Computer Aided Process Design for Hydrogenation of Oil using Jet Loop Reactor

Bhavika J. Parmar[1], Prof. S. M. Dutta[2], Prof. S. B. Thakore[3]

[1]Chemical Engg. Dept., L. D. College of Engineering, Ahmedabad – 380015
[2]Chemical Engg. Dept., L. D. College of Engineering, Ahmedabad – 380015
[3]Chemical Engg. Dept., L. D. College of Engineering, Ahmedabad – 380015

Abstract:

The paper presented here is study about jet loop reactor technology for hydrogenation amination alkylation. A Jet Loop Reactor consists of a reaction autoclave, a circulation pump, a heat exchanger, a venturi type ejector similar to Stirred Tank Reactor but is arranged in a completely different way. To provide ease to designing, a scilab based program is developed and tested for two types of oil, soyabean oil as well as palm oil.

Keyword: *Evaporative Condenser, Design of Condenser, scilab, Program for Evaporative Condenser*

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1. INTRODUCTION

The Loop Reactor consists of a reaction autoclave, a circulation pump, a heat exchanger and a venturi type ejector. This system requires the same number of elements as that of a stirred vessel system, but is arranged in a completely different way.
The reaction vessel of a Loop Reactor does not need baffles and is normally built with a larger L/D than the stirred vessel and is thus lower in cost, especially for high-pressure reactions.
The external heat exchanger are built as large as needed and is not limited by the reactor's working volume. The full heat exchanger area is available, also if the reactor is operated with reduced working volumes.
The circulation pump allows high power input per m^3 working volume in those cases where high mass transfer rates have to be achieved.
Pump designs with mechanical seals that can be operated at pressures of up to 200 bar g. A unique impeller and a special hydrodynamic pump house profile allow pumping of liquids with a high solid content and high gas loads, without the aid of an inducer and thus avoiding abrasion problems where heterogeneous catalysts are used.
The down flow Jet Mixer is a high performance gassing tool. The ability to finely disperse very small gas bubbles to the liquid with a gas-liquid ratio between 0.5 and 2.0, or even more, makes this an ideal tool for gas-liquid reactions.

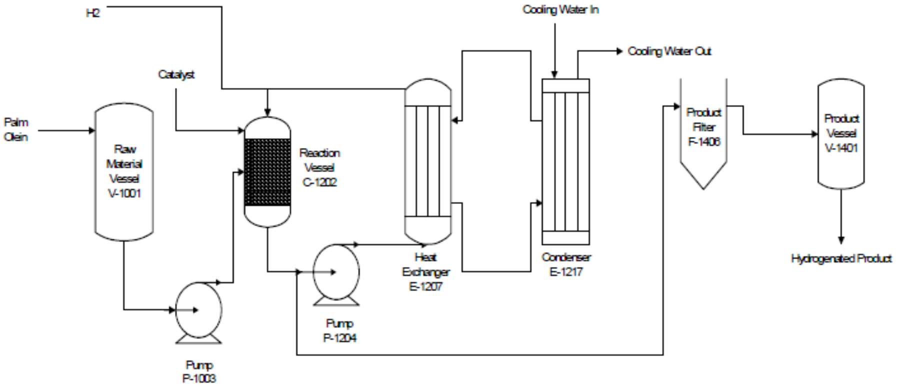

Fig. 1 Process flow design for Hydrogenation of Palm Oil

Advantages

Jet Loop Reactor possess several benefits which makes it substantial for various industrial applications, these benefits include; Firstly, it promotes a faster reaction rate by exerting its higher mass transfer rate & mixing intensity as compare to continuous stirred tank reactor (CSTR).

Secondly, absence of moving parts in jet loop reactors eliminates the sealing problems and allows easier operation at elevated pressure. Third, Length to diameter ratio of jet reactor is higher than same of agitated vessel, thus it requires less cost particularly for high pressure reactions.

Next, the external heat exchanger can be built as needed and can have accurate temperature control even if the reactor is operated with reduced working volumes.

Moreover, the maximum power input per unit volume is often a limiting factor, especially for large reactors with an agitator. Since there is no agitator in the jet reactor, this limitation does not exist.

Lastly, the circulation pump can provide very high power per m^3 of working volumes if it is required to achieve the desired mass transfer rate

Table 1: Properties comparison Palm Oil and Soybean Oil

Properties	**Palm oil**	**Soybean oil**
Density, Kg/L	0.856	0.825
Specific heat, KJ/(Kg.^{o} C)	2.56	2.56
Viscosity, mPa. s	2.387	2.0
Thermal conductivity, W/(m.^{o} C)	0.1664	0.16
Fire Point(^{0}C)	341	342
Flash Point(^{0}C)	314	317
Iodine Value(g/100g)	50.6 - 55	125 - 128
Melting Point (^{0}C)	30.8	0.6
Ponification value (mg KOG/g oil)	190 - 202	188 - 195
Smoke point (^{0}C)	223	-
Unsaponifiable (g)	0.2 - 1.0	$<_=$ 15

2. DESIGN EQUATIONS

The preliminary design equations that are employed in the design of jet loop rector are as follows:

Volume of inside the jet reactor

$V_L = \pi/4\, D_i^{\,2}\, h_i$ + inside volume of torispherical head

Height of the liquid in the reactor

$h_L = 1.5\, D_i$

Diameter of Reactor

$V_L = \pi/4\, D_i^{\,2}\, h_i + 0.084672\, D_i^3 + \pi/4\, D_i^{\,2}\, S_F$

Total height of reactor

$H = 2 * D_i$

Other equations employed are based on Kern's method of Shell and Tube Heat Exchanger is used for design of preheater as well as cooler.

3. CASE STUDY

Case Study – 1 (Hydrogenation of Soybean Oil)

Hydrogenation of edible oil is carried out to produce 'vanaspati oil' (hydrogenated fat) in presence of nickel catalyst in a batch reactor. In the standard age old process, edible oil is hydrogenated at about 2 bar g and 160-175 ^{0} C in 8 to 10hours (excluding heating / cooling). During this period, iodine value of mass is reduced from 128 to 68. Final mass has a melting (split) point of 39 ^{0} C. The batch reactor has jacket for heating the initial charge with circulation hot oil. Cooling requirements are met by passing cooling water in internal coils. In a newly developed jet reactor, it is planned to complete the reaction in 5 hours by improving mass transfer in the reactor and cooling the mass in external heat exchanger, thereby maintaining near isothermal conditions.

Soybean oil, having iodine value (IV) of 128 is to be hydrogenated in the jet reactor at 5 bar g and 165 C. initially the charge is heated from 30C to 140C with the circulating hot oil external heat exchanger. Hydrogen is introduced in hot soybean oil and pressure is maintained in the reactor at 5 bar g. reaction is exothermic and the temperature of mass increases. Cold oil flow in the external heat exchanger controls the temperature at 165 C as per the requirement; IV reduction is desired up to 68 when the reaction is considered over. Thereafter hydrogenated mass is cooled to 60C IN about 1.5h before it is discharged to filter. 150 kg spent nickel catalyst is charged with soybean oil while fresh 5 to 10 kg nickel catalyst is charged at intervals in the reactor under pressure. A bleed is maintained from the system to purge out water vapor and non-condensables. Design the jet reactor for the following duty.

1] Charge = 10t soybean oil with 128 IV
2] Average molar mass of soybean oil = 278
3] Average chain length of fatty acids = 17.78
4] Product specifications: 68IV, 39 ^{0}C melting point (max.). Assume linear drop of IV in 5 hours.
5] Average exothermic heat of reaction = 7.1 kJ/kg of IV reduction
6] Hydrogen feed rate = 110 to 125 Nm^3/h
Bleed rate = 1 to 2 Nm^3/h
7] Thermic fluid or oil is used as both, heating medium in starting of reaction and cooling medium in running of reaction.
8] Cooling water is available at 2 bar g and 32C .a rise of 5C is permitted. Cooling water is used for cooling water is used for cooling the oil from 80C to 70C in oil cooler (HE-2) of oil cycle.
9] Assume following properties of fluids for the design.
Average properties of edible oil and circulating oil

Table 2: Properties of Soybean Oil

Properties	**Soybean oil or hardened fat**	**Circulating oil(thermic fluid)**
Density ,kg/L	0.825	0.71
Specific heat, kJ/(kg ^{0}C)	2.56	2.95
Viscosity, mPa s	2.0	0.5
Thermal conductivity, W/(m ^{0}C)	0.16	0.1

Case Study -2 (Hydrogenation of Palm Oil)

Hydrogenation of palm oil is carried out to produce (hydrogenated fat) in the presence of nickel catalyst in batch reactor. In which iodine value of the mass is reduced from 64 to 10. The batch reactor has a jacket for heating the initial charge with circulating hot oil. Cooling requirements are met by passing cooling water in internal coils. In a newly developed jet loop reactor, it is planned to complete the reaction in 3 hours by improving mass transfer in the reactor and cooling the mass in external heat exchanger, thereby maintaining near isothermal condition. Palm oil, having iodine value (IV) of 64 is to be hydrogenated in the jet reactor at 5 bar g and 195˚ C. initially the charge is heated from 50˚C to 160˚C with the circulating hot oil external heat exchanger. Hydrogen is introduced in hot palm oil and pressure is maintained in the reactor at 5 bar g. reaction is exothermic and the temperature of mass increases. Cold oil flow in the external heat exchanger controls the temperature at 195˚C as per the requirement; IV reduction is desired up to 10 when the reaction is considered over. Thereafter hydrogenated mass is cooled to 110˚C in about 1.5 h before it is discharged to filter. 150 kg spent nickel catalyst is charged with palm oil while fresh 5 to 10 kg nickel catalyst is charged at intervals in the reactor under pressure. A bleed is maintained from the system to purge out water vapor and non-condensable.

Input Parameters for the Design
The presented design of jet reactor incorporates charge of 1t palm oil 64 IV for a product specification of 10 IV, 24℃ melting point (max).

The following data is taken into consideration:

- Average molar mass of palm oil is 270
- Average chain length of fatty acids is 16.98
- Average exothermic heat of reaction is 0.942 kcal /kg or 3.941 kJ /kg
- Hydrogen feed rate is from 110 to 125 Nm^3/h
- Bleed rate is 1 to 2 Nm^3/h

Thermic fluid or oil is used as both, heating medium in starting of reaction and cooling medium in running of reaction. Cooling water is available at 2 bar g and 32˚C. A rise of 5˚C is permitted over here. Cooling water is used for cooling the oil from 80˚C to 70˚C in oil cooler (HE-2) of oil cycle.

The following average properties of fluids for the design are taken:

Table 3: Properties of Palm Oil

Properties	**Palm oil or hardened fat**	**Circulating oil (thermic fluid)**
Density, kg / L	0.856	0.71
Specific heat, kJ /(kg˚C)	2.56	2.95
Viscosity, mPa s	2.387	0.5
Thermal conductivity, W/(m˚C)	0.1664	0.1

3. RESULTS

The case study on soybean oil was run on program and was verified with the results given in the text. The results obtained for the case study is tabulated as below.

Table 4: Results obtained via program as well as given in-text for process design of Soybean Oil

Sr. No.	**Properties**	**Results by Program**	**Results by Manual Calculation**
1	Volume of inside the jet reactor		12.12 m^3
2	Diameter of Reactor	2.6449142 m	2.115m
3	Total height of reactor	5.2898 m	4.23m
Design of Shell and Tube Heat Exchanger used for cooling of Soybean Oil (HE – 1)			
4	Heat Duty Required	236.856 kW	236.67 kW or 852000 kJ/h
5	Mean temp. difference	87.14117˚ C	87.141˚C
6	Tube side mass velocity (kg/m^2·s)	1237.5 kg / m^{2}s	1237kg / m^{2}s
7	Tube side flow area (m^2)	0.0131.481 m^2	0.013148 m^2
8	Total number of tube	33.2864 == 34	34
9	Tube side Reynold's Number	13673.137	13673.14
10	Tube side Prandtl's Number	32	32
11	Tube side heat transfer coefficient	1063.8708 W/m^2˚C	1063.87 W/m^2˚C
25.4 mm (1 in) OD and 31.75 (1.25 in) triangular pitch; Type of baffle =25 % cut segmental Baffle spacing, B_s =150mm			
12	Shell side flow area	0.00762 m^2	7.62×10^{-3} m^2
13	Shell side mass velocity	1053.6768 kg/m^{2}s	1052.89kg/m^{2}s
14	Shell side velocity	1.4840518 m/s	1.483m/s
15	Shell side equivalent diameter	18.31467m	18.3147 m
16	Shell side Reynold's numbers	38595.484	38566.7
17	Shell side Prandtl's numbers	14.75	14.75
18	Shell side heat transfer coefficient	1591.4751W/m^2 ˚C	1408.8 W/m^2˚C
Thermic fluid (oil) side fouling coefficients, h_{od}=5000 W/m^2 ^{0}C Palm oil side fouling coefficients, h_{id}=3000 W/m^2 ^{0}C Tube material = SS 316 Thermal conductivity of tube material k_w = 16.26 W/m^2 ^{0}C			
19	Overall heat transfer coefficient	416.54873 W/m^2˚C	416.5W/m^2˚C
20	Heat transfer area required	6.5252204 m^2	6.52 m^2
21	Length of tube	2.4063174= = 3 m	2.403 m
22	Heat Transfer Area Provided	6.5252204m^2	8.139 m^2
23	% excess heat transfer area	24.671835%	24.83 %
R_e = 11886 and 25 % cur segmental baffles			

$J_f = 0.047$			
24	Tube side pressure drop	6.8563565 kPa	6.856 kPa
25	Shell side pressure drop	69.397057 kPa	69.3 kPa
Parameters of Shell and Tube Heat Exchanger used for preheating of Soybean Oil before Reaction (HE -1)			
26	Time required for heating the palm oil from 50 to 160		7600 s
27	K_2 Constant	1.0812546	1.0813
28	Temperature of heating medium inlet, t_1	235.919227℃	217.83℃
Design of cooler of oil cycle (HE – 2)			
BEM type fixed tube sheet Tube side fluid : cooling water Shell side fluid oil : (Thermic oil) Cooling water inlet temp. = 32˚C Cooling water outlet temp. = 37˚C			
29	Cooling water flow rate	40731.9012kg/h	40700 kg/h
30	Mean Temperature Difference	40.448507˚C	40.04485˚ C
31	Volumetric flow rate of water	0.0113804 m^3/h	0.01137 m^3/h
32	Tube side flow area	0.0075869 m^2	7.58 × 10^{-3} m^2
33	Number of tubes	77.942= =78	78
For 25.4 mm triangular pitch , $N_p = 2$, shell ID = 305mm			
34	Tube side Reynold's numbers	32171.287	32171.3
35	Tube Side Prandtl's numbers	4.8668217	4.867
36	Heat Transfer Coefficient of Tube Side	6240.6211 W/m^2 ˚C	6240.7 W/m^2 ˚C
37	Shell side flow area	0.0095312 m^2	9.5312 × 10^{-3} m^2
38	Shell side mass velocity	842.38866kg/m^2s	841.757 kg/m^2s
39	Shell side velocity	1.1864629m/s	1.1856m/s
40	Shell side equivalent diameter	18.25 mm	18.25 mm
41	Shell side Reynolds numbers	30742	30742
42	Shell side Prandtl's number	14.75	14.75
43	Shell side heat transfer coefficient	1409.4981 W/ m^2˚C	1408.8
44	Overall heat transfer coefficient	723.84589 W/ m^2˚C	723.66 W/ m^2˚C
45	Heat transfer area required	8.1714774m^2	8.167 m^2
46	Tube length	1.7513839 = = 2m	1.7495 m
47	Area Available	9.331452m^2	9.336 m^2
48	% excess heat transfer area	14.195409%	14.31%
49	Tube side pressure drop	13.547012 kPa	13.547 kPa
50	Shell side pressure drop	43.83644kPa	43.06 kPa

The case study on palm oil was run on program and was verified with the results obtained by design calculations. The results obtained for the case study is tabulated as below.

Table 5: Results obtained via program as well as manual calculation for process design of Palm Oil

Sr. No.	Properties	Results obtained by Coding in scilab	Results by Design Calculation
1	Volume of inside the jet reactor		11.682 m^3
2	Diameter of Reactor	2.645 m	2.1 m
3	Total height of reactor	5.2898 m	4.2 m
Design of Shell and Tube Heat Exchanger used for cooling of Palm Oil (HE – 1)			
4	Heat Duty Required	197.2 kW	196.99 kW or 425628 kJ/h
5	Mean temp. difference	117.14 ˚C	117.1459˚ C
6	Tube side mass velocity (kg/m^2·s)	1284 kg / m^2s	1284 kg / m^2s
7	Tube side flow area (m^2)	0.0127 m^2	0.012671 m^2
8	Total number of tube	33.04 == 34	34

9	Tube side Reynold’s Number	11886.817	11886
10	Tube side Prandtl’s Number	36.723	36
11	Tube side heat transfer coefficient	1035.17 W/m^2˚C	1028.339 W/m^2˚C
25.4 mm (1 in) OD and 31.75 (1.25 in) triangular pitch; Type of baffle =25 % cut segmental Baffle spacing , B_s =150mm			
12	Shell side flow area	0.00762 m^2	7.62×10^{-3} m^2
13	Shell side mass velocity	877.3 kg/m^{2}s	876.350 kg/m^{2}s
14	Shell side velocity	1.236 m/s	1.2342 m/s
15	Shell side equivalent diameter	18.3146 m	18.3147 m
16	Shell side Reynold’s numbers	32134.81	32100.175
17	Shell side Prandtl’s numbers	14.75	14.75
18	Shell side heat transfer coefficient	1438.94 W/m^2˚C	1438.080 W/m^2˚C
Thermic fluid (oil) side fouling coefficients, h_{od}=5000 W/m^2 ^{0}C Palm oil side fouling coefficients, h_{id}=3000 W/m^2 ^{0}C Tube material = SS 316 Thermal conductivity of tube material k_w = 16.26 W/m^2 ^{0}C			
19	Overall heat transfer coefficient	435.94 W/m^2 C	399.2075 W/m^2 C
20	Heat transfer area required	3.8615 m^2	4.21248 m^2
21	Length of tube	1.42 = = 2 m	1.5526 m
22	Heat Transfer Area Provided	5.4234 m^2	5.4261 m^2
23	% excess heat transfer area	40.44%	28.81 %
R_e = 11886 and 25 % cur segmental baffles J_f = 0.047			
24	Tube side pressure drop	5.684 kPa	7.323 kPa
25	Shell side pressure drop	36.0812 kPa	53.97 kPa
Parameters of Shell and Tube Heat Exchanger used for preheating of Palm Oil before Reaction (HE -1)			
26	Time required for heating the palm oil from 50 to 160		7600 s
27	K_2 Constant	1.05346	1.0463
28	Temperature of heating medium inlet, t_1	322.9197℃	321.605477℃
Design of cooler of oil cycle (HE – 2)			
BEM type fixed tube sheet Tube side fluid : cooling water Shell side fluid oil : (Thermic oil) Cooling water inlet temp. = 32˚C Cooling water outlet temp. = 37˚C			
29	Cooling water flow rate	33912 kg/h	33877.73 kg/h
30	Mean Temperature Difference	40.04˚C	40.04˚C
31	Volumetric flow rate of water	0.009475 m^3/h	9.465×10^{-3} m^3/h
32	Tube side flow area	0.00632 m^2	6.3102×10^{-3} m^2
33	Number of tubes	64.85 = = 65	66
For 25.4 mm triangular pitch , N_p= 2 , shell ID = 305mm			
34	Tube side Reynold’s numbers	32171.3	32171.3
35	Tube Side Prandtl’s numbers	4.866	4.867
36	Heat Transfer Coefficient of Tube Side	6240.62 W/m^2 ˚C	6340.7 W/m^2 ˚C
37	Shell side flow area	0.0095312 m^2	9.5312×10^{-3} m^2
38	Shell side mass velocity	701.3775 kg/m^{2}s	700.62 kg/m^{2}s
39	Shell side velocity	0.98786 m/s	0.9867 m/s
40	Shell side equivalent diameter	18.25 mm	18.25 mm
41	Shell side Reynolds numbers	25596.28	25572.63
42	Shell side Prandtl’s number	14.75	14.75
43	Shell side heat transfer coefficient	1274.4011 W/ m^2˚C	
44	Overall heat transfer coefficient	686.474 W/ m^2˚C	682.2290 W/ m^2˚C
45	Heat transfer area required	7.174 m^2	7.2110 m^2

46	Tube length	1.845 = = 2m	1.82560 m
47	Area Available	7.77621 m^2	7.89984 m^2
48	% excess heat transfer area	8.394%	9.5598 %
49	Tube side pressure drop	13547 kPa	13547 kPa
50	Shell side pressure drop	30.388 kPa	31.791 kPa

4. CONCLUSION

The results show that jet loop reactor can be well used for hydrogenation of Palm oil and can replace conventional CSTRs. The Program made was first tested with data available for hydrogenation of Soybean oil given in text and later ran for Palm Oil. The results obtained for Palm Oil are well within the acceptable limits and can be applied for scale up plants.

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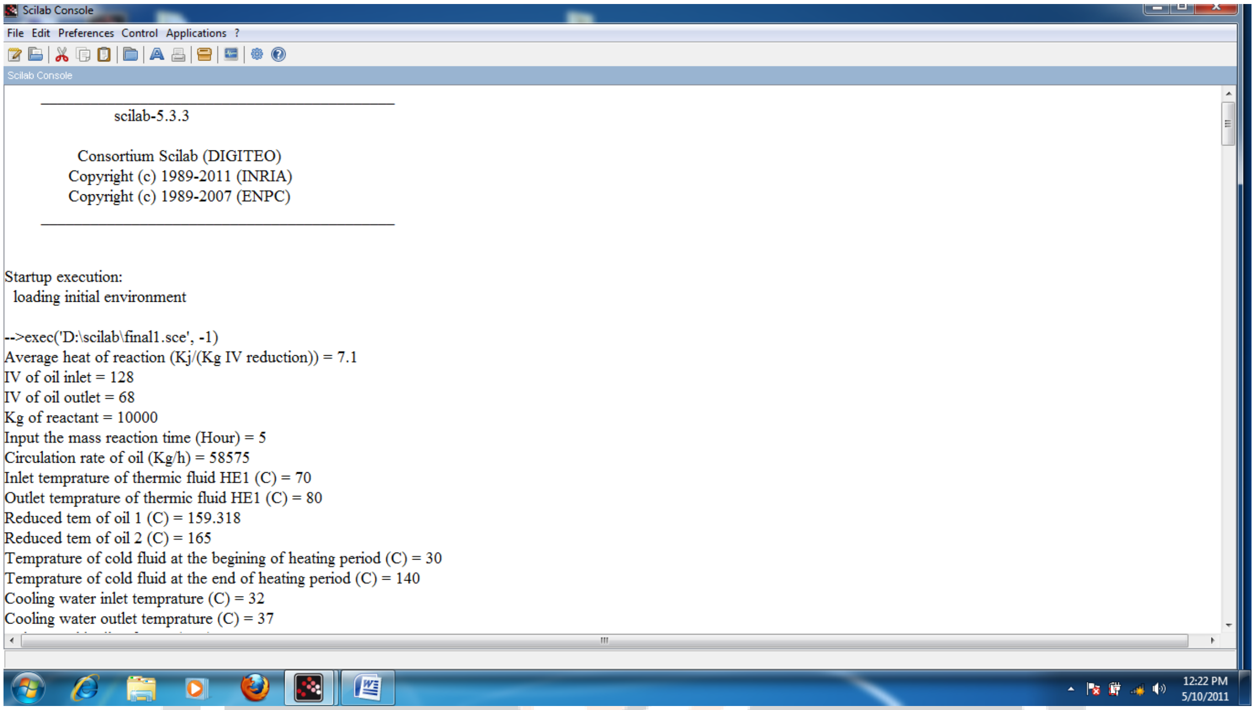
6. APPENDIX- 1 (OUTPUT WINDOWS FOR SOYBEAN OIL



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        scilab-5.3.3

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Startup execution:
  loading initial environment

-->exec('D:\scilab\final1.sce', -1)
Average heat of reaction (Kj/(Kg IV reduction)) = 7.1
IV of oil inlet = 128
IV of oil outlet = 68
Kg of reactant = 10000
Input the mass reaction time (Hour) = 5
Circulation rate of oil (Kg/h) = 58575
Inlet temprature of thermic fluid HE1 (C) = 70
Outlet temprature of thermic fluid HE1 (C) = 80
Reduced tem of oil 1 (C) = 159.318
Reduced tem of oil 2 (C) = 165
Temprature of cold fluid at the begining of heating period (C) = 30
Temprature of cold fluid at the end of heating period (C) = 140
Cooling water inlet temprature (C) = 32
Cooling water outlet temprature (C) = 37
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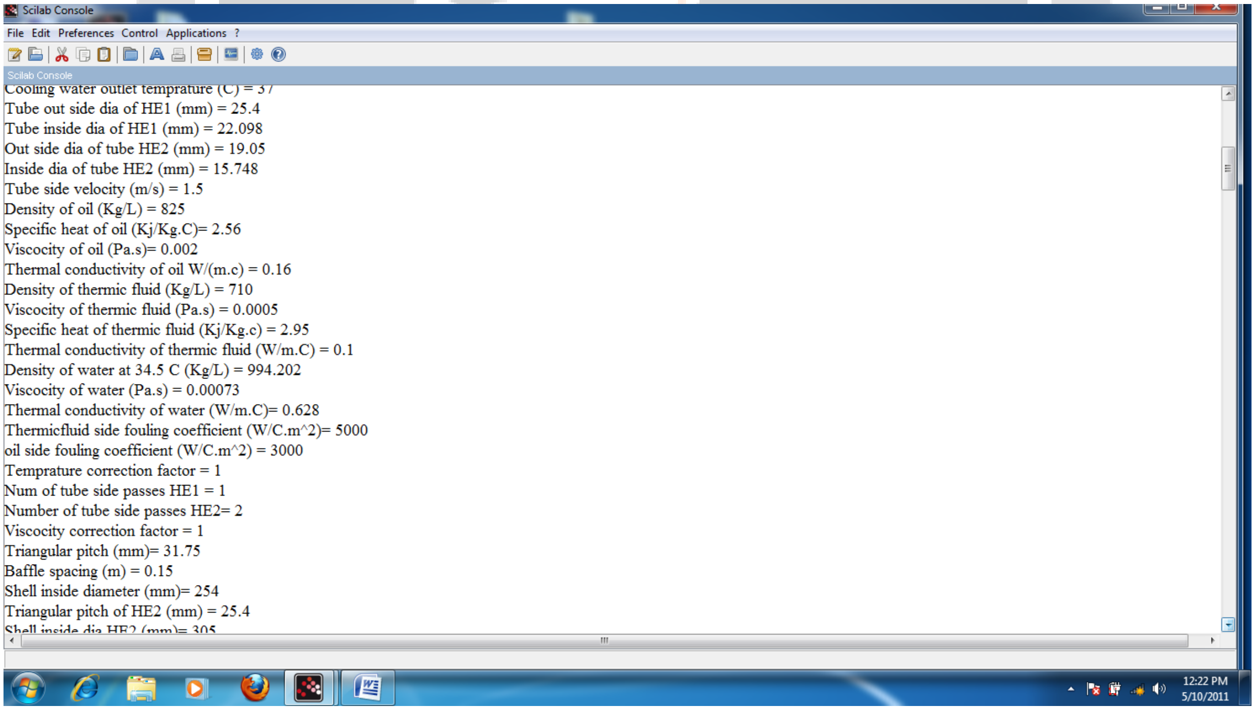
Figure 2: Output Window – 1 for Soybean Oil



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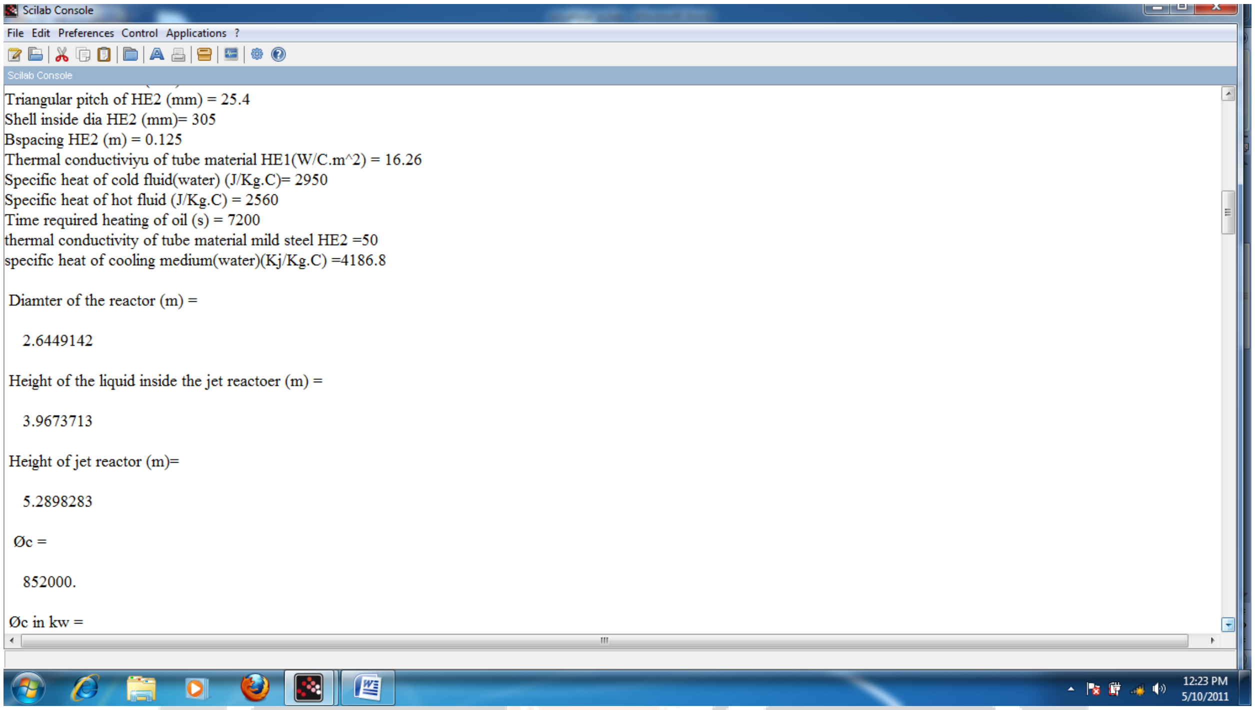
Cooling water outlet temprature (C) = 37
Tube out side dia of HE1 (mm) = 25.4
Tube inside dia of HE1 (mm) = 22.098
Out side dia of tube HE2 (mm) = 19.05
Inside dia of tube HE2 (mm) = 15.748
Tube side velocity (m/s) = 1.5
Density of oil (Kg/L) = 825
Specific heat of oil (Kj/Kg.C)= 2.56
Viscocity of oil (Pa.s)= 0.002
Thermal conductivity of oil W/(m.c) = 0.16
Density of thermic fluid (Kg/L) = 710
Viscocity of thermic fluid (Pa.s) = 0.0005
Specific heat of thermic fluid (Kj/Kg.c) = 2.95
Thermal conductivity of thermic fluid (W/m.C) = 0.1
Density of water at 34.5 C (Kg/L) = 994.202
Viscocity of water (Pa.s) = 0.00073
Thermal conductivity of water (W/m.C)= 0.628
Thermicfluid side fouling coefficient (W/C.m^2)= 5000
oil side fouling coefficient (W/C.m^2) = 3000
Temprature correction factor = 1
Num of tube side passes HE1 = 1
Number of tube side passes HE2= 2
Viscocity correction factor = 1
Triangular pitch (mm)= 31.75
Baffle spacing (m) = 0.15
Shell inside diameter (mm)= 254
Triangular pitch of HE2 (mm) = 25.4
Shell inside dia HE2 (mm)= 305
```

Figure 3: Output Window – 2 for Soybean Oil



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Triangular pitch of HE2 (mm) = 25.4
Shell inside dia HE2 (mm)= 305
Bspacing HE2 (m) = 0.125
Thermal conductiviyu of tube material HE1(W/C.m^2) = 16.26
Specific heat of cold fluid(water) (J/Kg.C)= 2950
Specific heat of hot fluid (J/Kg.C) = 2560
Time required heating of oil (s) = 7200
thermal conductivity of tube material mild steel HE2 =50
specific heat of cooling medium(water)(Kj/Kg.C) =4186.8

 Diamter of the reactor (m) =

    2.6449142

 Height of the liquid inside the jet reactoer (m) =

    3.9673713

 Height of jet reactor (m)=

    5.2898283

  Øc =

    852000.

 Øc in kw =
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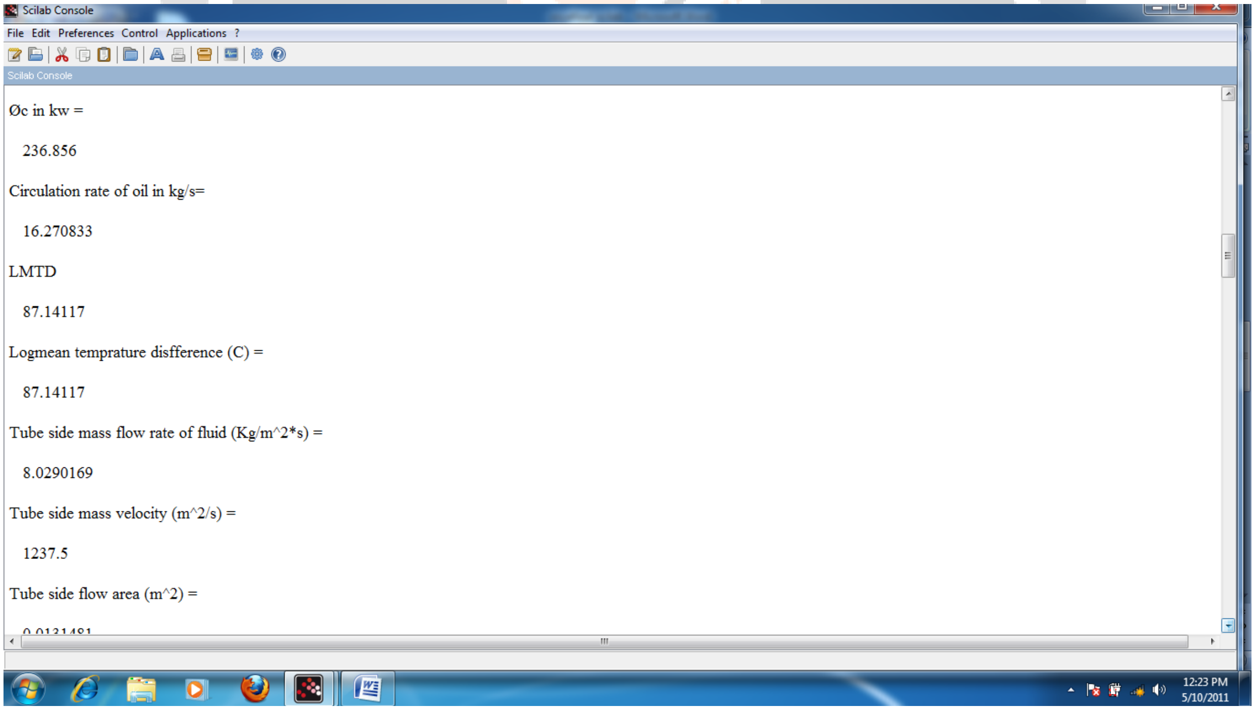
Figure 4: Output Window – 3 for Soybean Oil



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 Øc in kw =

    236.856

 Circulation rate of oil in kg/s=

    16.270833

 LMTD

    87.14117

 Logmean temprature disfference (C) =

    87.14117

 Tube side mass flow rate of fluid (Kg/m^2*s) =

    8.0290169

 Tube side mass velocity (m^2/s) =

    1237.5

 Tube side flow area (m^2) =

    0.0131481
```
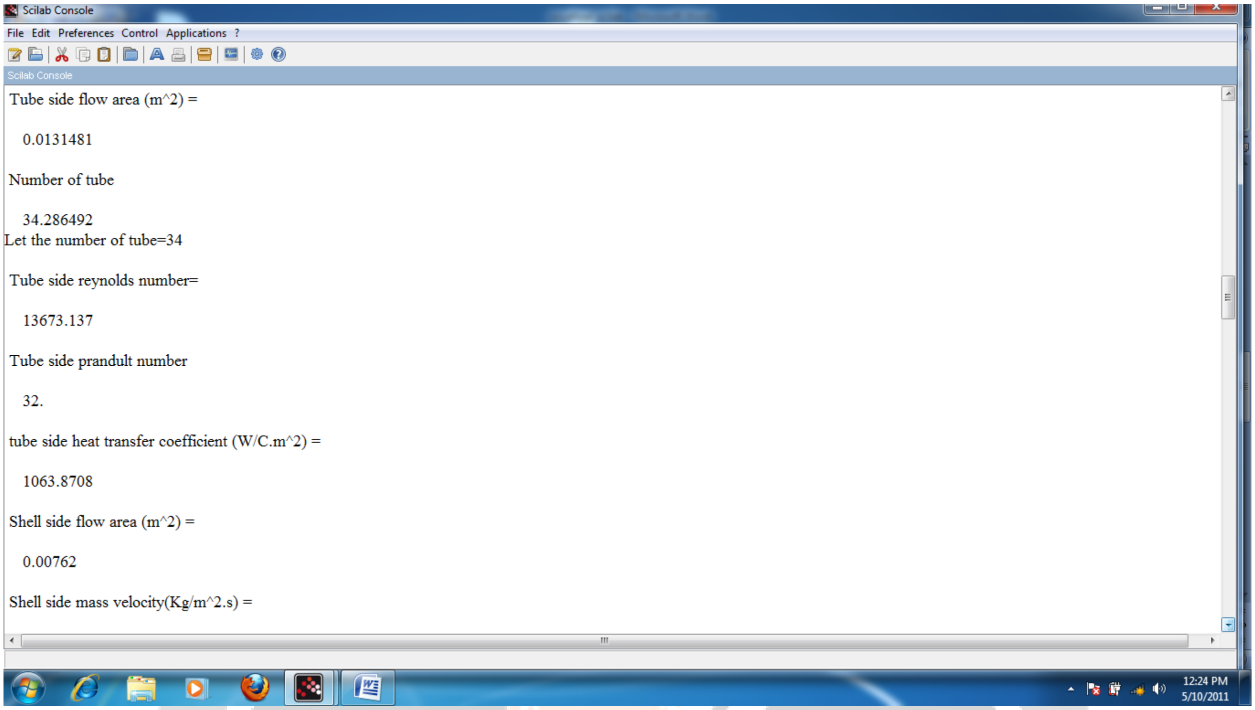
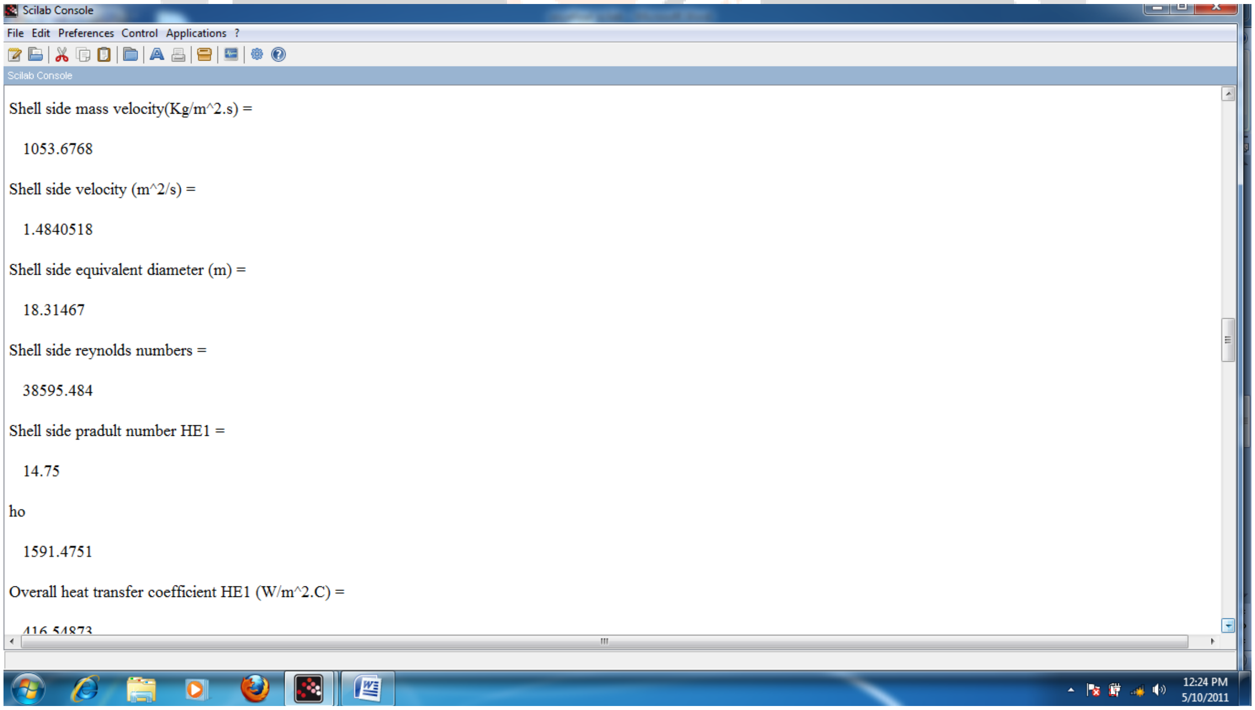

Figure 5: Output Window – 4 for Soybean Oil



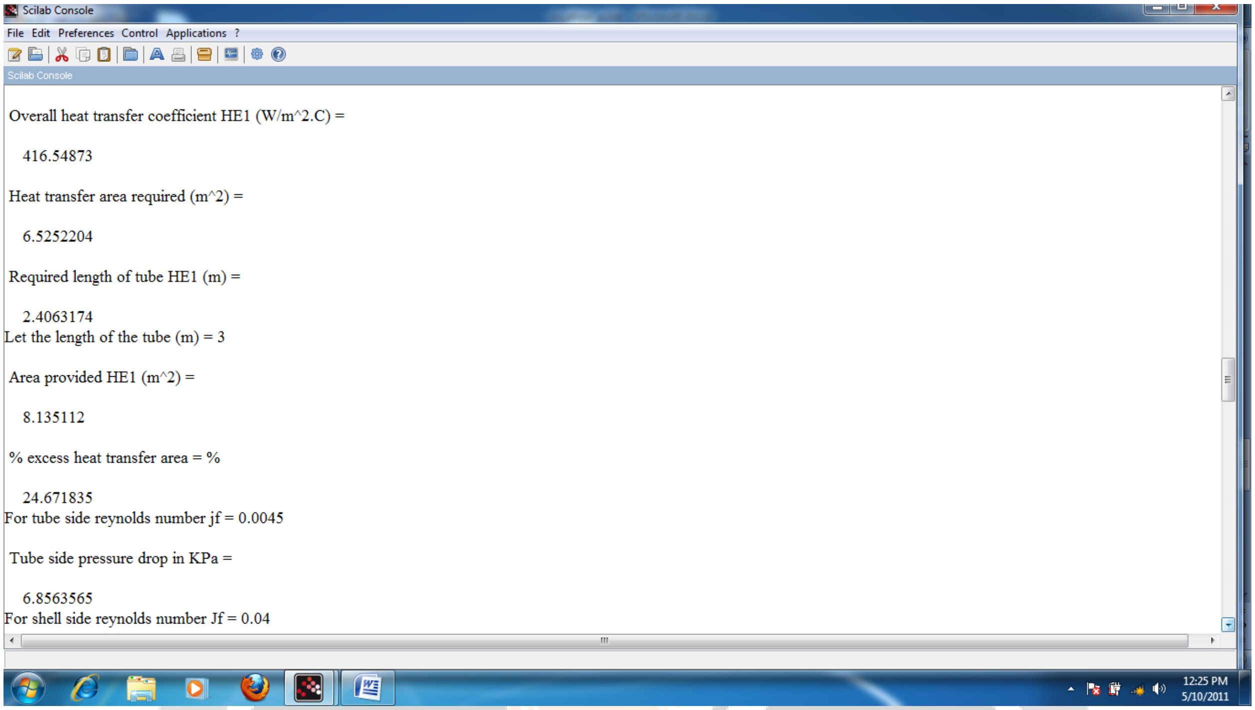
```
Tube side flow area (m^2) =

   0.0131481

Number of tube

   34.286492
Let the number of tube=34

Tube side reynolds number=

   13673.137

Tube side prandult number

   32.

tube side heat transfer coefficient (W/C.m^2) =

   1063.8708

Shell side flow area (m^2) =

   0.00762

Shell side mass velocity(Kg/m^2.s) =
```

Figure 6: Output Window – 5 for Soybean Oil



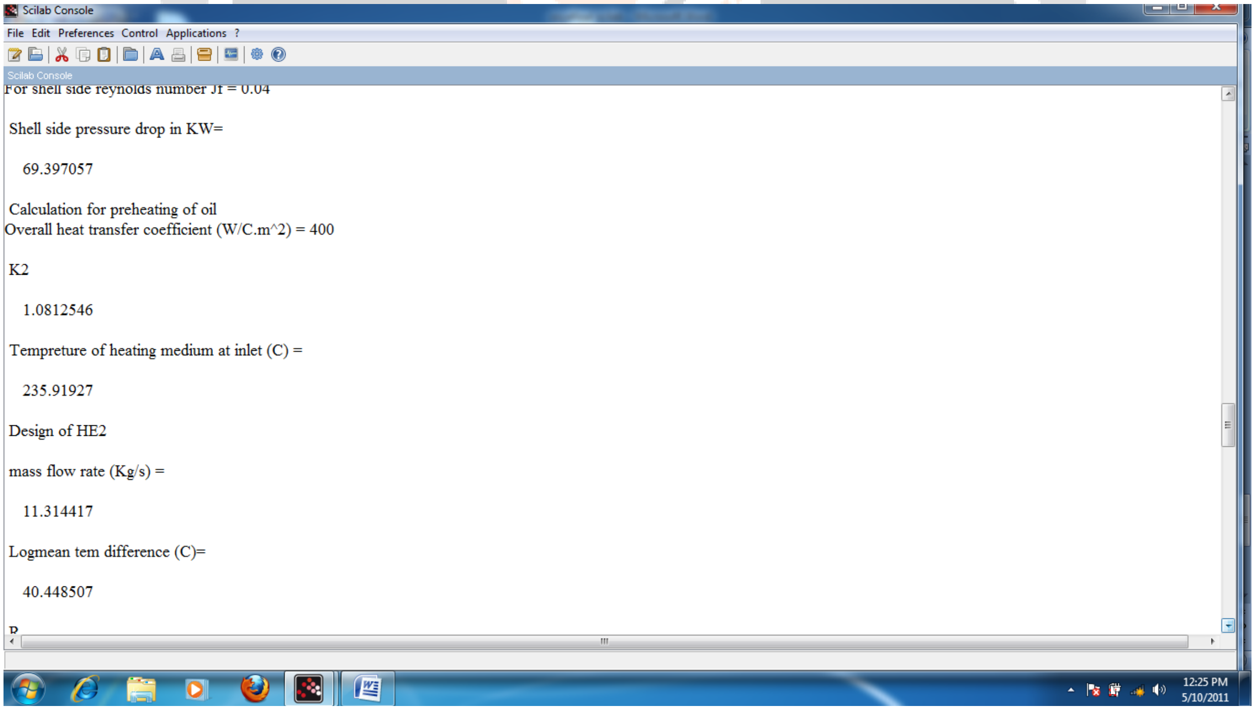
```
Shell side mass velocity(Kg/m^2.s) =

   1053.6768

Shell side velocity (m^2/s) =

   1.4840518

Shell side equivalent diameter (m) =

   18.31467

Shell side reynolds numbers =

   38595.484

Shell side pradult number HE1 =

   14.75

ho

   1591.4751

Overall heat transfer coefficient HE1 (W/m^2.C) =

   416.54873
```

Figure 7: Output Window – 6 for Soybean Oil



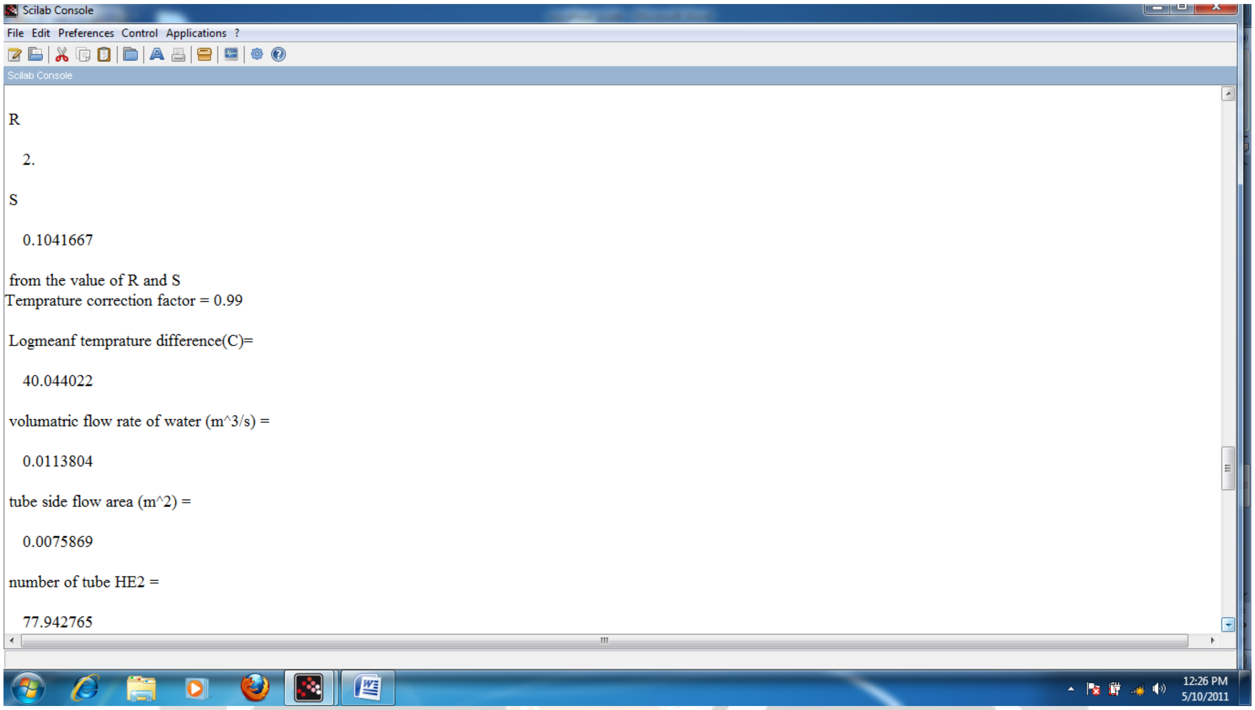
```
 Overall heat transfer coefficient HE1 (W/m^2.C) =

    416.54873

 Heat transfer area required (m^2) =

    6.5252204

 Required length of tube HE1 (m) =

    2.4063174
Let the length of the tube (m) = 3

 Area provided HE1 (m^2) =

    8.135112

 % excess heat transfer area = %

    24.671835
For tube side reynolds number jf = 0.0045

 Tube side pressure drop in KPa =

    6.8563565
For shell side reynolds number Jf = 0.04
```

Figure 8: Output Window – 7 for Soybean Oil



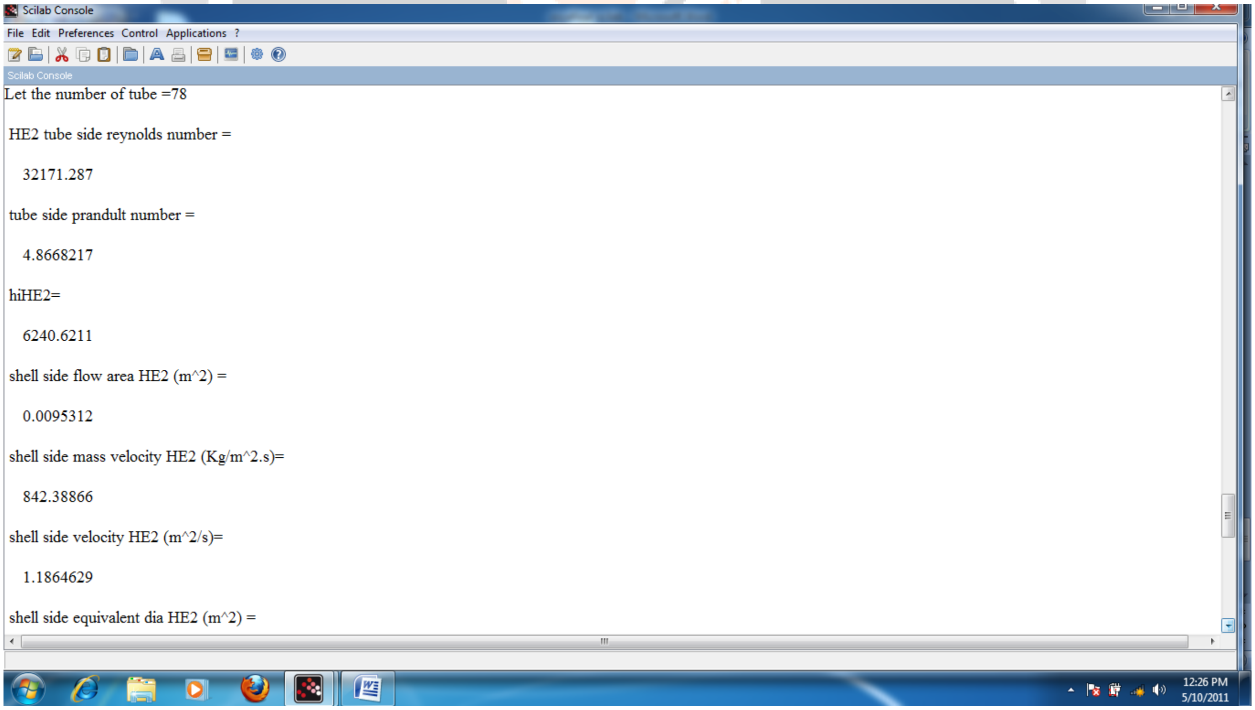
```
For shell side reynolds number Jf = 0.04

 Shell side pressure drop in KW=

    69.397057

 Calculation for preheating of oil
Overall heat transfer coefficient (W/C.m^2) = 400

 K2

    1.0812546

 Tempreture of heating medium at inlet (C) =

    235.91927

 Design of HE2

 mass flow rate (Kg/s) =

    11.314417

 Logmean tem difference (C)=

    40.448507

 P
```

Figure 9: Output Window – 8 for Soybean Oil



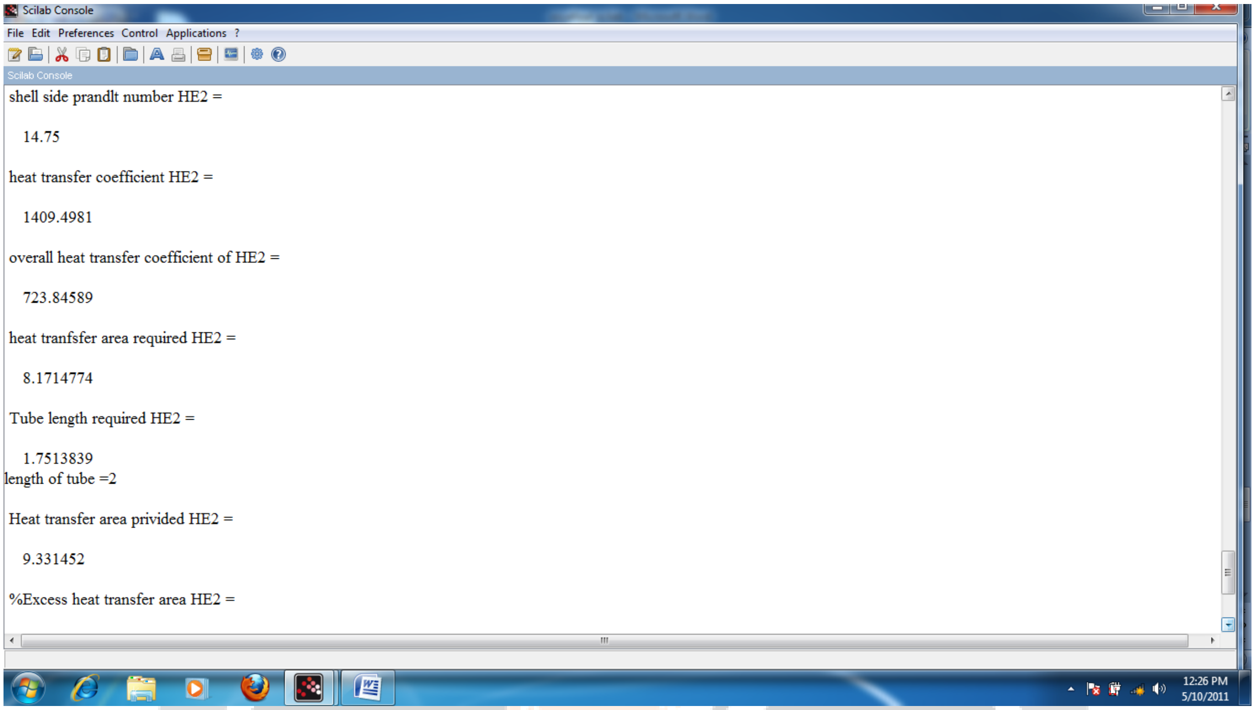
```
R

   2.

S

   0.1041667

from the value of R and S
Temprature correction factor = 0.99

Logmeanf temprature difference(C)=

   40.044022

volumatric flow rate of water (m^3/s) =

   0.0113804

tube side flow area (m^2) =

   0.0075869

number of tube HE2 =

   77.942765
```

Figure 10: Output Window – 9 for Soybean Oil



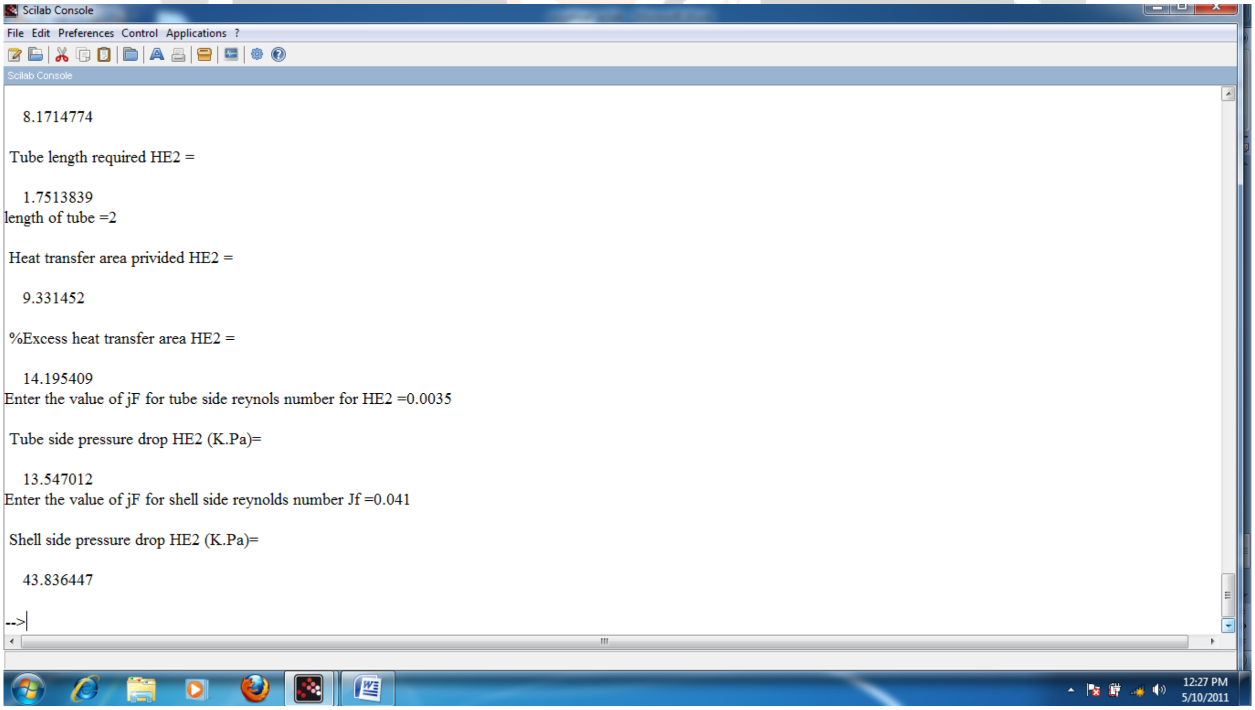
```
Let the number of tube =78

HE2 tube side reynolds number =

   32171.287

tube side prandult number =

   4.8668217

hiHE2=

   6240.6211

shell side flow area HE2 (m^2) =

   0.0095312

shell side mass velocity HE2 (Kg/m^2.s)=

   842.38866

shell side velocity HE2 (m^2/s)=

   1.1864629

shell side equivalent dia HE2 (m^2) =
```

Figure 11: Output Window – 10 for Soybean Oil



```
shell side prandlt number HE2 =

   14.75

heat transfer coefficient HE2 =

   1409.4981

overall heat transfer coefficient of HE2 =

   723.84589

heat tranfsfer area required HE2 =

   8.1714774

Tube length required HE2 =

   1.7513839
length of tube =2

Heat transfer area privided HE2 =

   9.331452

%Excess heat transfer area HE2 =
```

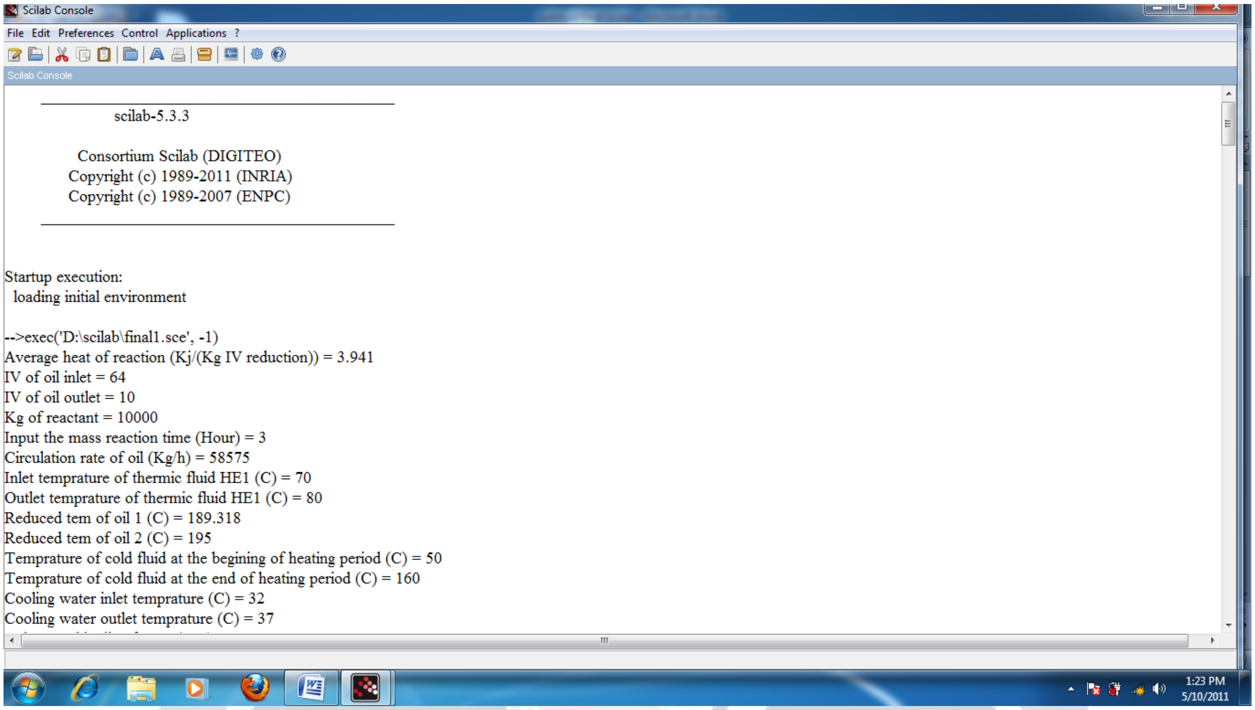
Figure 12: Output Window – 11 for Soybean Oil



```
   8.1714774

Tube length required HE2 =

   1.7513839
length of tube =2

Heat transfer area privided HE2 =

   9.331452

%Excess heat transfer area HE2 =

   14.195409
Enter the value of jF for tube side reynols number for HE2 =0.0035

Tube side pressure drop HE2 (K.Pa)=

   13.547012
Enter the value of jF for shell side reynolds number Jf =0.041

Shell side pressure drop HE2 (K.Pa)=

   43.836447

-->
```

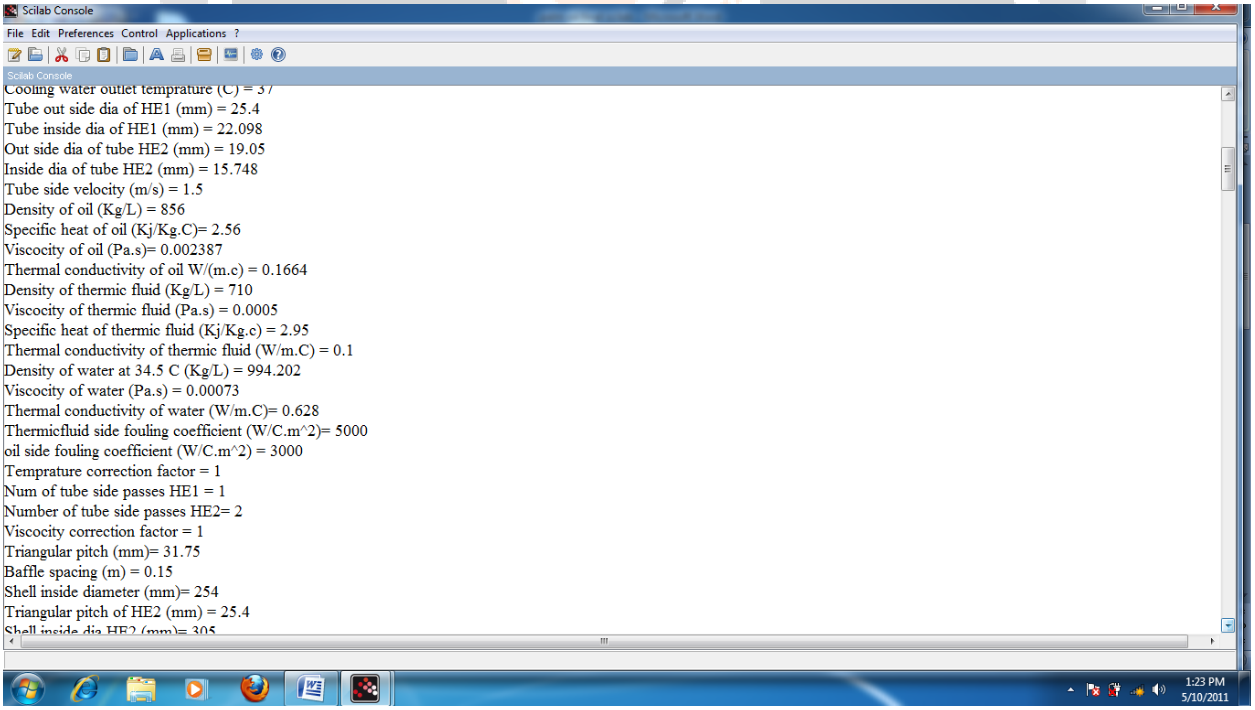
Figure 13: Output Window – 12 for Soybean Oil

7. APPENDIX – 2 (Output Windows for Palm Oil)



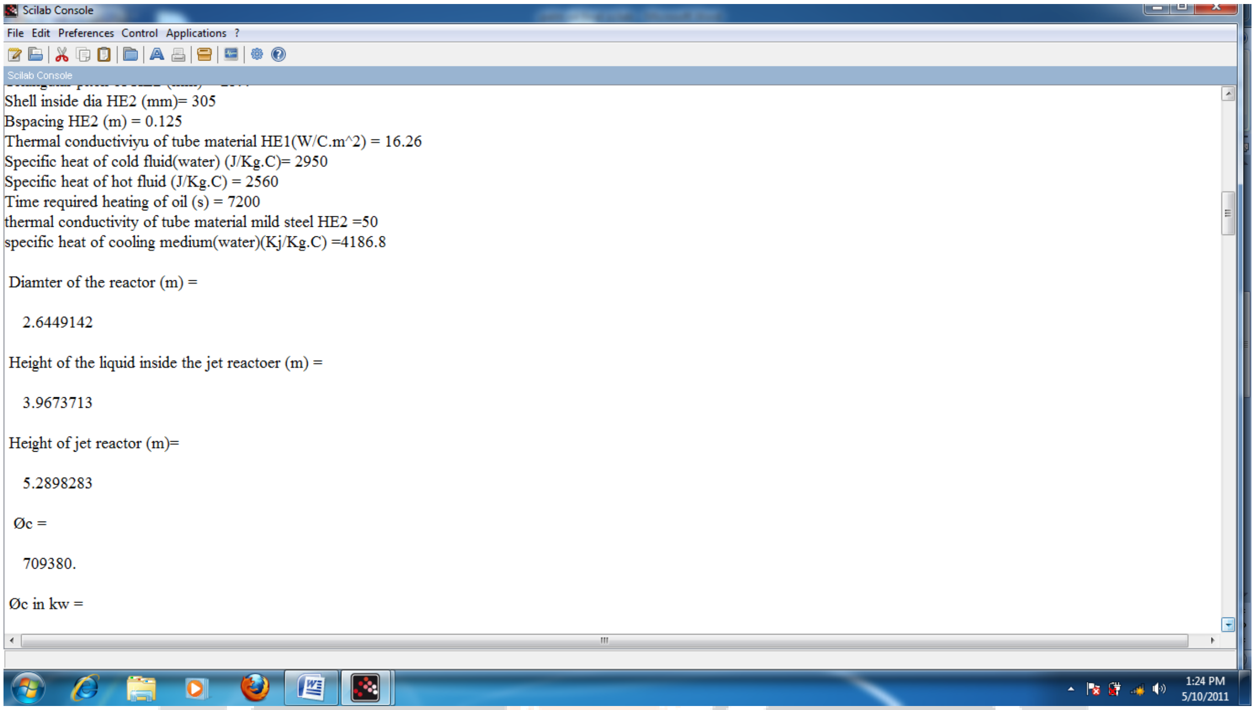
```
                  ________________________________________
                  scilab-5.3.3

                  Consortium Scilab (DIGITEO)
                  Copyright (c) 1989-2011 (INRIA)
                  Copyright (c) 1989-2007 (ENPC)
                  ________________________________________


Startup execution:
  loading initial environment

-->exec('D:\scilab\final1.sce', -1)
Average heat of reaction (Kj/(Kg IV reduction)) = 3.941
IV of oil inlet = 64
IV of oil outlet = 10
Kg of reactant = 10000
Input the mass reaction time (Hour) = 3
Circulation rate of oil (Kg/h) = 58575
Inlet temprature of thermic fluid HE1 (C) = 70
Outlet temprature of thermic fluid HE1 (C) = 80
Reduced tem of oil 1 (C) = 189.318
Reduced tem of oil 2 (C) = 195
Temprature of cold fluid at the begining of heating period (C) = 50
Temprature of cold fluid at the end of heating period (C) = 160
Cooling water inlet temprature (C) = 32
Cooling water outlet temprature (C) = 37
```

Figure 14: Output Window – 1 for Palm Oil



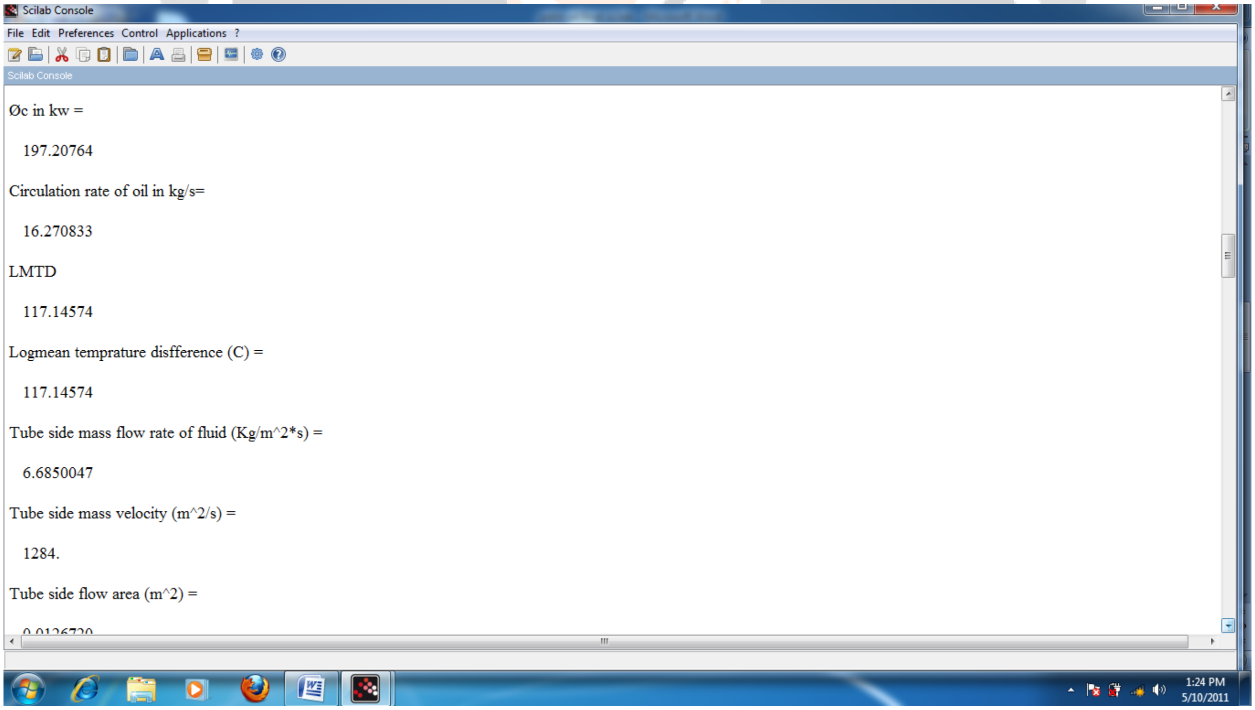
```
Cooling water outlet temprature (C) = 37
Tube out side dia of HE1 (mm) = 25.4
Tube inside dia of HE1 (mm) = 22.098
Out side dia of tube HE2 (mm) = 19.05
Inside dia of tube HE2 (mm) = 15.748
Tube side velocity (m/s) = 1.5
Density of oil (Kg/L) = 856
Specific heat of oil (Kj/Kg.C)= 2.56
Viscocity of oil (Pa.s)= 0.002387
Thermal conductivity of oil W/(m.c) = 0.1664
Density of thermic fluid (Kg/L) = 710
Viscocity of thermic fluid (Pa.s) = 0.0005
Specific heat of thermic fluid (Kj/Kg.c) = 2.95
Thermal conductivity of thermic fluid (W/m.C) = 0.1
Density of water at 34.5 C (Kg/L) = 994.202
Viscocity of water (Pa.s) = 0.00073
Thermal conductivity of water (W/m.C)= 0.628
Thermicfluid side fouling coefficient (W/C.m^2)= 5000
oil side fouling coefficient (W/C.m^2) = 3000
Temprature correction factor = 1
Num of tube side passes HE1 = 1
Number of tube side passes HE2= 2
Viscocity correction factor = 1
Triangular pitch (mm)= 31.75
Baffle spacing (m) = 0.15
Shell inside diameter (mm)= 254
Triangular pitch of HE2 (mm) = 25.4
Shell inside dia HE2 (mm)= 305
```

Figure 15: Output Window – 2 for Palm Oil



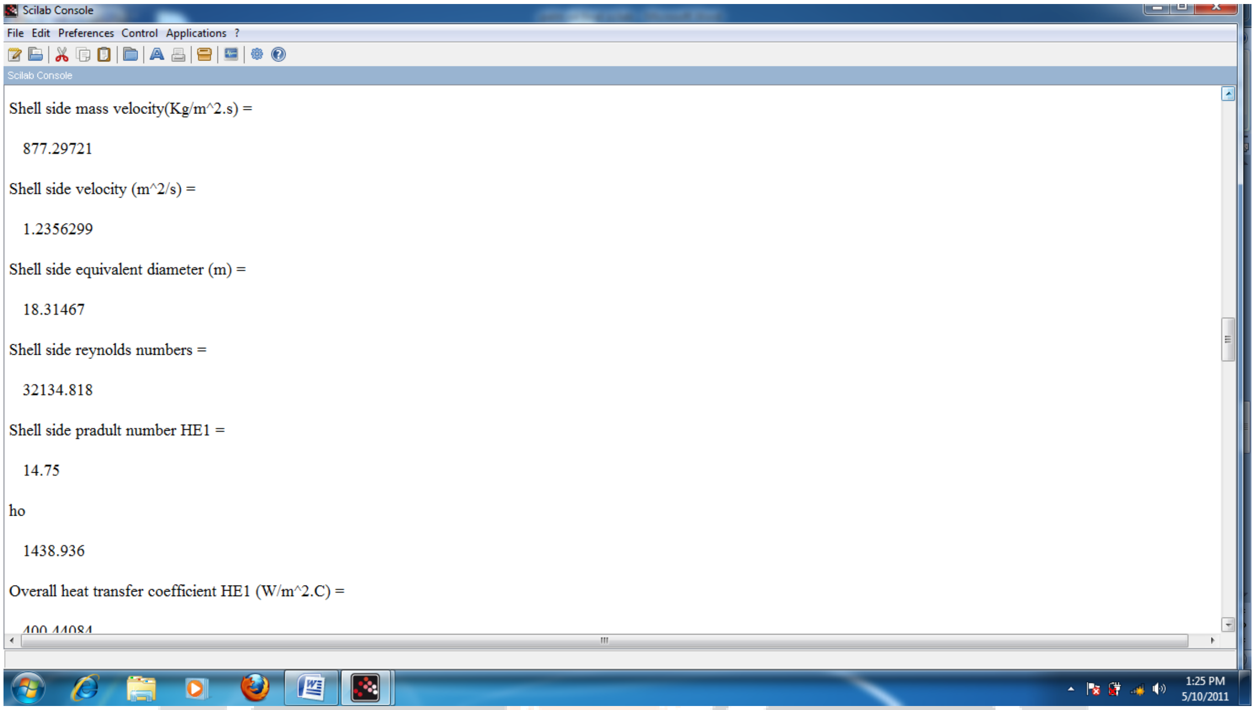
```
Shell inside dia HE2 (mm)= 305
Bspacing HE2 (m) = 0.125
Thermal conductiviyu of tube material HE1(W/C.m^2) = 16.26
Specific heat of cold fluid(water) (J/Kg.C)= 2950
Specific heat of hot fluid (J/Kg.C) = 2560
Time required heating of oil (s) = 7200
thermal conductivity of tube material mild steel HE2 =50
specific heat of cooling medium(water)(Kj/Kg.C) =4186.8

 Diamter of the reactor (m) =

    2.6449142

 Height of the liquid inside the jet reactoer (m) =

    3.9673713

 Height of jet reactor (m)=

    5.2898283

  Øc =

    709380.

 Øc in kw =
```

Figure 16: Output Window – 3 for Palm Oil



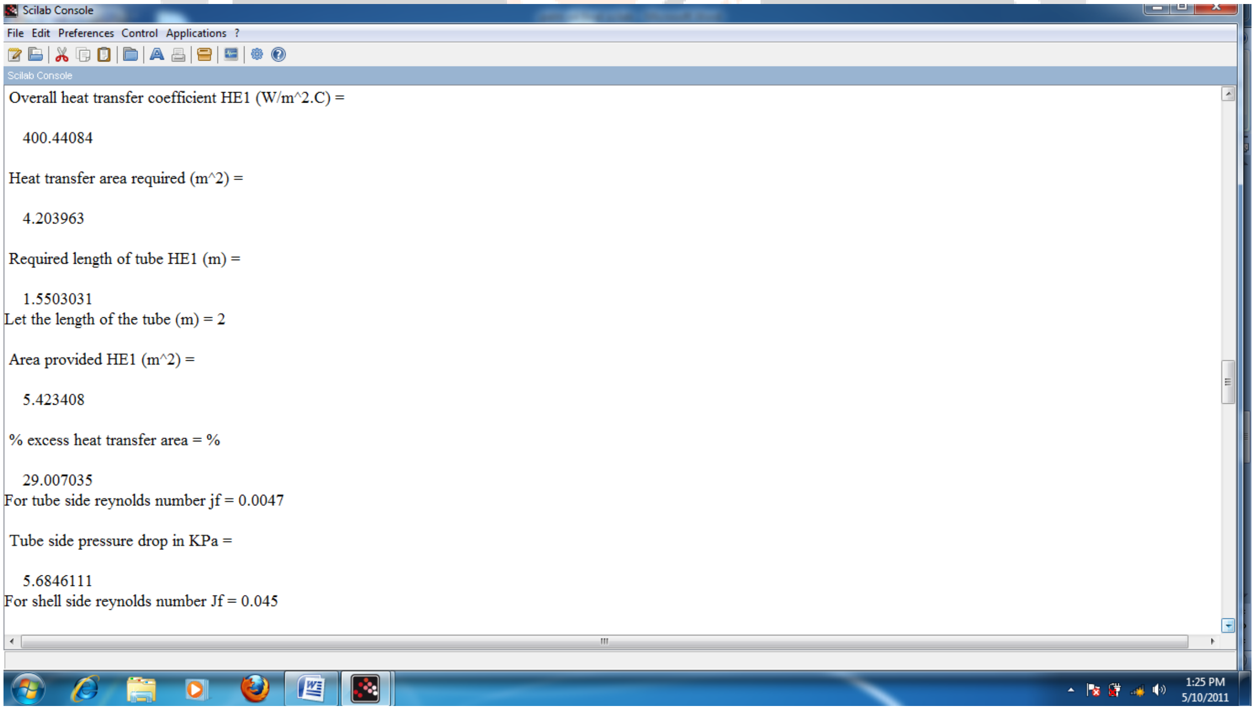
```
 Øc in kw =

    197.20764

 Circulation rate of oil in kg/s=

    16.270833

 LMTD

    117.14574

 Logmean temprature disfference (C) =

    117.14574

 Tube side mass flow rate of fluid (Kg/m^2*s) =

    6.6850047

 Tube side mass velocity (m^2/s) =

    1284.

 Tube side flow area (m^2) =

    0.0126720
```

Figure 17: Output Window – 4 for Palm Oil



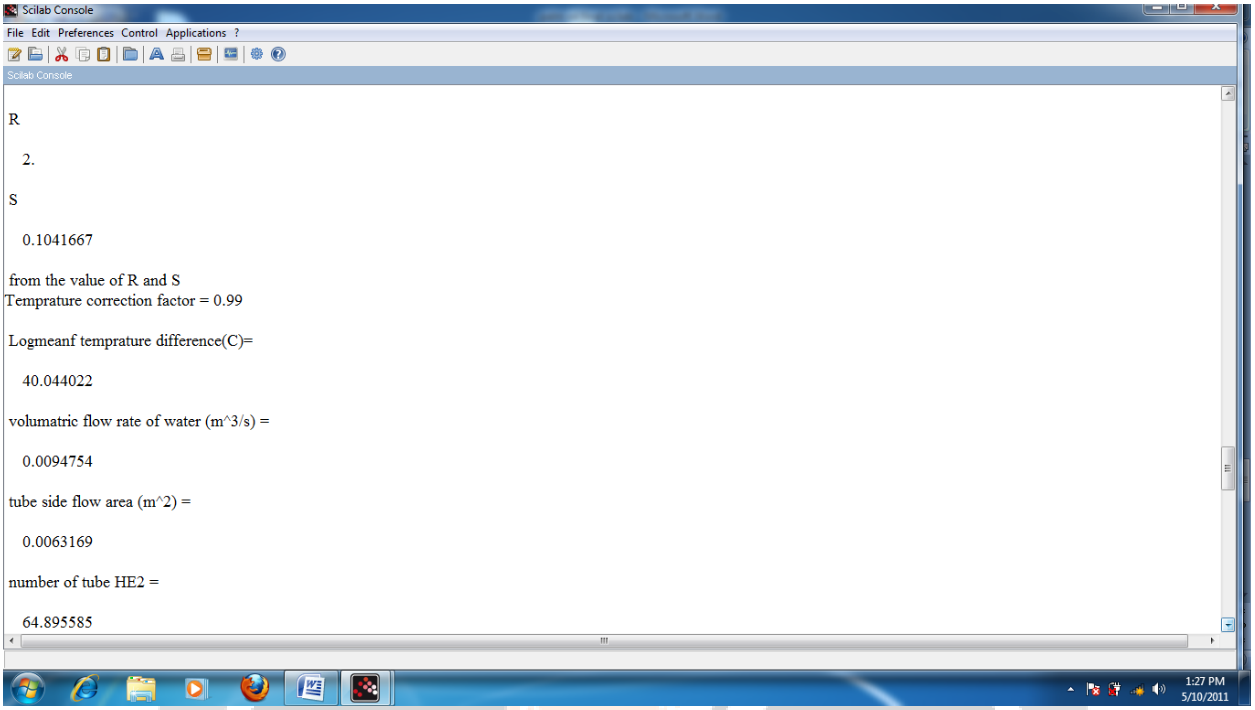
```
Shell side mass velocity(Kg/m^2.s) =

  877.29721

Shell side velocity (m^2/s) =

  1.2356299

Shell side equivalent diameter (m) =

  18.31467

Shell side reynolds numbers =

  32134.818

Shell side pradult number HE1 =

  14.75

ho

  1438.936

Overall heat transfer coefficient HE1 (W/m^2.C) =

  400.44084
```

Figure 18: Output Window – 5 for Palm Oil



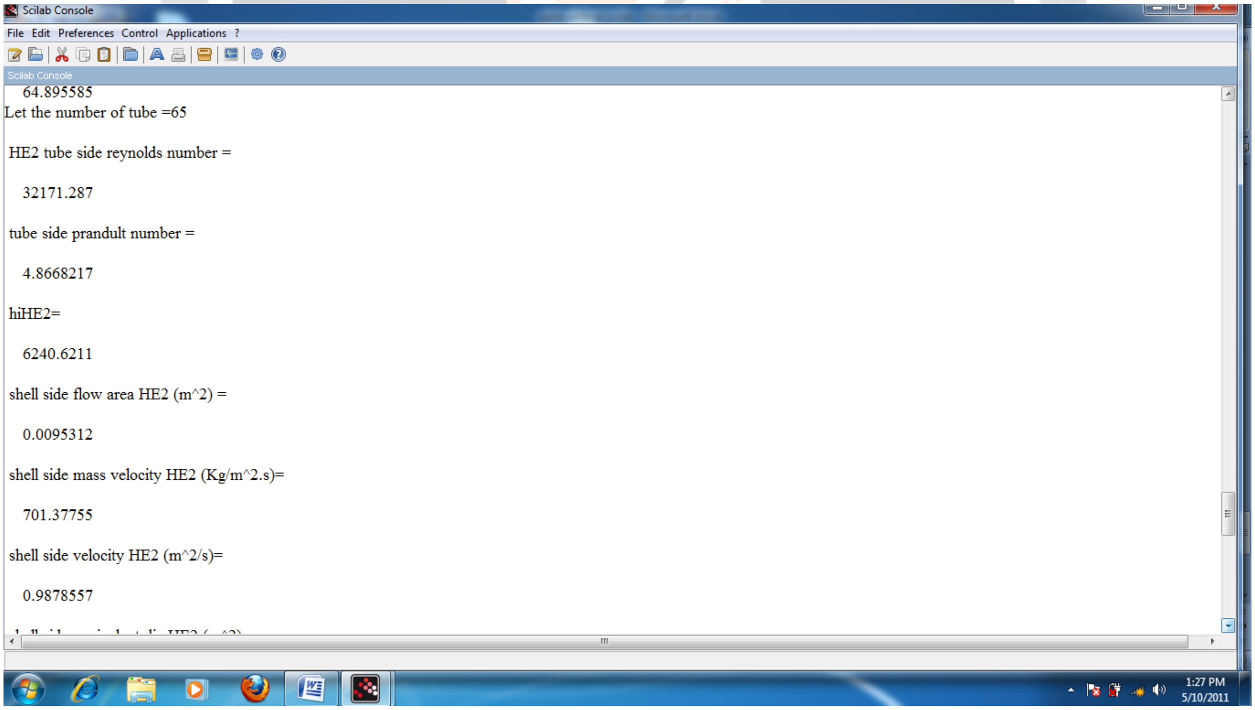
```
Overall heat transfer coefficient HE1 (W/m^2.C) =

  400.44084

Heat transfer area required (m^2) =

  4.203963

Required length of tube HE1 (m) =

  1.5503031
Let the length of the tube (m) = 2

Area provided HE1 (m^2) =

  5.423408

% excess heat transfer area = %

  29.007035
For tube side reynolds number jf = 0.0047

Tube side pressure drop in KPa =

  5.6846111
For shell side reynolds number Jf = 0.045
```

Figure 19: Output Window – 6 for Palm Oil



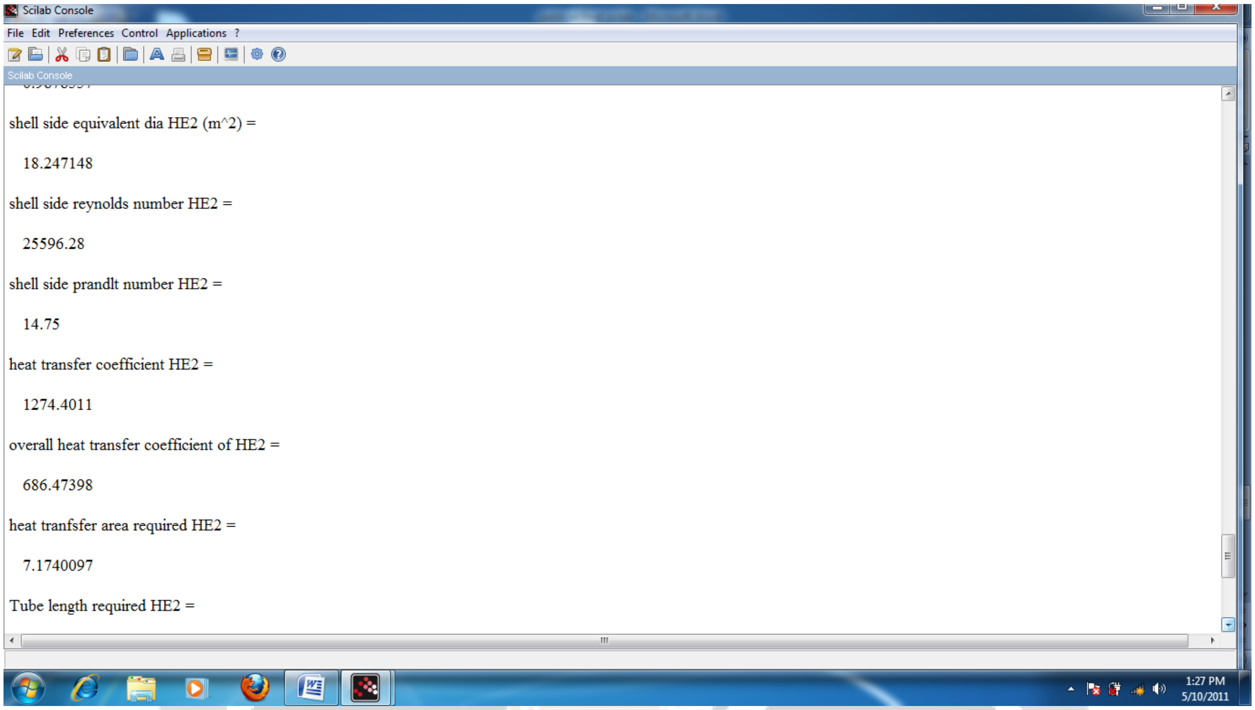
```
R

   2.

S

   0.1041667

from the value of R and S
Temprature correction factor = 0.99

Logmeanf temprature difference(C)=

   40.044022

volumatric flow rate of water (m^3/s) =

   0.0094754

tube side flow area (m^2) =

   0.0063169

number of tube HE2 =

   64.895585
```

Figure 20: Output Window – 7 for Palm Oil



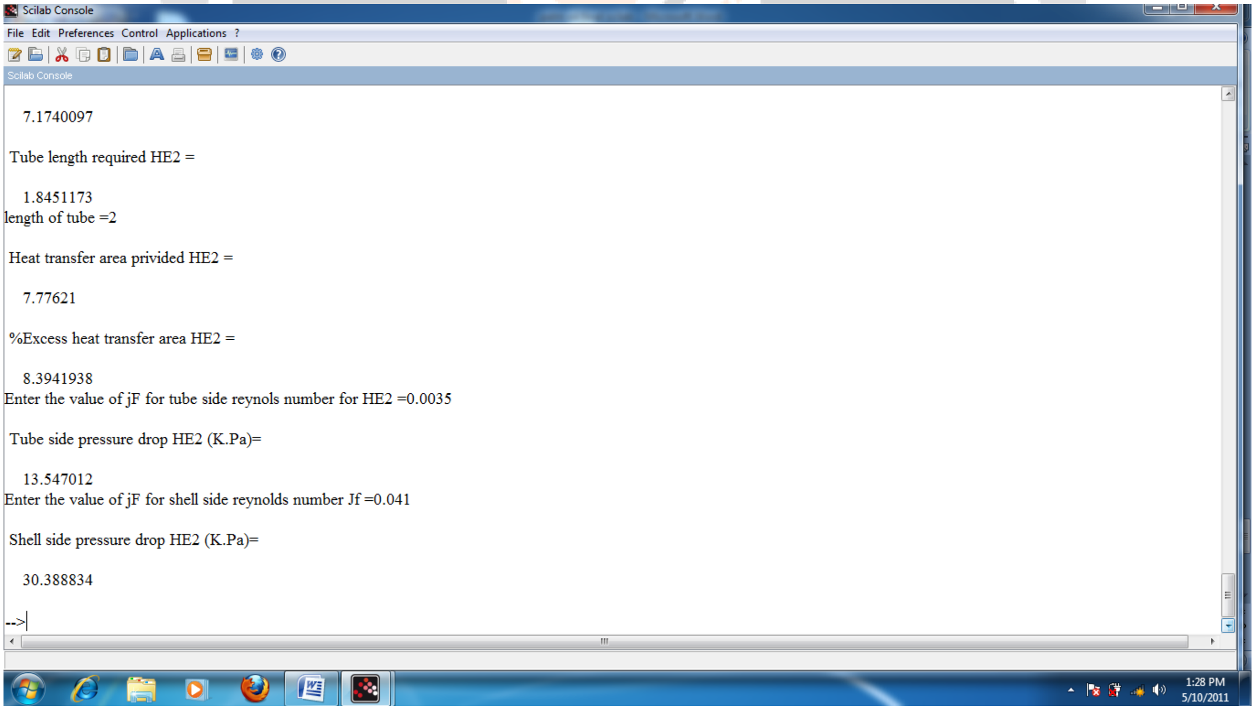
```
   64.895585
Let the number of tube =65

HE2 tube side reynolds number =

   32171.287

tube side prandult number =

   4.8668217

hiHE2=

   6240.6211

shell side flow area HE2 (m^2) =

   0.0095312

shell side mass velocity HE2 (Kg/m^2.s)=

   701.37755

shell side velocity HE2 (m^2/s)=

   0.9878557
```

Figure 21: Output Window – 8 for Palm Oil



```
shell side equivalent dia HE2 (m^2) =

   18.247148

shell side reynolds number HE2 =

   25596.28

shell side prandlt number HE2 =

   14.75

heat transfer coefficient HE2 =

   1274.4011

overall heat transfer coefficient of HE2 =

   686.47398

heat tranfsfer area required HE2 =

   7.1740097

Tube length required HE2 =
```

Figure 22: Output Window – 9 for Palm Oil



```
   7.1740097

Tube length required HE2 =

   1.8451173
length of tube =2

Heat transfer area privided HE2 =

   7.77621

%Excess heat transfer area HE2 =

   8.3941938
Enter the value of jF for tube side reynols number for HE2 =0.0035

Tube side pressure drop HE2 (K.Pa)=

   13.547012
Enter the value of jF for shell side reynolds number Jf =0.041

Shell side pressure drop HE2 (K.Pa)=

   30.388834

-->
```

Figure 23: Output Window – 10 for Palm Oil