



Hydrocarbon Fluid Wave and it's resonance

G.K. Batta*, D.S. Manral, G.V.J. Rao, and S.K. Basha, Oil India limited, India

gnangp@gmail.com

Keywords

Hydrocarbon fluid wave, seismic acoustic impedance, law of inertia, law of conservation of energy and resonance in physics

Summary

The observation of hydrocarbon fluid wave over subsurface fractured hydrocarbon porous rock at low frequency (2-4 Hz) is main subject of our discussion. The theory of seismic wave propagation cannot explain this phenomena well enough. We develop a theory for possibility of hydrocarbon fluid wave from multi-fluid filled fractured subsurface porous rock where multi-fluids are being associated with abnormal high pressure zones. It has low frequency, low velocity and high amplitude in character. Results of the theoretical research corresponds to the data of field experiment.

Introduction

If any seismic energy applied on fluid free or water saturated subsurface porous rock, it spreads out as body waves and gets reflected, refracted and transmitted. It is also similar case with subsurface fractured porous rock filled with gas, oil and water, but not the same. It is also associating with hydrocarbon fluid wave, as multi low density fluids in fractured porous rock are subjected to relatively high pore pressures. In this paper, technical content is associating with key fundamentals in physics and rock physics.

Theory

Hydrocarbon fluid wave is a fluid generated seismic wave in the subsurface porous rock formations as per **law of inertia** in physics. This is possible due to following fundamentals that are associating with subsurface oil and gas deposits in porous rock.

- Low density and low acoustic velocity of hydrocarbon fluid media at subsurface rock fractures or faults
- Fluids have potential energy due to gravity

- Naturally existing forces (surface tensions) along the fluid contacts.
- Fluids are subjected to high pore pressures
- Seismic energy trapping mechanism due to low acoustic impedance.
- System stored vibrational seismic energy leads to move the low density fluid media under resonant mode. It tends to produce oscillations or generate waves along fluid contacts in fractures which is known as **interfacial waves or surface types of waves**.

Principle

If seismic wave (earthquake, manmade earthquake etc-seismic body wave) passing through multi-fluid phase (gas, oil and water) porous rock, a maximum part of seismic energy trapped in pure gas and oil fluid media in subsurface fractures due to its key physical property of *low acoustic impedance* or *high acoustic impedance contrast* to the surrounding host rock (see Figure-01). Trapped seismic energy in pure gas and oil media at subsurface fractures or faults acts as system stored vibrational energy and leads to motion of fluid contacts under resonant mode. Therefore, resonant motion of multi - low density fluids (gas or oil) in subsurface fractures at high pore pressure generates fluid pressure wave due fluid coupling with surrounding host rock and can be named as **resonant hydrocarbon fluid wave**. Natural frequency of resonant hydrocarbon fluid wave depends on restoring force constant of hydrocarbon fluids. It's velocity depends on total fluid pressure-potential energy.

Frequency of hydrocarbon fluid wave

The following basic physical concept helps to estimate frequency of hydrocarbon fluid wave. As per classical physics, time period of any oscillator of mass (M), in the state of resonance is given by

Hydrocarbon Fluid wave and it's resonance

$$T = 2\pi / \omega'' = 2\pi \sqrt{M/K} \quad (1)$$

$$\text{or} \\ \omega'' = \sqrt{K/M} \quad (2)$$

Resonant frequency or natural frequency of unit mass $\omega'' = \sqrt{K}$, where K = Restoring force constant that follows the force equation and responsible for harmonic motion.

As per oscillation theory in Physics, there is an expression of "Time period of oscillations of a frictionless piston of a cylinder filled with gas" and is given below

$$T = 2\pi \sqrt{MV / \gamma PA^2} \quad (3)$$

where M is mass of gas, P is atmospheric pressure, γ is adiabatic constant, (C_p/C_v) , A is cross sectional area of piston, V=volume of gas, C_p is specific heat of gas at constant pressure and C_v is specific heat of gas at constant volume.

From equation (1) and (2),

$$K = \gamma PA^2/V \quad (4)$$

The gas constant occurs in the ideal gas law, as follows

$$PV = nRT \quad (5)$$

Where P is the absolute pressure (SI units Pascal), V is the volume of gas (SI units cubic meters), n is the chemical amount of gas (SI units mole), T is the thermodynamic temperature (SI units kelvin) and R is Universal gas constant (8.314 J/mol-K)

$$PV = RT \text{ (For unit mole and unit temperature)} \quad (6)$$

$$P = R/V \quad (7)$$

From equation (4) and (7),

$$K = \gamma R(A^2/V^2) \quad (8)$$

Therefore, restoring force constant for unit area, unit volume of ideal gas and unit or constant thermodynamic temperature is given below

$$K = \gamma R \quad (9)$$

Restoring force constant of gases are varying from 11 to 13. For methane, it is 11. Resonant frequency (ω'') of methane per unit mass is square root of restoring force (K) constant for natural gas. Resonant frequency of methane gas, $\omega'' = \sqrt{K} = \sqrt{11.1} = 3.33$ Hz.

As per oscillation theory in Physics, there is an expression of Time period of oscillations of a test tube filled with low dense liquid on water and is given below

$$T = 2\pi \sqrt{m / Adg} \quad (11)$$

where d= density of liquid, A= radius of test tube.

From equation (1) and (11)

Restoring force constant of floating oil on water

$$K = Adg \\ = A(m/v)g \quad (12)$$

For unit area, unit volume and unit mass,

$$K = g \quad (13)$$

Free oscillations or natural oscillations of oil which float on water is mainly due to restoring force that equals to gravity. Natural frequency of oil which float on water is square root of restoring force constant per unit mass and unit area or volume is \sqrt{K} .

i.e., $\sqrt{K} = \sqrt{g} = \sqrt{9.8} = 3.13$ Hz.

Velocity of hydrocarbon fluid wave

It can be derived from **law of conservation of energy**. As per law of conservation of energy, total potential energy of fluids at high pore pressure when fluid is in rest equals to its kinetic energy when it is in motion.

$$mgh = mv^2/2 \text{ (or)}$$

$$v = \sqrt{2gh} \quad (14)$$

Where m is mass of fluids, v is velocity of resonant hydrocarbon fluid wave and h is fluid head or fluid height.

Fluid head can also be expressed in pressure and vice versa. For example, 1 psi equals to 0.703 meter head of water of density 1000 kg/m^3 or 0.782 meter head of oil of density 900 kg/m^3 .

Estimation of Fluid head at exiting high pore fluid pressure in porous rock formation depends on its porosity also. Higher the pressure potential energy of

fluid, higher the fluid head and vice versa. Higher the pressure potential energy, higher the fluid wave velocity at constant porosity.

Further, higher the porosity lower the fluid wave velocity and vice versa. It increases exponentially with increasing fluid head or pore pressure. Hydrocarbon fluid wave velocity in the subsurface porous rock depends on both porosity and pore pressure (see Figure-02).

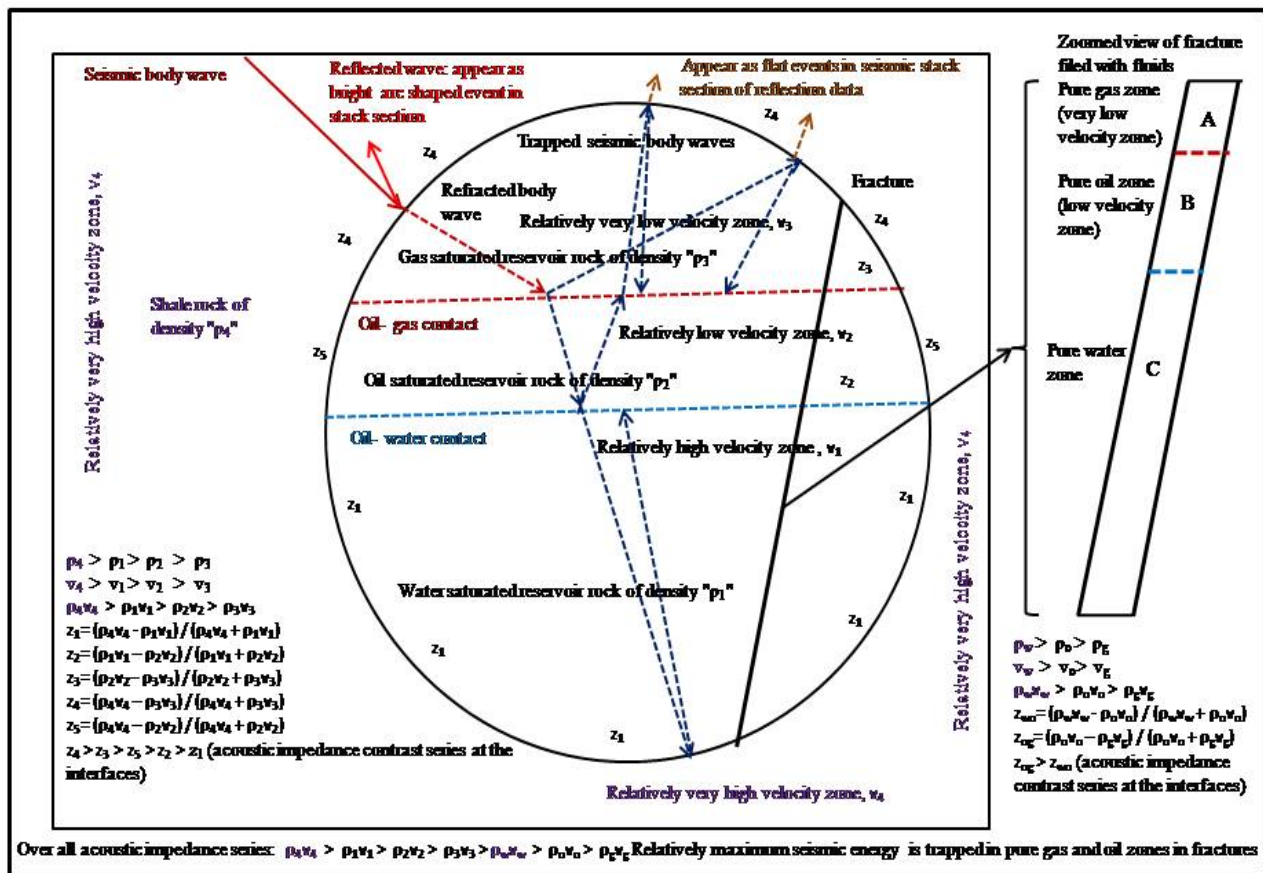


Figure-01. Vertical cross section of multi-fluid phase fractured spherical porous rock in impermeable shale rock. Note trapped seismic energy in porous rock trapped in the form of multi-reflections and refractions due to existing multi acoustic impedance contrasts.

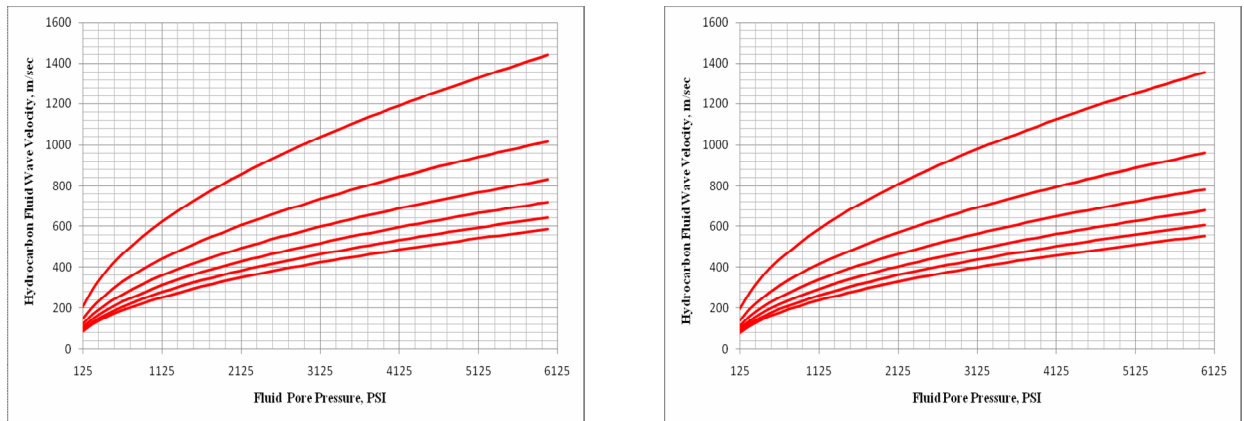


Figure-02: Theoretical hydrocarbon fluid wave velocity plots against fluid pore pressure in the subsurface porous rocks for two different densities of oil: 0.8 gm/cc (left) and 0.9 gm/cc (right).

Field Experiment evidence: Resonant hydrocarbon fluid wave is coming from subsurface oil and gas deposits in Oil India Limited's producing fields of Upper Assam in India. The phase of resonant hydrocarbon fluid wave or energy appears as quasi-hyperbolic events at late part of processed conventional seismic record after all primary waves are gone. It has low frequency spectral high signature at very close to 3 Hz. It's phase velocity so far noticed is varying from 300 m/s to 500 m/s. One of such evidence is shown in Figure-03.

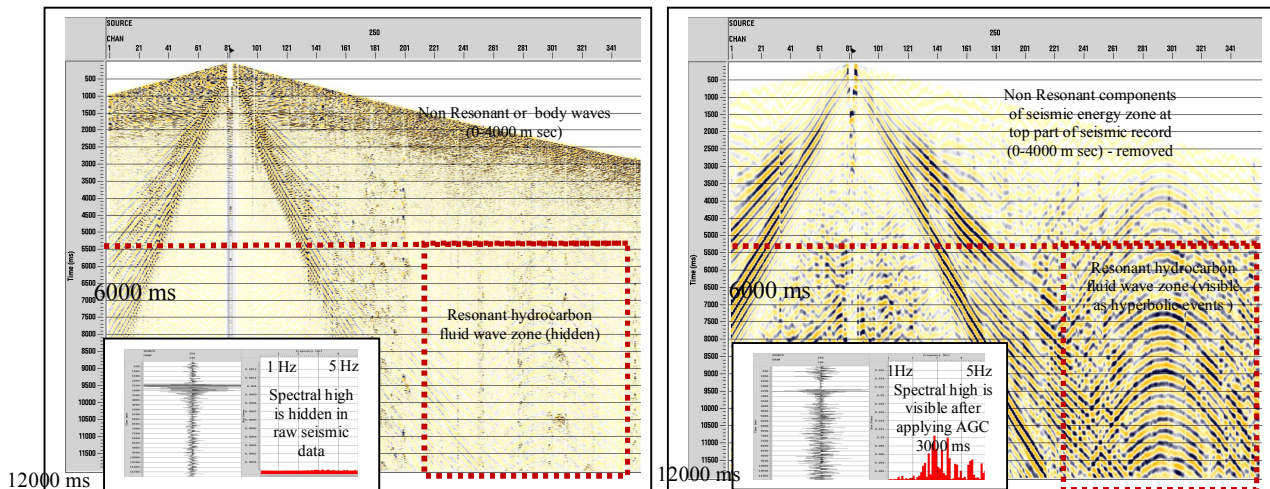


Figure-03. Raw seismic record contains multi-frequency multi level strong energy components that hidden the resonant fluid wave energy(left). Processed seismic record clearly shows the resonant fluid wave energy at late part of seismic record (right).

A few prospects are also identified in Moran area by using resonant energy analysis method in conventional seismic data and results are quite supported by established seismic reflection datasets. A geophysical note was generated and submitted to management to review the identified prospects. Further, Oil India Limited has filed an Indian patent application: 1211/KOL/2014 dated November 20, 2014, entitle as "An Apparatus and Resonant energy analysis method for active seismic operations". It was also published in official Journal of Indian Patent Office on 12.12.2014.

Laws of motion of fluid contacts in subsurface fractures or faults

Laws of motion of fluid contacts in subsurface fractures or faults are as similar as Newton's laws of motion in classical physics. Newton's laws of motion are laid the foundation for classical mechanics. They describe the relationship between a body and the forces acting on it, and its motion in response to said forces. Here, laws of motion of fluid contacts in subsurface fractures or faults are laid the foundation for fluid mechanics in subsurface rock fractures filled with multi-low density fluids. They describe the relationship between multi-low density fluids in fractures of subsurface rock and seismic energy acting upon it, and its fluids or fluid interface motion in response to said seismic energy.

First law : Multi-low density fluids in fractures of subsurface rock either remains at rest or continues to oscillate or move in vertical direction from its mean position, unless acted upon by an external seismic energy.

Second law: Total fluid force of multi-fluids in subsurface fractured porous rock acted on surrounding host rock is equal to rate of change of momentum of existing fluids.

Third law: As long as system stored vibrational seismic energy sustained in subsurface rock fractures filled with multi-fluids, natural oscillations of fluid contacts at fractures continues and leads to resonance phenomena.

Benefits

- Reduce the risk of drill dry well with integrated approach of available seismic datasets and well data.
- Play a very key role in place of seismic imaging challenges for improved accuracy in locating "paying quantities of hydrocarbon fluids"
- Fit for all geologic settings for identification of hydrocarbon prospects as it has low frequency (close to 3 Hz) which is in line with the basic

fundamental "Earth acts as low pass frequency filter".

- Estimation of Pore fluid pressure at hydrocarbon zones
- Reduce the present seismic exploration risk.

Recommendations

1. Seismic data shall be acquired with sufficient seismic record length in order to have both slow resonant fluid wave energy and fast reflected wave energy in seismic records.
2. Seismic data can be acquired with broad band sensors which have linear phase and amplitude responses from DC to higher end frequencies, if possible.

Conclusions

Hydrocarbon fluid wave is a fluid generated seismic wave in the subsurface porous rock formations as per application of **law of inertia** in physics. Theoretically, it has low frequency (close to 3 Hz) and low velocity in character. Therefore, they travel longer distances as earth acts as low pass frequency filter and expected to appear as hyperbolic events at late part of conventional seismic records after all primary waves are gone. Field data has also confirmed the same at hydrocarbon producing wells in Oil India Limited's operational areas of Upper Assam in India. Noticed Spectral high at around 3 Hz frequency and its phase velocity of 400 m/s meets the hydrocarbon pay zones. Utilization of hydrocarbon fluid wave in conventional seismic records is a value added opportunity and helps to get improved accuracy in locating "paying quantities of hydrocarbon fluids in the subsurface".

References

G K Batta, S.N.Singh, Oil India Limited, Listen to the melody of oil and gas from broad band seismic : IME Journal, June 20, 2014.

Indian patent application: 1211/KOL/2014 dated November 20, 2014, entitle as "An Apparatus and Resonant energy analysis method for active seismic

Hydrocarbon Fluid wave and it's resonance

operations" and Official Journal of Patent Office,
India-issue no. 50/2014, 13667

Fundamentals of Oscillation theory, Kinetic theory
of gases and Newton's laws of motion in Physics and
basic fundamental in rock physics.