

Research on Tubing Leak Detection and Location Technology of Horizontal Well based on Negative Pressure Wave Technology in Intelligent Well

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Abstract: The down-hole tubing real-time leak detection and location has been a blind spot in the field of oil pipeline monitoring. Once the tubing was damaged, all of the down-hole tubing must be replaced at the well site, as it is hard to find the leakage point for lacking of down-hole tubing leak detection and location technique. With the development of Intelligent well technology, the installation of permanent sensor provides the possibility of down-hole real-time tubing detection. In this paper, a new method based on annulus negative pressure wave is proposed to detect tubing leak. The research was focused on the model of annulus negative pressure wave, down-hole negative pressure wave velocity, signal processing, time interval of negative pressure wave. A new method for down-hole tubing leak detection and location is shown in this paper.

Keywords Intelligent Well; Horizontal Well; Annular; Negative Pressure Wave; Leak Detection Location

INTRODUCTION

In the past ten years, Intelligent Well Technology developed rapidly. It plays an important role in raising management level of reservoir/well production and enhancing reservoir recovery. Down-hole permanent sensors were used to collect real-time down-hole working condition of equipment and parameters of pay-streak such as pressure, temperature, flow rate and composition. More than 800 intelligent well systems were installed around the world, the related research of intelligent well becomes more and more, however, research on the leakage detection of tubing in horizontal well of intelligent well has hardly been founded. In the drilling site, if the producer founded the damage of the tubing in horizontal well, they took the measurement of replacing all tubing because they could not find the accurate leak point. Replacing all tubing cost a lot, besides, finding leakage timely can prevent blowout. So it is important to have a research on Tubing leak detection and location technology.

Our team put forward a technology of Tubing leak detection and location of the horizontal well in intelligent well based on negative pressure wave technology. The research focused on three aspects as follows:

- 1) Introduction of Intelligent Well System
- 2) Research on down-hole pressure wave model.
- 3) Critical technology of Tubing leak detection and location in horizontal well based on negative pressure wave technology

The research may contribute to the monitoring technology of intelligent well.

INTELLIGENT WELL SYSTEM REVIEW

Intelligent well system is mainly composed of down-hole sensor information collection system, down-hole production control system and down-hole data transmission system, ground data processing system, Smart Well System developed by Halliburton is shown in Figure 1. The research focus on horizontal well. From Figure 1, we can see that the horizontal segment was divided into four oil production horizons, each horizon consists of tubing, casing, annulus, Interval Control Valve, Permanent Down-hole Gauge, Fiber Optic Cable. Permanent down-hole

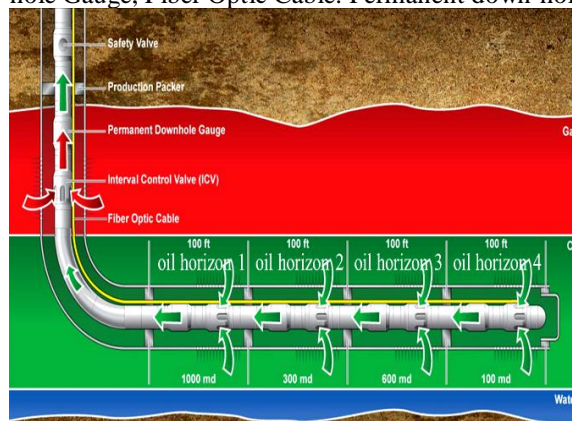


Figure 1. Halliburton Smart Well System

Gauge contains a lot of down-hole temperature, pressure, flow sensors, which are used to obtain real-time down-hole conditions. Tubing leak detection and location technology which we put forward based on this Smart Well structure and working condition.

FEASIBILITY ANALYSIS OF NEGATIVE PRESSURE WAVE TECHNOLOGY

To some extent, down-hole hostile environment limits the research on Tubing leak detection and location technology. With the development of intelligent well technology, the installation of Permanent down-hole gauge provided the possibility to go on this research. At present, there is a lot of long-distance pipeline leakage detection technology, such as magnetic flux leakage testing, eddy current testing, acoustic method, Ultrasonic guided wave method, distributed fiber optical technology, Negative pressure wave method and so on. The down-hole tubing and gauges are made through special processes, adding any new sensor or gauge need to redesign the tubing system. Comparison of various detection technology, we chose the Negative pressure wave method, as it is simple to design, easy to install, besides, the technology is advanced.

The theory of negative pressure wave leak detection and location is below: when the oil pipeline leaks, pressure of leak point drops quickly, the pressure of adjacent area is higher than leak point, negative pressure wave occurs at once. it spreads to both ends of the pipeline at a finite speed, time interval generates as different distance from leak

point to both ends of the pipeline. Using the pressure transducers which were installed at both ends of the pipeline can detect time interval, leak detection and location will be realized with the time interval and velocity of negative pressure wave. Permanent Down-hole Gauge in horizontal well is shown in Figure.2. It is possibility for tubing leak detection and



Figure 2 .Permanent Down-hole Gauge

location with the down-hole pressure gauge and negative pressure wave technology in horizontal well of intelligent well.

MODEL OF ANNULUS NEGATIVE PRESSURE WAVE

From Figure.1, the horizontal well consists of tubing, casing, annulus, casing perforation and so on, oil can flow into annulus with the casing perforation. The pressure of annulus is higher than tubing, when tubing leaks, the oil in annulus flows into tubing, under this circumstances, traditional methods of negative pressure wave can not fit, so we modified traditional negative pressure wave model in this paper, the model focused on annulus is shown in Figure.3

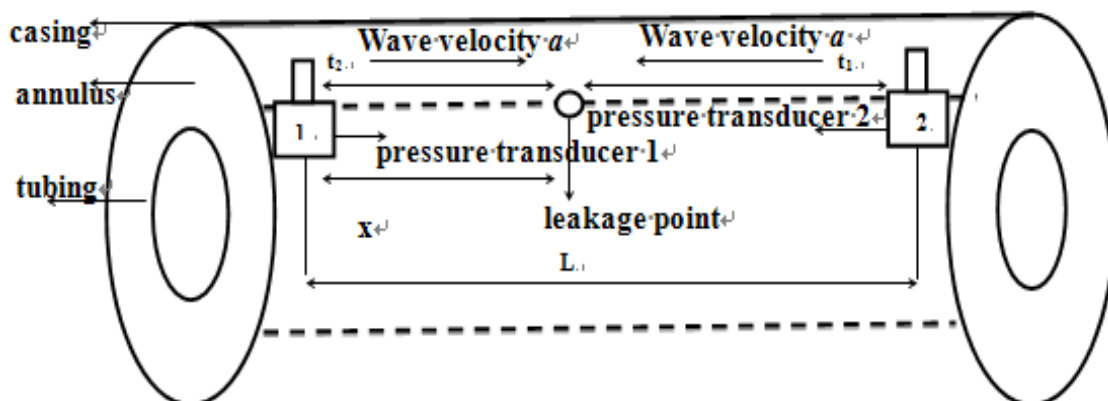


Figure.3 Model of Annulus Negative Pressure Wave

when tubing leaks, negative pressure wave forms in the annulus, we use pressure transducer 1, 2 to detect the pressure signal. After data analysis and disposal, we can achieve location information of leakage point. To this model, theoretical derivation were given as follows.

$$\Delta t = |t_1 - t_2| \quad (1)$$

$$\Delta t = \left| \frac{L - X}{a} - \frac{X}{a} \right| \quad (2)$$

$$X = \frac{L \pm a \Delta t}{2} \quad (3)$$

In eqs. (1) (2) (3), t_1 and t_2 are the pressure changing moment that the pressure transducer detected, Δt stands for time interval, L stands for the length of the tubing, the distance of two pressure

transducers roughly equal to L/X stands for the distance from leakage point to pressure transducer1, a is the velocity of negative pressure wave. In eqs. (3), constraint condition should be given to confirm the unique solution, constraint condition is given as follows: if $t_1 > t_2$ then $X < L/2$, if $t_1 \leq t_2$ then $X \geq L/2$. All the location formulas contribute to find the leakage point.

ANALYSIS OF CRITICAL ANNULUS LEAK DETECTION AND LOCATION TECHNOLOGY BASED ON NEGATIVE PRESSURE WAVE

Whether precise positioning can be achieved depends on the accurate velocity of negative pressure wave, besides signal processing of negative pressure wave and research on time interval play an important role too, we analyzed the critical technology according to the application of Long-distanced pipeline leakage detection based on negative pressure wave.

Research on Velocity of Negative Pressure Wave

Negative pressure wave velocity is one of the most important parameters of down-hole leak detection and location. Too many parameters can affect wave velocity as shown in equation (4).

$$a = \sqrt{\frac{k/\rho}{1 + \left(\frac{K}{E}\right)\left(\frac{D}{e}\right)c_1}} \quad \dots\dots\dots(4)$$

In eqs. (4), a is the velocity of negative pressure wave, k is coefficient of liquid cubical elasticity, ρ is the density of the fluid, E is elasticity modulus of tubing, D is diameter of tubing, e is thickness of tube wall, c_1 is corrected coefficient of related tubing constraint conditions.

From the research on Long-distanced pipeline, the velocity is between 1000m/s to 1200m/s. As the particular down-hole environment, the down-hole negative pressure wave velocity must be changed, research must be focused on it. From equation four, coefficient of liquid cubical elasticity K and density of the fluid ρ are the two main variable that affect negative pressure wave velocity.

Metrology institute of HeBei province measured 11 kinds of cubical elasticity from different Oilfield, including Daqing field, Xinjiang field, Shengli field and so on, research shows that cubical elasticity K influences by temperature and density, as equation (5) reveals.

$$\ln (F \times 10^{10}) = 0.51992 + 0.0023662t + 846596/\rho_0^2 + 2366.7t/\rho_0^2 \quad (5)$$

$$K = 1/F \quad \dots\dots\dots(6)$$

In eqs. (5)(6), F is compression coefficient, ρ_0 is standard density, t is temperature of liquid.

Another research shows that the density of oil is scarcely influenced by pressure and greatly affected by temperature. equation (7) shows the relation.

$$\rho(t) = \rho_{20} - \varepsilon \times (t - 20) \quad \dots\dots\dots(7)$$

In eqs. (7), $\rho(t)$ stands for the density in $t^\circ\text{C}$, ρ_{20} is the density in 20°C , ε is the coefficient of oil cubic expansion.

We conduct research on each oil production horizon in intelligent well, both ends of tubing are fixed constraint. The diameter of tubing is 73mm, thickness is 5.5mm, the diameter of casing is 127mm, thickness is 7.5mm. Divide the average diameter by average thickness, Arithmetic result you get is less than 25, so correction coefficient c_1 must be accorded with equation (8).

$$C_1 = \frac{2}{D/e}(1+u) + \frac{1}{1+e/D}(1-u^2) \quad \dots\dots\dots(8)$$

In eqs. (8), u is Poisson's coefficient, D is average diameter, e is average thickness.

Through calculation of the elastic coefficient, density and correction coefficient, we can deduce the velocity equation of down-hole negative pressure wave, as shown in equation (9).

$$a = \sqrt{\frac{1/F(t)/\rho t}{1 + \left(\frac{1/F(t)}{E}\right)\left(\frac{D}{e}\right)\left(\frac{2}{D/e}(1+u) + \frac{1}{1+e/D}(1-u^2)\right)}} \quad \dots\dots\dots(9)$$

In eqs. (9), F is compression coefficient, $\rho(t)$ stands for the density in $t^\circ\text{C}$, u is Poisson's coefficient, D is average diameter, e is average thickness. $F(t)$ and $\rho(t)$ can be deduced from equation (3)(4).

From the velocity equation of down-hole negative pressure wave, we can find that the change of velocity influenced by down-hole temperature and physical characteristics of fluid. At present, application of measuring down-hole temperature and density of fluid has been applied in intelligent well, which can contribute to achieve down-hole negative pressure wave velocity.

Signal Processing of Down-hole Negative Pressure Wave

Signal processing technology is one of the most important technology about tubing leak detection and location. When processing the signal, we should find the drop pressure point, The sharper and markedly the pressure signal changed, the easier the time of pressure changing can be found, positional accuracy can be improved. Actually the down-hole working condition is complicated, the pressure signal was collected using coding techniques to transmit to the surface. The signal decoded usually contains high-frequency noise, it is uneasy to find changed negative pressure wave. Wavelet analysis has been proved to be the effective way to process signal, wavelet analysis can undo noise, the method is bellowing: At first, changing time-domain signal to frequency domain signal, after removing interference wave, changing frequency domain signal to time-domain signal. By using the wavelet transform, IPC (industry control computer) can work out time interval easily, it is contribute to find leakage point. Equation (10)(11) show the wavelet transform, a schematic diagram of down-hole negative pressure wave signal processing is shown in Figure.4

$$WT_x(a, \tau) = \frac{1}{a} \int_{-\infty}^{\infty} x(t) * \theta\left(\frac{t-\tau}{a}\right) dt \dots\dots(10)$$

$$WT_x(a, \tau) = \frac{\sqrt{a}}{2\pi} \int_{-\infty}^{\infty} x(\omega) * \theta'(a\omega) e^{j\omega\tau} d\omega \dots\dots (11)$$

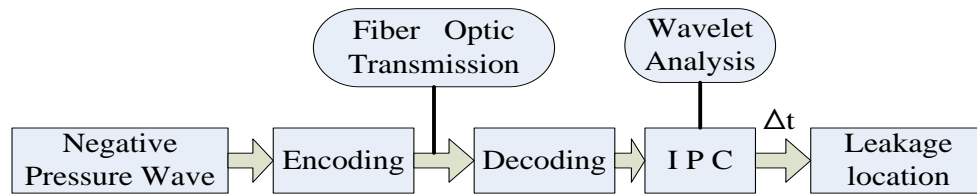


Figure.4 Diagram of Down-hole Negative Pressure Wave Signal Processing

Research on Detecting Time Interval of Downhole Pressure Transducers

Time interval (Δt) can affect the accuracy of tubing leak detection and location. On Long-distanced pipeline, producer use GPS time label location method to synchronize the time of industry control computers, then producer use wavelet transform to process the signal, so time interval can be obtained. Different from Long-distanced pipeline, Only one industry control computer used to process signal with wavelet transform method because of the optical used to transmit the pressure signal of the both ends. Compared with the long-distanced pipeline, the down-hole tubing leak detection and location system in horizontal well does not have the following trouble:

- (1). Industry control computer systems' times are not in synch
- (2). Sampling period of transducers is not consistent.
- (3). System response time is not consistent.

Without these problems, the time interval of down-hole negative pressure wave would be more accurate, however, the down-hole environment is complex, we should pay more attention on the design, installation and detection of down-hole transducers, which is the base of obtaining time interval.

CONCLUSION

A new method based on annulus negative pressure wave for down-hole tubing leak detection and location is shown in this paper. We put research emphasis on model of tubing leak detection and location, deducing of theoretical formula, down-hole negative pressure wave velocity, signal processing,

time interval of negative pressure wave. The research filled the void of down-hole tubing leak detection theory, intelligent well monitoring theory is enriched, and have a certain value.

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