ULTRASONIC BOREHOLE FLOWMETER

M.DU PREEZ AND P. HERTZOG

ABSTRACT

Although research has been conducted in the field of Acoustic Doppler Borehole Flowmeters (ADBF), it has been focused on point source of flow and three dimensional borehole flow techniques. However as of yet, no studies have been conducted on the possible use of Acoustic Doppler Borehole Profiling (ADBP). This technique of borehole flow measurement is possibly a revolutionary concept in how vertical flow in a borehole is measured. It makes use of a single inexpensive transducer that can float on the surface of the water in a borehole and use Acoustic Doppler techniques to profile the flow in a borehole. No complicated and expensive flow probe winching systems will be required. Another added benefit of the ADBP will be the non-evasive technologies that comprise its design. Current borehole flow probes are required to be present at the point of flow measurement in the borehole. The presence of the probe inadvertently alters the flow in the borehole by adding resistance to the flow in the borehole. Under stressed or pumped flow tests these flow resistance effects cause sufficient pressure gradients at the flow sensors to divert part of the flow away from the sensor. This causes erroneous readings of flow as a part of the flow in the borehole is not accounted for. In ADBP the sensor is not physically present at the point of flow being read. This makes the ADBP technique of borehole flow measurement far more representative of the natural flow conditions in the borehole under ambient and stressed conditions.

Key words: doppler borehole flowmeters, acoustic doppler borehole profiling, flow measurement, flow resistance.

1. INTRODUCTION

Vertical flowmeter logging measures vertical movement of fluid in a borehole. Flowmeter data can provide critical information for the design and interpretation of hydraulic testing and chemical sampling in ground water investigations, helping to refine site conceptual models. The results of flowmeter logging can also be used to design borehole completions used to prevent cross-contamination and to monitor head and (or) water chemistry. Vertical flowmeter logging can be conducted in boreholes, in fractured-rock aquifers, and in wells in unconsolidated sand and gravel aquifers.

2. AIM OF STUDY

The aim of this study is to develop a system that will use acoustic doppler theory and techniques to measure the vertical flow of water in a borehole.

3. METHODOLOGY

The principle on which the results for this study will be obtained is by comparison of data measured with the system developed in this study to measurements taken by an existing borehole flowmeter. The comparison of the data will give a good indication of how accurate the doppler velocity measurements are.

4. DOPPLER PRINCIPLE APPLIED TO MOVING OBJECTS

Acoustic Doppler Borehole Profiling uses sound to measure water velocity. The sound transmitted by the ADBP is in the ultrasonic range (well above the range of the human ear). The lowest frequency to be used by ADBP's is around 150 kHz, and the proposed range used by ADBP for test measurements is between 150 to 1,200 kHz.

The ADBP measures water velocity using a principle of physics discovered by Christian Johann Doppler. Doppler's principle relates the change in frequency of a source to the relative velocities of the source and the observer. The Doppler principle can be described best using the water-wave analogy. To visualize the Doppler effect, imagine a stationary observer watching a series of waves that are passing at a rate of one wave per second. This rate is analogous to a transmit frequency of 1 Hz. Now visualize the observer moving toward the wave source at a rate of four wavelengths per second. Because the waves are passing at a rate of one wave per second, the observer notices the passage of five waves during each second he moves in the direction of the source. He senses that the rate of the passing waves is 5 Hz, though the wave source is still emitting waves at 1 Hz. This phenomenon is known as the Doppler effect.

Many people have experienced the Doppler effect while on a busy street. The sound of a car horn seems to drop in frequency as the car passes and recedes from the observer. The apparent lowering of frequency is called the Doppler shift. The car is a moving sound-wave source; therefore, when the car is approaching an observer, the frequency of the sound waves striking the observer's ear drums is proportional to the speed of the car (in wavelengths per second) plus the frequency of the car horn in hertz. When the car is receding from the observer, the frequency of the sound waves striking the observer's ear drums is proportionally lower

5. BACKSCATTERED SOUND TO MEASURE VELOCITY

The ADBP uses the Doppler effect by transmitting sound at a fixed frequency and listening to echoes returning from sound reflectors in the water[1]. These sound reflectors are small particles or biologicals in the water that reflect the sound back to the ADBP. Reflectors in the borehole are all moving in the direction of the water flow. The majority of the sound that passes though the reflectors is not affected and only a small amount is reflected back to the transducer. The small amount that reflects back is Doppler-shifted to the frequency. If the source frequency is known, then the change in frequency can be calculated.

The equation below can be used to calculate the Doppler shift due to the relative velocities of the source and observer.

The equation for the Doppler shift in this situation is[3]:

$$Fd = Fs\left(\frac{V}{C}\right)$$

where:

- FdistheDopplershiftfrequency.
- Fsisthetransmittedfrequencyofthesound.
- V is the relative velocity between the sound source and the sound receiver.
- C is the speed of sound.

When sound scatterers move away from the ADBP, then the doppler shift is to the lower part of transmitted frequency. The backscattered sound then appears to the ADBP as if the scatterers were the sound source, the ADBP hears the backscattered sound Doppler shifted a second time. Therefore, the Doppler shift is doubled, changing to[21]:

$$Fd = 2 \times Fs\left(\frac{V}{C}\right)$$

6. VELOCITY PROFILE

ADBP measures flow profiles. This is done by dividing the entire borehole into flow cells. Each cell can be compared to a flow meter at a given depth. This means a flow profile can be compared to a string of flow meters at different depths taking flow measurements at the same time. We can then surmise that the cell length is the same as the distance between two flow meters and the numberof cells is the same as the number of flow meters on the string.

The two differences between an ADBP and a standard flow meter is that the ADBP measures flow at regular intervals, and each cell flow measure is the average flow in that cell, as opposed to the discrete, irregularly placed flow measurements of a standard flow meter. Regular spacing of velocity data over the profile makes it easier to process and interpret the measured data.

7. AVERAGING OVER THE RANGE OF EACH DEPTH CELL

Conventional flow meters measure actual flow at a discrete point in a borehole. ADBPs do not measure flows in small, localized volumes of water. They average velocity over the depth range of entire depth cells. This averaging reduces the effects of spatial aliasing. This aliasing effect causes false flow calculations which are constant over depth. Smoothing the observed velocity over the range of the depth cell rejects these false flow calculations and in effect smoothes out any uncertainties in the data.

8. RANGE GATING

Range gating is the process of determining flow profiles by looking at the reflected signals. Range gating breaks the received signal into successive segments for independent processing. The deeper the reflector is in the borehole the longer it will take the echo to return to the transducer. Thus, successive range gates correspond to echoes from increasingly distant depth cells. A depth cell averages velocity over a range within the water column, however, this averaged flow is not uniformly distributed over the cell. Instead, the depth cell is most sensitive to velocities at the centre of the cell and least sensitive at the edges. This allows the flow in a cell to be defined more clearly from these adjacent to it, improving the resolution of the profile.

9. EXPECTED OUTCOMES

The expected outcome of the study is to prove that the Doppler technique is applicable to measuring the flow of water in a borehole. These results will be obtained by the measurement of actual borehole flows using conventional equipment and comparing them to the flows measured in the study.

10. CONCLUSIONS

The Acoustic Doppler borehole profiling method appears to provide an effective method to measure the vertical flow of water in a borehole without placing the flow meter at the point of measurement. The method should also be simpler and cheaper to implement than current systems used to measure borehole flow. Although the average flow in a flow cell at any given depth is measured, should the measured cell be small enough, an accurate measure of flow will be represented.

11. REFERENCES

1. Arbeille, P., Eder, V. and Casset, D. Real-Time 3-D Ultrasound Acquisition and display for cardiac volume and ejection fraction evaluation. France, Elsevier, 1999.
2. Bastos, C.A.C., Fish, P.J. and St eel, R. Doppler power spectrum from a Gaussian sample volume. United Kingdom, Elsevier, 1999.
3. Bou Matar, O., Remenieras, J.P and Bruneel, C. Ultrasonic sensing of vibrations. France, Elsevier, 1998.
4. Mcbeath, M.K. and Neuhoff, J.G. The Ultrasonic Doppler effect is not what you think it is: Dramatic pitch change due to dynamic intensity change. U.S.A, *Psychonomic Bulletin & Review,* 2002.
5. Von Kruger, M.A. and Evans, D.H. Doppler Ultrasound Tracking Instrument for Monitoing Blood Flow Velocity. UK, Elsevier, 2002.
6. Tsochatzidis, N.A, Guiraud, P. and W ilhelm, A.M. Determination of velocity, size and concentration of ultrasonic cavitation bubbles by the phase Doppler technique. France, Pergamon, 2000.