ACOUSTIC BEHAVIOR OF MULTIPHASE FLOW CONDITIONS IN A VERTICAL WELL

An Undergraduate Research Scholars Thesis

by

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ABSTRACT

Acoustic Behavior of Multiphase Flow Conditions in a Vertical Well. (May 2015)

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Operation and service companies in the oil and gas industry have recently deployed Distributed Acoustic Sensing (DAS) technology as a hydraulic fracturing diagnostic tool. However the uses of DAS technology are limited to qualitative analysis of sound generation along the wellbore by pinpointing the location and measuring the intensity of noise source. Increasing reservoir complexities require future DAS applications to be equipped with quantitative analysis of the fluid flow rate, multiphase fluid injection and flowing reservoir fluid properties from the acoustic data.

Signal processing technique is used in this paper to determine the flow rates from a simulated vertical fractured well. Reservoir fluid production is simulated by injecting liquid and gas through a 2 inch pipe into a 5 ½ inch diameter well. The noise produced is recorded by a hydrophone located at the perforation. The acoustic signal of sound is recorded in the time domain and is transformed into the frequency domain by Fast Fourier Transform (FFT) algorithm software to obtain the acoustic data for quantitative analysis.

The experimental results show that fluid flows into the wellbore through perforation produces different acoustic pressure magnitudes and sound frequencies. The fluids used for injection in this study are water and nitrogen gas. The peak frequency indicates the type of fluid injected and its magnitude indicates the flow rate. The sound frequencies of interest are distinct for different fluids as for liquid, it is in the hundreds Hz range and for gas, it is in the thousands Hz range. It is found that there is correlation between the acoustic pressures and the flow rate of both fluids. Acoustic pressure increases with the flow rate injected.

DEDICATION

This thesis is dedicated to my parents who have given me unconditional love and support throughout my life.

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CHAPTER I

INTRODUCTION

Noise has long considered an undesired signal that causes disturbances in collecting sound signal. For the purpose of this study, collecting noise is useful as fluid turbulence generates sound through leaks or perforations producing high distinctive sound amplitudes. Noise log, first introduced by Enright in 1955 is defined as a record of sound measured at different positions in the borehole. The peak noise recorded is associated with the point of origin of a leak which associated with the primary function of noise log as leak detector.

It was not commercially used until 1973 when McKinley, Bower and Rumble from Esso Production Research Company utilized the noise log as a spectrum graph of relative amplitude against frequency. It is found that as the pressure gradient increases, the noise amplitude increases and the maximum noise amplitude shift to slightly higher frequencies.

Robinson in his paper back in 1976 introduced the fundamental concept that for any fluid composition flowing in a well it generates 200 to 6000 Hz audible sound frequencies and for a single-phase flow, the 1000 Hz peak is collected across a pressure difference. It is found that typical noise in 200 to 600 Hz band is proportional to gas rate while liquid content has higher frequency noise.

In addition to these traditional noise logging tools, Distributed Acoustic Sensing (DAS) system which utilized fiber optic technology is recently introduced to sense and measure sound produced in the wellbore robustly on a larger scale. This sensing technology composes of a long telecom fiber optic cable and a laser source. The cable acts like an array of individual hydrophones, sensing the disturbance along the wellbore by the sound signal from the fluid production. The disturbance interfere with the laser light and backscattered pressure wave is generated. The wave generated indicates the sound location and its intensity measurement.

Shell and QinetiQ OptaSense have successfully completed the very first downhole application trial for DAS in a tight gas well in February 2009. The specific case study has employed the idea that a 5 meters spatial resolution will be able to generate 1000 channels along 5000 meters long fiber sampled at 10 kHz. These parameters, according to them, are adjustable in order to optimize reservoir performance. Recordings made during the operation indicated that DAS is a sensitive technology with a broad frequency content that enables the outcome of different perforations to be discriminated.

Recent study by Martinez, Hill and Zhu in 2014 found that the sound level of peak frequencies are linearly related to the fluid flow rate. The dominant peaks are observed at 1000-1500 Hz and the frequency range is in congruence with the work of McKinley for sound of throttling gas through a channel. Of all the spectrum observed across the injection pressures and proppant sizes variation, the dominant frequency is distinct and is present at all-time due to fluid expansion across the perforation.

Despite the increase in usage of DAS system in flow rate measurement, the data collected were considered inefficient and difficult to interpret. This is due to the insufficient noise log research based data is documented in academia. Since the well completion is the single largest cost component of the well after drilling, therefore providing accurate acoustic data to DAS system is crucial for the petroleum engineers who to distinguish the type of reservoir fluid flows in a specific well, its flow rate and ultimately to determine the optimal fracture zone. Achieving this will enable the hydraulic fracturing stimulation to be operate more effectively especially to exploit low permeability unconventional reservoirs like tight sand and shale gas.

CHAPTER II

METHODS

Experimental Instruments

The hydrophone used is Bruel & Kjaer Hydrophone Type 8103, which is a small, high-sensitivity transducer used to collect sound signal from the perforation. It has the frequency range of 0.1Hz to 180 kHz with receiving sensitivity of 1V/μPa.

The charge amplifier, Bruel & Kjaer Type 2692 is used to amplify the sound signal collected by the hydrophone. It converts the acoustic pressure of the collected noise into an amplitude voltage.

Fast Fourier Transform (FFT) in LabView software by National Instruments is used for the spectral analysis. FFT is an algorithm that converts the time data into frequency data and store them in a large memory. Important FFT settings are sampling rates and frequency. Sampling rates is the number of samples taken per unit time from a continuous signal to make a discrete signal. Frequency for this setting must be doubled the needed frequency.

Experimental Set Up

The set up in **Figure 1** is a 5 – ½ inch well perforated with a ¼ inch hole size to simulate a fractured oil well. Production into the fractured well is simulated by injecting nitrogen gas through a 2 inch long pipe into the wellbore. The gas is injected at different flow rates by controlling the pressure at the gas tank. Noise produced from the flowing gas at the perforation is recorded using a hydrophone. A charge amplifier is used to amplify the recorded acoustic signal and to convert the acoustic pressure of the collected signal into a sound amplitude voltage. The signal was transformed into a frequency domain from a time domain by a Fast Fourier Transform (FFT) algorithm for a further quantitative analysis. The procedure is repeated by injecting water.

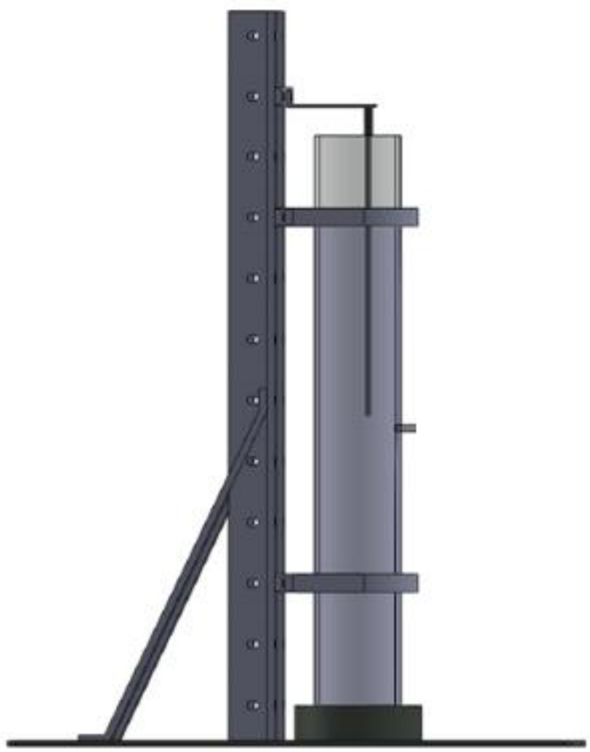

Figure 1 – The vertical well injection set up.

CHAPTER III

RESULTS AND DISCUSSIONS

The main goal in this study is to investigate the relationship between acoustic signals and its flow conditions in a vertical well. For each experiment, sound level as a function of the fluid flow rate is recorded.

Sound is measured in frequency with an assigned unit of Hertz (Hz). Frequency is defined as the number of repetitive wave cycles per second and the sound amplitude is expressed as the ratio of the sound pressure to a reference acoustic pressure, which in this study is an air pressure. As the nitrogen gas injected through the pipe into the perforation at the well, the fluid expands and creates a whistling phenomenon, which produces a high sound peak at its natural frequency.

Sound signal recorded in time domain as shown in **Figure 2**, which in this case at 100 scf/hr, 180 scf/hr and 250 scf/hr injection rate. As expected, the highest flow rate produces the highest voltage of sound amplitude. The data is analyzed in frequency domain as shown in **Figure 3** for 100 scf/hr injection rate, converted from time domain by Fast Fourier Transform (FFT) algorithm software.

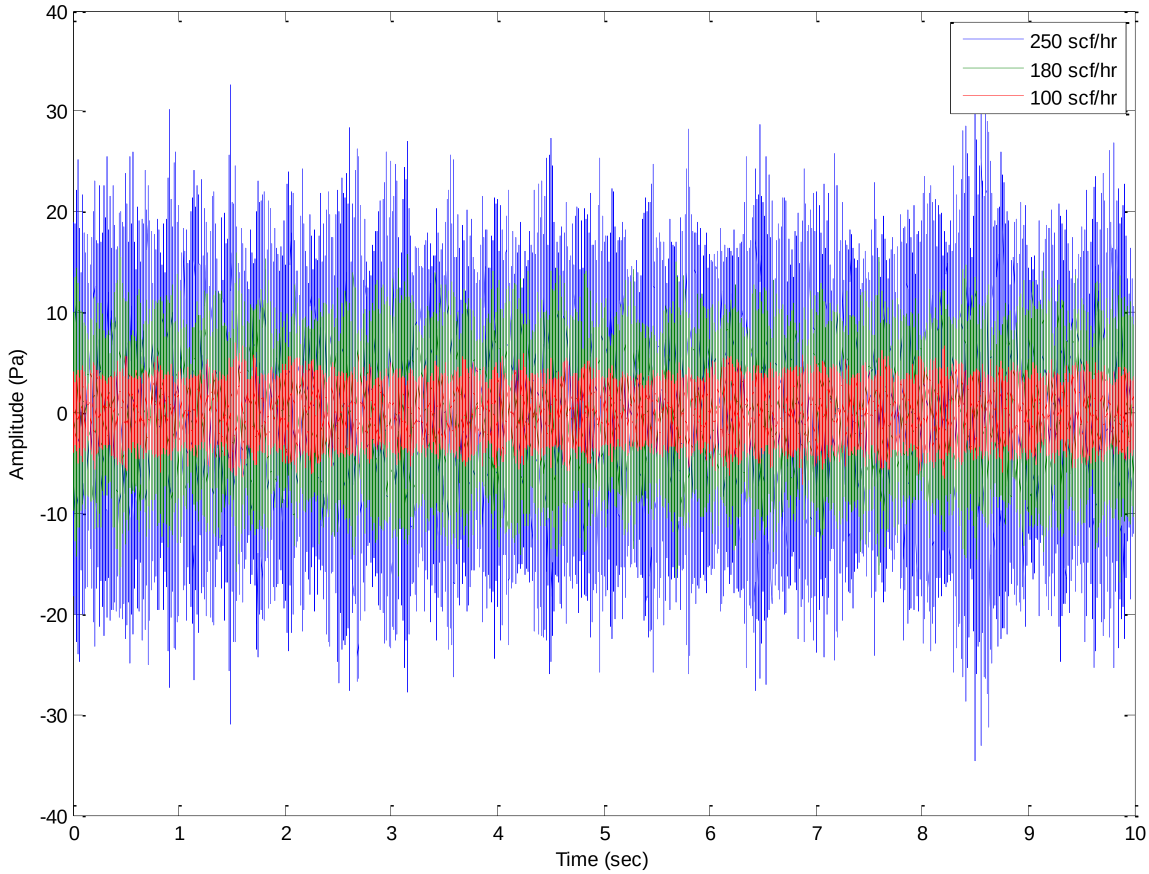

Figure 2 – Sampled sound signal in the time domain at 100 scf/hr, 180 scf/hr and 250 scf/hr

The background noise as seen in **Figure 3** exists as the small peaks (below 1 Pa^2) and therefore by applying the filter shown in **Figure 4**, it is found that the frequency range for nitrogen gas is from 3300 Hz to 3800 Hz for every 10 seconds of sound signal recorded. This frequency is distinctive only for nitrogen gas because different fluid has a different unique frequency at which it resonates.

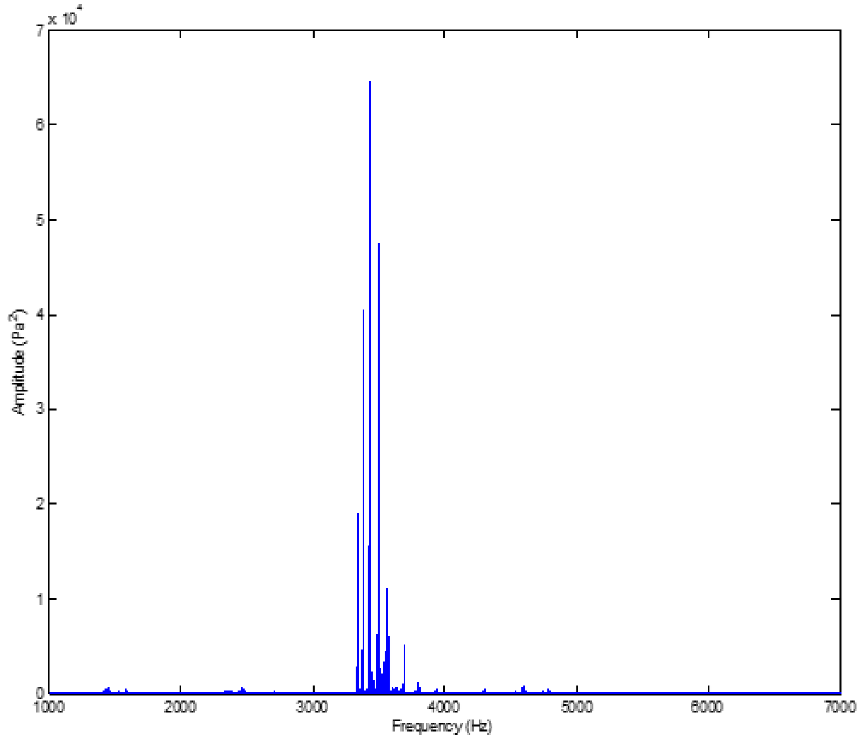

Figure 3 – Sampled sound signal in the frequency domain at 100 scf/hr injection rate

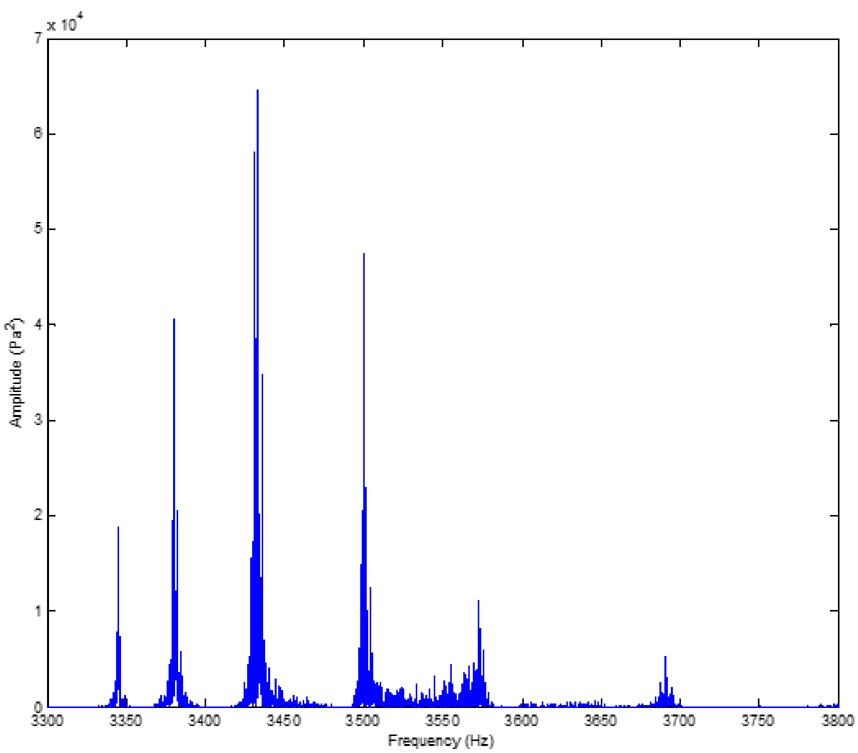

Figure 4 – Sampled sound signal at 100 scf/hr injection rate with background noise filtered out

The dominant frequency is always present at different injection rates. **Figure 5** further confirms this as both 180 scf/hr and 250 scf/hr injection rates have the same peaks existed within the same range. The difference in amplitude shows that a higher injection rate produces higher sound level at the perforation.

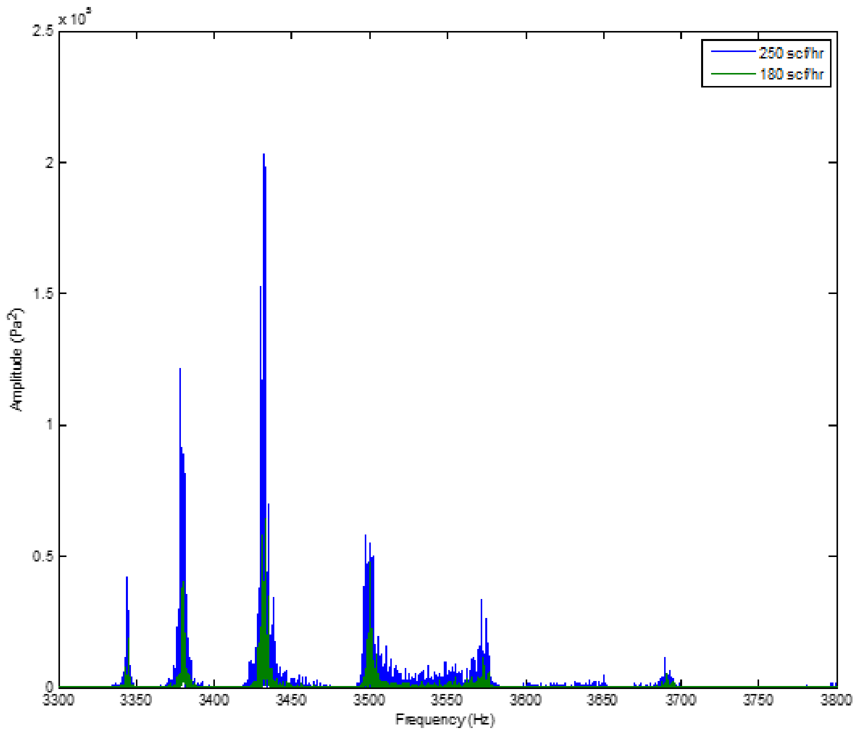

Figure 5 – Sound signal recorded at 180 scf/hr and 250 scf/hr injection rates

A visual representation of the sound spectrum frequency in variation with time is shown in **Figure 6** for 100 scf/hr injection rate. The color indicates energy that ranges from red (the highest energy) to blue (the lowest energy). From this spectrogram, the highest acoustic energy is recorded around 3000 – 4000 Hz range, which signifies the peak frequency for nitrogen gas, the same as from the previous sound signal recorded.

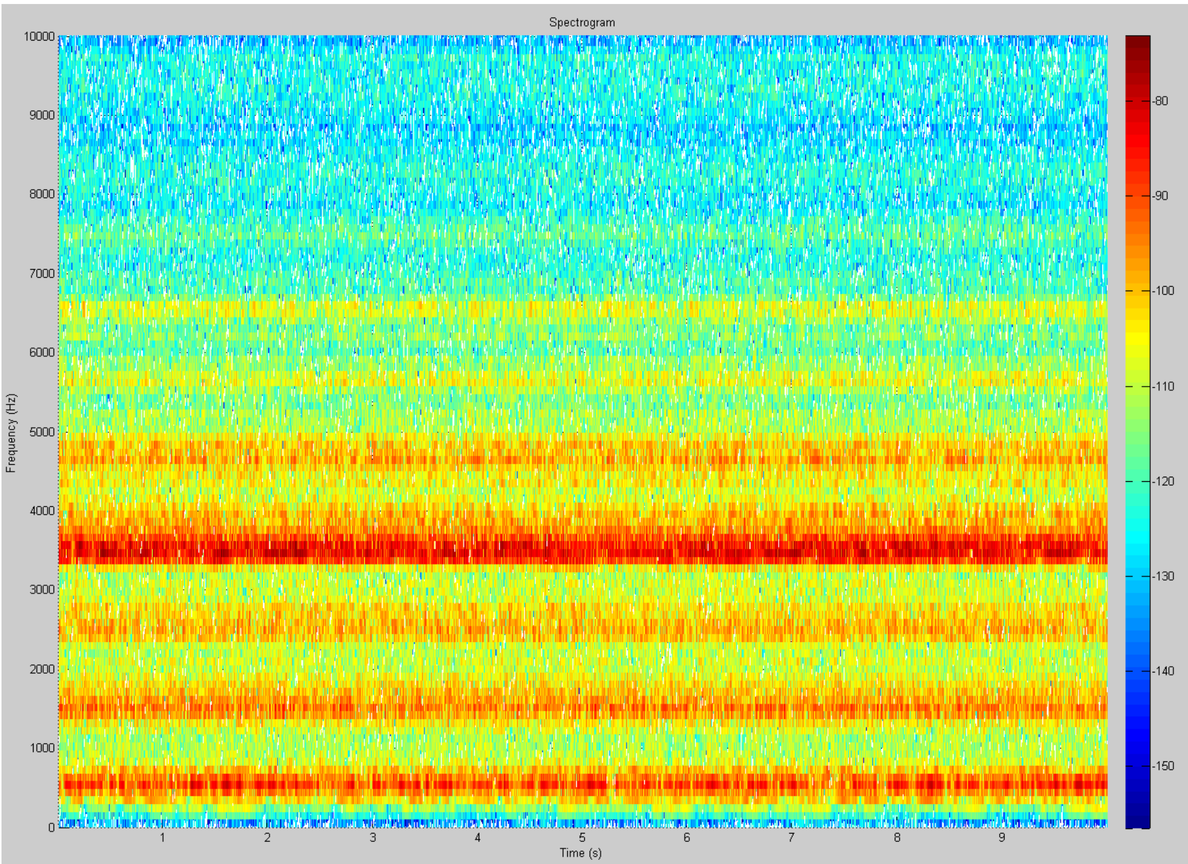

Figure 6 – Spectrogram of sound signals recorded at 100 scf/hr injection rate with 1 kHz – 7 kHz bandpass filter

The experiment is repeated using water as the injected fluid and thus, the similar correlation that the sound amplitude increases with the flow rate can be made. This is shown in **Figure 7** with the peak sound amplitude is the highest at 11.9 gal/min. However the 2.2 gal/min water injection rate produces relatively small sound amplitude that the peaks seemed non-existence at this resolution. It is also found that the dominant frequency range for water is present at all injection rates, which is between 500 Hz and 1000 Hz.

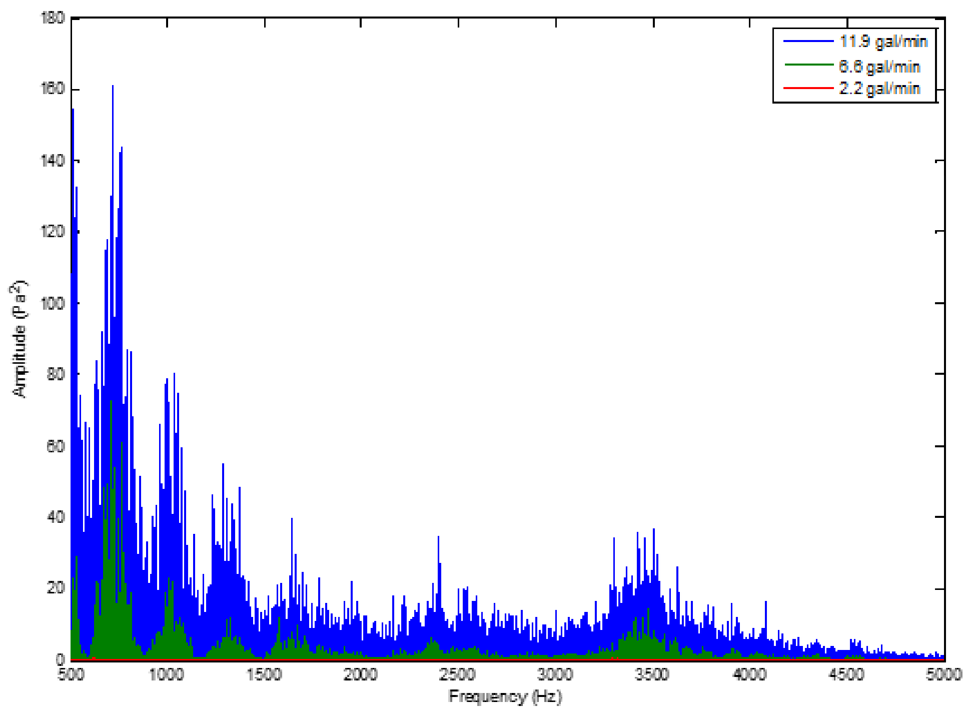

Figure 7 – Sound signal recorded for water injection rate of 11.9 gal/min, 6.6 gal/min and 2.2 gal/min

Nitrogen gas in comparison with water has a different frequency range as shown in **Figure 8**. Water sound spectrums injected at 11.9 gal/min and 6.6 gal/min have same peak distributions while gas injected at 100 scf/hr has a different and distinctive peak range. The water injection rate of 11.9 gal/min and 6.6 gal/min at equivalent gas rate of 96 cf/hr and 53 cf/hr respectively has smaller sound amplitude than the gas. This shows that sound levels are related to the flow rate of both fluids.

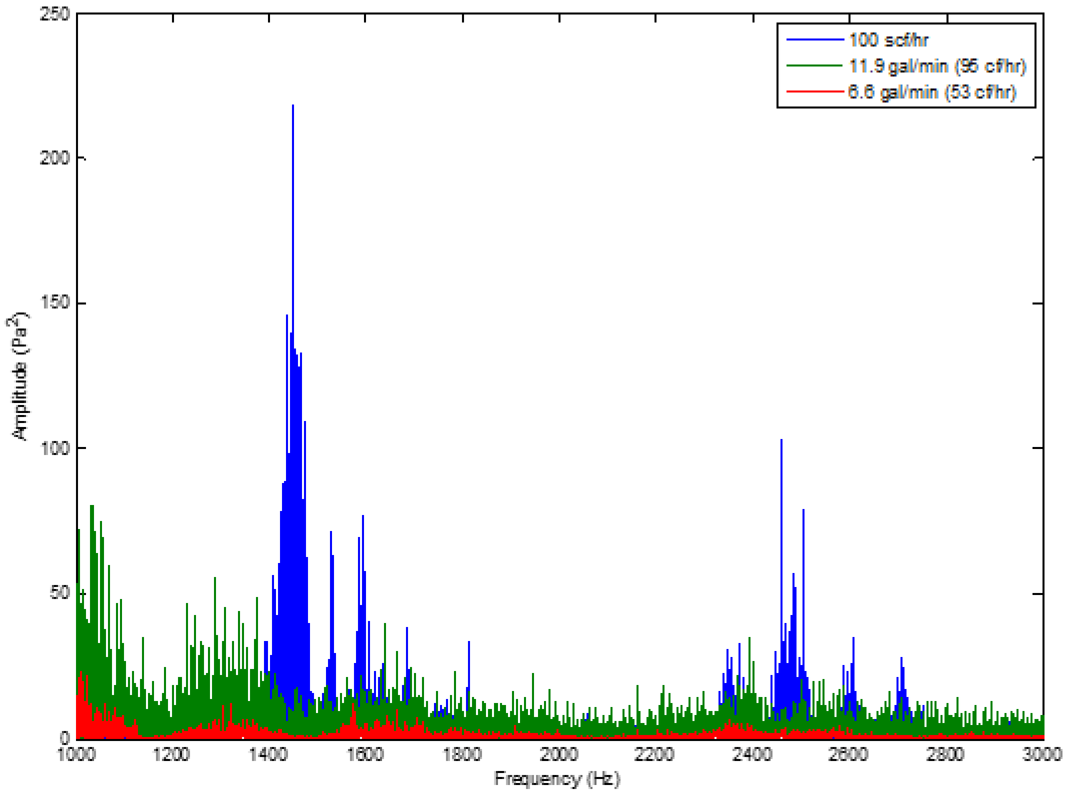

Figure 8 – Sound signal recorded for nitrogen gas injection rate of 100 scf/hr and water injection rate of 11.9 gal/min and 6.6 gal/min

CHAPTER IV

CONCLUSION

In this study, the sounds generated by fluids moving through a pipe into a perforation and into a simulated vertical well are measured. The dominant frequency range for different fluid phase is studied and the relationship between the sound level and fluid flow rate is examined for both gas and liquid. Based on the experimental observations and data analysis, the following conclusions are made:

1. The dominant peak frequency of sound spectrum indicates the fluid phase.
2. Gas flows at a higher phase frequency than liquid.
3. Nitrogen gas has a frequency range of 3300 Hz to 3800 Hz
4. Water has a frequency range of 500 Hz to 1000 Hz.
5. The magnitude of sound produced indicates the fluid flow rate.
6. Sound amplitude increases with flow rate for both gas and liquid injection.

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