

Supplementary Material

Description of Matlab Script

The input variables in the Matlab script (page 2) are the viscosity ratio (“n”), the viscosity of the more viscous fluid (“miu_MV”) and the volume of each solution (“VMV_t” and “VLV_t”). The output variables are the mass of glycerol (“mMV_g”) and water (“mMV_2w”) to prepare the more viscous fluid; the mass of glycerol (“mLV_g”), water (“mLV_w”) and $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ (“mMV_Cacl2”) to prepare the less viscous fluid. The units of mass are kg. If the output variables are 0 for all parameters, it means that it is not possible to prepare aqueous solutions of glycerol for the pre-defined rheological and physical properties. This solution occurs when $x_{\text{CaCl}_2 \cdot 2\text{H}_2\text{O}} < 0$, $x_{\text{CaCl}_2 \cdot 2\text{H}_2\text{O}} > 1$, $x_{0,\text{glycerol}} < 0$, $x_{0,\text{glycerol}} > 1$, $x_{\text{MV,glycerol}} < 0$ or $x_{\text{MV,glycerol}} > 1$, where $x_{\text{MV,glycerol}}$ is the mass fraction of glycerol in the more viscous fluid. This Matlab algorithm also estimates the density and the viscosity of each fluid and the respective refractive index at $\theta = 293.15$ K.

Each step is explaining the Matlab script, and the following list summarizes this calculation:

0. The user defines the viscosity ratio (“n”), the viscosity of the more viscous fluid (“miu_MV”) and the volume of each solution (“VMV_t” and “VLV_t”);
1. Estimation of the viscosity of the less viscous fluid (“miu_LV”) from viscosity ratio (“n”);
2. Calculation of the mass fraction of glycerol in the more viscous (MV) fluid from Equation 11;
3. Calculation of the water density in MV fluid from Equation 6;
4. Calculation of the glycerol density in MV fluid from Equation 6;
5. Calculation of the variable Q and κ from Equation 5 and 4;
6. Calculation of the glycerol volume fraction in MV fluid from Equation 7;
7. Calculation of the MV fluid density from Equation 3;
8. Calculation of the MV fluid refractive index from Equation 12, considering $RI_{\text{water}} = 1.325$ and $RI_{\text{glycerol}} = 1.470$;
9. Define that refractive indices of MV and less viscous (LV) fluids are the same;
10. Solve an equation system using Equations 10, 12, 14 and 18;
11. Calculation of the mass of glycerol and water required to prepare the MV fluid;
12. Calculation of the mass of glycerol, water and calcium chloride required to prepare the LV fluid;
13. If the output variables are $\neq 0$ for all parameters, it means that it is possible to prepare aqueous solutions of glycerol for the pre-defined rheological and physical properties.

Matlab Script

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%Design of model fluids for multiphase flow studies
clear
clc

%Input variables
%Viscosity ratio
n=2;
%viscosity of the more viscous (MV) fluids [mPa.s]
miu_MV=40;
%volume of the less viscous (LV) fluid [L]
VLV_t=10;
%volume of MV fluid [L]
VMV_t=10;

%Method to design model fluids

%Viscosity of the Less Viscous Fluid [mPa.s]
miu_LV=miu_MV/n;

syms x
P_w=5.17e-4; %Pw constant
Q_w=2.22e3; %Qw constant
P_g=7.06e-9; %Pg constant
Q_g=7.64e3; %Qg constant
k1=-0.32; %k constant
teta=293.15; %temperature

%Mass fraction of glycerol in MV Fluid
eqn1=miu_MV==(((1-x)*(P_w*exp(Q_w/teta))^k1+x*(P_g*exp(Q_g/teta))^k1)^(1/k1)); %Equation 10
xMV_g=double(solve(eqn1,x)); %equation solver
xMV_g=xMV_g(imag(xMV_g)==0); %mass fraction of glycerol in MV fluid

%Density of MV Fluid [kg/m^3]
rho_w=1000*(1-(abs((teta-277.13)/615))^1.71); %density of water [kg/m3] - Equation 6
rho_g=(1440.17-0.612*teta); %density of water [kg/m3] - Equation 6
Q=1.78e-6*teta^2-1.15e-3*teta+1.97e-1; % Q constant - Equation 5
k2=1+Q*sin(xMV_g^1.31*pi())^0.81; %volume contraction - Equation 4
fi_g=(-k2*rho_w+(k2^2*rho_w^2+4*k2*(rho_g-rho_w)*xMV_g)^(1/2))/(2*k2*(rho_g-rho_w)); %volume fraction of glycerol in MV fluid - Equation 7
rho_MV=k2*(fi_g*rho_g+(1-fi_g)*rho_w); %density of MV fluid [kg/m3] - Equation 3

%Refractive Index in MV Fluid
RI_w=1.3247; %refractive index of water at 298.15K
RI_g=1.46; %refractive index of glycerol at 298.15K
RI_MV=RI_w*(1-xMV_g)+RI_g*xMV_g; %refractive index of the MV fluid - Equation 13

%Mathing of refractive index
RI_LV=RI_MV;
syms x0 RI0 miu_0 x_Cacl2
eqn2=RI_LV==(-0.12*x0+0.21)*x_Cacl2+RI0; %Equation 14
eqn3=RI0==RI_w*(1-x0)+RI_g*x0; %Equation 12
eqn4=miu_0==((1-x0)*(P_w*exp(Q_w/teta))^k1+x0*(P_g*exp(Q_g/teta))^k1)^(1/k1); %Equation 10
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eqn5=miu_LV==miu_0*exp((-0.058*miu_0.^2+0.26*miu_0+4.41)*x_CaCl2);
%Equation 18

sol = vpasolve([eqn2, eqn3, eqn4, eqn5], [x0, RI0, miu_0, x_CaCl2]);
%system solver
x0 = double(sol.x0); %initial mass fraction of glycerol in LV fluid
RI0 = double(sol.RI0); %initial refractive index of aqueous solution of
glycerol (LV fluid)
miu_0 = double(sol.miu_0); %initial viscosity of aqueous solution of
glycerol (LV fluid) [mPa.s]
x_CaCl2 = double(sol.x_CaCl2); %mass fraction of CaCl2.2H2O

%Determination of mass of CaCl2.2H2O, glycerol and water in each solution
if (x_CaCl2>=0) && (x0>=0) && (xMV_g>=0) && (x0<=1) && (xMV_g<=1) &&
(x_CaCl2<=1)
    %Determination of mass of glycerol and water in MV fluid
    VMV_t=VMV_t*10^-3;
    mMV_t=rho_MV*VMV_t; %total mass of MV fluid [kg]
    mMV_g=xMV_g*mMV_t; %mass of glycerol in MV fluid [kg]
    mMV_w=(1-xMV_g)*mMV_t; %mass of water in LV fluid [kg]

    %Determination of mass of CaCl2.2H2O, glycerol and water in LV fluid
    %Determination of density of LV fluid
    VLV_t=VLV_t*10^-3;
    rho_CaCl2=1.71e3; %density of CaCl2.2H2O at 298.15K [kg/m3]
    rho_0=x0*rho_g+(1-x0)*rho_g; %density of the initial solution [kg/m3]
    rho_LV=x_CaCl2*rho_CaCl2+(1-x_CaCl2)*rho_0; %density of LV fluid [kg/m3]
- Equation 15
    fi_CaCl2= x_CaCl2*(rho_LV/rho_CaCl2); %volume fraction of CaCl2.2H2O in
LV fluid
    V_CaCl2=VLV_t*fi_CaCl2; %volume of CaCl2.2H2O in LV fluid [L]
    mLV_CaCl2=V_CaCl2*rho_CaCl2; %mass of CaCl2.2H2O in LV fluid [kg]
    V_0=VLV_t-V_CaCl2; %volume of initial solution [L]
    fi_g0=x0*(rho_0/rho_g); %volume fraction of CaCl2.2H2O in initial
solution
    V_g0=fi_g0*V_0; %volume of glycerol in initial solution [L]
    V_w0=V_0-V_g0; %volume of water in initial solution [L]
    mLV_g=V_g0*rho_g; %mass of glycerol in LV fluid [kg]
    mLV_w=V_w0*rho_w; %mass of glycerol in LV fluid [kg]

    else
        % It is not possible to prepare these solutions
        mMV_g=0;
        mMV_w=0;
        mLV_CaCl2=0;
        mLV_g=0;
        mLV_w=0;
end

clear eqn1 eqn2 eqn3 eqn4 eqn5 fi_g k1 k2 P_g P_w Q Q_g Q_w C1 rho_g rho_w
RI_g RI_w sol x n V0 VLV_CaCl2 VLV_g VLV_w VMV_w VMV_t Vt x0 xMV_g xLV_g
xL_w fi0_g fi0_w mV_t mLV_t rho_CaCl2 RI0 VLV_t xLV_w C teta miu_0 miu_LV
miu_MV miu_LV rho_Lv RI_LV RI_MV mMV_t rho_LV rho_MV fi_CaCl2 fi_g0 rho_0
V_0 V_CaCl2 V_g0 V_w0 x_CaCl2 ans

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