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Lifetime prediction of natural gas polyethylene pipes with internal pressures

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ABSTRACT

The purpose of this study was to propose a lifetime prediction model of aging natural gas polyethylene (PE) pipeline with various internal pressures by thermal-oxidative aging (TOA) test and oxidative induction time (OIT) test. By using a pressured natural gas PE80 pipe under the condition similar to actual urban natural gas working condition, an improved TOA experimental set-up was built, and had been used for accelerated TOA test of pressured PE pipes at different test temperatures. By using dynamic curve linearization method and based on Arrhenius fit of the data, an empirical lifetime prediction model of thermal oxidative aging law for PE pipes was developed to extrapolate lifetime of PE80 pipes with internal pressures. The results show that under the test internal pressure of 0.1 MPa, 0.2 MPa, 0.3 MPa, and 0.4 MPa, the lifetimes of aging PE gas pipes with internal pressure are 14%, 24.5%, 36.1%, and 41.6% shorter than those without internal pressure.

1. Introduction

Typical requirements for natural gas PE pipes are at least 50 years [1,2]. Up to now, with increasing service life of PE pipes, aging pipes made of PE with a lower performance have been used for decades. The safety issue of aging polyethylene pipes can be solved by lifetime prediction methods [3,4]. A great number of researches on aging tests method and lifetime prediction of PE pipes have been extensively carried out at home and abroad. Chaoui, et al. found a certain correlation between failure times under both constant and fluctuating loading patterns [5]. Ifwarson found that PE pipes' lifetime was more than 50 years at a dimensioning stress of 5 MPa at 45 °C [6]. Hoàng and Lowe extrapolated the lifetime of plastic pipes by using a very powerful tool which is the combination of pressure test and chemical analysis tests [7]. Frank predicted the lifetime of PE pipes by using a fracture mechanics extrapolation procedure [3]. Pinter et al. researched the main elements for lifetime and safety assessment of PE pressure pipes for arbitrary installation conditions based on modern methods of fracture mechanics [8]. Langlois et al. studied the earliest rate change associated with the end of the induction period by using the thermos-oxidative aging of extruded ribbons of linear PE cross-linked [9]. Abdelaal and Rowe investigated two different methods of establishing the length of the antioxidant depletion stage using Arrhenius modeling for the 4-parameter model at 20 °C, 30 °C, 50 °C and 90 °C [10]. Vogt et al. studied the resistance to thermal degradation on pipes made from a PE 100 resin containing a usual antioxidant system at 80 °C, 90 °C, 100 °C and 110 °C [11]. Mahl et al. researched the effect of temperature on the mechanical behavior of the HDPE experimentally in a range of 223 K to 373 K [12]. Lan et al. found the

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Nomenclature

f(p)	a function describing the stage
t	reaction time, h
A	a constant
E	activation energy, J•mol^{-1}
K	reaction rate, h^{-1}
R	gas constant, 8.31 J•K^{-1}•mol^{-1}
T	absolute temperature, K
Z	frequency factor, h^{-1}

lives of PE gas pipes with internal pressure are 9.6% shorter than those without internal pressure by accelerated thermal oxidative aging test under the pressure 0.1 MPa [13–15]. Milani et al. found mechanical properties decrease with time and temperature, whereas in vulcanization such properties increase (applied for vulcanization of wires, but aging has exactly a mirrored behavior) [16–19]. From the above research, it can be seen that there are some problems needed to solve. Firstly, the traditional method to assess the aging lifetime of PE pipe is to use a hydrostatic pressure test [7,20]. However, it takes a long time and is very expensive. Moreover, lifetime extrapolation from hydrostatic pressure tests tends to provide unrealistic lifetime figures. For example, previous studies based on hydrostatic pressure testing on HDPE pipes conducted at 60 °C and 80 °C extrapolated a service lifetime of about 500 years at ambient temperature [21]. If the aging test condition is similar to actual working situation of urban gas PE pipes under internal pressure, a more real results would be obtained. For these reasons, based on thermal oxidative aging test under different pressures in PE pipes, a new method is used to predict the lifetime of PE80 grade pipe in this paper.

2. Experiment

2.1. Materials

A high-density polyethylene (PE80 classification) pipe for natural gas transportation was tested. The density of the PE material (granule) was 0.95 g/cm^3 and its melt mass flow rate (190 °C/5 kg) was 0.90 g/10 min. The outer diameter of PE pipe materials was 40 mm and the wall thickness was 4 mm. Under the long-term pressure of 20 °C and 50 years, the minimum value of circumferential tensile strength (TS) was 8 MPa (MRS).

2.2. Experimental set-ups

The previous thermal oxidative aging test of pressured PE pipes [13,14] was operated by raising the pressure of PE pipes beyond the aimed pressure slightly before shutting down the air pump and valve. Then the internal pressure of PE pipes was adjusted to test pressure value by relief valve. Since the internal pressure would decrease during the long time test, internal pressure of the PE pipes must be pressured regularly. It should be noted that if the output pressure of air pump was not controlled properly, the aging test results would be unreliable. To avoid that adverse effect, a thermal oxidative aging test of pressured PE pipes [13] had been improved from the previous one (as shown in Fig.1 and Fig.2). In order to reduce the effect of pressure difference between internal pressure and external pressure on the experiment when the pressure of aging PE pipes needed to increase, a pressure gage (3) and a valve (4) are installed in the improved test platform for monitoring external pressure. In addition, seal component has been replaced to reduce the gas leakage and ensure that the pressure can be kept in a stable range (5%) in a long time. In Fig.1, PE pipe is sealed by sealing clamp in the thermal oxidative aging oven, PE pipe and other components (air pump, valves, pressure gauge, relief valve, and pressure gauge) are connected with a closed pipeline. Then the thermal oxidative aging test is carried out under different conditions.

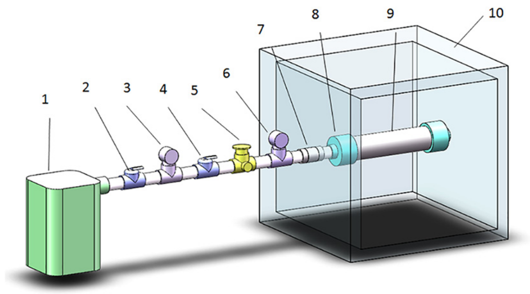

Fig. 1. Thermal oxidative aging experimental set-ups of pressured PE pipes (1- air pump, 2- valve, 3- pressure gage, 4- valve, 5- relief valve, 6- pressure gage, 7- gasket ring, 8- sealing clamp, 9- PE pipe, 10- aging oven).