## REFERENCES


1. Foust, A.S., et al. Principles of Unit Operations. Japan : Toppan Company., 1959.
2. Earle, R.L. Unit Operations in Food Processing. New South Wales : Pergamon Press. Pty., 1966.
3. Bielig, H.J., and Werner, J. Fruit Juice Processing. Agricultural Services Bulletin, No.13. Rome : Food and Agriculture Organization of the United Nations, 1973.
4. Bennett, C.O., and Myers, J.E. Momentum, Heat and Mass Transfer. New York : McGraw-Hill Book Co., 1962.
5. Perry, J.H. Chemical Engineers' Handbook. 4th ed. Tokyo : McGraw-Hill Book Co., 1963.
6. Shocylas, A. "Thin Film Evaporator Construction and Performance." British Chemical Engineering 12(1967) : 1235-1239.
7. Schneider, R. "Liquid Films in Viscous Flow." Chem. Ing. Techn. 27(1955) : 257.
8. Jone, H.H.M. "Characteristics of Flow in Falling Liquid Films." Ind. Chemist 2(1960) : 599.
9. Agarwal, H.C. "Gravity-Flow Falling Film Evaporator." Chemical Age of India 21(1970) : 591-594.

10. McCabe, W.L., and Smith, J.C. Unit Operations of Chemical Engineering. New York : McGraw-Hill Book Co., 1956.

11. Wiegand, J. "Falling Film Evaporators and Their Applications." J. Appl. Chem. Biotechnol. 21(1971) : 351-358.

12. Chun, K.R., and Seban, R.A. "Heat Transfer to Evaporating Liquid Films." J. of Heat Transfer 93(1971) : 391-396.

13. Gray, R.M. "The Plate Evaporator." J. Appl. Chem. Biotechnol. 21(1971) : 359-362.

14. Mc Adams, W.H., et al. "Heat Transfer to Falling-Water Films." Trans. Am. Soc. Mech. Engrs. 62(1940) : 627-635.

15. Kntadeladze, S.A. Fundamentals of Heat Transfer. London : Edward Arnold, 1963.

16. Dukler, A.E. "Fluid Mechanics and Heat Transfer in Vertical Falling Film Systems." Chem. Engng. Prog. Symp. Ser. 50(1960) : 1-10.

17. Wilke, W. "The Mechanics of Film Flow on a Vertical Surface." Chem. Engrg. Prog. 490(1962) : 557.

18. Chun, K.R. "Evaporation from Thin Liquid Film." Ph.D. Dissertation, Univ. of California, Berkeley, 1969.

19. Chen, W. "Heat Transfer in Liquid-Film Flow." I & EC Fundamentals. 8(1963) : 400-405.

20. Penman, T.O., and Tait, W.F. "Heat Transfer in Liquid Film Flow." I & EC Fundamentals 4(1965) : 407-416.

21. Wallgren, W. "Heat Transfer in Liquid Film Flow." I & EC Fundamentals. 6(1967) : 479-480.

22. Meade, G.P. Cane Sugar Handbook. New York : John Wiley & Sons., 1963.

# Appendix A

## CALIBRATION DATA

### 1. Calibration of Rotameter

A rotameter of "BROOKS" tube size R.6.15.B with ruby spherical float was calibrated. Triplicated data were obtained and only the average values were reported here.

Table A-1

| Rotameter reading | Conc$^{\underline{n}}$ of sucrose sol$^{\underline{n}}$ (Brix) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0 | | 5 | | 10 | | 15 | |
| | wt. of sol$^n$ (lb/hr) | $\Gamma_o$ (lb/hr ft) | wt. of sol$^n$ (lb/hr) | $\Gamma_o$ (lb/hrft) | wt. of sol$^n$ (lb/hr) | $\Gamma_o$ (lb/hrft) | wt. of sol$^n$ (lb/hr) | $\Gamma_o$ (lb/hrft) |
| 1 | 4.0 | 30 | | | | | | |
| 2 | 8.6 | 66 | | | | | | |
| 3 | 15.8 | 120 | 15.0 | 115 | 14.2 | 108 | 13.5 | 103 |
| 4 | 24.6 | 188 | | | | | | |
| 5 | 29.7 | 227 | 29.9 | 228 | 28.3 | 217 | 25.7 | 207 |
| 6 | 37.0 | 282 | | | | | | |
| 7 | 46.2 | 253 | 45.1 | 344 | 43.8 | 334 | 43.0 | 330 |
| 8 | 54.5 | 416 | | | | | | |
| 9 | 62.0 | 474 | 60.5 | 461 | 59.0 | 450 | 59.0 | 450 |
| 10 | 70.0 | 535 | | | | | | |
| 11 | 78.7 | 600 | 76.9 | 587 | 76.6 | 585 | 75.1 | 577 |
| 12 | 87.8 | 670 | | | | | | |
| 13 | 95.0 | 726 | 95.0 | 726 | 95.1 | 726 | 91.8 | 702 |

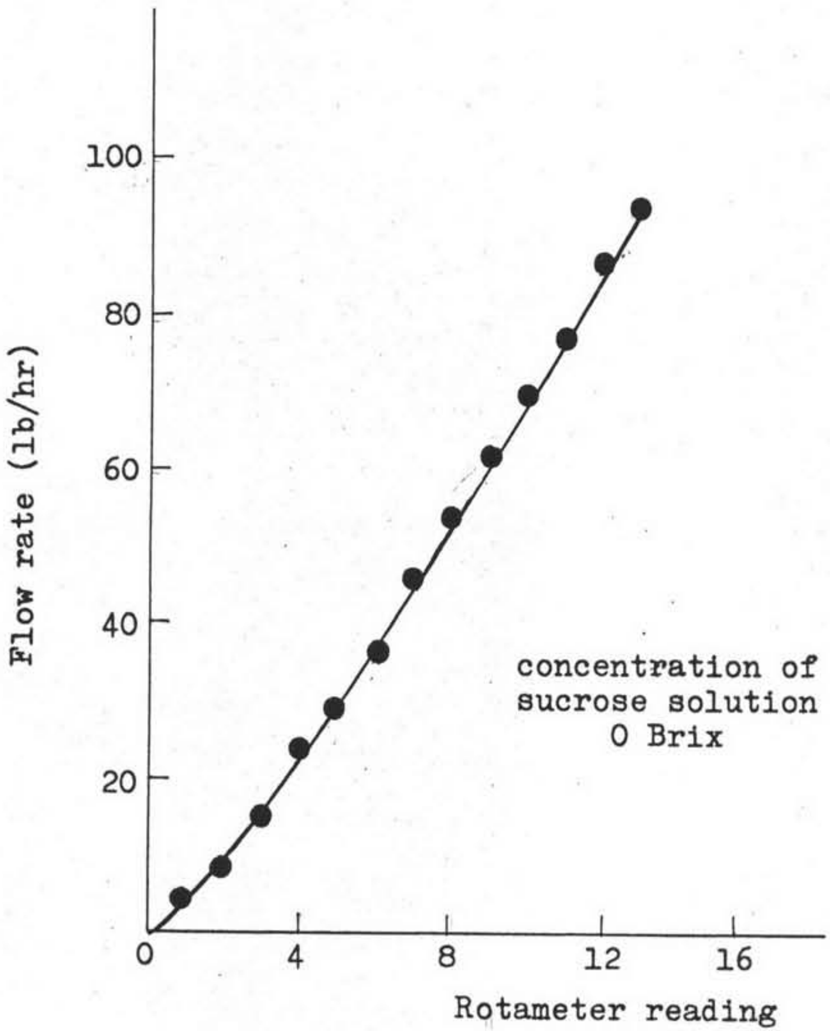



Fig. A.1 Calibration of rotameter

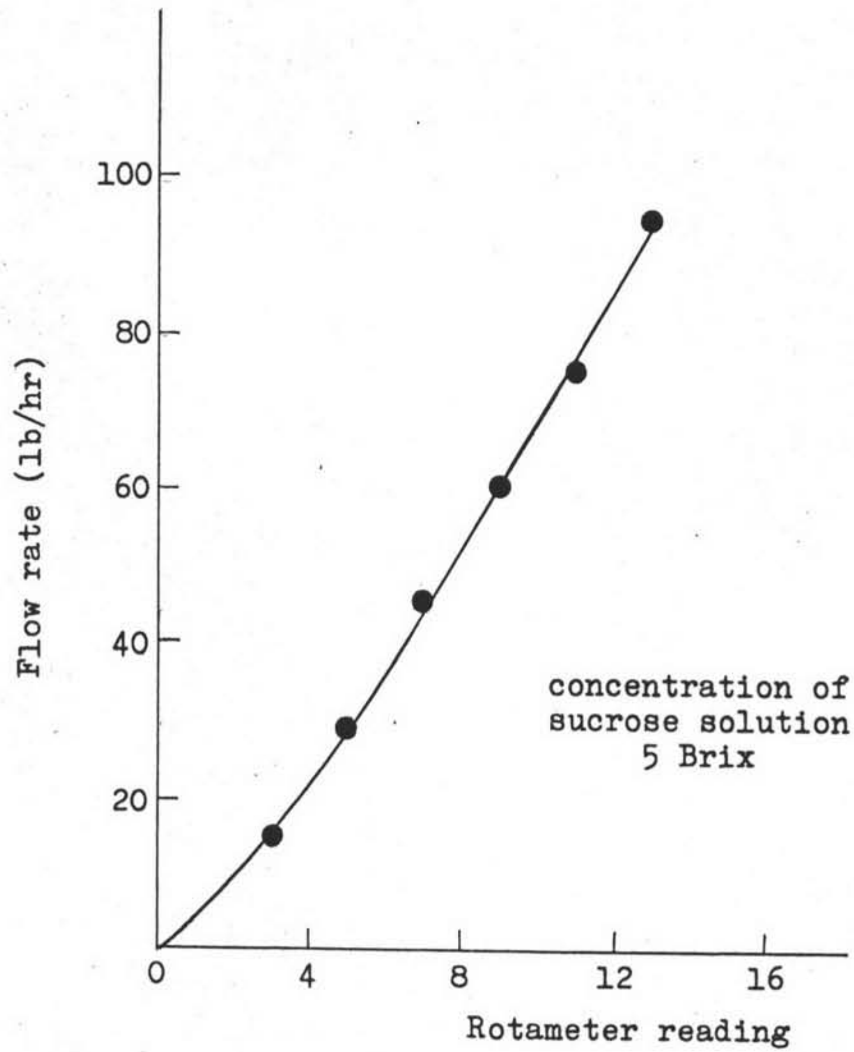



Fig. A.2 Calibration of rotameter

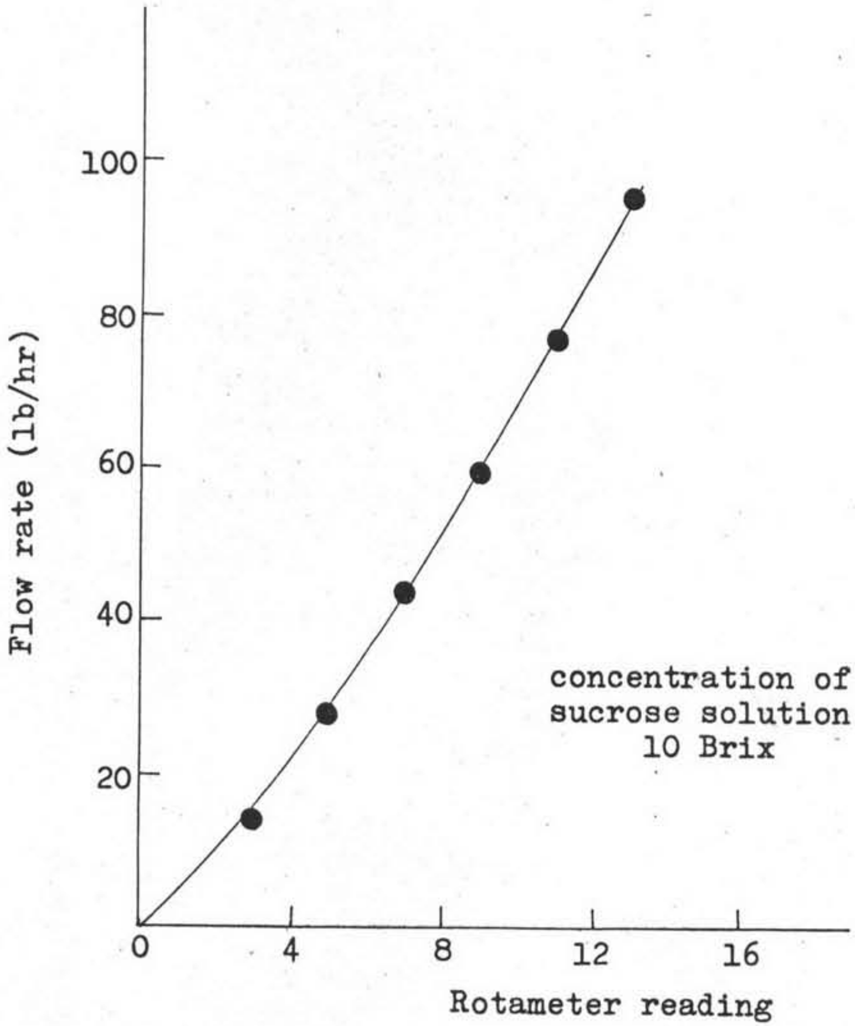



Fig. A.3 Calibration of rotameter

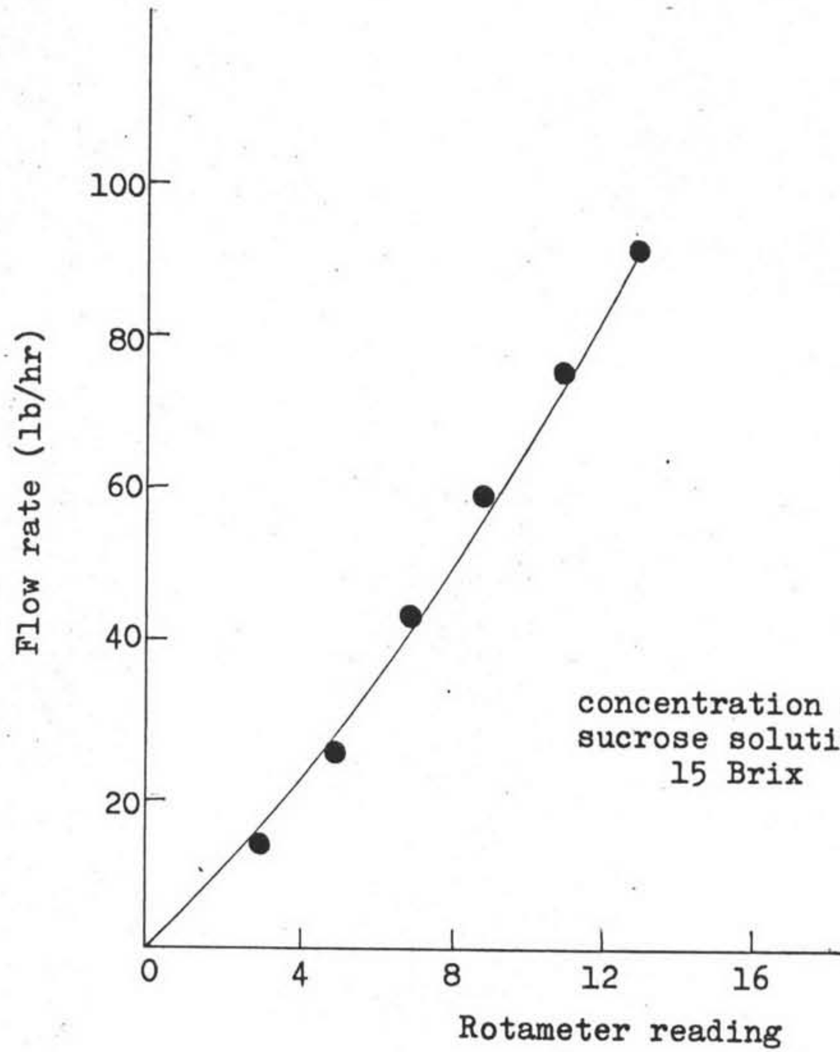



Fig. A.4 Calibration of rotameter

| Temp. (°F) | 68 | 86 | 104 | 122 | 140 | 176 | 203 |
|---|---|---|---|---|---|---|---|
| Emf.reading (mv) | 0.80 | 1.23 | 1.65 | 2.07 | 2.50 | 3.33 | 3.95 |

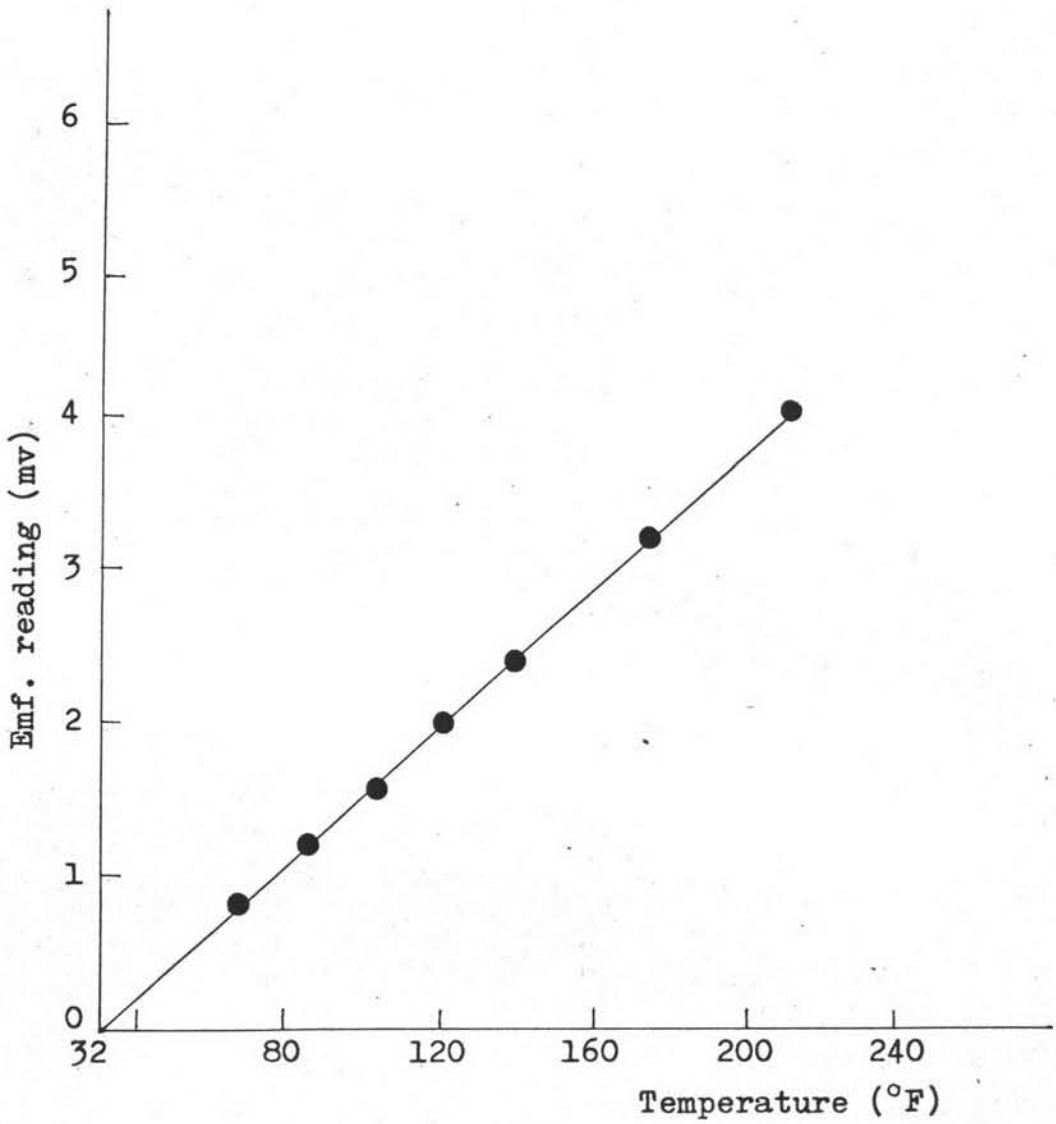
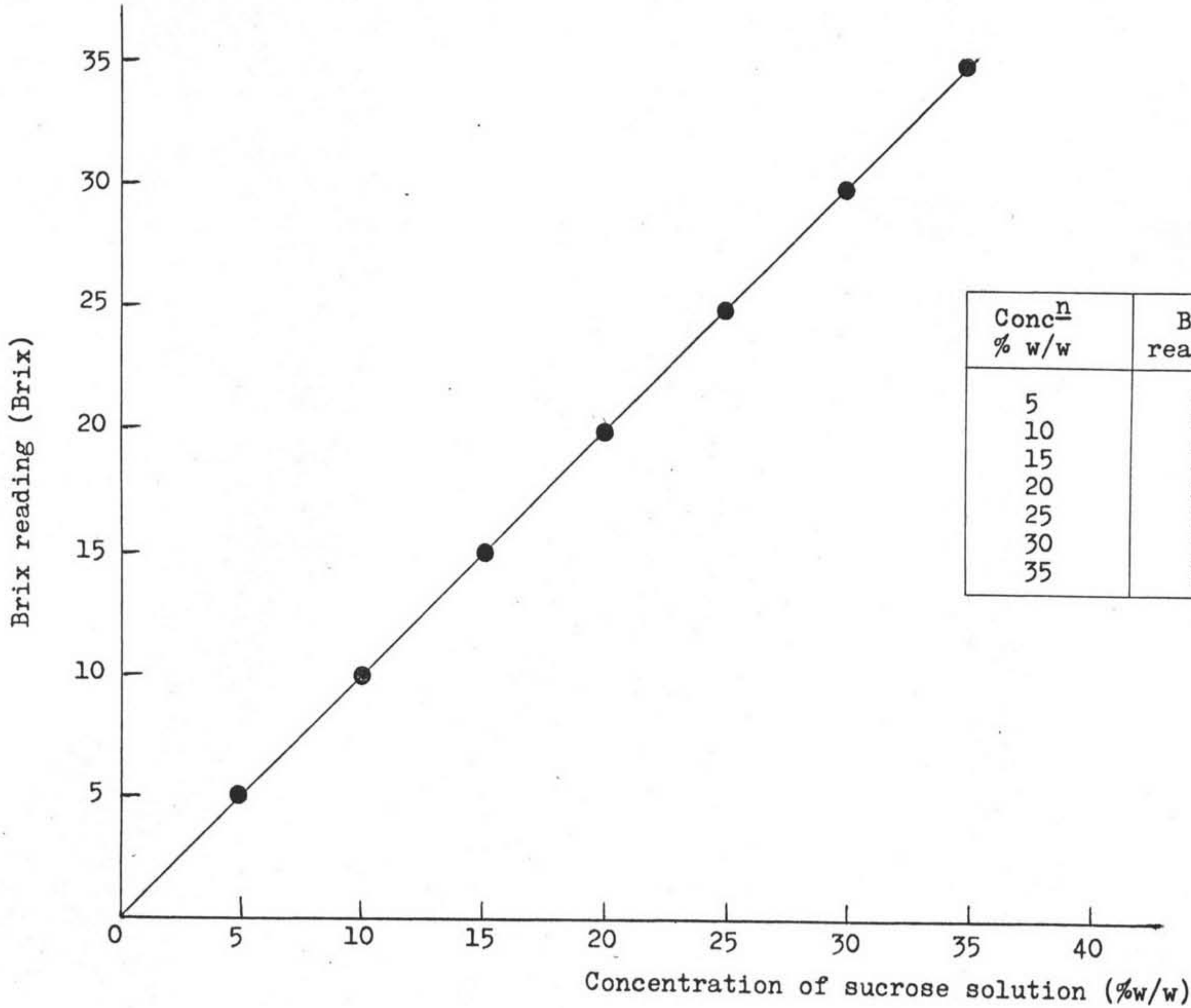



Fig. A.5 Calibration of chromel - alumel thermocouple




| Conc$^{\underline{n}}$ % w/w | Brix reading |
|---|---|
| 5 | 5 |
| 10 | 10 |
| 15 | 15.1 |
| 20 | 19.9 |
| 25 | 24.9 |
| 30 | 30 |
| 35 | 34.9 |

Fig. A.6 Calibration of Brix refractometer

## Appendix B

## SOME PROPERTIES OF SUCROSE SOLUTION

1. Specific Heat and Thermal Conductivity of Sucrose Solution

Hugot[22] cites the equation c=1-0.006B, where B is the Brix of the solution. For an 80 Brix molasses this figures to a specific heat (c) of about 0.5.

The heat conductivity of 60 percent sucrose solution at 50°C is about 0.37[22].

2. Viscosity of Sucrose Solution

The viscosity of any sugar liquor will be reduced sharply by dilution i.e. by changing in Brix. Triplicated data were obtained in measurement of viscosity of sucrose solutions at concentration of 5, 10, 15 and 20 Brix and only the average values were reported here.

Table B-1

| Temperature ($^oC$) | viscosity (centipoise) | | | |
|---|---|---|---|---|
| | Concentration of sucrose solution(Brix) | | | |
| | 5 | 10 | 15 | 20 |
| 30 | 0.939 | 1.060 | 1.295 | 1.511 |
| 40 | 0.780 | 0.869 | 1.038 | 1.214 |
| 50 | 0.658 | 0.721 | 0.858 | 1.005 |
| 60 | 0.581 | 0.616 | 0.726 | 0.851 |
| 70 | 0.512 | 0.529 | 0.628 | 0.730 |

From the following form

$$\log \eta = \frac{A}{T} + B$$

A and B were found for sucrose $sol^{\underline{n}}$ 0-40 Brix and were shown in Table B-2

Table B-2

| $Conc^{\underline{n}}$ of sucrose $sol^n$ (Brix) | $A = \alpha_1 + \beta_1 c^{n_1}$ | $B = \alpha_2 + \beta_2 c^{n_2}$ |
|---|---|---|
| 0 | 17.29 | 0.6168 |
| 5 | 16.04 | 0.505 |
| 10 | 17.74 | 0.507 |
| 15 | 18.50 | 0.446 |
| 20 | 18.48 | 0.3780 |
| 30 | 19.25 | 0.2406 |
| 40 | 20.70 | 0.0488 |

Hence, for sucrose $sol^n$ 0-40 Brix

$$\log \eta = \frac{(\alpha_1 + \beta_1 c^{n_1})}{t} - (\alpha_2 + \beta_2 c^{n_2})$$

$\alpha_1 = 17.3, \alpha_2 = 0.62, \beta_1 = 0.184, \beta_2 = 0.04$

$n_1 = 0.71, n_2 = 1.09$

$c$ = $conc^{\underline{n}}$ of sucrose $sol^n$, Brix, $t$ = temperature, $^oC$

## Appendix C

### 1. Measurement of heated wall temperature

characteristic of feed : water

length of heated tube : 1 ft

Table C-1

| Steam inlet temp ($^{o}F$) | Wall temp. ($^{o}F$) |
|---|---|
| 235 | 232.75 |
| 259 | 256.75 |
| 272 | 269.75 |
| 284 | 281.75 |
| 293 | 290.75 |
| for all feed rates | |

2. Measurement of vapor phase temperature

characteristic of feed : water

feed rate : 46.2 lb/hr

a) length of heated tube : 1 ft

Table C-2

| Steam inlet temp (°F) | Vapor phase temp.(°F) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Distance from the lower end of the heated tube (in.) | | | | | | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 259 | 184.5 | 197.1 | 202.1 | 205 | 207 | 207 | 208 | 210 | 210 | 210.8 | 210.8 | 210.8 |
| 272 | 209.3 | 210.2 | 210.2 | 211 | 211 | 212 | 212 | 212 | 212 | 212 | 212 | 212 |

b) Length of heated tube : 2 ft

Table C-3

| Distance from the lower end of the heated tube (in.) | Vapor temperature (°F) | |
|---|---|---|
| | Steam inlet temperature (°F) | |
| | 259 | 272 |
| 1 | 210 | 212 |
| 2 | " | " |
| 3 | " | " |
| 4 | " | " |
| 5 | " | " |
| 6 | " | " |
| 7 | " | 213 |
| 8 | " | " |
| 9 | " | " |
| 10 | " | " |
| 11 | " | " |
| 12 | " | " |
| 13 | " | 212 |
| 14 | " | " |
| 15 | " | " |
| 16 | 208 | " |
| 17 | " | " |
| 18 | " | " |
| 19 | " | " |
| 20 | " | " |
| 21 | " | 213 |
| 22 | " | " |
| 23 | " | " |
| 24 | " | " |

Appendux D

# NUMERICAL RESULTS

## Part I Experiments Using Water as Feed

a) Length of heated tube 2 ft

Table D-1

| Steam inlet temp. (°F) | Feed temp. (°F) | Feed rate (lb/hr) | Concentrate | | Condensate | | Vapor temp. (°F) | Evaporated fraction | $h_m$ Btu/hr ft$^2$ °F |
|---|---|---|---|---|---|---|---|---|---|
| | | | Flow rate (lb/hr) | Temp. (°F) | Flow rate (lb/hr) | Temp. (°F) | | | |
| 272 | 198 | 15.8 | 4.82 | 204.8 | 12.1 | 204.8 | 212 | 0.695 | 718 |
| | | 29.7 | 19.03 | " | 13.5 | " | " | 0.359 | 711 |
| | | 46.2 | 35.05 | " | 13.5 | " | " | 0.241 | 758 |
| | | 62.0 | 50.75 | " | 13.8 | " | " | 0.182 | 779 |
| | | 78.7 | 68.64 | " | 13.8 | " | " | 0.127 | 717 |
| | | 95.0 | 86.66 | " | 13.8 | " | " | 0.087 | 623 |
| 284 | 93 | 15.8 | 4.0 | 204.8 | 16.2 | 204.8 | 210 | 0.750 | 730 |
| | | 29.7 | 18.9 | " | 14.6 | " | " | 0.364 | 768 |
| | | 46.2 | 33.9 | " | 15.5 | " | " | 0.265 | 854 |
| | | 62.0 | 53.9 | 206.6 | 15.3 | " | " | 0.132 | 934 |
| | | 78.7 | 72.9 | 207.5 | 14.6 | " | " | 0.073 | 826 |
| | | 95.0 | 92.9 | " | 15.0 | " | " | 0.021 | 730 |
| | 198 | 15.8 | 1.0 | 206.6 | 15.4 | 204.8 | 212 | 0.936 | 798 |
| | | 29.7 | 16.7 | " | " | " | " | 0.436 | 714 |
| | | 46.2 | 32.1 | " | 15.2 | " | " | 0.305 | 784 |
| | | 62.0 | 46.7 | " | 15.8 | " | " | 0.247 | 860 |
| | | 78.7 | 66.5 | " | 15.8 | " | " | 0.155 | 708 |
| | | 95.0 | 85.1 | " | 15.7 | " | " | 0.102 | 598 |

Table D-2

Length of heated tube 2 ft

| Feed temp (°F) | Steam temp (°F) | $Re \times 10^{-3}$ | Concentrate $\Gamma_{L\,exp}$ (lb/hrft) | $\Gamma_{L\,theo}$ (lb/hrft) | $h_m \left(\frac{\mu^2}{\rho^2 g k^3}\right)^{1/3}$ |
|---|---|---|---|---|---|
| 93 | 284 | 0.7 | - | - | 0.127 |
| | | 1.3 | - | - | 0.134 |
| | | 2.0 | - | - | 0.166 |
| | | 2.6 | - | - | 0.145 |
| | | 3.4 | - | - | 0.144 |
| | | 4.0 | - | - | 0.127 |
| 198 | 272 | 0.7 | 36.9 | 0.0 | 0.125 |
| | | 1.3 | 137.9 | 142.7 | 0.123 |
| | | 2.0 | - | - | 0.132 |
| | | 2.6 | - | - | 0.136 |
| | | 3.4 | - | - | 0.125 |
| | | 4.0 | - | - | 0.108 |
| 198 | 284 | 0.7 | 7.7 | 0.0 | 0.139 |
| | | 1.3 | 128.2 | 134.0 | 0.124 |
| | | 2.0 | - | - | 0.134 |
| | | 2.6 | - | - | 0.150 |
| | | 3.4 | - | - | 0.123 |
| | | 4.0 | - | - | 0.104 |

b) Length of heated tube : 2 ft

Steam inlet temperature : 284 °F

Table D-3

| Feed rate (lb/hr) | Feed temp. (°F) | Concentrate | | Condensate | | Vapor temp. (°F) | Evaporated fraction | $h_m$ Btu/hr ft² °F |
|---|---|---|---|---|---|---|---|---|
| | | Flow rate (lb/hr) | Temp. (°F) | Flow rate (lb/hr) | Temp. (°F) | | | |
| 46.20 | 93 | 33.9 | 204.8 | 13.9 | 204.8 | 212 | 0.265 | 954 |
| | 126 | 33.6 | " | " | " | " | 0.272 | 887 |
| | 148 | 33.3 | " | " | " | " | 0.279 | 847 |
| | 163 | 33.0 | " | 13.2 | " | " | 0.286 | 825 |
| | 181 | 32.6 | " | 13.5 | " | " | 0.294 | 801 |
| | 198 | 32.1 | " | " | " | " | 0.305 | 785 |
| 95.00 | 93 | 92.9 | 204.8 | 14.5 | 204.8 | 100 | 0.021 | 730 |
| | 111 | 92.7 | 206.6 | " | " | " | 0.024 | 647 |
| | 133 | 91.9 | 206.6 | 13.9 | " | " | 0.032 | 575 |
| | 149 | 90.4 | 208.4 | " | " | " | 0.047 | 572 |
| | 163 | 89.8 | 208.4 | " | " | " | 0.054 | 531 |
| | 180 | 89.1 | 206.6 | " | " | " | 0.061 | 428 |
| | 198 | 88.5 | 206.6 | " | " | " | 0.067 | 401 |

c) Feed rate 29.70 lb/hr

Table D-4

| Length of heated tube (ft) | Feed temp. (°F) | Steam inlet temp. (°F) | Concentrate Flow rate (lb/hr) | Concentrate Temp. (°F) | Condensate Flow rate (lb/hr) | Condensate Temp. (°F) | Vapor temp. (°F) | Evaporate fraction | $h_m$ Btu/hr $ft^2$ °F |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 93 | 235 | 29.7 | 166.1 | 3.7 | 199.4 | - | - | 760 |
| | | 259 | 29.0 | 183.2 | 4.4 | 203.9 | 210 | 0.022 | 573 |
| | | 272 | 28.1 | 203.9 | 5.7 | " | " | 0.053 | 628 |
| | | 284 | 27.1 | 205.7 | 6.4 | " | " | 0.088 | 649 |
| | | 293 | 26.4 | 207.5 | 7.0 | " | " | 0.111 | 690 |
| 2 | 93 | 235 | 28.6 | 204.8 | 5.3 | 204.8 | 210 | 0.071 | 974 |
| | | 259 | 24.4 | 206.6 | 9.9 | " | " | 0.177 | 886 |
| | | 272 | 20.1 | 204.8 | 13.5 | " | " | 0.324 | 826 |
| | | 284 | 18.9 | " | 14.6 | " | " | 0.364 | 715 |
| | | 293 | 17.0 | " | 14.5 | " | " | 0.428 | 760 |
| | 198 | 235 | 26.0 | 206.6 | 14.5 | 204.8 | 212 | 0.145 | 737 |
| | | 259 | 22.1 | " | " | " | " | 0.257 | 665 |
| | | 272 | 19.0 | " | 13.5 | " | " | 0.359 | 714 |
| | | 284 | 16.8 | " | 15.4 | " | " | 0.436 | 708 |
| | | 293 | 15.2 | " | 15.2 | " | " | 0.487 | 702 |

Table D-5

| Length of heated tube (ft) | Feed temp ($^oF$) | Re $\times 10^{-3}$ | Steam temp ($^oF$) | Concentrate $\Gamma_{L exp}$ (lb/hrft) | $\Gamma_{L theo}$ (lb/hrft) |
|---|---|---|---|---|---|
| 1 | 93 | 1.3 | 235 | 221.8 | 213.1 |
| | | | 259 | 215.5 | 198.3 |
| | | | 272 | 206.8 | 189.1 |
| | | | 284 | 199.3 | 182.0 |
| | | | 293 | 194.0 | 179.7 |
| 2 | 93 | 1.3 | 235 | 202.9 | 199.8 |
| | | | 259 | 179.5 | 169.2 |
| | | | 272 | 152.4 | 149.4 |
| | | | 284 | 137.9 | 134.0 |
| | | | 293 | 125.0 | 128.7 |
| | 198 | 1.3 | 235 | 202.3 | 199.8 |
| | | | 259 | 165.0 | 169.2 |
| | | | 272 | 144.6 | 149.4 |
| | | | 284 | 128.2 | 134.0 |
| | | | 293 | 116.5 | 128.7 |

d) Feed rate 46.20 lb/hr

Table D-6

| Length of heated tube (ft) | Feed temp. (°F) | Steam inlet temp. (°F) | Concentrate Flow rate (lb/hr) | Concentrate Temp. (°F) | Condensate Flow rate (lb/hr) | Condensate Temp. (°F) | Vapor temp. (°F) | Evaporated fraction | $h_m$ Btu/hr ft$^2$ °F |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 93 | 235 | 46.2 | 154.4 | 4.2 | 203.9 | - | - | 1018 |
| | | 259 | 45.3 | 164.3 | 4.7 | " | 210 | 0.020 | 726 |
| | | 272 | 44.5 | 186.8 | 6.1 | " | " | 0.037 | 784 |
| | | 284 | 43.6 | 199.4 | 6.0 | " | " | 0.057 | 825 |
| | | 293 | 42.9 | 203.0 | 7.1 | " | " | 0.072 | 868 |
| 2 | 93 | 235 | 45.1 | 185.9 | 6.7 | 204.8 | 210 | 0.023 | 965 |
| | | 259 | 40.1 | 204.8 | 9.6 | " | " | 0.131 | 851 |
| | | 272 | 38.0 | " | 13.7 | " | " | 0.177 | 855 |
| | | 284 | 33.9 | " | 15.5 | " | " | 0.265 | 867 |
| | | 293 | 33.5 | 205.7 | 17.0 | " | " | 0.274 | 917 |
| | 198 | 235 | 42.7 | 204.8 | 14.5 | 204.8 | 212 | 0.074 | 744 |
| | | 259 | 38.1 | " | " | " | " | 0.176 | 726 |
| | | 272 | 35.1 | " | 13.5 | " | " | 0.241 | 755 |
| | | 284 | 32.1 | " | 15.2 | " | " | 0.305 | 785 |
| | | 293 | 30.3 | " | 15.8 | " | " | 0.344 | 779 |

Part II Experiments Using Sucrose Solution as Feed

Length of heated tube : 2 ft

Steam inlet temperature : 284 °F

Table D-7

| Conc$^{n}$ of sucrose sol$^{n}$ | Feed rate (lb/hr) | Concentrate | | | Condensate | | Vapor temp. (°F) | $h_m$ Btu/hr ft$^2$ °F |
|---|---|---|---|---|---|---|---|---|
| | | Flow rate (lb/hr) | Conc$^{n}$ (Brix) | Temp. (°F) | Flow rate (lb/hr) | Temp. (°F) | | |
| 5 | 15.0 | 3.1 | 21.4 | 204.8 | 13.8 | 204.8 | 212 | 732 |
| | 29.9 | 20.6 | 7.0 | " | 13.9 | " | " | 732 |
| | 45.1 | 35.7 | 6.3 | " | 15.3 | " | " | 791 |
| | 60.5 | 51.3 | 5.8 | " | 15.4 | " | " | 896 |
| | 76.9 | 71.4 | 5.3 | " | 15.5 | " | " | 847 |
| | 95.0 | 95.0 | 5.0 | " | 15.7 | " | " | 600 |
| 10 | 28.3 | 17.9 | 14.8 | " | 13.9 | " | " | 730 |
| | 43.8 | 34.1 | 12.4 | " | 14.3 | " | " | 793 |
| | 59.2 | 50.7 | 11.4 | " | 14.6 | " | " | 816 |
| | 76.6 | 69.5 | 10.8 | " | 14.9 | " | " | 855 |
| | 95.0 | 87.9 | 10.4 | " | 15.8 | " | " | 719 |
| 15 | 25.7 | 17.2 | 22.0 | " | 13.6 | " | " | 664 |
| | 43.0 | 33.9 | 18.8 | " | 14.3 | " | " | 735 |
| | 59.0 | 50.0 | 17.6 | " | 14.5 | " | " | 835 |
| | 75.1 | 69.2 | 16.3 | " | 14.6 | " | " | 852 |
| | 91.9 | 86.5 | 15.8 | " | 15.4 | " | " | 653 |

Table D-8 The Component mass balance

| Conc$^n$ of sucrose sol$^n$ (Brix) | Feed | | Concentrate | | solid loss | % loss |
|---|---|---|---|---|---|---|
| | Flow rate (lb/hr) | Solid content (lb) | Flow rate (lb/hr) | Solid content (lb) | | |
| 5 | 15.0 | 0.75 | 3.2 | 0.69 | 0.06 | 8.70 |
| | 29.9 | 1.49 | 20.6 | 1.42 | 0.07 | 3.50 |
| | 45.1 | 2.25 | 35.7 | 2.25 | 0.01 | 0.44 |
| | 60.5 | 3.01 | 51.3 | 2.98 | 0.03 | 1.00 |
| | 76.9 | 3.85 | 71.4 | 3.78 | 0.07 | 1.82 |
| | 95.0 | 4.75 | 95.0 | 4.75 | - | |
| 11 | 28.3 | 2.83 | 17.9 | 2.65 | 0.18 | 6.36 |
| | 43.8 | 4.38 | 34.1 | 4.23 | 0.15 | 3.42 |
| | 59.2 | 5.92 | 50.7 | 5.79 | 0.13 | 2.19 |
| | 76.6 | 7.66 | 69.5 | 7.51 | 0.15 | 1.96 |
| | 92.8 | 9.28 | 87.9 | 9.15 | 0.13 | 1.40 |
| 15 | 27.7 | 4.06 | 17.2 | 3.78 | 0.28 | 6.90 |
| | 43.0 | 6.38 | 33.9 | 6.37 | 0.01 | 0.15 |
| | 58.0 | 8.85 | 50.0 | 8.80 | 0.05 | 0.56 |
| | 75.1 | 11.32 | 69.2 | 11.28 | 0.04 | 0.35 |
| | 91.9 | 13.77 | 86.5 | 13.67 | 0.10 | 0.73 |

Table D-9

Length of heated tube 2 ft

Steam temperature 284$^{o}$F

| Conc$^{n}$ of sucrose sol$^{n}$ (Brix) | Re X10$^{-3}$ | Concentrate | | $h_m \left(\frac{\mu^2}{\rho^2 g k^3}\right)^{1/3}$ |
|---|---|---|---|---|
| | | $\Gamma_{L\ exp}$ (lb/hrft) | $\Gamma_{L\ theo}$ (lb/hrft) | |
| 5 | 0.4 | 24.7 | 18.3 | 0.150 |
| | 0.8 | 165.2 | 139.0 | 0.150 |
| | 1.3 | - | - | 0.170 |
| | 1.8 | - | - | 0.157 |
| | 2.2 | - | - | 0.168 |
| | 2.8 | - | - | 0.130 |
| 10 | 0.8 | 156.4 | 135.0 | 0.158 |
| | 1.4 | - | - | 0.170 |
| | 1.7 | - | - | 0.174 |
| | 2.1 | - | - | 0.179 |
| | 2.7 | - | - | 0.152 |
| 15 | 0.6 | 140.8 | 114.4 | 0.165 |
| | 1.1 | 259.4 | 260.0 | 0.175 |
| | 1.5 | - | - | 0.196 |
| | 1.8 | - | - | 0.199 |
| | 2.3 | - | - | 0.218 |

## Appendix E

## SAMPLE OF CALCULATIONS

### For 5 degree Brix Sucrose Solution

1. <u>Calculation of $\Gamma_o$ and Re</u>

feed rate is 29.9 lb/hr

$\Gamma_o$ = mass flow rate per unit width calculated from feed rate and tube perimeter.

$$\text{Hence} \quad \Gamma_o = \frac{29.9}{\frac{22}{7} \times \frac{1}{2} \times \frac{2.54}{30.48}} = \frac{29.9}{0.13} = 227 \ \text{lb}/\text{hrft}$$

$$Re = \frac{4\Gamma}{\mu}$$

Where $\mu$ = viscosity of sucrose solution at average concentration and saturation temperature, 212°F.

$$= 0.45 \quad \text{centipoise}$$

$$= 0.45 \times 2.42 \quad \text{lb/hr ft}$$

$$\text{so} \quad Re = \frac{4 \times 227}{0.45 \times 2.42} = 0.8 \times 10^3$$

2. <u>The Component Mass Balance</u>

Feed ( $w_o$) was 29.9 lb/hr at concentration of 5 Brix

Therefore, the solid content in feed = (29.9)(0.05) lb

= 1.495 lb

Concentrate was 20.6 lb/hr at concentration of 7 Brix

Therefore, the solid content in concentrate

= (20.6)(0.07) lb

= 1.442 lb

Solid content loss = 1.495-1.442 lb

= 0.053 lb

% loss $= \frac{0.053}{1.495} \times 100$

= 3.5 %

wt. of concentrate loss $= \frac{100 \times 0.053}{7}$

= 0.75 lb/hr

total wt. of concentrate ($w_L$) = 206 + 0.75

= 21.35 lb/hr

3. <u>The Mean Film Heat Transfer Coefficient</u>

From the equation of

$$q = h_m \pi DL(T_s - T_v) = w_o c_{p_m}(T_v - T_F) + \lambda(w_o - w_L)$$

Hence,
$$h_m = \frac{w_o c_{p_m}(T_v - T_F) + (w_o - w_L)\lambda}{\pi DL(T_s - T_v)}$$

$c_{p_m}$ = mean heat capacity of sucrose solution at average concentration and temperature
= 0.8 Btu/lb $^oF$

$\lambda$ = heat of vaporization at 212$^oF$ = 970.3 Btu/lb

$w_o$ = feed rate = 29.9 lb/hr

$w_L$ = concentrate rate = 21.35 lb/hr

D = inside diameter of tube = $\frac{1 \times 2.54}{2 \times 30.48}$ ft
= $4.16 \times 10^{-2}$ ft

L = length of tube = 2 ft

$T_F$ = feed temperature = 93$^oF$

$T_s$ = wall temperature = 281.75$^oF$

$T_v$ = evaporating temperature = 212$^oF$

So
$$h_m = \frac{29.9(0.8)(212-93)+(970.3)(29.9-21.35)}{\frac{22}{7} \times 4.16 \times 10^{2} \times 2(281.75-212)}$$

= 732 Btu/hr ft$^2$ $^oF$

4. Calculation of $\Gamma_L$ Theoretical

From the equation of

$$\Gamma_o^{4/3} - \Gamma_L^{4/3} = 0.925\, L\, \frac{T_s - T_v}{\lambda} \left( \frac{\rho^2 k^3 g}{\mu} \right)^{1/3} \qquad (2.23)$$

Physical properties $\rho$, k, $\mu$ is determined from average concentration at saturation temperation

$\rho$ = 68.57 $lb/ft^3$

g = $32.174 \times 3600^2$ $ft/hr^2$

k = 0.393 Btu/hr ft $^oF$ (from Perry)

(based on the assumption that the thermal conductivity of sucrose solution was equal to that of water)

$$(227)^{4/3} - \Gamma_L^{4/3} = (0.925)(2)\frac{(281.75-212)}{970.3} \left( \frac{68.57^2 X\ 0.393^3 X\ 32.174\ X\ 3600^2}{0.45\ X\ 2.42} \right)^{1/3}$$

$\Gamma_L$ = 139 lb/hr ft

$\Gamma_{L_{exp}}$ = 165 lb/hr ft

# VITA

Miss Sodsri Chaijareonswad was obtained her Bachelor Degree of Science in major field of Chemical Engineering from the Department of Chemical Technology, Faculty of Science, Chulalongkorn University in 1974.

She has joined King Mongkut's Institue of Technology Thonburi as a full time-lecturer from 1976 to 1977. However, in order to have more time to devote herself in studying and doing the laboratory work of this thesis, she has transferred to be a visiting lecturer of the same institution from 1977 up to now.

She began her master study in 1975 and completed the program in 1979.