Heat and mass transfer calculation for carbon capture pilot plant

Engineering

Heat transfer aspects Experiment Temperature reduction for the Hot Fluid Δt

Hot = T1 – T2 = 57. 5 – 53. 2 = 4. 3K

Temperature increase for the Cold Fluid Δt Cold= T4 – T3

= 25. 4 – 13. 2

= 12. 2K

Table below shows the summary of the observations and calculations

Obs. No.

Vhot(g/s)

Vcold(g/s)

T1°C

T2°C

T3°C

T4°C

Δt Hot (T1-T2) K

Δt Cold (T4-T3) K

1

50

15

57. 5

53. 2

13. 2

25. 4

4. 3

12. 2

2

50

20

57. 2

52. 7

13. 3

23. 3

4. 5

10

3

50

27

56. 9

52. 4

13. 1

20. 8

4. 5

7. 7

4

50

31

56. 7

51. 4

13. 3

21. 5

5. 3

8. 2

Experiment 2

Mean Temperature = (T1 + T2)/2

= (57. 5 + 53. 2)/2

= 55. 350C

Cp of Water at Temperature T equals

6x10-9 T4 – 1x10-6 T3 + 7. 0487x10-5T2 – 2. 4403x10-3 T +4. 2113

Cp at 55. 350C= 4. 1789J/g

The power emission rate from the hot water stream Qhot is

= Vhot x Cphot(T1 – T2) J/s (Incropera and DeWitt 236)

= 50 x 4. 1789 (57. 5 – 53. 2)

= 898. 5J/s

Cold water

Mean Temperature = (T3 + T4)/2

= (13. 2+ 25. 4)/2

= 19. 30C

At 19. 30C the specific heat of water calculated using the above equation is

Cp at 19. 30C= 4. 1841J/g

The power absorption rate from the cold water stream Qcold is

= Vcold x Cpcold(T4 – T3) J/s

= 15 x 4. 1841 (25. 4 – 13. 2)

= 765. 7J/s

Therefore the overall exchange efficiency η

= 85. 2%

The calculations for all observations are presented in Table-2 (a) and (b)

Ob. No.

Vhot (g/s)

Vcold (g/s)

Δt Hot (T1-T2) K

Δt Cold (T4-T3) K

Average Temp Hot Stream

Average Temp Cold Stream

Cp of the hot stream

Cp of the cold stream

1

50

15

4. 3

12. 2

55. 35

19. 3

4. 1789

4. 1841

2

50

20

4. 5

10

54. 95

18. 3

4. 1788

4. 1848

3

50

27

4. 5

7. 7

54. 65

16. 95

4. 1788

4. 1858

4

50

31

5. 3

8. 2

54. 05

17. 4

4. 1786

4. 1855

Calculation of Cp for both streams using the prescribed formula

Obs. No.

Heat loss rate for hot stream

Heat gain rate for cold stream

Thermal Efficiency

1

898. 5

765. 7

85. 2%

2

940. 2

837. 0

89. 0%

3

940. 2

870. 2

92. 6%

4

1107. 3

1063. 9

96. 1%

Calculation of Thermal Efficiencies

We observe two important things from our findings. The first is that holding the mass flow rate and temperature of the hot stream steady and increasing the flow of the cold stream led to a steady improvement of the thermal efficiency of the apparatus. This supports the theory that increased flow creates more turbulence and improvement in the heat transfer coefficient. The second observation is that the improvement of efficiency might also have resulted in a gradual reduction of heat losses from the system as the experiments were performed one after the other and despite the fact that

sufficient time was allowed for the system to become stable.

Experiment 3

A sample of the calculations is as follows:

Temperature reduction for the Hot Fluid Δt Hot= T1 – T2

= 56. 4 – 48. 3

= 8. 1K

Temperature increase for the Cold Fluid Δt Cold= T4 – T3

= 42. 9 – 21. 3

= 21. 6K

the summary of the observations and calculations

Obs. No.

Vhot(g/s)

Vcold(g/s)

T1°C

T2°C

T3°C

T4°C

Δt Hot (T1-T2) (K)

Δt Cold (T4-T3) (K)

1

40

14

56. 4

48. 3

21. 3

42. 9

8. 1

21. 6

2

34

20

55. 5

43. 4

21. 3

40. 7

12. 1

19. 4

3

28

26

56. 4

40. 4

21. 1

37. 4

16. 0

16. 3

4

22

32

56. 8

35. 8

21. 2

34. 9

21. 0

13. 7

The calculations show that with increase in the flow rate of both streams the temperature drop of the hot stream increased steadily. On the other hand, the temperature rise of the cold stream decreased substantially. The clear jacket allowed the observation that the jacket was continuously full at all times and because neither stream had any color, it was not possible to notice whether the turbulence of the two streams changed at all. In future experiments it might be a good idea to introduce a small stream of dye into both streams to observe turbulence. However, this would lead to a change in the mass flow rate and more importantly in the specific heat capacity, which would have to be accounted for in subsequent calculations.

Experiment 4

Mean Temperature = (T1 + T2)/2

= (56. 4 + 48. 3)/2

= 52. 350C

Cp of Water at Temperature T equals

6x10-9 T4 – 1x10-6 T3 + 7. 0487x10-5T2 – 2. 4403x10-3 T +4. 2113

Cp at 52. 350C= 4. 1783J/g

The power emission rate from the hot water stream Qhot is

= Vhot x Cphot(T1 – T2) J/s

= 40 x 4. 1783 (56. 4 – 48. 3)

= 1353. 8J/s

Cold Stream

Mean Temperature = (T3 + T4)/2

= (21. 3+ 42. 9)/2

= 21. 60C

At 21. 60C the specific heat of water calculated using the above equation is

Cp at 21. 60C= 4. 1783J/g

The power absorption rate from the cold water stream Qcold is

= Vcold x Cpcold(T4 – T3) J/s

= 14 x 4. 1783 (42. 9 – 21. 3)

= 1263. 7J/s

Therefore the overall thermal efficiency η

= 93. 3%

The calculations for all observations are presented in Table-4 (a) and (b)

Obs. No.

Vhot (g/s)

Vcold (g/s)

Δt Hot (T1-T2) (K)

Δt Cold (T4-T3) (K)

Average Temp Hot Stream

Average Temp Cold Stream

Cp of the hot stream

Cp of the cold stream

1

40

14

8. 1

21. 6

52. 35

32. 1

4. 1783

4. 1789

2

34

20

12. 1

19. 4

49. 45

31

4. 1779

4. 1791

3

28

26

16. 0

16. 3

48. 4

29. 25

4. 1779

4. 1796

4

22

32

21. 0

13. 7

46. 3

28. 05

4. 1777

4. 1800

Calculation of Cp for both streams using the prescribed formula

Obs. No.

Heat loss rate for hot stream

Heat gain rate for cold stream

Thermal Efficiency

1

1353. 8

1263. 7

93. 3%

2

1718. 8

1621. 5

94. 3%

3

1871. 7

1771. 3

94. 6%

4

1930. 1

1832. 5

94. 9%

Important findings of this experiment are that the thermal efficiency of the plate and frame heat exchanger is better than that of the concentric tube heat exchanger and secondly, with the increase in flow rate the efficiency improved only marginally. This is perhaps because with the multiple pass arrangement where the two streams changed direction frequently an element of turbulence was already present that did not change much with the change in flow rates. However, the observations taken are too few to arrive at this conclusion with confidence.

Experiment 5

Mean Temperature = (T1 + T2)/2

= (57. 9 + 53. 6)/2

= 55. 750C

Cp of Water at Temperature T equals

6x10-9 T4 – 1x10-6 T3 + 7. 0487x10-5T2 – 2. 4403x10-3 T +4. 2113

Cp at 55. 750C= 4. 1790J/g

The power emission rate from the hot water stream Qhot is

= Vhot x Cphot(T1 – T2) J/s

= 50 x 4. 1790 (57. 9 – 53. 6)

= 898. 5J/s

Cold Stream

Mean Temperature = (T3 + T4)/2

= (14. 2+ 25. 5)/2

= 19. 850C

At 19. 850C the specific heat of water calculated using the above equation is

Cp at 19. 850C= 4. 1837J/g

The power absorption rate from the cold water stream Qcold is

= Vcold x Cpcold(T4 – T3) J/s

= 16 x 4. 1837 (25. 5 – 14. 2)

= 756. 4J/s

Therefore the overall thermal efficiency η

(Dincer and Konoglu 136)

= 84. 2%

The calculations for all observations are presented in Tables below

Calculation of Cp

Obs. No.

Vhot (g/s)

Vcold (g/s)

Δt Hot (T1-T2) (K)

Δt Cold (T4-T3) (K)

Average Temp Hot Stream

Average Temp Cold Stream

Cp of the hot stream

Cp of the cold stream

1

50

16

4. 3

11. 3

55. 75

19. 85

4. 1790

4. 1837

2

50

20

4. 6

10. 1

55. 5

19. 15

4. 1790

4. 1842

3

50

26

4. 9

8. 3

55. 35

18. 05

4. 1789

4. 1850

4

50

34

5. 2

6. 8

55

16. 90

4. 1788

4. 1859

Calculation of exchange Efficiencies

Obs. No.

Heat loss rate for hot stream

Heat gain rate for cold stream

Thermal Efficiency

1

898. 5

756. 4

84. 2%

2

961. 2

845. 2

87. 9%

3

1023. 8

903. 1

88. 2%

4

1086. 5

967. 8

89. 1%

Calculation of exchange Efficiencies

Important findings of this experiment are that the thermal efficiency of the plate and frame heat exchanger is comparable to that of the concentric tube heat exchanger but lower than that of the plate and frame heat exchanger. Secondly, with the increase in flow rate of the cold stream the efficiency improved marginally. In this case again, the conclusion can be that the design allows for introducing greater turbulence in the shell-side stream through the baffles provided.

Mass transfer aspects

Mass transfer is calculated as shown below;

Mass transfer = Overall mass transfer coefficient x Actual driving force

mol/m3

Overall mass transfer coefficient= (Kreith, Manglik and Bohn 175)

KG Mass transfer coefficient in the gas phase m/s

KL Mass transfer coefficient in the liquid phase m/s

Kov Overall mass transfer coefficient m/s

m Solubility of carbon dioxide at equilibrium

E = = 1. 011

Ha = = 0. 382

Ha -Hatta modules

D CO_2 , am - CO_2 diffusivity in the MEA solution m2/s

k2 Forward second order reaction rate constant m3/mol. s

CMEA - MEA concentration mol/m3

E Enhancement factor

E = = 57. 25

Overall mass transfer coefficient= = 0. 716

Mass transfer = 0. 716 x 0. 278 = 0. 1991

Works Cited

Incropera, Frank and David, DeWitt. Fundamentals of Heat and Mass Transfer. New York: John Wiley & Sons, 2002. Print

Dincer, Ibrahim & Mehmet Konoglu. Refrigeration system and application. Chichester : John Wiley & sons ltd, 2011. Print

Kreith, Frank, Raj, Manglik & Mark, Bohn. Principles of heat transfer. Stanford: Cengage Learning, Stanford UK, 2011. Print