Bibliografia

[1] ALLAN, J. M.; TEJA, A. S.. **Correlation and prediction of viscosity of defined and undefined hydrocarbon liquids**. The Canadian Journal of Chemical Engineering, 69(4):986–991, 1991.

[2] AMIN, M. B.; MADDOX, R. N.. **Estimation of viscosity versus temperature**. Hydrocarbon Process, 59:131–135, 1980.

[3] API. **Technical data book**. 2001.

[4] ASTM. **Standard test method for viscosity-temperature chart for liquid petroleum products**. ASTM International.

[5] ASTM. **Standard test method for density of semi-solid bituminous materials (pycnometer method)**. ASTM International.

[6] ASTM. **Standard test method for determination of asphaltenes (heptane insolubles) in crude petroleum and petroleum products**. ASTM International.

[7] BALTATU, M. E.; CHONG, R. A.; HUBER, M. L. ; LAESECKE, A.. **Transport properties of petroleum fractions**. International Journal of Thermophysics, 20(1):85–95, 1999.

[8] BEGGS, H. D.; ROBINSON, J. R.. **Estimating the viscosity of crude oil systems**. Journal of Petroleum Technology, p. 1140–1141, September 1975.

[9] BEG, S. A.; AMIN, M. B. ; HUSSAIN, I.. **Generalized kinematic viscosity-temperature correlation for undefined petroleum fractions**. The Chemical Engineering Journal, 38:123–136, 1988.

[10] BIPM; IEC; IFCC; ISO; IUPAC; IUPAP ; OIML. **Guia para a expressão da incerteza de medição**. ABNT e INMETRO, 1998.

[11] ELSHARKAWY, A. M.; HASSAN, S. A.; HASHIM, Y. S. K. ; FAHIM, M. A.. **New compositional models for calculating the viscosity of crude oils**. Industrial Engineering Chemistry Research, 42:4132–4142, 2003.

[12] ELY, J. F.; HANLEY, H. J. M.. **Prediction of transport-properties. 1. viscosity of fluids and mixtures**. Industrial & Engineering Chemistry Fundamentals, 20:323–332, 1981.

[13] ELY, J. F.; HANLEY, H. J. M.. **Prediction of transport-properties. 2. thermal-conductivity of pure fluids and mixtures**. Industrial & Engineering Chemistry Fundamentals, 22:90–97, 1983.

[14] AMINU, M. O.; ELLIOTT, J. A. W.; MCCAFFREY, W. C. ; GRAY, M. R.. **Fluid properties at coking process conditions**. Ind. Eng. Chem. Res., 43:2929–2935, 2004.

[15] GRAY, M. R.; ELLIOTT, J. A. W. ; MCCAFFREY, W. C.. **Measurement of vacuum residue and asphaltene fluid properties at process conditions**. Journal of the Japan Petroleum Institute, 48(4):181–188, 2005.

[16] GUO, X.-Q.; SUN, C.-Y.; RONG, S.-X.; CHEN, G.-J. ; GUO, T.-M.. **Equation of state analog correlations for the viscosity and thermal conductivity of hydrocarbons and reservoir fluids**. Journal of Petroleum Science and Engineering, 30:15–27, 2001.

[17] HANLEY, H. J. M.. **Prediction of the viscosity and thermal conductivity coefficients of mixtures**. Cryogenics, p. 643–651, November 1976.

[18] HILDEBRAND, J. H.. **Motion of molecules in liquids - viscosity and diffusivity**. Science, 174:490, 1971.

[19] INCROPERA, F. P.; WITT, D. P.. **Fundamentos de transferência de calor e massa**. LTC - Livros Técnicos e Científicos Editora S.A., 1992.

[20] ISO. **Crude petroleum and petroleum products - determination of density - oscillating u-tube method**. International Organization for Standardization, 2001.

[21] JOHNSON, S. E.; SVRCEK, W. Y. ; MEHROTRA, A. K.. **Viscosity prediction of athabasca bitumen using the extended principle of corresponding states**. Industrial Engineering Chemistry Research, 26:2290–2298, 1987.

[22] KARTOATMODJO, T.; SCHMIDT, Z.. **Large data bank improves crude physical property correlations**. Oil & Gas Journal, 92(27):51–55, 1994.

[23] KESLER, M. G.; LEE, B. I.. **Improve prediction of enthalpy of fractions**. Hydrocarbon Processing, 55:153–158, 1976.

[24] KIMOTHI, S. K.. **The uncertainty of measurements: physical and chemical metrology: impact and analysis**. 2002.

[25] LEACH, J. W.; CHAPPELEAR, P. S. ; LELAND, T. W.. **Use of molecular shape factors in vapor-liquid equilibrium calculations with the correspondig states principle**. AIChE Journal, p. 568–576, July 1968.

[26] LI, S.; LIU, C.; QUE, G.; LIANG, W. ; YAJIE, Z.. **Colloidal structures of three chinese petroleum vacuum residues**. Fuel, 75(8):1025–1029, 1996.

[27] LI, S.; LIU, C.; QUE, G. ; LIANG, W.. **Colloidal structures of vacuum residua and their thermal stability in terms of saturate, aromatic, resin and asphaltene composition**. Journal of Petroleum Science and Engineering, 22:37–45, 1999.

[28] MEHROTRA, A. K.. **A generalized viscosity equation for pure heavy hydrocarbons**. Industrial Engineering Chemistry Research, 30:420–427, 1991.

[29] MEHROTRA, A. K.; MONNERY, W. D. ; SVRCEK, W. Y.. **A review of practical calculation methods for the viscosity of**

liquid hydrocarbons and their mixtures. Fluid Phase Equilibria, 117:344–355, 1996.

[30] MOHARAM, H. M.; FAHIM, M. A.. **Prediction of viscosity of heavy petroleum fractions and crude oils using a corresponding states method**. Industrial Engineering Chemistry Research, 34:4140–4144, 1995.

[31] MONNERY, W. D.; SVRCEK, W. Y. ; MEHROTRA, A. K.. **Viscosity: a critical review of practical predictive and correlative methods**. The Canadian Journal of Chemical Engineering, 73:3–40, 1995.

[32] OZDOGAN, S.; YUCEL, H. G.. **Correlation towards prediction of petroleum fraction viscosities: a semi-theoretical approach**. Fuel, 79:1209–1214, 2000.

[33] PEDERSEN, K. S.; FREDENSLUND, A.; CHRISTENSEN, P. L. ; THOMASSEN, P.. **Viscosity of crude oils**. Chemical Engineering Science, 39(6):1011–1016, 1984.

[34] PEREIRA, R. C. L.. **Procedimento para detalhamento composicional de óleo na estimação de propriedades**. Dissertação de Mestrado - Escola de Química da Universidade Federal do Rio de Janeiro, 2003.

[35] QUIÑONES-CISNEROS, S. E.; ZÉBERG-MIKKELSEN, C. K. ; STENBY, E. H.. **The friction theory (*f-theory*) for viscosity modeling**. Fluid Phase Equilibria, 169:249–276, 2000.

[36] QUIÑONES-CISNEROS, S. E.; ANDERSEN, S. I. ; CREEK, J.. **Density and viscosity modeling and characterization of heavy oils**. Energy & Fuels, 19:1314–1318, 2005.

[37] REID, R. C.; PRAUSNITZ, J. M. ; POLING, B. E.. **The properties of gases and liquids**. McGraw-Hill, April 1987.

[38] RIAZI, M. R.; AL-OTAIBI, G. N.. **Estimation of viscosity of liquid hydrocarbon systems**. Fuel, 80:27–32, 2001.

[39] RIAZI, M. R.. **Characterization and properties of petroleum fractions**. ASTM, January 2005.

[40] ROWLINSON, J. S.; WATSON, I. D.. **The prediction of the thermodynamic properties of fluids and fluid mixtures - 1. the principle of corresponding states and its extensions**. Chemical Engineering Science, 24:1565–1574, 1969.

[41] SHEU, E. Y.. **Petroleum asphaltene - properties, characterization, and issues**. Energy & Fuels, 16:74–82, 2002.

[42] SPENCER, C.; ADLER, S. A.. **A critical review of equations for predicting saturated liquid density**. Journal of Chemical Engineering Data, 23:81–89, 1978.

[43] STORM, D. A.; BARRESI, R. J. ; DECANIO, S. J.. **Colloidal nature of vacuum residue**. Fuel, 70:779–782, 1991.

[44] STORM, D. A.; BARRESI, R. J. ; SHEU, E. Y.. **Rheological study of ratawi vacuum residue in the 298-673 k temperature range**. Energy & Fuels, 9:168–176, 1995.

[45] SVRCEK, W. Y.; MEHROTRA, A. K.. **One parameter correlation for bitumen viscosity**. Chemical Engineering Research and Design, 66:323–327, 1988.

[46] TEJA, A. S.; RICE, P.. **Generalized corresponding states method for the viscosities of liquid mixtures**. Industrial Engineering Chemistry Fundamentals, 20:77–81, 1981.

[47] TEJA, A. S.; THURNER, P. A. ; PASUMARTI, B.. **Calculation of transport properties of mixtures for synfuels process design**. Industrial Engineering Chemistry Design Development, 24:344–349, 1985.

[48] TWU, C. H.. **An internally consistent correlation for predicting liquid viscosities of petroleum fractions**. Industrial & Engineering Chemistry, Process Design & Development, 24(4):1289–1293, 1985.

[49] WIEHE, I. A.; LIANG, K. S.. **Asphalthenes, resins and other petroleum macromolecules**. Fluid Phase Equilibria, 117:201–210, 1996.

8
Apêndice A

8.1
Equações de Riazi-Daubert para prop. críticas e peso molecular

Temperatura crítica -T_c (K)

$$T_c = 35,9413\, exp[-6.9\times10^{-4} T_b - 1,4442\, D60 + 4,91\times10^{-4}\, T_b\, D60]$$

$$T_b^{0,7293}\, D60^{1,2771} \qquad (8\text{-}1)$$

Pressão crítica - P_c (bar)

$$P_c = 6,9575\, exp[-1,35\times10^{-2}\, T_b - 0,3129\, D60 + 9,174\times10^{-3}\, T_b\, D60]$$

$$T_b^{0,6791}\, D60^{-0,6807} \qquad (8\text{-}2)$$

Volume crítico - V_c (cm^3/mol)

$$V_c = 6,2\times10^{10} exp[-7,58\times10^{-3} T_b - 28,5524 D60 + 1,172\times10^{-2} T_b D60]$$

$$T_b^{1,20493} D60^{17,2074} \qquad (8\text{-}3)$$

Peso molecular (PM)

$$PM = 42,965 exp[2,907 \times 10^{-4} T_b - 7,78712 D60 + 2,08476 \times 10^{-3} T_b D60]$$

$$T_b^{1,26007} D60^{4,98308} \qquad (8\text{-}4)$$

8.2 Cálculo da massa específica (ρ)

$$\rho = 1000 \, \frac{PM}{VL} \qquad (8\text{-}5)$$

$$VL = \frac{R \, T_c}{P_c} \, Z_{RA}{}^{\frac{nr}{nz}} \qquad (8\text{-}6)$$

$$nr = 1 \, + \, (1 \, - \, \frac{T}{T_c})^{2/7} \qquad (8\text{-}7)$$

$$nz = 1 \, + \, (1 \, - \, \frac{288,7}{T_c})^{2/7} \qquad (8\text{-}8)$$

$$Z_{RA} = \frac{PM \, P_c}{0,999 \, D60 \, R \, T_c} \qquad (8\text{-}9)$$

$$R = 83,14 \, \frac{cm^3 \, bar}{mol \, K}$$

8.3
Fator acêntrico (ω) segundo a definição de Kesler-Lee

$$\omega = (-\frac{\ln(P_c)}{1,01325} - 5,92714 + \frac{6,09648}{T_{br}} + 1,28862\ \ln(T_{br}) - 0,169347\ T_{br}^6)/$$

$$(15,2518\ -\ \frac{15,6875}{T_{br}}\ -\ 13,4721\ \ln(T_{br})\ +\ 0,43577\ T_{br}^6)$$

se $T_{br} \leq 0,8$

$$\omega = -7,904\ +\ 0,1352\ k_w\ -\ 0,007465\ {k_w}^2\ +\ 8,359\ T_{br}\ +$$

$$\frac{1,408\ -\ 0,01063\ k_w}{T_{br}} \tag{8-10}$$

se $T_{br} > 0,8$

onde

$T_{br} = \frac{T_b}{T_c}$ é a temperatura de ebulição reduzida

9
Apêndice B

9.1
Simulação numérica

Com o objetivo de verificar a influência da velocidade de rotação do cilindro do viscosímetro na transferência de calor, foi feita uma simulação dos fenômenos envolvidos utilizando o programa CFX. Foi construída uma geometria com as mesmas dimensões do equipamento real, e a partir desta foi gerada uma malha. Foram resolvidas as equações de conservação de massa, quantidade de movimento e energia para o fluido. As hipóteses feitas são as seguintes:

– material do equipamento - aço inoxidável AISI 304

– fluido - óleo de máquina com propriedades descritas no Apêndice A de Incropera e Witt [19]

– interface fluido - ar com coeficiente de película fixo ($h = 50$ W/m^{2}K)

– sem deslizamento nas paredes e na interface fluido - ar

– condição de contorno na parede do copo - temperatura fixa de 100^{o}C

– temperatura do ar igual a 25^{o}C

– condução de calor no cilindro imerso no fluido

O problema foi resolvido como sendo um caso transiente, onde as condições iniciais são o fluido sem movimento na temperatura de 25^{o}C. As rotações do cilindro consideradas foram: 50, 100 e 150 rpm. Estes são valores típicos do teste com óleo padrão.

A solução é considerada convergida quando os resíduos são menores que 10^{-6}.

Os resultados obtidos são qualitativos somente, e servem somente para indicar uma tendência, uma vez que não foi feito um teste de malhas, e o coeficiente de película se manteve fixo.

As figuras (9.1) e (9.2) mostra o perfil de temperaturas no caso com rotação igual a 100 rpm.

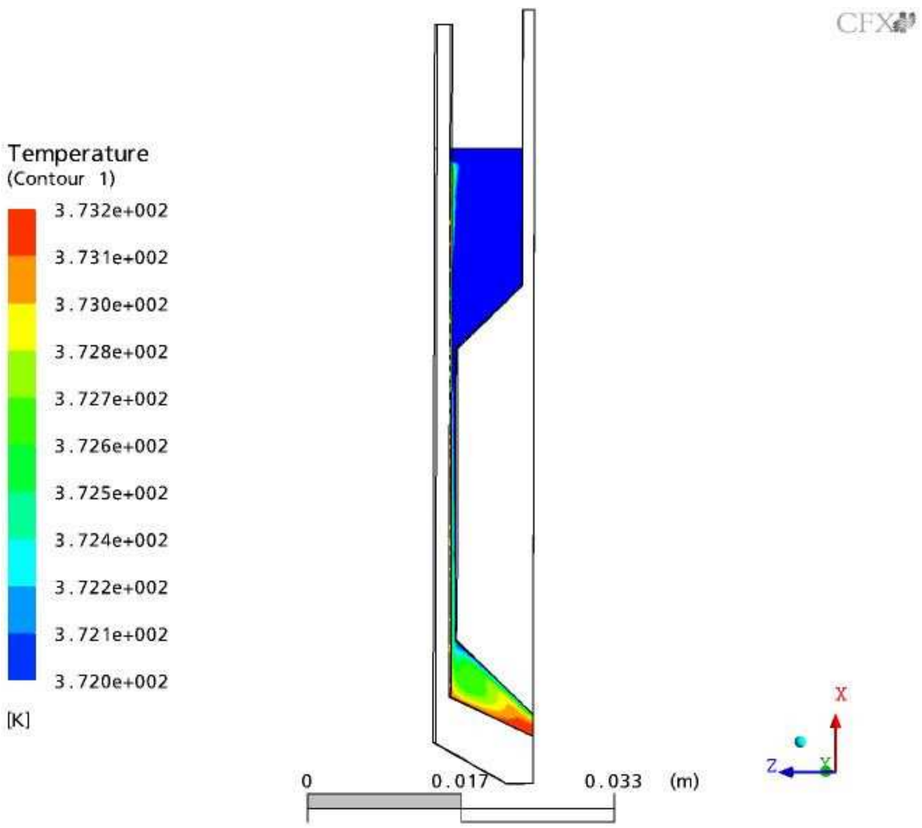

Figura 9.1: Perfil de temperaturas do fluido a 100 rpm

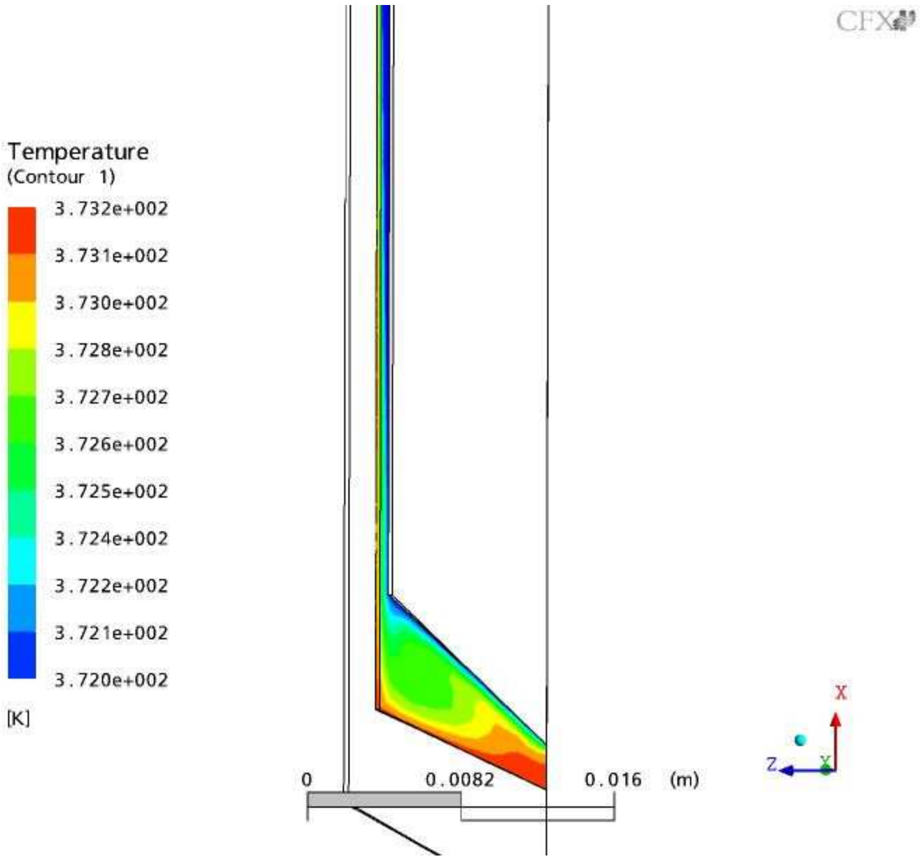

Figura 9.2: Perfil detalhado de temperaturas do fluido a 100 rpm

As figuras (9.3) e (9.4) mostram o perfil de temperaturas no caso com rotação igual a 150 rpm.

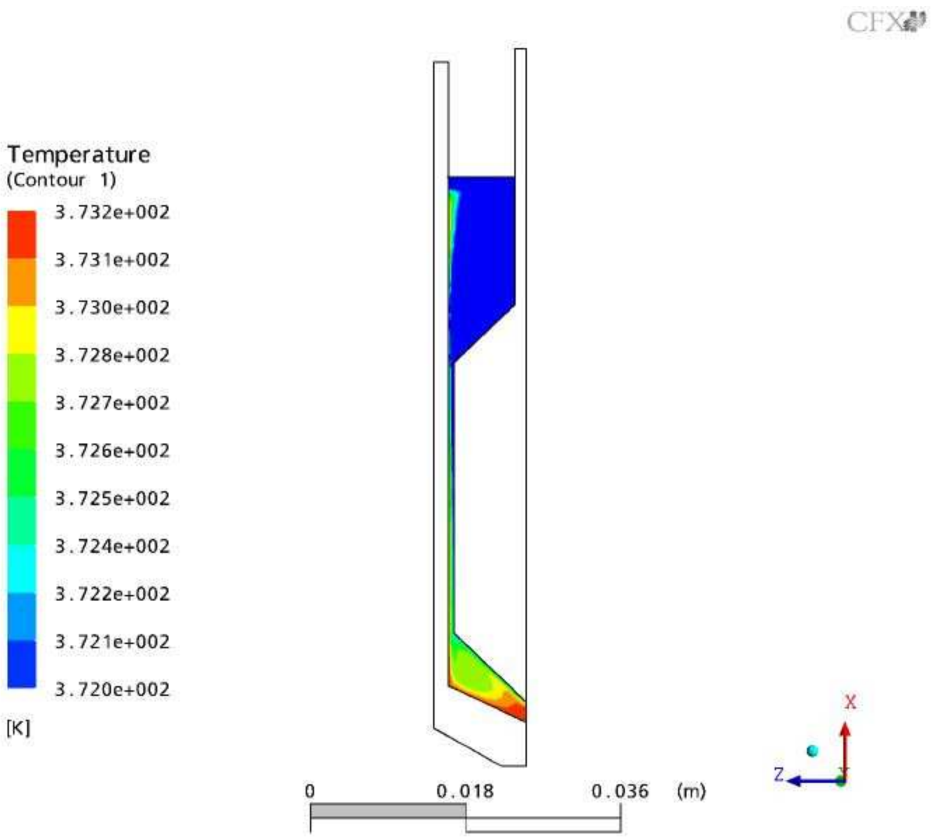

Figura 9.3: Perfil de temperaturas do fluido a 150 rpm

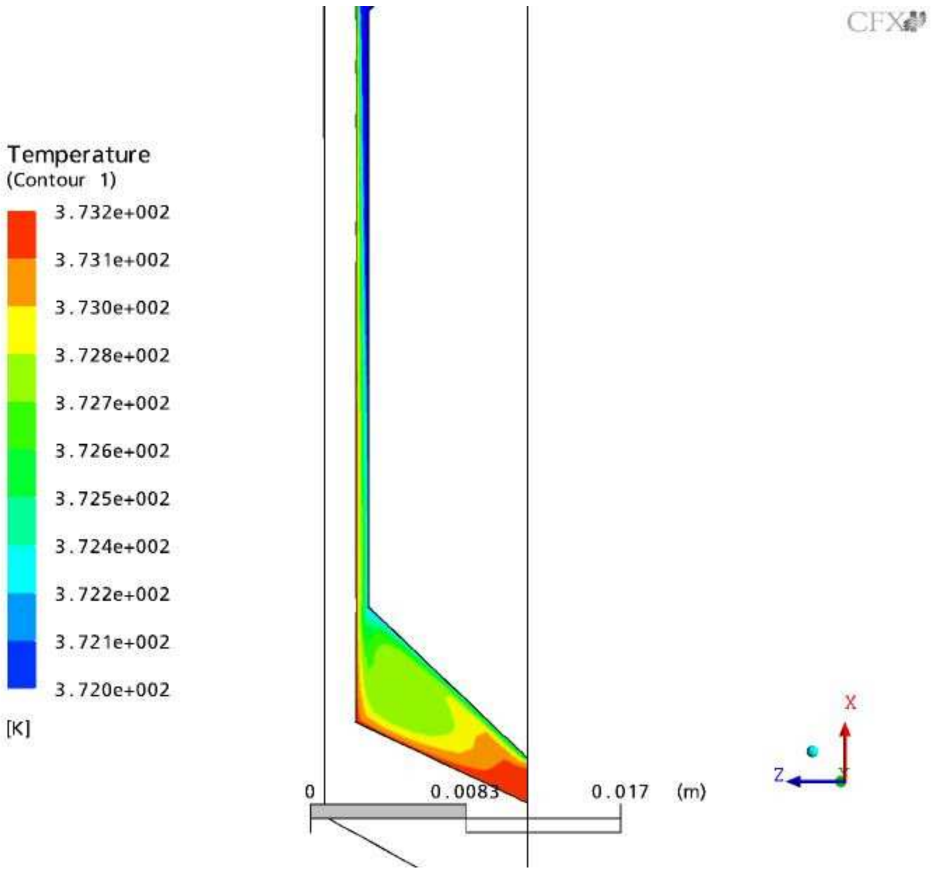

Figura 9.4: Perfil detalhado de temperaturas do fluido a 150 rpm

Os perfis de temperatura mostram que na maior rotação (150 rpm) as temperaturas em torno do cilindro são menores, e consequentemente a viscosidade é maior.

Os resultados desta simulação apresentam a mesma tendência observada experimentalmente, ou seja, a rotação do cilindro influencia na transferência de calor.