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Numerical Simulation of Transient Flow in Product Pipeline

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Abstract

In this paper, explicit difference scheme, implicit difference scheme and characteristics method are compared to simulate transient flow in product pipeline. The simulation results of pressure and temperature can be used to prevent water hammer in the pipeline and improve the efficiency and safety in oil transmission. The stability and accuracy of the three methods are compared by adopting different time steps. For explicit method, large fluctuation may occur in case of large time step. For implicit method, the results are affected little by time step, only if the relaxation factor selected is reasonable. For characteristics method, the results have a good convergency and high precision. The results show that, in the situation of valve shut down in terminal station, it takes about 1.1×10^4 seconds to return to a new steady state.

1. Introduction

The horizontal diesel pipeline consists of first station, intermediate station and terminal station. The diameter is 457×7.1mm and length is 218km. The distance between the intermediate station and the first station is 130km. Density of the diesel ρ =840kg/m^3.Viscosity υ =7.02 × 10^{-6}m^2/s. Flow rate Q=625m^3/h. Pipe surface roughness e=0.01mm. The elastic modulus K=1.39 × 10^{9}Pa.Young' s elastic modulus E=207×10^{9}Pa. Centrifugal pumps named 1# and 2# are in series in the first station and 3#centrifugal pump is used in the intermediate station. At first, the pipeline is operated in a steady state. The simulation is about shut down of valve in

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the terminal station; time of shut down is 10seconds.The other related parameters are shown in the following tables [1]-[3].

Table 1 The relationship between the resistance coefficient and the valve opening（$Kv/s^2/m^5$）

Valve opening %	100	90	80	70	60	50	40	30	20	10	1
Resistance coefficient	1.75	8.45	18	40	87	191	382	419	916	2×10^3	1×10^6

Table 2 Centrifugal pump parameters

Table			1			The		
Table	1	The	m^3/h	m	kw	m^3/h	m	kw
Table	1	The	411	280	387	350	306	385
Table	1	The	634	255	485	602	295	511
Table	1	The	853	232	539	855	273	644

2. Mathematical model

Assuming that the constraint of the pipe is double-ended beams, the Poisson ratio μ is set as 0.3.The wave velocity is described as

$$a=\sqrt{\frac{k}{\rho(1+\frac{kD}{E\delta}\varphi)}}$$,

Where, $\varphi=1-\mu^2$ [4].

The kinematic equation and the continuity equation, separately as an expression of momentum conservation and mass conservation, can be expressed as Eqs. (1) and (2)

$$\frac{dV}{dt}+\frac{1}{\rho}\frac{\partial P}{\partial x}+\frac{\lambda}{2D}V|V|=0 \quad , \qquad (1)$$

$$\frac{dP}{dt}+\rho a^2\frac{\partial V}{\partial x}=0 \quad . \qquad (2)$$

The Eqs. (4), (6), (8)and(10) were solved with the values of the previous time layer at every time step , until the final results were obtained.

1) The explicit difference scheme

Each section of the kinematic Eq.(1) is discreted by the explicit discrete format [5].

$$\frac{V_i^{n+1}-V_i^n}{\Delta t}+V_i^n\frac{V_i^n-V_{i-1}^n}{\Delta x}+\frac{P_i^n-P_{i-1}^n}{\rho\Delta x}+\frac{\lambda V_i^n|V_i^n|}{2D}=0 \quad . (3)$$

In the kinematic Eq. (1), the velocity can be written as:

$$V_i^{n+1}=\left(V_i^n-\frac{\Delta t V_i^n}{\Delta x}(V_i^n-V_{i-1}^n)-\frac{\Delta t}{\rho\Delta x}(P_i^n-P_{i-1}^n)-\frac{\lambda\Delta t V_i^n|V_i^n|}{2D}\right) \quad . (4)$$

Each section of the continuity Eq. (2) is discreted by the explicit discrete format [6].

$$\frac{P_i^{n+1}-P_i^n}{\Delta t}+\frac{V_i^n+V_{i+1}^n}{2}\times\frac{P_i^n-P_{i-1}^n}{\Delta x}+\rho a^2\frac{V_{i+1}^n-{}_i^n}{\Delta x}=0 \quad . \quad (5)$$

Then the discretization pressure expression is obtained, in Eq.(2):

$$P_i^{n+1}=[P_i^n-\frac{\Delta t(V_i^n+V_{i+1}^n)}{2}\times\frac{P_i^n-P_{i-1}^n}{\Delta x}-\rho a^2\Delta t\frac{V_{i+1}^n-V_i^n}{\Delta x}] \quad . \quad (6)$$

2) The implicit difference scheme

Each section of the kinematic Eq.(1) is discreted by the implicit discrete format [7]-[8].

$$\frac{V_i^{n+1}-V_i^n}{\Delta t}+V_i^{n+1}\frac{V_i^{n+1}-V_{i-1}^{n+1}}{\Delta x}+\frac{P_i^{n+1}-P_{i-1}^{n+1}}{\rho\Delta x}+\frac{\lambda V_i^{n+1}|V_i^{n+1}|}{2D}=0 \quad . (7)$$

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The velocity, which adopts the relaxation factor ϖ, can be described as follow:

$$V_i^{n+1}=\varpi\left(V_i^n-\frac{\Delta t V_i^{n+1}}{\Delta x}(V_i^{n+1}-V_{i-1}^{n+1})-\frac{\Delta t}{\rho\Delta x}(P_i^{n+1}-P_{i-1}^{n+1})-\frac{\lambda\Delta t V_i^{n+1}|V_i^{n+1}|}{2D}\right)+(1-\varpi)\ V_i^{n+1} \quad . (8)$$

Each section of the continuity Eq. (2) is discreted by the implicit discrete format [9]-[11].

$$\frac{P_i^{n+1}-P_i^n}{\Delta t}+\frac{V_i^{n+1}+V_{i+1}^{n+1}}{2}\times\frac{P_i^{n+1}-P_{i-1}^{n+1}}{\Delta x}+\rho a^2\frac{V_{i+1}^{n+1}-V_i^{n+1}}{\Delta x}=0 \quad . (9)$$

The pressure, which adopts the relaxation factor ϖ, can be calculated as Eq.(10)

$$P_i^{n+1}=\varpi[P_i^n-\frac{\Delta t(V_i^{n+1}+V_{i+1}^{n+1})}{2}\times\frac{P_i^{n+1}-P_{i-1}^{n+1}}{\Delta x}-\rho\alpha^2\Delta t\frac{V_{i+1}^{n+1}-V_i^{n+1}}{\Delta x}]+(1-\varpi)\ P_i^{n+1} \quad . (10)$$

3) The characteristic line method [12]-[15]

(1)Interior points for interpolation

$$\begin{cases}Q_{A'}=\phi(Q_A-Q_{A^*})+Q_{A^*}\\ H_{A'}=\phi(H_A-H_{A^*})+H_{A^*}\end{cases},\begin{cases}Q_{B'}=\phi(Q_B-Q_{B^*})+Q_{B^*}\\ H_{B'}=\phi(H_B-H_{B^*})+H_{B^*}\end{cases} \quad , \quad (11)$$

$$C^+:H_{pi}=R_{i-1}^+-S_{i-1}^+Q_{pi},C^-:H_{pi}=R_{i+1}^-+S_{i+1}^-Q_{pi} \quad , \quad (12)$$

Where, C+ and C- are the characteristic lines,

$$\begin{cases}R_{i-1}^+=H_{i-1}^++C_wQ_{i-1}\\ R_{i+1}^-=H_{i+1}^--C_wQ_{i+1}\end{cases},\begin{cases}S_{i-1}^+=C_w+f|Q_{i-1}|\Delta X\\ S_{i+1}^+=C_w+f|Q_{i+1}|\Delta X\end{cases} .$$

The value of H_{i-1}^+, H_{i-1}^+, H_{i-1}^+ and H_{i-1}^+ are confirmed by the interior points. Expressions of Q_{pi} and H_{pi} are shown as follows, calculating friction with Repin-Formula.

$$Q_{pi}=\frac{R_{i-1}^+-R_{i+1}^-}{S_{i-1}^++S_{i+1}^-},H_{pi}=R_{i-1}^+-S_{i-1}^+\frac{R_{i-1}^+-R_{i+1}^-}{S_{i-1}^++S_{i+1}^-} . \quad (13)$$

(2)The boundary conditions

The boundary condition of the terminal station is expressed as Eq. (14).

$$C^+\quad H_{p2,N}=R_{2,N-1}^+-S_{2,N-1}^+Q_{p2,N}\quad H_{p2,N}-H_d=KQ_{p2,N}^2 \quad . \quad (14)$$

The intermediate station's boundary condition is described in Eq.(15)

$$Q_p=\frac{(S_{1,N-1}^++S_{2,1}^-)-\sqrt{(S_{1,N-1}^++S_{2,1}^-)^2-4(B_3-K_2)(R_{1,N-1}^+-R_{2,1}^-+A_3)}}{2(B_3-K_2)} \quad . \quad (15)$$

The following Eq.(16) is the boundary condition of the first station

$$Q_{p1,0}=\frac{S_{1,1}^--\sqrt{(S_{1,1}^-)^2-4(B_1+B_2-K_1)(H_{1j}+A_1+A_2-R_{1,1}^-)}}{2(B_1+B_2-K_1)} \quad . \quad (16)$$

3. Numerical Results

In Figure1, results of explicit difference, implicit difference scheme and characteristics method.

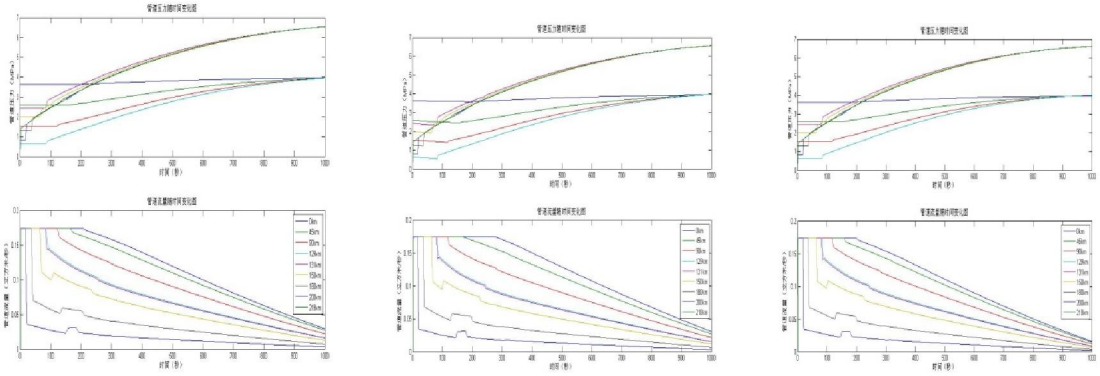

Fig. 1 The distribution diagrams of the pip-head and the flow rate from 0 to 10^3s

4. Conclusion

The stability and accuracy of the three methods are compared by adopting different time steps. For explicit method, large fluctuation may occur in case

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of large time step. For implicit method, the results are affected little by time step, only if the relaxation factor selected is reasonable. For characteristics method, the results have a good convergency and high precision. Different points in the pipeline respond to the pressure wave at different time, because wave transmission will cost some time. Unstable condition caused by the valve shut down in the product pipeline tended to a new steady state after about 1.1×10^4 seconds.

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