“FluidSeis” user’s guide (a Matlab fluid substitution program)

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SUMMARY

FluidSeis is a Matlab program that performs time-lapse well-log seismic modelling. It calculates fluid and rock bulk moduli, densities and undrained velocities. Given reservoir conditions after fluid substitution, it calculates new bulk moduli, densities and undrained velocities that form new logs. It also calculates the mean changes, standard deviations and percentage changes of the logs and bulk moduli before and after production for time-lapse seismic feasibility study.

The whole program includes three functions. The fluidk.m is for fluid densities and bulk moduli. The rockk.m uses density logs and velocity logs and the results from fluidk.m to calculate dry rock bulk modulus. FluidSeis.m is the main function that uses the results from above two functions to calculate the undrained bulk modulus using Gassmann’s equation and calculates the undrained rock density.

FluisSeis can be used to calculate only fluid properties, dry rock properties or calculate the undrained rock properties. The program generates well logs with Vp, Vs and density. The well logs can be used with other software to calculate synthetic seismograms for conditions before and after production. Comparisons can be used in feasibility studies and interpreting 4-D seismic surveys.

THEORY

FluidSeis is based on the procedure described by Bentley and Zhang (1999). A brief description of the procedure is presented here plus some revisions to the original scheme. Refer to Bentley and Zhang (1999) for more details. The Gassmann’s equation relates the bulk modulus of a saturated rock (Ku), to the dry rock bulk modulus (Kd), the solid grain modulus (Ks), the fluid bulk modulus (Kf) and the porosity ϕ (Wang and Nur, 1992),

$$Ku = Kd + \frac{(1 - Kd/Ks)^2}{\frac{\phi}{Kf} + \frac{1-\phi}{Ks} - \frac{Kd}{Ks^2}} \tag{1}$$

Density is calculated,

$$\rho_f = Sg\rho_g + So\rho_o + Sw\rho_w \tag{2}$$

$$\rho_o = \frac{\rho_o^{std} + Rs\rho_g^{std}}{Bo} \tag{3}$$

$$\rho_u = \rho_s(1-\phi) + \rho_f\phi \tag{4}$$

where $\rho_o,\rho_g,\rho_w,\rho_s,\rho_u,\rho_f,$ are the densities of oil, gas, water, solid grains, saturated reservoir rock and fluid mixture at reservoir condition; ρ^{std} is the density of oil or gas at standard conditions, R_s is the gas-oil ratio, and *Bo* is the oil formation volume factor.

The equations of Batzle and Wang (1992) are used to calculate ρ_g,, *Kg*, ρ_w, and *Kw* (adiabatic) using the known reservoir pressure, temperature, gas specific gravity and water salinity. From (2) and (3) we have obtained ρ_f and from (4) we can get undrained rock density ρ_u .

We can get ϕ and *Ks* from core test. Using the empirical equations developed by Vasquez and Beggs (1980) *Co* (*Ko=1/Co*) can be calculated if we know the specific gravity of gas, separator pressure and temperature, and oil API gravity.

The fluid mixture bulk density has the limiting values (Biondi et al., 1998),

$$\frac{1}{K_{f1}} = \frac{Sg}{Kg} + \frac{So}{Ko} + \frac{Sw}{Kw} \tag{5}$$

$$K_{f2} = SgKg + SoKo + SwKw \tag{6}$$

Equation (5) is for homogeneous fluid distribution and Equation (6) is for patchy fluid distribution. We take an average of these two to get K_f.

The undrained bulk and shear moduli are computed from P- and S-velocity, and density logs using,

$$K_u = \rho_u(V_p^2 - \frac{4}{3}V_s^2) \tag{7}$$

$$\mu_u = \rho_u V_s^2 \tag{8}$$

K_d can be calculated from K_u, the porosity, and estimate of K_s, an estimate of K_f porosity and the Gassman equation. New reservoir pressure, temperature, and saturations are specified by the analyst. Gas, oil, and water bulk moduli and densities are computed using Batzle and Wang (1992). Equations (2) and (4), the new fluid density, the new fluid saturation, the porosity and the solid grain density are used to calculate the new undrained bulk density. The percentage change in undrained bulk density is calculated using the new and old bulk densities. The original density logs are multiplied by the percentage change to generate an updated density log. For sandstone, the change in K_d and μ_d due to changes in effective stress are computed using the relationship derived by Zhang, et al. (1999),

$$\frac{dKd}{dP_{eff}} = 0.746\exp(-0.0773 P_{eff}) \tag{9}$$

$$\frac{d\mu_u}{dP_{eff}} = 0.372\exp(-0.0791 P_{eff}) \tag{10}$$

The updated values can be used with the Gasssman equation and density equations to update the undrained bulk and shear moduli and the undrained density. These are used to update the velocity logs.

THE INPUT FILES

Input data for FluidSeis are density logs, P-wave velocity logs, S-wave velocity logs, reservoir PVT data and reservoir rock properties. The input file names are formed by project name plus extensions. They are:

projectname.*fluidin*, projectname.*rockin*, projectname.*fluidfin* projectname.*header*.

projectname.fluidin contains the specification of fluid density, specific gravity, reservoir PVT data, fluid saturation of fluids and reservoir pressure and temperature.

projectname.rockin specifies rock porosity, solid grain density, solid grain bulk modulus and solid grain shear modulus.

projectname.fluidfin has the same parameters as project.fluidin but for the reservoir scenario after production.

Well log files in the LAS format without the header are also needed. The file name should be set to *editedlog.txt*.

The sample input files that following are for the calculation of White Rose project (Zou and Bentley, 2001). The input file format has to be kept.

Whitrose.fluidin

White Rose L-08 May/99
Input for the calculation of fluid density and moduli

From Rock Properties--Average Oil and Gas Compositions, Table 1.2-5
If iapi=1, the second number is standard API, iapi=2, it is density, iapi=3, it is mole weight.
1 31
From Rock Properties--Summary of Avalon PVT, Table 1.2-7
Oil formation volume factor.
1.37
From Rock Properties--South Avalon Pool Gas gravity, Table 1.2-6
Gas Specific Gravity, Solution Gas.
0.7345
From Rock Properties--Summary of Avalon PVT, Table 1.2-7

If irs=0, Rs(cm gas/cm oil)
0 122
Reservoir Temp. from Reservoir Engineering, Table 4-1
If itemp=0, degrees C
0 106
Reservoir Pressure from Reservoir Engineering, Table 4-1
If ip=0, KPa
0 29400.0
Water Salinity, in water zone--3094.5M
ppm
28118
Separator P and T
If ip=1, Psi, Deg. F
1 100 60
Fluid Saturations
gas, oil, water
0.0 0.78 0.22 3

Whiterose.rockin

White Rose Acoustic Core Studies May/99
Input for calculation of dry bulk modulus

Solid Rock density and bulk modulus--from Ken Hedlin,
density (KG/M**3) Ks (GPa)
2640 36
Average porosity from Lab test
0.18

THE OUTPUT FILES

The output file names are formed by project name plus extensions. They are:

.fluidout, *.rockout*, *fluidfout*, *.LAS*, and *.simout*.

projectname.fluidout is the output for the calculated fluid moduli and density. It contains input information and the calculated gas, water, oil and fluid moduli and densities.

projectname.rockout is the output for the dry rock modulus and density. It has the pre-production dry rock bulk moduli and the undrained bulk moduli for every input depth.

project.fluidfout has the same calculated information as projectname.fluidout but for the reservoir after pressure changes and fluid substitution. This file can be used as input to calculate synthetic seismograms. The new synthetic seismograms can be compared to synthetic seismograms from the original reservoir conditions in feasibility studies.

projectname.LAS file is the standard LAS file with calculated undrained densities, P-wave velocities and S-wave velocities for the reservoir after fluid substitution.

projectname.simout gives meam change and standard deviation, percentage change and standard deviation for calculated properties.

Here are sample output files (partial).

Whiterose.fluidout

White Rose L-08 May/99
Output of Function fluidk.m

From Rock Properties--Average Oil and Gas Compositions, Table 1.2-5
If iapi=1, the second number is standard API, iapi=2, it is density, iapi=3, it is mole weight.
api: 31.000000
density: 870.769231 KG/M**3

From Rock Properties--Summary of Avalon PVT, Table 1.2-7
Oil formation volume factor.
fvfo: 1.370000 M**3 Res./M**3 Std.

From Rock Properties--South Avalon Pool Gas gravity, Table 1.2-6
Gas Specific Gravity, Solusion Gas.
specific gravity of gas: 0.734500
density of gas: 0.897426 KG/M**3

From Rock Properties--Summary of Avalon PVT, Table 1.2-7
If irs=0, Rs(cm gas/cm oil)
gas oil ratio: 684.957627 Scf/Stb
gas oil ratio: 122.000000 cum/cum

Reservoir Temp. from Reservoir Engineering, Table 4-1
If itemp=0, degrees C
temperature: 222.800000 F
temperature: 106.000000 C

Reservoir Pressure from Reservoir Engineering, Table 4-1
If ip=0, KPa
pressure: 4263.959391 Psi
pressure: 29400.000000 KPa

Water Salinity, in water zone--3094.5M
ppm
salinity: 28118.000000 ppm

Separator P and T
If ip=1, Psi, Deg. F
seperator P: 100.000000 Psi
seperator T: 60.000000 F
gas specific gravity at 100 psi: 0.734500

oil compressibility, Vasquez and Beggs(1980) Equation(5)
co: 1.254268e-005 Psi**-1
co: 1.819098e-006 KPa**-1

Bulk Modules=1/compressibility
ko: 7.972777e+004 Psi
ko: 5.497230e-001 GPa

density of oil in reservoir condition:
density: 715.514728 KG/M**3

density of gas in reservoir condition:

Equation (10) Batzle and Wang (1992)
Pseudo Reduced Pressure: 6.398712
Pseudo Reduced Temprature: 1.722345
Compressibility factor Z: 0.948477
density: 208.009854 KG/M**3

Bulk modulus and compressibility of gas in res. condition
Bulk modulus Kg: 0.0693167 GPa

Whiterose.rockout

Pore fluid and undrained rock densities and modulus:
density of pore fluid: 775.514 KM/M**3
density of undrained rock: 2304.39 KM/M**3
bulk modulus of pore fluid Kf: 1.00247 GPa
bulk modulus of solid rock Ks: 36 GPa
bulk modulus of undrained rock Ku: MAX 29.6287 GPa MIN 16.0354 GPa

shear modulus of undrained rock: MAX 21.16 GPa MIN 12.098 GPa

bulk modulus of dry rock: MAX 29.4441 GPa MIN 14.103 GPa

Undrained bulk modulus and dried bulk modulus:

~A DEPTH	Ku	Kd
2903.000000	22.141922	21.237614
2903.125000	22.091535	21.180422
2903.250000	22.091535	21.180422
2903.375000	22.091535	21.180422
2903.500000	22.091535	21.180422
2903.625000	22.088080	21.176500

… …

Whiterose.LAS

```
~VERSION INFORMATION
VERS.          2.0: LAS LOG ASCII STANDARD VERSION 2.0
WRAP.          NO: ONE LINE PER DEPTH STEP
~WELL INFORMATION
#MNEM.UNIT     DATA               DESCRIPTION
#-------------------------------------------------
STRT.M     823.0000              :
STOP.M     3117.5000             :
STEP.M     0.1250                :
NULL.      -999.25               :
WELL.      L-08-R12              : Well Name
OPER.      HUSKY OIL LIMITED     : Operator
FLD.       White Rose            : Field
DATE.      15-MAY-1999           : Date Logged
SRVC.                            : SERVICE COMPANY
UWI.       L-08-R12              : UNIQUE WELL ID
PROV.      Newfoundland          : Province
AREA.      Jeanne d'Arc Basin    : Area
PROS.      White Rose            : Prospect
LOC.       48° 01' 20.22" W - 46° 47' 30. : Location Descrip
~TOPS
LSrt            823.00
TrtA            1068.00
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TrtB            1300.00
TrtC            1630.00
TrtD            1940.00
TrtE            2110.00
SMar            2260.00
BTrt            2316.00
DCyn            2316.00
Petl            2317.00
Naut            2466.00
AlAp            2702.00
Aval            2816.50
GOC             2903.50
OWC             2996.00
Tpsy            2999.00
AlBa            3096.00
EShl            3096.00
~CURVE INFORMATION
#MNEM.UNIT     API CODE            CURVE DESCRIPTION
#----------------------------------------------------
DEPT.M                        : 1 DEPTH
RHOZ.KG/M^3                   : 2 RHOZ
PVEL.M/S                      : 3 PVEL
SVEL.M/S                      : 4 SVEL
~PARAMETER INFORMATION
#MNEM.UNIT     VALUE              DESCRIPTION
#-----------------------------------------------
EKB.M         25.000              : ELEVATION KB
EGL.M       -120.0000             : GL Elevation
DFM.        EShl - Eastern Shoals Formatio : Deepest Formatio
PZONE.      Avalon Formation              : Producing Zone
TLI.M       2633.6250             : Log Run Top
BLI.M       3138.1250             : Log Run Base
BHT.DEGF    -999.2500             : Bottom Hole Temp
BS.MM       215.9000              : Minimum Bitsize
DFD.KG/M3   951.0000              : Mud Density
Density, Velocities and Acoustic Impedences after production:
~A  DEPTH        RHOZ        PVEL        SVEL
2903.000000  2401.149115  4186.988537  2397.193081
2903.125000  2401.149115  4187.290164  2400.576626
2903.250000  2401.149115  4187.290164  2400.576626
2903.375000  2401.149115  4187.290164  2400.576626
2903.500000  2401.149115  4187.290164  2400.576626
2903.625000  2402.356334  4187.310881  2400.808444
2903.750000  2402.890844  4191.930036  2412.410079
2903.875000  2410.913953  4194.102239  2414.547181
2904.000000  2412.264523  4200.318676  2428.686972
   … …
```

Whiterose.simout

The changes of Undrained bulk moduli:

MAX Ku defference before and after production: 1.6828 GPa
MIN Ku defference before and after production: 0.181817 GPa
MEAN and STANDARD DEVIATION: 1.07791 GPa, 0.335992

MAX Ku percentage change before and after production: 0.104943
MIN Ku percentage change before and after production: 0.00613652

MEAN and STANDARD DEVIATION: 0.0558247, 0.0216283

The changes of Undrained shear moduli:

MAX defference before and after production: 0 GPa
MIN defference before and after production: 0 GPa

The changes of Undrained rock density:

Defference before and after production: 23.5633 Kg/M**3
Percentage change before and after production: 0.0102254

The changes of Velocities:

MAX Vp defference before and after production: 73.5877 M/S
MIN Vp defference before and after production: -14.435 M/S
MEAN and STANDARD DEVIATION: 36.3247 M/S, 20.1411

MAX Vp percentage change before and after production: 0.0190962
MIN Vp percentage change before and after production: -0.0031758
MEAN and STANDARD DEVIATION: 0.00908854, 0.00511876

MAX Vs defference before and after production: -11.6255 M/S
MIN Vs defference before and after production: -15.3749 M/S
MEAN and STANDARD DEVIATION: -12.4287 M/S, 0.594946

MAX Vs percentage change before and after production: -0.00507381
MIN Vs percentage change before and after production: -0.00507381
MEAN and STANDARD DEVIATION: -0.00507381, 8.72171e-017

COMMAND EXECUTION

If you only want to calculate fluid densities and bulk moduli, enter FluidSeis(1,'projectname') at the *Matlab* command line. If you want to calculate rock dry bulk modulus enter FluidSeis(2,'projectname'). If you want the undrained bulk modulus and the undrained velocities after fluid substitution enter FluidSeis(3,'projectname').

REFERENCES

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Vasques, M. and Beggs, H.D., 1980, Correlations for Fluid Physical Property Predictions: JPT, **32**, 968-970.

Wang, Z. and Nur, A., 1992, Elastic Wave Velocities in Porous Media: A theoretical Recipe in Seismic and Acoustic Velocities in Reservoir Rocks: **2** Theoretical and Model Studies, SEG, 1-35.

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