# SPE 112301

# Acoustic Surveillance of Production Impairment With Real-Time Completion Monitoring

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## Abstract

Deepwater production is challenged by well underperformance problems that are hard to diagnose early on and expensive to deal with later. Problems are amplified by reliance on few complex wells with sophisticated sand control media. New downhole data is required for better understanding and prevention of completion and formation damage. We introduce Real-Time Completion Monitoring (RTCM), a new non-intrusive surveillance method for identifying impairment in sand-screened completions that utilizes acoustic signals sent via the fluid column. These signals are carried by tube waves that move borehole fluid back and forth radially across the completion layers. Such tube waves are capable of “instant” testing of the presence or absence of fluid communication across the completion and are sensitive to changes occurring in sand screens, gravel sand, perforations, and possibly reservoir. The part of the completion that has different impairment from its neighbors will carry tube waves with modified signatures (velocity, attenuation) and also would produce a reflection from the boundary where impairment changes. The method relies on permanent acoustic sensors performing acoustic soundings at the start of production and then repeating these measurements during the life of the well. Thus, it could be thought of as “miniaturized” 4D seismic and “permanent log” in an individual wellbore. In the meantime repeated conventional wireline measurements can be performed to assess the completion permeability.

## Motivation

Completions lie at the heart of deepwater production and present a large portion of the overall well cost. Great multidisciplinary effort is invested upfront to design them right. This contrasts with the production stage where little information is available to detect problems, optimize the inflow and prevent expensive workovers. Incomplete gravel packing, development of "hot spots" in screens, destabilization of the annular pack, fines migration, sand screen plugging, near-wellbore damage, crossflow, differential depletion, compartmentalization, compaction represent a typical list of challenges that are extremely difficult to decipher based on just several permanent pressure and temperature gauges. [1,2] Many problems can be identified by production logging, but it is costly and not in real time.

Let us take the problem of underperforming wells in the Gulf of Mexico [1,2]. “Well performance” absorbs large-scale reservoir issues such as compartmentalization as well as changes in local well skin with time that further comprises of completion, perforations and near-wellbore effects. Therefore multiple explanations can be given to the problem. Apparent compartmentalization and ubiquitous U-shaped boundaries can be one answer on a “reservoir” scale. Yet those boundaries are rarely confirmed by 4D seismic or other data. Shale draping is an alternative reservoir-scale scenario that can lead to well underperformance. Another wellbore-scale explanation suggests that well productivity declines with time due to loss of so called “kh” where k and h are reservoir permeability and thickness respectively. The differential depletion model (Phil Fair and Fritz Rambow, personal communication) argues that this loss occurs mainly due to reduction in producing thickness although the exact mechanisms of flow impairment are still debated. Reduction in permeability is another alternative explanation offered by Pourciau [2] although the amount of this reduction (85-90%) is not consistent with laboratory measurements. Existing sparse data from wells can support any of these scenarios confirming that the problem is underconstrained. In the context of deepwater completions there is an additional emphasis on sand control because it is believed that “Managing produced sand, as we understand it, is generally a costly and mostly unworkable solution for the Gulf of Mexico, but can work well in other places where there is some grain-to-grain cementation present” (Scott Lester of Shell, Sand Control [3]).

To distinguish between different scenarios of underperformance we need more downhole data at various scales that can unambiguously characterize various components of the production system. The aim of this study is to develop new method, Real-Time Completion Monitoring (RTCM) that can characterize permeability impairment of the sand screen, gravel, perforations and the immediate near-wellbore space.

## Principles

Let us summarize the physical principles that allow estimation of permeability impairment from acoustics waves. These principles are well-known for open boreholes where "permeability from Stoneley wave" became the only "direct" and continuous technique of estimating in-situ permeability from wireline logs.[4] Figure 1 depicts a model of an open borehole in a porous permeable formation. Tube or Stoneley wave is a fundamental axisymmetric mode that represents a piston-like motion of the fluid column resisted by the borehole wall. When tube waves encounter a permeable region, their signatures change since the radial motion of the fluid is no longer fully resisted by the borehole wall and part of the fluid can escape in and out of the formation. This fluid communication at low frequencies implies that tube-wave velocity decreases and attenuation increases with increasing fluid mobility (permeability/viscosity). Boundaries between formations with different permeabilities also cause reflected tube waves.

We conclude that tube waves are capable of "instant" testing the presence or absence of "complete" fluid communication across the borehole wall inside a particular layer. If fluid communication is absent due to present mudcake or lack of formation permeability then no slow down or attenuation is observed. If fluid communication is present, then slow down and attenuation are observed. Similarly, in a reflection configuration increased fluid communication leads to a larger reflection. RTCM extends ideas of open-hole Stoneley-wave logging to a wells with sand-screened completions typical for deepwater. These wells have additional layers between the formation and borehole fluid such as sand screen, gravel sand, and casing (Figure 2). The sand screen and gravel pack prevent migration of reservoir sand into the wellbore and maintain the integrity of the reservoir around the wellbore. This more complex model of a completed well has one essential similarity to the simple open-hole model: in a normal scenario of a flowing well there has to be fluid communication across all layers of the completion. Lack of fluid communication in any intermediate layer (screen or perforations) will disconnect the flow of reservoir fluid into the borehole. The aim of the current study is to analyze the effect of broken fluid communication across the sand screen (or perforations) through the signatures of tube waves.

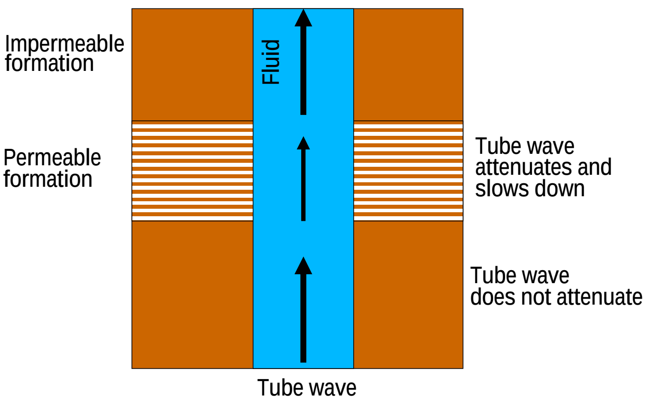


**Figure 1: Tube wave attenuates and slows down when it encounters permeable interval that can exchange fluids between borehole and formation.**

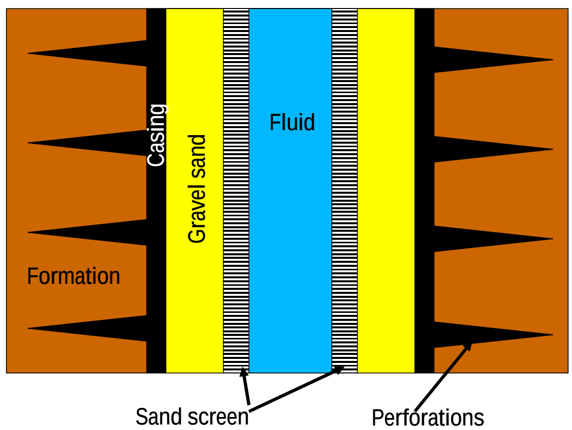


**Figure 2: Schematic cross-section of a sand-screened completion in a cased hole.**

## RTCM concept

Figure 3 depicts the conceptual design of the RTCM method. One can distinguish two RTCM configurations: "repeated or permanent log" (transmission) and "mini-4D seismic in a well" (reflection). In both cases we detect changes in acoustic signatures of tube waves over time and infer changes of permeability along the completion. In transmission configuration we measure velocity and attenuation of the tube waves(s) along the completion and thus have to have sensors along the entire sandface (Figure 3a). In reflection configuration we may have sensors only above the completion and analyze the change in reflected arrivals from permeability interfaces (Figure 3b). The depth location of the change can be found by analyzing the arrival times just like in reflection seismic.

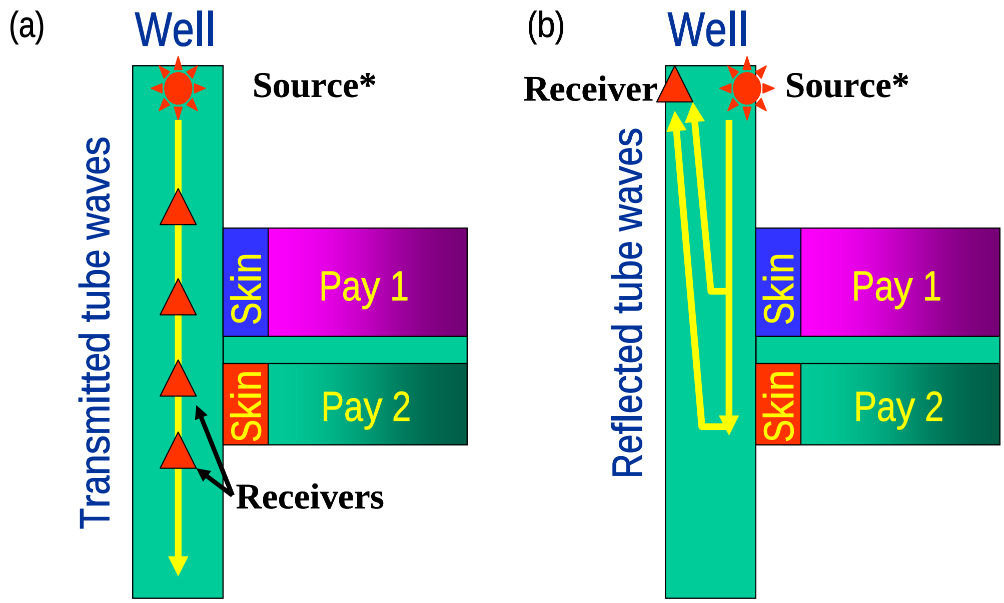


**Figure 3: Conceptual design of RTCM configurations: a) "Repeated or permanent log" (transmission configuration); b) "Mini-4D seismic in a well" (reflection configuration). *Acoustic source may be eliminated when noise is used (section Implementation)**

We envision that such measurements can be performed while the well is flowing or during brief shut-in periods (see last section on Implementation). This can provide valuable information about in-flow ability of the well in real time to well engineers or production technologists. Such information would:

- detect changes in permeability in and around the well (an thus the inflow ability) in real time
- identify the well structure responsible for any problems (screen, perforation etc)
- help design best practices for drawing the wells without impairing them
- raise red flags early on when problems are not acute and can be fixed with lighter effort, as opposed to major problems when intervention is unavoidable
- help characterize cross-flow and differential depletion in wells with multiple commingled producing intervals

Here we report on a full-scale laboratory test of the RTCM concept for a particular scenario when permeability impairment is caused by sand-screen plugging in a completion without gravel pack.

## Full-scale laboratory test

The horizontal flowloop setup at Shell's Bellaire Technology Center used for experimental measurements is pictured in Figure 4. It follows the schematics from Figure 3, except there is no formation, gravel pack, or perforations. The outer pipe (casing) consists of six 5-ft glass sections joined together (30 ft) and attached to the underlying support rail. The inner pipe (PVC sand screen) is positioned inside using plastic centralizers. To model an open sand screen ("open pores") we use a PVC pipe with 0.0002 m (0.008") slots (Figure 5a). The plugged sand screen was modeled with a blank PVC pipe without slots and is referred to as "closed pores". The annulus between the inner and the outer pipe is filled with water. Measurements are conducted with a hydrophone array and a piezoelectric source lying down at the bottom of the inner pipe. The source excites a broadband impulsive waveform with controlled dominant frequency. Twenty-four hydrophone sensors at 35 cm spacing record the resulting wavefield. In contrast to open-hole case there are two tube waves - fast and slow - that appear without gravel pack. The fast wave is related to the fluid column in the annulus between the sand screen and casing, whereas the slow tube wave is related to the fluid column inside the screen.

The intent of RTCM is to distinguish between four completion scenarios (Table 1) using tube-wave signatures. "Open" and "closed" denote two extreme cases of presence or absence of full fluid communication. "Partial" fluid communication should manifest itself with intermediate signatures between these two bounds. Signatures examined include propagation velocity and attenuation of tube waves as well as transmission and reflection amplitudes from interfaces where contacting media are described by different scenarios.

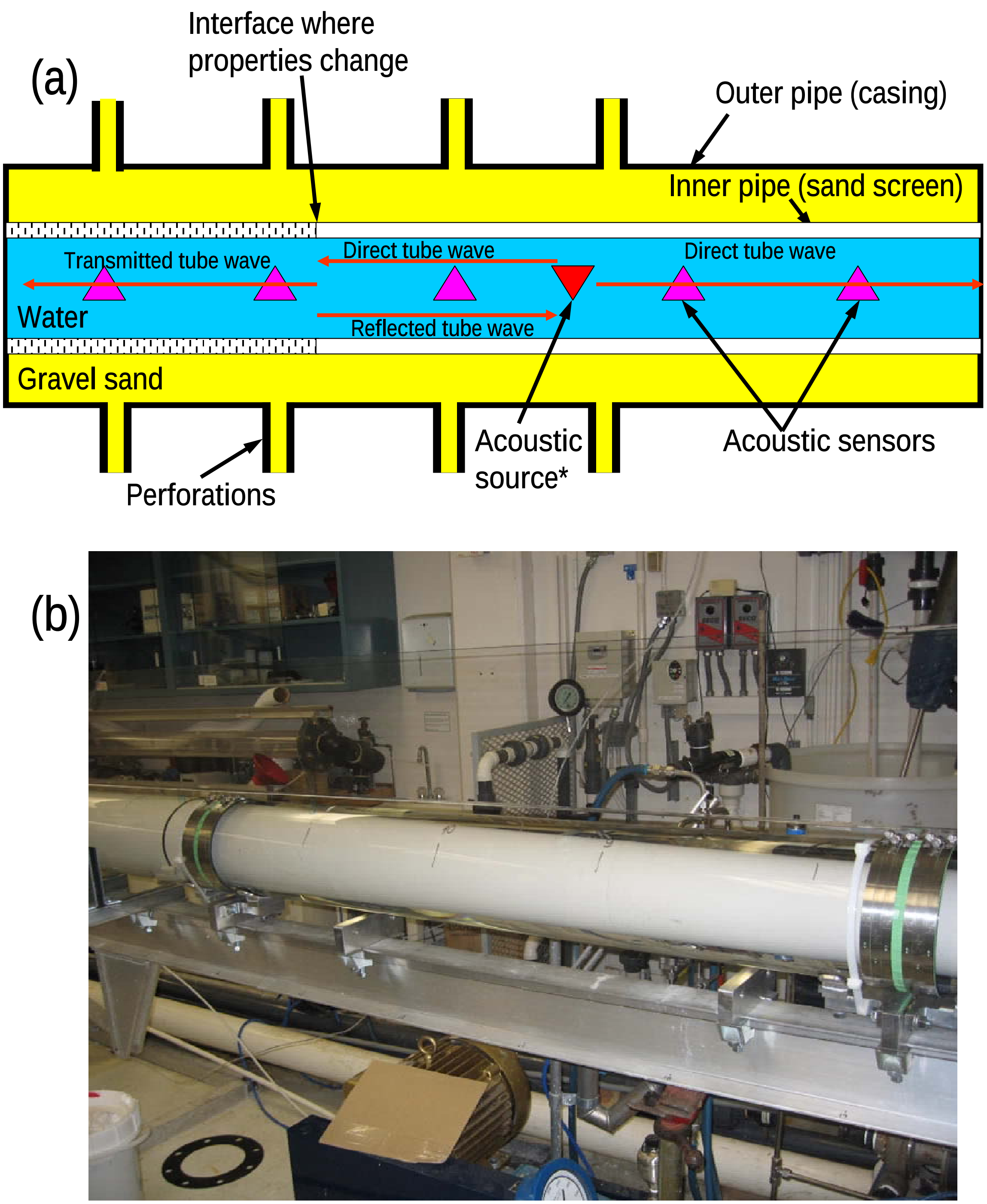


**Figure 4: (a) Sketch of the flowloop setup with the model of sand-screened completion in horizontal well. (b) Photograph of the actual flowloop setup at Shell's Bellaire Technology Center with a glass outer pipe (no perforations).**

**Table 1: Completion scenarios**

| | Screen ability to flow | Perforations ability to flow |
|---|---|---|
| Scenario 1 | Open | Closed |
| Scenario 2 | Closed | Closed |
| Scenario 3 | Open | Open |
| Scenario 4 | Closed | Open |

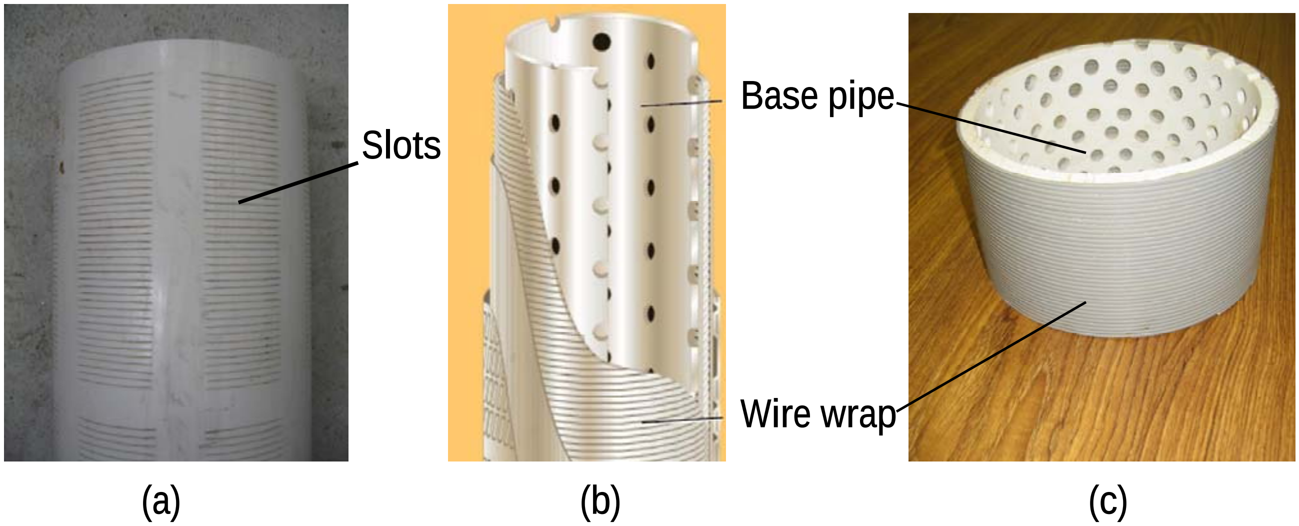


**Figure 5: Sand screens: a) slotted PVC screen (4% porosity) used in the current experiments; b) a premium screen, named as Excluder (from Baker website), c) wire-wrapped PVC screen (13 % porosity).**

In this study we present experimental measurements for scenarios 1 and 2 in the absence of gravel sand and compare them with modeling. In the next section we present numerical modeling of gravel-packed completions for the first two scenarios. Experiments with sand are underway and will be reported at a later date.

**"Repeated or permanent log" (transmission configuration)**

Let us first analyze transmission signatures – velocity and attenuation – in the presence of open and plugged screens. Figure 6 shows the raw acoustic wavefield recorded in the case of no screen and a screen with "open" or "closed" pores. The acoustic data look quite different in each case and are contaminated by reflections from pipe joints located every 5 ft that are not representative of field scenarios. Nevertheless first conclusion is immediate: in the absence of a screen, there is only one (fast) tube wave present with velocity of about 1050 m/s. When an impermeable inner pipe is added (closed pores) a slow tube wave appears, and the fast tube wave becomes more attenuative due to high absorption in PVC screen. When the inner pipe becomes slotted (open pores) then fluid on both sides of the PVC screen start to communicate, and this leads to a very strong attenuation of both tube waves. Thus a greatly increased attenuation of both fast and slow tube waves is the first-order diagnostic for open screens ("open pores"), whereas reduced attenuation is characteristic for plugged screens ("closed pores"). Thus if plugging develops we start to see a big signal.

Additional diagnostics can be established by analyzing energy distribution as a function of frequency between these two cases. Since the experimental data are complicated by the presence of additional reflections at the pipe joints, this analysis is best performed using the slowness-frequency spectra shown in Figure 7. Figure 8 represents the averaged velocity spectrum over the entire frequency range, or the horizontal stack of Figure 7. Both fast and slow tube waves with approximately the same velocities of 1100 m/s and 350 m/s are present in the plugged and open cases (Figure 8), however the slow wave is completely absent without a screen. In a plugged screen the fast wave carries maximum energy in the frequency range of 300-600 Hz close to the dominant frequency of the source, whereas lower and higher frequencies carry less energy (Figure 7). In contrast, the spectrum of the fast wave in an open screen has a big energy "hole" between 300 and 600 Hz where the fast wave is attenuated so strongly that even higher frequencies (600-900 Hz) carry more energy (Figure 7). This behavior is summarized in Figure 9, which confirms that fast-wave energy is severely attenuated in the medium frequency range whereas it is still preserved in the high-frequency range. As for the slow tube wave, it mainly exists at frequencies below 600 Hz and is also attenuated.

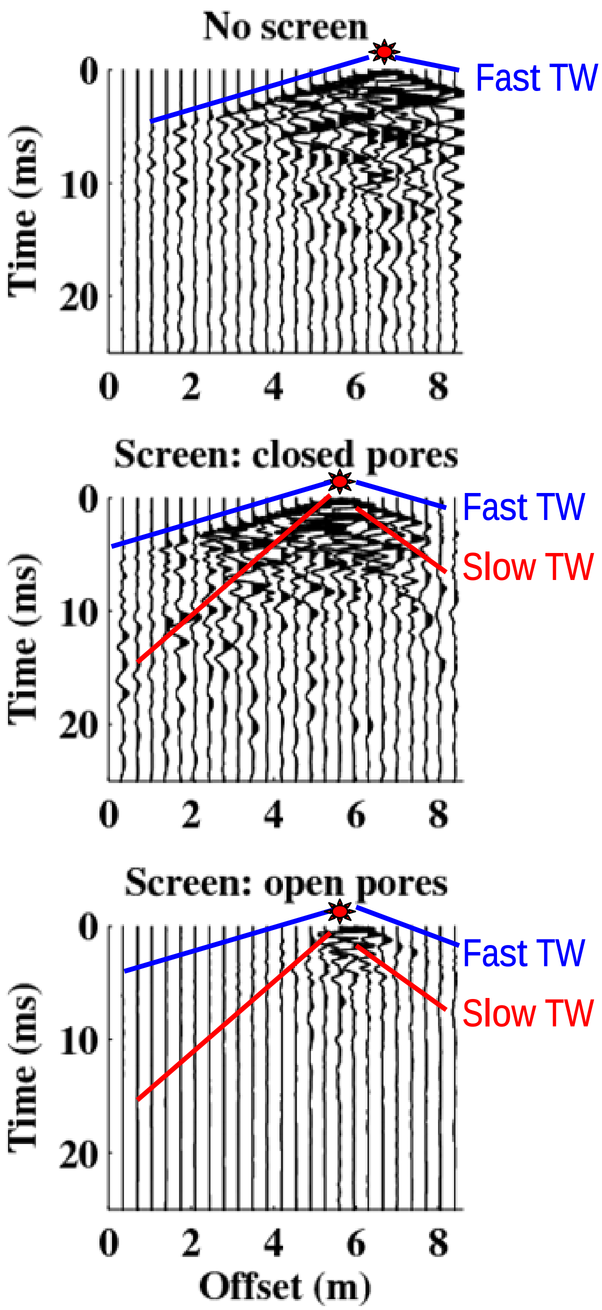


**Figure 6: Seismograms recorded in the laboratory test by a hydrophone array from a piezoelectric source (red symbol) with a dominant frequency of 500 Hz.**

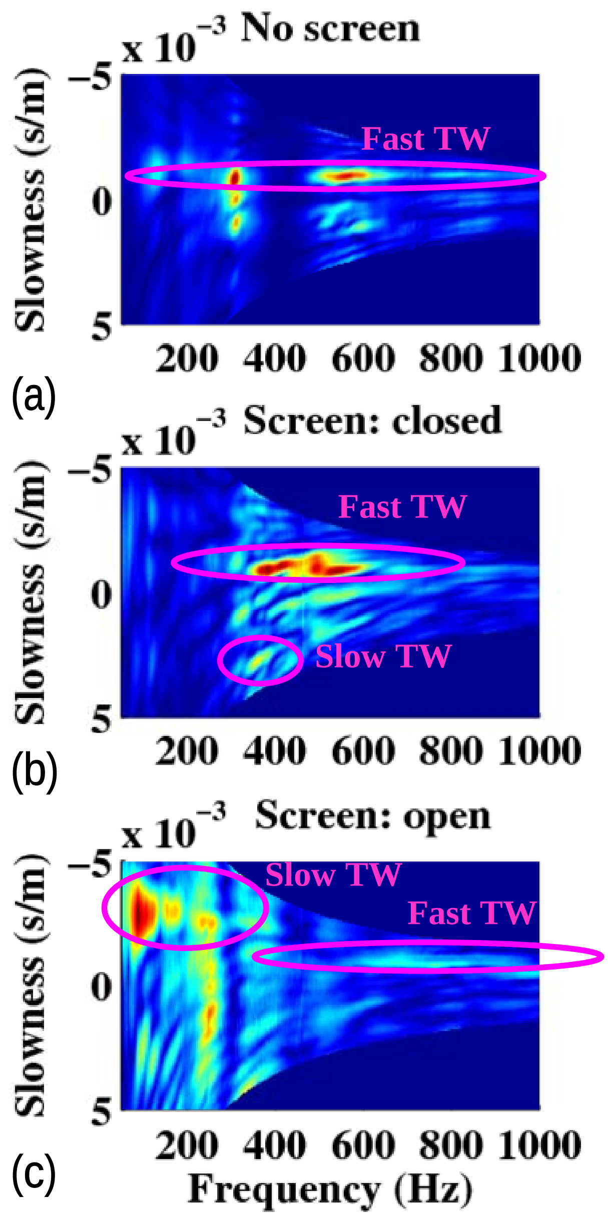


**Figure 7: Slowness-frequency displays of the data from Figure 6. Note that without sand screen we only have fast tube wave (a). With plugged sand screen slow tube wave appears (b), whereas permeable sand screen attenuates both tube waves to a great degree (c).**

Let us compare this behavior with the poroelastic reflectivity and finite-difference modeling. Figure 10 shows synthetic seismograms computed for a glass setup with our best guess of poroelastic parameters for the screen (130 Darcy). Similar to the experiment, in the case of closed pores we observe two tube waves with the fast tube wave dominating in amplitude. In the presence of a screen with open slots both waves experience strong changes. The fast tube wave experiences moderate attenuation and change of waveform. The slow tube wave transforms into a complex packet with weak amplitude.

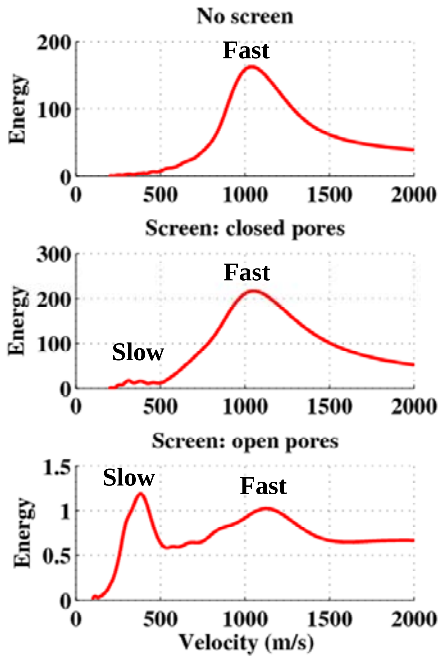


**Figure 8: Velocity spectra (stack of Figure 7). Note that without sand screen we only have fast tube wave (a). In the presence of screen we have "fast" and "slow" tube waves but their amplitude ratio is different.**

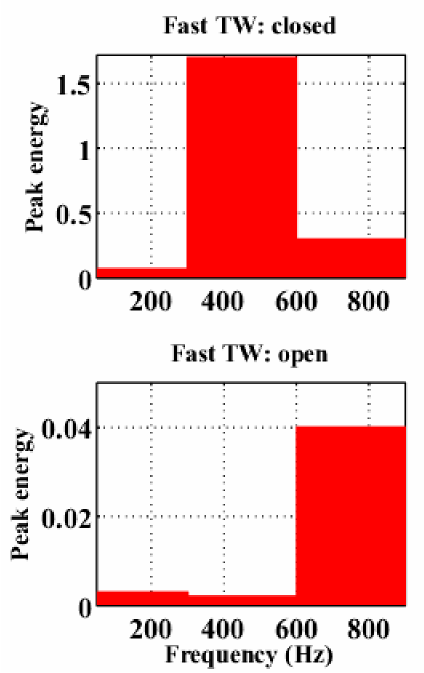


**Figure 9: Energy distribution vs. frequency for the fast tube waves in open and plugged screens. Note anomalous attenuation of the fast-wave energy in open screens between 300 and 600 Hz caused by fluid communication.**

The following physical interpretation can be given to the modeled results. A tube wave is born when the piston-like motion of the fluid inside the pipe creates a radial expansion that is resisted by the elastic pipe. The slow wave is supported mainly by the inner pipe. When this pipe becomes slotted, radial movement of the fluid is no longer resisted since liquid can freely escape to the annulus, thus leading to a strong attenuation of this wave. In contrast, the fast wave is supported mainly by the outer glass solid pipe. When the inner pipe becomes permeable, piston-like motion of the fluid in the fast wave can additionally exchange the fluid between the outer and the inner fluid columns, thus creating a moderate attenuation.

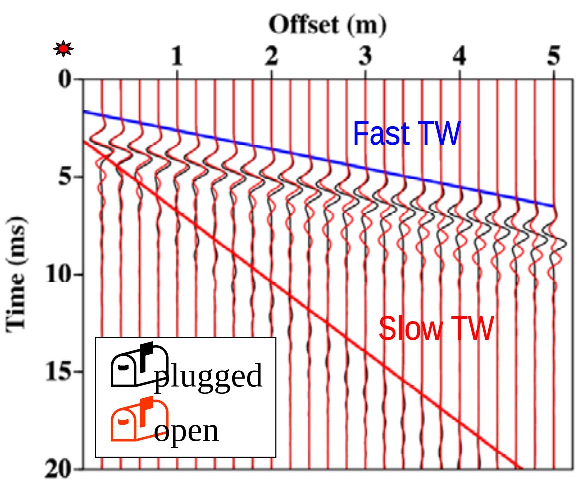


**Figure 10: Numerical modeling of waves in a laboratory setup with open and plugged screens. Note larger attenuation and dispersion of fast tube wave in open screens.**

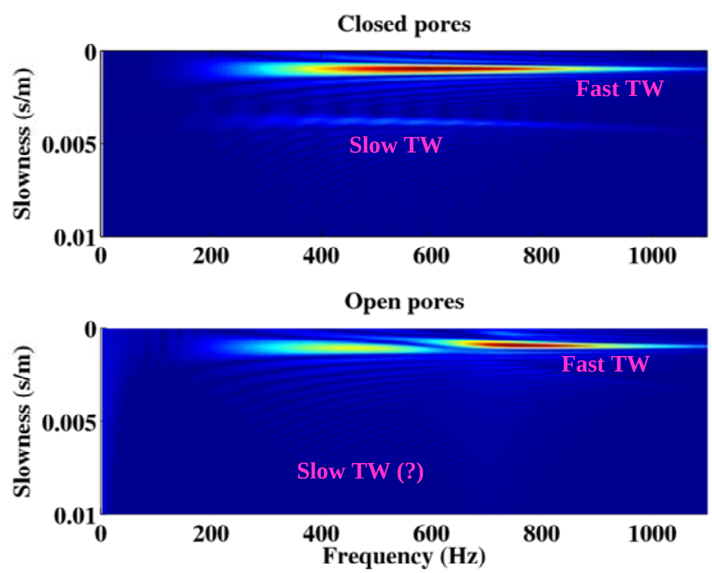


**Figure 11: Slowness-frequency display of synthetic data from Figure 10. Note "anomalous" attenuation of the fast wave between 350 and 700 Hz similar to Figure 7b-c of experiment.**

Slowness-frequency spectra for open pores (Figure 11) shows, that, similar to the experimental results the fast wave experiences anomalously high attenuation in the medium frequency range of 350-700 Hz. In addition, velocity slows down at low frequencies and the energy peak becomes broader, indicating dispersion. A more robust display averaging over "small", "medium" and "high" frequencies is shown on Figure 12. Comparison of Figure 12 and Figure 9 confirms the qualitative agreement between experiment and modeling: in both cases the fast wave exhibits anomalous amplitude decrease in the medium frequency range, while still preserving higher and lower frequencies. This amplitude decrease cannot be explained by the spectra of the source wavelet and therefore should be attributed to anomalous attenuation caused by fluid movement through the slotted porous screen. The frequency range with resonance attenuation is controlled by permeability - when permeability decreases from 130 to 50 Darcy then this band moves from 350-700 Hz to 600-1000 Hz, i.e. the lower the permeability, the higher the frequency of the band with anomalous attenuation of the fast wave. Therefore central frequency of the band with anomalous attenuation of the fast tube wave is an additional useful diagnostic of the screen permeability.

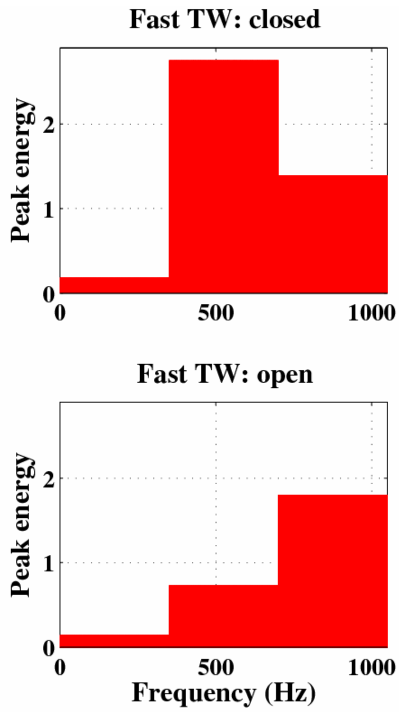


**Figure 12: Energy distribution vs. frequency for the fast wave as predicted by numerical modeling. Note "anomalous" attenuation of the fast wave between 350 and 700 Hz similar to Figure 9 of experiment.**

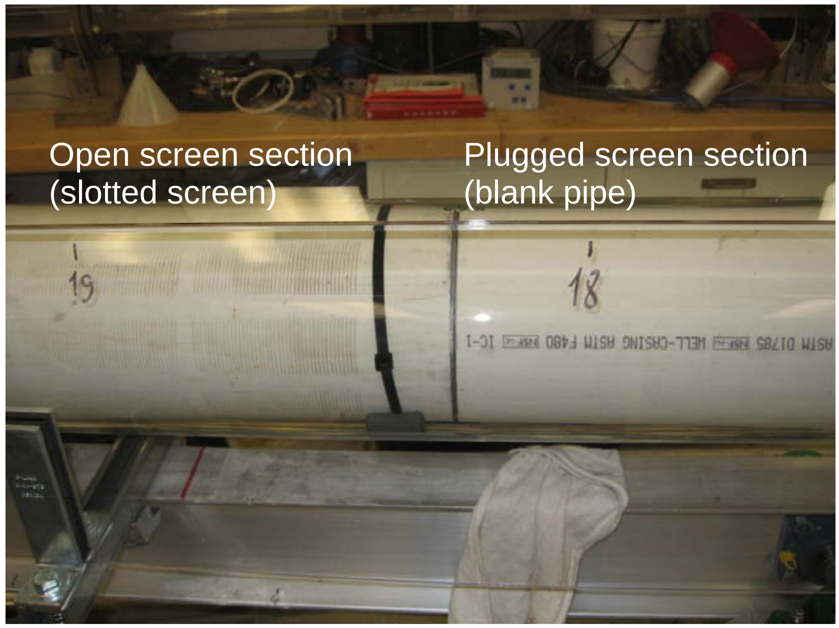


**Figure 13: Interface between open (left) and plugged (right) screen sections.**

**"Mini-4D seismic in a well" (reflection configuration)**

The difference in velocity and attenuation between completions with open and plugged screens also leads to reflections at the boundaries where properties change. We now examine transmission-reflection at the single interface between open and plugged sections of the screen (Figure 13).

***Interface plugged-open***

First, we consider a model when 2/3 of the setup consists of a blank pipe (closed pores), whereas the remaining 1/3 is occupied with a slotted screen (Figure 14). At low frequencies a source located in the middle of the blank pipe excites both fast and slow waves as shown on Figure 14. The fast wave becomes highly attenuative upon reaching the interface. The slow wave experiences a strong reflection that is more easily seen on the wavefield-separated display (bottom of Figure 14). At higher frequencies fast-wave reflections become more observable. Modeling shows qualitatively similar behavior, but it underestimates the amplitude of the slow wave in open pores.

***Interface open-plugged***

When the source is inside the open section, wave propagation changes. First, at low frequencies the slow tube wave dominating wave propagation in the open section converts into a fast wave in the plugged section (Figure 15). The interference between the strongly attenuating fast and slow waves creates the impression of a curved moveout around the source; however, it is clear that the fast wave is excited by a late-arriving direct slow wave. A simple inspection of the unprocessed gather reveals the location of the open-plugged interface where it manifests as the change in the slope of the dominant events.

Second, that same incident slow wave generates a strong reflection back into the open section (Figure 16) that is clearly larger than the earlier reflection from a pipe joint.

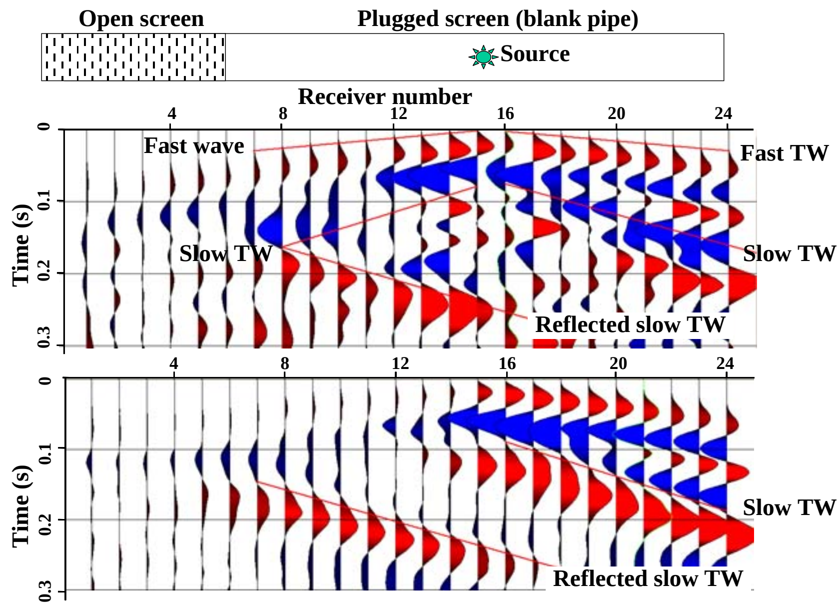


**Figure 14: Reflection at the interface between plugged and open sections of the sand screens. Top – full acoustic response, bottom – processed response after wave separation highlighting rightgoing slow tube waves.**

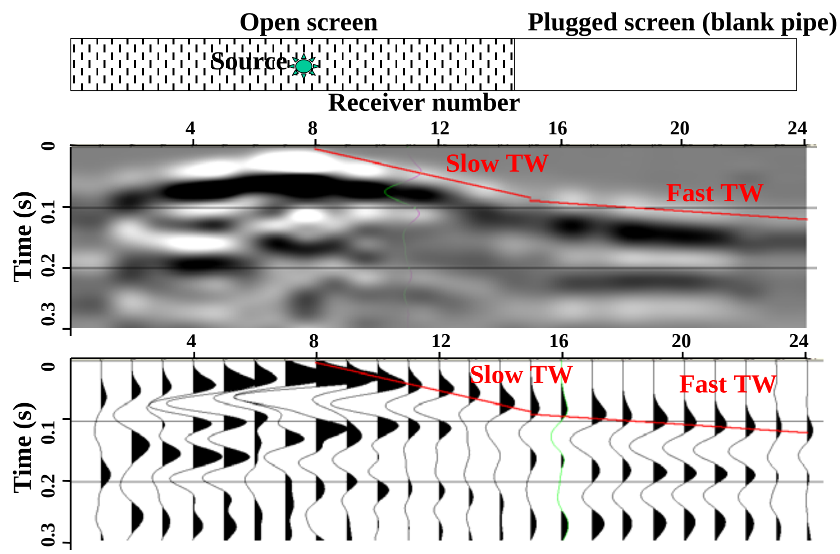


**Figure 15: Transmission at the open-plugged interface. Note excellent conversion of slow tube wave in open screen into fast tube wave in the plugged section.**

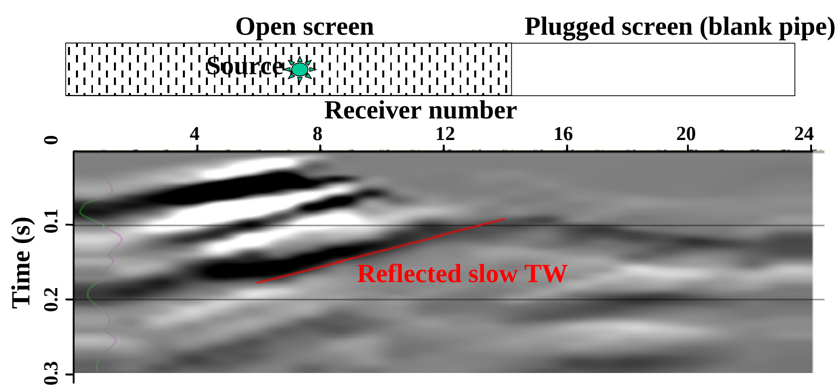


**Figure 16: Reflection from an open-plugged interface. Note strong reflected slow tube wave on a processed response after wavefield separation.**

## Completion with gravel pack: numerical modeling

In gravel-packed completions, the presence of a sand layer with presumably small (but non-zero) shear rigidity leads to the existence of only a single (fast) tube wave. This greatly simplifies wave propagation. Thus the presence of a second, slow tube wave may be diagnostic of completions with fluidized sand or lack of sand. Synthetic finite-difference seismograms (Figure 17) show that in the plugged section of the screen (closed pores) the tube wave has higher velocity (1020 m/s) and experiences very little attenuation (as expected). In contrast, open pores allow fluid communication between the liquid column inside the screen and pore fluid in the sand. As a result we observe a strong velocity slowdown (700 m/s) and dispersion and substantial attenuation. Thus, similar to open-hole logging methods, we can distinguish permeable and impermeable sections of the screen by examining velocity and attenuation. Slow-down in velocity and high attenuation are simple diagnostics of an open section, whereas speed-up and little or no attenuation are characteristics of plugged section.

Figure 17 also illustrates the reflection-transmission process at the plugged-open and open-plugged interface. The reflected tube wave is due to the difference in velocities and attenuations across the interface. Experiments are in progress to verify these predictions.

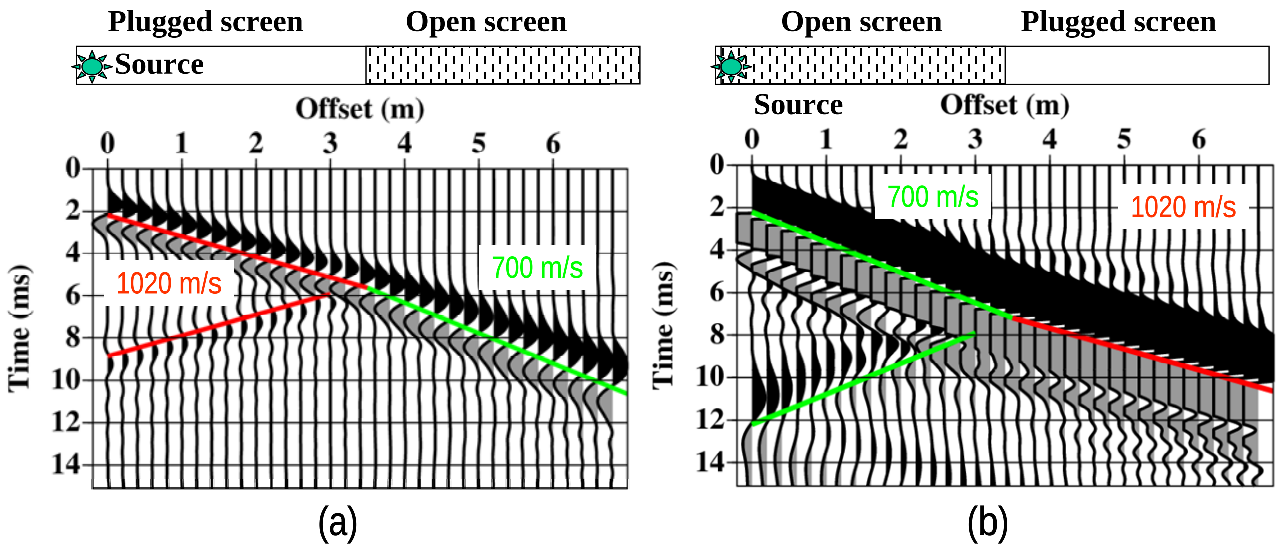


**Figure 17: Wave modeling in sand-screened gravel-packed completions without perforations: a) plugged-open interface; (b) open-plugged interface (direct wave is clipped in order to see weak reflection). Note substantial slowdown and higher attenuation/dispersion in the open screens. Wire-wrapped (aluminum) screen from Figure 5c is used in the modeling (50 Darcy).**

## Fiber-optic implementation

Laboratory experiments and modeling prove the concept of using tube-wave signals to monitor permeability changes along the completion. However, to implement this technique downhole one needs to instrument producing wells with acoustic sources and receivers. Tools used in the lab are not applicable for real wells: downhole deployment requires these sources and receivers to be protected and not obstruct the flow.

### Sensors

On the receiver side such an objective is well served by fiber-optic sensors that could be placed on the outside of the pipe (sand screen, tubing or casing). In addition, such sensors are completely passive and do not require electric power. We tested this idea by comparing records obtained with hydrophones inside the plastic pipe and fiber-optic “on the pipe” sensors (Figure 18a). Good agreement is observed between the two sets of measurements (Figure 18b). A fiber wrapped around the pipe detects the radial displacement of the pipe, which is characteristic of tube waves (often called “breathing” modes). In addition, azimuthal averaging performed by fiber-optic sensors tends to suppress other acoustic modes (plate or extensional pipe wave) as well as various noises thus highlighting the “breathing” tube wave.

The idea of wrapping fiber on the outside of the sand screen or casing is utilized by the real-time casing imager (RTCI) tool[5], which aims to measure deformations of the pipe. RTCI sensors are finely spaced and wrapped in continuous helical fashion to detect asymmetric static deformations, whereas RTCM averages around the circumference of the pipe at discrete locations, but at a fine sampling interval in time.

There are opportunities to combine static and dynamic surveillance on the same fiber using new interferometric technologies such as Blue ROSE developed by the Naval Undersea Warfare Center for military security applications.[6] Blue ROSE is the codename of the project where Blue is from the blue color in the sky as this is caused by Rayleigh scattering; ROSE is short for Rayleigh Optical Scattering and Encoding. Blue ROSE technology detects Rayleigh backscattering profiles (or “finger print”) along the length of the fiber.

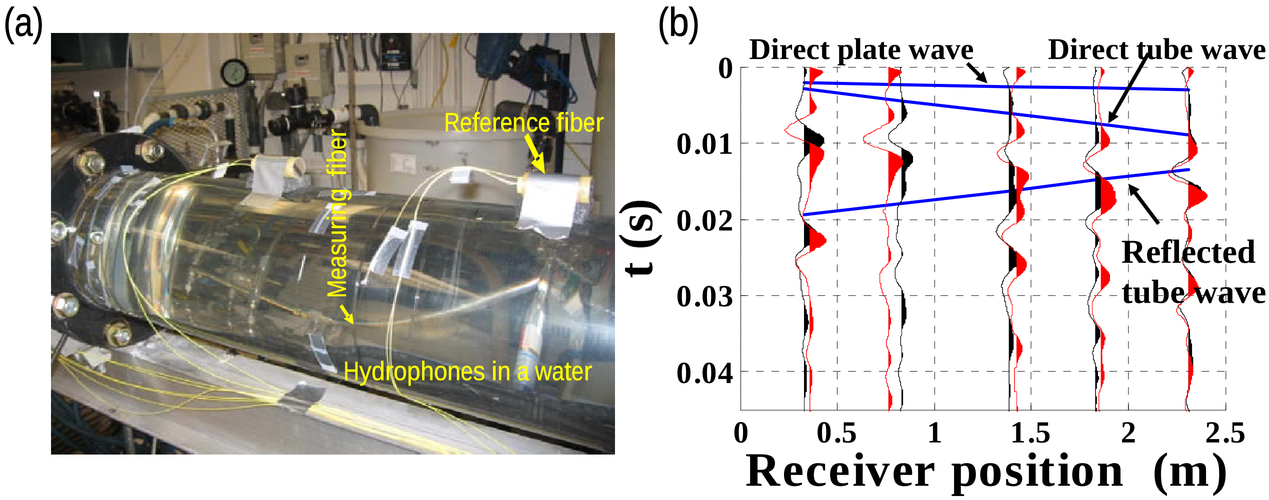


**Figure 18: (a) Photograph of the flowloop setup with fiber-optic sensors installed on the outside of the pipe. Conventional hydrophone sensors are present inside the fluid. (b) Comparison of traces recorded with hydrophones (black) and fiber-optic sensors (red). Note excellent agreement between the two.**

Each segment of the optical fiber has a unique scattering profile due to the random impurities in the fiber that cause Rayleigh scattering. The Blue ROSE system uses the Rayleigh fingerprints in the optical fiber as Fabry-Perot reflectors. The system can dynamically use different Rayleigh fingerprints anywhere along the length of the fiber. Blue ROSE gives a promise for combining RTCI and RTCM systems in a single cable which would be desirable for integrated downhole surveillance (Figure 19).

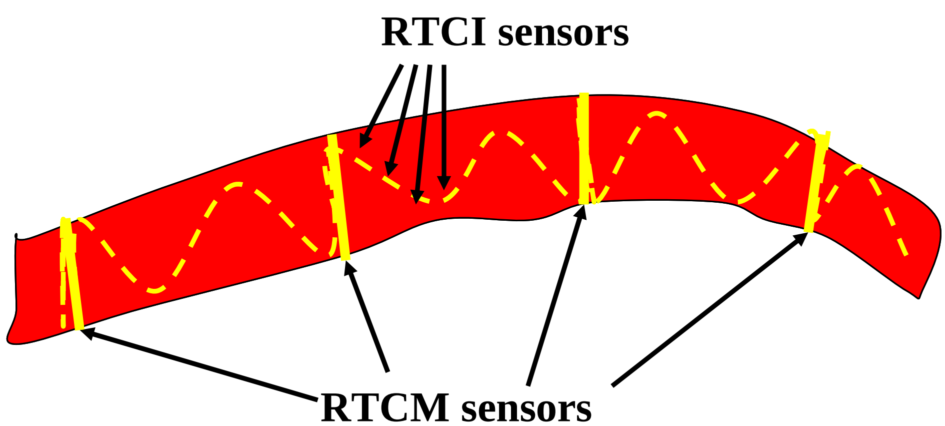


**Figure 19: Schematic of combined RTCI and RTCM sensors on the same fiber using "Blue ROSE" interferometric technology.**

**Sources**

Both transmission and reflection configurations of RTCM require repeatable excitation of the tube waves downhole. This can be achieved with active or passive acoustic sources. In principle, a dedicated active source can be mechanically clamped on the outside of the tubing or screen and can be mechanical or magnetostrictive. Apart from additional installation in the well, this approach also requires an electric power cable to supply the source.

A less demanding alternative may be to use flow noise or other disturbances as a passive signal and obtain the response between two sensors using crosscorrelation. So called "noise correlators" have been used for decades to detect the location of subsurface leaks in pipes. Lately similar cross-correlation of fiber-optic "on-the pipe" sensors was utilized to measure tube-wave velocity and invert for fluid composition and flow speed in surface and downhole pipes.[7] In the downhole case, the acoustic flowmeter contains an array of fiber-optic sensors installed on the outside of the tubing near the completion and performs acoustic measurements in real time while the well is flowing.[7] Successful use of acoustic flowmeters confirms the feasibility of downhole measurements of tube-wave velocity inside the producing and flowing well.

Crosscorrelation is a 1D version of the more general Virtual Source method.[8] After cross-correlation of a recording at the first receiver with those at the remaining sensors we obtain a response as if the signal was actually emitted from a Virtual Source placed at the location of the first receiver. Similarly distant weak active sources (further from completion) can be utilized with the Virtual Source technique. Since we directly measure the incident signal in the Virtual Source – we know the source signature and can modify it to our desired form by signal processing to achieve a repeatable time-lapse monitoring.[8]

Therefore the Virtual Source Method may allow the implementation of a completely passive version of RTCM without active sources downhole.

## Conclusions

We propose a new non-intrusive real-time technique that monitors changes in permeability along sand-screened completions utilizing acoustic signals in the fluid column. Various impairment mechanisms can impede production in real wells. We presented a full-scale laboratory test verifying the method for a scenario where impairment is caused by sand-screen plugging in a completion without a gravel pack. We observe two tube waves supported by the screen and casing, with the slow tube wave being a diagnostic of a completion without a gravel pack. Simple inspection of the raw data allows identification of plugged and open sections of the screen: plugged sections give large signal, whereas open sections have low signal (greatly increased attenuation of both fast and slow tube waves). Straightforward processing allows locating the interfaces between open and closed sections with a higher confidence. We conclude that experimental monitoring of the tube-wave signatures over time can reveal plugging of the sand screen or its parts. Similarly repeated production logging with acoustic tools can quantify completion impairment but not in real time.

We further compared experimental results with simple poroelastic modeling and found a qualitative agreement between most of the experimentally measured and predicted signatures. Modeling of a completion with gravel packs predicts that unimpaired flowing sections exhibit reduced velocity and strong attenuation of the single tube wave observed in this case. An impairment in a gravel-packed completion leads to increase in tube-wave velocity and reduced attenuation.

We outlined possible ways for permanent instrumentation of producing wells with required tools and speculated on different methods of achieving such measurements in practice. Permanently placed fiber-optic “on the pipe” sensors provide a best chance for RTCM monitoring of production impairment. While such systems are developed, conventional wireline acoustic techniques can be used to characterize permeability along the completion. For example, running production logging with conventional acoustic tools inside the sand screens can deliver the same information albeit not in real time.

In essence, the acoustic monitoring method is like a permanently installed “sonograph” on the chest of the patient (sandface of the reservoir). The sonograph constantly conducts active “health check” of the well. Early detection and proper diagnostics follow as a natural outcome of permanent monitoring, so that proper treatment (workover) can be delivered before issues get out of hand. Permanent monitoring serves as additional insurance to safeguard expensive completion and sand control “jewelries” as well as the borehole itself.

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