APPENDIX-A

SAMPLE CALCULATIONS

A.1 Sample Calculations for Calibration of Measuring Devices

A.1.1 Calibration of Flow Measuring Device

Observation no. 1

Working fluid = Water

Pump speed = 5 rpm

Volume of liquid collected = 100 ml = 0.000l m^3

Time required for collected volume = 522 s

Volumetric flow rate from equation 3.1

$$= \frac{0.0001}{522} = 1.92 \times 10^{-7}$$

$$= 1.92\times10^{-7}\ m^3/s \qquad (A.1)$$

Flow rates at different pump speed is given in Table D.2.1

A.1.2 Calibration of Power

Observation no. 1

Working fluid = Water

Pump speed = 10 rpm

DC power reading V = 28.37 Volt and I = 1.41 A

Inlet temperature of water (T_{in}) = 30 ^{0}C or 303 K

Outlet temperature of water (T_{out}) =77.5 ^{0}C or 350.5 K

Bulk fluid temperature of water (T_b) = 53.75 ^{0}C or 326.75K

All the physical properties are evaluated at bulk fluid temperature

Density of water is estimated at bulk fluid temperature and correlated with temperature as shown in Figure A.1. Density of water = 982.1899 Kg/m^3 at T_b = 326.75K

Heat Capacity of water is estimated from figure A.2. Value of Cp = 4169.231 J/Kg.K at T_b = 326.75 K

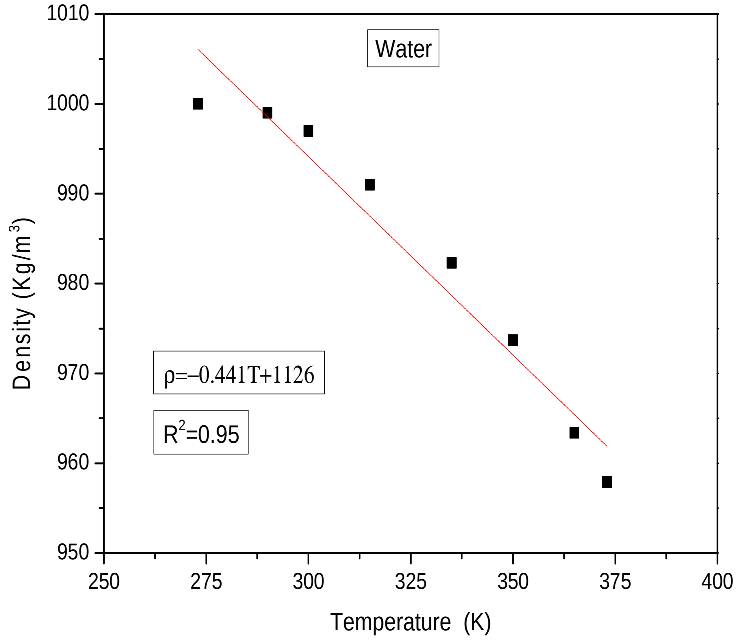

Fig. A.1 Density of water vs. temperature

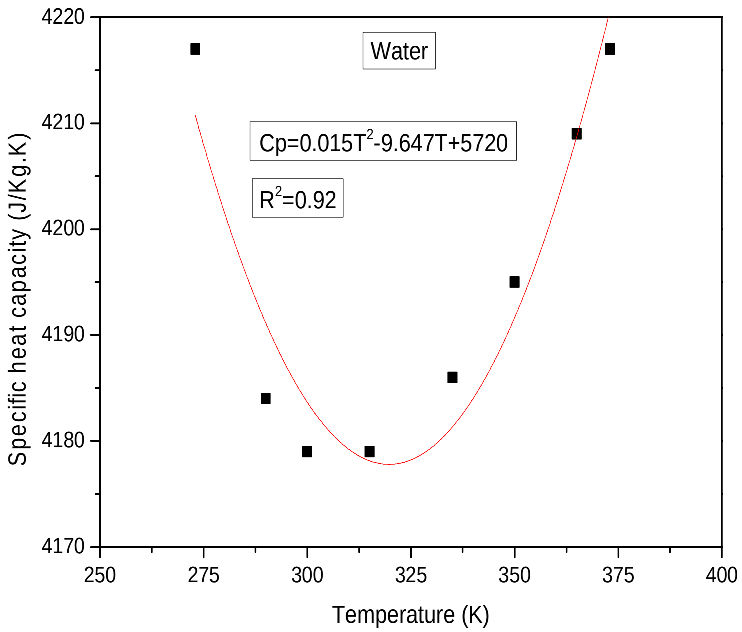

Fig. A.2 Specific heat capacity of water vs. temperature

Electrical power input (ϕ) from equation 3.9

$$= 28.37\times1.41$$

$$\phi = 40 \text{ W} \quad \text{(A.2)}$$

Mass flow rate of water = Density of fluid× volumetric flow rate

$$= 982.1899\times (0.0001/510)$$

$$= 982.1899\times (1.96*10^{-7})$$

$$= 0.0001926 \text{ kg/s} \quad \text{(A.3)}$$

Heat transfer rate (Q) from equation 3.10

= 0.0001926×4169.231× (350.5-303)

Q = 38.14 W (A.4)

Percentage deviation between heat transfer rate and electrical power input

$$= \frac{\phi - Q}{\phi} \times 100$$

$$= \frac{40 - 38.14}{40} \times 100 = 4.65\ \%$$

= 4.65 % (A.5)

Heat transfer rate and electrical power input are given in Table D.2.2

A.2 Sample calculation for friction factor in straight tube section (d_i=720 μm)

A.2.1 Friction factor in straight tube section with water as working fluid

Tube inner diameter = 720 μm = 0.00072 m

Length for pressure drop across test section = 0.68 m

Pump speed = 5 rpm

Due to peristaltic pump digital manometer gives minimum and maximum pressure drop across test sections.

$(\Delta P)_{max}$ = 335 mbar

$(\Delta P)_{min}$ = 17 mbar

Average pressure drop across test section

$$\Delta P = \frac{(\Delta P)_{max} + (\Delta P)_{min}}{2} = \frac{335 + 17}{2} = 176 \text{ mbar}$$

1 mbar = 100 Pa

= 176×100 = 17600 Pa

ρ = 995.772 kg/m^3 (from figure A.1 at operating temperature 30 ^{0}C)

Viscosity of water at operating temperature is calculated from figure A.3. Value of μ = 0.0008 Pa.s at operating temperature 30 ^{0}C.

Volumetric flow rate of water in straight tube section

= 1.92×10^{-7} m^3/s (from equation A.1)

Flow area from equation 3.3

$$= \frac{3.14 \times (0.00072)^2}{4}$$

= 4.07×10^{-7} m^2 (A.6)

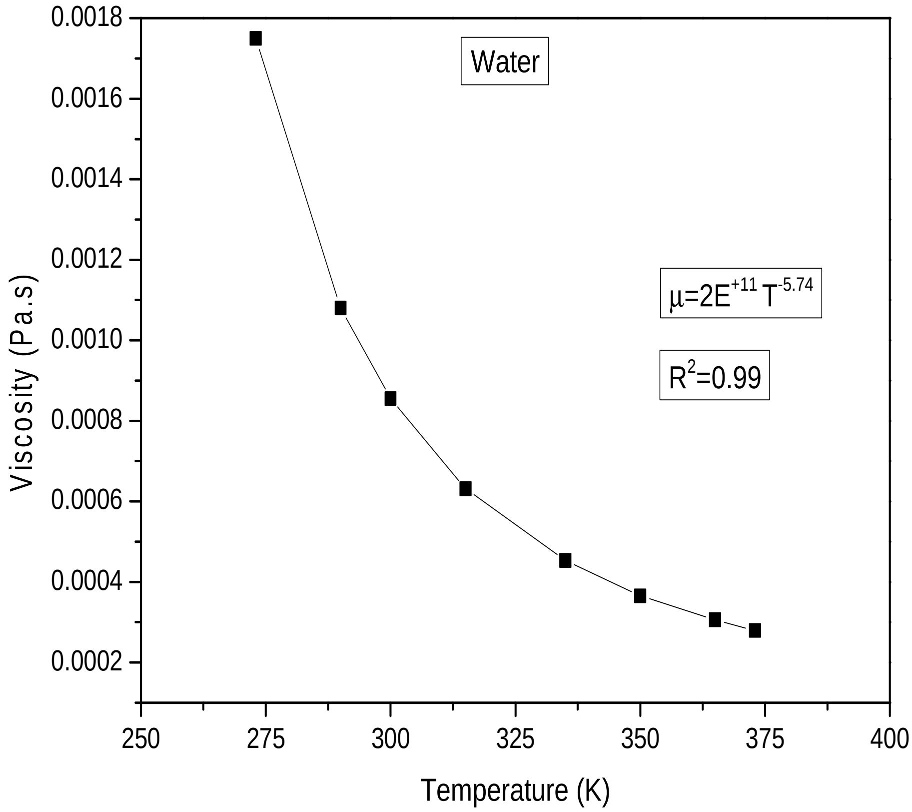

Fig. A.3 Viscosity of water vs. temperature

Fluid velocity from equation 3.2

$$= \frac{1.97\times10^{-7}}{4.07\times10^{-7}} = 0.47$$

$$u = 0.47 \text{ m/s} \tag{A.7}$$

Reynolds number from equation 3.4

$$\mathrm{Re} = \frac{0.00072\times0.47\times995.772}{0.0008}$$

$$= 422 \tag{A.8}$$

Friction factor in straight sections from equation 3.7

$$f = \frac{17600\times0.00072}{2\times0.68\times995.72\times0.47^{2}}$$

$$f = 0.0422 \tag{A.9}$$

Friction factor in straight sections from equation 3.8

$$f_s = \frac{16}{422}$$

$$f_s = 0.0379 \tag{A.10}$$

The percent deviation between experimentally obtained friction factor and theoretically friction factor defined as

$$= \frac{f_{theorectcally} - f_{\exp erimentally}}{f_{theorectcally}} \times 100 \qquad \text{(A.11)}$$

$$= \frac{0.0379 - 0.0422}{0.0379} \times 100$$

= -11.32 % (A.12)

A.2.2 Friction factor in straight tube section with methanol as working fluid

Pump speed = 2 rpm

$(\Delta P)_{\max}$ = 160 mbar

$(\Delta P)_{\min}$ = 2 mbar

$$\Delta P = \frac{160 + 2}{2} = 81 \text{ mbar}$$

ΔP = 81×100 = 8100 Pa

Volume of liquid collected = 100 ml = 0.000l m^3

Time required for collected volume = 634 s

Density and viscosity of methanol are calculated at operating temperature and correlated with temperature as shown Figure A.4 and A.5 respectively.

Value of ρ = 783.05 kg/m^3 at operating temperature 30 ^{0}C

Value of µ = 0.0005 Pa.s at operating temperature 30 ^{0}C

$$\text{Volumetric flow rate} = \frac{0.0001}{634} = 1.58 \times 10^{-7}$$

$$= 1.92 \times 10^{-7} \text{ m}^3\text{/s} \qquad \text{(A.13)}$$

$$\text{Fluid velocity} = \frac{1.58 \times 10^{-7}}{4.07 \times 10^{-7}}$$

$$u = 0.388 \text{ m/s} \qquad \text{(A.14)}$$

$$\text{Reynolds number} = \frac{0.00072 \times 0.388 \times 783.05}{0.0005}$$

$$= 449 \qquad \text{(A.15)}$$

$$\text{Friction factor} = \frac{8100 \times 0.00072}{2 \times 0.68 \times 783.05 \times 0.388^2}$$

$$= 0.036445 \qquad \text{(A.16)}$$

Friction factor in straight sections from equation 3.8

$$f_s = \frac{16}{449}$$

f_s = 0.035617 (A.17)

$$\text{Percent deviation} = \frac{0.035617 - 0.036445}{0.035617} \times 100$$

$= -2.33\ \%$ (A.18)

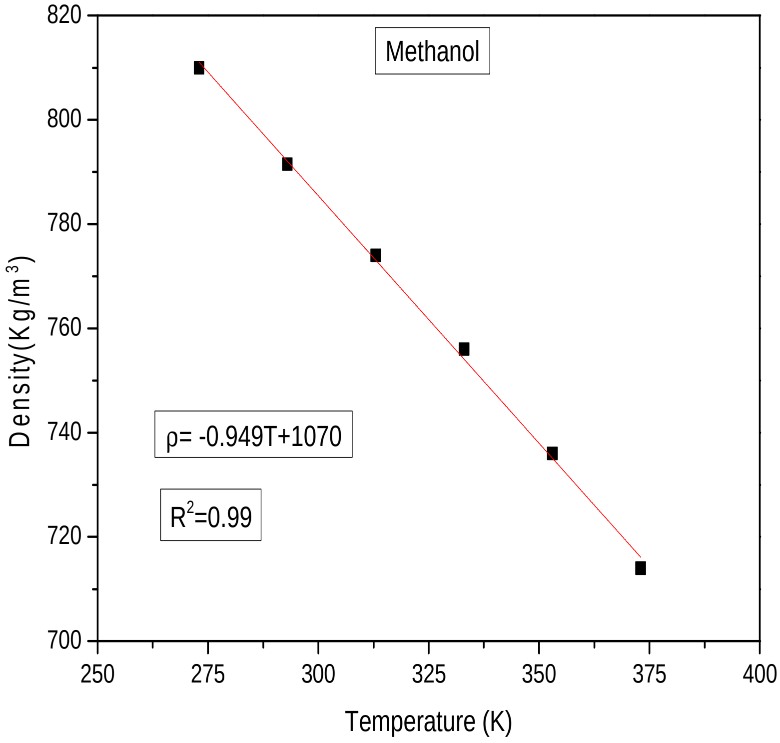

Fig. A.4 Density of methanol vs. temperature

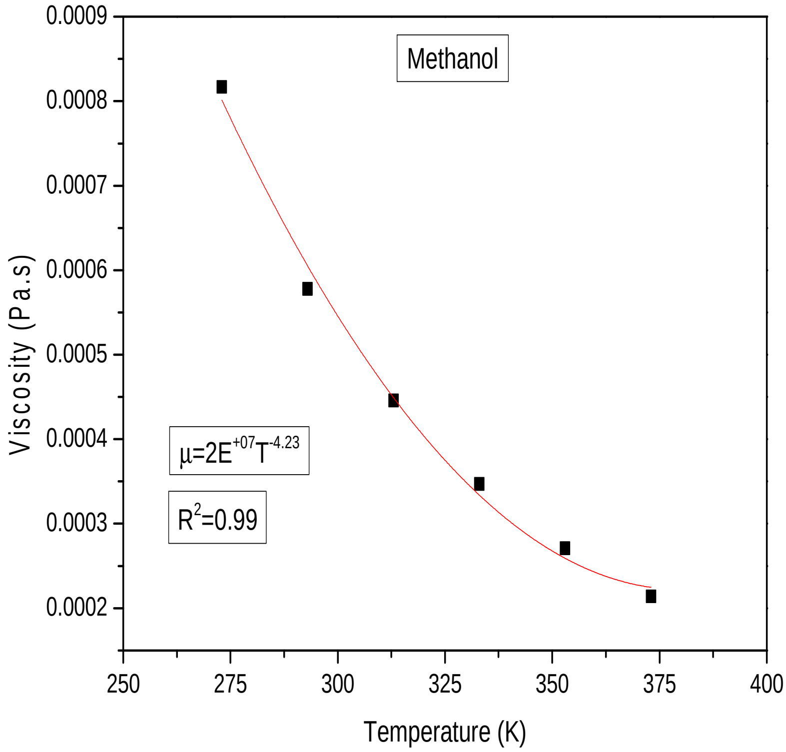

Fig. A.5 Vicosity of methanol vs. temperature

A.2.3 Friction factor in straight tube section with acetone as working fluid

Pump speed = 1 rpm

$(\Delta P)_{max}$ = 104 mbar

$(\Delta P)_{min}$ = 0 mbar

$\Delta P = \dfrac{104+0}{2}$ = 52 mbar

ΔP = 52×100 = 5200 Pa

Volume of liquid collected = 100 ml = 0.0001 m^3

Time required for collected volume = 642 s

Density of acetone is calculated from figure A.6. Value of ρ = 780.199 kg/m^3 at operating temperature 30 ^{0}C

Viscosity of acetone at operating temperature 30 ^{0}C from = 0.0003 Pa.s (figure A.7)

Volumetric flow rate $= \dfrac{0.00005}{321} = 1.56\times10^{-7}$

$= 1.56\times10^{-7}$ m^3/s (A.19)

Fluid velocity $= \dfrac{1.56\times10^{-7}}{4.07\times10^{-7}}$ = 0.383

u = 0.383 m/s (A.20)

Reynolds number $= \dfrac{0.00072\times0.383\times780.199}{0.0003}$

= 729 (A.21)

Friction factor $= \dfrac{5200\times0.00072}{2\times0.68\times780.199\times0.382^2}$

= 0.024 (A.22)

Friction factor in straight sections from equation 3.8

$f_s = \dfrac{16}{449}$

f_s = 0.02195 (A.23)

Percent deviation $= \dfrac{0.02195-0.024}{0.02195}\times100$

= -9.70% (A.24)

Friction factor in all straight tube sections experimentally and theoretically are given in Table D.3 for all three working fluids.

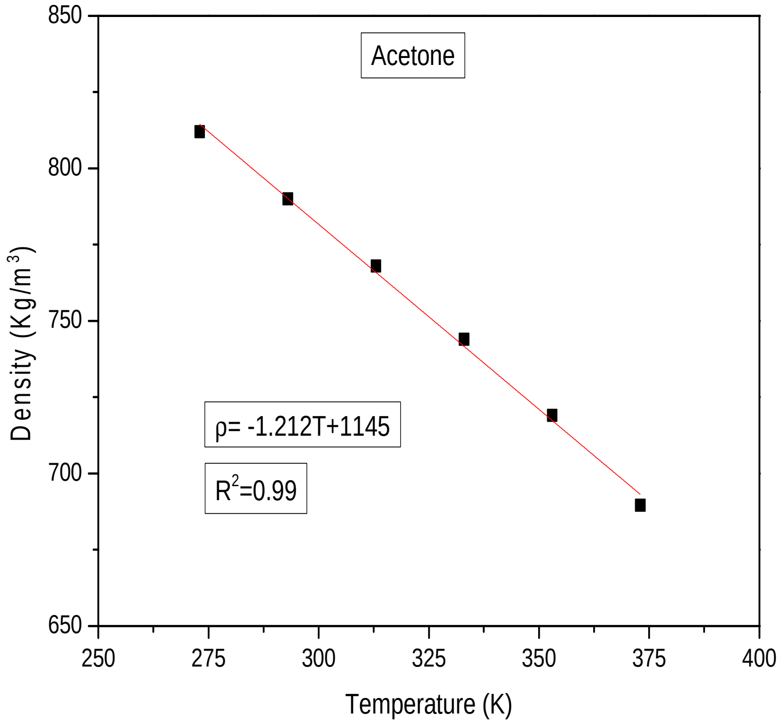

Fig. A.6 Density of acetone vs. temperature

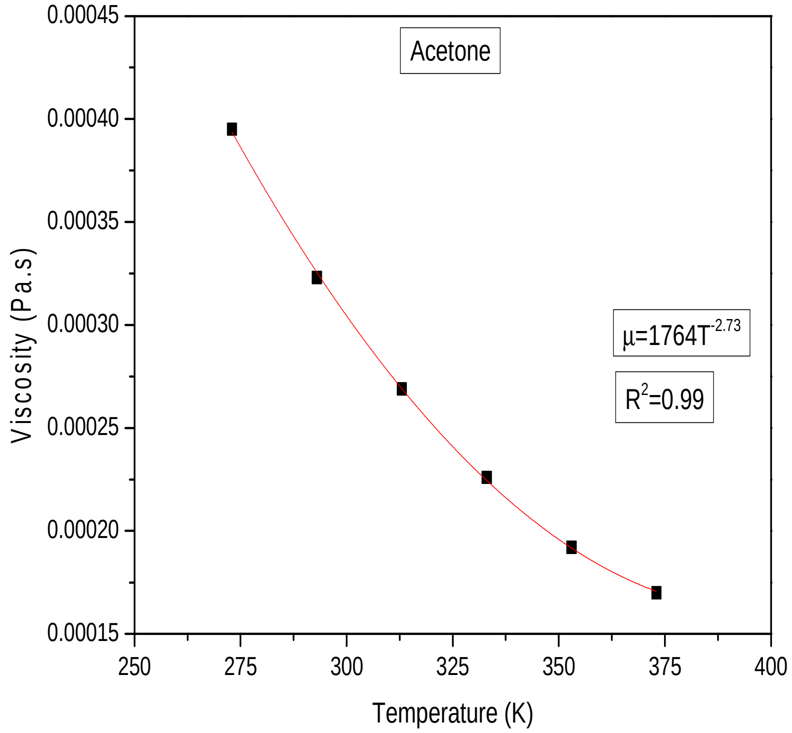

Fig. A.7 Viscosity of acetone vs. temperature

A.3 Sample calculation for friction factor in helical coil (d_i=720 μm) section

A.3.1 Friction factor in helical coil section with water as working fluid

Pump speed = 10 rpm

$(\Delta P)_{max}$ = 340 mbar

$(\Delta P)_{min}$ = 24 mbar

$\Delta P = \dfrac{340+24}{2}$ = 182 mbar

ΔP = 182×100 =18200 Pa

Volume of liquid collected = 100 ml = 0.0001 m^3

Time required for collected volume = 525 s

Volumetric flow rate of water in helical coil section

$$= \frac{0.00002}{105} = 1.905\times10^{-7}$$

$$= 1.905\times10^{-7}\ m^3/s \qquad (A.25)$$

Fluid velocity $= \dfrac{1.905\times10^{-7}}{4.07\times10^{-7}}$ = 0.468

$$u = 0.468\ m/s \qquad (A.26)$$

Reynolds number $= \dfrac{0.00072\times0.468\times995.772}{0.0008}$

$$= 420 \qquad (A.27)$$

Friction factor in helical coil, $f_c = \dfrac{18200\times0.00072}{2\times0.68\times995.72\times0.468^2}$

$$f_c = 0.0442 \qquad (A.28)$$

Prediction of friction factor in helical coil from correlation of Srinivasan et al. (1968) from equation 2.49

$$f_c = 5.22\left(420\sqrt{\frac{0.060}{0.00072}}\right)^{-0.6}$$

$$f_c = 0.0369 \qquad (A.29)$$

Percent deviation between experimental friction factor and value predicted from correlation of Srinivasan et al. (1968)

$= \dfrac{0.0369-0.04415}{0.0369}\times100$ (from equation A.11)

$$= -19.46\ \% \qquad (A.30)$$

A.3.2 Friction factor in helical coil section with methanol as working fluid

Pump speed = 5 rpm

$(\Delta P)_{max}$ = 223 mbar

$(\Delta P)_{min}$ = 11mbar

$\Delta P = \dfrac{223+11}{2}$ =117 mbar

ΔP =117×100 = 11700 Pa

Volume of liquid collected = 100 ml = 0.0001 m^3

Time required for collected volume = 520 s

Volumetric flow rate of water in helical coil section

$$= \frac{0.00002}{104} = 1.92\times10^{-7}$$

$$= 1.92\times10^{-7}\ m^3/s \qquad (A.31)$$

Fluid velocity $= \dfrac{1.92\times10^{-7}}{4.07\times10^{-7}}$ = 0.473

$$u = 0.473\ m/s \qquad (A.32)$$

Reynolds number $= \dfrac{0.00072\times0.473\times783.05}{0.0005}$

$$= 548 \qquad (A.33)$$

Friction factor in helical coil, $f_c = \dfrac{11700\times0.00072}{2\times0.68\times783.05\times0.473^2}$

$$f_c = 0.0354 \qquad (A.34)$$

Prediction of friction factor in helical coil from correlation of Srinivasan et al. (1968)

$$f_c = 5.22\left(548\sqrt{\frac{0.060}{0.00072}}\right)^{-0.6}$$

$$f_c = 0.0315 \qquad (A.35)$$

Percent deviation = $\dfrac{0.0315-0.0354}{0.0315}\times100$

$$= -12.43\ \% \qquad (A.36)$$

A.3.3 Friction factor in helical coil section with acetone as working fluid

Pump speed = 2 rpm

$(\Delta P)_{max}$ = 134 mbar

$(\Delta P)_{min}$ = 0 mbar

$\Delta P = \dfrac{134+0}{2}$ = 67 mbar

ΔP = 67×100 = 6700 Pa

Volume of liquid collected = 100 ml = 0.0001 m^3

Time required for collected volume = 645 s

Volumetric flow rate of water in helical coil section

$$= \frac{0.00002}{105} = 1.55 \times 10^{-7}$$

$$= 1.55 \times 10^{-7}\ m^3/s \qquad (A.37)$$

Fluid velocity $= \dfrac{1.55 \times 10^{-7}}{4.07 \times 10^{-7}}$ = 0.468

$$u = 0.381\ m/s \qquad (A.38)$$

Reynolds number $= \dfrac{0.00072 \times 0.381 \times 780.199}{0.0003}$

$$= 726 \qquad (A.39)$$

Friction factor in helical coil, $f_c = \dfrac{6700 \times 0.00072}{2 \times 0.68 \times 780.199 \times 0.381^2}$

$$f_c = 0.0313 \qquad (A.40)$$

Prediction of friction factor in helical coil from correlation of Srinivasan et al. (1968)

$$f_c = 5.22\left(726\sqrt{\frac{0.060}{0.00072}}\right)^{-0.6}$$

$$f_c = 0.0266 \qquad (A.41)$$

Percent deviation = $\dfrac{0.0266 - 0.0313}{0.0266} \times 100$

$$= -17.69\ \% \qquad (A.42)$$

Experimentally calculated friction factor and value predicted from correlation of Srinivasan et al. (1968) *in all helical coils for all three working fluids are given in Table D.4.*

A.4 Sample calculation for average heat transfer coefficient in a helical coil (d_i=720 μm)

A.4.1 Average heat transfer coefficient in a helical coil with water as working fluid

Pump speed = 10 rpm

Heated length = 0.565 m

Inlet temperature of water (T_{in}) = 30 ^{0}C or 303 K

Outlet temperature of water (T_{out}) = 77.5 ^{0}C or 350.5 K

Bulk fluid temperature of water = 53.75 ^{0}C or 326.75 K

Density of water (ρ) = 982.1899 Kg/m^3 at T_b = 326.75 K (from figure A.1)

Viscosity (μ) = 0.000749 Pa.s at T_b = 326.75K (from figure A.2)

Heat Capacity of water (Cp) = 4169.231 J/Kg.K at T_b = 326.75 K (from figure A.3)

Thermal conductivity of water is calculated at bulk fluid temperature and correlated with temperature as shown in Figure A.8.

Thermal conductivity (k) = 0.6038 (W/m.K) at bulk fluid temperature (T_b = 326.75 K)

Wall temperature (RTD reading); T_1 = 82.05 ^{0}C, T_2 = 80.43 ^{0}C and T_3 = 79.11 ^{0}C

Heat transfer rate

Q=38.14 W (from equation A.4)

Surface area of heat exchanger from equation 3.20

$$A_w = 3.14 \times 0.00072 \times 0.565$$

$$A_w = 1.3 \times 10^{-3}\,\text{m}^2 \qquad \text{(A.43)}$$

Heat flux from equation 3.19

$$q = \frac{38.14}{1.3 \times 10^{-3}} = 29338$$

$$q = 29338\ \text{W/m}^2 \qquad \text{(A.44)}$$

Average wall temperature from equation 3.14

$$\overline{T}_w = \frac{82.05 + 80.43 + 79.11}{3} = 80.53$$

$$\overline{T}_w = 80.53\ ^0\text{C} \qquad \text{(A.45)}$$

$$= 80.53+273 = 353.53\ \text{K} \qquad \text{(A.46)}$$

Bulk fluid temperature from equation 3.15

$$T_b = \frac{30 + 77.5}{2} = 53.75$$

$$T_b = 53.75\ ^0\text{C} \qquad \text{(A.47)}$$

$$= 53.75+273 = 326.75\ \text{K} \qquad \text{(A.48)}$$

Average heat transfer coefficient from equation 3.13

$$\bar{h} = \frac{29338}{(353.53 - 326.75)} = 1095.52$$

$$\bar{h} = 1095.52 \text{ W/m}^2.\text{K} \tag{A.49}$$

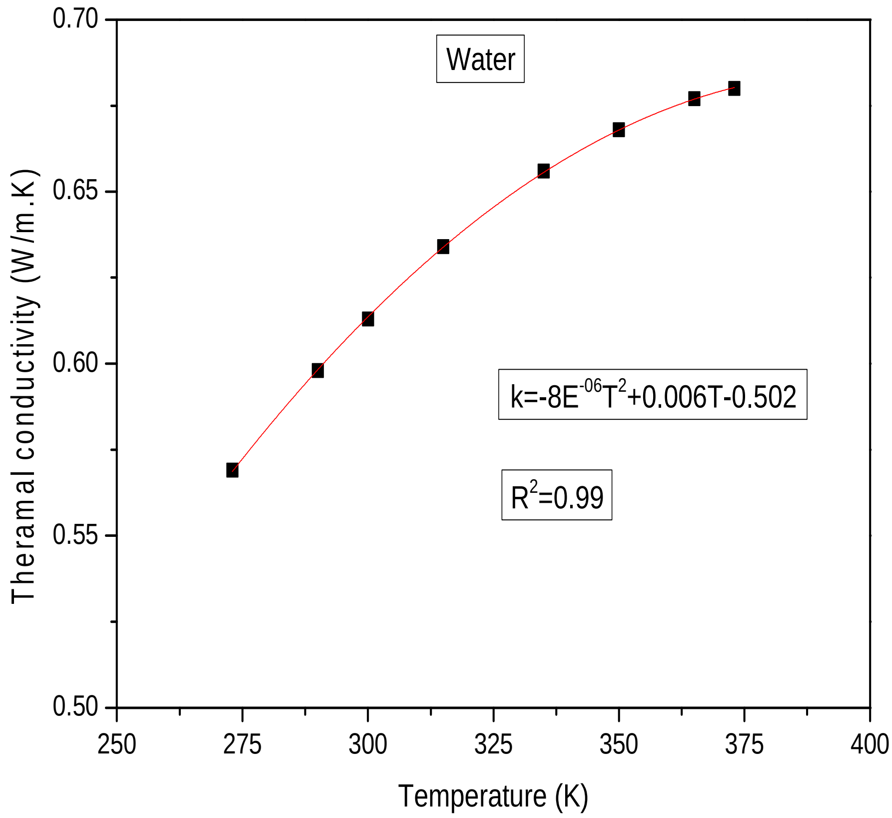

Fig. A.8 Thermal conductivity of water vs. temperature

A.4.2 Average heat transfer coefficient in a helical coil with methanol as working fluid

Inlet temperature of methanol (T_{in}) = 30 ^{0}C or 303 K

Outlet temperature of methanol (T_{out}) = 44.5 ^{0}C or 317.5 K

Bulk fluid temperature of methanol (T_b) = 37.25 ^{0}C or 310.25K

Value of ρ at bulk temperature ($T_b = 310.25$K) = 774.3865 Kg/m^3 (from figure A.4)

Value of μ at bulk temperature ($T_b = 310.25$K) = 0.000567 Pa.s (from figure A.5)

Heat Capacity of methanol is calculated at bulk temperature and correlated with temperature as shown in Figure A.9. Value of Cp at bulk temperature ($T_b = 310.25$K) = 2514.081 J/Kg.K.

Thermal conductivity of methanol is calculated from figure A.10. Value of k = 0.202195 W/m.K at $T_b = 310.25$K

Wall temperature (RTD reading); T_1 = 51.2 ^{0}C, T_2 = 49.21 ^{0}C and T_3 = 48.12 ^{0}C

DC power reading V = 12.41 Volt and I = 0.81 A

Volume of liquid collected = 100 ml = 0.000l m^3

Time required for collected volume = 515 s

Electrical power input (ϕ) from equation 3.9

$= 12.41 \times 0.81$

$\phi = 10$ W (A.50)

Mass flow rate of water = 774.3865× (0.0001/515)

= 0.00015 kg/s (A.51)

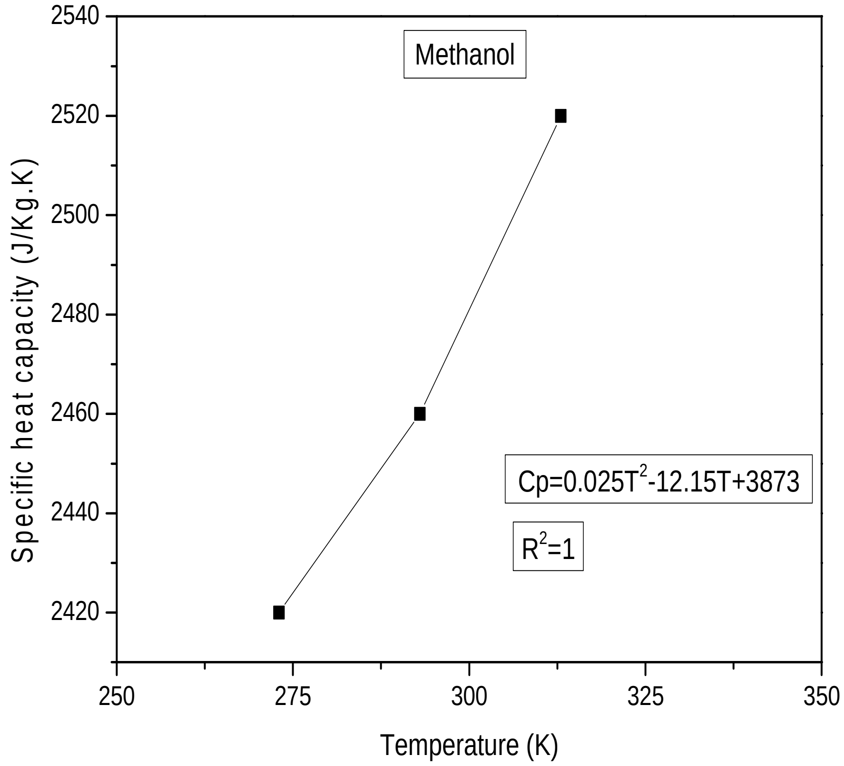

Fig. A.9 Specific heat capacity of methanol vs. temperature

Heat transfer rate = 0.00015×2514.081× (320-303)

Q = 5.48 W (A.52)

Heat flux $= \dfrac{5.48}{1.3\times10^{-3}}$ = 4216.523

q = 4216.523 W/m^2 (A.53)

Average wall temperature, $\overline{T}_w = \dfrac{51.2+49.21+48.12}{3}$ = 49.51

$\overline{T}_w = 49.51\,^0$C (A.54)

= 49.51+273 = 322.51 K (A.55)

Average heat transfer coefficient, $\bar{h} = \dfrac{4216.523}{(322.51 - 310.25)} = 343.925$

$$\bar{h} = 343.925 \text{ W/m}^2\text{.K} \quad \text{(A. 56)}$$

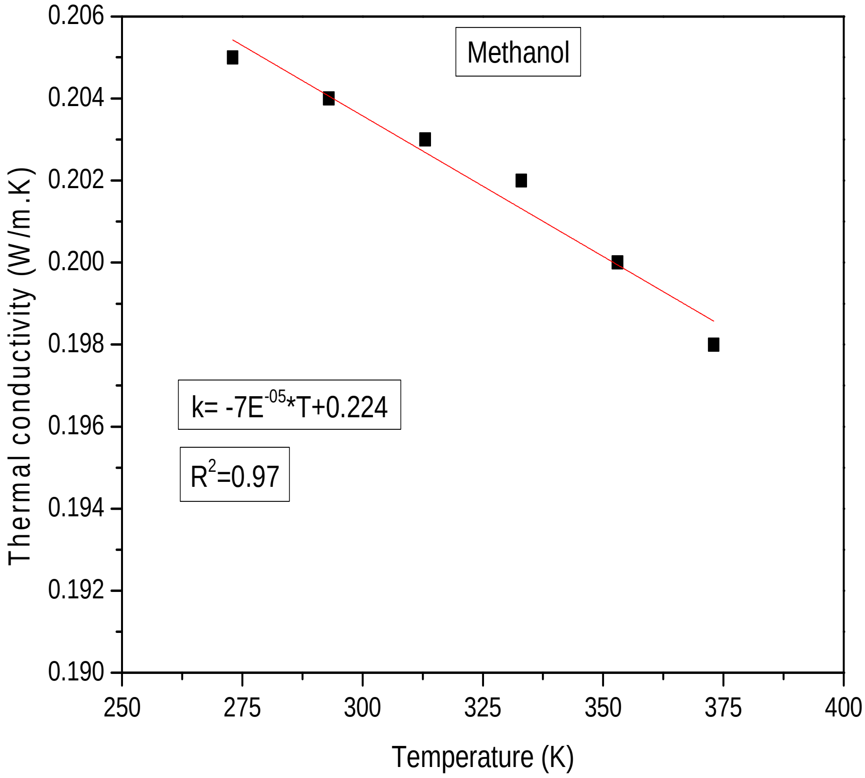

Fig. A.10 Thermal conductivity of methanol vs. temperature

A.4.3 Average heat transfer coefficient in a helical coil with acetone as working fluid

Inlet temperature of water (T_{in}) = 30 ^{0}C or 303 K

Outlet temperature of water (T_{out}) = 39.5 ^{0}C or 312.5 K

Bulk fluid temperature of acetone = 34.75 ^{0}C or 307.75 K

Value of ρ at bulk temperature (T_b = 307.75 K) = 772.007 Kg/m^3 (from figure A.6)

Value of μ at bulk temperature (T_b = 307.75 K) = 0.000284 Pa.s (from figure A.7)

Heat Capacity of acetone is calculated at bulk temperature and correlated with temperature as shown in Figure A.11. Value of Cp at bulk temperature (T_b = 307.75 K) = 2172.395 J/kg.K.

Thermal conductivity of methanol is calculated from figure A.12. Value of k = 0.179 W/m.K at T_b = 307.75 K

Wall temperature (RTD reading); T_1 = 42.42 ^{0}C, T_2 = 41.48 ^{0}C and T_3 = 39.95 ^{0}C

DC power reading V = 9.61 Volt and I = 0.52 A

Volume of liquid collected = 100 ml = 0.0001 m^3

Time required for collected volume = 660 s

Electrical power input (ϕ) from equation 3.9

$$= 9.61\times0.52$$

$$\phi = 5 \text{ W} \quad (A.57)$$

Mass flow rate of water = 772.007× (0.0001/660)

$$= 0.000117 \text{ Kg/s} \quad (A.58)$$

Heat transfer rate = 0.000117×2172.395× (312.5-303)

$$Q = 2.41\text{W} \quad (A.59)$$

$$\text{Heat flux} = \frac{2.41}{1.3\times10^{-3}} = 1856.93$$

$$q = 1856.93 \text{ m}^2 \quad (A.60)$$

$$\text{Average wall temperature, } \bar{T}_w = \frac{42.42 + 41.48 + 39.95}{3} = 41.28$$

$$\bar{T}_w = 41.28\,^0\text{C} \quad (A.61)$$

$$= 41.28+273 = 314.28 \text{ K} \quad (A.62)$$

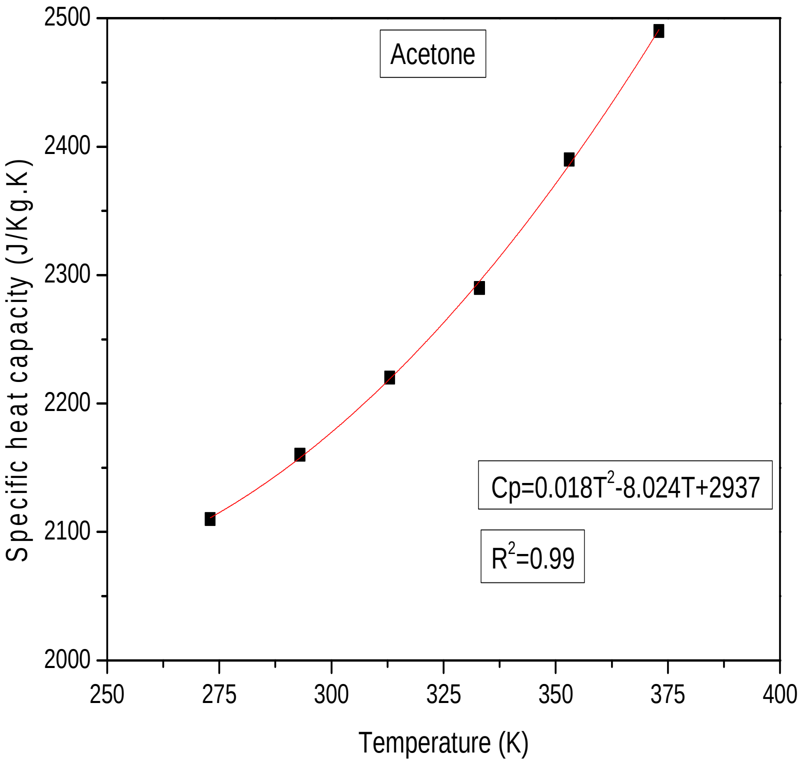

Fig. A.11 Specific heat capacity of acetone vs. temperature

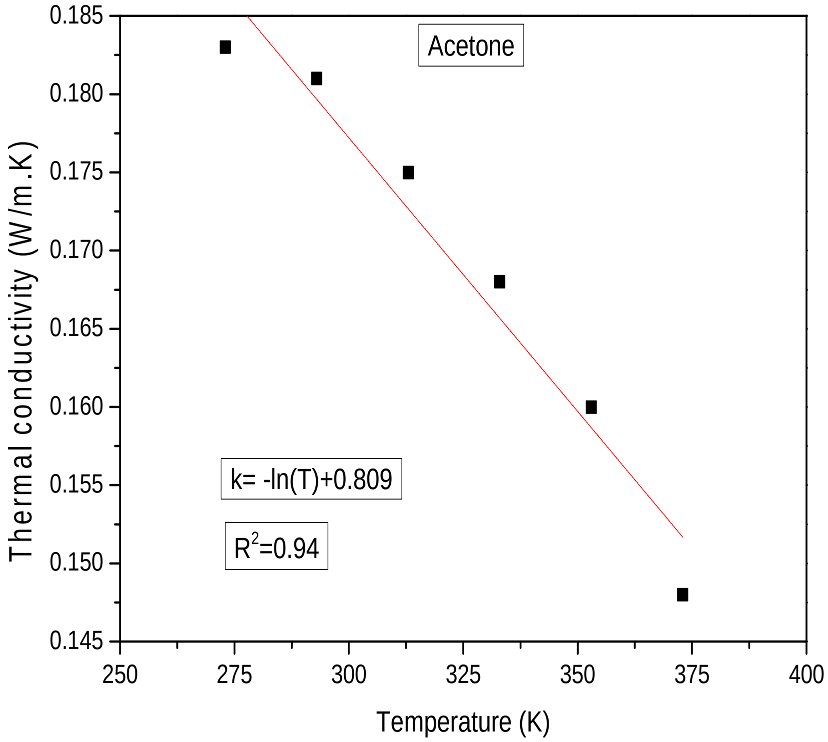

Fig. A.12 Thermal conductivity of acetone vs. temperature

Average heat transfer coefficient, $\bar{h} = \dfrac{1856.93}{(314.28 - 307.75)} = 284.225$

$$\bar{h} = 284.225 \text{ W/m}^2\text{.K} \tag{A.63}$$

Average heat transfer coefficient in a helical coil for all working fluids is given in Table D.5.

A.5 Sample calculation for Nusselt number in helical coil

A.5.1 Nusselt number in helical coil with water as working fluid

$$\text{Re} = \frac{0.00072 \times 0.48 \times 982.1899}{0.000749} = 455$$

$$\text{Re} = 455 \tag{A.64}$$

Prandtl number from equation 3.18

$$\text{Pr} = \frac{4169.231 \times 0.000749}{0.6038}$$

$$\text{Pr} = 5.17 \tag{A.65}$$

Average Nusselt number from equation 3.16

$$\overline{Nu} = \frac{1095.52 \times 0.00072}{0.6038} = 1.3$$

$$\overline{Nu}_c = 1.3 \tag{A.66}$$

A.5.2 Nusselt number in helical coil with methanol as working fluid

Reynolds number = $\frac{0.00072 \times 0.46 \times 774.3865}{0.000567}$ = 447

$$\text{Re} = 447 \tag{A.67}$$

Prandtl number = $\frac{2514.081 \times 0.000567}{0.202}$

$$\text{Pr} = 7.05 \tag{A.68}$$

Average Nusselt number $= \frac{343.925 \times 0.00072}{0.202}$ = 1.22

$$\overline{Nu}_c = 1.22 \tag{A.69}$$

A.5.3 Nusselt number in helical coil with acetone as working fluid

Reynolds number = $\frac{0.00072 \times 0.37 \times 772.007}{0.000284}$ = 728

$$\text{Re} = 728 \tag{A.70}$$

Prandtl number = $\frac{2172.395 \times 0.000284}{0.179}$

$$\text{Pr} = 3.45 \tag{A.71}$$

Average Nusselt number $= \frac{284.225 \times 0.00072}{0.179}$ = 1.15

$$\overline{Nu}_c = 1.15 \tag{A.72}$$

Average Nusselt number in a helical coil for all working fluids is given in Table D.6.

APPENDIX-B

DEVELOPMENT OF CORRELATIONS

B.1 Development of correlation for friction factor

The ratio of friction factor for helical coil to that for straight tube in case of laminar flow data of three coils having constant pitch and coil diameter is shown in Figure B.1 as a function of Dean number. Friction factor for straight tube was calculated from equation 16/Re.

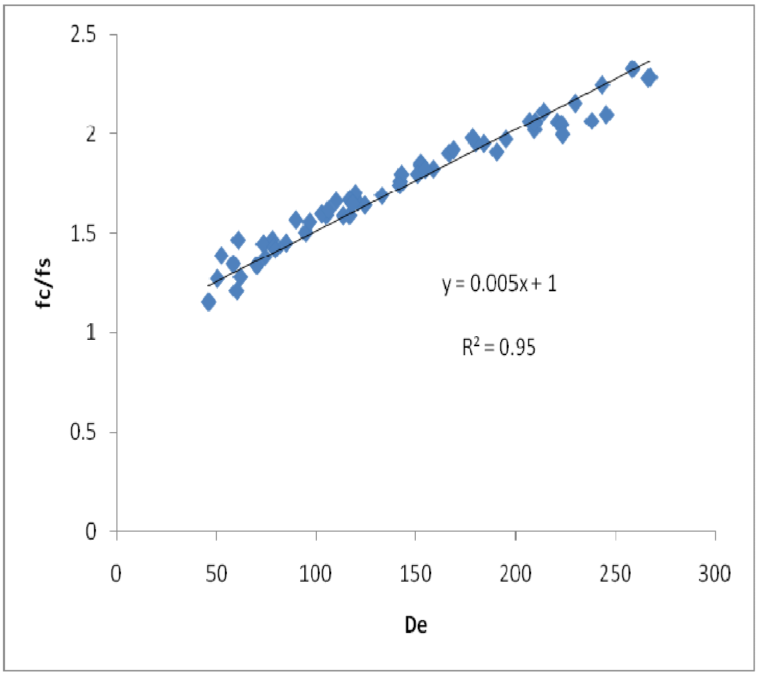

Fig. B.1 Friction factor for helical coil to that for straight tube (f_c / f_s) in case of laminar flow as a function of Dean number

A least squares analysis of all laminar flow data for linear fit gave

$$y = 1 + 0.005x \tag{B.1}$$

Here y = f_c / f_s and x = De

$$\frac{f_c}{f_s} = 1 + 0.005De \tag{B.2}$$

correlates present data with a standard deviation of $\pm$ 5%.

B.1.1 Sample calculation for correlation of friction factor

Tube inside diameter =720 μm = 0.00072 m

Helical coil diameter = 0.060 m

Curvature ratio (δ) = 0.012

Working fluid = water

Re = 420 (from equation A.27)

f_c = 0.0442 (from equation A.28)

f_s is calculated from equation 3.8

$$f_s = 16/420$$

$$= 0.0381 \qquad \text{(B.3)}$$

$$\frac{f_c}{f_s} = \frac{0.0442}{0.038095}$$

$$= 1.1578 \qquad \text{(B.4)}$$

Dean is calculated from equation 3.5

$$De = 420 \times \sqrt{0.012}$$

$$= 45.95 \qquad \text{(B.5)}$$

Prediction of f_c / f_s from equation B.2

$$\frac{f_c}{f_s} = 1 + 0.005 \times 45.95$$

$$= 1.2297 \qquad \text{(B.6)}$$

Friction factor ratios (f_c / f_s) experimental and those predicted from present correlation are given in Table D.7.

B.1.2 Comparison with other available correlations for friction factor

Prediction of f_c / f_s from Mishra and Gupta's (1979) correlation (equation 2.3)

$$\frac{f_c}{f_s} = 1 + 0.033 \times (\log 45.95)^4$$

$$= 1.252 \qquad \text{(B.7)}$$

Prediction of f_c / f_s from Ito's (1969) correlation (equation 2.1)

$$\frac{f_c}{f_s} = 21.5\left[\frac{45.95}{(1.56+\log_{10} 45.95)^{5.73}}\right]$$

$= 1.21$ (B.8)

Prediction of f_c / f_s from White's (1934) correlation (equation 2.45)

$$\frac{f_c}{f_s} = \left[\left\{1-\left(1-\frac{11.6}{45.95}\right)^{0.45}\right\}^{2.2}\right]^{-1}$$

$= 1.223$ (B.9)

Prediction of f_c / f_s from Mori and Nakayama's (1967) correlation (equation 2.46)

$$\frac{f_c}{f_s} = \frac{0.1080\sqrt{45.95}}{1-(3.253/\sqrt{45.95}}$$

$= 1.407$ (B.10)

Friction factor for helical coil to that for straight tube (f_c / f_s) predicted from Mishra and Gupta (1979), Ito (1969), White (1934) and Mori and Nakayama (1967) correlations are given in Table D.8.

Similarly Cioncolini and Santini's (2006) friction factor data predicted from present, Mishra and Gupta (1979), Ito (1969), White (1934) and Mori and Nakayama (1967) correlations are shown in Table D.10 to D.12.

B.1.3 Generalized correlation for friction factor

Equation B.2 reveals that at low De, helical coil hydrodynamically behave as straight tubes Thus it is advisable to correlate $(f_c / f_s - 1)$ as a function of De. In an attempt to obtain such a desirable correlation the same was plotted. Laminar flow friction data of present and Cioncolini and Santini (2006) are depicted in Figure B.2.

A least squares analysis of all laminar flow data for power fit indicated following correlation

$y = 0.008x^{0.897}$ (B.11)

Here $y = (f_c / f_s - 1)$ and x = De

$(f_c / f_s - 1) = 0.008De^{0.897}$ (B.12)

with standard deviation of ± 8 %.

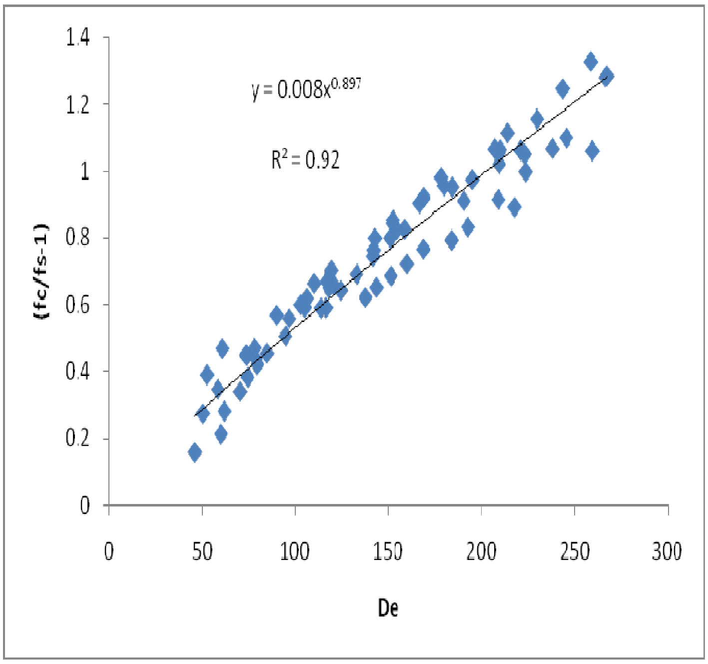

Fig. B.2 $(f_c / f_s - 1)$ vs. De

Predicting of f_c / f_s from generalized correlation (equation B.12)

$$(f_c / f_s - 1) = 0.008De^{0.897}$$

$$f_c / f_s = 1 + 0.008(45.95)^{0.897}$$

$$f_c / f_s = 1.2478 \quad \text{(B.13)}$$

Experimental f_c / f_s of both (present and Cioncolini and Santini (2006)) and values predicted from the generalized correlation is given in Table D.13.

B.2 Development of correlation for Nusselt number

From the previous studies on laminar flow heat transfer in helical coils and heat exchangers it is advisable to correlate $Nu / \Pr^{1/3}$ as a function of Dean number. An attempt to obtain such a desirable correlation the same was plotted. This could not give any suitable equation therefore these plots are not shown in present work. However from these plots the idea of obtaining a suitable correlation by plotting $Nu / \Pr^{0.75}$ against De was found. The Nusselt number laminar flow data of a helically coil micro-diameter tube heat exchanger having curvature ratio 0.012 is shown in Figure B.3.

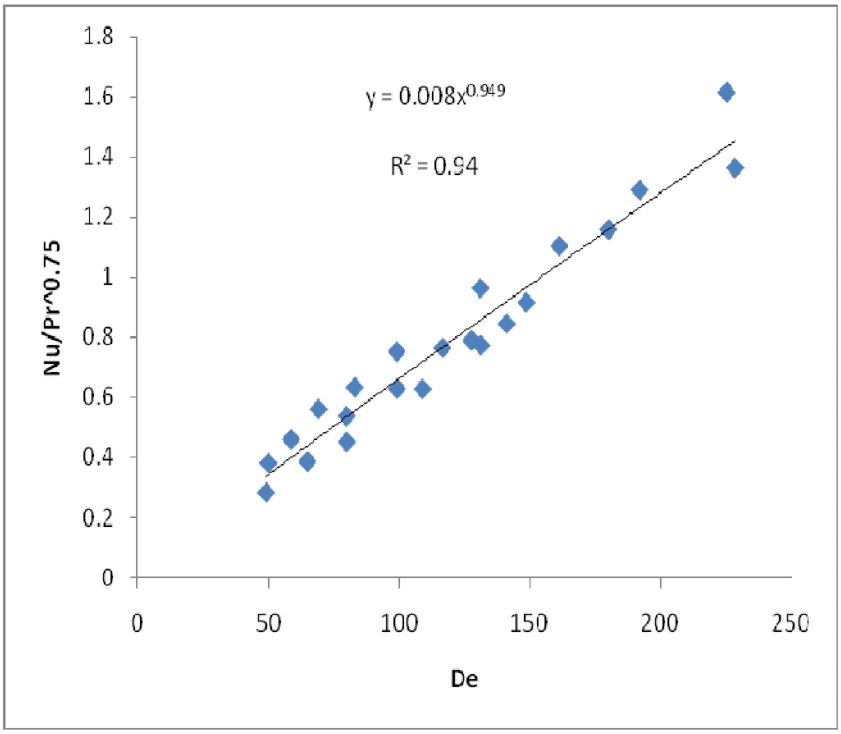

Fig. B. 3 $Nu/\Pr^{0.75}$ vs. De

A least squares analysis of all laminar flow data for power fit predicted following equation

$y = 0.008\ x^{0.949}$ (B.14)

Here y = $Nu/\Pr^{0.75}$ and x =De

$$Nu/\Pr^{0.75} = 0.008 De^{0.949}$$

$$Nu = 0.008 De^{0.949} \Pr^{0.75} \quad \text{(B.15)}$$

and correlates the present data quite well with standard deviation of ±6 %.

B.2.1 Sample calculation for correlation of Nusselt number

Tube inside diameter =720 μm = 0.00072 m

Helical coil diameter = 0.060 m

Curvature ratio (δ) = 0.012

Working fluid = Water

Reynolds no = 455 (from equation A.64)

Prandtl number = 5.17 (from equation A.65)

Nusselt number = 1.3 (from equation A.66)

Dean number $= 455 \times \sqrt{0.012}$

$$De = 49.85 \quad \text{(B.16)}$$

Predicting Nu from equation B.15

$Nu = 0.008 \times 49.85^{0.949} \times 5.17^{0.75}$

$Nu = 1.12$ (B.17)

Experimental Nusselt number and those predicted from present correlation for all working fluids is given in Table D.14.

B.2.2 Comparison with other available correlations for Nusselt number

Nusselt number from Kalb and Seider's (1974) correlation (equation 2.52)

$Nu = 0.836 \times 49.85^{0.5} \times 5.17^{0.1}$

$Nu = 6.956$ (B.18)

Nusselt number from Dravid et al.'s (1974) correlation (equation 2.62)

$Nu = \left[0.76 + 0.65 \times 49.85^{0.5}\right] \times 5.17^{0.175}$

$= 7.13$ (B.19)

Nusselt number predicted from above correlations for all working fluids is depicted in Table D.15.

Similarly Kahani et al.'s (2013) Nusselt number data predicted for average Prandtl number (Pr=7.38) from present, Kalb and Seider (1974) and Dravid et al. (1974) correlations are shown in Table D.17 and D.18.

B.2.3 Generalized correlation for Nusselt number

Using present and Kahani et al. (2013) laminar flow data for in helical coils a generalized correlation has been developed. To develop such a correlation $Nu / \Pr^{0.89}$ plotted against Dean number as shown in Figure B.4.

Power fitting of laminar flow data gave following equation with standard deviation ± 18 %.

$y = 0.002De^{1.262}$ (B.20)

Here $y = Nu / \Pr^{0.89}$ and x = De

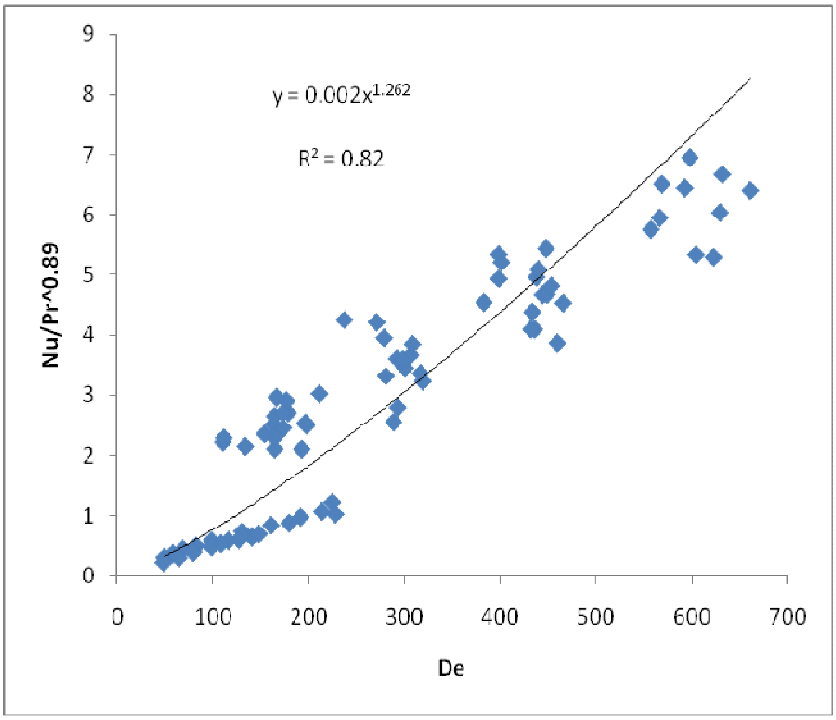

Fig. B.4 $Nu/\Pr^{0.89}$ vs. De

$$Nu = 0.002\, De^{1.262}\ \Pr^{0.89} \tag{B.21}$$

Predicting of Nu from generalized correlation (equation B.21)

$$Nu = 0.002 \times 85^{1.262} \times 5.17^{0.89}$$

$$Nu = 1.198 \tag{B.22}$$

Experimental Nusselt number of both (present and Kahani et al. (2013)) and those predicted from the generalized correlation is given in Table D.19.

APPENDIX-C

UNCERTAINTY ANALYSIS

C.1 Uncertainty propagation

No physical quantity can be measured with perfect certainty; there are always some errors in any measurement. This means that if we measure some quantity and, then, repeat the measurement, we will almost certainly measure a different value the second time. So great care in measurements and more refined experimental methods is needed to reduce the errors, so that our approximate more closely the true value.

All the quantities that are measured friction factor, Reynolds number and Nusselt number are subjected to certain uncertainties because of errors associated in the experimental measurements. These individual uncertainties as well as combined effect of these are discussed in the present study. The analysis is carried out on the basis suggestion made by Kline and Mclintok (1953) and Steele and Coleman (1989). It was kept in mind that uncertainties associated with experimental data are calculated on the basis 95% confidence level.

C.2 Uncertainty in friction factor

$$f = \frac{1}{2}\left(\frac{\Delta P}{L}\right)\left(\frac{\rho d_i^{\,3}}{\mathrm{Re}^2 \mu^2}\right) \tag{C.1}$$

$$\left(\frac{\Delta f}{f}\right) = \left[\left\{\frac{\Delta(\Delta P)}{\Delta P}\right\}^2 + \left\{\frac{\Delta L}{L}\right\}^2 + \left\{\frac{3\Delta d_i}{d_i}\right\}^2 + \left\{\frac{2\Delta \mathrm{Re}}{\mathrm{Re}}\right\}^2\right]^{0.5} \quad \text{C.2)}$$

$$\mathrm{Re} = \frac{4O\rho}{\pi D_h \mu} \tag{C.3}$$

$$\frac{\Delta \mathrm{Re}}{\mathrm{Re}} = \left[\left(\frac{\Delta O}{O}\right)^2 + \left(\frac{\Delta d_i}{d_i}\right)^2\right]^{0.5} \tag{C.4}$$

The uncertainty in friction factor and Reynolds number is calculated from equations C.2 and C.4 respectively.

C.3 Uncertainty in Nusselt number

The average Nusselt number is calculated as

$$\overline{Nu} = \frac{\bar{h} d_i}{k} \tag{C.5}$$

Uncertainty in average Nusselt number is calculated as

$$\frac{\Delta\overline{Nu}}{\overline{Nu}} = \left[\left(\frac{\Delta\bar{h}}{\bar{h}}\right)^2 + \left(\frac{\Delta d_i}{d_i}\right)^2\right]^{0.5} \tag{C.6}$$

$$\bar{h} = \frac{Q}{A_w(\Delta T_b)} \tag{C.7}$$

$$\left(\frac{\Delta\bar{h}}{\bar{h}}\right)^2 = \left[\left(\frac{\Delta Q}{Q}\right)^2 + \left(\frac{\Delta d_i}{d_i}\right)^2 + \left(\frac{\Delta L}{L}\right)^2 + \left(\frac{\Delta(\Delta T)}{\Delta T_b}\right)^2\right]^2 \tag{C.8}$$

$$Q = O\rho cp\Delta T \tag{C.9}$$

$$\left(\frac{\Delta Q}{Q}\right)^2 = \left[\left(\frac{\Delta O}{O}\right)^2 + \left(\frac{\Delta(\Delta T}{\Delta T}\right)^2\right]^2 \tag{C.10}$$

C.4 Sample calculations for uncertainty

C.4.1 Sample calculations for uncertainty in friction factor

Straight tube section

Working fluid = Water

Pressure drop = 17600 Pa

Flow rate = 1.92×10^{-7} m^3/s= 0.192 ml/s

Uncertainty in friction factor is calculated from equation C.2

$$\left(\frac{\Delta f}{f}\right) = \left[\left\{\frac{\Delta(\Delta P)}{\Delta P}\right\}^2 + \left\{\frac{\Delta L}{L}\right\}^2 + \left\{\frac{3\Delta d_i}{d_i}\right\}^2 + \left\{\frac{2\Delta \mathrm{Re}}{\mathrm{Re}}\right\}^2\right]^{0.5}$$

For $\frac{\Delta P}{P}$

$$\left\{\frac{\Delta(\Delta P)}{\Delta P}\right\}^2 = \left\{\frac{0.02}{17600}\right\}^2 = 1.29 \times 10^{-12}$$

$$= 1.29 \times 10^{-12} \tag{C.11}$$

For $\frac{\Delta L}{L}$

Accuracy in measurement of length is 0.002 m

$$\left\{\frac{\Delta L}{L}\right\}^2 = \left\{\frac{0.002}{0.68}\right\}^2$$

$$= 8.65\times10^{-6} \tag{C.12}$$

For $\frac{\Delta d_i}{d_i}$

Accuracy in measurement of diameter is 0.00002 m

$$\left\{\frac{\Delta d_i}{d_i}\right\}^2 = \left\{\frac{0.00002}{0.00072}\right\}^2$$

$$= 0.00077 \tag{C.13}$$

For $\frac{\Delta \mathrm{Re}}{\mathrm{Re}}$ (From equation C.3)

For $\frac{\Delta O}{O}$

For volumetric flow rate estimating the tank volume and collecting time is ±1second and ±2.5 ml. A volumetric flask has total capacity of 100 ml.

$$\Delta O = \frac{2.5}{100} = 0.025\text{ml/s}$$

$$\left\{\frac{\Delta O}{O}\right\}^2 = \left\{\frac{0.025}{0.192}\right\}^2 = 0.017$$

$$= 0.017 \tag{C.14}$$

$$\left\{\frac{\Delta \mathrm{Re}}{\mathrm{Re}}\right\}^2 = [0.00077 + 0.017]^2$$

$$= 3.16\times10^{-4} \tag{C.15}$$

Uncertainty in Reynolds number

$$\left\{\frac{\Delta \mathrm{Re}}{\mathrm{Re}}\right\} = [0.00077 + 0.017]^{0.5}$$

$$= 0.13 \tag{C.16}$$

Substituting all above values from equation C.11 to C.15 in the uncertainty equation of friction factor

$$\left(\frac{\Delta f}{f}\right) = \left[(1.29\times10^{-14}) + (8.65\times10^{-6}) + (3^2\times0.00077) + (2^2\times(2.05\times10^{-5})\right]^{0.5}$$

$$= 0.09 \qquad \text{(C.17)}$$

% uncertainty in friction factor is 9.0 %.

Uncertainty analysis of friction factor in straight tube and helical coil sections for all working fluids is given in Table D.20 and D.21.

C.4.2 Sample calculations for uncertainty in Nusselt number

Working fluid = Water

Tube inside diameter = 0.00072 m

Heated length = 0.565 m

Inlet temperature of water (T_{in}) = 30 ^{0}C

Outlet temperature of water (T_{out}) = 77.5 ^{0}C

For $\frac{\Delta Q}{Q}$

$$\left\{\frac{\Delta O}{O}\right\}^2 = \left\{\frac{0.025}{0.196}\right\}^2$$

$$= 0.01625 \qquad \text{(C.18)}$$

The measurement accuracy in temperature is 0.5 ^{0}C

$$\left\{\frac{\Delta(\Delta T)}{\Delta T}\right\}^2 = \left\{\frac{0.5}{77.5-30}\right\}^2$$

$$= 0.00011 \qquad \text{(C.19)}$$

From equation C.18, C.19 and C.8

$$\frac{\Delta Q}{Q} = \left[0.01625^2 + 0.00011^2\right]^2$$

$$= 0.000268 \qquad \text{(C.20)}$$

For $\frac{\Delta L}{L}$

$$\left\{\frac{\Delta L}{L}\right\}^2 = \left\{\frac{0.002}{0.565}\right\}^2$$

$$= 1.25303\times10^{-5} \qquad \text{(C.21)}$$

For $\frac{\Delta(\Delta T)}{\Delta T_b}$

$\overline{T}_w$ = 80.53 and T_b =53.75

$$\left\{\frac{\Delta(\Delta T)}{\Delta T_b}\right\}^2 = \left\{\frac{0.5}{80.53-53.75}\right\}^2$$

$$= 0.000349 \qquad \text{(C.22)}$$

Substituting all above values from equations C.20 to C.22 and C.13 in C.8

$$\left(\frac{\Delta\overline{h}}{\overline{h}}\right)^2 = [0.000268 + 0.00077 + .0000125 + 0.000349]^2$$

$$= 1.96\times10^{-6} \qquad \text{(C.23)}$$

From equation C.13, C.23 and C.6

$$\frac{\Delta\overline{N}u}{\overline{N}u} = [0.019313 + 0.00077]^{0.5}$$

$$= 0.0277 \qquad \text{(C.24)}$$

% uncertainty in Nusselt number

= 2.77 %

Uncertainty analysis of Nusselt number in helical coil for all working fluids is given in Table D.22.

APPENDIX-D

ASSOCIATED TABLES

D.1 Thermo physical properties of working fluids

D.1.1 Thermo physical properties of water

T (K)	ρ (Kg/m^3)	μ (Pa.s)	Cp (J/Kg.K)	k (W/m.K)
273	1000	0.00175	4217	0.569
290	999	0.00108	4184	0.598
300	997	0.000855	4179	0.613
315	991	0.000631	4179	0.634
335	982.3	0.000453	4186	0.656
350	973.7	0.000365	4195	0.668
365	963.4	0.000306	4209	0.677
373	957.9	0.000279	4217	0.68

D.1.2 Thermo physical properties of methanol

T (K)	ρ (Kg/m^3)	μ (Pa.s)	Cp (J/Kg.K)	k (W/m.K)
273	810	0.000817	2420	0.205
293	791.5	0.000578	2460	0.204
313	774	0.000446	2520	0.203
333	756	0.000347	-	0.202
353	736	0.000271	-	0.2
373	714	0.000214	-	0.198

D.1.3 Thermo physical properties of acetone

T (K)	ρ (Kg/m^3)	μ (Pa.s)	Cp (J/Kg.K)	k (W/m.K)
273	812	0.000395	2110	0.183
293	790	0.000323	2160	0.181
313	768	0.000269	2220	0.175
333	744	0.000226	2290	0.168
353	719	0.000192	2390	0.16
373	689.6	0.00017	2490	0.148

D.2 Calibration of measuring devices

D.2.1 Calibration of flow measuring device

Pump speed (rpm)	Volume collected (m^3)	Time required (s)	Flow rates (m^3/s)
5	0.0001	522	1.92E-07
10	0.0001	445	2.25E-07
20	0.0001	319	3.13E-07
30	0.0001	227	4.41E-07
40	0.0001	164	6.1E-07
50	0.0001	138	7.25E-07
60	0.0001	110	9.09E-07

D.2.2 Calibration of power

Pump speed (rpm)	V	I	ϕ (W)	Volume collected (m^3)	Time (s)	Flow rates (m^3/s)	ρ (Kg/m^3)	Cp (J/Kg.K)	*m* (kg/s)	T_i (K)	T_o (K)	Q (W)	$\frac{\phi - Q}{\phi}$	% Deviation
10	28.37	1.41	40	0.0001	510	1.96E-07	982.1899	4169.231	0.000192586	303	350.5	38.13949	0.046513	4.65127
20	28.37	1.41	40	0.0001	395	2.53E-07	984.6154	4168.937	0.00024927	303	340.8	39.28138	0.017966	1.796562
30	28.37	1.41	40	0.0001	315	3.17E-07	986.181	4169.229	0.000313073	303	331.5	37.20032	0.069992	6.999198
40	28.37	1.41	40	0.0001	250	4E-07	987.3496	4169.694	0.00039494	303	325.8	37.54654	0.061336	6.133647
50	28.37	1.41	40	0.0001	200	5E-07	988.4742	4170.339	0.000494237	303	319.8	34.62709	0.134323	13.43227
60	28.37	1.41	40	0.0001	145	6.9E-07	989.5105	4171.107	0.000682421	303	316.5	38.42709	0.039323	3.932268
70	28.37	1.41	40	0.0001	115	8.7E-07	990.1059	4171.623	0.000860962	303	313.3	36.99356	0.075161	7.516107
80	28.37	1.41	40	0.0001	95	1.05E-06	990.5028	4171.998	0.001042634	303	311.5	36.58874	0.085282	8.528154
90	28.37	1.41	40	0.0001	80	1.25E-06	990.7894	4172.283	0.001238487	303	309.1	31.52064	0.211984	21.19841

D.3 Friction factor in straight tube sections

D.3.1 Friction factor in a straight tube of inner diameter 720 μm for water

Pump speed (rpm)	$(\Delta P)_{max}$ (mbar)	$(\Delta P)_{min}$ (mbar)	$(\Delta P)_{avg}$ (mbar)	ΔP (Pa)	Volume collected (m^3)	Time (s)	d_i (m)	L (m)	ρ (Kg/m^3)	μ (Pa.s)	Flow rates (m^3/s)	Flow area (m^2)	u (m/s)	Re	$f_{exp}=\frac{\Delta P d}{2L\rho u^2}$	f_{theo} =16/Re	$(f_{theo}-f_{exp})/f_{theo}$	% Deviation
5	335	17	176	17600	0.0001	522	0.00072	0.68	995.772	0.008	1.92E-07	4.069×10^{-7}	0.470805803	422	0.042215	0.037921	-0.11324	-11.324
10	367	29	198	19800	0.0001	445	0.00072	0.68	995.772	0.008	2.25E-07	4.069×10^{-7}	0.552271077	495	0.034514	0.032327	-0.06765	-6.765
20	477	43	260	26000	0.0001	319	0.00072	0.68	995.772	0.008	3.13E-07	4.069×10^{-7}	0.770409496	690	0.02329	0.023174	-0.005	-0.500
30	633	63	348	34800	0.0001	227	0.00072	0.68	995.772	0.008	4.41E-07	4.069×10^{-7}	1.082645943	970	0.015785	0.01649	0.042786	4.2786
40	898	92	495	49500	0.0001	164	0.00072	0.68	995.772	0.008	6.1E-07	4.069×10^{-7}	1.498540422	1343	0.011719	0.011914	0.016322	1.6322
50	1159	131	645	61000	0.0001	138	0.00072	0.68	995.772	0.008	7.25E-07	4.069×10^{-7}	1.780874124	1596	0.010226	0.010025	-0.02003	-2.003
60	1435	179	807	80700	0.0001	110	0.00072	0.68	995.772	0.008	9.09E-07	4.069×10^{-7}	2.234187538	2002	0.008595	0.007991	-0.07565	-7.565

D.3.2 Friction factor in a straight tube of inner diameter 720 μm for methanol

Pump speed (rpm)	$(\Delta P)_{max}$ (mbar)	$(\Delta P)_{min}$ (mbar)	$(\Delta P)_{avg}$ (mbar)	ΔP (Pa)	Volume collected (m^3)	Time (s)	d_i (m)	L (m)	ρ (Kg/m^3)	μ (Pa.s)	Flow rates (m^3/s)	Flow area (m^2)	u (m/s)	Re	$f_{exp}=\frac{\Delta P d}{2L\rho u^2}$	f_{theo} =16/Re	$(f_{theo}-f_{exp})/f_{theo}$	% Deviation
2	160	2	81	8100	0.0001	634	0.00072	0.68	783.05	0.005	1.58E-07	4.069×10^{-7}	0.387635	449	0.036445	0.035617	-0.02326	-2.32582
5	198	4	101	10100	0.0001	498	0.00072	0.68	783.05	0.005	2.01E-07	4.069×10^{-7}	0.493495	572	0.028039	0.027977	-0.00222	-0.22168
10	232	8	120	12000	0.0001	413	0.00072	0.68	783.05	0.005	2.42E-07	4.069×10^{-7}	0.595062	690	0.022912	0.023202	0.012488	1.248831
20	414	16	215	21500	0.0001	235	0.00072	0.68	783.05	0.005	4.26E-07	4.069×10^{-7}	1.04579	1212	0.013291	0.013202	-0.00674	-0.67399
30	594	26	310	31000	0.0001	161	0.00072	0.68	783.05	0.005	6.21E-07	4.069×10^{-7}	1.526464	1769	0.008995	0.009045	0.005514	0.551436
40	750	48	399	39900	0.0001	137	0.00072	0.68	783.05	0.005	7.3E-07	4.069×10^{-7}	1.793873	2079	0.008383	0.007696	-0.08919	-8.91919

D.3.3 Friction factor in a straight tube of inner diameter 720 μm for acetone

Pump speed (rpm)	$(\Delta P)_{max}$ (mbar)	$(\Delta P)_{min}$ (mbar)	$(\Delta P)_{avg}$ (mbar)	ΔP (Pa)	Volume collected (m^3)	Time (s)	d_i (m)	L (m)	ρ (Kg/m^3)	μ (Pa.s)	Flow rates (m^3/s)	Flow area (m^2)	u (m/s)	Re	$f_{\exp} = \frac{\Delta P d}{2L\rho u^2}$	f_{theo} =16/Re	$(f_{theo} - f_{exp})/f_{theo}$	% Deviation
1	104	0	52	5200	0.0001	642	0.00072	0.68	780.199	0.003	1.56E-07	4.069×10^{-7}	0.382805	729	0.024079	0.02195	-0.09701	-9.70089
3	118	2	60	6000	0.0001	534	0.00072	0.68	780.199	0.003	1.87E-07	4.069×10^{-7}	0.460226	876	0.019222	0.018257	-0.05284	-5.28446
5	125	3	64	6400	0.0001	478	0.00072	0.68	780.199	0.003	2.09E-07	4.069×10^{-7}	0.514144	979	0.016429	0.016343	-0.00526	-0.52629
10	161	7	84	8400	0.0001	362	0.00072	0.68	780.199	0.003	2.76E-07	4.069×10^{-7}	0.678897	1293	0.012367	0.012377	0.000783	0.078342
20	276	10	143	14300	0.0001	228	0.00072	0.68	780.199	0.003	4.39E-07	4.069×10^{-7}	1.077897	2053	0.008352	0.007795	-0.07138	-7.13778

D.3.4 Friction factor in a straight tube of inner diameter 850 μm for water

Pump speed (rpm)	$(\Delta P)_{max}$ (mbar)	$(\Delta P)_{min}$ (mbar)	$(\Delta P)_{avg}$ (mbar)	ΔP (Pa)	Volume collected (m^3)	Time (s)	d_i (m)	L (m)	ρ (Kg/m^3)	μ (Pa.s)	Flow rates (m^3/s)	Flow area (m^2)	u (m/s)	Re	$f_{\exp} = \frac{\Delta P d}{2L\rho u^2}$	f_{theo} =16/Re	$(f_{theo} - f_{exp})/f_{theo}$	% Deviation
5	179	9	94	9400	0.0001	456	0.00085	0.68	995.772	0.008	2.19E-07	5.67×10^{-7}	0.386769393	409	0.039441	0.0391	-0.00871	-0.87063
10	243	15	129	12900	0.0001	330	0.00085	0.68	995.772	0.008	3.03E-07	5.67×10^{-7}	0.534444979	566	0.028347	0.028296	-0.00179	-0.17877
20	409	31	220	22000	0.0001	203	0.00085	0.68	995.772	0.008	4.93E-07	5.67×10^{-7}	0.868802182	919	0.018294	0.017406	-0.05097	-5.0971
30	518	38	278	27800	0.0001	158	0.00085	0.68	995.772	0.008	6.33E-07	5.67×10^{-7}	1.116245842	1180	0.014004	0.013548	-0.03365	-3.3651
40	645	49	347	34700	0.0001	133	0.00085	0.68	995.772	0.008	7.52E-07	5.67×10^{-7}	1.326066489	1402	0.012386	0.011404	-0.08606	-8.60583
50	761	61	411	41100	0.0001	113	0.00085	0.68	995.772	0.008	8.85E-07	5.67×10^{-7}	1.560768522	1651	0.01059	0.009689	-0.09293	-9.29299
60	836	84	460	46000	0.0001	99	0.00085	0.68	995.772	0.008	1.01E-06	5.67×10^{-7}	1.781483263	1884	0.009097	0.008489	-0.07168	-7.16798
70	945	101	523	52300	0.0001	89	0.00085	0.68	995.772	0.008	1.12E-06	5.67×10^{-7}	1.981649922	2097	0.008359	0.007631	-0.09538	-9.53773

D.3.5 Friction factor in a straight tube of inner diameter 850 μm for methanol

Pump speed (rpm)	$(\Delta P)_{max}$ (mbar)	$(\Delta P)_{min}$ (mbar)	$(\Delta P)_{avg}$ (mbar)	ΔP (Pa)	Volume collected (m^3)	Time (s)	d_i (m)	L (m)	ρ (Kg/m^3)	μ (Pa.s)	Flow rates (m^3/s)	Flow area (m^2)	u (m/s)	Re	$f_{exp} = \frac{\Delta P d}{2L\rho u^2}$	f_{theo} =16/Re	$(f_{theo} - f_{exp})/f_{theo}$	% Deviation
2	99	1	50	5000	0.0001	552	0.00085	0.68	783.05	0.005	1.81159E-07	5.67×10^{-7}	0.319505	437	0.039094	0.036603	-0.06804	-6.80418
5	139	5	72	7200	0.0001	391	0.00085	0.68	783.05	0.005	2.55754E-07	5.67×10^{-7}	0.451066	617	0.028245	0.025927	-0.0894	-8.94027
10	173	9	91	9100	0.0001	303	0.00085	0.68	783.05	0.005	3.30033E-07	5.67×10^{-7}	0.582069	796	0.021438	0.020092	-0.067	-6.6997
20	274	16	145	14500	0.0001	190	0.00085	0.68	783.05	0.005	5.26316E-07	5.67×10^{-7}	0.928247	1270	0.013432	0.012599	-0.06611	-6.6107
30	341	31	186	18600	0.0001	139	0.00085	0.68	783.05	0.005	7.19424E-07	5.67×10^{-7}	1.268826	1736	0.009221	0.009217	-0.00048	-0.04766
35	437	49	243	24300	0.0001	117	0.00085	0.68	783.05	0.005	8.54701E-07	5.67×10^{-7}	1.507409	2062	0.008536	0.007758	-0.1002	-10.0199

D.3.6 Friction factor in a straight tube of inner diameter 850 μm for acetone

Pump speed (rpm)	$(\Delta P)_{max}$ (mbar)	$(\Delta P)_{min}$ (mbar)	$(\Delta P)_{avg}$ (mbar)	ΔP (Pa)	Volume collected (m^3)	Time (s)	d_i (m)	L (m)	ρ (Kg/m^3)	μ (Pa.s)	Flow rates (m^3/s)	Flow area (m^2)	u (m/s)	Re	$f_{exp} = \frac{\Delta P d}{2L\rho u^2}$	f_{theo} =16/Re	$(f_{theo} - f_{exp})/f_{theo}$	% Deviation
1	57	-3	27	2700	0.0001	678	0.00085	0.68	780.199	0.003	1.47493E-07	5.67×10^{-7}	0.291085	654	0.025527	0.024451	-0.044	-4.40019
3	83	-1	41	4100	0.0001	464	0.00085	0.68	780.199	0.003	2.15517E-07	5.67×10^{-7}	0.425335	956	0.018155	0.016733	-0.08495	-8.49499
5	100	2	51	5100	0.0001	324	0.00085	0.68	780.199	0.003	3.08642E-07	5.67×10^{-7}	0.577063	1297	0.012269	0.012334	0.005272	0.527249
10	125	5	65	6500	0.0001	266	0.00085	0.68	780.199	0.003	3.7594E-07	5.67×10^{-7}	0.741938	1668	0.009459	0.009593	0.013941	1.394113
15	169	11	90	9000	0.0001	212	0.00085	0.68	780.199	0.003	4.71698E-07	5.67×10^{-7}	0.930922	2093	0.008319	0.007645	-0.08814	-8.81436

D.3.7 Friction factor in a straight tube of inner diameter 1000 μm for water

Pump speed (rpm)	$(\Delta P)_{max}$ (mbar)	$(\Delta P)_{min}$ (mbar)	$(\Delta P)_{avg}$ (mbar)	ΔP (Pa)	Volume collected (m^3)	Time (s)	d_i (m)	L (m)	ρ (Kg/m^3)	μ (Pa.s)	Flow rates (m^3/s)	Flow area (m^2)	u (m/s)	Re	$f_{exp}=\frac{\Delta P d}{2L\rho u^2}$	f_{theo} =16/Re	$(f_{theo} - f_{exp})/f_{theo}$	% Deviation
5	76	14	45	4500	0.0001	485	0.001	0.68	995.772	0.008	2.06E-07	7.85×10^{-7}	0.262656773	327	0.048166	0.04894	0.015819	1.581888
10	98	24	61	6100	0.0001	390	0.001	0.68	995.772	0.008	2.56E-07	7.85×10^{-7}	0.326637269	407	0.042218	0.039354	-0.07279	-7.27912
20	150	38	94	9400	0.0001	240	0.001	0.68	995.772	0.008	4.17E-07	7.85×10^{-7}	0.530785563	661	0.024637	0.024218	-0.01733	-1.73254
30	246	50	148	14800	0.0001	160	0.001	0.68	995.772	0.008	6.25E-07	7.85×10^{-7}	0.796178344	991	0.01724	0.016145	-0.06783	-6.78309
40	405	69	237	23700	0.0001	105	0.001	0.68	995.772	0.008	9.52E-07	7.85×10^{-7}	1.213224143	1510	0.01189	0.010595	-0.12217	-12.2169
50	457	83	270	27000	0.0001	90	0.001	0.68	995.772	0.008	1.11E-06	7.85×10^{-7}	1.415428167	1762	0.009952	0.009082	-0.09579	-9.57893
55	511	91	301	30100	0.0001	80	0.001	0.68	995.772	0.008	1.25E-06	7.85×10^{-7}	1.592356688	1982	0.008766	0.008073	-0.08587	-8.58686

D.3.8 Friction factor in a straight tube of inner diameter 1000 μm for methanol

Pump speed (rpm)	$(\Delta P)_{max}$ (mbar)	$(\Delta P)_{min}$ (mbar)	$(\Delta P)_{avg}$ (mbar)	ΔP (Pa)	Volume collected (m^3)	Time (s)	d_i (m)	L (m)	ρ (Kg/m^3)	μ (Pa.s)	Flow rates (m^3/s)	Flow area (m^2)	u (m/s)	Re	$f_{exp}=\frac{\Delta P d}{2L\rho u^2}$	f_{theo} =16/Re	$(f_{theo} - f_{exp})/f_{theo}$	% Deviation
2	60	2	31	3100	0.0001	495	0.001	0.68	783.05	0.005	2.02E-07	7.85×10^{-7}	0.257351	414	0.043952	0.038627	-0.13788	-13.7876
5	64	4	34	3600	0.0001	430	0.001	0.68	783.05	0.005	2.33E-07	7.85×10^{-7}	0.296252	477	0.036377	0.033555	-0.08411	-8.41149
10	69	7	38	4300	0.0001	355	0.001	0.68	783.05	0.005	2.82E-07	7.85×10^{-7}	0.358841	578	0.027711	0.027702	-0.00032	-0.03221
20	108	12	60	7100	0.0001	210	0.001	0.68	783.05	0.005	4.76E-07	7.85×10^{-7}	0.606612	976	0.015311	0.016387	0.065674	6.567393
30	181	17	99	11000	0.0001	135	0.001	0.68	783.05	0.005	7.41E-07	7.85×10^{-7}	0.943619	1519	0.01044	0.010535	0.008947	0.894699
35	254	24	139	13900	0.0001	105	0.001	0.68	783.05	0.005	9.52E-07	7.85×10^{-7}	1.213224	1953	0.008868	0.008194	-0.08226	-8.2261

D.3.9 Friction factor in a straight tube of inner diameter 1000 μm for acetone

Pump speed (rpm)	$(\Delta P)_{max}$ (mbar)	$(\Delta P)_{min}$ (mbar)	$(\Delta P)_{avg}$ (mbar)	ΔP (Pa)	Volume collected (m^3)	Time (s)	d_i (m)	L (m)	ρ (Kg/m^3)	μ (Pa.s)	Flow rates (m^3/s)	Flow area (m^2)	u (m/s)	Re	$f_{exp} = \frac{\Delta P d}{2 L \rho u^2}$	f_{theo} =16/Re	$(f_{theo} - f_{exp})/f_{theo}$	% Deviation
1	34	-2	16	1600	0.0001	548	0.001	0.68	780.199	0.003	1.82E-07	7.85×10^{-7}	0.232461	615	0.027905	0.026025	-0.07223	-7.22333
3	40	0	20	2000	0.0001	434	0.001	0.68	780.199	0.003	2.3E-07	7.85×10^{-7}	0.293522	776	0.021878	0.020611	-0.06147	-6.14718
5	53	1	27	2700	0.0001	342	0.001	0.68	780.199	0.003	2.92E-07	7.85×10^{-7}	0.372481	986	0.01834	0.016242	-0.12922	-12.922
10	59	3	31	3100	0.0001	274	0.001	0.68	780.199	0.003	3.65E-07	7.85×10^{-7}	0.464922	1230	0.013516	0.013012	-0.03873	-3.8726
20	73	5	39	3900	0.0001	204	0.001	0.68	780.199	0.003	4.9E-07	7.85×10^{-7}	0.624454	1652	0.009426	0.009688	0.027066	2.70656
23	103	9	56	5600	0.0001	162	0.001	0.68	780.199	0.003	6.17E-07	7.85×10^{-7}	0.786349	2080	0.008535	0.007693	-0.10941	-10.9409

D.4 Friction factor in helical coils

D.4.1 Friction factor in a helical coil of inner diameter 720 μm for water

Pump speed (rpm)	$(\Delta P)_{max}$ (mbar)	$(\Delta P)_{min}$ (mbar)	$(\Delta P)_{avg}$ (mbar)	ΔP (Pa)	Volume collected (m^3)	Time (s)	d_i (m)	L (m)	ρ (Kg/m^3)	μ (Pa.s)	Flow rates (m^3/s)	Flow area (m^2)	u (m/s)	Re	$f_c = \frac{\Delta P d}{2 L \rho u^2}$	Srinivasan et al.'s (1968) *fc*	$(f_{theo} - f_{exp})/f_{theo}$	% Deviation
10	340	24	182	18200	0.0001	525	0.00072	0.68	995.772	0.008	1.9E-07	4.069×10^{-7}	0.468115484	420	0.044157	0.036963	-0.19461	-19.4614
20	503	39	271	27100	0.0001	390	0.00072	0.68	995.772	0.008	2.56E-07	4.069×10^{-7}	0.630155459	565	0.036283	0.030925	-0.17326	-17.3256
30	645	57	351	35100	0.0001	325	0.00072	0.68	995.772	0.008	3.08E-07	4.069×10^{-7}	0.756186551	678	0.032635	0.027721	-0.17727	-17.7272
40	769	73	421	42100	0.0001	285	0.00072	0.68	995.772	0.008	3.51E-07	4.069×10^{-7}	0.862317997	773	0.030101	0.02562	-0.17489	-17.4892
50	1055	87	571	57100	0.0001	230	0.00072	0.68	995.772	0.008	4.35E-07	4.069×10^{-7}	1.068524475	958	0.026589	0.022527	-0.18029	-18.0288
60	1270	98	684	68400	0.0001	200	0.00072	0.68	995.772	0.008	5E-07	4.069×10^{-7}	1.228803146	1101	0.024084	0.020715	-0.1626	-16.2602
70	1601	111	856	85600	0.0001	170	0.00072	0.68	995.772	0.008	5.88E-07	4.069×10^{-7}	1.44565076	1296	0.021776	0.018791	-0.15887	-15.8871
80	2007	159	1083	108300	0.0001	145	0.00072	0.68	995.772	0.008	6.9E-07	4.069×10^{-7}	1.694900891	1519	0.020043	0.01708	-0.17348	-17.3483
90	2761	201	1481	148100	0.0001	115	0.00072	0.68	995.772	0.008	8.7E-07	4.069×10^{-7}	2.137048949	1915	0.017241	0.014863	-0.16002	-16.0019

D.4.2 Friction factor in a helical coil of inner diameter 720 μm for methanol

Pump speed (rpm)	$(\Delta P)_{max}$ (mbar)	$(\Delta P)_{min}$ (mbar)	$(\Delta P)_{avg}$ (mbar)	ΔP (Pa)	Volume collected (m^3)	Time (s)	d_i (m)	L (m)	ρ (Kg/m^3)	μ (Pa.s)	Flow rates (m^3/s)	Flow area (m^2)	u (m/s)	Re	$f_c = \frac{\Delta P d}{2 L \rho u^2}$	Srinivasan et al.'s (1968) *fc*	$(f_{theo} - f_{exp})/f_{theo}$	% Deviation
5	223	11	117	11700	0.0001	520	0.00072	0.68	783.05	0.005	1.92E-07	4.069×10^{-7}	0.472617	548	0.035414	0.031499	-0.12428	-12.4284
10	284	18	151	15100	0.0001	445	0.00072	0.68	783.05	0.005	2.25E-07	4.069×10^{-7}	0.552271	640	0.033472	0.028689	-0.16672	-16.6719
20	427	31	229	22900	0.0001	330	0.00072	0.68	783.05	0.005	3.03E-07	4.069×10^{-7}	0.744729	863	0.027915	0.023977	-0.16423	-16.4235
30	541	39	290	29000	0.0001	275	0.00072	0.68	783.05	0.005	3.64E-07	4.069×10^{-7}	0.893675	1036	0.02455	0.021493	-0.14222	-14.2219
40	665	57	361	36100	0.0001	235	0.00072	0.68	783.05	0.005	4.26E-07	4.069×10^{-7}	1.04579	1212	0.022316	0.019558	-0.14101	-14.1005
50	833	69	451	45100	0.0001	205	0.00072	0.68	783.05	0.005	4.88E-07	4.069×10^{-7}	1.198832	1389	0.021216	0.01802	-0.17738	-17.7382
60	959	83	521	52100	0.0001	185	0.00072	0.68	783.05	0.005	5.41E-07	4.069×10^{-7}	1.328436	1540	0.01996	0.016943	-0.17805	-17.805
70	1139	99	619	61900	0.0001	160	0.00072	0.68	783.05	0.005	6.25E-07	4.069×10^{-7}	1.536004	1780	0.017738	0.01553	-0.14221	-14.2205
80	1362	108	735	73500	0.0001	140	0.00072	0.68	783.05	0.005	7.14E-07	4.069×10^{-7}	1.755433	2034	0.016126	0.014334	-0.125	-12.4999

D.4.3 Friction factor in a helical coil of inner diameter 720 μm for acetone

Pump speed (rpm)	$(\Delta P)_{max}$ (mbar)	$(\Delta P)_{min}$ (mbar)	$(\Delta P)_{avg}$ (mbar)	ΔP (Pa)	Volume collected (m^3)	Time (s)	d_i (m)	L (m)	ρ (Kg/m^3)	μ (Pa.s)	Flow rates (m^3/s)	Flow area (m^2)	u (m/s)	Re	$f_c = \frac{\Delta P d}{2L\rho u^2}$	Srinivasan et al.'s (1968) *fc*	$(f_{theo} - f_{exp})/f_{theo}$	% Deviation
2	134	0	67	6700	0.0001	645	0.00072	0.68	780.199	0.003	1.55E-07	4.069×10^{-7}	0.381024	726	0.031315	0.026609	-0.17688	-17.6885
5	217	3	110	11000	0.0001	440	0.00072	0.68	780.199	0.003	2.27E-07	4.069×10^{-7}	0.558547	1064	0.023926	0.021152	-0.1311	-13.1103
10	315	7	161	16100	0.0001	340	0.00072	0.68	780.199	0.003	2.94E-07	4.069×10^{-7}	0.722825	1376	0.02091	0.018121	-0.15391	-15.391
15	493	9	251	25100	0.0001	245	0.00072	0.68	780.199	0.003	4.08E-07	4.069×10^{-7}	1.003105	1910	0.016927	0.014886	-0.13706	-13.7056

D.4.4 Friction factor in a helical coil of inner diameter 850 μm for water

Pump speed (rpm)	$(\Delta P)_{max}$ (mbar)	$(\Delta P)_{min}$ (mbar)	$(\Delta P)_{avg}$ (mbar)	ΔP (Pa)	Volume collected (m^3)	Time (s)	d_i (m)	L (m)	ρ (Kg/m^3)	μ (Pa.s)	Flow rates (m^3/s)	Flow area (m^2)	u (m/s)	Re	$f_c = \frac{\Delta P d}{2L\rho u^2}$	Srinivasan et al.'s (1968) *fc*	$(f_{theo} - f_{exp})/f_{theo}$	% Deviation
10	237	9	123	12300	0.0001	440	0.00085	0.68	995.772	0.008	2.27E-07	5.67×10^{-7}	0.400833734	424	0.04805	0.038462	-0.24928	-24.928
20	393	17	205	20500	0.0001	300	0.00085	0.68	995.772	0.008	3.33E-07	5.67×10^{-7}	0.587889477	622	0.037229	0.030566	-0.21799	-21.7992
30	601	31	316	31600	0.0001	215	0.00085	0.68	995.772	0.008	4.65E-07	5.67×10^{-7}	0.820310898	868	0.029475	0.025028	-0.17766	-17.7665
40	734	48	391	39100	0.0001	185	0.00085	0.68	995.772	0.008	5.41E-07	5.67×10^{-7}	0.953334287	1009	0.027003	0.02287	-0.1807	-18.0696
50	1023	63	543	54300	0.0001	145	0.00085	0.68	995.772	0.008	6.9E-07	5.67×10^{-7}	1.216323055	1286	0.023037	0.01976	-0.16583	-16.5832
60	1301	81	691	69100	0.0001	120	0.00085	0.68	995.772	0.008	8.33E-07	5.67×10^{-7}	1.469723692	1555	0.020078	0.017639	-0.13829	-13.8289
70	1655	97	876	87600	0.0001	100	0.00085	0.68	995.772	0.008	0.000001	5.67×10^{-7}	1.76366843	1866	0.017676	0.015811	-0.11796	-11.7956
80	1864	118	991	99100	0.0001	90	0.00085	0.68	995.772	0.008	1.11E-06	5.67×10^{-7}	1.959631589	2073	0.016197	0.014843	-0.09127	-9.12744

D.4.5 Friction factor in a helical coil of inner diameter 850 µm for methanol

Pump speed (rpm)	$(\Delta P)_{max}$ (mbar)	$(\Delta P)_{min}$ (mbar)	$(\Delta P)_{avg}$ (mbar)	ΔP (Pa)	Volume collected (m^3)	Time (s)	d_i (m)	L (m)	ρ (Kg/m^3)	µ (Pa.s)	Flow rates (m^3/s)	Flow area (m^2)	u (m/s)	Re	$f_c = \frac{\Delta P d}{2L\rho u^2}$	Srinivasan et al.'s (1968) *fc*	$(f_{theo} - f_{exp})/f_{theo}$	% Deviation
5	138	4	71	7100	0.0001	490	0.00085	0.68	783.05	0.005	2.04E-07	5.67×10^{-7}	0.359932	492	0.043743	0.035164	-0.24396	-24.3959
10	183	9	96	9600	0.0001	390	0.00085	0.68	783.05	0.005	2.56E-07	5.67×10^{-7}	0.452223	619	0.037468	0.030664	-0.2219	-22.1898
20	336	16	176	17600	0.0001	245	0.00085	0.68	783.05	0.005	4.08E-07	5.67×10^{-7}	0.719865	985	0.027108	0.0232	-0.16847	-16.8472
30	495	29	262	26200	0.0001	180	0.00085	0.68	783.05	0.005	5.56E-07	5.67×10^{-7}	0.979816	1341	0.021782	0.019282	-0.12968	-12.9682
40	604	54	329	32900	0.0001	150	0.00085	0.68	783.05	0.005	6.67E-07	5.67×10^{-7}	1.175779	1609	0.018995	0.017284	-0.099	-9.8998
50	808	82	445	44500	0.0001	120	0.00085	0.68	783.05	0.005	8.33E-07	5.67×10^{-7}	1.469724	2011	0.016443	0.015118	-0.08764	-8.76446

D.4.6 Friction factor in a helical coil of inner diameter 850 µm for acetone

Pump speed (rpm)	$(\Delta P)_{max}$ (mbar)	$(\Delta P)_{min}$ (mbar)	$(\Delta P)_{avg}$ (mbar)	ΔP (Pa)	Volume collected (m^3)	Time (s)	d_i (m)	L (m)	ρ (Kg/m^3)	µ (Pa.s)	Flow rates (m^3/s)	Flow area (m^2)	u (m/s)	Re	$f_c = \frac{\Delta P d}{2L\rho u^2}$	Srinivasan et al.'s (1968) *fc*	$(f_{theo} - f_{exp})/f_{theo}$	% Deviation
2	94	0	47	4700	0.0001	585	0.00085	0.68	780.199	0.003	1.71E-07	5.67×10^{-7}	0.33736	758	0.033082	0.027138	-0.21903	-21.903
5	128	2	65	6500	0.0001	445	0.00085	0.68	780.199	0.003	2.25E-07	5.67×10^{-7}	0.443495	997	0.026473	0.02303	-0.14952	-14.9518
10	183	5	94	9400	0.0001	340	0.00085	0.68	780.199	0.003	2.94E-07	5.67×10^{-7}	0.580457	1305	0.022349	0.019596	-0.1405	-14.0504
20	287	11	149	14900	0.0001	235	0.00085	0.68	780.199	0.003	4.26E-07	5.67×10^{-7}	0.83981	1888	0.016924	0.015701	-0.0779	-7.79029

D.4.7 Friction factor in a helical coil of inner diameter 1000 μm for water

Pump speed (rpm)	$(\Delta P)_{max}$ (mbar)	$(\Delta P)_{min}$ (mbar)	$(\Delta P)_{avg}$ (mbar)	ΔP (Pa)	Volume collected (m^3)	Time (s)	d_i (m)	L (m)	ρ (Kg/m^3)	μ (Pa.s)	Flow rates (m^3/s)	Flow area (m^2)	u (m/s)	Re	$f_c = \frac{\Delta p d}{2L\rho u^2}$	Srinivasan et al.'s (1968) *fc*	$(f_{theo} - f_{exp})/f_{theo}$	% Deviation
10	148	8	78	7800	0.0001	395	0.001	0.68	995.772	0.008	2.53E-07	7.85×10^{-7}	0.32250262	401	0.055377	0.042135	-0.31427	-31.4274
20	229	17	123	12300	0.0001	265	0.001	0.68	995.772	0.008	3.77E-07	7.85×10^{-7}	0.480711453	598	0.039304	0.033161	-0.18524	-18.5236
30	329	39	184	18400	0.0001	195	0.001	0.68	995.772	0.008	5.13E-07	7.85×10^{-7}	0.653274539	813	0.031837	0.027587	-0.15404	-15.4042
40	496	54	275	27500	0.0001	145	0.001	0.68	995.772	0.008	6.9E-07	7.85×10^{-7}	0.878541621	1094	0.026309	0.023094	-0.13921	-13.9209
50	683	71	377	37700	0.0001	115	0.001	0.68	995.772	0.008	8.7E-07	7.85×10^{-7}	1.107726392	1379	0.022687	0.020096	-0.12895	-12.8948
60	825	91	458	45800	0.0001	100	0.001	0.68	995.772	0.008	0.000001	7.85×10^{-7}	1.27388535	1586	0.02084	0.018479	-0.12777	-12.7771
70	954	108	531	53100	0.0001	90	0.001	0.68	995.772	0.008	1.11E-06	7.85×10^{-7}	1.415428167	1762	0.019571	0.017347	-0.12821	-12.8209
80	1053	119	586	58600	0.0001	85	0.001	0.68	995.772	0.008	1.18E-06	7.85×10^{-7}	1.498688647	1865	0.019265	0.016762	-0.14932	-14.9316
90	1159	131	645	64500	0.0001	80	0.001	0.68	995.772	0.008	1.25E-06	7.85×10^{-7}	1.592356688	1982	0.018784	0.016164	-0.16209	-16.2094

D.4.8 Friction factor in a helical coil of inner diameter 1000 μm for methanol

Pump speed (rpm)	$(\Delta P)_{max}$ (mbar)	$(\Delta P)_{min}$ (mbar)	$(\Delta P)_{avg}$ (mbar)	ΔP (Pa)	Volume collected (m^3)	Time (s)	d_i (m)	L (m)	ρ (Kg/m^3)	μ (Pa.s)	Flow rates (m^3/s)	Flow area (m^2)	u (m/s)	Re	$f_c = \frac{\Delta P d}{2L\rho u^2}$	Srinivasan et al.'s (1968) *fc*	$(f_{theo} - f_{exp})/f_{theo}$	% Deviation
5	87	3	45	4500	0.0001	440	0.001	0.68	783.05	0.005	2.27273E-07	7.85×10^{-7}	0.289519	466	0.050411	0.038528	-0.30844	-30.8441
10	106	8	57	5700	0.0001	340	0.001	0.68	783.05	0.005	2.94118E-07	7.85×10^{-7}	0.374672	603	0.038128	0.033006	-0.15519	-15.519
20	189	17	103	10300	0.0001	215	0.001	0.68	783.05	0.005	4.65116E-07	7.85×10^{-7}	0.592505	954	0.02755	0.025071	-0.0989	-9.89021
30	329	27	178	17800	0.0001	150	0.001	0.68	783.05	0.005	6.66667E-07	7.85×10^{-7}	0.849257	1367	0.023175	0.0202	-0.14724	-14.7244
40	410	46	228	22800	0.0001	125	0.001	0.68	783.05	0.005	0.0000008	7.85×10^{-7}	1.019108	1640	0.020614	0.018107	-0.13846	-13.8457
50	547	69	308	30800	0.0001	100	0.001	0.68	783.05	0.005	0.000001	7.85×10^{-7}	1.273885	2050	0.017822	0.015838	-0.12527	-12.5275

D.4.9 Friction factor in a helical coil of inner diameter 1000 μm for acetone

Pump speed (rpm)	$(\Delta P)_{max}$ (mbar)	$(\Delta P)_{min}$ (mbar)	$(\Delta P)_{avg}$ (mbar)	ΔP (Pa)	Volume collected (m^3)	Time (s)	d_i (m)	L (m)	ρ (Kg/m^3)	μ (Pa.s)	Flow rates (m^3/s)	Flow area (m^2)	u (m/s)	Re	$f_c = \frac{\Delta P d}{2L\rho u^2}$	Srinivasan et al.'s (1968) *fc*	$(f_{theo} - f_{exp})/f_{theo}$	% Deviation
2	57	-1	28	2800	0.0001	455	0.001	0.68	780.199	0.003	2.1978E-07	7.85×10^{-7}	0.279975	741	0.033665	0.029181	-0.15364	-15.3645
5	68	0	34	3400	0.0001	400	0.001	0.68	780.199	0.003	0.00000025	7.85×10^{-7}	0.318471	842	0.031593	0.027011	-0.16966	-16.9664
10	91	1	46	4600	0.0001	310	0.001	0.68	780.199	0.003	3.22581E-07	7.85×10^{-7}	0.410931	1087	0.025673	0.02318	-0.10755	-10.7547
20	163	7	85	8000	0.0001	210	0.001	0.68	780.199	0.003	4.7619E-07	7.85×10^{-7}	0.606612	1604	0.020489	0.01835	-0.11659	-11.6593
25	215	11	113	11300	0.0001	165	0.001	0.68	780.199	0.003	6.06061E-07	7.85×10^{-7}	0.772052	2042	0.017867	0.015878	-0.12526	-12.5263

D.5 Average heat transfer coefficient in a helical coil

D.5.1 Average heat transfer coefficient in a helical coil of inner diameter 720 μm for water

Volume collected (m^3)	Time (s)	Flow rate (m^3/s)	*m* (Kg/s)	ϕ (W)	T_{in} (^0C)	T_o (^0C)	T_1 (^0C)	T_2 (^0C)	T_3 (^0C)	$\overline{T}_w$ (^0C)	T_b (^0C)	ρ (Kg/m^3)	Cp ($J/Kg.^0C$)	Q (W)	A_w (m^2)	q (W/m^2)	$\overline{h}$ ($W/m^{2\,0}C$)
0.0001	510	1.96E-07	0.000192586	40	30	77.5	82.05	80.43	79.11	80.53	53.75	982.1899	4169.231	38.13949	1.3×10^{-3}	29338.07	1095.522
0.0001	395	2.53E-07	0.00024927	40	30	67.8	71.08	70.11	69.23	70.14	48.9	984.6154	4168.937	39.28138	1.3×10^{-3}	30216.44	1422.62
0.0001	315	3.17E-07	0.000313073	40	30	58.5	60.87	60.12	59.05	60.013	44.25	986.181	4169.229	37.20032	1.3×10^{-3}	28615.63	1815.329
0.0001	250	4E-07	0.00039494	40	30	52.8	55.21	54.91	54.91	55.01	41.4	987.3496	4169.694	37.54654	1.3×10^{-3}	28881.95	2122.113
0.0001	200	5E-07	0.000494237	40	30	46.8	48.61	48.61	48.62	48.61	38.4	988.4742	4170.339	34.62709	1.3×10^{-3}	26636.22	2607.985
0.0001	145	6.9E-07	0.000682421	40	30	43.5	45.33	45.32	45.32	45.32	36.75	989.5105	4171.107	38.42709	1.3×10^{-3}	29559.3	3447.819
0.0001	115	8.7E-07	0.000860962	40	30	40.3	42.25	42.21	42.21	42.22	35.15	990.1059	4171.623	36.99356	1.3×10^{-3}	28456.58	4023.08
0.0001	95	1.05E-06	0.001042634	40	30	38.5	40.05	40.04	40.4	40.16	34.25	990.5028	4171.998	36.58874	1.3×10^{-3}	28145.18	4759.614
0.0001	80	1.25E-06	0.001238487	40	30	36.1	37.08	37.08	37.09	37.08	33.05	990.7894	4172.283	31.52064	1.3×10^{-3}	24246.64	6011.564

D.5.2 Average heat transfer coefficient in a helical coil of inner diameter 720 μm for methanol

Volume collected (m^3)	Time (s)	Flow rate (m^3/s)	*m* (Kg/s)	ϕ (W)	T_{in} (^0C)	T_o (^0C)	T_1 (^0C)	T_2 (^0C)	T_3 (^0C)	$\overline{T}_w$ (^0C)	T_b (^0C)	ρ (Kg/m^3)	Cp ($J/Kg.^0C$)	Q (W)	A_w (m^2)	q (W/m^2)	$\overline{h}$ ($W/m^{2\,0}C$)
0.0001	540	1.85185E-07	0.000143	10	30	44.5	51.2	49.21	48.12	49.51	37.25	774.3865	2514.081	5.48148	1.3×10^{-3}	4216.523	343.9252
0.0001	400	0.00000025	0.000194	10	30	42.1	46.43	45.31	44.91	45.55	36.05	775.9524	2508.498	5.888087	1.3×10^{-3}	4529.298	476.7682
0.0001	320	3.125E-07	0.000243	10	30	41.2	43.68	43.41	43.11	43.40	35.6	777.2335	2504.031	6.811759	1.3×10^{-3}	5239.815	671.7711
0.0001	255	3.92157E-07	0.000305	10	30	39.7	42.05	42.04	42.05	42.05	34.85	777.9453	2501.589	7.402809	1.3×10^{-3}	5694.469	791.2647
0.0001	215	4.65116E-07	0.000362	10	30	38.3	40.12	40.12	40.11	40.12	34.15	778.6096	2499.335	7.512489	1.3×10^{-3}	5778.838	968.5203
0.0001	195	5.12821E-07	0.0004	10	30	37.1	38.97	38.97	38.97	38.97	33.55	779.179	2497.423	7.085214	1.3×10^{-3}	5450.165	1005.565
0.0001	175	5.71429E-07	0.000446	10	30	35.9	37.61	37.62	37.61	37.61	32.95	779.7484	2495.528	6.560409	1.3×10^{-3}	5046.468	1082.159
0.0001	165	6.06061E-07	0.000473	10	30	34.7	35.97	35.96	35.96	35.96	32.35	780.3178	2493.652	5.542697	1.3×10^{-3}	4263.613	1179.967
0.0001	135	7.40741E-07	0.000578	10	30	33.4	34.21	34.21	34.21	34.21	31.70	780.9346	2491.639	4.900551	1.3×10^{-3}	3769.655	1501.854
0.0001	105	9.52381E-07	0.000745	10	30	32.2	32.53	32.52	33.52	32.86	31.10	781.9311	2488.433	4.076878	1.3×10^{-3}	3136.06	1785.233

D.5.3 Average heat transfer coefficient in a helical coil of inner diameter 720 μm for acetone

Volume collected (m^3)	Time (s)	Flow rate (m^3/s)	m (Kg/s)	ϕ (W)	T_{in} (^0C)	T_o (^0C)	T_1 (^0C)	T_2 (^0C)	T_3 (^0C)	$\overline{T}_w$ (^0C)	T_b (^0C)	ρ (Kg/m^3)	Cp ($J/Kg.^0C$)	Q (W)	A_w (m^2)	q (W/m^2)	$\overline{h}$ ($W/m^2\,^0C$)
0.0001	660	1.52E-07	0.000117	5	30	39.5	42.42	41.48	39.95	41.28333	34.75	772.007	2172.395	2.414014	1.3×10^{-3}	1856.934	284.2245
0.0001	480	2.08E-07	0.000161	5	30	37.2	38.47	38.47	38.46	38.46667	33.6	773.4008	2168.906	2.51615	1.3×10^{-3}	1935.5	397.7055
0.0001	395	2.53E-07	0.000196	5	30	35	35.81	35.82	35.81	35.81333	32.5	774.734	2165.613	2.123764	1.3×10^{-3}	1633.665	493.0578
0.0001	240	4.17E-07	0.000323	5	30	33	33.48	33.48	33.48	33.48	31.5	775.946	2162.657	2.097631	1.3×10^{-3}	1613.562	814.9304

D.6 Average Nusselt number in a helical coil

D.6.1 Average Nusselt number in a helical coil of inner diameter 720 μm for water

Volume collected (m^3)	Time (s)	Flow rate (m^3/s)	u (m/s)	d_i (m)	ρ (Kg/m^3)	μ (Pa.s)	Cp (J/Kg.K)	k (W/m.K)	Pr	Re	$\bar{h}$ ($W/m^2 K$)	$\overline{Nu}_c = \frac{\bar{h}d}{k}$
0.0001	510	1.96E-07	0.481884	0.00072	982.1899	0.000749	4169.231	0.60387	5.170217	455	1095.522	1.3062
0.0001	395	2.53E-07	0.622179	0.00072	984.6154	0.000826	4168.937	0.599325	5.74331	534	1422.62	1.709066
0.0001	315	3.17E-07	0.780192	0.00072	986.181	0.00088	4169.229	0.596134	6.15557	629	1815.329	2.19252
0.0001	250	4E-07	0.983043	0.00072	987.3496	0.000924	4169.694	0.593621	6.487465	757	2122.113	2.5739
0.0001	200	5E-07	1.228803	0.00072	988.4742	0.000968	4170.339	0.591097	6.828013	904	2607.985	3.176722
0.0001	145	6.9E-07	1.694901	0.00072	989.5105	0.001011	4171.107	0.588678	7.161622	1195	3447.819	4.216957
0.0001	115	8.7E-07	2.137049	0.00072	990.1059	0.001036	4171.623	0.587249	7.36238	1470	4023.08	4.932523
0.0001	95	1.05E-06	2.586954	0.00072	990.5028	0.001054	4171.998	0.58628	7.50008	1750	4759.614	5.845202
0.0001	80	1.25E-06	3.072008	0.00072	990.7894	0.001067	4172.283	0.585572	7.601507	2054	6011.564	7.391627

D.6.2 Average Nusselt number in a helical coil of inner diameter 720 μm for methanol

Volume collected (m^3)	Time (s)	Flow rate (m^3/s)	u (m/s)	d_i (m)	ρ (Kg/m^3)	μ (Pa.s)	Cp (J/Kg.K)	k (W/m.K)	Pr	Re	$\bar{h}$ ($W/m^2 K$)	$\overline{Nu}_c = \frac{\bar{h}d}{k}$
0.0001	540	1.85185E-07	0.455112	0.00072	774.3865	0.000567	2514.081	0.202195	7.051984	447	343.9252	1.22469
0.0001	400	0.00000025	0.614402	0.00072	775.9524	0.00058	2508.498	0.202311	7.19208	592	476.7682	1.696764
0.0001	320	3.125E-07	0.768002	0.00072	777.2335	0.000591	2504.031	0.202405	7.309693	727	671.7711	2.389641
0.0001	255	3.92157E-07	0.963767	0.00072	777.9453	0.000597	2501.589	0.202458	7.376227	904	791.2647	2.813976
0.0001	215	4.65116E-07	1.143073	0.00072	778.6096	0.000603	2499.335	0.202507	7.43911	1063	968.5203	3.443517
0.0001	195	5.12821E-07	1.260311	0.00072	779.179	0.000608	2497.423	0.202549	7.493622	1163	1005.565	3.574488
0.0001	175	5.71429E-07	1.404346	0.00072	779.7484	0.000613	2495.528	0.202591	7.548706	1287	1082.159	3.845958
0.0001	165	6.06061E-07	1.489458	0.00072	780.3178	0.000618	2493.652	0.202633	7.604369	1354	1179.967	4.192694
0.0001	135	7.40741E-07	1.820449	0.00072	780.9346	0.000624	2491.639	0.202678	7.665333	1641	1501.854	5.335237
0.0001	105	9.52381E-07	2.340577	0.00072	781.9311	0.000633	2488.433	0.202752	7.765294	2083	1785.233	6.339623

D.6.3 Average Nusselt number in a helical coil of inner diameter 720 μm for acetone

Volume collected (m^3)	Time (s)	Flow rate (m^3/s)	u (m/s)	d_i (m)	ρ (Kg/m^3)	μ (Pa.s)	Cp (J/Kg.K)	k (W/m.K)	Pr	Re	$\overline{h}$ ($W/m^2 K$)	$\overline{Nu}_c = \frac{\overline{h} d}{k}$
0.0001	660	1.52E-07	0.372365	0.00072	772.007	0.000284	2172.395	0.178778	3.454155	728	284.2245	1.144667
0.0001	480	2.08E-07	0.512001	0.00072	773.4008	0.000287	2168.906	0.17919	3.476027	993	397.7055	1.598012
0.0001	395	2.53E-07	0.622179	0.00072	774.734	0.00029	2165.613	0.179586	3.497256	1197	493.0578	1.976783
0.0001	240	4.17E-07	1.024003	0.00072	775.946	0.000293	2162.657	0.179946	3.51682	1955	814.9304	3.260697

D.7 Experimentally calculated friction factor ratio (f_c / f_s) and those predicted from present correlation

D.7.1 Friction factor ratio helical coil to that for straight tube of inner diameter 720 μm for water

d_i (m)	Re	De	f_c	f_s =16/Re	$(f_c / f_s)_{exp.}$	$(f_c / f_s)_{predicted}$	Reference line			
									5% data (+)	5% data (-)
0.00072	420	46	0.044157	0.038139	1.157803	1.229782	1.0	1.0	1.05	0.95
0.00072	565	62	0.036283	0.028332	1.280671	1.309322	1.3	1.3	1.365	1.235
0.00072	678	74	0.032635	0.02361	1.382274	1.371186	1.5	1.5	1.575	1.425
0.00072	773	85	0.030101	0.020704	1.453887	1.423283	1.7	1.7	1.785	1.615
0.00072	958	105	0.026589	0.016708	1.591357	1.524502	1.9	1.9	1.995	1.805
0.00072	1101	121	0.024084	0.014529	1.657639	1.603178	2.1	2.1	2.205	1.995
0.00072	1296	142	0.021776	0.01235	1.763301	1.709621	2.3	2.3	2.415	2.185
0.00072	1519	166	0.020043	0.010534	1.902831	1.831969	2.4	2.4	2.52	2.28
0.00072	1915	210	0.017241	0.008354	2.063748	2.049005	2.5	2.5	2.625	2.375

D.7.2 Friction factor ratio helical coil to that for straight tube of inner diameter 720 μm for methanol

d_i (m)	Re	De	f_c	f_s =16/Re	$(f_c / f_s)_{exp.}$	$(f_c / f_s)_{predicted}$	Reference line			
									5% data (+)	5% data (-)
0.00072	548	60	0.035414	0.029213	1.212272	1.299991	1.0	1.0	1.05	0.95
0.00072	640	70	0.033472	0.024999	1.338899	1.350552	1.3	1.3	1.365	1.235
0.00072	863	95	0.027915	0.018539	1.505776	1.472714	1.5	1.5	1.575	1.425
0.00072	10366	114	0.02455	0.015449	1.589065	1.567256	1.7	1.7	1.785	1.615
0.00072	1212	133	0.022316	0.013202	1.690386	1.663811	1.9	1.9	1.995	1.805
0.00072	1389	152	0.021216	0.011517	1.842219	1.760954	2.1	2.1	2.205	1.995
0.00072	1540	169	0.01996	0.010393	1.920527	1.843219	2.3	2.3	2.415	2.185
0.00072	1780	195	0.017738	0.008989	1.973429	1.974972	2.4	2.4	2.52	2.28
0.00072	2034	223	0.016126	0.007865	2.050342	2.114254	2.5	2.5	2.625	2.375

D.7.3 Friction factor ratio helical coil to that for straight tube of inner diameter 720 μm for acetone

d_i (m)	Re	De	f_c	f_s =16/Re	$(f_c/f_s)_{exp.}$	$(f_c/f_s)_{predicted}$	Reference line			
									5% data (+)	5% data (-)
0.00072	726	80	0.031315	0.022052	1.420059	1.397401	1.0	1.0	1.05	0.95
0.00072	1064	117	0.023926	0.015043	1.590439	1.582554	1.5	1.5	1.575	1.425
0.00072	1376	151	0.02091	0.011624	1.798774	1.753893	2.0	2.0	2.1	1.9
0.00072	1910	209	0.016927	0.008376	2.020745	2.046219	2.5	2.5	2.625	2.375

D.7.4 Friction factor ratio helical coil to that for straight tube of inner diameter 850 μm for water

d_i (m)	Re	De	f_c	f_s =16/Re	$(f_c/f_s)_{exp.}$	$(f_c/f_s)_{predicted}$	Reference line			
									5% data (+)	5% data (-)
0.00085	424	50	0.04805	0.037728	1.273591	1.250892	10	1.0	1.05	0.95
0.00085	622	74	0.037229	0.025724	1.447262	1.367975	1.3	1.3	1.365	1.235
0.00085	868	102	0.029475	0.018435	1.598813	1.513454	1.5	1.5	1.575	1.425
0.00085	1009	119	0.027003	0.015863	1.702239	1.596717	1.7	1.7	1.785	1.615
0.00085	1287	152	0.023037	0.012433	1.852848	1.761328	1.9	1.9	1.995	1.805
0.00085	1555	184	0.020078	0.01029	1.951333	1.919938	2.1	2.1	2.205	1.995
0.00085	1866	221	0.017676	0.008575	2.061466	2.103926	2.3	2.3	2.415	2.185
0.00085	2073	245	0.016197	0.007717	2.098883	2.226584	2.5	2.5	2.625	2.375

D.7.5 Friction factor ratio helical coil to that for straight tube of inner diameter 850 μm for methanol

d_i (m)	Re	De	f_c	f_s =16/Re	$(f_c / f_s)_{exp.}$	$(f_c / f_s)_{predicted}$	Reference line			
									5% data (+)	5% data (-)
0.00085	492	58	0.043743	0.032492	1.346274	1.291327	1.0	1.0	1.05	0.95
0.00085	619	73	0.037468	0.025861	1.448822	1.366026	1.25	1.25	1.3125	1.1875
0.00085	985	117	0.027108	0.016246	1.668622	1.582654	1.5	1.5	1.575	1.425
0.00085	1341	159	0.021782	0.011936	1.824958	1.793056	2.0	2.0	2.1	1.9
0.00085	1609	190	0.018995	0.009946	1.909705	1.951668	2.25	2.25	2.3625	2.1375
0.00085	2011	238	0.016443	0.007957	2.066429	2.189584	2.5	2.5	2.625	2.375

D.7.6 Friction factor ratio helical coil to that for straight tube of inner diameter 850 μm for acetone

d_i (m)	Re	De	f_c	f_s =16/Re	$(f_c / f_s)_{exp.}$	$(f_c / f_s)_{predicted}$	Reference line			
									5% data (+)	5% data (-)
0.00085	758	90	0.033082	0.021097	1.568056	1.448673	1.0	1.0	1.05	0.95
0.00085	997	118	0.026473	0.016048	1.64961	1.589828	1.5	1.5	1.575	1.425
0.00085	1305	154	0.022349	0.012262	1.822698	1.771981	2.0	2.0	2.1	1.9
0.00085	1888	223	0.016924	0.008475	1.996926	2.116908	2.5	2.5	2.625	2.375

D.7.7 Friction factor ratio helical coil to that for straight tube of inner diameter 1000 μm for water

d_i (m)	Re	De	f_c	f_s =16/Re	$(f_c / f_s)_{exp.}$	$(f_c / f_s)_{predicted}$	Reference line			
									5% data (+)	5% data (-)
0.001	401	52	0.055377	0.039858	1.389353	1.261696	1.0	1.0	1.05	0.95
0.001	598	78	0.039304	0.02674	1.469846	1.390076	1.3	1.3	1.365	1.235
0.001	813	106	0.031837	0.019677	1.61798	1.530103	1.5	1.5	1.575	1.425
0.001	1094	143	0.026309	0.014631	1.798132	1.712897	1.7	1.7	1.785	1.615
0.001	1379	180	0.022687	0.011604	1.955059	1.89887	1.9	1.9	1.995	1.805
0.001	1586	207	0.02084	0.010091	2.065315	2.033701	2.1	2.1	2.205	1.995
0.001	1762	230	0.019571	0.009082	2.155052	2.148556	2.3	2.3	2.415	2.185
0.001	1865	243	0.019265	0.008577	2.246143	2.216118	2.4	2.4	2.52	2.28
0.001	1982	258	0.018784	0.008073	2.326861	2.292126	2.5	2.5	2.625	2.375

D.7.8 Friction factor ratio helical coil to that for straight tube of inner diameter 1000 μm for methanol

d_i (m)	Re	De	f_c	f_s =16/Re	$(f_c / f_s)_{exp.}$	$(f_c / f_s)_{predicted}$	Reference line			
									5% data (+)	5% data (-)
0.001	466	61	0.050411	0.034335	1.468227	1.303794	1.0	1.0	1.05	0.95
0.001	603	79	0.038128	0.026532	1.437082	1.393145	1.25	1.25	1.3125	1.1875
0.001	954	124	0.02755	0.016777	1.642115	1.621717	1.5	1.5	1.575	1.425
0.001	1367	178	0.023175	0.011705	1.979881	1.891128	2.0	2.0	2.1	1.9
0.001	1640	214	0.020614	0.009754	2.113357	2.069354	2.25	2.25	2.3625	2.1375
0.001	2050	267	0.017822	0.007803	2.283908	2.336692	2.5	2.5	2.625	2.375

D.7.9 Friction factor ratio helical coil to that for straight tube of inner diameter 1000 μm for acetone

d_i (m)	Re	De	f_c	f_s =16/Re	$(f_c / f_s)_{exp.}$	$(f_c / f_s)_{predicted}$	Reference line			
									5% data (+)	5% data (-)
0.001	741	97	0.033665	0.021608	1.557967	1.482722	1.0	1.0	1.05	0.95
0.001	842	110	0.031593	0.018996	1.663136	1.549096	1.25	1.25	1.3125	1.1875
0.001	1087	142	0.025673	0.014722	1.743847	1.708511	1.5	1.5	1.575	1.425
0.001	1604	209	0.020489	0.009973	2.054462	2.045897	2.0	2.0	2.1	1.9
0.001	2042	267	0.017867	0.007836	2.280086	2.331142	2.5	2.5	2.625	2.375

D.8 Experimentally calculated friction factor ratio (f_c / f_s) and those predicted from correlations of Mishra and Gupta (1979), Ito (1969), White (1934) and Mori and Nakayama (1967)

D.8.1 Friction factor ratio helical coil to that for straight tube of inner diameter 720 μm for water

d_i (m)	Re	De	f_c	f_s =16/Re	$(f_c / f_s)_{exp.}$	Mishra and Gupta (1979) $(f_c / f_s)_{predicted}$	Ito (1969) $(f_c / f_s)_{predicted}$	White (1934) $(f_c / f_s)_{predicted}$	Mori and Nakayama (1967) $(f_c / f_s)_{predicted}$	Reference line			
												10% data (+)	10% data (-)
0.00072	420	46	0.044157	0.038139	1.157803	1.252	1.210481	1.223568	1.407581	1.0	1.0	1.1	0.9
0.00072	565	62	0.036283	0.028332	1.280671	1.339879	1.301075	1.327245	1.448566	1.3	1.3	1.43	1.17
0.00072	678	74	0.032635	0.02361	1.382274	1.404071	1.365759	1.400915	1.494959	1.5	1.5	1.65	1.35
0.00072	773	85	0.030101	0.020704	1.453887	1.455655	1.417027	1.458977	1.537166	1.7	1.7	1.87	1.53
0.00072	958	105	0.026589	0.016708	1.591357	1.550285	1.509822	1.563234	1.62099	1.9	1.9	2.09	1.71
0.00072	1101	121	0.024084	0.014529	1.657639	1.61944	1.576865	1.637858	1.685372	2.1	2.1	2.31	1.89
0.00072	1296	142	0.021776	0.01235	1.763301	1.707829	1.661894	1.731655	1.769916	2.3	2.3	2.53	2.07
0.00072	1519	166	0.020043	0.010534	1.902831	1.803185	1.75307	1.831199	1.862932	2.4	2.4	2.64	2.16
0.00072	1915	210	0.017241	0.008354	2.063748	1.959	1.901434	1.99098	2.017405	2.5	2.5	2.75	2.25

D.8.2 Friction factor ratio helical coil to that for straight tube of inner diameter 720 μm for methanol

d_i (m)	Re	De	f_c	f_s =16/Re	$(f_c/f_s)_{exp.}$	Mishra and Gupta (1979) $(f_c/f_s)_{predicted}$	Ito (1969) $(f_c/f_s)_{predicted}$	White (1934) $(f_c/f_s)_{predicted}$	Mori and Nakayama (1967) $(f_c/f_s)_{predicted}$	Reference line			
												10% data (+)	10% data (-)
0.00072	548	60	0.035414	0.029213	1.212272	1.329896	1.290913	1.315636	1.442248	1.0	1.0	1.1	0.9
0.00072	640	70	0.033472	0.024999	1.338899	1.383033	1.344677	1.376951	1.478835	1.3	1.3	1.43	1.17
0.00072	863	95	0.027915	0.018539	1.505776	1.50273	1.463366	1.511179	1.578072	1.5	1.5	1.65	1.35
0.00072	10366	114	0.02455	0.015449	1.589065	1.588302	1.546744	1.604404	1.656144	1.7	1.7	1.87	1.53
0.00072	1212	133	0.022316	0.013202	1.690386	1.670463	1.626023	1.6922	1.733932	1.9	1.9	2.09	1.71
0.00072	1389	152	0.021216	0.011517	1.842219	1.748586	1.70092	1.774392	1.809489	2.1	2.1	2.31	1.89
0.00072	1540	169	0.01996	0.010393	1.920527	1.811655	1.761149	1.83997	1.871261	2.3	2.3	2.53	2.07
0.00072	1780	195	0.017738	0.008989	1.973429	1.907554	1.852492	1.938566	1.966139	2.4	2.4	2.64	2.16
0.00072	2034	223	0.016126	0.007865	2.050342	2.003036	1.943318	2.035613	2.061456	2.5	2.5	2.75	2.25

D.8.3 Friction factor ratio helical coil to that for straight tube of inner diameter 720 μm for acetone

d_i (m)	Re	De	f_c	f_s =16/Re	$(f_c/f_s)_{exp.}$	Mishra and Gupta (1979) $(f_c/f_s)_{predicted}$	Ito (1969) $(f_c/f_s)_{predicted}$	White (1934) $(f_c/f_s)_{predicted}$	Mori and Nakayama (1967) $(f_c/f_s)_{predicted}$	Reference line			
												10% data (+)	10% data (-)
0.00072	726	80	0.031315	0.022052	1.420059	1.430294	1.391891	1.43055	1.516003	1.0	1.0	1.1	0.9
0.00072	1064	117	0.023926	0.015043	1.590439	1.601649	1.559668	1.618772	1.66863	1.5	1.5	1.65	1.35
0.00072	1376	151	0.02091	0.011624	1.798774	1.743047	1.695621	1.768601	1.804093	2.0	2.0	2.2	1.8
0.00072	1910	209	0.016927	0.008376	2.020745	1.957094	1.89962	1.989043	2.015502	2.5	2.5	2.75	2.25

D.8.4 Friction factor ratio helical coil to that for straight tube of inner diameter 850 μm for water

d_i (m)	Re	De	f_c	f_s =16/Re	$(f_c / f_s)_{exp.}$	Mishra and Gupta (1979) $(f_c / f_s)_{predicted}$	Ito (1969) $(f_c / f_s)_{predicted}$	White (1934) $(f_c / f_s)_{predicted}$	Mori and Nakayama (1967) $(f_c / f_s)_{predicted}$	Reference line			
												10% data (+)	10% data (-)
0.00085	424	50	0.04805	0.037728	1.273591	1.275955	1.235447	1.252161	1.414704	10	1.0	1.1	0.9
0.00085	622	74	0.037229	0.025724	1.447262	1.400821	1.362508	1.397224	1.49242	1.3	1.3	1.43	1.17
0.00085	868	102	0.029475	0.018435	1.598813	1.540283	1.500078	1.552338	1.611855	1.5	1.5	1.65	1.35
0.00085	1009	119	0.027003	0.015863	1.702239	1.613891	1.571504	1.631913	1.680139	1.7	1.7	1.87	1.53
0.00085	1287	152	0.023037	0.012433	1.852848	1.74888	1.7012	1.774698	1.809774	1.9	1.9	2.09	1.71
0.00085	1555	184	0.020078	0.01029	1.951333	1.86821	1.815041	1.898264	1.927094	2.1	2.1	2.31	1.89
0.00085	1866	221	0.017676	0.008575	2.061466	1.996144	1.936762	2.028641	2.054551	2.3	2.3	2.53	2.07
0.00085	2073	245	0.016197	0.007717	2.098883	2.076236	2.012965	2.109384	2.134979	2.5	2.5	2.75	2.25

D.8.5 Friction factor ratio helical coil to that for straight tube of inner diameter 850 μm for methanol

d_i (m)	Re	De	f_c	f_s =16/Re	$(f_c / f_s)_{exp.}$	Mishra and Gupta (1979) $(f_c / f_s)_{predicted}$	Ito (1969) $(f_c / f_s)_{predicted}$	White (1934) $(f_c / f_s)_{predicted}$	Mori and Nakayama (1967) $(f_c / f_s)_{predicted}$	Reference line			
												10% data (+)	10% data (-)
0.00085	492	58	0.043743	0.032492	1.346274	1.320551	1.281373	1.30473	1.436623	1.0	1.0	1.1	0.9
0.00085	619	73	0.037468	0.025861	1.448822	1.398844	1.36053	1.394976	1.490884	1.25	1.25	1.375	1.125
0.00085	985	117	0.027108	0.016246	1.668622	1.601735	1.559751	1.618865	1.668711	1.5	1.5	1.65	1.35
0.00085	1341	159	0.021782	0.011936	1.824958	1.773514	1.724746	1.800388	1.833834	2.0	2.0	2.2	1.8
0.00085	1609	190	0.018995	0.009946	1.909705	1.891013	1.83675	1.921646	1.949705	2.25	2.25	2.475	2.025
0.00085	2011	238	0.016443	0.007957	2.066429	2.052472	1.990349	2.085489	2.111072	2.5	2.5	2.75	2.25

D.8.6 Friction factor ratio helical coil to that for straight tube of inner diameter 850 μm for acetone

d_i (m)	Re	De	f_c	f_s =16/Re	$(f_c/f_s)_{exp.}$	Mishra and Gupta (1979) $(f_c/f_s)_{predicted}$	Ito (1969) $(f_c/f_s)_{predicted}$	White (1934) $(f_c/f_s)_{predicted}$	Mori and Nakayama (1967) $(f_c/f_s)_{predicted}$	Reference line			
												10% data (+)	10% data (-)
0.00085	758	90	0.033082	0.021097	1.568056	1.480051	1.441089	1.486118	1.558134	1.0	1.0	1.1	0.9
0.00085	997	118	0.026473	0.016048	1.64961	1.60795	1.565762	1.62554	1.674547	1.5	1.5	1.65	1.35
0.00085	1305	154	0.022349	0.012262	1.822698	1.757196	1.709152	1.783383	1.817886	2.0	2.0	2.2	1.8
0.00085	1888	223	0.016924	0.008475	1.996926	2.004804	1.944999	2.0374	2.063226	2.5	2.5	2.75	2.25

D.8.7 Friction factor ratio helical coil to that for straight tube of inner diameter 1000 μm for water

d_i (m)	Re	De	f_c	f_s =16/Re	$(f_c/f_s)_{exp.}$	Mishra and Gupta (1979) $(f_c/f_s)_{predicted}$	Ito (1969) $(f_c/f_s)_{predicted}$	White (1934) $(f_c/f_s)_{predicted}$	Mori and Nakayama (1967) $(f_c/f_s)_{predicted}$	Reference line			
												10% data (+)	10% data (-)
0.001	401	52	0.055377	0.039858	1.389353	1.288034	1.247954	1.266485	1.419695	1.0	1.0	1.1	0.9
0.001	598	78	0.039304	0.02674	1.469846	1.423022	1.384659	1.422356	1.510074	1.3	1.3	1.43	1.17
0.001	813	106	0.031837	0.019677	1.61798	1.555327	1.514729	1.568716	1.625614	1.5	1.5	1.65	1.35
0.001	1094	143	0.026309	0.014631	1.798132	1.710465	1.664421	1.734428	1.772465	1.7	1.7	1.87	1.53
0.001	1379	180	0.022687	0.011604	1.955059	1.852884	1.800445	1.882511	1.911928	1.9	1.9	2.09	1.71
0.001	1586	207	0.02084	0.010091	2.065315	1.948498	1.891444	1.980305	2.006922	2.1	2.1	2.31	1.89
0.001	1762	230	0.019571	0.009082	2.155052	2.025727	1.964903	2.058535	2.084209	2.3	2.3	2.53	2.07
0.001	1865	243	0.019265	0.008577	2.246143	2.069547	2.006599	2.102664	2.128246	2.4	2.4	2.64	2.16
0.001	1982	258	0.018784	0.008073	2.326861	2.117543	2.052299	2.150806	2.176618	2.5	2.5	2.75	2.25

D.8.8 Friction factor ratio helical coil to that for straight tube of inner diameter 1000 μm for methanol

d_i (m)	Re	De	f_c	f_s =16/Re	$(f_c / f_s)_{exp.}$	Mishra and Gupta (1979) $(f_c / f_s)_{predicted}$	Ito (1969) $(f_c / f_s)_{predicted}$	White (1934) $(f_c / f_s)_{predicted}$	Mori and Nakayama (1967) $(f_c / f_s)_{predicted}$	Reference line			
												10% data (+)	10% data (-)
0.001	466	61	0.050411	0.034335	1.468227	1.333974	1.295068	1.320383	1.444793	1.0	1.0	1.1	0.9
0.001	603	79	0.038128	0.026532	1.437082	1.426074	1.387695	1.425797	1.512554	1.25	1.25	1.375	1.125
0.001	954	124	0.02755	0.016777	1.642115	1.635239	1.592111	1.654746	1.700329	1.5	1.5	1.65	1.35
0.001	1367	178	0.023175	0.011705	1.979881	1.847214	1.795043	1.876675	1.906323	2.0	2.0	2.2	1.8
0.001	1640	214	0.020614	0.009754	2.113357	1.97286	1.914617	2.00505	2.031254	2.25	2.25	2.475	2.025
0.001	2050	267	0.017822	0.007803	2.283908	2.145083	2.078541	2.178347	2.204434	2.5	2.5	2.75	2.25

D.8.9 Friction factor ratio helical coil to that for straight tube of inner diameter 1000 μm for acetone

d_i (m)	Re	De	f_c	f_s =16/Re	$(f_c / f_s)_{exp.}$	Mishra and Gupta (1979) $(f_c / f_s)_{predicted}$	Ito (1969) $(f_c / f_s)_{predicted}$	White (1934) $(f_c / f_s)_{predicted}$	Mori and Nakayama (1967) $(f_c / f_s)_{predicted}$	Reference line			
												10% data (+)	10% data (-)
0.001	741	97	0.033665	0.021608	1.557967	1.512055	1.472502	1.521438	1.586379	1.0	1.0	1.1	0.9
0.001	842	110	0.031593	0.018996	1.663136	1.572285	1.531209	1.587104	1.641255	1.25	1.25	1.375	1.125
0.001	1087	142	0.025673	0.014722	1.743847	1.706935	1.661037	1.730714	1.769051	1.5	1.5	1.65	1.35
0.001	1604	209	0.020489	0.009973	2.054462	1.956873	1.89941	1.988819	2.015281	2.0	2.0	2.2	1.8
0.001	2042	267	0.017867	0.007836	2.280086	2.141676	2.075294	2.174944	2.200991	2.5	2.5	2.75	2.25

D.9 Cioncolini and Santini's (2006) friction factor data

δ	log Re	log f	Re	f_c	De	f_s	f_c / f_s
0.012	**3.099**	**-1.685**	**1256**	**0.02065**	**138**	**0.012739**	**1.621025**
0.012	**3.117**	**-1.685**	**1309**	**0.02018**	**143**	**0.012223**	**1.650976**
0.012	**3.14**	**-1.709**	**1380**	**0.01954**	**151**	**0.011594**	**1.685325**
0.012	**3.164**	**-1.724**	**1459**	**0.01888**	**160**	**0.010966**	**1.72162**
0.012	**3.187**	**-1.736**	**1538**	**0.01837**	**169**	**0.010403**	**1.765816**
0.012	**3.222**	**-1.767**	**1677**	**0.0171**	**184**	**0.009541**	**1.792294**
0.012	**3.245**	**-1.778**	**1758**	**0.01667**	**193**	**0.009101**	**1.831616**
0.012	**3.28**	**-1.794**	**1906**	**0.01607**	**209**	**0.008395**	**1.914339**
0.012	**3.298**	**-1.817**	**1986**	**0.01524**	**218**	**0.008056**	**1.891665**
0.012	**3.374**	**-1.856**	**2366**	**0.01393**	**259**	**0.006762**	**2.059899**

D.10 Cioncolini and Santini's (2006) experimental friction factor data and (f_c / f_s) predicted from present correlation

De	Cioncolini and Santini (2006) (f_c / f_s)$_{exp}$	Present correlation (f_c / f_s)$_{pred.}$	Reference line			
					10% data (+)	10% data (-)
138	**1.621025**	**1.68794**	**1.0**	**1.0**	**1.1**	**0.9**
143	**1.650976**	**1.716969**	**1.2**	**1.2**	**1.32**	**1.08**
151	**1.685325**	**1.755857**	**1.4**	**1.4**	**1.54**	**1.26**
160	**1.72162**	**1.799127**	**1.8**	**1.8**	**1.98**	**1.62**
169	**1.765816**	**1.842397**	**2.0**	**2.0**	**2.2**	**1.8**
184	**1.792294**	**1.918531**	**2.1**	**2.1**	**2.31**	**1.89**
193	**1.831616**	**1.962896**	**2.2**	**2.2**	**2.42**	**1.98**
209	**1.914339**	**2.043959**	**2.3**	**2.3**	**2.53**	**2.07**
218	**1.891665**	**2.087777**	**2.4**	**2.4**	**2.64**	**2.16**
259	**2.059899**	**2.295912**	**2.5**	**2.5**	**2.75**	**2.25**

D.11 Cioncolini and Santini's (2006) experimental friction factor data and predicted from correlations of Mishra and Gupta (1979) and Ito (1969)

De	Cioncolini and Santini (2006) $(f_c / f_s)_{exp.}$	Mishra and Gupta (1979) $(f_c / f_s)_{pred.}$	Ito (1969) $(f_c / f_s)_{pred.}$	Reference line			
						5% data (+)	5% data (-)
138	1.621025	1.690265	1.645045	1.0	1.0	1.05	0.95
143	1.650976	1.713734	1.667554	1.2	1.2	1.26	1.14
151	1.685325	1.74459	1.697097	1.4	1.4	1.47	1.33
160	1.72162	1.778182	1.729204	1.8	1.8	1.89	1.71
169	1.765816	1.811038	1.760561	2.0	2.0	2.1	1.9
184	1.792294	1.867191	1.814071	2.1	2.1	2.205	1.995
193	1.831616	1.899004	1.844356	2.2	2.2	2.31	2.09
209	1.914339	1.955545	1.898147	2.3	2.3	2.415	2.185
218	1.891665	1.985309	1.926457	2.4	2.4	2.52	2.28
259	2.059899	2.119899	2.054543	2.5	2.5	2.625	2.375

D.12 Cioncolini and Santini's (2006) friction factor data and (f_c / f_s) (f_c / f_s) predicted from correlations of White (1929) and Mori and Nakayama (1967)

De	Cioncolini and Santini (2006) $(f_c / f_s)_{exp.}$	White (1929) $(f_c / f_s)_{pred.}$	Mori and Nakayama (1967) $(f_c / f_s)_{pred.}$	Reference line			
						10% data (+)	10% data (-)
138	1.621025	1.713144	1.752963	1.0	1.0	1.1	0.9
143	1.650976	1.737865	1.775629	1.2	1.2	1.32	1.08
151	1.685325	1.770215	1.805595	1.4	1.4	1.54	1.26
160	1.72162	1.805245	1.838403	1.8	1.8	1.98	1.62
169	1.765816	1.839331	1.870654	2.0	2.0	2.2	1.8
184	1.792294	1.897218	1.926085	2.1	2.1	2.31	1.89
193	1.831616	1.929825	1.957642	2.2	2.2	2.42	1.98
209	1.914339	1.98747	2.013956	2.3	2.3	2.53	2.07
218	1.891665	2.01767	2.043705	2.4	2.4	2.64	2.16
259	2.059899	2.153165	2.178996	2.5	2.5	2.75	2.25

D.13 Experimental friction factor ratio (f_c / f_s) of both (present and Cioncolini and Santini's (2006))and those predicted from the generalized correlation

D.13.1 Friction factor ratio in tube diameter of 720 μm and those predicted from generalized correlation for water

De	$(f_c / f_s)_{exp.}$	$(f_c / f_s)_{predicted}$ (Generalized correlation)	Reference line			
					8% data (+)	8% data (-)
46	1.157803	1.247865	1.0	1.0	1.08	0.92
62	1.280671	1.323603	1.3	1.3	1.404	1.196
74	1.382274	1.381099	1.5	1.5	1.62	1.38
85	1.453887	1.428747	1.7	1.7	1.836	1.564
105	1.591357	1.51967	1.9	1.9	2.052	1.748
121	1.657639	1.589079	2.1	2.1	2.268	1.932
142	1.763301	1.681529	2.3	2.3	2.484	2.116
166	1.902831	1.78605	2.4	2.4	2.592	2.208
210	2.063748	1.967724	2.5	2.5	2.7	2.3

D.13.2 Friction factor ratio in tube diameter of 720 μm and those predicted from generalized correlation for methanol

De	$(f_c / f_s)_{exp.}$	$(f_c / f_s)_{predicted}$ (Generalized correlation)	Reference line			
					8% data (+)	8% data (-)
60	1.212272	1.314833	1.0	1.0	1.08	0.92
70	1.338899	1.36204	1.3	1.3	1.404	1.196
95	1.505776	1.4734	1.5	1.5	1.62	1.38
114	1.589065	1.557512	1.7	1.7	1.836	1.564
133	1.690386	1.64193	1.9	1.9	2.052	1.748
152	1.842219	1.725592	2.1	2.1	2.268	1.932
169	1.920527	1.795577	2.3	2.3	2.484	2.116
195	1.973429	1.906233	2.4	2.4	2.592	2.208
223	2.050342	2.021548	2.5	2.5	2.7	2.3

D.13.3 Friction factor ratio in tube diameter of 720 μm and those predicted from generalized correlation for acetone

De	$(f_c / f_s)_{exp.}$	$(f_c / f_s)_{predicted}$ (Generalized correlation)	Reference line			
					8% data (+)	8% data (-)
80	1.420059	1.397401	1.0	1.0	1.08	0.92
117	1.590439	1.582554	1.5	1.5	1.62	1.38
151	1.798774	1.753893	2.0	2.0	2.16	1.84
209	2.020745	2.046219	2.5	2.5	2.7	2.3

D.13.4 Friction factor ratio in tube diameter of 850 μm and those predicted from generalized correlation for water

De	$(f_c / f_s)_{exp.}$	$(f_c / f_s)_{predicted}$ (Generalized correlation)	Reference line			
					8% data (+)	8% data (-)
50	1.273591	1.268197	1.0	1.0	1.08	0.92
74	1.447262	1.37814	1.3	1.3	1.404	1.196
102	1.598813	1.50984	1.5	1.5	1.62	1.38
119	1.702239	1.583415	1.7	1.7	1.836	1.564
152	1.852848	1.725912	1.9	1.9	2.052	1.748
184	1.951333	1.860212	2.1	2.1	2.268	1.932
221	2.061466	2.01305	2.3	2.3	2.484	2.116
245	2.098883	2.113462	2.5	2.5	2.7	2.3

D.13.5 Friction factor ratio in tube diameter of 850 μm and those predicted from generalized correlation for methanol

De	$(f_c/f_s)_{exp}$	$(f_c/f_s)_{predicted}$ (Generalized correlation)	Reference line			
					8% data (+)	8% data (-)
58	1.346274	1.306664	1.0	1.0	1.08	0.92
73	1.448822	1.376343	1.25	1.25	1.35	1.15
117	1.668622	1.571067	1.5	1.5	1.62	1.38
159	1.824958	1.752991	2.0	2.0	2.16	1.84
190	1.909705	1.886779	2.25	2.25	2.43	2.07
238	2.066429	2.083287	2.5	2.5	2.7	2.3

D.13.6 Friction factor ratio in tube diameter of 850 μm and those predicted from generalized correlation for acetone

De	$(f_c/f_s)_{exp.}$	$(f_c/f_s)_{predicted}$ (Generalized correlation)	Reference line			
					8% data (+)	8% data (-)
90	1.568056	1.448673	1.0	1.0	1.08	0.92
118	1.64961	1.589828	1.5	1.5	1.62	1.38
154	1.822698	1.771981	2.0	2.0	2.16	1.84
223	1.996926	2.116908	2.5	2.5	2.7	2.3

D.13.7 Friction factor ratio in tube diameter of 1000 μm and those predicted from generalized correlation for water

De	$(f_c / f_s)_{exp}$	$(f_c / f_s)_{predicted}$ (Generalized correlation)	Reference line			
					8% data (+)	8% data (-)
52	1.389353	1.278534	1.0	1.0	1.08	0.92
78	1.469846	1.398451	1.3	1.3	1.404	1.196
106	1.61798	1.524644	1.5	1.5	1.62	1.38
143	1.798132	1.684351	1.7	1.7	1.836	1.564
180	1.955059	1.84252	1.9	1.9	2.052	1.748
207	2.065315	1.95505	2.1	2.1	2.268	1.932
230	2.155052	2.049713	2.3	2.3	2.484	2.116
243	2.246143	2.104936	2.4	2.4	2.592	2.208
258	2.326861	2.166687	2.5	2.5	2.7	2.3

D.13.8 Friction factor ratio in tube diameter of 1000 μm and those predicted from generalized correlation for methanol

De	$(f_c / f_s)_{exp}$	$(f_c / f_s)_{predicted}$ (Generalized correlation)	Reference line			
					8% data (+)	8% data (-)
61	1.468227	1.31841	1.0	1.0	1.08	0.92
79	1.437082	1.401262	1.25	1.25	1.35	1.15
124	1.642115	1.605295	1.5	1.5	1.62	1.38
178	1.979881	1.836008	2.0	2.0	2.16	1.84
214	2.113357	1.984546	2.25	2.25	2.43	2.07
267	2.283908	2.202719	2.5	2.5	2.7	2.3

D.13.9 Friction factor ratio in tube diameter of 1000 μm and those predicted from generalized correlation for acetone

De	$(f_c / f_s)_{exp.}$	$(f_c / f_s)_{predicted}$ (Generalized correlation)	Reference line			
					8% data (+)	8% data (-)
97	1.557967	1.482381	1.0	1.0	1.08	0.92
110	1.663136	1.541475	1.25	1.25	1.35	1.15
142	1.743847	1.680573	1.5	1.5	1.62	1.38
209	2.054462	1.965151	2.0	2.0	2.16	1.84
267	2.280086	2.198238	2.5	2.5	2.7	2.3

D.13.10 Friction factor ratio of Cioncolini and Santini (2006) and those predicted from generalized correlation

De	$(f_c / f_s)_{exp.}$	$(f_c / f_s)_{predicted}$ (Generalized correlation)	Reference line			
					8% data (+)	8% data (-)
138	1.621025	1.662821	1.0	1.0	1.08	0.92
143	1.650976	1.687856	1.2	1.2	1.296	1.104
151	1.685325	1.721231	1.4	1.4	1.512	1.288
160	1.72162	1.758159	1.8	1.8	1.944	1.656
169	1.765816	1.794882	2.0	2.0	2.16	1.84
184	1.792294	1.859031	2.1	2.1	2.268	1.932
193	1.831616	1.896158	2.2	2.2	2.376	2.024
209	1.914339	1.963547	2.3	2.3	2.484	2.116
218	1.891665	1.999747	2.4	2.4	2.592	2.208
259	2.059899	2.169753	2.5	2.5	2.7	2.3

D.14 Experimental Nusselt number and those predicted from present correlation in a helical coil

D.14.1 Experimental Nusselt number and those predicted from present correlation in a helical coil of inner diameter 720 μm for water

De	Pr	$Nu_{exp.}$	$0.008 \times De^{0.949}$	$Nu / Pr^{0.75}$	Present correlation $Nu_{pred.}$	Reference line			
								6% data (+)	6% data (-)
50	5.170217	1.3062	0.326718	0.380959	1.120224	0	0	0	0
59	5.74331	1.709066	0.38042	0.460667	1.41135	1	1	1.06	0.94
69	6.15557	2.19252	0.444478	0.561038	1.737006	2	2	2.12	1.88
83	6.487465	2.5739	0.529338	0.633192	2.151739	3	3	3.18	2.82
99	6.828013	3.176722	0.626476	0.75207	2.646214	4	4	4.24	3.76
131	7.161622	4.216957	0.816546	0.963254	3.574696	5	5	5.3	4.7
161	7.36238	4.932523	0.994084	1.103584	4.443106	6	6	6.36	5.64
192	7.50008	5.845202	1.173306	1.289734	5.317538	7	7	7.42	6.58
225	7.601507	7.391627	1.365676	1.614601	6.25205	8	8	8.48	7.52

D.14.2 Experimental Nusselt number and those predicted from present correlation in a helical coil of inner diameter 720 μm for methanol

De	Pr	$Nu_{exp.}$	$0.008 \times De^{0.949}$	$Nu / Pr^{0.75}$	Present correlation $Nu_{pred.}$	Reference line			
								6% data (+)	6% data (-)
49	7.051984	1.22469	0.321501	0.283004	1.391283	0	0	0	0
65	7.19208	1.696764	0.41922	0.38635	1.841123	1	1	1.06	0.94
80	7.309693	2.389641	0.509891	0.537537	2.266739	2	2	2.12	1.88
99	7.376227	2.813976	0.62689	0.628702	2.805868	3	3	3.18	2.82
116	7.43911	3.443517	0.730964	0.764472	3.292583	4	4	4.24	3.76
127	7.493622	3.574488	0.796212	0.789214	3.606179	4.5	4.5	4.77	4.23
141	7.548706	3.845958	0.876017	0.844501	3.989486	5	5	5.3	4.7
148	7.604369	4.192694	0.919689	0.915579	4.211514	6	6	6.36	5.64
180	7.665333	5.335237	1.103966	1.158125	5.085738	7	7	7.42	6.58
228	7.765294	6.339623	1.383692	1.36284	6.436618	8	8	8.48	7.52

D.14.3 Experimental Nusselt number and those predicted from present correlation in a helical coil of **inner diameter 720 μm for acetone**

De	Pr	$Nu_{exp.}$	$0.008 \times De^{0.949}$	$Nu/\Pr^{0.75}$	Present correlation $Nu_{pred.}$	Reference line			
								6% data (+)	6% data (-)
80	3.454155	1.144667	0.51038	0.451776	1.293152	0	0	0	0
109	3.476027	1.598012	0.684973	0.627722	1.743757	2	2	2.12	1.88
131	3.497256	1.976783	0.817837	0.772971	2.091521	4	4	4.24	3.76
214	3.51682	3.260697	1.303083	1.26969	3.346453	8	8	8.48	7.52

D.15 Experimental Nusselt number and those predicted from correlations of Kalb and Seider (1974) and Dravid et al. (1971) in a helical coil

D.15.1 Experimental Nusselt number and those predicted from correlations Kalb and Seider (1974) and Dravid et al. (1971) in a helical coil for water

De	Pr	$(Nu)_{exp.}$	Kalb and Seider(1974) $Nu_{pred.}$	Dravid et al. (1971) $Nu_{pred.}$	Reference line			
							30% data (+)	10% data (-)
50	5.170217	7.006503	6.956476	7.13116	4	4	5.2	3.6
59	5.74331	7.681369	7.616848	7.783769	6	6	7.8	5.4
69	6.15557	8.188653	8.325216	8.462751	8	8	10.4	7.2
83	6.487465	8.538319	9.176073	9.262818	12	12	15.6	10.8
99	6.828013	9.062163	10.0793	10.11496	8	8	10.4	7.2
131	7.161622	9.578758	11.64481	11.56719	9	9	11.7	8.1
161	7.36238	10.24551	12.9524	12.77505	10	10	13	9.0
192	7.50008	10.98586	14.16066	13.88751	12	12	15.6	10.8
225	7.601507	11.87495	15.36055	14.98918	16	16	20.8	14.4

D.15.2 Experimental Nusselt number and those predicted from correlations Kalb and Seider (1974) and Dravid et al. (1971) in a helical coil for methanol

De	Pr	$(Nu)_{exp.}$	Kalb and Seider(1974) $Nu_{pred.}$	Dravid et al. (1971) $Nu_{pred.}$	Reference line			
							30% data (+)	10% data (-)
49	7.051984	6.632927	7.11518	7.474674	4	4	5.2	3.6
65	7.19208	7.343651	8.199123	8.465006	6	6	7.8	5.4
80	7.309693	8.032789	9.104883	9.294602	8	8	10.4	7.2
99	7.376227	8.628599	10.16098	10.25579	12	12	15.6	10.8
116	7.43911	9.005457	11.02679	11.04575	8	8	10.4	7.2
127	7.493622	9.200205	11.5433	11.51967	9	9	11.7	8.1
141	7.548706	9.483383	12.148	12.07392	10	10	13	9.0

148	7.604369	9.778931	12.47257	12.37519	12	12	15.6	10.8
180	7.665333	10.31961	13.74331	13.53455	14	14	18.2	12.6
228	7.765294	11.62391	15.49999	15.14191	16	16	20.8	14.4

D.15.3 Experimental Nusselt number and those predicted from correlations Kalb and Seider (1974) and Dravid et al. (1971) in a helical coil for acetone

De	Pr	$(Nu)_{exp.}$	Kalb and Seider(1974) $Nu_{pred.}$	Dravid et al. (1971) $(Nu)_{pred.}$	Reference line			
							30% data (+)	10% data (-)
80	3.454155	6.506996	8.45158	8.155529	4	4	5.2	3.6
109	3.476027	7.445512	9.874968	9.375086	8	8	10.4	7.2
131	3.497256	8.16454	10.8484	10.21131	12	12	15.6	10.8
214	3.51682	9.809643	13.87383	12.80109	16	16	20.8	14.4

D.16 Kahani et al.'s (2006) heat transfer data

Coil	Fluids	Nu	Re	De	Pr
1	Water	12.44	863.093	192.9935	5.89-8.87
		15.119	1291.905	288.8787	
		22.878	2055.595	459.645	
	0.25% Al_2O_3	12.696	600.123	134.1916	
		14.77	885.9	198.0933	
		19.124	1428.288	319.3749	
		25.967	1938.707	433.5081	

	0.50% Al_2O_3	**15.044**	**881.214**	**197.045**	
		19.915	**1418.016**	**317.078**	
		27.652	**1986.445**	**444.1826**	
	0.75% Al_2O_3	**13.129**	**496.107**	**110.9329**	
		16.045	**800.504**	**178.9981**	
		20.422	**1345.991**	**300.9727**	
		29.372	**1958.576**	**437.9509**	
	1.00% Al_2O_3	**13.535**	**500.1**	**111.8258**	
		17.89	**946.491**	**211.6418**	
		21.728	**1371.992**	**306.7867**	
		31.641	**1782.587**	**398.5986**	
2	**Water**	**13.954**	**533.049**	**168.5649**	
		24.219	**1378.408**	**435.8909**	
		31.624	**1910.807**	**604.2502**	
	0.25% Al_2O_3	**14.898**	**516.894**	**163.4562**	
		21.368	**924.293**	**292.2871**	
		26.91	**1211.287**	**383.0426**	
		35.232	**1791.192**	**566.4246**	
	0.50% Al_2O_3	**15.707**	**520.616**	**164.633**	
		23.37	**882.378**	**279.0324**	
		29.212	**1260.56**	**398.6241**	
		38.168	**1873.96**	**592.5982**	
	0.75% Al_2O_3	**17.199**	**559.624**	**176.9686**	
		24.931	**857.129**	**271.048**	
		30.164	**1391.007**	**439.875**	
		38.548	**1798.598**	**568.7666**	
	1.00% Al_2O_3	**17.539**	**527.626**	**166.85**	
		25.173	**751.406**	**237.6154**	
		30.874	**1269.557**	**401.4692**	
		41.179	**1891.598**	**598.1758**	

3	**Water**	**12.45**	**521.465**	**164.9017**	
		16.559	**927.47**	**293.2918**	
		24.222	**1366.825**	**432.228**	
		31.377	**1968.906**	**622.6227**	
	0.25% Al_2O_3	**13.666**	**517.937**	**163.786**	
		19.626	**887.891**	**280.7758**	
		26.844	**1473.093**	**465.8329**	
		34.055	**1762.33**	**557.2977**	
	0.50% Al_2O_3	**14.529**	**549.48**	**173.7608**	
		20.506	**950.524**	**300.5821**	
		27.72	**1419.608**	**448.9195**	
		35.757	**1990.444**	**629.4337**	
	0.75% Al_2O_3	**13.933**	**487.769**	**154.2461**	
		21.271	**943.981**	**298.513**	
		28.506	**1434.255**	**453.5513**	
		37.913	**2090.048**	**660.9312**	
	1.00% Al_2O_3	**16.016**	**548.204**	**173.3573**	
		22.767	**975.765**	**308.564**	
		32.226	**1416.316**	**447.8784**	
		39.49	**1997.816**	**631.7649**	

D.17 Kahani et al.'s (2013) experimental Nusselt number and those predicted from present correlation

De	Kahani et al. (2013) $Nu_{exp.}$	Pr	Present correlation $Nu_{pred.}$	Reference line			
						5% data (+)	62% data (-)
192.9935	12.44	7.38	5.285818	0	0	0	0
288.8787	15.119	7.38	7.750886	1	1	1.05	0.38
459.645	22.878	7.38	12.04401	2	2	2.1	0.76
134.1916	12.696	7.38	3.744066	3	3	3.15	1.14
198.0933	14.77	7.38	5.418282	4	4	4.2	1.52
319.3749	19.124	7.38	8.525379	5	5	5.25	1.9
433.5081	25.967	7.38	11.39312	6	6	6.3	2.28
197.0454	15.044	7.38	5.39108	7	7	7.35	2.66
317.078	19.915	7.38	8.467182	8	8	8.4	3.04
444.1826	27.652	7.38	11.65918	9	9	9.45	3.42
110.9329	13.129	7.38	3.12532	9.5	9.5	9.975	3.61
178.9981	16.045	7.38	4.921364	10	10	10.5	3.8
300.9727	20.422	7.38	8.058506	10.5	10.5	11.025	3.99
437.9509	29.372	7.38	11.5039	11	11	11.55	4.18
111.8258	13.535	7.38	3.149187	11.5	11.5	12.075	4.37
211.6418	17.89	7.38	5.769366	12	12	12.6	4.56
306.7867	21.728	7.38	8.206164	12.5	12.5	13.125	4.75
398.5986	31.641	7.38	10.5206	13	13	13.65	4.94
168.5649	13.954	7.38	4.648729	13.5	13.5	14.175	5.13
435.8909	24.219	7.38	11.45254	14	14	14.7	5.32
604.2502	31.624	7.38	15.61374	14.5	14.5	15.225	5.51

D.18 Kahani et al.'s (2013) experimental Nusselt number and those predicted from correlations of kalb & Seider (1974) and Dravid et al. (1971)

De	Kahani et al. (2013) $Nu_{exp.}$	Pr	Kalb and Seider (1974) $Nu_{pred.}$	Dravid et al. (1974) $Nu_{pred.}$	Reference line			
							10% data (+)	40% data (-)
192.9935	12.44	7.38	14.18349	13.8896	0	0	0	0
288.8787	15.119	7.38	17.35281	16.7523	1	1	1.1	0.6
459.645	22.878	7.38	21.88886	20.84953	2	2	2.2	1.2
134.1916	12.696	7.38	11.827	11.76108	3	3	3.3	1.8
198.0933	14.77	7.38	14.36967	14.05776	4	4	4.4	2.4
319.3749	19.124	7.38	18.24577	17.55888	5	5	5.5	3.0
433.5081	25.967	7.38	21.25742	20.27917	6	6	6.6	3.6
197.0454	15.044	7.38	14.33161	14.02339	7	7	7.7	4.2
317.078	19.915	7.38	18.18005	17.49951	8	8	8.8	4.8
444.1826	27.652	7.38	21.51754	20.51413	9	9	9.9	5.4
110.9329	13.129	7.38	10.75331	10.79126	9.5	9.5	10.45	5.7
178.9981	16.045	7.38	13.65954	13.41634	10	10	11	6.0
300.9727	20.422	7.38	17.71232	17.07704	10.5	10.5	11.55	6.3
437.9509	29.372	7.38	21.36607	20.37731	11	11	12.1	6.6
111.8258	13.535	7.38	10.7965	10.83027	11.5	11.5	12.65	6.9
211.6418	17.89	7.38	14.85295	14.49429	12	12	13.2	7.2
306.7867	21.728	7.38	17.88258	17.23083	12.5	12.5	13.75	7.5
398.5986	31.641	7.38	20.38355	19.48984	13	13	14.3	7.8
168.5649	13.954	7.38	13.25548	13.05136	13.5	13.5	14.85	8.1
435.8909	24.219	7.38	21.31576	20.33187	14	14	15.4	8.4
604.2502	31.624	7.38	25.09691	23.74722	14.5	14.5	15.95	8.7

163.4562	14.898	7.38	4.514922	15	15	15.75	5.7
292.2871	21.368	7.38	7.837646	15.5	15.5	16.275	5.89
383.0426	26.91	7.38	10.13057	16	16	16.8	6.08
566.4246	35.232	7.38	14.68467	16.5	16.5	17.325	6.27
164.6332	15.707	7.38	4.545769	17	17	17.85	6.46
279.0324	23.37	7.38	7.499953	17.5	17.5	18.375	6.65
398.6241	29.212	7.38	10.52124	18	18	18.9	6.84
592.5982	38.168	7.38	15.32787	18.5	18.5	19.425	7.03
176.9686	17.199	7.38	4.868396	19	19	19.95	7.22
271.048	24.931	7.38	7.296139	20	20	21	7.6
439.875	30.164	7.38	11.55186	20.5	20.5	21.525	7.79
568.7666	38.548	7.38	14.74228	21	21	22.05	7.98
166.85	17.539	7.38	4.603836	21.5	21.5	22.575	8.17
237.6154	25.173	7.38	6.43928	22	22	23.1	8.36
401.4692	30.874	7.38	10.59249	22.5	22.5	23.625	8.55
598.1758	41.179	7.38	15.46475	23	23	24.15	8.74
164.9017	12.45	7.38	4.552804	23.5	23.5	24.675	8.93
293.2918	16.559	7.38	7.863209	24	24	25.2	9.12
432.228	24.222	7.38	11.36119	24.5	24.5	25.725	9.31
622.6227	31.377	7.38	16.06393	25	25	26.25	9.5
163.7861	13.666	7.38	4.523567	26.5	26.5	27.825	10.07
280.7758	19.626	7.38	7.544415	27	27	28.35	10.26
465.8329	26.844	7.38	12.19783	27.5	27.5	28.875	10.45
557.2977	34.055	7.38	14.46002	28	28	29.4	10.64
173.7608	14.529	7.38	4.784611	28.5	28.5	29.925	10.83
300.5821	20.506	7.38	8.048579	29	29	30.45	11.02
448.9195	27.72	7.38	11.77715	29.5	29.5	30.975	11.21
629.4337	35.757	7.38	16.23064	30	30	31.5	11.4
154.2461	13.933	7.38	4.273144	31	31	32.55	11.78
298.513	21.271	7.38	7.995993	32	32	33.6	12.16

163.4562	14.898	7.38	13.05307	12.86854	15	15	16.5	9.0
292.2871	21.368	7.38	17.45488	16.8445	15.5	15.5	17.05	9.3
383.0426	26.91	7.38	19.98184	19.12699	16	16	17.6	9.6
566.4246	35.232	7.38	24.2987	23.02623	16.5	16.5	18.15	9.9
164.6332	15.707	7.38	13.09998	12.91091	17	17	18.7	10.2
279.0324	23.37	7.38	17.05451	16.48286	17.5	17.5	19.25	10.5
398.6241	29.212	7.38	20.3842	19.49043	18	18	19.8	10.8
592.5982	38.168	7.38	24.85376	23.52759	18.5	18.5	20.35	11.1
176.9686	17.199	7.38	13.58189	13.34619	19	19	20.9	11.4
271.048	24.931	7.38	16.80873	16.26087	20	20	22	12.0
439.875	30.164	7.38	21.41295	20.41966	20.5	20.5	22.55	12.3
568.7666	38.548	7.38	24.34888	23.07155	21	21	23.1	12.6
166.85	17.539	7.38	13.18788	12.9903	21.5	21.5	23.65	12.9
237.6154	25.173	7.38	15.73799	15.29371	22	22	24.2	13.2
401.4692	30.874	7.38	20.45681	19.55602	22.5	22.5	24.75	13.5
598.1758	41.179	7.38	24.97045	23.63299	23	23	25.3	13.8
164.9017	12.45	7.38	13.11066	12.92055	23.5	23.5	25.85	14.1
293.2918	16.559	7.38	17.48485	16.87157	24	24	26.4	14.4
432.228	24.222	7.38	21.22601	20.2508	24.5	24.5	26.95	14.7
622.6227	31.377	7.38	25.4756	24.08927	25	25	27.5	15.0
163.7861	13.666	7.38	13.06623	12.88043	26.5	26.5	29.15	15.9
280.7758	19.626	7.38	17.1077	16.53091	27	27	29.7	18.9
465.8329	26.844	7.38	22.03571	20.98217	27.5	27.5	30.25	16.2
557.2977	34.055	7.38	24.10214	22.84868	28	28	30.8	16.5
173.7608	14.529	7.38	13.45823	13.2345	28.5	28.5	31.35	19.95
300.5821	20.506	7.38	17.70082	17.06665	29	29	31.9	16.8
448.9195	27.72	7.38	21.63197	20.61749	29.5	29.5	32.45	17.1
629.4337	35.757	7.38	25.61456	24.21479	30	30	33	18.0
154.2461	13.933	7.38	12.67999	12.53155	33	33	36.3	19.8
298.513	21.271	7.38	17.6398	17.01153	35	35	38.5	21.0

453.5513	28.506	7.38	11.89243	33	33	34.65	12.54
660.9312	37.913	7.38	17.00046	34	34	35.7	12.92
173.3573	16.016	7.38	4.774066	35	35	36.75	13.3
308.564	22.767	7.38	8.251272	37	37	38.85	14.06
447.8784	32.226	7.38	11.75123	39	39	40.95	14.82
631.7649	39.49	7.38	16.28769	40	40	42	15.2

453.5513	28.506	7.38	21.74328	20.71803	37	37	40.7	22.2
660.9312	37.913	7.38	26.24763	24.78661	39	39	42.9	23.4
173.3573	16.016	7.38	13.44259	13.22037	41	41	45.1	24.6
308.564	22.767	7.38	17.9343	17.27754	43	43	47.3	25.8
447.8784	32.226	7.38	21.60688	20.59482	45	45	49.5	27
631.7649	39.49	7.38	25.66195	24.25759	50	50	55	30

D.19. Experimental Nusselt number of both (present and Kahani et al. (2013)) and those predicted from the generalized correlation

De	Present and Kahani et al.'s Nu	Pr	Nu Predicted	Reference line			
						18% data (+)	18% data (-)
50	1.3062	5.170217	1.198133	0	0	0	0
59	1.709066	5.74331	1.610735	0.5	0.5	0.59	0.41
69	2.19252	6.15557	2.107158	1	1	1.18	0.82
83	2.5739	6.487465	2.78552	1.5	1.5	1.77	1.23
99	3.176722	6.828013	3.647419	2	2	2.36	1.64
131	4.216957	7.161622	5.413209	2.5	2.5	2.95	2.05
161	4.932523	7.36238	7.207156	3	3	3.54	2.46
192	5.845202	7.50008	9.133931	3.5	3.5	4.13	2.87
225	7.391627	7.601507	11.31185	4	4	4.72	3.28
49	1.22469	7.051984	1.545902	4.5	4.5	5.31	3.69
65	1.696764	7.19208	2.239034	5	5	5.9	4.1
80	2.389641	7.309693	2.947216	5.5	5.5	6.49	4.51
99	2.813976	7.376227	3.910374	6	6	7.08	4.92
117	3.443517	7.43911	4.832862	6.5	6.5	7.67	5.33
127	3.574488	7.493622	5.450119	7	7	8.26	5.74
141	3.845958	7.548706	6.228783	7.5	7.5	8.85	6.15
148	4.192694	7.604369	6.68867	8	8	9.44	6.56
180	5.335237	7.665333	8.588172	8.5	8.5	10.03	6.97
228	6.339623	7.765294	11.7312	9	9	10.62	7.38
80	1.144667	3.454155	1.514326	9.1	9.1	10.738	7.462
109	1.598012	3.476027	2.252081	9.3	9.3	10.974	7.626
131	1.976783	3.497256	2.866319	9.5	9.5	11.21	7.79
214	3.260697	3.51682	5.351933	10	10	11.8	8.2
192.9935	12.44	7.38	9.077263	10.5	10.5	12.39	8.61

288.8787	**15.119**	**7.38**	**15.10161**	**11**	**11**	**12.98**	**9.02**
459.645	**22.878**	**7.38**	**27.13797**	**11.5**	**11.5**	**13.57**	**9.43**
134.1916	**12.696**	**7.38**	**5.738382**	**12**	**12**	**14.16**	**9.84**
198.0933	**14.77**	**7.38**	**9.381013**	**12.5**	**12.5**	**14.75**	**10.25**
319.3749	**19.124**	**7.38**	**17.14067**	**13**	**13**	**15.34**	**10.66**
433.5081	**25.967**	**7.38**	**25.20523**	**13.5**	**13.5**	**15.93**	**11.07**
197.0454	**15.044**	**7.38**	**9.318434**	**14**	**14**	**16.52**	**11.48**
317.078	**19.915**	**7.38**	**16.98525**	**14.5**	**14.5**	**17.11**	**11.89**
444.1826	**27.652**	**7.38**	**25.99099**	**15**	**15**	**17.7**	**12.3**
110.9329	**13.129**	**7.38**	**4.51301**	**15.5**	**15.5**	**18.29**	**12.71**
178.9981	**16.045**	**7.38**	**8.25458**	**16**	**16**	**18.88**	**13.12**
300.9727	**20.422**	**7.38**	**15.90382**	**16.5**	**16.5**	**19.47**	**13.53**
437.9509	**29.372**	**7.38**	**25.53166**	**17**	**17**	**20.06**	**13.94**
111.8258	**13.535**	**7.38**	**4.558899**	**17.5**	**17.5**	**20.65**	**14.35**
211.6418	**17.89**	**7.38**	**10.19786**	**18**	**18**	**21.24**	**14.76**
306.7867	**21.728**	**7.38**	**16.29251**	**18.5**	**18.5**	**21.83**	**15.17**
398.5986	**31.641**	**7.38**	**22.67129**	**19**	**19**	**22.42**	**15.58**
168.5649	**13.954**	**7.38**	**7.652094**	**20**	**20**	**23.6**	**16.4**
435.8909	**24.219**	**7.38**	**25.38019**	**20.5**	**20.5**	**24.19**	**16.81**
604.2502	**31.624**	**7.38**	**38.3262**	**21**	**21**	**24.78**	**17.22**
163.4562	**14.898**	**7.38**	**7.360594**	**21.5**	**21.5**	**25.37**	**17.63**
292.2871	**21.368**	**7.38**	**15.32682**	**22**	**22**	**25.96**	**18.04**
383.0426	**26.91**	**7.38**	**21.56046**	**22.5**	**22.5**	**26.55**	**18.45**
566.4246	**35.232**	**7.38**	**35.32365**	**23**	**23**	**27.14**	**18.86**
164.6332	**15.707**	**7.38**	**7.427544**	**23.5**	**23.5**	**27.73**	**19.27**
279.0324	**23.37**	**7.38**	**14.45494**	**24**	**24**	**28.32**	**19.68**
398.6241	**29.212**	**7.38**	**22.67312**	**24.5**	**24.5**	**28.91**	**20.09**
592.5982	**38.168**	**7.38**	**37.39587**	**25**	**25**	**29.5**	**20.5**
176.9686	**17.199**	**7.38**	**8.136644**	**26.5**	**26.5**	**31.27**	**21.73**

271.048	**24.931**	**7.38**	**13.93492**	**27**	**27**	**31.86**	**22.14**
439.875	**30.164**	**7.38**	**25.6733**	**27.5**	**27.5**	**32.45**	**22.55**
568.7666	**38.548**	**7.38**	**35.50806**	**28**	**28**	**33.04**	**22.96**
166.85	**17.539**	**7.38**	**7.55398**	**28.5**	**28.5**	**33.63**	**23.37**
237.6154	**25.173**	**7.38**	**11.80196**	**29**	**29**	**34.22**	**23.78**
401.4692	**30.874**	**7.38**	**22.87754**	**29.5**	**29.5**	**34.81**	**24.19**
598.1758	**41.179**	**7.38**	**37.84061**	**30**	**30**	**35.4**	**24.6**
164.9017	**12.45**	**7.38**	**7.442834**	**31**	**31**	**36.58**	**25.42**
293.2918	**16.559**	**7.38**	**15.39333**	**32**	**32**	**37.76**	**26.24**
432.228	**24.222**	**7.38**	**25.11134**	**33**	**33**	**38.94**	**27.06**
622.6227	**31.377**	**7.38**	**39.80266**	**34**	**34**	**40.12**	**27.88**
163.7861	**13.666**	**7.38**	**7.379342**	**35**	**35**	**41.3**	**28.7**
280.7758	**19.626**	**7.38**	**14.56901**	**36**	**36**	**42.48**	**29.52**
465.8329	**26.844**	**7.38**	**27.59984**	**37**	**37**	**43.66**	**30.34**
557.2977	**34.055**	**7.38**	**34.60686**	**38**	**38**	**44.84**	**31.16**
173.7608	**14.529**	**7.38**	**7.950958**	**39**	**39**	**46.02**	**31.98**
300.5821	**20.506**	**7.38**	**15.87777**	**40**	**40**	**47.2**	**32.8**
448.9195	**27.72**	**7.38**	**26.34127**	**41**	**41**	**48.38**	**33.62**
629.4337	**35.757**	**7.38**	**40.35292**	**42**	**42**	**49.56**	**34.44**
154.2461	**13.933**	**7.38**	**6.841108**	**43**	**43**	**50.74**	**35.26**
298.513	**21.271**	**7.38**	**15.73997**	**44**	**44**	**51.92**	**36.08**
453.5513	**28.506**	**7.38**	**26.68472**	**45**	**45**	**53.1**	**36.9**
660.9312	**37.913**	**7.38**	**42.91779**	**46**	**46**	**54.28**	**37.72**
173.3573	**16.016**	**7.38**	**7.927664**	**47**	**47**	**55.46**	**38.54**
308.564	**22.767**	**7.38**	**16.41171**	**48**	**48**	**56.64**	**39.36**
447.8784	**32.226**	**7.38**	**26.26421**	**49**	**49**	**57.82**	**40.18**
631.7649	**39.49**	**7.38**	**40.54163**	**50**	**50**	**59**	**41**

Uncertainty Analysis

D.20 Uncertainty in friction factor for straight tubes

D.20.1 Uncertainty in friction factor for a straight tube of inner diameter 720 μm with water

O (ml/s)	ΔP (Pa)	d_i (m)	L (m)	$\pm\Delta d_i$ (m)	$\pm\Delta L$ (m)	$\pm\Delta O$ (ml/s)	$\pm\Delta(\Delta P)$ (Pa)	$\left\{\frac{\Delta(\Delta P)}{\Delta P}\right\}^2$	$\left\{\frac{\Delta L}{L}\right\}^2$	$\left\{\frac{\Delta d_i}{d_i}\right\}^2$	$\left\{\frac{\Delta O}{O}\right\}^2$	$\left\{\frac{\Delta Re}{Re}\right\}^2$	Uncertainty in (±) Re	% Uncertainty in (±) Re	Uncertainty in (±) *f*	% Uncertainty in (±) *f*
0.191571	17600	0.00072	0.68	0.00002	0.002	0.025	0.02	1.29132E-12	8.65052E-06	0.000772	0.01703	0.00031690	0.133424	13.34236	0.090668	9.0668
0.224719	19800	0.00072	0.68	0.00002	0.002	0.025	0.02	1.0203E-12	8.65052E-06	0.000772	0.01237	0.00017287	0.114665	11.46655	0.087433	8.7433
0.31348	30100	0.00072	0.68	0.00002	0.002	0.025	0.02	4.41496E-13	8.65052E-06	0.000772	0.00636	5.0860E-05	0.084449	8.44492	0.084596	8.4596
0.440529	41200	0.00072	0.68	0.00002	0.002	0.025	0.02	2.35649E-13	8.65052E-06	0.000772	0.00322	1.5937E-05	0.063184	6.31836	0.083767	8.3767
0.609756	54700	0.00072	0.68	0.00002	0.002	0.025	0.02	1.33686E-13	8.65052E-06	0.000772	0.00168	6.0152E-06	0.049524	4.952378	0.083529	8.3529
0.724638	64500	0.00072	0.68	0.00002	0.002	0.025	0.02	9.61481E-14	8.65052E-06	0.000772	0.00119	3.8488E-06	0.044293	4.429283	0.083477	8.3477
0.909091	80700	0.00072	0.68	0.00002	0.002	0.025	0.02	6.14204E-14	8.65052E-06	0.000772	0.00075	2.3343E-06	0.039088	3.908779	0.083441	8.3441

D.20.2 Uncertainty in friction factor for a straight tube of inner diameter 720 μm with methanol

O (ml/s)	ΔP (Pa)	d_i (m)	L (m)	$\pm\Delta d_i$ (m)	$\pm\Delta L$ (m)	$\pm\Delta O$ (ml/s)	$\pm\Delta(\Delta P)$ (Pa)	$\left\{\frac{\Delta(\Delta P)}{\Delta P}\right\}^2$	$\left\{\frac{\Delta L}{L}\right\}^2$	$\left\{\frac{\Delta d_i}{d_i}\right\}^2$	$\left\{\frac{\Delta O}{O}\right\}^2$	$\left\{\frac{\Delta Re}{Re}\right\}^2$	Uncertainty in (±) Re	% Uncertainty in (±) Re	Uncertainty in (±) *f*	% Uncertainty in (±) *f*
0.15772	8800	0.00072	0.68	0.00002	0.002	0.025	0.02	5.16529E-12	8.65052E-06	0.000772	0.025122	0.00067	0.160916	16.09157	0.098158	9.815835
0.20080	11100	0.00072	0.68	0.00002	0.002	0.025	0.02	3.24649E-12	8.65052E-06	0.000772	0.0155	0.000265	0.127561	12.75612	0.089511	8.951083
0.24213	13400	0.00072	0.68	0.00002	0.002	0.025	0.02	2.22767E-12	8.65052E-06	0.000772	0.010661	0.000131	0.106921	10.69213	0.086463	8.646313
0.42553	24700	0.00072	0.68	0.00002	0.002	0.025	0.02	6.55641E-13	8.65052E-06	0.000772	0.003452	1.78E-05	0.064986	6.49859	0.083812	8.381191
0.62111	35100	0.00072	0.68	0.00002	0.002	0.025	0.02	3.24673E-13	8.65052E-06	0.000772	0.00162	5.72E-06	0.048905	4.890468	0.083522	8.35223
0.72992	39900	0.00072	0.68	0.00002	0.002	0.025	0.02	2.51255E-13	8.65052E-06	0.000772	0.001173	3.78E-06	0.044098	4.409838	0.083476	8.347588

D.20.3 Uncertainty in friction factor for a straight tube of inner diameter 720 μm with acetone

O (ml/s)	ΔP (Pa)	d_i (m)	L (m)	$\pm\Delta d_i$ (m)	$\pm\Delta L$ (m)	$\pm\Delta O$ (ml/s)	$\pm\Delta(\Delta P)$ (Pa)	$\left\{\frac{\Delta(\Delta P)}{\Delta P}\right\}^2$	$\left\{\frac{\Delta L}{L}\right\}^2$	$\left\{\frac{\Delta d_i}{d_i}\right\}^2$	$\left\{\frac{\Delta O}{O}\right\}^2$	$\left\{\frac{\Delta \mathrm{Re}}{\mathrm{Re}}\right\}^2$	Uncertainty in (±) Re	% Uncertainty in (±) Re	Uncertainty in (±) f	% Uncertainty in (±) f
0.155763	5400	0.00072	0.68	0.00002	0.002	0.025	0.02	1.37174E-11	8.65052E-06	0.000772	0.02576	0.000704	0.162886	16.2886	0.098838	9.88375
0.187266	6400	0.00072	0.68	0.00002	0.002	0.025	0.02	9.76563E-12	8.65052E-06	0.000772	0.01782	0.000346	0.136359	13.63593	0.091302	9.130181
0.209205	7100	0.00072	0.68	0.00002	0.002	0.025	0.02	7.93493E-12	8.65052E-06	0.000772	0.01428	0.000227	0.122686	12.2686	0.088653	8.865285
0.276243	9500	0.00072	0.68	0.00002	0.002	0.025	0.02	4.43213E-12	8.65052E-06	0.000772	0.00819	8.03E-05	0.094667	9.466707	0.08529	8.528983
0.438596	14300	0.00072	0.68	0.00002	0.002	0.025	0.02	1.95609E-12	8.65052E-06	0.000772	0.00324	1.62E-05	0.063408	6.340824	0.083772	8.377205

D.20.4 Uncertainty in friction factor for a straight tube of inner diameter 850 μm with water

O (ml/s)	ΔP (Pa)	d_i (m)	L (m)	$\pm\Delta d_i$ (m)	$\pm\Delta L$ (m)	$\pm\Delta O$ (ml/s)	$\pm\Delta(\Delta P)$ (Pa)	$\left\{\frac{\Delta(\Delta P)}{\Delta P}\right\}^2$	$\left\{\frac{\Delta L}{L}\right\}^2$	$\left\{\frac{\Delta d_i}{d_i}\right\}^2$	$\left\{\frac{\Delta O}{O}\right\}^2$	$\left\{\frac{\Delta \mathrm{Re}}{\mathrm{Re}}\right\}^2$	Uncertainty in (±) Re	% Uncertainty in (±) Re	Uncertainty in (±) f	% Uncertainty in (±) f
0.219298	10900	0.00085	0.68	0.00002	0.002	0.025	0.02	3.36672E-12	8.65E-06	0.000554	0.012996	0.000184	0.116403	11.64029	0.075668	7.566849
0.30303	14300	0.00085	0.68	0.00002	0.002	0.025	0.02	1.95609E-12	8.65E-06	0.000554	0.006806	5.42E-05	0.08579	8.578976	0.072167	7.216662
0.492611	23500	0.00085	0.68	0.00002	0.002	0.025	0.02	7.2431E-13	8.65E-06	0.000554	0.002576	9.79E-06	0.055939	5.593921	0.070926	7.092614
0.632911	29400	0.00085	0.68	0.00002	0.002	0.025	0.02	4.6277E-13	8.65E-06	0.000554	0.00156	4.47E-06	0.045977	4.597699	0.070776	7.077587
0.75188	34700	0.00085	0.68	0.00002	0.002	0.025	0.02	3.32201E-13	8.65E-06	0.000554	0.001106	2.75E-06	0.040733	4.073323	0.070727	7.072737
0.884956	41100	0.00085	0.68	0.00002	0.002	0.025	0.02	2.36797E-13	8.65E-06	0.000554	0.000798	1.83E-06	0.036765	3.676541	0.070701	7.070119
1.010101	47900	0.00085	0.68	0.00002	0.002	0.025	0.02	1.74337E-13	8.65E-06	0.000554	0.000613	1.36E-06	0.03415	3.414961	0.070688	7.068797
1.123596	52300	0.00085	0.68	0.00002	0.002	0.025	0.02	1.46237E-13	8.65E-06	0.000554	0.000495	1.1E-06	0.032384	3.238357	0.070681	7.068061

D.20.5 Uncertainty in friction factor for a straight tube of inner diameter 850 μm with methanol

O (ml/s)	ΔP (Pa)	d_i (m)	L (m)	$\pm \Delta d_i$ (m)	$\pm \Delta L$ (m)	$\pm \Delta O$ (ml/s)	$\pm \Delta(\Delta P)$ (Pa)	$\left\{\frac{\Delta(\Delta P)}{\Delta P}\right\}^2$	$\left\{\frac{\Delta L}{L}\right\}^2$	$\left\{\frac{\Delta d_i}{d_i}\right\}^2$	$\left\{\frac{\Delta O}{O}\right\}^2$	$\left\{\frac{\Delta \mathrm{Re}}{\mathrm{Re}}\right\}^2$	Uncertainty in (±) Re	% Uncertainty in (±) Re	Uncertainty in (±) *f*	% Uncertainty in (±) *f*
0.181159	5300	0.00085	0.68	0.00002	0.002	0.025	0.02	1.42399E-11	8.65E-06	0.000554	0.019044	0.000384	0.139992	13.99915	0.080794	8.079368
0.255754	7500	0.00085	0.68	0.00002	0.002	0.025	0.02	7.11111E-12	8.65E-06	0.000554	0.009555	0.000102	0.100542	10.0542	0.073485	7.348532
0.330033	9600	0.00085	0.68	0.00002	0.002	0.025	0.02	4.34028E-12	8.65E-06	0.000554	0.005738	3.96E-05	0.07932	7.932021	0.071761	7.176135
0.526316	15300	0.00085	0.68	0.00002	0.002	0.025	0.02	1.70874E-12	8.65E-06	0.000554	0.002256	7.9E-06	0.053008	5.300833	0.070873	7.087264
0.719424	21100	0.00085	0.68	0.00002	0.002	0.025	0.02	8.98452E-13	8.65E-06	0.000554	0.001208	3.1E-06	0.041967	4.19666	0.070737	7.073724
0.854701	24300	0.00085	0.68	0.00002	0.002	0.025	0.02	6.77404E-13	8.65E-06	0.000554	0.000856	1.99E-06	0.037539	3.753926	0.070706	7.070568

D.20.6 Uncertainty in friction factor for a straight tube of inner diameter 850 μm with acetone

O (ml/s)	ΔP (Pa)	d_i (m)	L (m)	$\pm \Delta d_i$ (m)	$\pm \Delta L$ (m)	$\pm \Delta O$ (ml/s)	$\pm \Delta(\Delta P)$ (Pa)	$\left\{\frac{\Delta(\Delta P)}{\Delta P}\right\}^2$	$\left\{\frac{\Delta L}{L}\right\}^2$	$\left\{\frac{\Delta d_i}{d_i}\right\}^2$	$\left\{\frac{\Delta O}{O}\right\}^2$	$\left\{\frac{\Delta \mathrm{Re}}{\mathrm{Re}}\right\}^2$	Uncertainty in (±) Re	% Uncertainty in (±) Re	Uncertainty in (±) *f*	% Uncertainty in (±) *f*
0.147493	2900	0.00085	0.68	0.00002	0.002	0.025	0.02	4.75624E-11	8.65E-06	0.000554	0.02873	0.000858	0.171125	17.11253	0.091769	9.176891
0.215517	4300	0.00085	0.68	0.00002	0.002	0.025	0.02	2.16333E-11	8.65E-06	0.000554	0.013456	0.000196	0.118362	11.83623	0.076003	7.600282
0.308642	5900	0.00085	0.68	0.00002	0.002	0.025	0.02	1.1491E-11	8.65E-06	0.000554	0.006561	5.06E-05	0.084348	8.434829	0.072068	7.206817
0.37594	7400	0.00085	0.68	0.00002	0.002	0.025	0.02	7.3046E-12	8.65E-06	0.000554	0.004422	2.48E-05	0.07054	7.053994	0.071347	7.134695
0.471698	9000	0.00085	0.68	0.00002	0.002	0.025	0.02	4.93827E-12	8.65E-06	0.000554	0.002809	1.13E-05	0.057988	5.798822	0.070969	7.096886

D.20.7 Uncertainty in friction factor for a straight tube of inner diameter 1000 μm with water

O (ml/s)	ΔP (Pa)	d_i (m)	L (m)	$\pm \Delta d_i$ (m)	$\pm \Delta L$ (m)	$\pm \Delta O$ (ml/s)	$\pm \Delta(\Delta P)$ (Pa)	$\left\{\frac{\Delta(\Delta P)}{\Delta P}\right\}^2$	$\left\{\frac{\Delta L}{L}\right\}^2$	$\left\{\frac{\Delta d_i}{d_i}\right\}^2$	$\left\{\frac{\Delta O}{O}\right\}^2$	$\left\{\frac{\Delta Re}{Re}\right\}^2$	Uncertainty in (±) Re	% Uncertainty in (±) Re	Uncertainty in (±) f	% Uncertainty in (±) f
0.206186	5200	0.001	0.68	0.00002	0.002	0.025	0.02	1.47929E-11	8.65E-06	0.0004	0.014702	0.000228	0.122888	12.28884	0.067237	6.723748
0.25641	6500	0.001	0.68	0.00002	0.002	0.025	0.02	9.46746E-12	8.65E-06	0.0004	0.009506	9.81E-05	0.09953	9.953015	0.063255	6.325493
0.416667	10200	0.001	0.68	0.00002	0.002	0.025	0.02	3.84468E-12	8.65E-06	0.0004	0.0036	0.000016	0.063246	6.324555	0.060602	6.06024
0.625	15700	0.001	0.68	0.00002	0.002	0.025	0.02	1.62278E-12	8.65E-06	0.0004	0.0016	0.000004	0.044721	4.472136	0.060205	6.020507
0.952381	23700	0.001	0.68	0.00002	0.002	0.025	0.02	7.12137E-13	8.65E-06	0.0004	0.000689	1.19E-06	0.033001	3.300095	0.060112	6.011152
1.111111	27400	0.001	0.68	0.00002	0.002	0.025	0.02	5.32793E-13	8.65E-06	0.0004	0.000506	8.21E-07	0.030104	3.010399	0.060099	6.009938
1.25	30100	0.001	0.68	0.00002	0.002	0.025	0.02	4.41496E-13	8.65E-06	0.0004	0.0004	6.4E-07	0.028284	2.828427	0.060093	6.009335

D.20.8 Uncertainty in friction factor for a straight tube of inner diameter 1000 μm with methanol

O (ml/s)	ΔP (Pa)	d_i (m)	L (m)	$\pm \Delta d_i$ (m)	$\pm \Delta L$ (m)	$\pm \Delta O$ (ml/s)	$\pm \Delta(\Delta P)$ (Pa)	$\left\{\frac{\Delta(\Delta P)}{\Delta P}\right\}^2$	$\left\{\frac{\Delta L}{L}\right\}^2$	$\left\{\frac{\Delta d_i}{d_i}\right\}^2$	$\left\{\frac{\Delta O}{O}\right\}^2$	$\left\{\frac{\Delta Re}{Re}\right\}^2$	Uncertainty in (±) Re	% Uncertainty in (±) Re	Uncertainty in (±) f	% Uncertainty in (±) f
0.20202	3100	0.001	0.68	0.00002	0.002	0.025	0.02	4.16233E-11	8.65E-06	0.0004	0.015314	0.000247	0.125356	12.53557	0.067797	6.779659
0.232558	3600	0.001	0.68	0.00002	0.002	0.025	0.02	3.08642E-11	8.65E-06	0.0004	0.011556	0.000143	0.109345	10.93446	0.064656	6.465646
0.28169	4300	0.001	0.68	0.00002	0.002	0.025	0.02	2.16333E-11	8.65E-06	0.0004	0.007877	6.85E-05	0.090976	9.097561	0.062311	6.231097
0.47619	7100	0.001	0.68	0.00002	0.002	0.025	0.02	7.93493E-12	8.65E-06	0.0004	0.002756	9.96E-06	0.056181	5.618051	0.060403	6.04028
0.740741	11000	0.001	0.68	0.00002	0.002	0.025	0.02	3.30579E-12	8.65E-06	0.0004	0.001139	2.37E-06	0.039231	3.923089	0.060151	6.015086
0.952381	13900	0.001	0.68	0.00002	0.002	0.025	0.02	2.07029E-12	8.65E-06	0.0004	0.000689	1.19E-06	0.033001	3.300095	0.060112	6.011152

D.20.9 Uncertainty in friction factor for a straight tube of inner diameter 1000 μm with acetone

O (ml/s)	ΔP (Pa)	d_i (m)	L (m)	$\pm \Delta d_i$ (m)	$\pm \Delta L$ (m)	$\pm \Delta O$ (ml/s)	$\pm \Delta(\Delta P)$ (Pa)	$\left\{\frac{\Delta(\Delta P)}{\Delta P}\right\}^2$	$\left\{\frac{\Delta L}{L}\right\}^2$	$\left\{\frac{\Delta d_i}{d_i}\right\}^2$	$\left\{\frac{\Delta O}{O}\right\}^2$	$\left\{\frac{\Delta \mathrm{Re}}{\mathrm{Re}}\right\}^2$	Uncertainty in (±) Re	% Uncertainty in (±) Re	Uncertainty in (±) *f*	% Uncertainty in (±) *f*
0.182482	1700	0.001	0.68	0.00002	0.002	0.025	0.02	1.38408E-10	8.65E-06	0.0004	0.018769	0.000367	0.138452	13.84522	0.071263	7.126326
0.230415	2100	0.001	0.68	0.00002	0.002	0.025	0.02	9.07029E-11	8.65E-06	0.0004	0.011772	0.000148	0.110328	11.03279	0.064817	6.481748
0.292398	2700	0.001	0.68	0.00002	0.002	0.025	0.02	5.48697E-11	8.65E-06	0.0004	0.00731	5.94E-05	0.087808	8.780803	0.06202	6.201969
0.364964	3300	0.001	0.68	0.00002	0.002	0.025	0.02	3.67309E-11	8.65E-06	0.0004	0.004692	2.59E-05	0.07136	7.136	0.060929	6.092926
0.490196	4400	0.001	0.68	0.00002	0.002	0.025	0.02	2.06612E-11	8.65E-06	0.0004	0.002601	9.01E-06	0.054781	5.478138	0.060371	6.037114
0.617284	5600	0.001	0.68	0.00002	0.002	0.025	0.02	1.27551E-11	8.65E-06	0.0004	0.00164	4.16E-06	0.045169	4.516913	0.06021	6.021047

D.21 Uncertainty in friction factor for helical coils

D.21.1 Uncertainty in friction factor for a helical coil of inner diameter 720 μm with water

O (ml/s)	ΔP (Pa)	d_i (m)	L (m)	$\pm \Delta d_i$ (m)	$\pm \Delta L$ (m)	$\pm \Delta O$ (ml/s)	$\pm \Delta(\Delta P)$ (Pa)	$\left\{\frac{\Delta(\Delta P)}{\Delta P}\right\}^2$	$\left\{\frac{\Delta L}{L}\right\}^2$	$\left\{\frac{\Delta d_i}{d_i}\right\}^2$	$\left\{\frac{\Delta O}{O}\right\}^2$	$\left\{\frac{\Delta \mathrm{Re}}{\mathrm{Re}}\right\}^2$	Uncertainty in (±) Re	% Uncertainty in (±) Re	Uncertainty in (±) *f*	% Uncertainty in (±) *f*
0.19047	18200	0.00072	0.68	0.00002	0.002	0.025	0.02	1.20758E-12	8.65052E-06	0.000772	0.017227	0.000324	0.134157	13.41572	0.090823	9.082308
0.25641	27100	0.00072	0.68	0.00002	0.002	0.025	0.02	5.44655E-13	8.65052E-06	0.000772	0.009506	0.000106	0.10138	10.13798	0.085882	8.58815
0.30769	35100	0.00072	0.68	0.00002	0.002	0.025	0.02	3.24673E-13	8.65052E-06	0.000772	0.006602	5.44E-05	0.085867	8.586715	0.084679	8.46791
0.35087	42100	0.00072	0.68	0.00002	0.002	0.025	0.02	2.25681E-13	8.65052E-06	0.000772	0.005077	3.42E-05	0.076473	7.647331	0.084202	8.420154
0.43478	57100	0.00072	0.68	0.00002	0.002	0.025	0.02	1.22684E-13	8.65052E-06	0.000772	0.003306	1.66E-05	0.063858	6.385808	0.083783	8.378312
0.5	68400	0.00072	0.68	0.00002	0.002	0.025	0.02	8.54964E-14	8.65052E-06	0.000772	0.0025	1.07E-05	0.057198	5.719795	0.083642	8.364155
0.58823	85600	0.00072	0.68	0.00002	0.002	0.025	0.02	5.45899E-14	8.65052E-06	0.000772	0.001806	6.65E-06	0.050773	5.077258	0.083544	8.354446
0.68965	108300	0.00072	0.68	0.00002	0.002	0.025	0.02	3.41038E-14	8.65052E-06	0.000772	0.001314	4.35E-06	0.045669	4.566911	0.083489	8.348949
0.86956	148100	0.00072	0.68	0.00002	0.002	0.025	0.02	1.82369E-14	8.65052E-06	0.000772	0.000827	2.55E-06	0.039977	3.997709	0.083446	8.344646

D.21.2 Uncertainty in friction factor for a helical coil of inner diameter 720 μm with methanol

O (ml/s)	ΔP **(Pa)**	$\mathbf{d_i}$ **(m)**	**L (m)**	$\pm\Delta d_i$ **(m)**	$\pm\Delta L$ **(m)**	$\pm\Delta O$ **(ml/s)**	$\pm\Delta(\Delta P)$ **(Pa)**	$\left\{\frac{\Delta(\Delta P)}{\Delta P}\right\}^2$	$\left\{\frac{\Delta L}{L}\right\}^2$	$\left\{\frac{\Delta d_i}{d_i}\right\}^2$	$\left\{\frac{\Delta O}{O}\right\}^2$	$\left\{\frac{\Delta Re}{Re}\right\}^2$	**Uncertainty in (±) Re**	**% Uncertainty in (±) Re**	**Uncertainty in (±) *f***	**% Uncertainty in (±) *f***
0.192308	**11700**	**0.00072**	**0.68**	**0.00002**	**0.002**	**0.025**	**0.02**	**2.92205E-12**	**8.65052E-06**	**0.000772**	**0.0169**	**0.000312**	**0.132935**	**13.29346**	**0.090566**	**9.05662**
0.224719	**15100**	**0.00072**	**0.68**	**0.00002**	**0.002**	**0.025**	**0.02**	**1.75431E-12**	**8.65052E-06**	**0.000772**	**0.012377**	**0.000173**	**0.114665**	**11.46655**	**0.087433**	**8.743336**
0.30303	**22900**	**0.00072**	**0.68**	**0.00002**	**0.002**	**0.025**	**0.02**	**7.62762E-13**	**8.65052E-06**	**0.000772**	**0.006806**	**5.74E-05**	**0.087051**	**8.705088**	**0.084751**	**8.475135**
0.363636	**29000**	**0.00072**	**0.68**	**0.00002**	**0.002**	**0.025**	**0.02**	**4.75624E-13**	**8.65052E-06**	**0.000772**	**0.004727**	**3.02E-05**	**0.07415**	**7.414963**	**0.084107**	**8.410716**
0.425532	**36100**	**0.00072**	**0.68**	**0.00002**	**0.002**	**0.025**	**0.02**	**3.06934E-13**	**8.65052E-06**	**0.000772**	**0.003452**	**1.78E-05**	**0.064986**	**6.49859**	**0.083812**	**8.381191**
0.487805	**45100**	**0.00072**	**0.68**	**0.00002**	**0.002**	**0.025**	**0.02**	**1.96656E-13**	**8.65052E-06**	**0.000772**	**0.002627**	**1.15E-05**	**0.058294**	**5.82938**	**0.083662**	**8.366173**
0.540541	**52100**	**0.00072**	**0.68**	**0.00002**	**0.002**	**0.025**	**0.02**	**1.47362E-13**	**8.65052E-06**	**0.000772**	**0.002139**	**8.47E-06**	**0.053951**	**5.39506**	**0.083588**	**8.358817**
0.625	**61900**	**0.00072**	**0.68**	**0.00002**	**0.002**	**0.025**	**0.02**	**1.04395E-13**	**8.65052E-06**	**0.000772**	**0.0016**	**5.62E-06**	**0.048699**	**4.869913**	**0.08352**	**8.352002**
0.714286	**73500**	**0.00072**	**0.68**	**0.00002**	**0.002**	**0.025**	**0.02**	**7.40432E-14**	**8.65052E-06**	**0.000772**	**0.001225**	**3.99E-06**	**0.044683**	**4.468339**	**0.083481**	**8.348078**

D.21.3 Uncertainty in friction factor for a helical coil of inner diameter 720 μm with acetone

O (ml/s)	ΔP **(Pa)**	$\mathbf{d_i}$ **(m)**	**L (m)**	$\pm\Delta d_i$ **(m)**	$\pm\Delta L$ **(m)**	$\pm\Delta O$ **(ml/s)**	$\pm\Delta(\Delta P)$ **(Pa)**	$\left\{\frac{\Delta(\Delta P)}{\Delta P}\right\}^2$	$\left\{\frac{\Delta L}{L}\right\}^2$	$\left\{\frac{\Delta d_i}{d_i}\right\}^2$	$\left\{\frac{\Delta O}{O}\right\}^2$	$\left\{\frac{\Delta Re}{Re}\right\}^2$	**Uncertainty in (±) Re**	**% Uncertainty in (±) Re**	**Uncertainty in (±) *f***	**% Uncertainty in (±) *f***
0.15503	**6700**	**0.00072**	**0.68**	**0.00002**	**0.002**	**0.025**	**0.02**	**8.91067E-12**	**8.65052E-06**	**0.000772**	**0.026002**	**0.000717**	**0.163625**	**16.36251**	**0.099097**	**9.909745**
0.22727	**11000**	**0.00072**	**0.68**	**0.00002**	**0.002**	**0.025**	**0.02**	**3.30579E-12**	**8.65052E-06**	**0.000772**	**0.0121**	**0.000166**	**0.113453**	**11.34531**	**0.087269**	**8.72686**
0.29411	**16100**	**0.00072**	**0.68**	**0.00002**	**0.002**	**0.025**	**0.02**	**1.54315E-12**	**8.65052E-06**	**0.000772**	**0.007225**	**6.39E-05**	**0.089424**	**8.942374**	**0.084905**	**8.490511**
0.40816	**25100**	**0.00072**	**0.68**	**0.00002**	**0.002**	**0.025**	**0.02**	**6.34911E-13**	**8.65052E-06**	**0.000772**	**0.003752**	**2.05E-05**	**0.067254**	**6.72545**	**0.083874**	**8.38745**
0.52631	**34500**	**0.00072**	**0.68**	**0.00002**	**0.002**	**0.025**	**0.02**	**3.36064E-13**	**8.65052E-06**	**0.000772**	**0.002256**	**9.17E-06**	**0.055026**	**5.502595**	**0.083605**	**8.360482**

D.21.4 Uncertainty in friction factor for a helical coil of inner diameter 850 μm with water

O (ml/s)	ΔP (Pa)	d_i (m)	L (m)	$\pm \Delta d_i$ (m)	$\pm \Delta L$ (m)	$\pm \Delta O$ (ml/s)	$\pm \Delta(\Delta P)$ (Pa)	$\left\{\frac{\Delta(\Delta P)}{\Delta P}\right\}^2$	$\left\{\frac{\Delta L}{L}\right\}^2$	$\left\{\frac{\Delta d_i}{d_i}\right\}^2$	$\left\{\frac{\Delta O}{O}\right\}^2$	$\left\{\frac{\Delta \mathrm{Re}}{\mathrm{Re}}\right\}^2$	Uncertainty in (±) Re	% Uncertainty in (±) Re	Uncertainty in (±) *f*	% Uncertainty in (±) *f*
0.227273	12300	0.00085	0.68	0.00002	0.002	0.025	0.02	2.64393E-12	8.65E-06	0.000554	0.0121	0.00016	0.112488	11.24884	0.075045	7.504537
0.333333	20500	0.00085	0.68	0.00002	0.002	0.025	0.02	9.51814E-13	8.65E-06	0.000554	0.005625	3.82E-05	0.078604	7.860428	0.071722	7.172204
0.465116	31600	0.00085	0.68	0.00002	0.002	0.025	0.02	4.00577E-13	8.65E-06	0.000554	0.002889	1.19E-05	0.058674	5.867449	0.070984	7.098421
0.540541	39100	0.00085	0.68	0.00002	0.002	0.025	0.02	2.61641E-13	8.65E-06	0.000554	0.002139	7.25E-06	0.051891	5.189119	0.070854	7.085444
0.689655	54300	0.00085	0.68	0.00002	0.002	0.025	0.02	1.35663E-13	8.65E-06	0.000554	0.001314	3.49E-06	0.043217	4.321685	0.070748	7.074816
0.833333	69100	0.00085	0.68	0.00002	0.002	0.025	0.02	8.3773E-14	8.65E-06	0.000554	0.0009	2.11E-06	0.038127	3.812654	0.070709	7.070928
1	87600	0.00085	0.68	0.00002	0.002	0.025	0.02	5.21257E-14	8.65E-06	0.000554	0.000625	1.39E-06	0.034331	3.433123	0.070689	7.06888
1.111111	99100	0.00085	0.68	0.00002	0.002	0.025	0.02	4.07298E-14	8.65E-06	0.000554	0.000495	1.1E-06	0.032384	3.238357	0.070681	7.068061

D.21.5 Uncertainty in friction factor for a helical coil of inner diameter 850 μm with methanol

O (ml/s)	ΔP (Pa)	d_i (m)	L (m)	$\pm \Delta d_i$ (m)	$\pm \Delta L$ (m)	$\pm \Delta O$ (ml/s)	$\pm \Delta(\Delta P)$ (Pa)	$\left\{\frac{\Delta(\Delta P)}{\Delta P}\right\}^2$	$\left\{\frac{\Delta L}{L}\right\}^2$	$\left\{\frac{\Delta d_i}{d_i}\right\}^2$	$\left\{\frac{\Delta O}{O}\right\}^2$	$\left\{\frac{\Delta \mathrm{Re}}{\mathrm{Re}}\right\}^2$	Uncertainty in (±) Re	% Uncertainty in (±) Re	Uncertainty in (±) *f*	% Uncertainty in (±) *f*
0.204082	7100	0.00085	0.68	0.00002	0.002	0.025	0.02	7.93493E-12	8.65E-06	0.000554	0.015006	0.000242	0.124739	12.47393	0.0772	7.719967
0.25641	9600	0.00085	0.68	0.00002	0.002	0.025	0.02	4.34028E-12	8.65E-06	0.000554	0.009506	0.000101	0.100299	10.0299	0.073459	7.345852
0.408163	17600	0.00085	0.68	0.00002	0.002	0.025	0.02	1.29132E-12	8.65E-06	0.000554	0.003752	1.85E-05	0.065614	6.561399	0.071172	7.117224
0.555556	26200	0.00085	0.68	0.00002	0.002	0.025	0.02	5.82717E-13	8.65E-06	0.000554	0.002025	6.65E-06	0.05078	5.078024	0.070837	7.083747
0.666667	32900	0.00085	0.68	0.00002	0.002	0.025	0.02	3.69546E-13	8.65E-06	0.000554	0.001406	3.84E-06	0.044271	4.427057	0.070758	7.075814
0.833333	44500	0.00085	0.68	0.00002	0.002	0.025	0.02	2.01995E-13	8.65E-06	0.000554	0.0009	2.11E-06	0.038127	3.812654	0.070709	7.070928

D.21.6 Uncertainty in friction factor for a helical coil of inner diameter 850 μm with acetone

O (ml/s)	ΔP (Pa)	d_i (m)	L (m)	$\pm\Delta d_i$ (m)	$\pm\Delta L$ (m)	$\pm\Delta O$ (ml/s)	$\pm\Delta(\Delta P)$ (Pa)	$\left\{\frac{\Delta(\Delta P)}{\Delta P}\right\}^2$	$\left\{\frac{\Delta L}{L}\right\}^2$	$\left\{\frac{\Delta d_i}{d_i}\right\}^2$	$\left\{\frac{\Delta O}{O}\right\}^2$	$\left\{\frac{\Delta Re}{Re}\right\}^2$	Uncertainty in (±) Re	% Uncertainty in (±) Re	Uncertaint y in (±) f	% Uncertainty in (±) f
0.17094	4700	0.00085	0.68	0.00002	0.002	0.025	0.02	1.81077E-11	8.65E-06	0.000554	0.021389	0.000481	0.148131	14.81307	0.08317	8.317017
0.224719	6500	0.00085	0.68	0.00002	0.002	0.025	0.02	9.46746E-12	8.65E-06	0.000554	0.012377	0.000167	0.113711	11.3711	0.075234	7.52337
0.294118	9400	0.00085	0.68	0.00002	0.002	0.025	0.02	4.52694E-12	8.65E-06	0.000554	0.007225	6.05E-05	0.088197	8.819656	0.072342	7.234209
0.425532	14900	0.00085	0.68	0.00002	0.002	0.025	0.02	1.80172E-12	8.65E-06	0.000554	0.003452	1.6E-05	0.063287	6.328662	0.071102	7.110215
0.512821	20300	0.00085	0.68	0.00002	0.002	0.025	0.02	9.70662E-13	8.65E-06	0.000554	0.002377	8.59E-06	0.054131	5.413128	0.070892	7.089213

D.21.7 Uncertainty in friction factor for a helical coil of inner diameter 1000 μm with water

O (ml/s)	ΔP (Pa)	d_i (m)	L (m)	$\pm\Delta d_i$ (m)	$\pm\Delta L$ (m)	$\pm\Delta O$ (ml/s)	$\pm\Delta(\Delta P)$ (Pa)	$\left\{\frac{\Delta(\Delta P)}{\Delta P}\right\}^2$	$\left\{\frac{\Delta L}{L}\right\}^2$	$\left\{\frac{\Delta d_i}{d_i}\right\}^2$	$\left\{\frac{\Delta O}{O}\right\}^2$	$\left\{\frac{\Delta Re}{Re}\right\}^2$	Uncertainty in (±) Re	% Uncertainty in (±) Re	Uncertainty in (±) f	% Uncertainty in (±) f
0.253165	7800	0.001	0.68	0.00002	0.002	0.025	0.02	6.57462E-12	8.65E-06	0.0004	0.009752	0.000103	0.100755	10.0755	0.06341	6.341031
0.377358	12300	0.001	0.68	0.00002	0.002	0.025	0.02	2.64393E-12	8.65E-06	0.0004	0.004389	2.29E-05	0.069203	6.920305	0.060831	6.083084
0.512821	18400	0.001	0.68	0.00002	0.002	0.025	0.02	1.18147E-12	8.65E-06	0.0004	0.002377	7.71E-06	0.052693	5.26931	0.060328	6.032817
0.689655	27500	0.001	0.68	0.00002	0.002	0.025	0.02	5.28926E-13	8.65E-06	0.0004	0.001314	2.94E-06	0.041401	4.140124	0.06017	6.016978
0.869565	37700	0.001	0.68	0.00002	0.002	0.025	0.02	2.81434E-13	8.65E-06	0.0004	0.000827	1.5E-06	0.035022	3.502231	0.060122	6.012211
1	45800	0.001	0.68	0.00002	0.002	0.025	0.02	1.9069E-13	8.65E-06	0.0004	0.000625	1.05E-06	0.032016	3.201562	0.060107	6.010701
1.111111	53100	0.001	0.68	0.00002	0.002	0.025	0.02	1.41864E-13	8.65E-06	0.0004	0.000506	8.21E-07	0.030104	3.010399	0.060099	6.009938
1.176471	58600	0.001	0.68	0.00002	0.002	0.025	0.02	1.16484E-13	8.65E-06	0.0004	0.000452	7.25E-07	0.029182	2.918154	0.060096	6.009618
1.25	64500	0.001	0.68	0.00002	0.002	0.025	0.02	9.61481E-14	8.65E-06	0.0004	0.0004	6.4E-07	0.028284	2.828427	0.060093	6.009335

D.21.8 Uncertainty in friction factor for a helical coil of inner diameter 1000 μm with methanol

O (ml/s)	ΔP (Pa)	d_i (m)	L (m)	$\pm \Delta d_i$ (m)	$\pm \Delta L$ (m)	$\pm \Delta O$ (ml/s)	$\pm \Delta(\Delta P)$ (Pa)	$\left\{\frac{\Delta(\Delta P)}{\Delta P}\right\}^2$	$\left\{\frac{\Delta L}{L}\right\}^2$	$\left\{\frac{\Delta d_i}{d_i}\right\}^2$	$\left\{\frac{\Delta O}{O}\right\}^2$	$\left\{\frac{\Delta \mathrm{Re}}{\mathrm{Re}}\right\}^2$	Uncertainty in (±) Re	% Uncertainty in (±) Re	Uncertainty in (±) *f*	% Uncertainty in (±) *f*
0.227273	4500	0.001	0.68	0.00002	0.002	0.025	0.02	1.97531E-11	8.65E-06	0.0004	0.0121	0.000156	0.111803	11.18034	0.065067	6.506651
0.294118	5700	0.001	0.68	0.00002	0.002	0.025	0.02	1.23115E-11	8.65E-06	0.0004	0.007225	5.81E-05	0.087321	8.732125	0.061978	6.197752
0.465116	10300	0.001	0.68	0.00002	0.002	0.025	0.02	3.77038E-12	8.65E-06	0.0004	0.002889	1.08E-05	0.05735	5.735035	0.060431	6.043114
0.666667	17800	0.001	0.68	0.00002	0.002	0.025	0.02	1.26247E-12	8.65E-06	0.0004	0.001406	3.26E-06	0.0425	4.25	0.060181	6.018057
0.8	22800	0.001	0.68	0.00002	0.002	0.025	0.02	7.69468E-13	8.65E-06	0.0004	0.000977	1.89E-06	0.037102	3.710206	0.060135	6.01351
1	30800	0.001	0.68	0.00002	0.002	0.025	0.02	4.21656E-13	8.65E-06	0.0004	0.000625	1.05E-06	0.032016	3.201562	0.060107	6.010701

D.21.9 Uncertainty in friction factor for a helical coil of inner diameter 1000 μm with acetone

O (ml/s)	ΔP (Pa)	d_i (m)	L (m)	$\pm \Delta d_i$ (m)	$\pm \Delta L$ (m)	$\pm \Delta O$ (ml/s)	$\pm \Delta(\Delta P)$ (Pa)	$\left\{\frac{\Delta(\Delta P)}{\Delta P}\right\}^2$	$\left\{\frac{\Delta L}{L}\right\}^2$	$\left\{\frac{\Delta d_i}{d_i}\right\}^2$	$\left\{\frac{\Delta O}{O}\right\}^2$	$\left\{\frac{\Delta \mathrm{Re}}{\mathrm{Re}}\right\}^2$	Uncertainty in (±) Re	% Uncertainty in (±) Re	Uncertainty in (±) *f*	% Uncertainty in (±) *f*
0.21978	2800	0.001	0.68	0.00002	0.002	0.025	0.02	5.10204E-11	8.65E-06	0.0004	0.012939	0.000178	0.115495	11.54949	0.06573	6.572954
0.25	3400	0.001	0.68	0.00002	0.002	0.025	0.02	3.46021E-11	8.65E-06	0.0004	0.01	0.000108	0.10198	10.19804	0.063571	6.357115
0.322581	4600	0.001	0.68	0.00002	0.002	0.025	0.02	1.89036E-11	8.65E-06	0.0004	0.006006	4.1E-05	0.080039	8.003905	0.061423	6.142321
0.47619	8000	0.001	0.68	0.00002	0.002	0.025	0.02	6.25E-12	8.65E-06	0.0004	0.002756	9.96E-06	0.056181	5.618051	0.060403	6.04028
0.606061	11300	0.001	0.68	0.00002	0.002	0.025	0.02	3.13259E-12	8.65E-06	0.0004	0.001702	4.42E-06	0.045843	4.58428	0.060219	6.021891

D.22 Uncertainty in Nusselt number for a helical coil

D.22.1 Uncertainty in Nusselt number for a helical coil of inner diameter 720 μm with water

O (ml/s)	d_i (m)	L (m)	T_i (^{0}C)	T_o (^{0}C)	$\overline{T}_w$ (^{0}C)	T_b (^{0}C)	$\pm \Delta d_i$ (m)	$\pm \Delta L$ (m)	$\pm \Delta O$ (ml/s)	$\left\{\frac{\Delta L}{L}\right\}^2$	$\left\{\frac{\Delta d_i}{d_i}\right\}^2$	$\left\{\frac{\Delta O}{O}\right\}^2$	$\left\{\frac{\Delta(\Delta T)}{\Delta T}\right\}^2$	$\left\{\frac{\Delta(\Delta T)}{\Delta T_b}\right\}^2$	$\left\{\frac{\Delta Q)}{Q}\right\}^2$	$\left\{\frac{\Delta \overline{h})}{\overline{h}}\right\}^2$	Uncertainty in (±) Nu	% Uncertainty in (±) Nu
0.196078	0.0072	0.565	30	77.5	80.53	53.75	0.00002	0.002	0.025	1.25E-05	0.00077	0.016256	0.000110803	0.000349	0.000268	1.96E-06	0.027784	2.778412
0.253165	0.0072	0.565	30	67.8	70.14	48.9	0.00002	0.002	0.025	1.25E-05	0.00077	0.009752	0.000174967	0.000554	9.85E-05	2.06E-06	0.027786	2.778596
0.31746	0.0072	0.565	30	58.5	60.01	44.25	0.00002	0.002	0.025	1.25E-05	0.00077	0.006202	0.000307787	0.001006	4.24E-05	3.35E-06	0.027809	2.780922
0.4	0.0072	0.565	30	52.8	55.01	41.4	0.00002	0.002	0.025	1.25E-05	0.00077	0.003906	0.000480917	0.00135	1.92E-05	4.63E-06	0.027832	2.783215
0.5	0.0072	0.565	30	46.8	48.61	38.4	0.00002	0.002	0.025	1.25E-05	0.00077	0.0025	0.000885771	0.002397	1.15E-05	1.02E-05	0.027932	2.79317
0.689655	0.0072	0.565	30	43.5	45.32	36.75	0.00002	0.002	0.025	1.25E-05	0.00077	0.001314	0.001371742	0.003401	7.21E-06	1.76E-05	0.028064	2.806358
0.869565	0.0072	0.565	30	40.3	42.22	35.15	0.00002	0.002	0.025	1.25E-05	0.00077	0.000827	0.00235649	0.004997	1.01E-05	3.35E-05	0.028346	2.834638
1.052632	0.0072	0.565	30	38.5	40.16	34.25	0.00002	0.002	0.025	1.25E-05	0.00077	0.000564	0.003460208	0.007149	1.62E-05	6.32E-05	0.028865	2.886475
1.25	0.0072	0.565	30	36.1	37.08	33.05	0.00002	0.002	0.025	1.25E-05	0.00077	0.0004	0.006718624	0.015368	5.07E-05	0.000262	0.032132	3.21321

D.22.2 Uncertainty in Nusselt number for a helical coil of inner diameter 720 μm with methanol

O (ml/s)	d_i (m)	L (m)	T_i (^{0}C)	T_o (^{0}C)	$\bar{T}_w$ (^{0}C)	T_b (^{0}C)	$\pm \Delta d_i$ (m)	$\pm \Delta L$ (m)	$\pm \Delta O$ (ml/s)	$\left\{\frac{\Delta L}{L}\right\}^2$	$\left\{\frac{\Delta d_i}{d_i}\right\}^2$	$\left\{\frac{\Delta O}{O}\right\}^2$	$\left\{\frac{\Delta(\Delta T)}{\Delta T}\right\}^2$	$\left\{\frac{\Delta(\Delta T)}{\Delta T_b}\right\}^2$	$\left\{\frac{\Delta Q)}{Q}\right\}^2$	$\left\{\frac{\Delta \bar{h})}{\bar{h}}\right\}^2$	Uncertainty in (±) Nu	% Uncertainty in (±) Nu
0.185185	0.0072	0.565	30	44.5	49.51	37.25	0.00002	0.002	0.025	1.25E-05	0.00077	0.018225	0.001189	0.001663	0.000377	7.97E-06	0.027892	2.789207
0.25	0.0072	0.565	30	42.1	45.55	36.05	0.00002	0.002	0.025	1.25E-05	0.00077	0.01	0.001708	0.00277	0.000137	1.36E-05	0.027993	2.79931
0.3125	0.0072	0.565	30	41.2	43.4	35.6	0.00002	0.002	0.025	1.25E-05	0.00077	0.0064	0.001993	0.004109	7.04E-05	2.46E-05	0.028189	2.818904
0.392157	0.0072	0.565	30	39.7	42.05	34.85	0.00002	0.002	0.025	1.25E-05	0.00077	0.004064	0.002657	0.004827	4.52E-05	3.2E-05	0.028319	2.831917
0.465116	0.0072	0.565	30	38.3	40.12	34.15	0.00002	0.002	0.025	1.25E-05	0.00077	0.002889	0.003629	0.007022	4.25E-05	6.16E-05	0.028837	2.883711
0.512821	0.0072	0.565	30	37.1	38.97	33.55	0.00002	0.002	0.025	1.25E-05	0.00077	0.002377	0.004959	0.00851	5.38E-05	8.74E-05	0.029281	2.928068
0.571429	0.0072	0.565	30	35.9	37.61	32.95	0.00002	0.002	0.025	1.25E-05	0.00077	0.001914	0.007182	0.011496	8.27E-05	0.000153	0.030378	3.037763
0.606061	0.0072	0.565	30	34.7	35.96	32.35	0.00002	0.002	0.025	1.25E-05	0.00077	0.001702	0.011317	0.019148	0.000169	0.000404	0.034264	3.426384
0.740741	0.0072	0.565	30	33.4	34.21	31.7	0.00002	0.002	0.025	1.25E-05	0.00077	0.001139	0.021626	0.039682	0.000518	0.00168	0.049493	4.949323
0.952381	0.0072	0.565	30	32.2	32.86	31.1	0.00002	0.002	0.025	1.25E-05	0.00077	0.000689	0.051653	0.081014	0.00274	0.007146	0.088974	8.897418

D.22.3 Uncertainty in Nusselt number for a helical coil of inner diameter 720 μm with acetone

O (ml/s)	d_i (m)	L (m)	T_i (^{0}C)	T_o (^{0}C)	$\bar{T}_w$ (^{0}C)	T_b (^{0}C)	$\pm \Delta d_i$ (m)	$\pm \Delta L$ (m)	$\pm \Delta O$ (ml/s)	$\left\{\frac{\Delta L}{L}\right\}^2$	$\left\{\frac{\Delta d_i}{d_i}\right\}^2$	$\left\{\frac{\Delta O}{O}\right\}^2$	$\left\{\frac{\Delta(\Delta T)}{\Delta T}\right\}^2$	$\left\{\frac{\Delta(\Delta T)}{\Delta T_b}\right\}^2$	$\left\{\frac{\Delta Q)}{Q}\right\}^2$	$\left\{\frac{\Delta \bar{h})}{\bar{h}}\right\}^2$	Uncertainty in (±) Nu	% Uncertainty in (±) Nu
0.151515	0.0072	0.565	30	39.5	41.28	34.75	0.00002	0.002	0.025	1.25E-05	0.00077	0.027225	0.00277	0.005857	0.0009	5.68E-05	0.028755	2.87548
0.208333	0.0072	0.565	30	37.2	38.47	33.6	0.00002	0.002	0.025	1.25E-05	0.00077	0.0144	0.004823	0.010555	0.00037	0.000137	0.030118	3.011751
0.253165	0.0072	0.565	30	35	35.81	32.5	0.00002	0.002	0.025	1.25E-05	0.00077	0.009752	0.01	0.022772	0.00039	0.000573	0.036652	3.665197
0.416667	0.0072	0.565	30	33	33.48	31.5	0.00002	0.002	0.025	1.25E-05	0.00077	0.0036	0.027778	0.063769	0.000985	0.004295	0.071169	7.116865