows x 19 columns]

```
In [76]: import numpy as np
import matplotlib.pyplot as plt
import scipy.stats as ss
Time = df['Time']
CoCIN = df['CoCIN']
CoCOUT = df['CoCOUT']
CoHIN= df['CoHIN']
CoHOUT= df['CoHOUT']
ConCIN= df['ConCIN']
ConCOUT= df['ConCOUT']
ConHIN= df['ConHIN']
ConHOUT= df['ConHOUT']
SiCIN= df['SiCIN']
SiCOUT= df['SiCOUT']
SiHIN= df['SiHIN']
SiHOUT= df['SiHOUT']
MPCIN= df['MPCIN']
MPCOUT= df['MPCOUT']
MPHIN= df['MPHIN']
MPHOUT= df['MPHOUT']
plt.figure(figsize = (15,15))
plt.suptitle('Temperature vs Time in Heat Exchanger Configurations')
plt.rcParams.update({'font.size':25})

plt.style.use('ggplot')
plt.subplot(221)
plt.title('Co Current Shell and Tube')
plt.plot(Time/3600,CoCIN,label = 'Cold In',linewidth=1,color = 'black')
plt.plot(Time/3600,CoCOUT,label = 'Cold Out',linestyle = ':',linewidth=1,color = 'red')
plt.plot(Time/3600,CoHIN,label='Hot In',linestyle = '--',linewidth=1,color = 'green')
plt.plot(Time/3600,CoHOUT,label='Hot Out',linestyle = '-.',linewidth=1,color = 'blue')
plt.legend(loc='best')
plt.grid(True)
```

```

plt.subplot(222)
plt.title('Counter Current Shell and Tube')
plt.plot(Time/3600,ConCIN,label='Cold In',linewidth=1,color='black')
plt.plot(Time/3600,ConCOUT,label='Cold Out',linestyle=':',linewidth=1,color='red')
plt.plot(Time/3600,ConHIN,label='Hot In',linestyle='--',linewidth=1,color='green')
plt.plot(Time/3600,ConHOUT,label='Hot Out',linestyle='-.',linewidth=1,color='blue')
plt.legend(loc='best')
plt.grid(True)

plt.subplot(223)
plt.title('Counter Current Double Pipe')
plt.plot(Time/3600,SiCIN,label='Cold In',linewidth=1,color='black')
plt.plot(Time/3600,SiCOUT,label='Cold Out',linestyle=':',linewidth=1,color='red')
plt.plot(Time/3600,SiHIN,label='Hot In',linestyle='--',linewidth=1,color='green')
plt.plot(Time/3600,SiHOUT,label='Hot Out',linestyle='-.',linewidth=1,color='blue')
plt.legend(loc='best')
plt.grid(True)

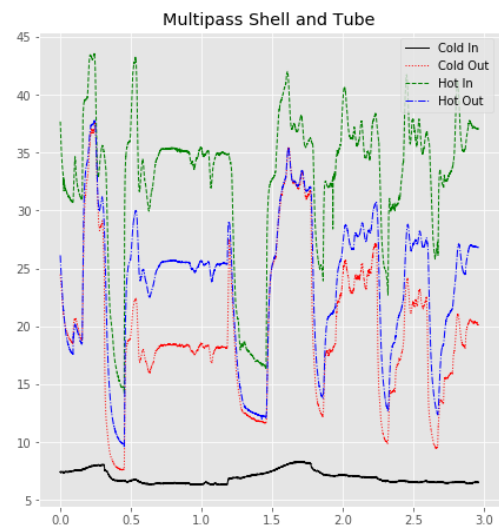
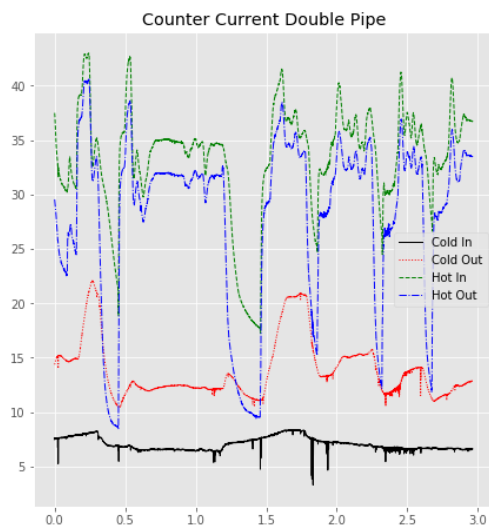
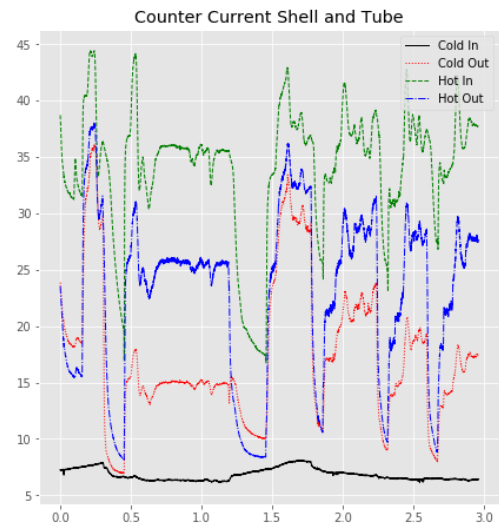
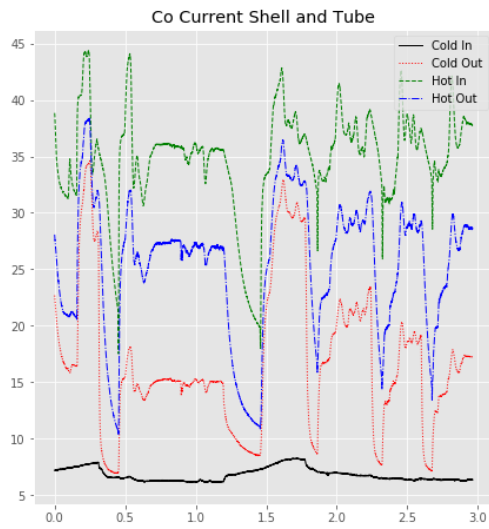
plt.subplot(224)
plt.title('Multipass Shell and Tube')
plt.plot(Time/3600,MPCIN,label='Cold In',linewidth=1,color='black')
plt.plot(Time/3600,MPCOUT,label='Cold Out',linestyle=':',linewidth=1,color='red')
plt.plot(Time/3600,MPHIN,label='Hot In',linestyle='--',linewidth=1,color='green')
plt.plot(Time/3600,MPHOUT,label='Hot Out',linestyle='-.',linewidth=1,color='blue')
plt.legend(loc='best')
plt.grid(True)

plt.subplots_adjust(top=0.92, bottom=0.08, left=0.10, right=0.95, hspace=0.25,
                    wspace=0.35)

plt.show()

```

Temperature vs Time in Heat Exchanger Configurations



NTU Calculations

```
In [111]: def UA_Calc(t1,t2,Vcold,Vhot):
           Time = df['Time'][t1:t2]
           CoCIN = df['CoCIN'][t1:t2]
           CoCOUT = df['CoCOUT'][t1:t2]
           CoHIN = df['CoHIN'][t1:t2]
           CoHOUT = df['CoHOUT'][t1:t2]
           ConCIN = df['ConCIN'][t1:t2]
           ConCOUT = df['ConCOUT'][t1:t2]
           ConHIN = df['ConHIN'][t1:t2]
           ConHOUT = df['ConHOUT'][t1:t2]
```

```

SiCIN=df['SiCIN'][t1:t2]
SiCOUT=df['SiCOUT'][t1:t2]
SiHIN=df['SiHIN'][t1:t2]
SiHOUT=df['SiHOUT'][t1:t2]
MPCIN=df['MPCIN'][t1:t2]
MPCOUT=df['MPCOUT'][t1:t2]
MPHIN=df['MPHIN'][t1:t2]
MPHOUT=df['MPHOUT'][t1:t2]

plt.figure(figsize = (15,15))
plt.suptitle('Temperature vs Time in Heat Exchanger Configurations')
plt.subplot(221)
plt.title('Co Current Shell and Tube')
plt.plot(Time,CoCIN,label = 'Cold In',linewidth=1,color = 'black')
plt.plot(Time,CoCOUT,label = 'Cold Out',linestyle = ':',linewidth=1,color = 'red')
plt.plot(Time,CoHIN,label='Hot In',linestyle = '--',linewidth=1,color = 'green')
plt.plot(Time,CoHOUT,label='Hot Out',linestyle = '-.',linewidth=1,color = 'blue')
plt.legend(loc='best')
plt.grid(True)

plt.subplot(222)
plt.title('Counter Current Shell and Tube')
plt.plot(Time,ConCIN,label = 'Cold In',linewidth=1,color = 'black')
plt.plot(Time,ConCOUT,label = 'Cold Out',linestyle = ':',linewidth=1,color = 'red')
plt.plot(Time,ConHIN,label='Hot In',linestyle = '--',linewidth=1,color = 'green')
plt.plot(Time,ConHOUT,label='Hot Out',linestyle = '-.',linewidth=1,color = 'blue')
plt.legend(loc='best')
plt.grid(True)

plt.subplot(223)
plt.title('Counter Current Double Pipe')
plt.plot(Time,SiCIN,label = 'Cold In',linewidth=1,color = 'black')
plt.plot(Time,SiCOUT,label = 'Cold Out',linestyle = ':',linewidth=1,color = 'red')
plt.plot(Time,SiHIN,label='Hot In',linestyle = '--',linewidth=1,color = 'green')
plt.plot(Time,SiHOUT,label='Hot Out',linestyle = '-.',linewidth=1,color = 'blue')
plt.legend(loc='best')
plt.grid(True)

plt.subplot(224)
plt.title('Multipass Shell and Tube')
plt.plot(Time,MPCIN,label = 'Cold In',linewidth=1,color = 'black')
plt.plot(Time,MPCOUT,label = 'Cold Out',linestyle = ':',linewidth=1,color = 'red')
plt.plot(Time,MPHIN,label='Hot In',linestyle = '--',linewidth=1,color = 'green')
plt.plot(Time,MPHOUT,label='Hot Out',linestyle = '-.',linewidth=1,color = 'blue')
plt.legend(loc='best')
plt.grid(True)

plt.subplots_adjust(top=0.92, bottom=0.08, left=0.10, right=0.95, hspace=0.25,

```



```

                                wspace=0.35)
plt.show()

#grams/second
mcold = Vcold*63.09
mhot = Vhot*63.09

#J/gK
cp = 4.19

if mcold == mhot:
    Cr = 1
    Cmin = mcold*cp
if mcold < mhot:
    Cr = mcold/mhot
    Cmin = mcold*cp
if mcold > mhot:
    Cr = mhot/mcold
    Cmin = mhot*cp

#CoCurrent
q = mcold*cp*(CoCOUT-CoCIN)
qmax = mcold*cp*(CoHIN-CoCIN)
eff = q/qmax
E = (2/eff-(1+Cr))/(1+Cr**(2))**(-1/2)
NTU = -(1+Cr**(2))**(-1/2)*np.log((E-1)/(E+1))
#W/K
UA = NTU*Cmin
UAA_Co = np.sum(UA)/len(UA)
SE = ss.sem(UA)
conf_Co = ss.norm.ppf(1-0.025)*SE
print('UA, for the cocurrent shell and tube is {} +- {}'.format(UAA_Co,conf_Co))

#CounterCurrent
q = mcold*cp*(ConCOUT-ConCIN)
qmax = mcold*cp*(ConHIN-ConCIN)
eff = q/qmax
E = (2/eff-(1+Cr))/(1+Cr**(2))**(-1/2)
NTU = -(1+Cr**(2))**(-1/2)*np.log((E-1)/(E+1))
UA = NTU*Cmin
UAA_Con = np.sum(UA)/len(UA)
SE = ss.sem(UA)
conf_Con = ss.norm.ppf(1-0.025)*SE
print('UA, for the countercurrent shell and tube is {} +- {}'.format(UAA_Con,conf_Con))

```

```

#Multipass
q = mcold*cp*(MPCOUT-MPCIN)
qmax = mcold*cp*(MPHIN-MPCIN)
eff = q/qmax
E = (2/eff-(1+Cr))/(1+Cr**(2))**(-1/2)
NTU = -(1+Cr**(2))**(-1/2)*np.log((E-1)/(E+1))
UA = NTU*Cmin
UAA_MP = np.sum(UA)/len(UA)
SE = ss.sem(UA)
conf_MP = ss.norm.ppf(1-0.025)*SE
print('UA, for the multipass shell and tube is {} +- {}'.format(UAA_MP, conf_MP))
UAA = np.array([UAA_Co,UAA_Con,UAA_MP])
conf = np.array([conf_Co,conf_Con,conf_MP])
return UAA, conf

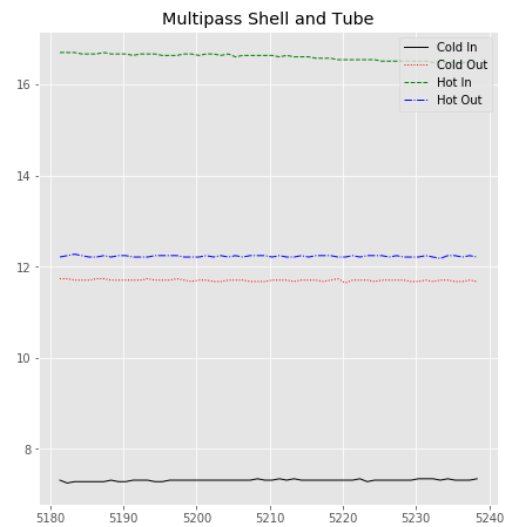
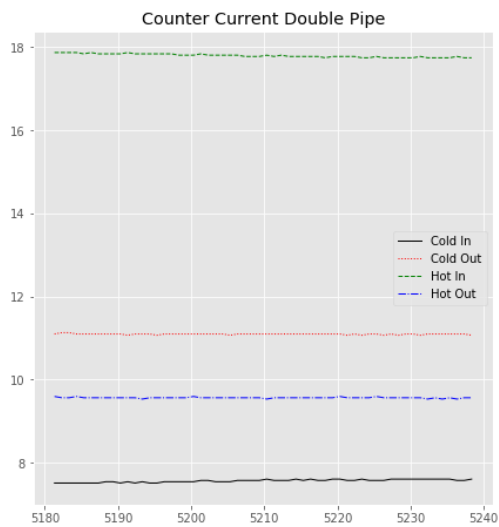
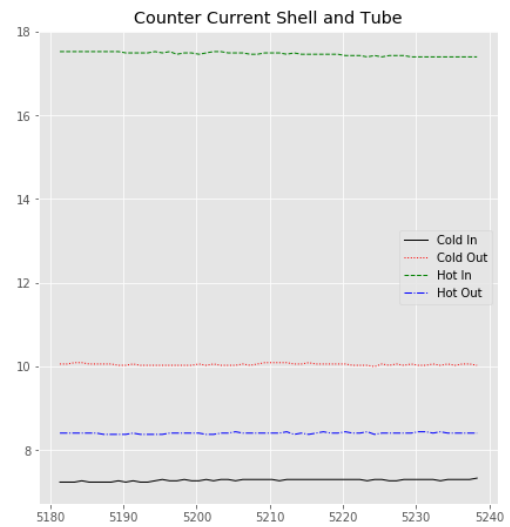
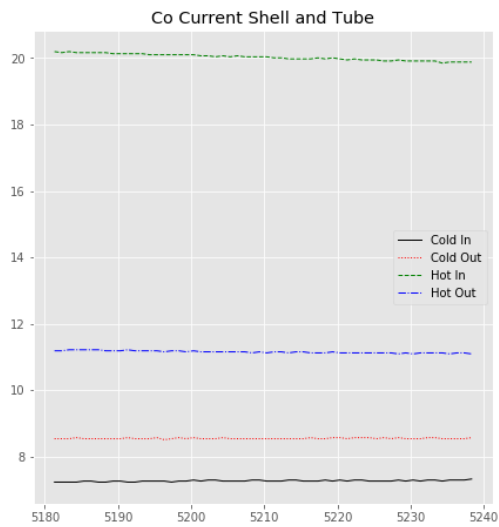
```

```

In [176]: #Test 1
          #0.2 GPM Cold , 0.2 GPM Hot
t1 = 5180
t2 = 5238
Vcold = 0.2
Vhot = 0.2
UA_1, conf_1 = UA_Calc(t1,t2,Vcold,Vhot)

```

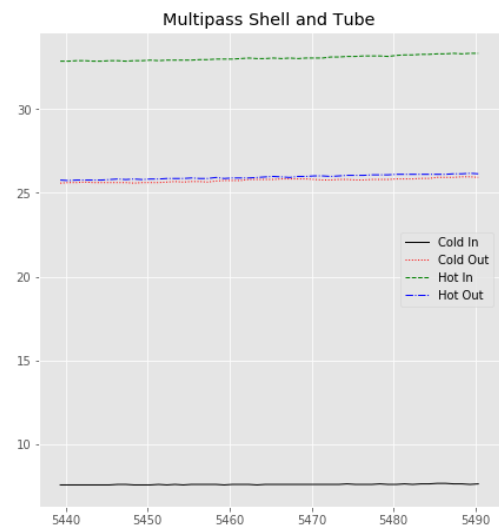
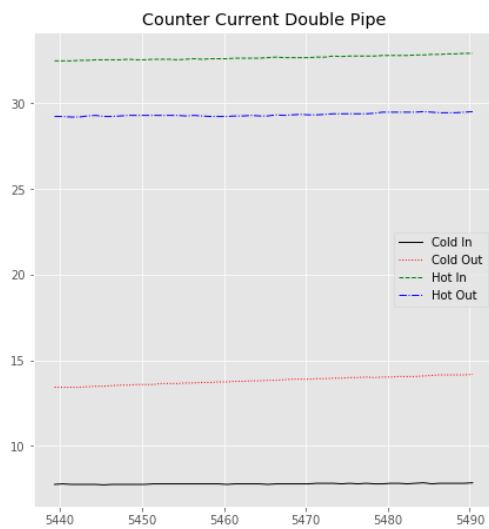
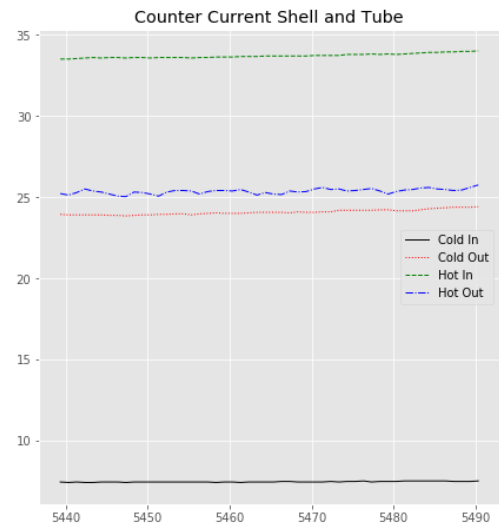
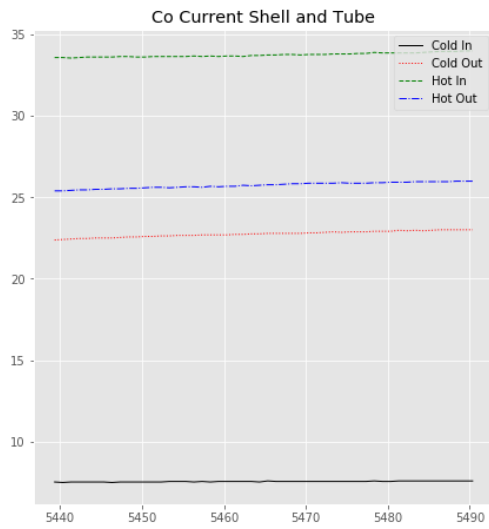
Temperature vs Time in Heat Exchanger Configurations



UA, for the cocurrent shell and tube is 2.946020665008893 +- 0.013545848300327621.
 UA, for the countercurrent shell and tube is 9.917759041549534 +- 0.03291178036872462.
 UA, for the multipass shell and tube is 24.5135190108312 +- 0.09120867732027504.

```
In [177]: #Test 2
          #0.2 GPM Cold , 0.4 GPM Hot
          t1 = 5438
          t2 = 5490
          Vcold = 0.2
          Vhot = 0.4
          UA_2, conf_2 = UA_Calc(t1,t2,Vcold,Vhot)
```

Temperature vs Time in Heat Exchanger Configurations



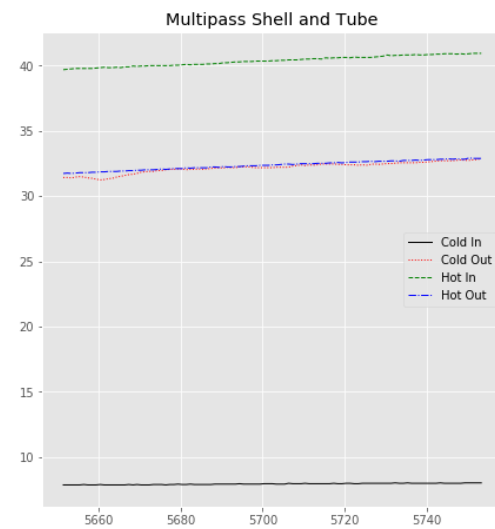
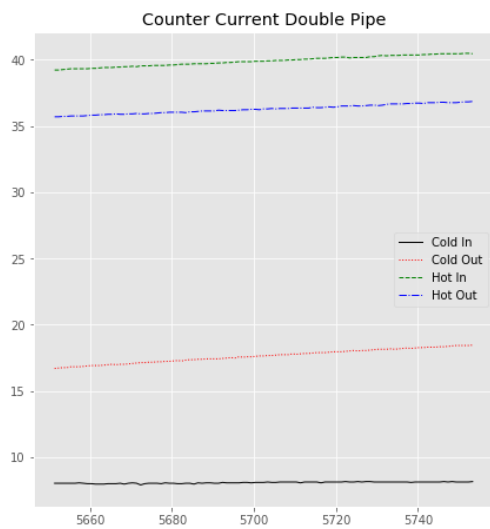
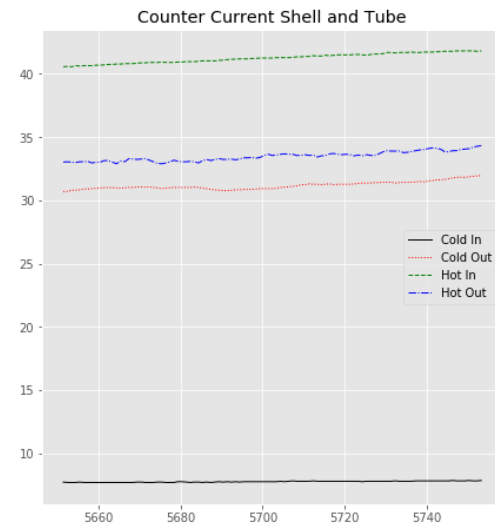
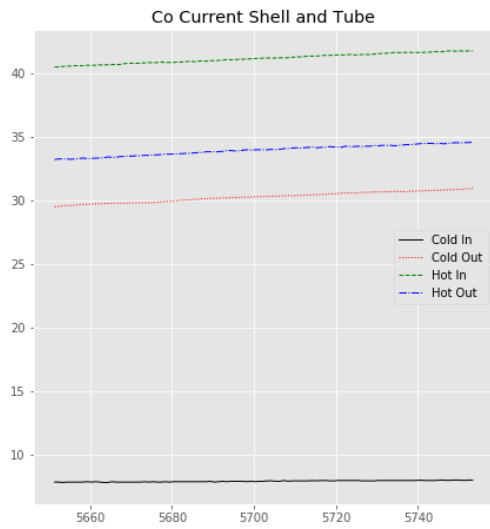
UA, for the cocurrent shell and tube is 46.97432462894309 +- 0.1825488261293224.

UA, for the countercurrent shell and tube is 56.96922584868917 +- 0.15715171694713745.

UA, for the multipass shell and tube is 79.45978011527805 +- 0.17234733638701763.

```
In [178]: #Test 3
          #0.2 GPM Cold , 0.6 GPM Hot
          t1 = 5650
          t2 = 5753
          Vcold = 0.2
          Vhot = 0.6
          UA_3, conf_3 = UA_Calc(t1,t2,Vcold,Vhot)
```

Temperature vs Time in Heat Exchanger Configurations



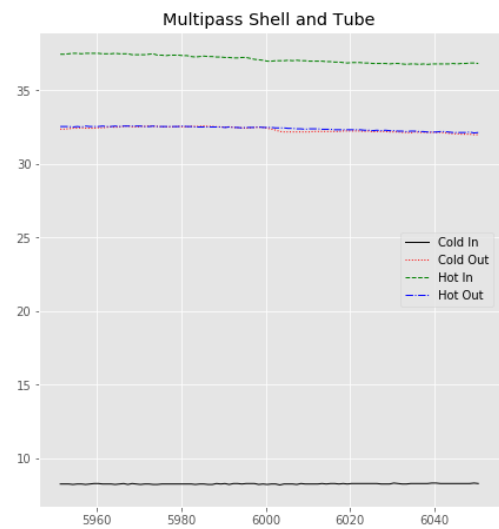
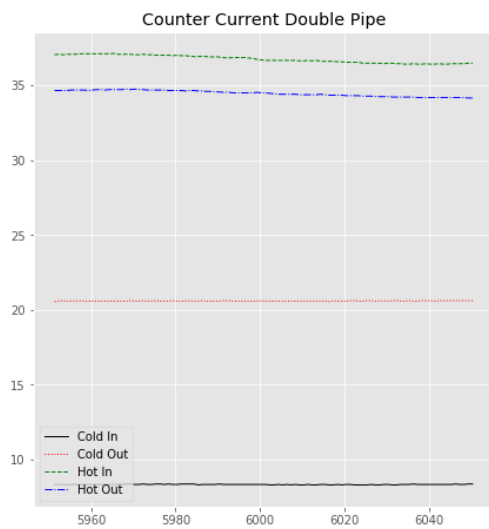
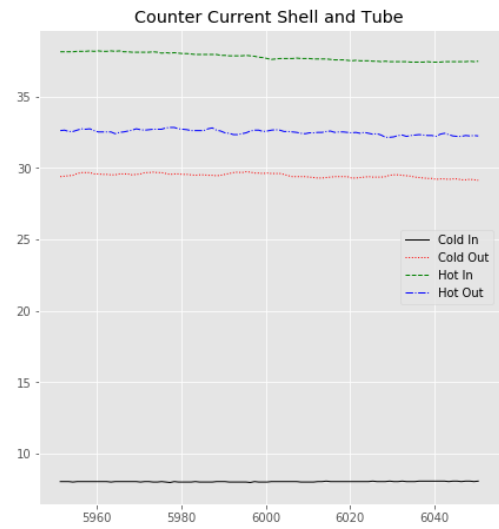
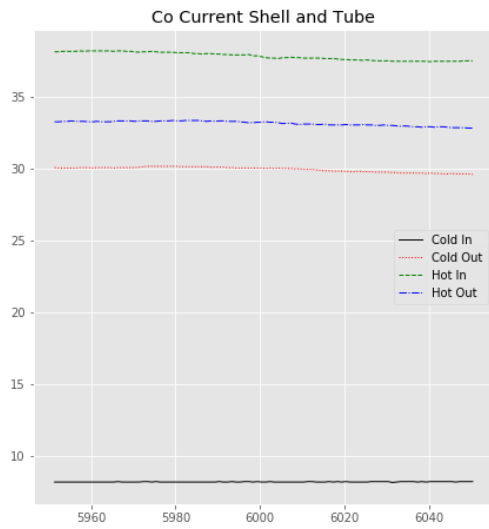
UA, for the cocurrent shell and tube is 66.13799709559925 +- 0.18339099004967896.

UA, for the countercurrent shell and tube is 72.94290554247172 +- 0.25287944098450077.

UA, for the multipass shell and tube is 88.4170376383238 +- 0.3675149961078776.

```
In [179]: #Test 4
          #0.2 GPM Cold , 0.8 GPM Hot
          t1 = 5950
          t2 = 6050
          Vcold = 0.2
          Vhot = 0.8
          UA_4, conf_4 = UA_Calc(t1,t2,Vcold,Vhot)
```

Temperature vs Time in Heat Exchanger Configurations



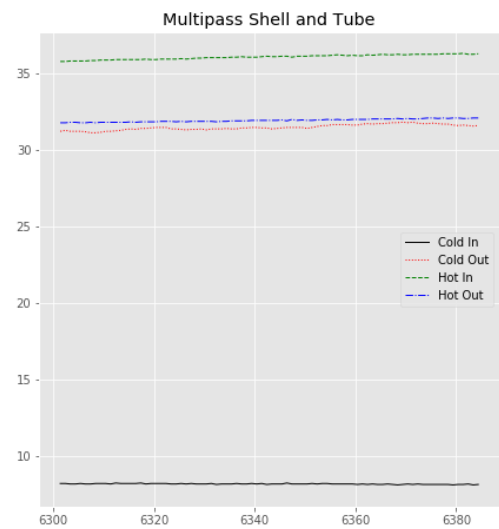
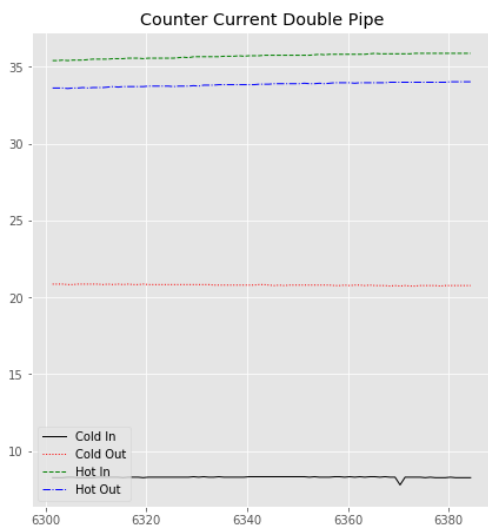
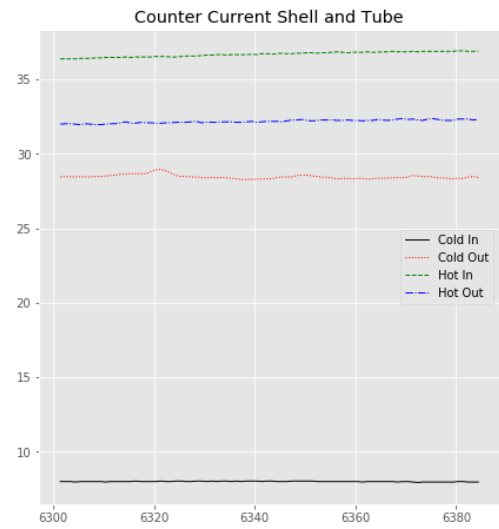
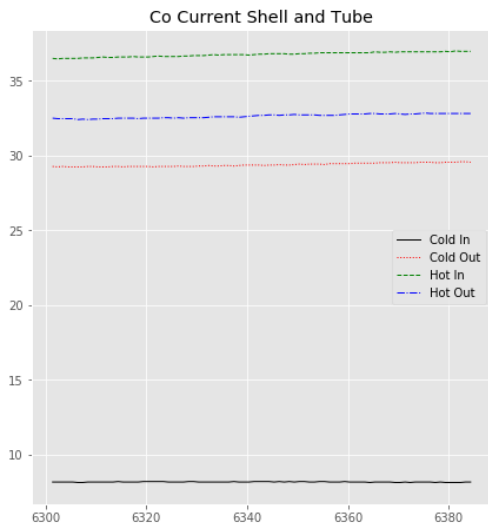
UA, for the cocurrent shell and tube is 80.94841367253231 +- 0.1738574943427902.

UA, for the countercurrent shell and tube is 77.13699112733848 +- 0.26218079826855983.

UA, for the multipass shell and tube is 127.18991926652126 +- 0.5722134696058737.

```
In [180]: #Test 5
          #0.2 GPM Cold , 1.0 GPM Hot
          t1 = 6300
          t2 = 6384
          Vcold = 0.2
          Vhot = 1.0
          UA_5, conf_5 = UA_Calc(t1,t2,Vcold,Vhot)
```

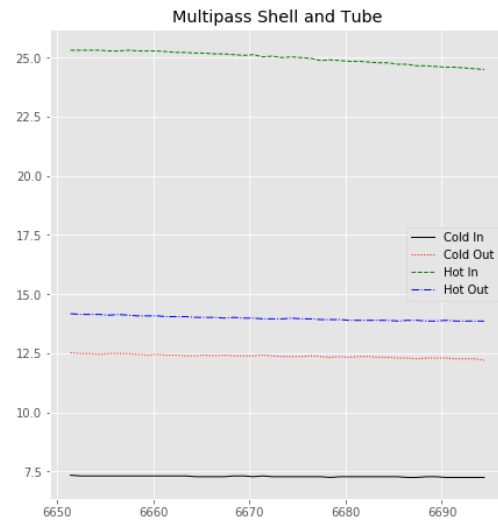
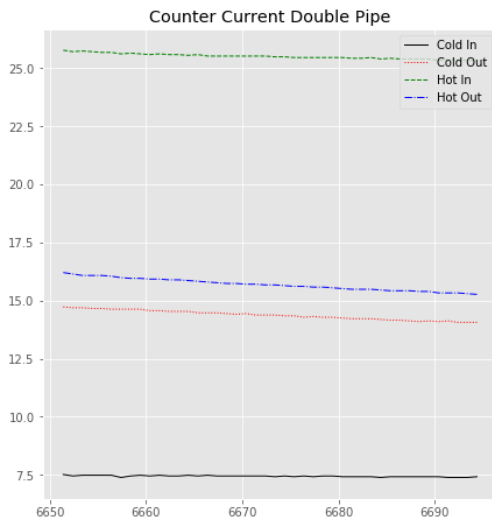
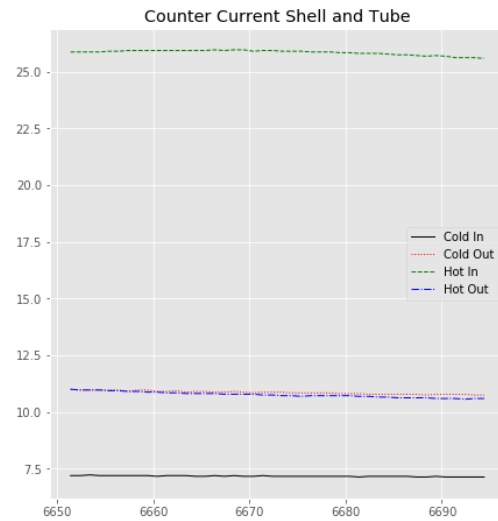
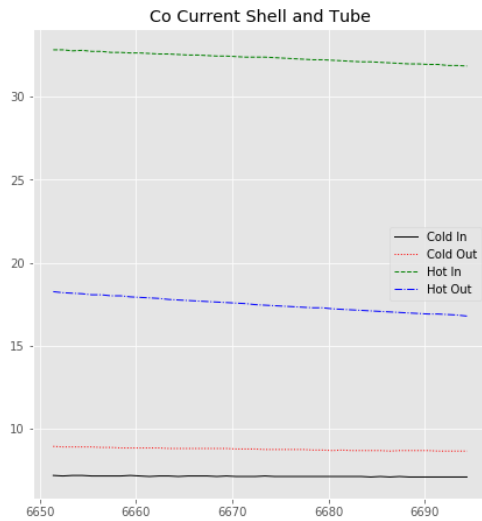
Temperature vs Time in Heat Exchanger Configurations



UA, for the cocurrent shell and tube is 81.40980663796772 +- 0.08513068068261878.
 UA, for the countercurrent shell and tube is 73.78407983206537 +- 0.41636489467560706.
 UA, for the multipass shell and tube is 120.41428187404469 +- 0.44967667764475794.

```
In [181]: #Test 6
          #0.4 GPM Cold , 0.2 GPM Hot
          t1 = 6650
          t2 = 6694
          Vcold = 0.4
          Vhot = 0.2
          UA_6, conf_6 = UA_Calc(t1,t2,Vcold,Vhot)
```

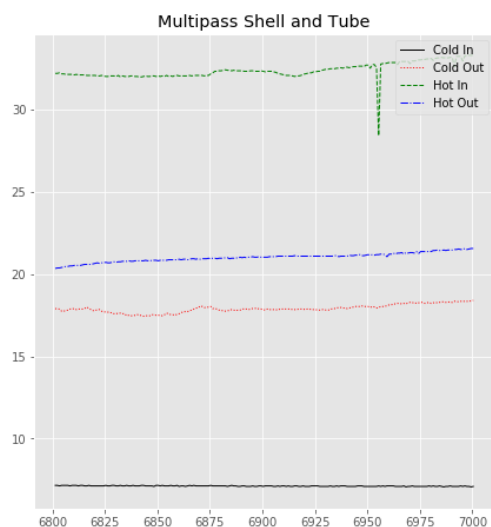
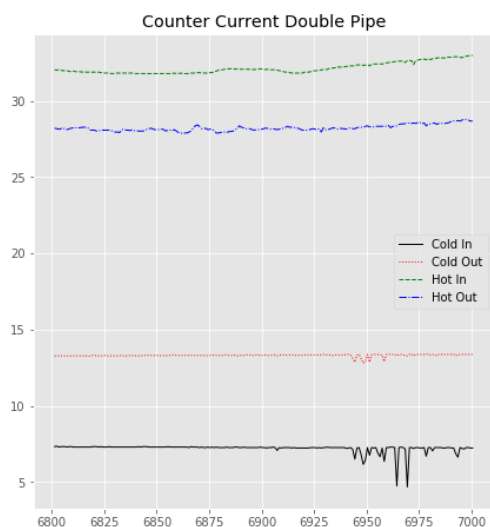
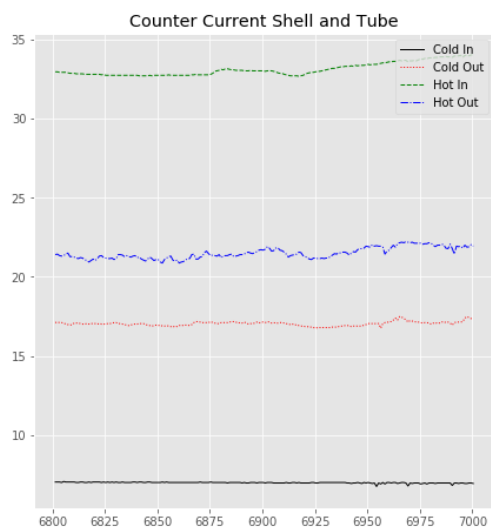
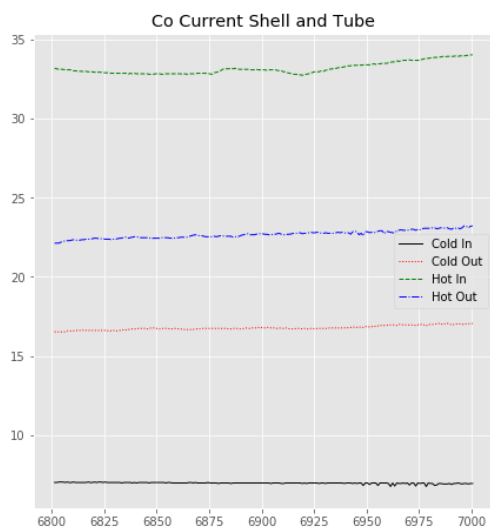
Temperature vs Time in Heat Exchanger Configurations



UA, for the cocurrent shell and tube is 2.8868299779296756 +- 0.02469985478177924.
 UA, for the countercurrent shell and tube is 9.837097950455771 +- 0.04318378795377017.
 UA, for the multipass shell and tube is 15.644073890793141 +- 0.03429466772886177.

```
In [182]: #Test 7
          #0.4 GPM Cold , 0.4 GPM Hot
          t1 = 6800
          t2 = 7000
          Vcold = 0.4
          Vhot = 0.4
          UA_7, conf_7 = UA_Calc(t1,t2,Vcold,Vhot)
```

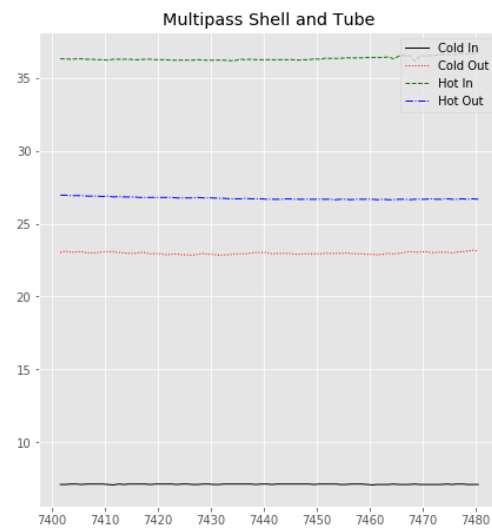
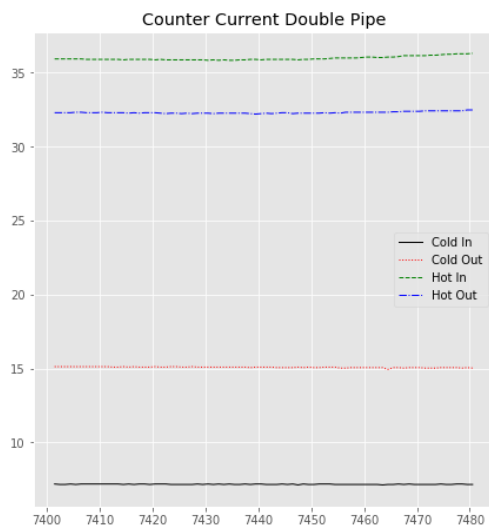
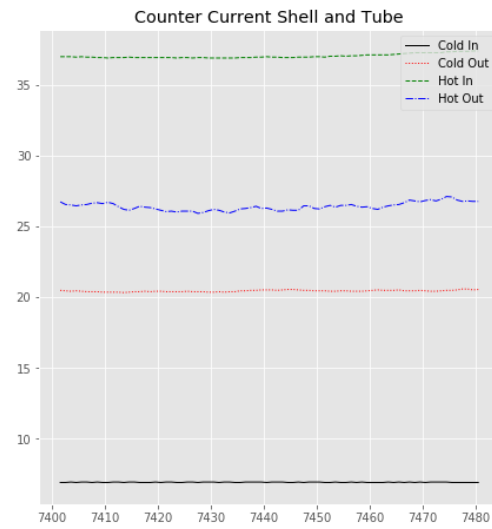
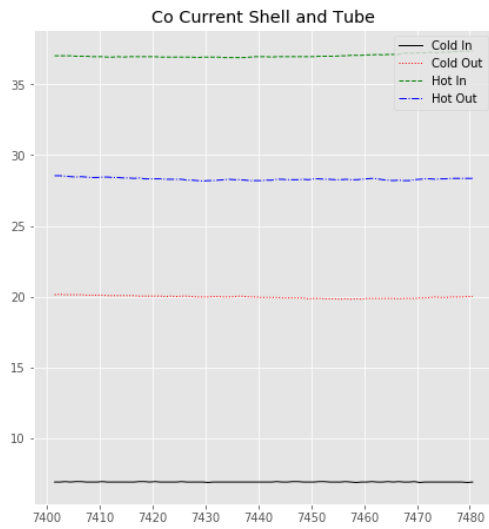

Temperature vs Time in Heat Exchanger Configurations



UA, for the cocurrent shell and tube is 32.10176420437789 +- 0.06047856325430589.
 UA, for the countercurrent shell and tube is 33.607813781106735 +- 0.11178589747298125.
 UA, for the multipass shell and tube is 40.340389073759404 +- 0.2092189642158121.

```
In [183]: #Test 8
          #0.4 GPM Cold , 0.6 GPM Hot
          t1 = 7400
          t2 = 7480
          Vcold = 0.4
          Vhot = 0.6
          UA_8, conf_8 = UA_Calc(t1,t2,Vcold,Vhot)
```

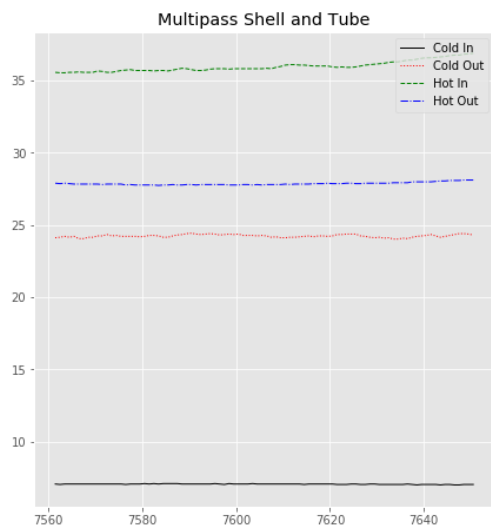
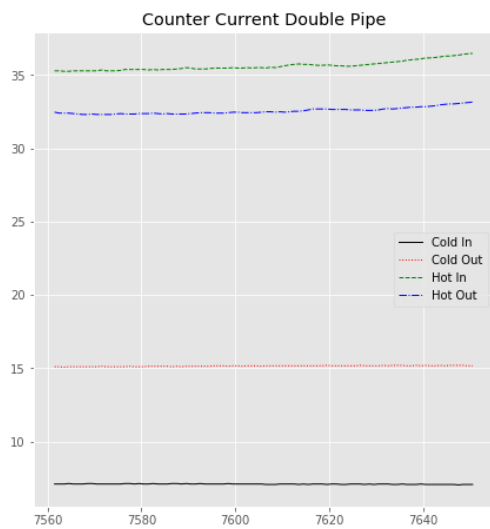
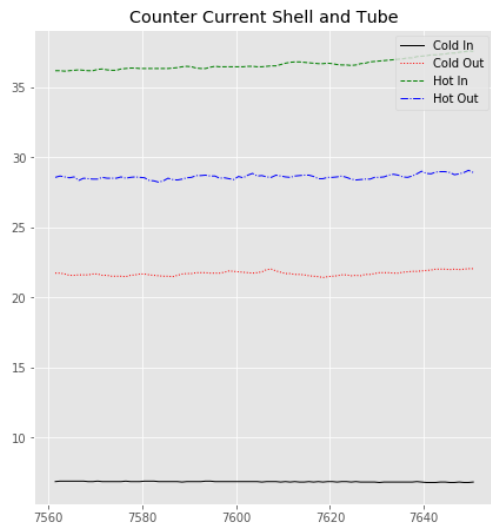
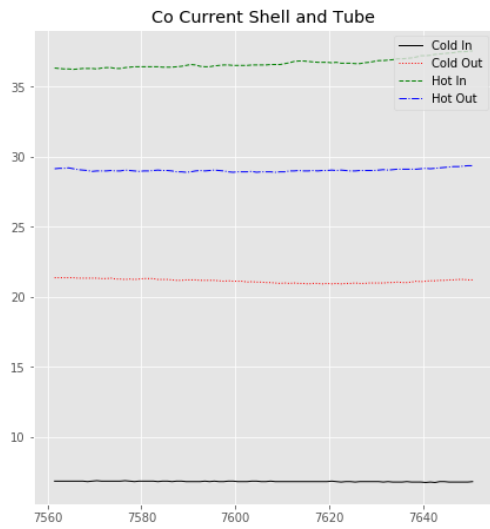
Temperature vs Time in Heat Exchanger Configurations



UA, for the cocurrent shell and tube is 51.154609598155695 +- 0.16681837001266164.
 UA, for the countercurrent shell and tube is 54.142457028524106 +- 0.09118547688672352.
 UA, for the multipass shell and tube is 77.09669170734115 +- 0.1551533498199552.

```
In [184]: #Test 9
          #0.4 GPM Cold , 0.8 GPM Hot
          t1 = 7560
          t2 = 7650
          Vcold = 0.4
          Vhot = 0.8
          UA_9, conf_9 = UA_Calc(t1,t2,Vcold,Vhot)
```

Temperature vs Time in Heat Exchanger Configurations



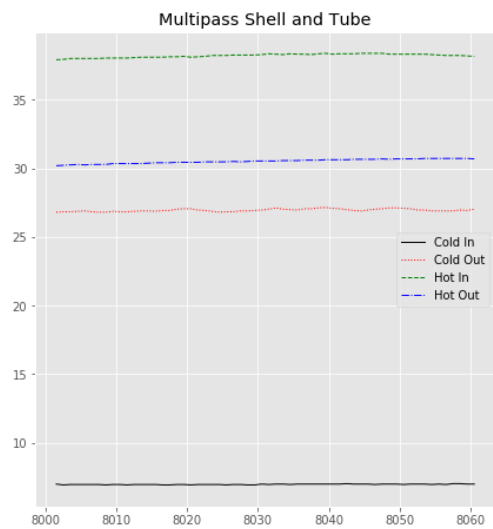
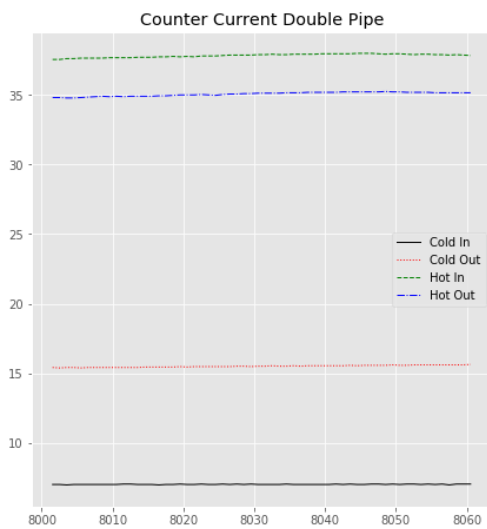
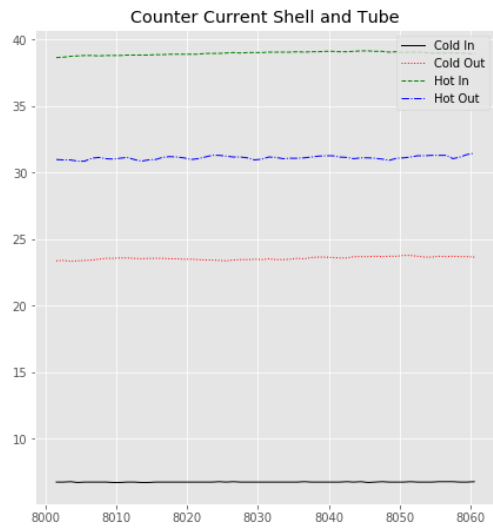
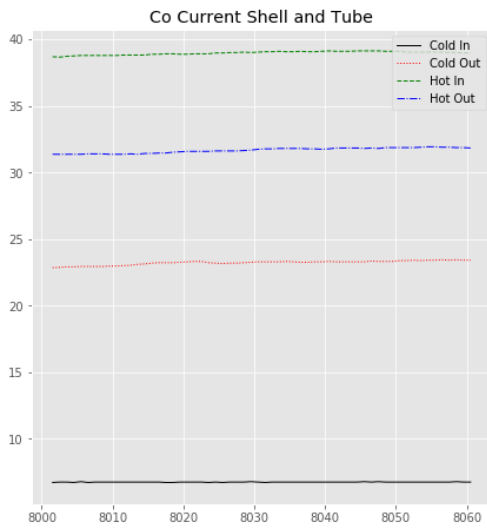
UA, for the cocurrent shell and tube is 65.92244760373623 +- 0.38896208013826994.

UA, for the countercurrent shell and tube is 70.57433260978317 +- 0.24776356763465826.

UA, for the multipass shell and tube is 98.8141305395154 +- 0.5686050332519913.

```
In [185]: #Test 10
          #0.4 GPM Cold , 1.0 GPM Hot
          t1 = 8000
          t2 = 8060
          Vcold = 0.4
          Vhot = 1.0
          UA_10, conf_10 = UA_Calc(t1,t2,Vcold,Vhot)
```

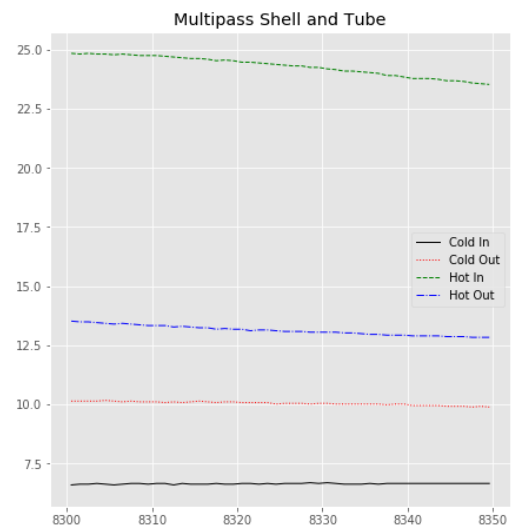
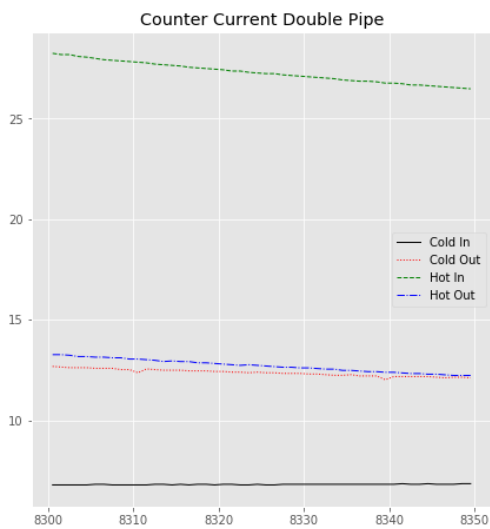
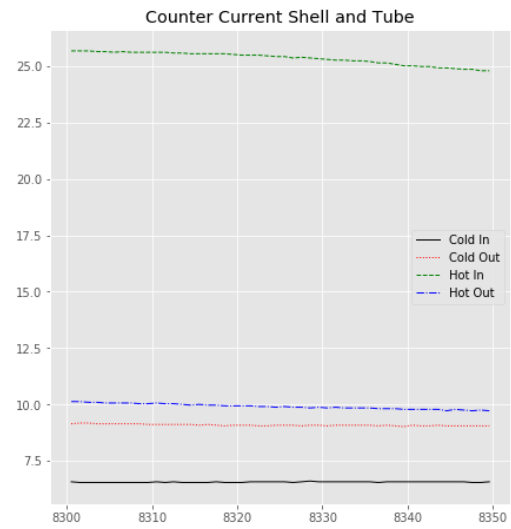
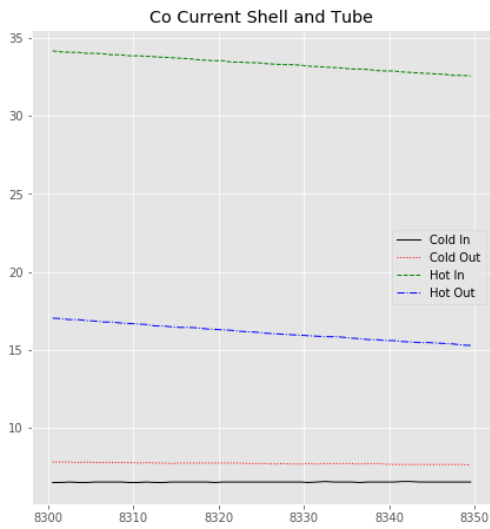
Temperature vs Time in Heat Exchanger Configurations



UA, for the cocurrent shell and tube is 76.20443916333303 +- 0.22538658352958563.
 UA, for the countercurrent shell and tube is 78.95634609820554 +- 0.20107891603887304.
 UA, for the multipass shell and tube is 117.95627131460765 +- 0.2576901014962902.

```
In [186]: #Test 11
          #0.6 GPM Cold , 0.2 GPM Hot
          t1 = 8299
          t2 = 8349
          Vcold = 0.6
          Vhot = 0.2
          UA_11, conf_11 = UA_Calc(t1,t2,Vcold,Vhot)
```

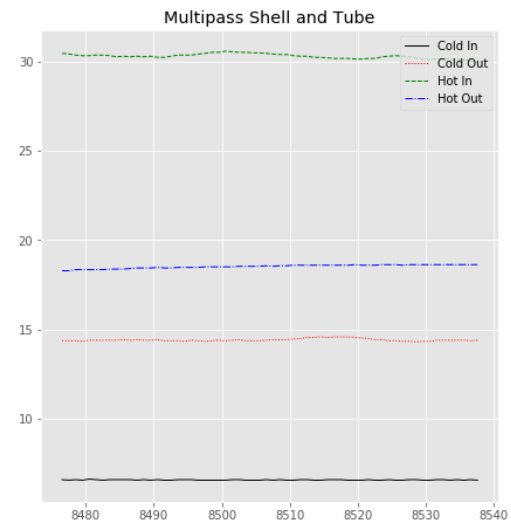
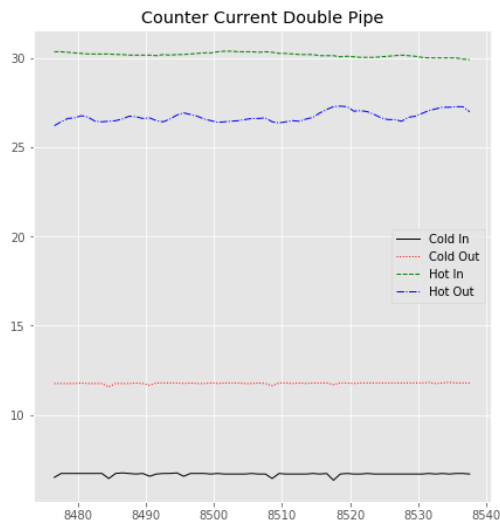
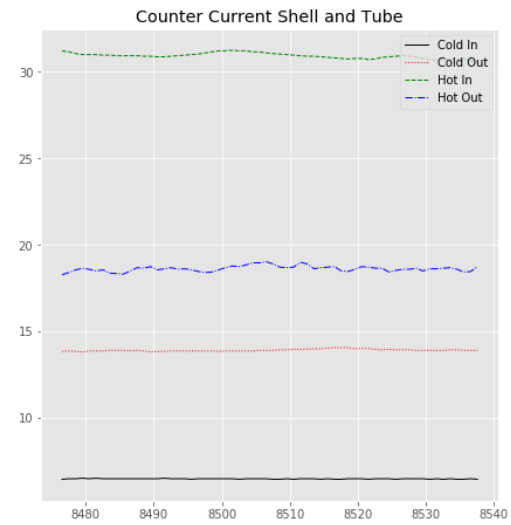
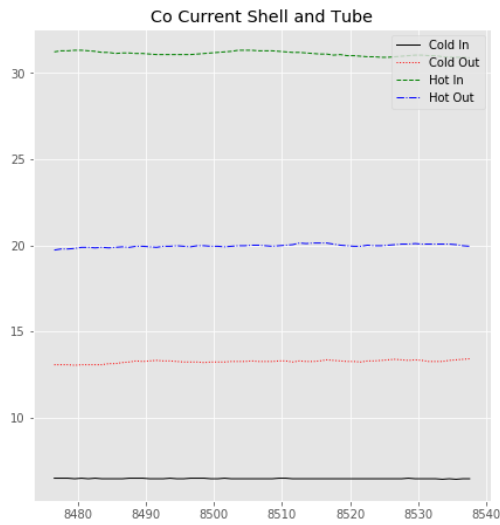
Temperature vs Time in Heat Exchanger Configurations



UA, for the cocurrent shell and tube is 2.181363637899717 +- 0.02076936410396069.
 UA, for the countercurrent shell and tube is 7.04575455061405 +- 0.026909256973940903.
 UA, for the multipass shell and tube is 10.551424100795964 +- 0.026298055361953634.

```
In [187]: #Test 12
          #0.6 GPM Cold , 0.4 GPM Hot
          t1 = 8475
          t2 = 8537
          Vcold = 0.6
          Vhot = 0.4
          UA_12, conf_12 = UA_Calc(t1,t2,Vcold,Vhot)
```

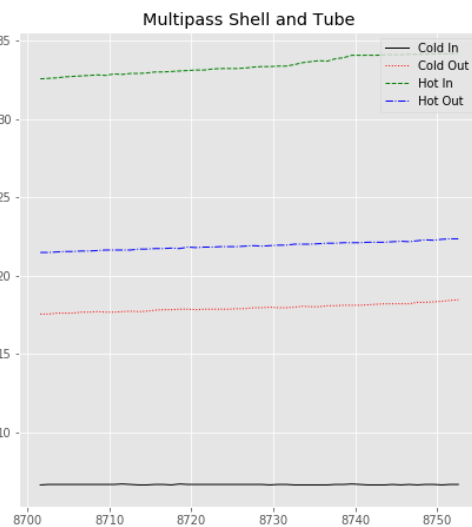
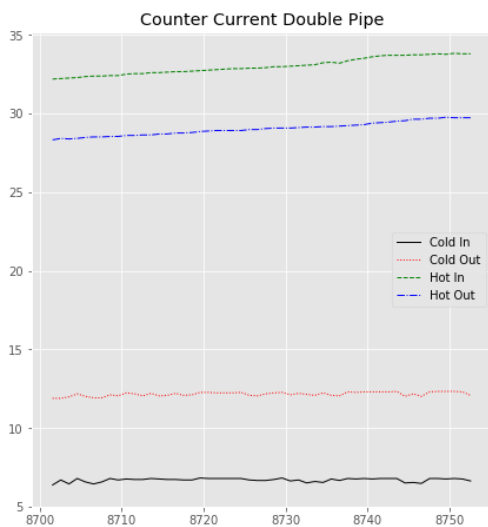
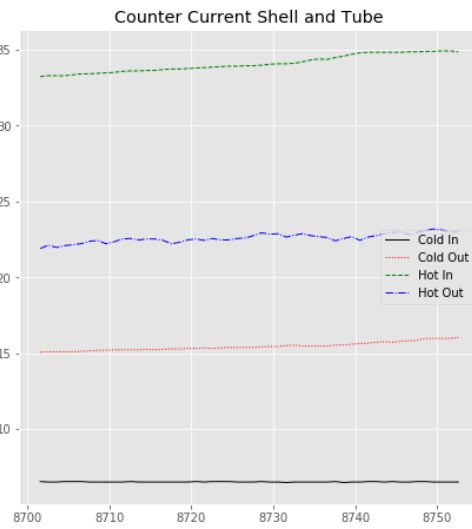
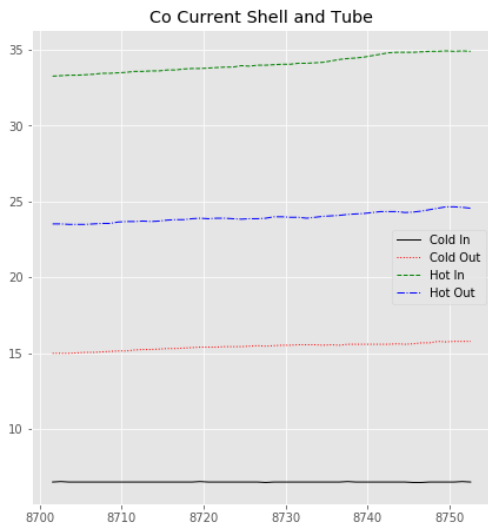
Temperature vs Time in Heat Exchanger Configurations



UA, for the cocurrent shell and tube is 26.364053712760228 +- 0.1516227009449264.
 UA, for the countercurrent shell and tube is 30.110653731128227 +- 0.13539531833590338.
 UA, for the multipass shell and tube is 33.79725319381394 +- 0.14600940543841961.

```
In [188]: #Test 13
          #0.6 GPM Cold , 0.6 GPM Hot
          t1 = 8700
          t2 = 8752
          Vcold = 0.6
          Vhot = 0.6
          UA_13, conf_13 = UA_Calc(t1,t2,Vcold,Vhot)
```

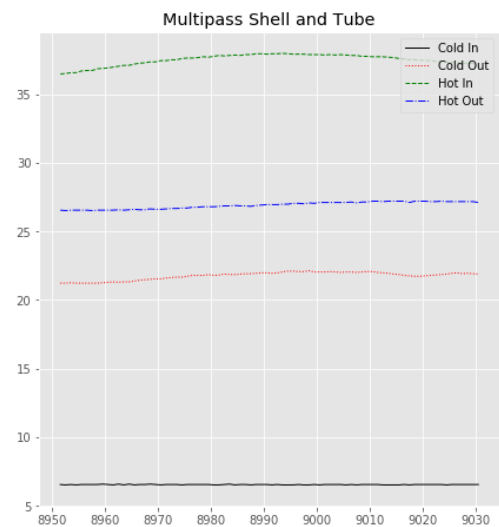
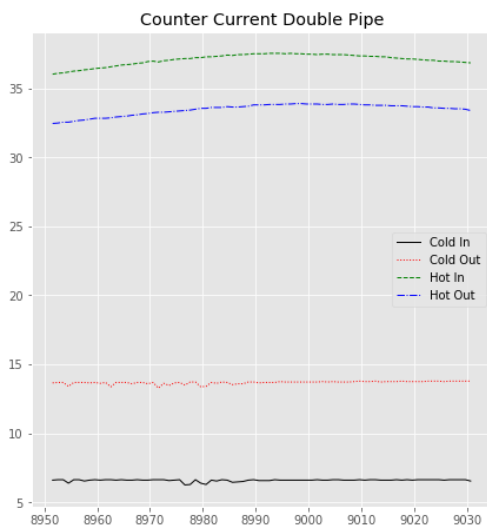
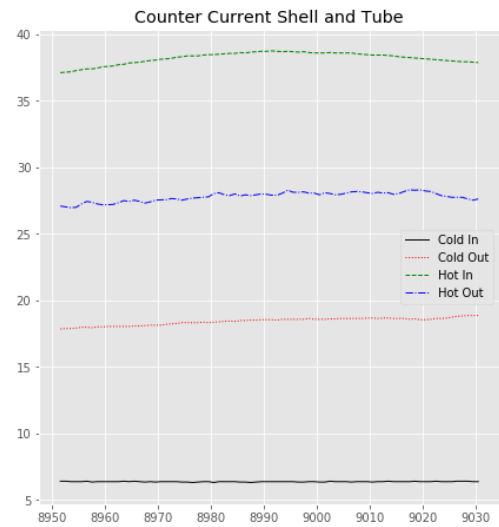
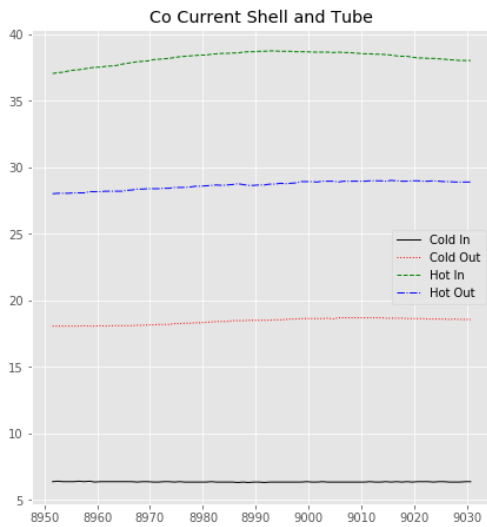
Temperature vs Time in Heat Exchanger Configurations



UA, for the cocurrent shell and tube is 38.302197050282636 +- 0.15860093508813328.
 UA, for the countercurrent shell and tube is 38.35492851837792 +- 0.19159554931785494.
 UA, for the multipass shell and tube is 59.219258945928964 +- 0.1441902515196569.

```
In [189]: #Test 14
          #0.6 GPM Cold , 0.8 GPM Hot
          t1 = 8950
          t2 = 9030
          Vcold = 0.6
          Vhot = 0.8
          UA_14, conf_14 = UA_Calc(t1,t2,Vcold,Vhot)
```

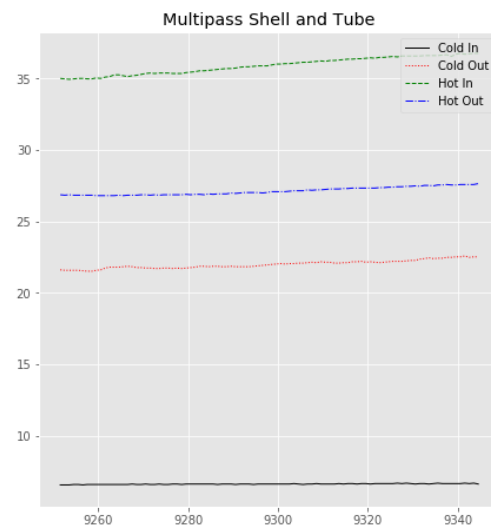
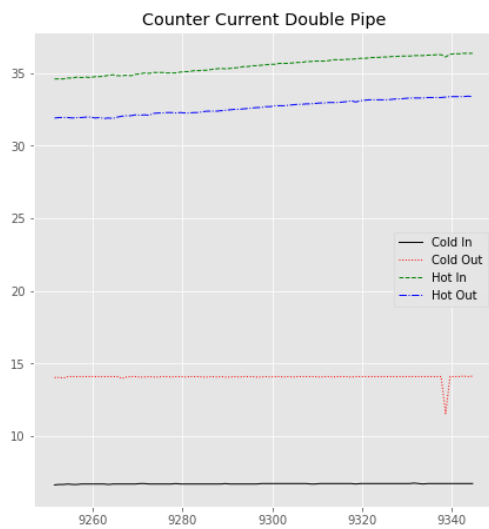
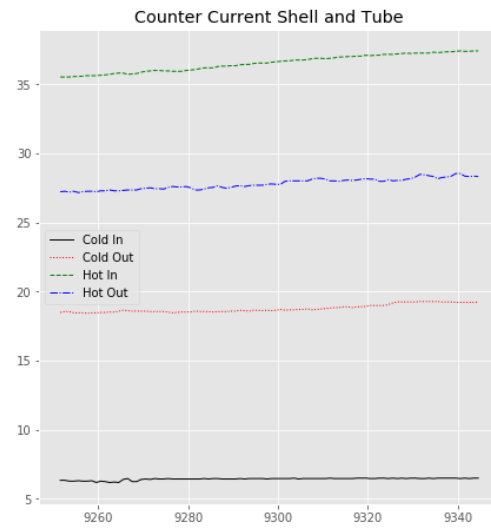
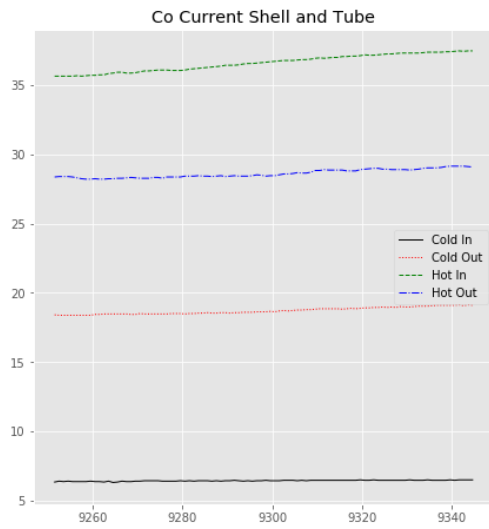
Temperature vs Time in Heat Exchanger Configurations



UA, for the cocurrent shell and tube is 58.47141980995129 +- 0.24097330335469963.
 UA, for the countercurrent shell and tube is 58.477580402628725 +- 0.33653747430127595.
 UA, for the multipass shell and tube is 91.36106234043962 +- 0.37641017824935996.

```
In [190]: #Test 15
          #0.6 GPM Cold , 1.0 GPM Hot
          t1 = 9250
          t2 = 9344
          Vcold = 0.6
          Vhot = 1.0
          UA_15, conf_15 = UA_Calc(t1,t2,Vcold,Vhot)
```


Temperature vs Time in Heat Exchanger Configurations

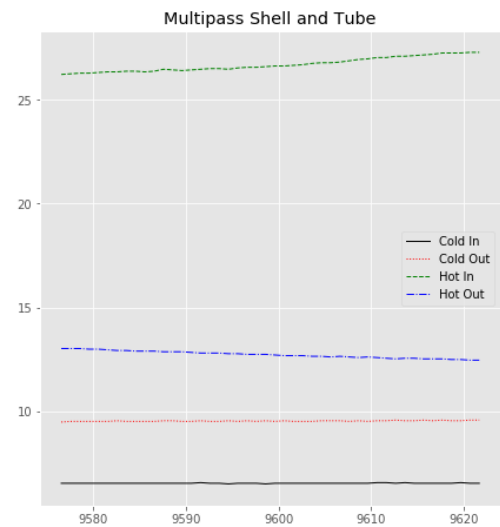
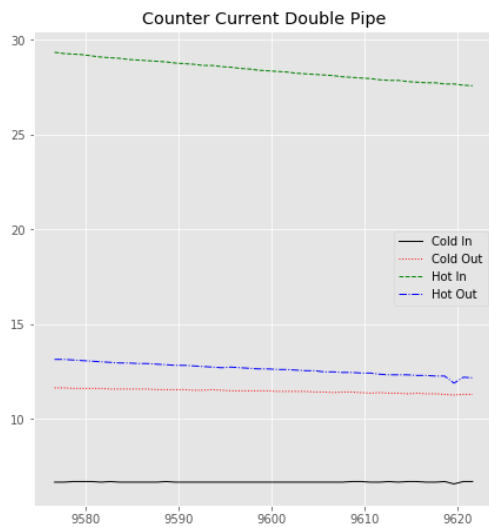
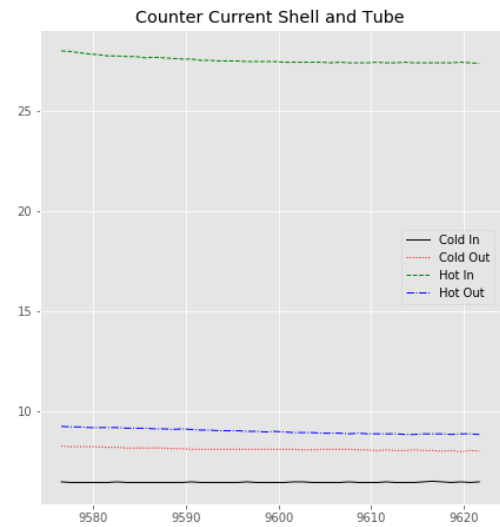
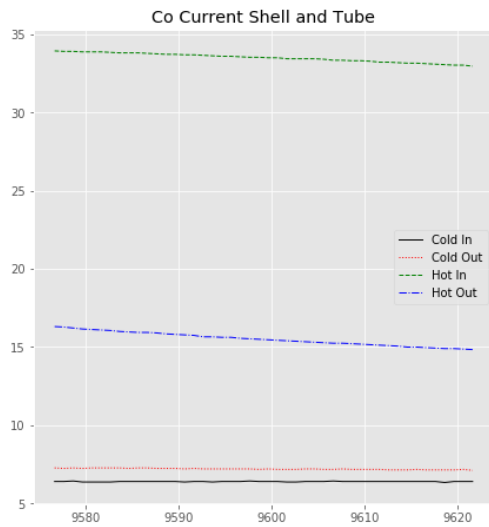


UA, for the cocurrent shell and tube is 71.95969881245608 +- 0.12411600211276078.
 UA, for the countercurrent shell and tube is 72.86522326304426 +- 0.27037429510941974.
 UA, for the multipass shell and tube is 111.45404326529065 +- 0.27743558573991817.

```
In [191]: #Test 16
          #0.8 GPM Cold , 0.2 GPM Hot
          t1 = 9575
          t2 = 9621
          Vcold = 0.8
          Vhot = 0.2
          UA_16, conf_16 = UA_Calc(t1,t2,Vcold,Vhot)
```

#Test did not go fully to steady state rip.

Temperature vs Time in Heat Exchanger Configurations

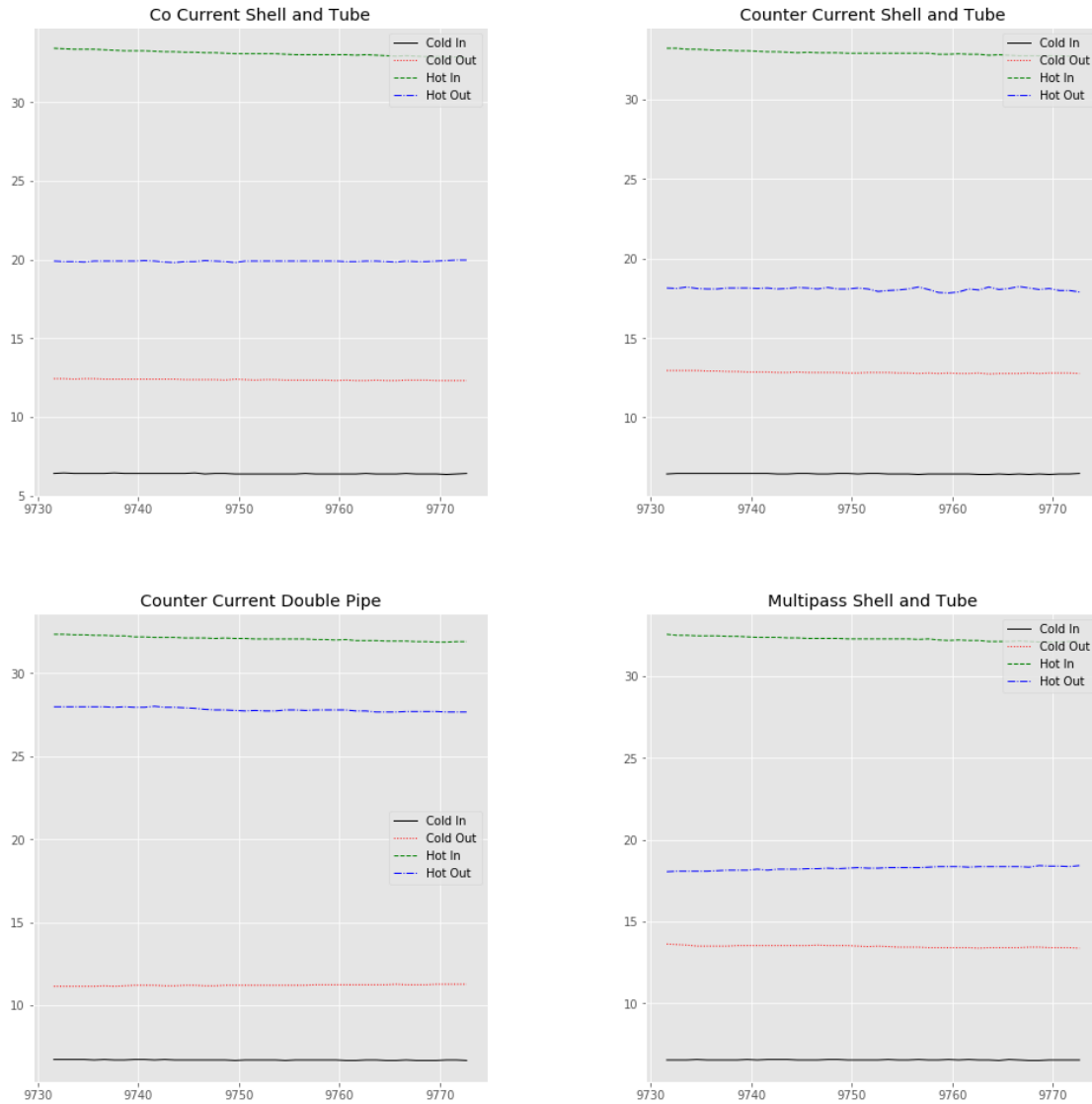


UA, for the cocurrent shell and tube is $1.505791628590328 \pm 0.022117015993480427$.
UA, for the countercurrent shell and tube is $4.109318629515145 \pm 0.04493795537534715$.
UA, for the multipass shell and tube is $8.17064433919698 \pm 0.036694059930151623$.

In [192]: *#Test 17*
#0.8 GPM Cold , 0.4 GPM Hot
t1 = 9730
t2 = 9772

$V_{cold} = 0.8$
 $V_{hot} = 0.4$
 $UA_{17}, conf_{17} = UA_Calc(t1, t2, V_{cold}, V_{hot})$

Temperature vs Time in Heat Exchanger Configurations



UA, for the cocurrent shell and tube is 22.806048446696995 +- 0.03175789197449102.
 UA, for the countercurrent shell and tube is 24.982456891583304 +- 0.04100590792019008.
 UA, for the multipass shell and tube is 28.744412478894816 +- 0.06681640217787192.

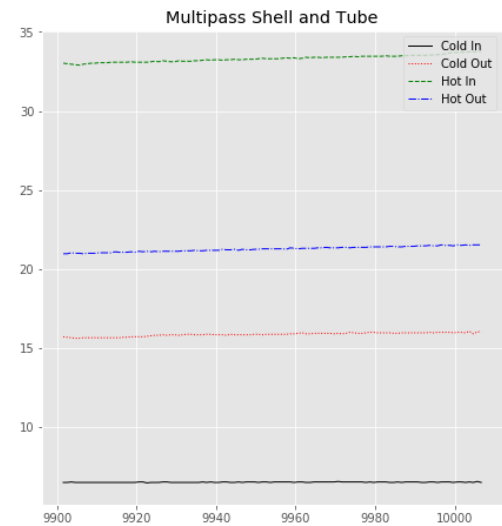
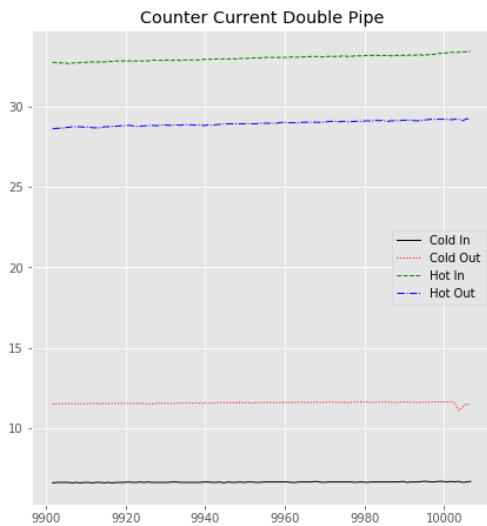
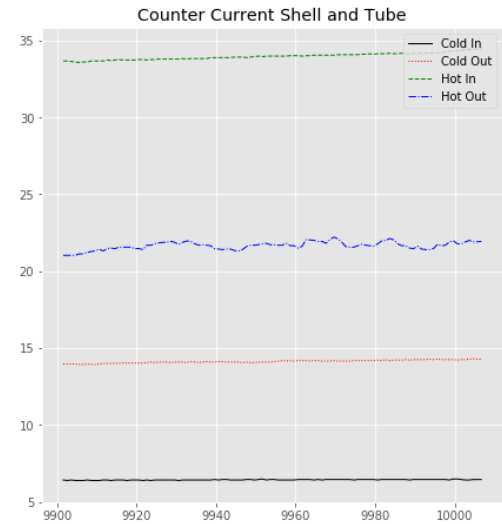
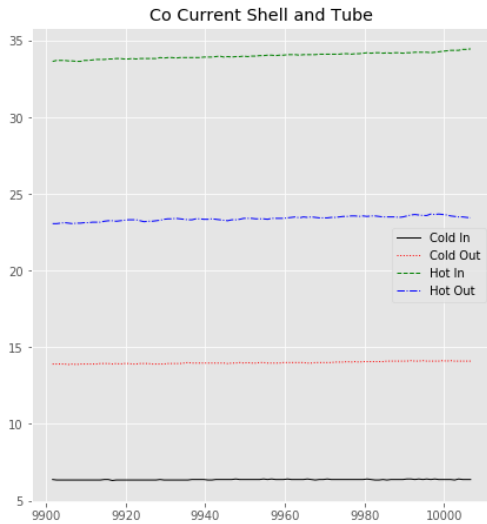
In [193]: #Test 18
 #0.8 GPM Cold , 0.6 GPM Hot
 t1 = 9900

```

t2 = 10006
Vcold = 0.8
Vhot = 0.6
UA_18, conf_18 = UA_Calc(t1,t2,Vcold,Vhot)

```

Temperature vs Time in Heat Exchanger Configurations



UA, for the cocurrent shell and tube is 37.19515174556759 +- 0.0342633484324561.
 UA, for the countercurrent shell and tube is 37.83014948833111 +- 0.04798579903481004.
 UA, for the multipass shell and tube is 51.65807942055473 +- 0.08331529907092183.

```

In [194]: #Test 19
          #0.8 GPM Cold , 0.8 GPM Hot

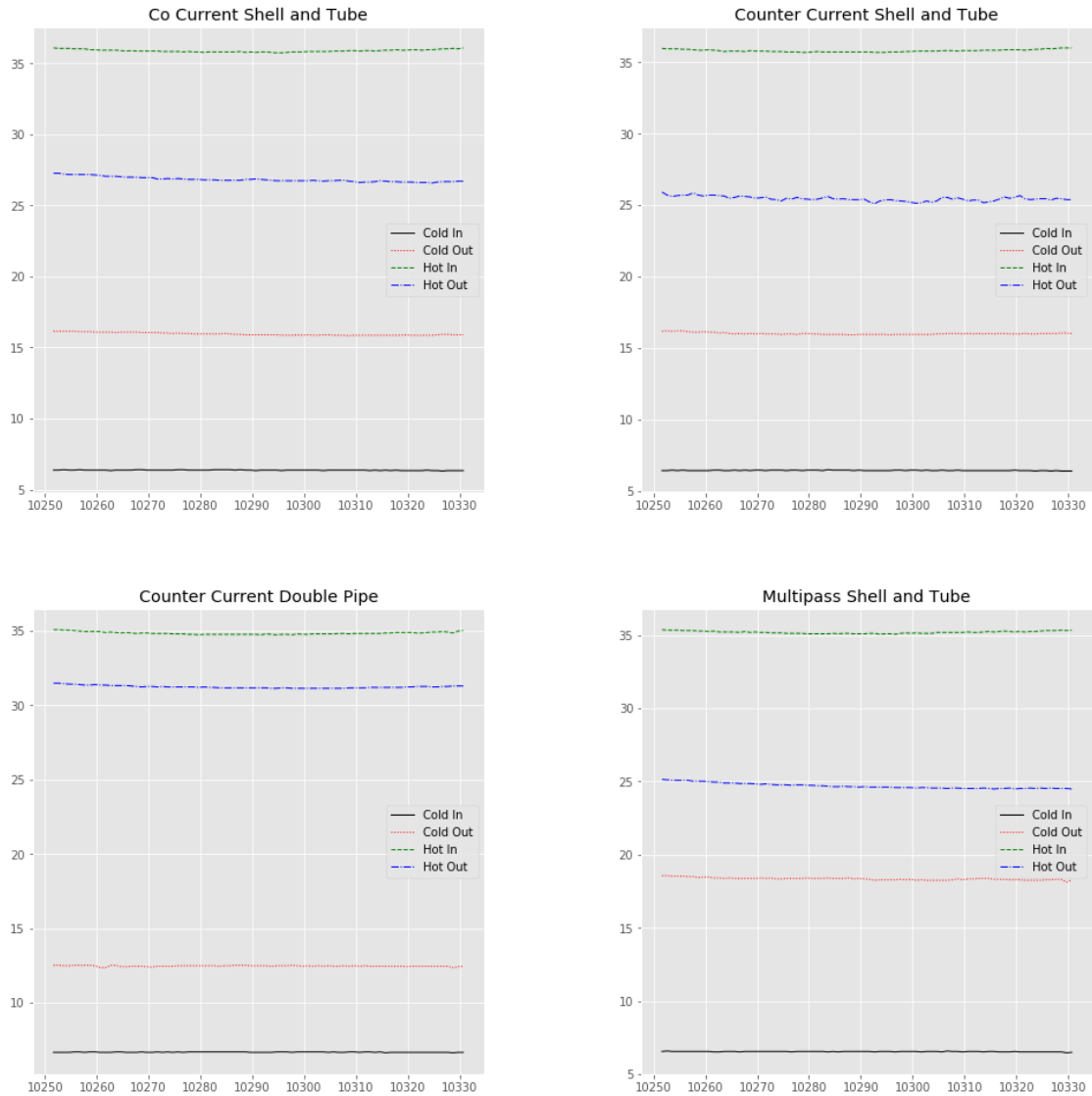
```

```

t1 = 10250
t2 = 10330
Vcold = 0.8
Vhot = 0.8
UA_19, conf_19 = UA_Calc(t1,t2,Vcold,Vhot)

```

Temperature vs Time in Heat Exchanger Configurations



UA, for the cocurrent shell and tube is 51.340535106889114 +- 0.14975680409608655.
 UA, for the countercurrent shell and tube is 51.63576863036476 +- 0.09843609011856497.
 UA, for the multipass shell and tube is 75.66879329282932 +- 0.1853171155530926.

```

In [195]: #Test 20
          #0.8 GPM Cold , 1.0 GPM Hot

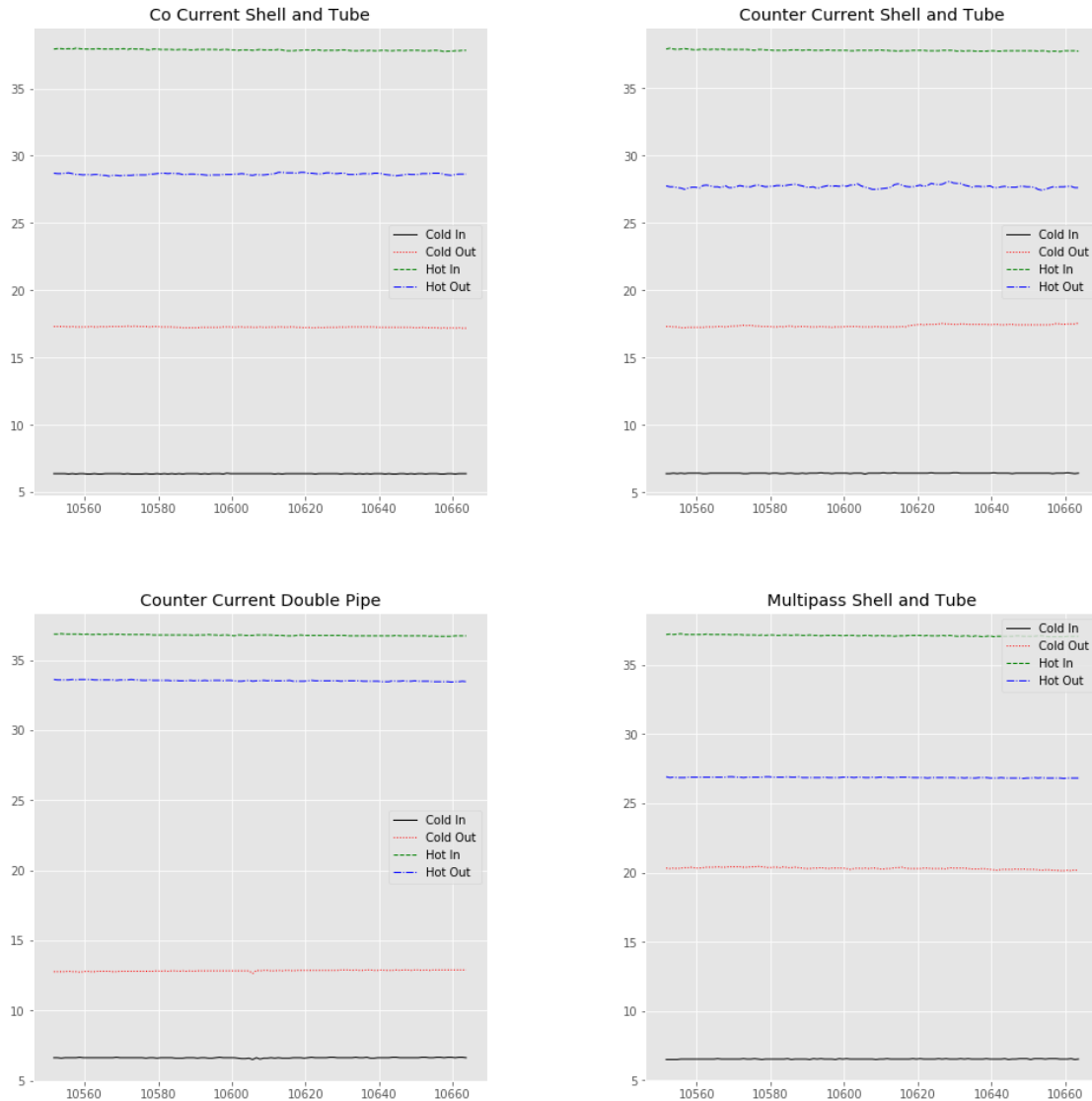
```

```

t1 = 10550
t2 = -1
Vcold = 0.8
Vhot = 1.0
UA_20, conf_20 = UA_Calc(t1,t2,Vcold,Vhot)

```

Temperature vs Time in Heat Exchanger Configurations



UA, for the cocurrent shell and tube is 65.57850388585868 +- 0.04891301942206674.

UA, for the countercurrent shell and tube is 66.41677303801548 +- 0.16874184577576304.

UA, for the multipass shell and tube is 100.57609865754472 +- 0.14822330622867963.

```

In [200]: UAdata = np.vstack((UA_1,UA_2,UA_3,UA_4,UA_5,UA_6,UA_7,UA_8,UA_9,UA_10,UA_11,UA_12,UA_13,UA_14,UA_15,UA_16,UA_17,UA_18,UA_19,UA_20))
          conf_data = np.vstack((conf_1,conf_2,conf_3,conf_4,conf_5,conf_6,conf_7,conf_8,conf_9,conf_10,conf_11,conf_12,conf_13,conf_14,conf_15,conf_16,conf_17,conf_18,conf_19,conf_20))

```

```

print(UAdata)
print(conf_data)

[[ 2.94602067  9.91775904 24.51351901]
 [ 46.97432463 56.96922585 79.45978012]
 [ 66.1379971  72.94290554 88.41703764]
 [ 80.94841367 77.13699113 127.18991927]
 [ 81.40980664 73.78407983 120.41428187]
 [  2.88682998  9.83709795 15.64407389]
 [ 32.1017642  33.60781378 40.34038907]
 [ 51.1546096  54.14245703 77.09669171]
 [ 65.9224476  70.57433261 98.81413054]
 [ 76.20443916 78.9563461 117.95627131]
 [  2.18136364  7.04575455 10.5514241 ]
 [ 26.36405371 30.11065373 33.79725319]
 [ 38.30219705 38.35492852 59.21925895]
 [ 58.47141981 58.4775804  91.36106234]
 [ 71.95969881 72.86522326 111.45404327]
 [  1.50579163  4.10931863  8.17064434]
 [ 22.80604845 24.98245689 28.74441248]
 [ 37.19515175 37.83014949 51.65807942]
 [ 51.34053511 51.63576863 75.66879329]
 [ 65.57850389 66.41677304 100.57609866]]

[[0.01354585 0.03291178 0.09120868]
 [0.18254883 0.15715172 0.17234734]
 [0.18339099 0.25287944 0.367515  ]
 [0.17385749 0.2621808  0.57221347]
 [0.08513068 0.41636489 0.44967668]
 [0.02469985 0.04318379 0.03429467]
 [0.06047856 0.1117859  0.20921896]
 [0.16681837 0.09118548 0.15515335]
 [0.38896208 0.24776357 0.56860503]
 [0.22538658 0.20107892 0.2576901 ]
 [0.02076936 0.02690926 0.02629806]
 [0.1516227  0.13539532 0.14600941]
 [0.15860094 0.19159555 0.14419025]
 [0.2409733  0.33653747 0.37641018]
 [0.124116   0.2703743  0.27743559]
 [0.02211702 0.04493796 0.03669406]]

```

```
In [ ]: plt.
```