IMPROVED DESCRIPTION AND MONITORING OF NEAR SURFACE HAZARDOUS INFILTRATE COMPLEXES BY SHEAR WAVES FOR EFFECTIVE CONTAINMENT RESPONSE

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Abstract

Among numerous causes of fluid releases and infiltration in near surface, resurgence in such anthropic activities associated with unconventional resource developments have brought about a resounding concern. Apart from the risk of an immediate chemical hazard, a long term possible recurrent geo-environmental risk since can also be envisaged as for various prevalent stake holders and broader initiatives. Urgency and exactness for spatiotemporal containment and remediation promotes the devising of efficient methods for monitoring near subsurface flow complexes caused by such spills. Swave (Shear waves) spectral imaging results, in relevant context, of a controlled immiscible fluid displacement monitoring experimental study are analysed and inferred. Against the prospective method as well evaluated, Swave diffraction associated spectral peculiarities are examined, importantly, given background medium characteristics definitions invoking fresh insights of microscale significance alongside macroscale potential.

Key words: Shear wave monitoring, geohydrological characterization, spill flows assessment

1 INTRODUCTION

Swave spectral analyses based extended results of a controlled immiscible fluid displacement monitoring study are inferred offering fresh insights, being central to the exposition of presented work. It is motivated or invoked especially by frequent occurrences of near surface fluid releases and infiltrating spills hazards, recently, predominantly of geohydrological and geotechnical consequences. Swave ultrasonic spectral peculiarities affected by wave diffraction and interference associated resonance are examined given background medium characteristics/definitions. Three experimental tests, distinct in time, with three different invasive flow rates, are evaluated where oil is displaced by brine through a vertical cylindrical granular sediment analogue. In the observed or resultant ultrasonic spectra acquired or generated at single fixed point, precisely two resonance spectral peaks are revealed repeatedly, marked by an amplitude and frequency shift in time, in each of three displacement tests. The spectral characteristics with direct observations enable isolating different fluid phases, separately. A well-defined repeated specific pattern of frequency dependence due to a viscosity and density complex and associated amplitude effects is consistently observed in spectral results of all testes, further discussed in detail in next sections.

Hazards associated with aqueous and/or non-aqueous toxic fluid-releases into near surface include environmental, geotechnical and geohydrological effects. The effects both exact and promote an improved and efficient monitoring for the source and sink given resource potential, and coexist in broad but inevitable sense. The potential of acoustic and electrical methods among non-destructive geophysical methods in assisting prevention and mitigation is well identified and established, also examined in a precursor of the presented work [1]. Usefulness of Swaves in comparison to that of acoustic methods in imaging the near surface for geoenvironmental investigations is not well appreciated and/or studied in comparison though. Acoustic probing can definitely offer ample information regarding the near surface structure, saturation state or the condition and competence of associated surrounding strata or sediments. Further, monitoring the variations in all these elements over time by applying appropriate strategies of survey design, no longer remains a remote possibility, referred more usually to as time lapse. Swave probing may, however, offer more distinctive information either alone or in an integrated setting. Swave contribution to the overall data could not only be of an added resolution and/or additional information making over all data more reliable, but assume the capacity to offer insights for identifying or examining new phenomena or contributory aspects thereof. The much foreseen effectiveness of Swaves is attributed to their mode of propagation and manner of interactions with the medium propagated through, in terms of "seeing" and/or sampling of a phenomenon. Unlike Pwaves, Swaves are capable

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of sampling the medium along and transverse to the ray path simultaneously, with many possibilities of particle polarization corresponding geometry and possible orientations of source. Phenomenologically, thus they retain or preserve more information and also encode the information to translated or acquired reconstructed signals and associated spectra differently. Apart from that, their slow velocity and relatively smaller wavelengths, for usual Pwave comparable bandwidths, make them more sensitive to subtle subsurface anomalies, in addition. Such characteristics translate to better illumination and resolution simultaneously, desired specifically in architecturally demanding and structurally complex situations. Such instances typically include achieving an efficacious response, much required, in dealing with contaminating or toxic fluid release infiltration hazards. Apart from the added advantage of improved resolution in general, Swave data may add significant quality to any kind of a corresponding legacy data subset for a corroborated re-evaluation.

Swave spectral analyses based extended results of a controlled immiscible fluid displacement monitoring study are inferred offering fresh insights, being central to the exposition of presented work. It is motivated or invoked especially by frequent occurrences of near surface fluid releases and infiltrating spills hazards, recently, predominantly of geohydrological and geotechnical consequences. Swave ultrasonic spectral peculiarities affected by wave diffraction and interference associated resonance are examined given background medium characteristics/definitions. Three experimental tests, distinct in time, with three different invasive flow rates, are evaluated where oil is displaced by brine through a vertical cylindrical granular sediment analogue. In the observed or resultant ultrasonic spectra acquired or generated at single fixed point, precisely two resonance spectral peaks are revealed repeatedly, marked by amplitude and frequency shift in time, in each of three displacement tests. Spectral characteristics with direct observation enable isolate different fluid phases, separately. A well-defined repeated specific pattern of frequency dependence due to density and viscosity complex and associated amplitude effects is consistently observed in spectral results of all testes, further discussed in detail in next sections.

2 MATERIALS AND METHODS

A clear and more compelling appreciation of the presented results is strictly contingent upon understanding of the functioning and arrangements of the apparatus components as interconnected in a laboratory setup. The results constitute a part of broader study performed to investigate into a better monitoring and/or mapping of near subsurface flows through unconsolidated sediments and/or porous media by applying integrated data acquisition strategies as indicated earlier. Near subsurface, the flows of non-aqueous and aqueous solvents may be monitored for occurrence of variety of causes, whether they are human induced or natural, owing to prevalent global geo-environmental concerns. In this regard, for assuming a practical relevance of the experimental process, an immiscible fluid displacement is imitated. Oil is displaced by brine solution against gravity to create and "image" most morphologies of practical interest, with variation of character, e.g., pure fractions, interfaces development/evolution, while the fluids body flows through an unconsolidated granular column comparable to the sediments core of porous medium. The core consisted of 0.5 mm spherical soda lime beads or grains packed in a 45 cm x 5.09 cm transparent PVC tube of a circular inner cross section, forming a flow cell system. The granular pack in flow cell could be sufficiently stressed using axially manoeuvrable end pieces at the bottom and the top by tension rods, anchored vertically into an adjustable aluminium base plate with isolation dampers. The displacement process in laboratory was affected by initially evacuating air and saturating the core analogue with oil. The oil was then displaced by brine under constant head flow conditions assisted with a flow control system driven and powered externally. Swave ultrasonic sensors, a source and receiver pair, were attached diametrically facing at the middle of the flow cell analogue tube. This arrangement allowed sufficient time for a flow type or process, after being initiated at the flow cell bottom, to fully develop and stabilize before repeatedly imaged by pulse transmission at single point mid span. The sequential imaging at sufficiently high temporal rate, therefore, was aimed at capturing all possible effects of an initial oil flow through the sediment, followed by a possible abstracted interface phenomenon, and displaced finally by a pure brine flow.

To facilitate the comprehension of the examination and evaluation of the presented graphical results for inferring, the events were identified alphabetically in the same order in which they were imaged in time. In the three experimental tests performed, three different invading flow rates were, in sequence of 4 L/d, 55 L/d, and 10 L/d (i.e., 0.044 ml/s, 0.64 ml/s, and 0.11 ml/s) for Test 1, Test 2 and Test 3, respectively, measured downstream. Such slower flow rates were chosen respectively to provide a sufficiently resolvable range of spread of measurement without violating the subsurface flow regime conditions. The details of the apparatus concept and functioning and data presentation could be understood from schematics and illustrations provided in [1, 2], of which illustrations relevant to exposition are shown in Fig 1.

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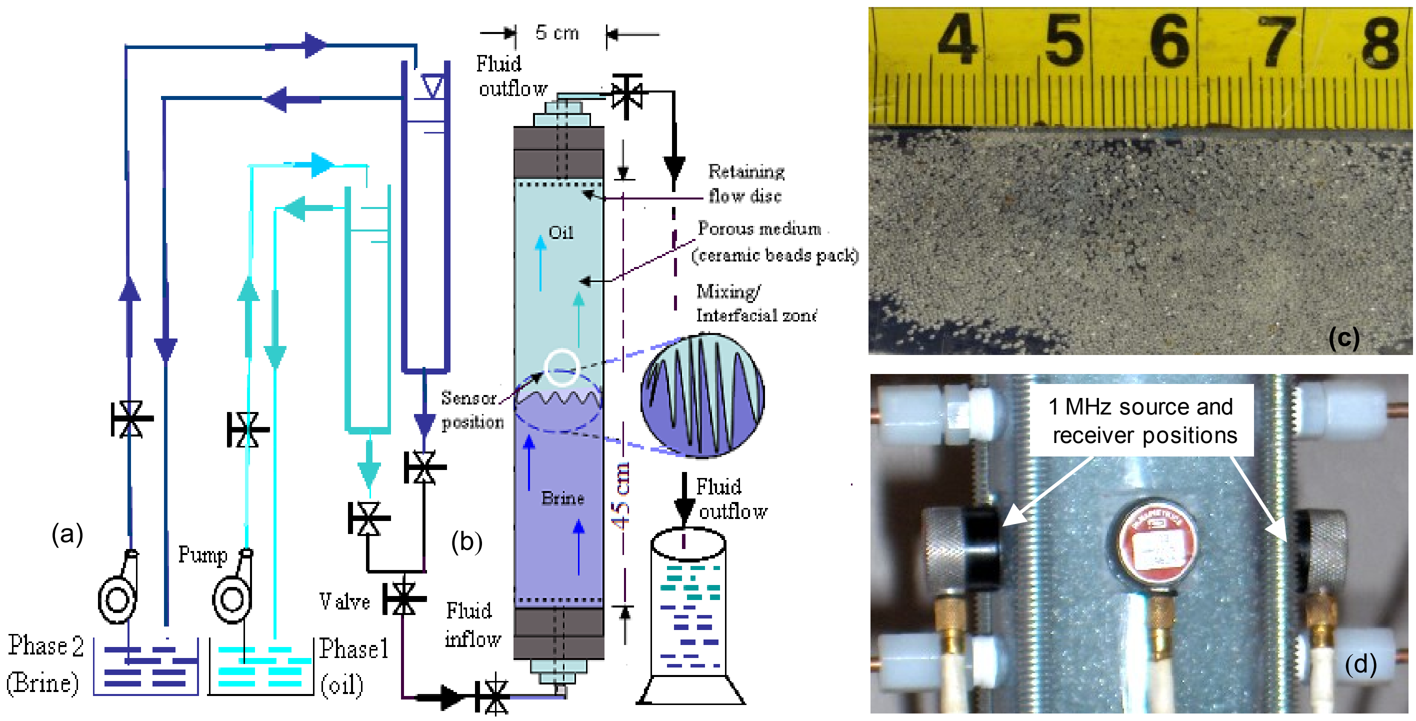

Fig. 1 Experimental configuration schematic and constituents: (a) Flow control system. (b) Flow cell containing unconsolidated sediment core analogue made of transparent PVC tube. (c) Snapshot of spherical ceramic beads or grains forming unconsolidated sediment core. (d) Snapshot of section of the flow cell showing through transmission measurement configuration using a I MHz SWave sensors midspan, with other sensors integrated, as marked on (b).

3 PERTINENT THEORY

In interpreting transmitted ultrasonic elastic wave response through a real or simulated model sediment either dry or saturated, understanding and knowledge of the properties of the arbitrary granular medium or background matrix are important, for qualifying any extended inferring. In such studies, at usual laboratory scales, delimiting aspects to interpretation are: type and relative size of confining geometry, degree of confinement, constancy of confining agent or force, nature and possible number of intergranular surface contacts in relation to grain material properties. Such factors as combined may add a complexity towards understanding and predicting the overall material behaviour. For brevity thus, the presentation of cumbersome mathematical details is avoided against an effort in the description of tentatively precise and relevant exposition of references only to facilitate the assimilation of results illustrated graphically, as such preferably without digressing from the examination of the presented situation. In assigning physical terms to theoretical delimitations, all the spherical beads or grains constituting the pack or granular analogue are assumed to be equally spherical with maximum elastic contact with each other, following mechanics of regular arrays and discrete particles. Such assumptions allow compliance, for instance, with the conditions of the Hertz theory confined within exact regimes for an overall oscillatory / dynamic behaviour analysis of granular media. Usefulness of such ideal model is mathematically well illustrated by [3]. The model [3] is necessarily a saturated cubic one capable of the description of both Pwave and Swave, where the plausibility of the model assumptions was observed held in terms of offering reasonably matched comparison of previously published predictions consistent with the similar theory, to those associated with and prior ones included in this study. The model with notions of underlying theory is of distinct salience regarding the ensuing description of analyses, especially. Since, further, certain peculiar observations in the ultrasonic Swaves acquired spectra differ in nature of character compared to those obtained for the concurrent Pwaves stimulated ones which were reported previously in [2].The Pwave spectra were demonstrable and explainable with usual and rather basic wave propagation models and/or understandings of elastic wave attenuation mechanisms for the reconciliatory description of the immiscible fluid displacement process against the consideration of an elapsed time, as the variability of spectral constituents in intensity was proportionate, in Debye model linearity type scaling sense, further discussion of which is rendered out of scope of the exposition.

Other theoretical considerations central to the lucidity of exposition of the results, owing to the same basic model, include the possibility of a change in the nature of the area of the intergranular contacts during the transmission of the elastic wave. In addition, the existence of a viscosity associated incompressible and rotational saturant boundary layer on the beads or grains, too adding to the effective diameter besides a non-rotational but viscous part. In this regard, given the context, [4, 5], while theoretically examining the wave propagation through a saturated unconsolidated granular medium (i.e., marine sediments), have specifically referred, taking also frequency dependence into account, when effects of intergranular friction and shearing find consideration. Apart from the intrinsic thermodynamics of the wave phenomenon where the attenuation is due to frictional heat loss, appreciating the effective attenuation exacts the consideration of amplitude loss caused by scattering from anomalies. The anomalies may arise or evolve due to the existence of inhomogeneities of the fluid lattice complex and lattice fragmentation during the wave propagation associated response. In [4], especially such aspects as micro events of stick slip type relaxation against dynamically accumulated strain in the presence of a saturant in addition to inter granular friction are more acutely elaborated upon. The association of such micro events with a frequency dependent viscous strain hardening is also explicitly identified by drawing its implications upon either holding with or transiting from the Navier-Stokes regime.

In order to render the understanding of the relatively involved concepts, simpler models discussed by [6,7] could be referred to regarding properties of the medium types in question or discussed, at this juncture. As contrary to the Hookean elastic model, which could suffice for the strength description of some earth materials, saturated sediments do not follow that linear model as implied before,for they fall into an anelastic viscoelastic regime. Due to the physical elastic properties empirically related to the measured dynamic response as formulations, viscoelastic models have to be conceptualized to arrive at such desired solutions. In this regard Kelvin, Voigt, Maxwell, Linear solid or Zener models are examples of few simpler models. Suitable combinations of these models could simulate materials with "viscoelastic properties" with time rate dependences and restrictions of structural and stimulation periodicity. Such models are thus capable of describing the material behaviour both in terms of strength related moduli and in attenuation characteristics sense. Attention as a cautioned inquiry of the appropriateness of descriptive capabilities of wave propagation models, also, is drawn by [8] by comparing grain shearing effects and a proposed viscous grain shearing model. While making a special mention of viscous effects with associated time dependencies, a further conceptual modification of such viscoelastic models is suggested and/or demonstrated by incorporating suitable elements. While transiting from low towards high frequency stimulations, saturated granular media may in response give rise to a complicated phenomenon. Where, still, certain attenuation or amplitude loss mechanisms may better be understood and approximated by considering aspects of ray based approach. The complexity evolves much further where S-waves are involved due to forward and/or backward scattering, mode conversions and ensuing interference. Interference effects hold importance in inferring received or reconstructed response signals especially where there could be a discontinuity associated scale dependence, affecting resonance conditions.

Given the discontinuity associated Swave scattering and interference effects, [9] has provided relevant accounts for understanding conditions for such phenomena to occur in a generic sense, though with sufficient specificity by addressing the issue of scattering caused by a spherical discontinuity. Particular cases when a scatterer is a cavity, a rigid sphere, a fluid-filled cavity, and an elastic material having acoustic properties different from those of the surrounding medium are sufficiently thoroughly analysed. Numerical experiments of [10] could also be cited for investigating the occurrence of the scattering phenomenon while evaluating solid elastic materials with solid inclusions. Their study is comparable to that of [9], as their analytical formulations for numerical experiments conceptually were similar. In their work, however, focus is reported on the case of the scattering of a transverse wave from a spherical elastic inhomogeneity or scatterer explicitly. Their findings clearly suggest the occurrence of resonance in observable spectra with further deducible insight that the scale dependence of Swave regarding resonance is of different kind than that of Pwave. The resonance phenomenon with assigning its possible significance to non-destructive evaluations in geological and non-geological engineering materials with focus on Swave propagation and transmission has been detailed and explained by [11]. The occurrence of resonance due to incidence and/or transmission Swave caused by idealized spherical fluid filled cavities (i.e., water), is examined and discussed, in a theoretical context. Scattering and interfering amplitudes are shown to exhibit the resonance fixed and scaled by frequency and scatterer and/or anomaly size. It is thus made evident that the Swave transmission, through granular media, of associated resonance spectra, not well appreciable through ray theory, is well observable as a phenomenon. Its extended prospects had been duly and rather readily appreciated, too, as [12] foresaw its usefulness primarily at laboratory scale involving non-destructive testing or evaluation of materials and/or compositions and medical diagnostics. While [13] viewed more promise in seismological and planetary and interplanetary related surface and subsurface studies. It, therefore, is well envisioned that the application to inferring and characterizations involving geo-environmental studies is not excluded. For a physical sense of parameters and their phenomenological control introduced into the examined process, important physical properties of the constituents of the unconsolidated sediment analogue in the fluid displacement study are provided in Table 1.

Tab. 1 Properties of constituents of the porous unconsolidated core analogue

No.	Property	Value	Units
1.	Bead/grain material density	2.6	sp. gravity
2.	Brine salinity	3.5	w/v %
3.	Brine density (displacing fluid phase)	1.026	sp. gravity
4.	Brine viscosity	1.3	cP
5.	Ceramic glass bead/grain dia.	0.5	mm
6.	Mineral oil density (displaced fluid phase)	0.76	sp. gravity
7.	Mineral oil viscosity	10	cP
8.	Porosity of granular pack	26	v/v %

4 DISCUSSION OF ILLUSTRATED RESULTS

The inferred results in the ensuing discussion are of twofold significance. Firstly, an adequate identification and descriptive analyses of the spectral features on scientific grounds and theory as explained above, and secondly imparting the features a practical geoenvironmental import in inferring given parameters. The Swave spectral results characterizing various instances of fluid displacement process in the context of the exposition, to recall, are marked with nonlinearity. They appear to be of a resonant type when considering amplitude and frequency shifts, and transmitted against received bandwidths in comparison to those for Pwaves, the detail could be sought for and understood from [14,15], further, in relation or with respect to delimitations of [2]. The graphically mapped events are presented alphabetically in the same temporal order as ultrasonically imaged and grouped further as the earliest, intermediate and the latest, to discriminate and specify a possible direct association with the flow of oil, an interface or eventual brine saturation, respectively. The graphical illustrations of spectral curves for all the experiments, corresponding to similar events/phenomena by definition, were distinctively colour coded and kept consistent, for maintaining relevance in all the presented analyses. The presented illustrations as graphical series allow each graph to be readily examinable self-contained alone while maintaining a meaningful comparative examinability for each and among all results.

Fig. 2 provides the details of spectral characteristics of transmitted and received bandwidths as standard bounds specific to interpretation. Fig. 2a and Fig. 2b show an ultrasonic source spectrum and a standard aluminium spectrum, respectively. The standard aluminium spectrum of Fig. 2b is a consequence of the spectrum of Fig. 2a transmitted as input through an aluminium sample of the same dimensions and geometry as unconsolidated granular sediment analogue core without altering ultrasonic source and receiver settings. This was done to examine the contribution of geometrical and/or stationary type spectral effects compared to the overall granular background habit. Fig. 2c is a typical time irrespective windowed Swave acquired or received signal trace for the pulse of Fig.2a transmitted through a dry granular medium. Fig.2d is the spectrum of signal shown in Fig 2c, clarifying that the signal distortion due to geometrical effects is insignificant, as it enables to comprehend the dry medium control of transmitted spectral characteristics. Figure 2 thus reasonably suffices or provides to understand the static characteristics of the background in relation to the spectra associated with the dynamics of the fluid displacement process, basic features of which are presented in Fig. 3 in the manner alluded to. Fig 3 depicts, given the explanation of Fig. 2, the fundamental spectral features of fluid displacement process as imaged, represented isolated in temporal sequence, as also shown in the heading identifier of each panel figure. The spectral curves are picked from a well examined subset of curves corresponding to Test 1. Fig 3a and Fig 3b show the spectra corresponding to the initial oil phase flow and the onset of an interfacial mixed zone, respectively. Fig 3c shows the spectrum of possible mixed zone evolution and a fingering type phenomenon while Fig 3d shows that of final brineflow with residual effects. Apart from a broad understandable process instance and the prominent/identified features association in each spectrum of Fig 3, they are also shown typified in each panel figure, where their significance would be automatically brought to attention with progressing discussion.

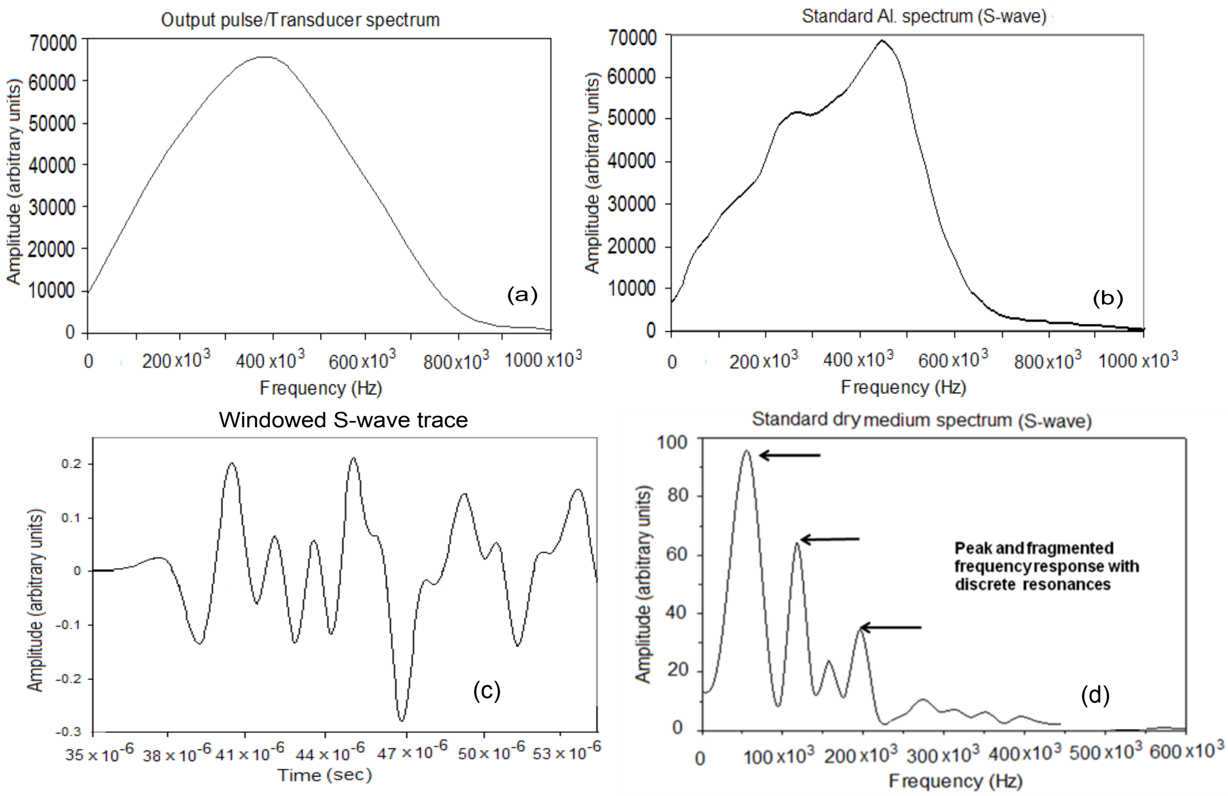

Fig. 2 Standard signals to facilitate detailed (FFT based) spectral analyses: (a) Swave sensor or transducer output s as source spectrum. (b) A standard aluminium transmitted spectrum. (c) Time irrespective windowed acquired trace. (d) Dry granular medium spectrum.

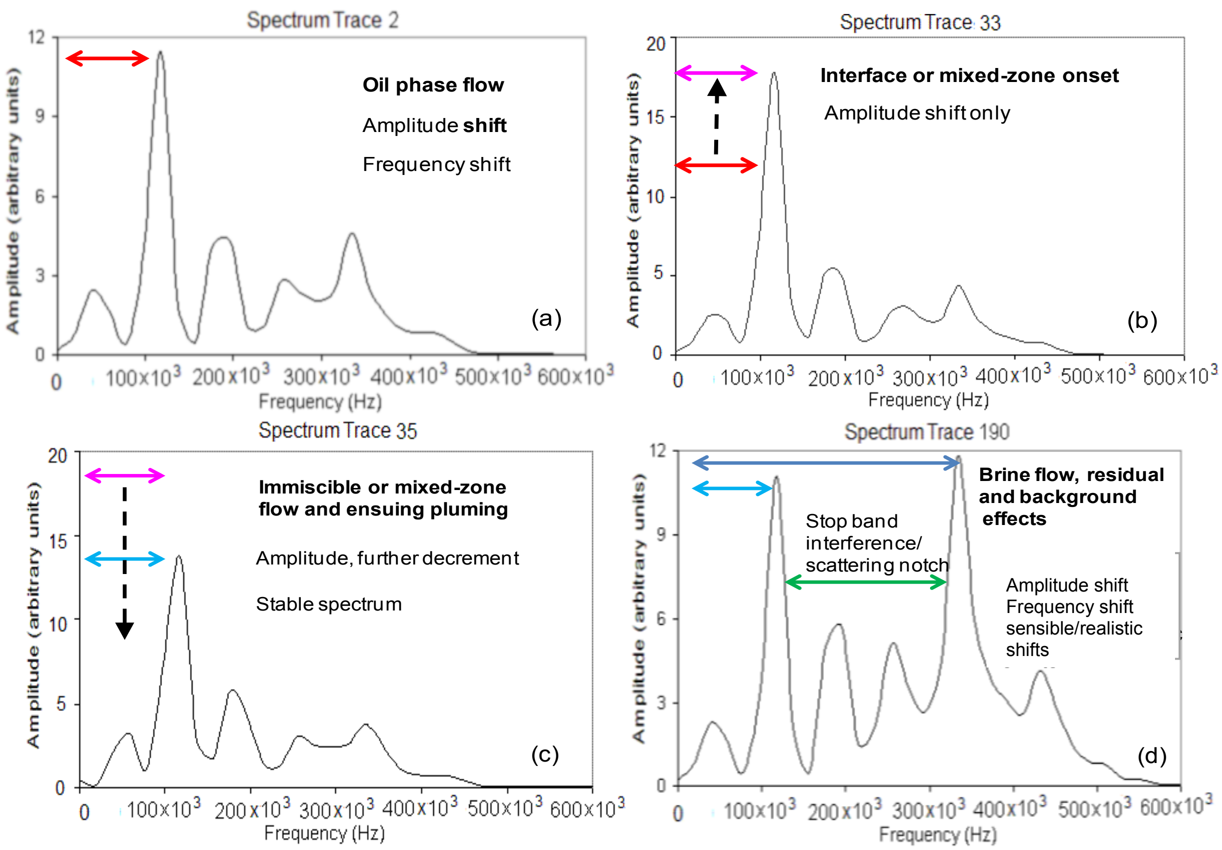

Fig.3 Sequentially picked (FFT), typified, spectra corresponding to different phases of immiscible displacement experiment Test 1 to demonstrate nature of consistent frequency and amplitude shifts observed in all tests.

Based on the description thus far, Fig. 4 through Fig 6 depict the Swave acquired response associated with the Test 1, Test 2 and Test 3, respectively. The panels a of each of Fig 4 through Fig 6 correspond to the time domain ultrasonogram sections formed from such time series traces as shown in Fig 2c while the adjoined panels b atop correspond to the spectra of such utrasonograms.

A systematic successive comparison of ultraonograms and corresponding or associated spectra (Fig. 4 through Fig 6) with the panels of Fig. 2 could easily enable the confirmation of an associative control of the background medium upon the fluid displacement process. It shall then facilitate the further examination of various ultrasonically “imaged” time and frequency domain events in each panel of Fig. 4 through Fig 6 in a broader, combined, geo and flow morphological context. Examining the panels of Fig. 3, directly, enables the identification of two resonance peaks at frequencies of about 100 kHz and 350 kHz marked by a significant apparent amplitude and frequency shift, further identifiable in the case of each of three tests as depicted in the corresponding panels of Fig 4 and Fig 6. Apart from that, also, the nature of three very prominent amplitude variation features as identified in the time domain section of Fig 4a, and also visible in other such time domain sections as in Fig 5a and Fig 6a, as moderately illuminated, dim and well illuminated regions offer a corroborating view while individually and mutually cross examining various spectra corresponding to all displacement tests.

Towards inferring, a closer examination of Fig. 4b following the time domain information of Fig 4a, thus, following the labelling orderand identifiers further clearly isolate each fluid phase distinctly, in a spatiotemporal sense. Vividly enough the highest amplitudes associate with the occurrence of earlier one to interface (or monolayer) intermediate events clearly, compared to those of the pure oil flow and the brine flow marked as the earliest and the latest events. This observation somehow contradicts with the information contained in the time domain ultrasonongrams in terms of apparent character, where the mixed phase appears significantly attenuating, termed as a dim spot. This leads to two very plausible deductions, firstly that at the scale of interest the initial formation of a “monolayer type” thin film structure does occur, not very clearly identifiable in the time domain though, and secondly for a low frequency viscous regime a slower global flow offers a more defined micro laminar structure, for the Swave to negotiate better displacement amplitude transmission, comparable to an enhanced viscous resilience effect. An analogy of interfacial tension between two immiscible fluids in an open fluid system could be assumed as a broad example.

Spectral magnitudes associated with brine and oil, given the relative time of occurrence on the same lines, are lower and relatively comparable but appear at different frequencies distinctively. Brine effected amplitudes unambiguously and isolatably assume higher frequencies only. Oil associated amplitudes, however, tend to overlap those of mixed phase in time sense, with oil associated amplitudes retaining or reappearing with the same resonant frequency apparently at the time instances of a more turbulent flow regime or a pure brine flow. This observation leads towards another important deduction that Swave has a significant degree of sensitivity to viscosity effects so much so that, not only the existence of the brine flow phase is unambiguously identifiable from oil in a macroscopic sense, any residual oil either flowing in traces as a global flow component or entrapped in cavities is “seen” by the Swaves too; further that possibly at the scale of interest viscosity effects of water and oil are amplified to an extent in a way where the viscosity is enhanced but viscosity contrasts may have been minimized and inhibited disproportionately. In general, however, for all the three tests, given spectral results as shown or depicted in Fig 4b, similar observations and arguments as for those of Fig. 5b and Fig. 6b could be arrived at respectively.

Where two resonant peaks are observed well defined, spatiotemporally given the measurement and geometrical restrictions of the process, with the intermediate bandwidth being significantly attenuated in comparison indicating that the flow regimes is turbulent losing structures such that Swave displacement amplitudes are not transmitted. The observations could be corroborated with the corresponding time domain information contained in the ultrasonogram sections (Fig 4a, Fig 5a and Fig 6a) in a manner self-evident, as of detailed evaluations of [16, 17]. Considering the sequence and direction of different fluid flows in macro or global sense, through the sediment analogue in relation to the sensor or imaging position, for any given test, it could be deduced that at lower frequencies the viscosity/viscous effects control amplitudes to a higher degree, while at higher frequencies they appear density/inertial effects sensitive. This phenomenon clearly indicates frequency sensitivity or the dependence of viscosity. At the primary resonance frequency, the apparent viscous strain hardening is pronounced affecting increased displacement communication response. However, when further increase in frequency causes the “viscous resilience” break down and inertial effects dominate, density effects so appear to manifest as a much higher frequency peak only.

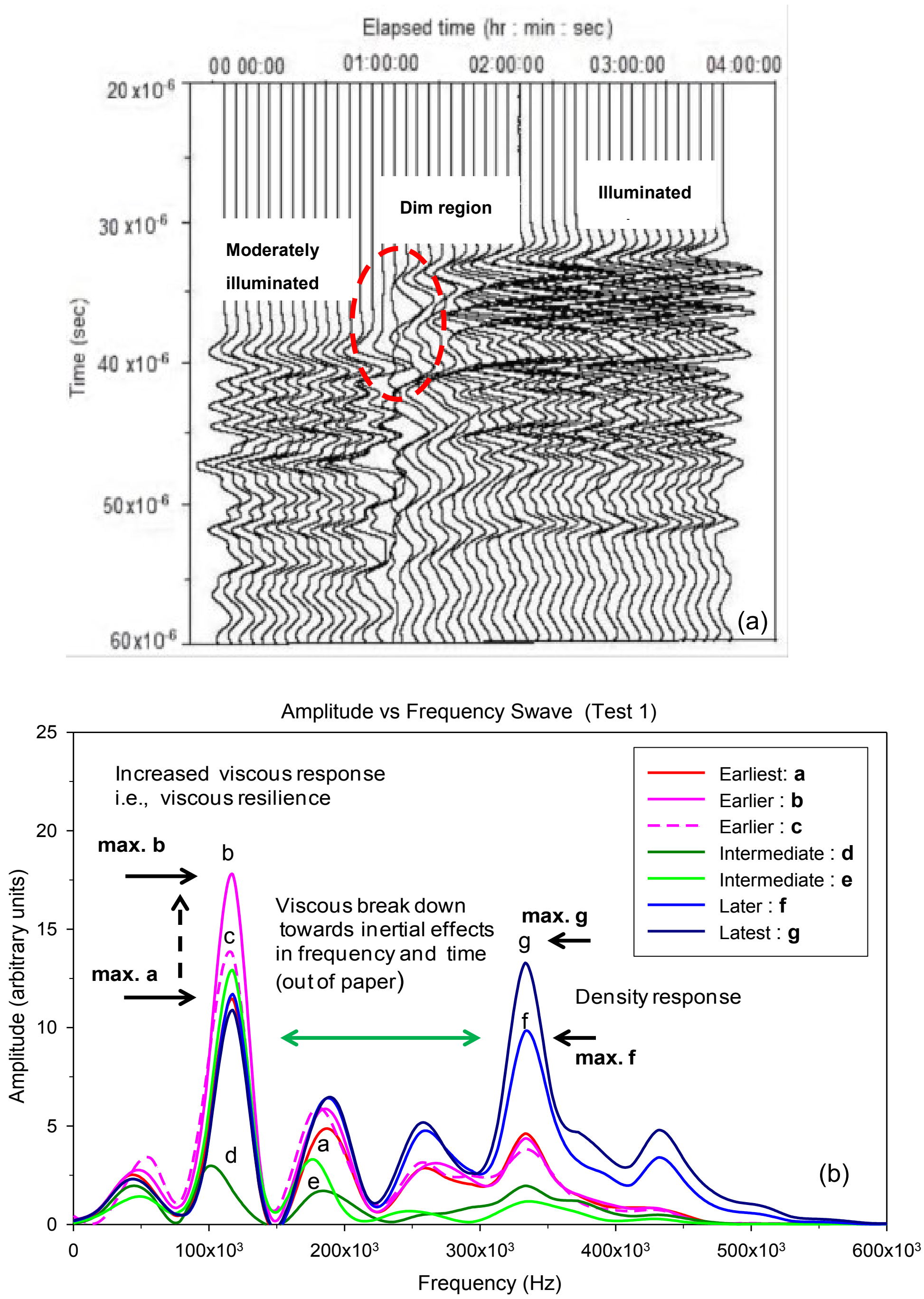

Fig. 4. (a) Time domain ultrasonogram 2D section formed of such traces as shown in Fig. 2c., for Test 1 showing readily observable dim and illuminated, prominent and remarkable features separated in time. (b) Spectral description of (a) above considering time irrespective windows of interest only.

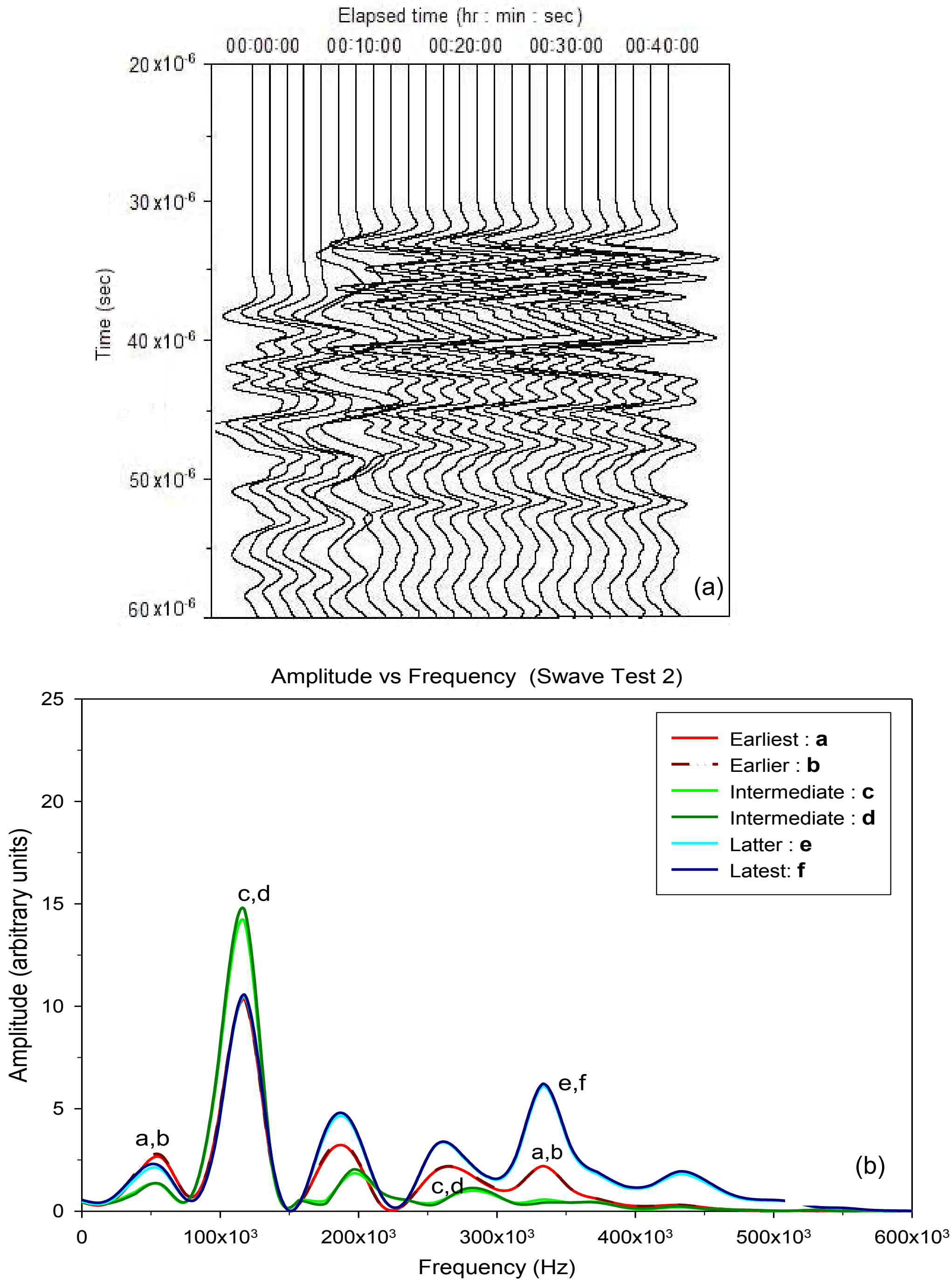

Fig. 5. (a) Time domain ultrasonogram 2D section formed of such traces as shown in Fig. 2c., for Test 2 showing readily observable dim and illuminated features, separated in time, as in Fig. 4a. (b) Spectral description of Fig. 5a as usual.

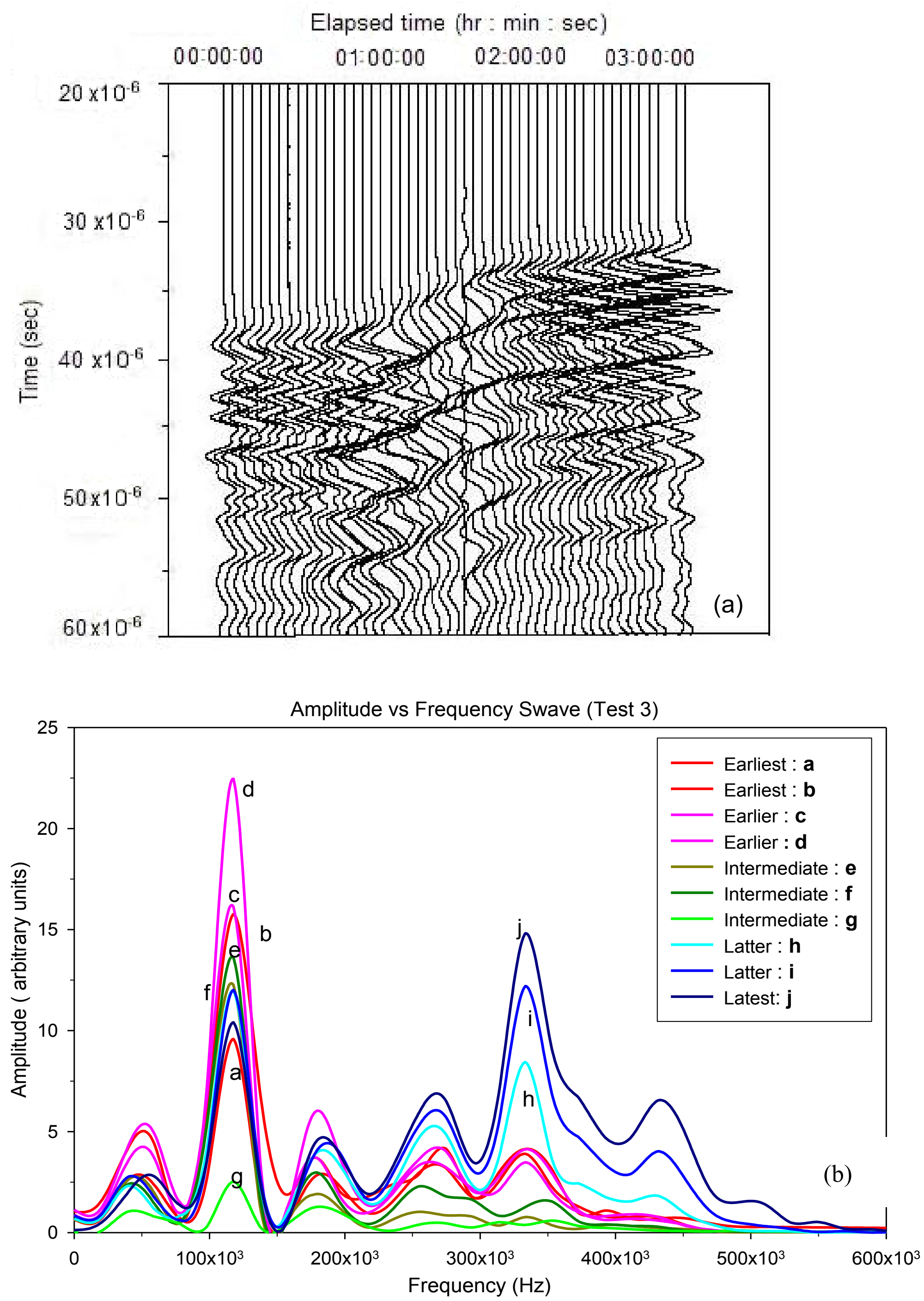

Fig. 6. Similar as on lines of Fig 4 and Fig. 5, (a) Time domain, and (b) Frequency domain spectral description relevant to immiscible displacement Test 3.

Given the morphological sense of the fluid flow process during the immiscible displacement, the flow rate effect variation upon amplitudes is easily deducible. The amplitudes for Test 2 with a global flow rate of 55L/d measured downstream, as shown if Fig.5b, appear much lower than those of rest of the two tests, Test 1 and Test 3, with the flow rates of 4.0 L/d and 10.0 L/d, respectively, when compared mutually. It is assumed that the high amplitude viscous strain hardening type response is flow rate dependent too, and further deducible, for it appears to occur due to complex viscous and interfacial effects combined, given the background, stimulated with typical Swave polarization.

The interface constitution, apart from conjectured and inferred above, appears to modify and evolve possibly in a surface energy minimization sense during the course of fluid displacement as plumes with a well-defined structure possibly due to vicious fingering type mechanism. The complexity of the occurrence of the phenomenon with associated reasons of an immiscible displacement could be understood from [18], the explanation of which is beyond the scope of this document. This pluming effect is assumed to have caused significant intermediate bandwidth loss due to diffraction and/or scattering affected by the destructive interference of tuning effects in addition to the identified/deducible effects of the flow rate and background intergranular shearing. The eventual flow of pure brine during the displacement is marked by high frequency amplitudes only, and, while occurring after the displacement of pure oil followed by the mixed phase, with elapsed time, clearly shows sensitivity retentivity of high frequency towards density instead of viscosity.

The sequentially acquired Swave spectra, fixed either in time or space, clearly not only help isolate different fluid phases in the time domain, but also provide peculiar, stable and reliable, resonant frequency signatures intimate significantly to vital parameters of density and viscosity. The density and viscosity information being a definitive kind in combination can form a particular and diagnostic characteristic parameter in enabling the identification of subsurface toxic or contaminant fluid percolations or flows and the assessment of fate with improved confidence.

5 CONCLUSIONSAND REMARKS

The Swaves spectral examination based efficient and prospectively reliable non-destructive “mapping” method for the identification of toxic contaminant or solvent chemical species when released into near surface is demonstrated in a flow morphology characterization context. The nature of the peculiar spectral sensitivity of parameters is persistively observed where precise knowledge of such parameters corresponds to the properties central to determining and predicting the nature of their overall fate. In order to improve mitigating or containing efficacy of any response towards the hazard associated with the identified chemical species,the adequate information about their possible life cycle in fate is imperative, further, since.As the infiltration of oil based viscous contaminating solvents as controlled releases during anthropic development activities into the near surface sediments coexists with concentrated brine infiltrations, investigating the possibility of their concurrent complex flows at various scales or degrees in morphology in a controlled immiscible setting is well justified, being a commonplace and not farfetched exacting reliable description or mapping, hence.

The interpreted results of the Swave imaged immiscible fluid displacement process in this regard are quite revealing. As marked by two definite resonant frequency restricted amplitude peaks, the amplitude effects precisely appear to be controlled by density, viscosity and surface tension type variations affected correspondingly during the flow of oil, interfacial and/or mixed zone and brine in a well-controlled sequence. A mutual comparative examination of spectra of all three experiments offered certain insightful peculiarities. The interfacial or mixed zone when intact and well morphed assumed the highest amplitudes, compared to those of oil and brine saturations, the former of which was clearly viscosity controlled as the latter appeared density effected. A combination of both flow rate variation and viscous fingering or pluming with background intergranular friction appear to cause a wavelength selective intermediate bandwidth and/or amplitude loss between resonant peaks, a stop band comparable effect. This also depicts a possible frequency dependent contributory elastic evolution and/or tuning introduced by background medium itself as response.

Swave surveys, given ambient conditions understood, definitely assume a capacity to produce a unique characteristic signature of density and viscosity. Such resonance response may not only help identify and resolve pure fluid fractions, but more importantly, also possible interfaces and the nature of their mixing and evolution when transported in near surface as their overall fate. The information could also help introduce geotechnical control in addition to the geohydrological one. The future of such studies could provide a sufficient knowledge base to calibrate methods and simulators by generating consistently appreciable and reliable inventory of outcomes. In addition to offering a potential macro scale method, the Swave manipulative capacity of probing could be applied to investigating such parameters as density and viscosity in terms of effective variations at micro and near nano scales.

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