lculation in saturated oil well, Prof. Milan Stanko (NTNU)

[Sm3/Sm3]	155.1
[m]	0.15
[m2]	0.0177
[m]	1.50E-05
[deg]	90
[Sm3/d]	100
[Sm3/d]	1.55E+04

		BO table column	3	4	5	6	8	10	7	9	11						Woldesemayat and Ghajar	
TVD [m]	T [C]	p[bara]	Rs [Sm3/Sm3]	rs [Sm3/Sm3]	Bo [m3/Sm3]	Bg [m3/Sm3]	deng [kg/m3]	viscg [cp]	deno [kg/m3]	viso [cp]	sigma_o_g [N/m]	qo [m3/d]	qg[m3/d]	uso [m/s]	usg [m/s]	lambdag[-]	e[-]	dp/dx [bara/m]
0	50.0	28	22.6	1.28E-05	1.2	3.44E-02	37.8	1.10E-02	728.8	1.8	1.15E-02	117.4	4.566E+02	0.077	0.299	0.80	0.49	0.0384
500	57.1	47.2	41.1	1.31E-05	1.2	1.90E-02	70.8	1.25E-02	708.8	1.2	8.37E-03	124.2	2.173E+02	0.081	0.142	0.64	0.34	0.0483
1000	64.3	71.4	65.3	1.43E-05	1.3	1.09E-02	119.4	1.49E-02	684.3	0.8	5.12E-03	133.2	9.832E+01	0.087	0.064	0.42	0.21	0.0556
1500	71.4	99.2	93.9	1.69E-05	1.4	7.29E-03	178.7	1.91E-02	657.3	0.6	2.64E-03	144.4	4.468E+01	0.095	0.029	0.24	0.12	0.0589
2000	78.6	128.6	124.4	2.13E-05	1.6	5.71E-03	228.2	2.38E-02	630.8	0.5	1.33E-03	156.8	1.761E+01	0.103	0.012	0.10	0.06	0.0597
2500	85.7	158.4	153.2	2.41E-05	1.7	4.49E-03	229.5	2.44E-02	607.9	0.4	6.71E-04	169.0	8.799E-01	0.111	0.001	0.01	0.00	0.0595
3000	92.9	188.2	155.1	0.00E+00	1.7	0.00E+00	0.0	0.00E+00	607.3	0.4	0.00E+00	169.5	0.000E+00	0.111	0.000	0.00	0.00	0.0602
3500	100.0	218.3	155.1	0.00E+00	1.7	0.00E+00	0.0	0.00E+00	607.4	0.4	0.00E+00	169.5	0.000E+00	0.111	0.000	0.00	0.00	0.0602

```
Function e_wolgha(usl, usg, denl, deng, sigma_lg, teta_deg, p, D)
    'p in bar
    'D in m
    'usl in m/s
    'usg in m/s
    'denl kg/m^3
    'deng kg/m^3
    'teta deg in deg
    'sigma_lg in N/m
    If usg = 0 Then
        e_wolgha = 0
    Else
        Pi = Atn(1) * 4
        teta = teta_deg * Pi / 180
        'void fraction correlation by Woldesemayat and Ghajar (2006)
        a = usg * (1 + ((usl / usg) ^ ((deng / denl) ^ 0.1)))
        B = 2.9 * ((9.81 * sigma_lg * D * (1 + Cos(teta)) * (denl - deng) / (denl ^ 2)) ^ 0.25)
        C = (1.22 + 1.22 * Sin(teta)) ^ (1.01325 / p)
        e_wolgha = usg / (a + (B * C))
    End If
End Function
```

```
Function dpdx_mpf(roughness, viscl, viscg, denl, deng, usl, usg, D, angle, voidfraction)
    'dpdx_mpf pressure gradient, in bar/m, for multiphase flow
    'denl, liquid density, [kg/m3]
    'deng, gas density, [kg/m3]
    'usl superficial liquid velocity, [m/s]
    'usg superficial gas velocity, [m/s]
    'angle, inclination angle of pipe with respect to horizontal [deg]
    'D hydraulic diameter of pipe [m]
    'roughness pipe roughness, [m]
    'viscl, liquid viscosity [cP]
    'viscg, gas viscosity, [cP]
    'voidfraction [-]
    Pi = Atn(1) * 4
    denm = voidfraction * deng + (1 - voidfraction) * denl
    If voidfraction = 0 Or usg = 0 Then
        ug = 0
        ul = usl
        fg = 0
        fl = ffactor(denl, viscl, D, roughness, ul)
    ElseIf voidfraction = 1 Or usl = 0 Then
        ug = usg
        ul = 0
        fl = 0
        fg = ffactor(deng, viscg, D, roughness, ug)
    Else
        ug = usg / voidfraction
        ul = usl / (1 - voidfraction)
        fg = ffactor(deng, viscg / 1000#, D, roughness, ug)
        fl = ffactor(denl, viscl / 1000, D, roughness, ul)
    End If
    dpdx_f = (fg * deng * (ug * Abs(usg)) * 0.5 / D) + (fl * denl * (ul * Abs(usl)) * 0.5 / D)
    dpdx_h = denm * 9.81 * Sin(angle * Pi / 180)
    dpdx_mpf = dpdx_f + dpdx_h
    dpdx_mpf = dpdx_mpf / 100000#
End Function
```

lculation in saturated oil well, Prof. Milan Stanko (NTNU)

[Sm3/Sm3]	155.1
[m]	0.15
[m2]	0.0177
[m]	1.50E-05
[deg]	90
[Sm3/d]	1000
[Sm3/d]	1.55E+05

		BO table column	3	4	5	6	8	10	7	9	11						Nagoo	
TVD [m]	T [C]	p[bara]	Rs [Sm3/Sm3]	rs [Sm3/Sm3]	Bo [m3/Sm3]	Bg [m3/Sm3]	deng [kg/m3]	viscg [cp]	deno [kg/m3]	viso [cp]	sigma_o_g [N/m]	qo [m3/d]	qg[m3/d]	uso [m/s]	usg [m/s]	lambdag[-]	e[-]	dp/dx [bara/m]
0	50.0	28	22.6	1.28E-05	1.2	3.44E-02	37.8	1.10E-02	728.8	1.8	1.15E-02	1174.3	4.566E+03	0.769	2.991	0.80	0.61	0.0313
500	57.1	43.7	37.3	1.29E-05	1.2	2.08E-02	63.4	1.22E-02	711.9	1.2	8.90E-03	1229.4	2.451E+03	0.805	1.605	0.67	0.50	0.0387
1000	64.3	63.0	56.3	1.36E-05	1.3	1.34E-02	100.1	1.40E-02	691.6	0.9	6.20E-03	1301.4	1.320E+03	0.852	0.865	0.50	0.38	0.0461
1500	71.4	86.1	79.2	1.53E-05	1.4	8.91E-03	146.3	1.68E-02	668.7	0.6	3.75E-03	1390.6	6.776E+02	0.911	0.444	0.33	0.26	0.0525
2000	78.6	112.3	105.7	1.84E-05	1.5	6.67E-03	195.8	2.08E-02	644.3	0.5	2.05E-03	1497.1	3.306E+02	0.981	0.217	0.18	0.16	0.0567
2500	85.7	140.7	134.2	2.32E-05	1.6	5.56E-03	234.6	2.48E-02	620.2	0.4	1.12E-03	1615.5	1.167E+02	1.058	0.076	0.07	0.06	0.0588
3000	92.9	170.1	154.6	1.91E-06	1.7	3.87E-04	17.9	1.91E-03	604.6	0.4	6.30E-05	1701.8	2.006E-01	1.115	0.000	0.00	0.00	0.0597
3500	100.0	200.0	155.1	0.00E+00	1.7	0.00E+00	0.0	0.00E+00	605.0	0.4	0.00E+00	1702.0	0.000E+00	1.115	0.000	0.00	0.00	0.0649

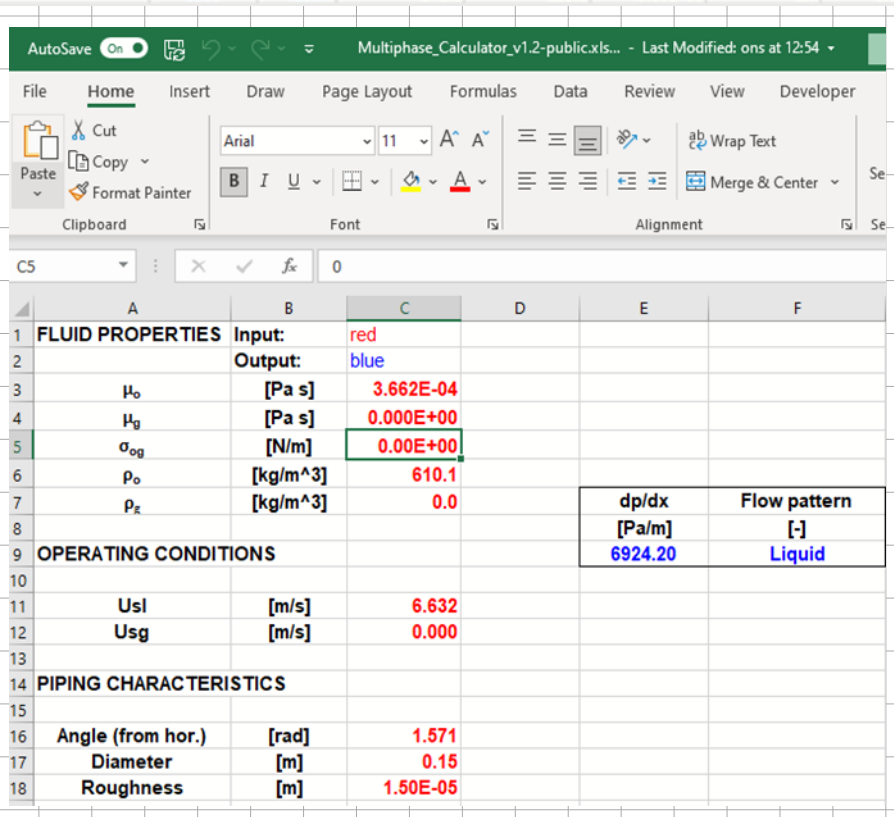
```
Function e_Nagoo(lambdag)
    ' e_Nagoo, the void fraction of gas, in fraction, using the ANSLIP equation by Nagoo, 2013
    'lambdag is non slip volume fraction of gas, in fraction
    If lambdag = 0 Then
        e_Nagoo = 0
    Else
        e_Nagoo = (lambdag + 1 - ((lambdag + 1) ^ 2 - 4 * (lambdag ^ 2)) ^ 0.5) / (2 * lambdag)
    End If
End Function
```

```
Function dpdx_mpf(roughness, viscl, viscg, denl, deng, usl, usg, D, angle, voidfraction)
    'dpdx_mpf pressure gradient, in bar/m, for multiphase flow
    'denl, liquid density, [kg/m3]
    'deng, gas density, [kg/m3]
    'usl superficial liquid velocity, [m/s]
    'usg superficial gas velocity, [m/s]
    'angle, inclination angle of pipe with respect to horizontal [deg]
    'D hydraulic diameter of pipe [m]
    'roughness pipe roughness, [m]
    'viscl, liquid viscosity [cP]
    'viscg, gas viscosity, [cP]
    'voidfraction [-]
    Pi = Atn(1) * 4
    denm = voidfraction * deng + (1 - voidfraction) * denl
    If voidfraction = 0 Or usg = 0 Then
        ug = 0
        ul = usl
        fg = 0
        fl = ffactor(denl, viscl, D, roughness, ul)
    ElseIf voidfraction = 1 Or usl = 0 Then
        ug = usg
        ul = 0
        fl = 0
        fg = ffactor(deng, viscg, D, roughness, ug)
    Else
        ug = usg / voidfraction
        ul = usl / (1 - voidfraction)
        fg = ffactor(deng, viscg / 1000#, D, roughness, ug)
        fl = ffactor(denl, viscl / 1000, D, roughness, ul)
    End If
    dpdx_f = (fg * deng * (ug * Abs(usg)) * 0.5 / D) + (fl * denl * (ul * Abs(usl)) * 0.5 / D)
    dpdx_h = denm * 9.81 * Sin(angle * Pi / 180)
    dpdx_mpf = dpdx_f + dpdx_h
    dpdx_mpf = dpdx_mpf / 100000#
End Function
```

Exercise: Pressure drop calculation in saturated oil well, Prof. Milan Stanko (NTNU)

GOR	[Sm3/Sm3]	155.1
Pipe ID	[m]	0.15
Pipe cross section area	[m2]	0.0177
Pipe roughness	[m]	1.50E-05
Pipe inclination from hor	[deg]	90
qo	[Sm3/d]	6000
qg	[Sm3/d]	9.31E+05

		BO table column	3	4	5	6	8	10	7	9	11						Mechanistic model	
TVD [m]	T [C]	p[bara]	Rs [Sm3/Sm3]	rs [Sm3/Sm3]	Bo [m3/Sm3]	Bg [m3/Sm3]	deng [kg/m3]	viscg [cp]	deno [kg/m3]	viso [cp]	sigma_o_g [N/m]	qo [m3/d]	qg[m3/d]	uso [m/s]	usg [m/s]	lambdag[-]	flowpattern	dp/dx [bara/m]
0	50.0	28	22.6	1.28E-05	1.2	3.44E-02	37.8	1.10E-02	728.8	1.8	1.15E-02	7046.0	2.740E+04	4.615	17.944	0.80	Slug	0.0492
500	57.1	52.6	46.8	1.34E-05	1.3	1.64E-02	82.1	1.29E-02	704.1	1.1	7.56E-03	7564.5	1.065E+04	4.954	6.976	0.58	Slug	0.0417
1000	64.3	73.5	67.6	1.45E-05	1.3	1.05E-02	125.0	1.53E-02	682.4	0.8	4.88E-03	8044.2	5.540E+03	5.269	3.628	0.41	Bubble	0.0605
1500	71.4	103.7	99.2	1.76E-05	1.5	6.90E-03	189.5	2.00E-02	653.3	0.6	2.35E-03	8781.2	2.322E+03	5.751	1.521	0.21	Bubble	0.0675
2000	78.6	137.5	134.8	2.33E-05	1.6	5.37E-03	243.1	2.55E-02	623.6	0.4	1.07E-03	9650.4	6.558E+02	6.321	0.430	0.06	Bubble	0.0708
2500	85.7	172.9	155.1	0.00E+00	1.7	0.00E+00	0.0	0.00E+00	609.0	0.4	0.00E+00	10144.6	0.000E+00	6.644	0.000	0.00	Liquid	0.0693
3000	92.9	207.5	155.1	0.00E+00	1.7	0.00E+00	0.0	0.00E+00	610.1	0.4	0.00E+00	10127.0	0.000E+00	6.633	0.000	0.00	Liquid	0.0693
3500	100.0	242.1	155.1	0.00E+00	1.7	0.00E+00	0.0	0.00E+00	610.1	0.4	0.00E+00	10125.7	0.000E+00	6.632	0.000	0.00	Liquid	0.0692



	A	B	C	D	E	F
1	FLUID PROPERTIES	Input:	red			
2		Output:	blue			
3	μ_o	[Pa s]	3.662E-04			
4	μ_g	[Pa s]	0.000E+00			
5	σ_{og}	[N/m]	0.00E+00			
6	ρ_o	[kg/m^3]	610.1			
7	ρ_g	[kg/m^3]	0.0		dp/dx	Flow pattern
8					[Pa/m]	[-]
9	OPERATING CONDITIONS				6924.20	Liquid
10						
11	Usl	[m/s]	6.632			
12	Usg	[m/s]	0.000			
13						
14	PIPING CHARACTERISTICS					
15						
16	Angle (from hor.)	[rad]	1.571			
17	Diameter	[m]	0.15			
18	Roughness	[m]	1.50E-05			

pwh=28 bara

Models	Wolgha	Nagoo	Mechanistic
qo	pwf	pwf	pwf
[Sm3/d]	[bara]	[bara]	[bara]
100	218.3	197.5	205.5
250	200.0	197.6	187.5
500	188.5	198.2	173.2
1000	182.4	200.0	165.6
2000	186.9	211.5	166.8
3000	199.2	223.7	178.4
4000	224.5	238.5	206.2
5000	245.2	266.9	224.2
6000	280.5	287.5	242.1