

# Implementation of Reservoir Fluid Property Models in Well Log Analysis Software

Debra Bolton

School of Mechanical Engineering

CEED Partner: Woodside Energy Ltd

## Abstract

*Hydrocarbon gas, oil and brine are commonly found in subsurface reservoirs. Knowledge of each fluids in-situ density and sonic velocity is essential to petrophysical well log analysis processes and consequently the accurate evaluation of the hydrocarbon content within the reservoir. The fluid properties density, gas-oil-ratio, gas specific gravity and brine salinity are usually well known from fluid analysis at surface conditions. At the high temperature and pressure environment within the reservoir, density measurements can vary significantly from their surface values, thermodynamic models are required to correct for this variation. Sonic velocity is not generally measured in surface fluid analysis, thus it must also be calculated from measured properties and mathematical models. This project aims to implement the most up-to-date fluid property models for in situ density and sonic velocity in Woodside Energy's well analysis software Paradigm Geolog 6.6, to increase the accuracy and efficiency of well log analysis. Accompanying the implementation will be a study into the variation between different fluid models and the impact of this variation on the well analysis. This paper gives an overview of the common well analysis processes and the implementation and review of fluid property models.*

## 1 Introduction

Oil and Gas companies worldwide invest billions of dollars each year into exploration of hydrocarbon fields to determine the size of reserves and feasibility of development – Woodside Concise Annual Report (2006). In the exploration process, 3D acoustic images of the subsurface, known as seismic surveys are taken, exploration wells are then drilled into the reservoir according to the surveys, then logged and analysed. Well measurements taken in the borehole, commonly known as logs, enable petrophysicists to calculate key reservoir properties such as porosity, lithology, hydrocarbon and water content. Acoustic logs, such as sonic velocity and density, are acquired to enable calibration of seismic surveys with well log information and to clarify the reflection properties of each reflection interface in the survey.

Both seismic surveys and acoustic logs are distinctly influenced by the presence of different fluids in the formation, hence the extensive use of this technology in reservoir evaluation. Bulk density and acoustic velocity information directly shows fluid saturated reservoir rock from non-porous unsaturated rock and also indicates the type of fluid in the pore space. This is because fluids return less dense and slower velocity measurements than solid rock, and fluids themselves have characteristic densities and velocities. The discrete difference in rock matrix and pore fluid properties also creates acoustic reflection interfaces, much like air-water interfaces reflect light, which are the basis of seismic surveys. Hydrocarbon reservoirs can be found by looking for low density and acoustic velocity events in log measurements and tying these with the presence of strong reflection interfaces in seismic surveys. To ensure the precision of potential reservoir findings the fluid properties used in calculations must be sufficiently accurate.

The process of drilling the well damages the near well-bore environment by the invasion of drilling mud. The raw bulk density and compressional sonic velocity log measurements recorded in the invaded zone differ from which would be obtained if the formation were undisturbed. Thus the acoustic logs need to be reconstructed for virgin conditions. The aim of this project was to implement existing fluid property models used to calculate figures for density and compressional velocity for virgin substitution and forward modelling fluid scenarios in Paradigm's well analysis software Paradigm Geolog 6.6.

## 2 Technical Background

To fully appreciate the significance of the project one must first understand the key measurements taken and the well analysis procedure.

### 2.1 Bulk Density and Sonic Velocity

Bulk density and sonic velocity measurements are key to successful well evaluation because they allow the acoustic calibration of well logs to seismic data. Density is defined as the mass-volume ratio for a material, and determined in the borehole by a gamma ray scatter and detection tool. Bulk density refers to the combined densities of the rock and pore fluid, as measured by the tool. Velocity is measured in two forms, compressional and shear, defined as the speed at which a compressional or shear acoustic wave moves through the rock matrix and pore fluid. These are measured simultaneously by transmitting and receiving a sonic pulse. The type and compactness of molecules determines density whereas the speed of wave propagation is dependent on aforementioned density and the materials elastic properties. With this knowledge the structure and components in the formation surrounding the borehole can be approximated. For example, at a given depth hydrocarbons in a porous sandstone formation are generally less dense than a shale formation. Also the ratio of effective shear to compressional velocity will be smaller in a hydrocarbon bearing rock than a shale because a fluid does not transfer shear waves.

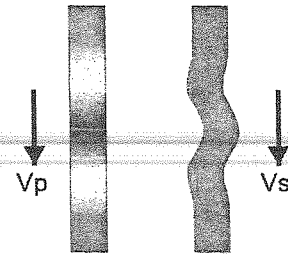


Figure 1 – Compressional and Shear Velocity representation

### 2.2 Paradigm Geolog 6.6

Paradigm Geotechnology provide imaging, modelling and analysis software solutions to the oil and gas industry. Their software application Geolog 6.6 is one of the most used petrophysical analysis and well data management programs worldwide. Customers include Woodside, Chevron, BP, Total and Saudi Aramco. Geolog allows well data storage, editing of raw data and visualisation of reservoir properties. It also incorporates a special property fundamental to this project - the program has the capability to have new functional modules coded in. The modules are created using 'Loglan' a specific object-orientated logging language similar to Java.

### 2.3 Well Analysis Processes

The drilling process alters the formation around the borehole from which measurements are taken. Invasion of high density drilling mud filtrate into hydrocarbon bearing sands alters the original (of virgin) conditions into a higher density, and higher velocity zone. Logs recorded in this invaded zone need correcting back to virgin conditions. To obtain accurate measurements the recorded logs are reconstructed using a substitution algorithm developed by Gassmann (1951). The substitution entails (1) correcting for drilling mud filtrate invasion, (2) removing all recorded fluid data (3) substituting calculated virgin fluid data and (4) repeating the fluid substitution with a brine-only case. A Gassmann substituted log will resemble Figure 2: where if zero porosity is recorded (eg in a shale) no fluid was present originally, none can be substituted, thus the new figures will overlay the existing. If a hydrocarbon is present in the rock matrix, a virgin substituted density log (left) will be less dense and a brine substituted log (right) will

sightly more dense than the recorded measurement. This is because the removal of filtrate will reduce bulk density in the virgin case whereas because the brine is much denser than a hydrocarbon fluid and results in a denser log. A virgin and brine substitution will similarly effect a compressional velocity log with a slower wave existing in the virgin case and marginally faster one in the brine case. A Gassmann substitution will only very marginally transform the Shear Velocity Log as fluid does not exhibit shear elastic properties.

Once all Gassmann substitutions have been carried out, corrected logs will undergo further modifications and analysis, outside the scope of this project. The supplementary focus of this project was to test the overall variation in synthetic seismic curves due to the use of different fluid property models. Synthetic seismic curves are generated from density and velocity logs giving a low frequency seismic signature, comparable to that generated in a 3D seismic survey. Seismic curves will have 'soft' and 'hard' inflections which can be seen in figure 3 which correspond to features within other logs in the layout. Lithology indicates the rock composition; the yellow indicating sandstone which is desirable in a reservoir and grey the shale non-reservoir. Water saturation is calculated from a log of resistivity, numbers to the left indicate the presence of hydrocarbons and numbers to the right indicate water-bearing sand or shale. Density and neutron porosity are overlaid, thus if a density drop is recorded it can be matched with an increase in porosity, a characteristic of a reservoir. The V-shale (volume of shale) curve in blue is overlaid with bulk density in brown, shale; a type of non-porous rock is not found within a reservoir but is commonly found above and below acting as a containing barrier. A drop in the shale reading will usually coincide with a measured density decrease indicating possible reservoir environment. Gassmann density, compressional and shear velocities are described above.

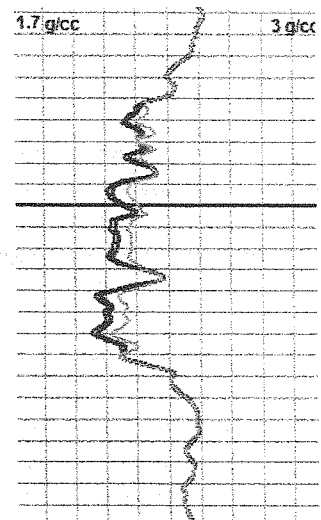


Figure 2 – Gassmann Substituted Density Log

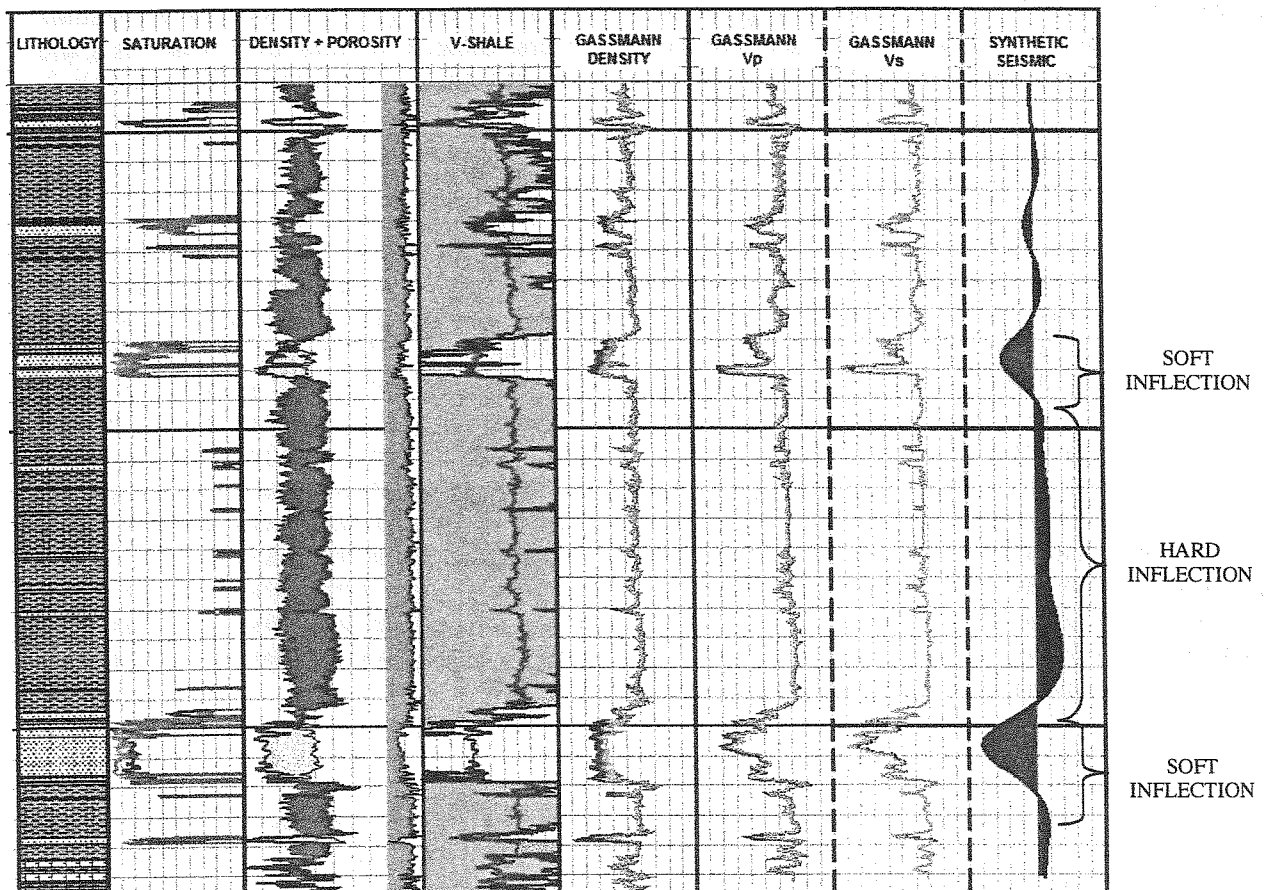


Figure 3 – Geolog Layout, including synthetic seismic curve

The synthetic seismic curve (the far right curve in figure 3) shows 'red' soft inflections (left of the middle) corresponding to hydrocarbon bearing sands as this is where the acoustic impedance contrast will be greatest. The larger the 'soft' inflection the greater the contrast between acoustic properties and consequently, this should correspond to a stronger reflection on an actual seismic survey. For example a gas filled sandstone and a shale formation, have extremely different acoustic properties, a seismic pulse which hit the interface would result in a sizeable reflection. If instead the sandstone was saturated with brine the acoustic properties would be different but not to the extent of a gas filled sandstone, resulting in a smaller reflection and a 'soft' inflection. The synthetic seismic curves are used for seismic-to-well ties to clarify actual seismic measurements which have accompanying noise and variation.

### **3 Module Construction and Implementation**

In this project, the most recent density and compressional velocity fluid property models for gas, oil and brine were implemented into Geolog 6.6 along with developing and coding new supporting modules. Some already working modules were also amended to allow for a different type of inputs.

#### **3.1 Fluid Property Modules**

Density and compressional velocity models for each fluid range from the simple ideal gas model to the complex equations of Batzle and Wang (1992). The Batzle and Wang models were further amended by the confidential HARC Fluids Consortium. The improvement included fitting the numerical models to an international data set and extending the valid range of the data, which resulted in the creation of the Flag 4.0 spreadsheets (these new models have not been published but are available to consortium members via the Flag 4.0 program). WEL Petrophysicists previously utilized these spreadsheets due to their high accuracy and the lack of the equations within Geolog 6.6. Consequently a separate program was required which decreased efficiency due to the need to transfer of data and the software licence contributed an additional expense. The Batzle and Wang models do exist in Geolog 6.6 as standard modules coded by Paradigm, however they are considered more difficult to use than the Flag 4.0 spreadsheets. The chief aim for this project was to implement the user friendly HARC models in Geolog 6.6.

##### **3.1.1 Gas**

The gaseous phase is the easiest to characterize as the molecules (methane, ethane, propane etc.) are relative simple and have well documented thermodynamic properties. Mixtures of gases are characterized by the specific gravity: the ratio of gas density to the density of air at 15°C. Common values range from 0.56 for pure Methane to 1.8 for gases with heavy components. The HARC model utilizes an improved model of van der Waals equation of state (1910), where the constants  $a$ , the attraction parameter and  $b$ , the volume dependent parameter are not calculated directly from the mixture's pseudocritical point. Instead the parameters  $a$  and  $b$  are numerically by fitting experimental pressure data a function of specific gravity and temperature. The results have proved quite accurate in gas density calculations. For compressional velocity the thermodynamic between it, density and bulk modulus is used. Unlike the model for density, the velocity equations show several percent error when compared to direct measurements for methane at reservoir conditions. This is due to the small error in density being amplified. However it is sufficiently accurate for Petrophysics applications and has the advantage of applicability to a wide range of compositions.

##### **3.1.2 Oil**

Crude oil found in a reservoir is a complex mixture of organic compounds, ranging from light – low carbon number – fluids through to heavy tars. Adding to the complexity of modelling oils is the characteristic of light oils to absorb significant quantities of hydrocarbon gas. Common

values of oil density range from 0.5 g/cc to 1 g/cc at room temperature, averaging at 0.7 g/cc. Oil acoustic models require inputs of room temperature (15.6°C) density, the gas-oil-ratio and the gas specific gravity; this information is readily available from standard laboratory fluid analysis. The HARC oil density model adopts the apparent fluid density calculation of Standing (1951) then follows the McCain (1973) live oil corrections for temperature and pressure. The velocity model is a complex function of pseudo liquid density published by Wang (1988) modified by fitting the international data set. Away from phase boundaries fluid properties are generally quite linear with pressure and temperature, thus this procedure yields acceptable estimates of density and velocity. Clarke (1992) demonstrated how live oils with high GOR can produce dramatic responses in sonic logs indicating that analysis based on dead oil or inaccurate GOR can be highly inaccurate. Ultimately however, these models are sufficiently accurate if pressure and temperature data is within specified boundaries and accurate modelling data is used (this is especially crucial for GOR figures).

### **3.1.3 Brine**

Saline water, primarily known as brine is the most common of the three pore fluids. Compositions can range from almost pure water to a fully saturated saline solution. The HARC models mirror the Batzle and Wang (1992) polynomials. For density these equations were derived from Keenen et al (1969) and property calculations of Helgson and Kirkham (1974) which are both for pure water. They were then extended to incorporate saline solutions by using the polynomial function of volume and a compressibility developed by Rowe and Chou (1970) which is over a limited temperature range, together with the sodium chloride solution density data published by Zarembo and Federov (1975) and Potter and Brown (1977). Acoustic properties of saline solutions have been extensively documented at conditions found in the ocean. Batzle and Wang discuss three different methods of calculating compressional velocity figures by extrapolation of ocean conditions and incorporation of salinity data. The HARC model for velocity is based on the third model published by Chen et al. (1978); however the coefficients were modified first by Batzle and Wang then again by HARC. The error in the density and compressional velocity calculations for brine are minor unless other mineral salts are present. Given that brine almost always contains other minerals this results in a considerable error. Nevertheless this model is still widely used due to its computational simplicity and the lack of other widely applicable models for high temperature, pressure and widely variable salinity.

## **3.2 Supporting and Amended Modules**

The implementation of the fluid property modules in Geolog 6.6 required the amending of subsequent modules and creation of new preceding modules. The fluid property modules require inputs of formation temperature and pressure, which were not previously contained in a consecutive frame log format. Although constant values can be used, a more accurate approach is to create a set of values to model the variation in temperature and pressure down the well. Modules were created to compose logs for formation temperature and pressure from field trend data and named to be consistent with the fluid property modules. The output from the fluid property modules are in log format however the inputs for the Invasion correction and Gassmann modules are set to constant values. Both modules needed to be coded to allow for log input whilst remaining able to accept constant inputs if required. The Invasion correction and Gassmann Modules were copied, amended and uploaded with the original creators' permission.

## **4 Review of Fluid Models**

To supplement the implementation of the fluid property modules a study was completed into the effect of employing the HARC modules as opposed to the original Batzle and Wang modules. The study was further developed by evaluating the end effect, where a variation in the fluid density and velocity figures carried through to creation of a synthetic seismic curve.

#### 4.1 Batzle and Wang comparison

The new modules were run for testing using a range of values within the model boundaries. A set of median values were chosen to test the Batzle and Wang Geolog Modules. The difference in the values stemmed from the difference in the coefficients, which were altered by the HARC Fluids Consortium. The result being a variation of less than five percent difference in any values tested and with all brine figures within one percent discrepancy. These results question the necessity of implementing the HARC models, however these new modules have been deemed slightly more accurate and tailored in Geolog specifically for WEL's use.

#### 4.2 Variation in Synthetic Seismic Curves

The variation in the synthetic seismic curve was tested in three methods. Firstly the new fluid property logs were run and compared to the synthetic seismic curves created from the original constant fluid property inputs. Then the fluid properties were varied by ten to twenty percent to determine whether this would be carried over or amplified in the synthetics. Finally formation conditions from a Miocene layer (2500m) were applied to a Cretaceous layer (3500m) to alter fluid properties and possibly synthetics. All three evaluations gave very similar results, the seismic reflected very little of the variation seen the fluid property figures. The greatest difference was two percent at the maximum value on a soft inflection, this occurred in the second test from which the fluid properties were varied up to twenty percent. The reason for the low transfer of variation is found in the Gassmann Substitution algorithm, where the rock matrix properties are key and dominate the result. The use of the fluid property modules is justified, as correct analysis procedure must be adhered to and it does improve calculation accuracy, albeit minimally.

### 5 Conclusions

This project has been successfully completed: current fluid property modules have been coded into Geolog 6.6 and developed for enhanced useability. The best practices and limits to the modules accuracy have been documented and the overall sensitivity has been briefly evaluated. The new modules do away with the need for the HARC Flag 4.0 spreadsheets and seen that fluid property evaluation is now fully integrated into the petrophysical workflow processes. Efficiency has thus been improved in this part of the Petrophysics process. The accompanying study has shown the precision and level of importance for using fluid property models however a more in-depth study is recommended.

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