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Failure analysis of high-drop pipeline in the process of dewatering

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ABSTRACT

A new built gas pipeline exploded twice in succession at the late stage of dewatering after the pressure test. On the basis of the field data and description, the hydraulic state of the pipe flow was deduced. Thereafter the mechanical model characterizing the motion of the liquid plug and the compressible flow dynamic model describing water hammer have been established. Development, propagation, reflection, transmission and interaction of water hammer wave have been presented by the models. The field phenomenon that a lot of water and gas spurted intermittently from the outlet could be explained by this study. The dangerous position prone to explosion is determined and accordant with the fact. It is found that the essential cause for the explosion is the restricted delivery capacity of the air compressor and the big elevation change of the pipeline, which lead to cavitation and column separation. The instantaneous ultrahigh pressure due to water hammer results in pipe explosion.

1. Introduction

Natural gas pipeline has many characteristics, such as large discharge rate, long distance, large-scale investment, and more crossings. It is the fact that the terrain condition of new built gas pipeline becomes more and more complicated, and the safety of pipelines attracts more and more attention [1–3]. Generally pigging and pressure test would be carried out in turn after a pipeline has been built. The pressure test, consisting of strength test and leak test, is followed by dewatering. In 2010, explosions happened twice in succession at almost the same location of a newly-built domestic gas line when it was drained after the pressure test. An on-site picture of the second explosion is shown in Fig. 1.

Fig. 2 shows the elevation of the whole pipeline, in which air compressor was installed at section S_α and the drain pipe was welded on the last tube at section S_ε that was ended by a header. The gulch was figured as segment S_β–S_γ–S_δ with bottom and eastern high-elevation point illustrated as section S_γ and S_δ respectively. The distance and elevation of the characteristic sections are listed in Table 1. The pipeline with an outer diameter of 1219 mm and a thickness of 18.4 mm was made of X80 steel (see details in Tables 2 and 3). After this pipeline had been laid, working procedures including pigging, water flooding, strength test, and leak test were carried out orderly. When the pressure test was considered valid, the water inside the pipeline was evacuated by use of a displacement pig being pushed by compressed air. After the dewatering had been proceeding for about 20 h, explosion happened at the last steel tube adjacent to the outlet and a part of the pipe was broken away from main pipe. After the pipeline was restored, the second pressure test was operated. During this dewatering, an air compressor

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Nomenclature

A	cross section area, m^2
C	wave speed, m/s
D	inner diameter of the pipe, m
E	modulus of elasticity, Pa
e	thickness of the pipe, mm
F	force, N
g	gravitational acceleration, $g = 9.8\ m/s^2$
H	pressure head, m
L_{AB}, L_{DE}	length of water column AB and DE, $L_{AB} = 275$ m, $L_{DE} = 378$ m
m	mass of the pig, kg
p_{ac}	relative pressure of the high-pressure air supplied by compressor, Pa
p	driving pressure applied on the water column AB by the pig, Pa
P_a	atmospheric pressure corresponding normal condition, $P_a = 101.326$ kPa
P_V	saturated vapor pressure of water under 20 °C, Pa
Q	delivery capacity of air compressor, $Q = 30\ m^3/min$
R	constant for gas, $R = 287$ J/(kg K)
s	curvilinear coordinate, m
S	denotation of section.
t	time, s
T	absolute temperature, K
u	displacement, m
v	velocity, m/s
V	volume occupied by high-pressure air in the pipeline, m^3
z	elevation, m
α	pipe slope, degree
ΔT	time interval needed by the pig to move from bottom of gulch to the section to explore, s
λ_H	Darcy-Weisbach friction factor
ν	Poisson ratio
ρ	density, kg/m^3
σ	stress, Pa
σ_u	ultimate strength, Pa
σ_y	yield stress, Pa

Subscripts

0	initial value of water hammer just before collision
A, B, D, E	beginning and last section of water column AB and DE respectively
G	air
H	water
j	computational grid
I	incident wave
r	radial
R	reflected wave
S	steel
T	transmission wave
z	longitudinal
θ	hoop

with a rated discharge of $30m^3/min$ and a rated pressure of 2.2 MPa was used to push the pig with wring being 5–8%, and the pig pushed the water. However the same explosion occurred at the last stage of dewatering when the driving pressure supplied by air compressor was 1.01 MPa [4]. There are some similar phenomena between these two explosions as follows: (1) the pipeline had not drained any water for a long period of time just before the pig reached the outlet. For the second explosion this period was almost 5.5 h. (2) The fracture of the pipe had a characteristic of ductile fracture. To explain the accidents, tensile test, metallographic analysis and scanning electron microscopy test had been carried out in the sample tube and the relevant criteria were all met [5,6]. For the third dewatering process, 4 draining outlets with diameter of 600 mm were opened at the end of the pipeline. This time the pipeline did not explode. But a pressure signal characterized by water hammer had been monitored near the header during the last 4 min of the process [4].

Generally leakage may occur during pressure test, while pipeline rarely breaks in the course of dewatering. Therefore there are few studies on this issue. The studies on water hammer in pipeline normally focus on the problems such as pipe