Iranian Polymer Journal
17 (7), 2008, 503-517

Applicability of Medium Density Polyethylene Gas Pipes in Hot Climate Areas of South-west Iran

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Received 16 December 2007; accepted 20 May 2008

A B S T R A C T

The applicability of medium density polyethylene (MDPE) gas pipes in hot climate areas of southern Iran (such as Khuzestan) has been one of the main concerns of local gas company officials and their engineers. This is due to the facts that buried pipes can experience severe stresses due to internal pressures, traffic load, soil height, daily and/or seasonal temperature variations if not properly designed and installed underground. This research investigates the sole effect of each parameter and their combination on maximum stress produced in MDPE gas pipes and their sockets which are made from PE100. The analysis was performed through a comprehensive finite element process and the results were compared to those of empirical equations, where possible. The maximum local stresses in pipes and sockets were determined and compared to their critical values for an operating pressure of 4 bars at various depths and temperatures. The design curves and the range of applicability of MDPE are then deduced based on a life time of 50 years. According to the results, assuming a target temperature of 30ºC for the pipe and its socket, then MDPE pipe and its HDPE socket (PE100) can well sustain the imposed load of a temperature rise of 15ºC at a depth of 120 cm, in presence of all other loads mentioned above. For higher temperature rises, some stress relief mechanisms must be employed. Hence, by applying the right procedure, these pipes can be used for gas transportation even in hot climate areas of Iran, where the ground surface temperature may reach a high value of 67ºC in summer time.

INTRODUCTION

It is known that polyethylene pipes offer many advantages over traditional ductile iron and steel pipes. These advantages include flexibility, coilability, high ductility, light weight, corrosion resistance, and reduced installation costs [1]. These features provide both performance and economic benefits which in turn have made polyethylene pipes popular in ploughing-in and trenchless technology applications.

Over the past 50 years, many improvements in polyethylene product technology have been made. These improvements have led to the development of the well
known PE80, PE80B, and PE80C materials which are now widely used throughout the world [2]. PE80B and PE80C pipe materials are recognized as offering excellent long term performance as pressure pipes. In particular, medium density PE80B materials have found great utility in ploughing-in applications due to their flexibility and ease of coiling.

As stated earlier, most PE piping is considered flexible. These pipes deflect under load, such as overburden load encountered when installed underground [3]. The designer and installer of the underground flexible piping must utilize the soil to construct an envelope of supporting material around the pipe, for the deflection to be maintained at an acceptable level. The extent to which the pipe deflects depends on this enveloping support and is a function of the depth of cover, surface loading, and standard dimension ratio (SDR) or ring stiffness of the pipe [3]. This deflection is affected when the pipe is pressurized inside or by any local discontinuities due to various joints or other available sources.

In general, the supporting envelop is built by surrounding the pipe with firm and stable materials. This envelope is often referred to as the “embedding”. The amount of support by the embedment is directly proportional to its stiffness. Thus, the embedding material is often compacted [4]. The stiffness of the material placed above the pipe may also affect the pipe’s performance. Considerable load reduction may occur due to arching, that is, the reduction of stresses in the soil above and around the pipe result in shifting of the load away from the pipe. The stiffer the backfill above the pipe, the more arching is going to happen. Obviously, upon usage of polyethylene in gas pipe industry, to fulfill the required standards, selective materials must be used in each layer around the pipe [5].

To better estimate the behaviour of PE pipes under the applied load, several authors [6,7] have tried to investigate the soil-pipe interaction effect of sewerage plastic pipes. The performance of buried high density polyethylene (HDPE) pipes at elevated temperature was also investigated by Alawaji [8]. In his work, the effect of temperature on deformation characteristics and performance of HDPE was investigated. The testing programme was composed of a ring pipe submerged in heated water at various temperatures.

Popelar has investigated the mechanical and creep properties of polyethylene gas pipe materials PE23061X and PE3408IV [9]. In his work, stress-strain diagrams were deduced under various conditions. Teoh and his colleague [10] have also investigated the pressure rupture of HDPE pipes. Harris [11] has studied the development of a patch consisting of a solvent swollen polyethylene film that can be applied to a live natural gas line. The patch was applied under elevated temperature conditions allowing for a modified solvent weld, effectively repairing pipe lines within quarter of the current time required to repair them.

Although in polyethylene gas pipe design, simple relations for stress calculations are available through many standards, due to complex interaction of soil-pipe, presence of traffic load, inside pressure, soil weight, temperature variations, and local discontinuities in geometry, local stresses may arise which might well exceed those predicted by the equations. This in turn will affect the pipe's life and performance. Since polyethylene resin has a relatively higher thermal expansion coefficient than metals, then, any temperature variation will in turn produce high thermal stresses which may well exceed the limit values assigned for the pipe in long term usage (usually 50 years). Although MDPE is now being used for gas transportations in many parts of the world, due to the vast and extreme temperature variations in Iran's climate, its application in hot climate areas, (such as Khuzestan) has raised many unresolved questions for the gas company officials, as well as their engineers. For this reason, steel pipes are now being used instead. Hence, the main solicitude in this research is to investigate the thermal stresses (as well as other factors) on MDPE buried pipe and deduce the design curves, if possible, to determine the applicability range of this material for gas transportation in hot climate areas of southern Iran.

**BASIC DESIGN THEORY**

The design of an underground pipe installation is based on the principle of soil-pipe interaction. That is, the pipe and its surrounding soil which act together to control the pipe performance. In the present work, to incorporate this interaction and determine its effect on the resulting stresses, the following loads were recog-
nized and applied to the buried MDPE gas pipe in all stress calculations.

(a) Temperature variations in the soil (and hence in the pipe and its socket) which may be either due to any meteorological, terrain, or subsurface temperature variations in the day time, or any seasonal changes which might happen throughout the year.

(b) Soil column weight above the pipe.

(c) Surcharge loads in terms of traffic and/or dead loads above the pipe.

(d) Gas pressure of 4 bars inside the pipe. This is the working pressure in metropolitan gas pipe transportation in Iran.

(e) Stress concentrations due to a local change in geometry (in form of a socket connection).

Temperature Variation in the Soil
Information on ground surface temperature is necessary for calculations of any thermal stress in a buried pipe. In this study, the selected area was city of Ahvaz (south-west of Iran) where the average ground surface temperature in the summer varies from 30°C in the morning up to about 67°C in the early afternoon [12]. For a cold winter day, this variation ranges from 0°C in the morning up to about 28°C in the afternoon. Obviously, if this variation takes place at any depth, the resulting pipe thermal stresses may cause severe damage to the gas pipeline.

Factors that determine the ground temperature at any depth can be grouped in three general categories: meteorological, terrain, and subsurface variations. Large scale regional differences in ground surface temperature are determined primarily by meteorolog-

\[ T(y,t) = T + A \exp\left(-\frac{y}{\alpha t_0}^{1/2}\right) \times \cos\left(\frac{2\pi t}{t_0} - \frac{\pi}{\alpha t_0}^{1/2}\right) \]

Figure 1 shows ground temperature variation at various depths for city of Ahvaz. The results are deduced from eqn (1) on daily basis for a typical hot summer day. Similar results are shown in Figure 2 for a cold winter day. According to Figure 1, on a daily basis, an increase in depth makes the soil to become more insensitive to any temperature variation which may occur at the ground surface. This variation vanishes at a depth of about 120 cm. To take an asphalt temperature of 60°C at the hottest time of a summer day [12] it becomes evident that at this depth, the soil temperature remains constant and equal to about 35°C. Any further logical increase in depth has no effect on this value. Hence it is recommended to use this magnitude
as an optimum depth for any pipe installation. As shown on Figure 2, for a cold winter day, a similar behaviour is observed. Again, on a daily basis, at a depth of about 120 cm, the ground temperature remains constant and equal to 13ºC. According to Figures 1 and 2, on yearly basis, a buried pipe (and its socket), at a depth of 120 cm, which is in direct contact with the soil can experience a temperature variation of 22ºC (ΔT=35-13ºC). To model the pipe (and its socket), its temperature is taken to be the same as that of the soil at any specific depth all around its circumference.

Although polyethylene is considered to be viscoelastic in nature, linear elasticity equations are used for stress calculations in many design references, provided some terms are used as correction factors for inclusion of time, temperature, and viscoelastic behaviour of this material. This procedure is done either by use of an effective modulus (along with other correcting parameters), or by using the minimum required strength (MRS) which its values are available for different types of PE grades. Among many cited publications one may find the necessary equations in refs [14-16]. According to ref. [14] in the absence of any other effects, thermal stresses induced in PE pipes are calculated by:

$$\sigma = E_p \alpha_t \Delta T$$ (2)

Due to high values of \(\alpha_t\) for MDPE, any noticeable change in temperature will result in aggravation of the pipe thermal stresses. This effect may be exaggerated if pipes are exposed to sunshine and are not cooled to their working temperature before their burial. In presence of other stresses, this may result in high values of stresses and hence, an unrecoverable damage to the pipeline.

**Soil Column Weight**

The load applied to a buried pipe consists of a dead load and a surcharge load. The dead load is the permanent load from the weight of the soil as well as the pavement. Surcharge loads are the loads applied at the surface and may or may not be permanent. Surcharge loads include the loads from vehicles (live loads) and substructures.

In polyethylene pipe design, for any dead load calculations, it is common to assume that the overburden load applied to the pipe crown is equal to the weight of the soil column projecting above the pipe [15]. This load is often referred to as prism load. The prism load is an easy way of calculating the earth pressure on PE pipes when estimating the vertical deflection. The actual load applied to a flexible pipe might indeed be considerably lower than the prism load, since shear resistance transfers part of the soil load to trench sidewalls and embedment. As described before, this transfer is called "arching". To account for this effect, the applied load at the pipe crown is calculated through Marston equation which is given by:

$$P_M = C_D W B_D$$ (3)

where,

- \(P_M\) = vertical soil pressure
- \(B_D\) = trench width at pipe crown
- \(C_D\) = load coefficient (given by eqn 4)
- \(W\) = unit weight of the soil

$$C_D = \frac{1-\exp (-2\kappa' H/B_D)}{2\kappa'}$$ (4)

and

$$K = \tan^2(45 - \Phi/2)$$ (5)

The values of \(\kappa'\) for various soil types are given in ref. [15].

A more conservative approach for flexible pipes is to use the modified arching load. According to ref. [15], this soil pressure load is given by:

$$P_C = 0.6 P_M + 0.4 P_E$$ (6)

where, \(P_E\) is the prism load and is given by

$$P_E = WH$$ (7)

It should be emphasized that eqns (3-7) give the value of pressure at the pipe crown. These equations assume that the resulting stress remains constant all around the pipe. Obviously, due to flexibility of PE pipes and soil-pipe interaction, this assumption is not correct and hence, the stress might change locally.
Surcharge Loads

Distributed Loads

The surcharge loads may be categorized as distributed loads (such as footing), a foundation pile, or point loads. As shown in Figure 3, the distributed surcharge load may either lie directly over the pipe crown or at its offset.

In Figure 3a, the point pressure is found by dividing the rectangular surcharge load area (ABCD) into four sub-areas (a, b, c, and d) which have a common corner, E, in surcharge area and over the pipe. In this case, the surcharge load is equal to:

\[ P_L = P_a + P_b + P_c + P_d \]  \hspace{1cm} (8)

and,

\[ P_x = I_c W_s \]  \hspace{1cm} (9)

where,

- \( P_x \) = sub-area (a, b, c, or d) surcharge load.
- \( I_c \) = influence coefficient (ref. [15]). The influence factor is dependent on the dimensions of the rectangular load area and the depth of the pipe crown.
- \( M, M_1 \) = horizontal distances normal to pipe centre-line, measured from the centre of the surcharge load to the load edge for each sub-area
- \( N \) = horizontal distance parallel to the pipe centre-line, from the centre of the surcharge load to the load edge
- \( W_s \) = distributed surcharge pressure acting over the ground surface

If all sub-areas are equivalent, eqn (8) can be reduced into:

\[ P_L = 4 I_c W_s \]  \hspace{1cm} (10)

In Figure 3(b), since there is no surcharge directly above the pipe centre-line, then an imaginary surcharge load of the same pressure per unit area as the actual load is applied to sub-areas c and d. To calculate the total surcharge load, first, the surcharge loads for sub-areas a+d and b+c were determined. Then the surcharge loads from the imaginary areas c and d are deducted to find the surcharge pressure on the pipe as follows:

\[ P_L = P_{a+d} + P_{b+c} - P_c - P_d \]  \hspace{1cm} (11)

Vehicular Loads

Vehicular Point Loads

Wheel loads from trucks, trains, or other vehicles are significant in buried pipe design. The pressure on the pipe due to a surface vehicular live load depends on vehicle weight, tyre pressure and size, vehicle speed, and many other factors.

The most common loading used for design is H20 highway loading. According to American Association of State Highway and Transportation Officials (AASHTO) Standards, wheel loading for H trucks are calculated according to Figure 4. Similar standards are available for HS20 static loading [15]. Wheel loading may be treated to act as distributed or concentrated on the pavement. For a flexible pavement, if the point load is directly over the pipe, the vertical pressure acting on the pipe crown is [15].
Where, 
\[ IL = \text{impact factor, ref. [16]} \]
\[ CH = \text{load coefficient} \]
\[ WL = \text{wheel load} \]
\[ L = \text{pipe length (for } L > 3 \text{ ft, use } L = 3 \text{ ft)} \]
\[ D = \text{pipe outside diameter} \]

For multiple wheel loads acting along the pipe length (as shown in Figure 5), the point load on pipe crown can be calculated from eqn (13).

\[ P_L = \frac{ILW_L}{LD} \]

Distributed Point Loads

If wheel loads are considered as distributed, then allowing for traveling vehicle impact and wheel over an area, eqn (10) becomes;

\[ P_L = 4IL\frac{W_L}{A_c} \]

Where, \( A_c \) is the contact area and it is determined according to ASSHTO Standards [15]. The pressure due to a distributed load and that due to a concentrated load begin to approach the same value at a depth of about twice the square root of the loaded area [15]. According to ref. [15], the distributed load method gives more realistic values where the pipe depth is less than twice the square root of the loaded area, whereas for deeper depths, point load method is preferred. Since in this research, the pipe depth is much greater than the square root of the loaded area, then the distributed point load is used in pressure calculations.
Designing Polyethylene Gas Pipes to Withstand Loads

Polyethylene gas pipes are subjected to stress from combination of internal and external forces applied to the pipe. Here, the most common internal force is stemmed from the gas pressure. For buried gas pipes, the most common external forces are earth and surcharge loads as well as thermal and soil-pipe interactions.

With buried pressure pipes, internal pressure may be greater than the radial external pressure from the soil. As a result, tensile stresses are produced in the pipe wall. Thus for pressure pipes, compressive wall stresses may usually be negligible. When subjected to a uniform radial soil pressure, the compressive stress in the pipe wall is given by:

$$\sigma_c = \frac{P_T D}{2h} \quad (17)$$

where,

- $\sigma_c$ = compressive stress
- $P_T$ = total vertical load applied to pipe
- $D$ = pipe outside diameter
- $h$ = pipe thickness

According to ISO Standard 12162 [17], or EN 1555-1 [18] for thermoplastic pipe materials, the design stress (or maximum allowable stress that can be applied to the pipe) at 20ºC and 50 years of life time is obtained from

$$\sigma_s = \frac{MRS}{C} \quad (18)$$

where,

- $\sigma_s$ = design stress
- $MRS$ = minimum required strength (accounting for viscoelasticity, time, and temperature)
- $C$ = design coefficient (at least 1.25 for all PE types)

Based on latter standard, which is widely used by Iranian Gas Company in northern part of the country, the maximum operating pressure (MOP) is given by:

$$MOP = \frac{20 \times MRS}{C \times (SDR - 1)} \quad (19)$$

Here, value of $C$ for PE gas pipe must be equal to 2. Similar equation is proposed by Plastic Pipe Institute [19].

Since in PE gas pipes spigot joint sealing capability may be affected by excessive pipe deflection, then it is important to properly control this deflection. In buried pipe design, the deflection, after completing the installation, is the sum of construction deflection and serviced load deflection. Other than any numerical solution, one way to calculate plastic pipe deflection is the Sprangler’s Modifies Iowa Formula [15] which has the form of:

$$\Delta x = \frac{P_T}{D_i} \left( \frac{K_b L_d}{144} \left( \frac{1}{(SDR - 1)} \right)^3 + 0.061 E' \right) \quad (20)$$

where

- $\Delta x$ = horizontal deflection
- $K_b$ = bedding factor (typically, 0.1)
- $L_d$ = deflection lag factor
- $D_i$ = pipe inside diameter

All other factors in eqn (20) are as described before. Obviously, in such pipes, the percent deflection is defined as:

$$\text{Deflection(%) = } \frac{\Delta x \times 100}{D_i} \quad (21)$$

According to ref. [15] for flexible pipes with SDR = 11 the maximum allowable deflection is 3%.

THEORETICAL MODELLING

Pipe Modelling and Calculations

To investigate the stress distribution in a pressurized PE gas pipe, a 90 mm-diameter pipe was selected with SDR = 11. Based on the selected diameter, pipe thickness was calculated according to its SDR value. The pipe and its surrounding were then modeled under various conditions while the results were compared to those obtained by means of equations introduced before. The finite element code used for corresponding modelling and analysis was ANSY8.0. The elements used to model the pipe, socket, and the surrounding medium were plane 42 and solid 45. The soil-pipe interaction was also incorporated into the model through the use of face to face contact elements (contacta 172).
Physical and mechanical properties of the pipe and its socket were selected according to literature [20-22]. Table 1 gives the physical and mechanical properties of two PE grades which are used in modelling. MDPE (3810 yellow) was selected for the pipe, while HDPE (7810) was used for the socket. Although each individual property has its own importance, among those listed on Table 1, only the elastic modulus, tensile strength-at-yield, and thermal expansion coefficient were used in calculations (modelling). Since polyethylene undergoes creep in long term life, then it is customary in design to use a reduced strength based on a 50 year life time and treat the material as linear elastic in calculations [14-16]. Table 2 gives the classification and designation of two PE compounds in terms of their MRS values for a 50 years life time period [23,24]. The short-term strengths of polyethylene are reduced to their tabulated values to account for creep behaviour of this material. Also, properties of the soil layers around the pipe are listed in Table 3.

Soil grades around the pipe circumference were selected according to ASTM standards. Based on Figures 1 and 2, an optimum burial depth of 120 cm was selected for the pipes. This way, any climate change (on daily basis) will not affect the pipe temperature. This is actually the same depth used by Iranian Gas Companies in their current excavations for steel gas pipes burial used throughout the country. The pipe is assumed to be buried in a trench of 50 cm wide while surrounded by a layer of fine gravel. The ground surface was assumed to be either cementitious or covered by a thick layer of asphalt. The effect of this thickness was later investigated on the results. The effect of traffic loads in terms of distributed and concentrated forces on pipe stresses were also investigated.

The applicability range of the foregoing equations, as well as the validity of the initial finite element model were investigated in the absence of any internal pressure, thermal stresses and stress concentrations stemmed from a socket joint. Once the validity of the initial model was checked, the foregoing loads were superimposed on the pipe and their effects were fully investigated through a comprehensive finite element study. This method of study is well being used by many design engineers in many fields of engineering [25]. It was assumed that any two successive pipes were joined by means of a PE100 socket according to European Standards EN 1555. The method of joining two pipes by means of a socket is well described in many standards and related literature [26]. The socket had the same SDR value as the pipe.

### RESULTS AND DISCUSSION

In order to examine the level of integrity and validity of the model, as well as the range of applicability of eqns (1) through (16), the proposed model was run based on the information given on Tables 1 and 3, as well as, those on Figure 6. Here, for clarity, the sur-
rounding soil has been removed from the pipe circumference. According to Figure 6, the magnitude of $S_x$ at the pipe crown (which resembles the hoop stress) is 0.22 MPa (compressive). The similar value at the pipe's bottom is 0.2 MPa (tensile). These values are due to both prismatic soil and the H20 traffic load of 71172 N imposed on the pipe. The soil top cover was assumed to be cementitious. A close examination of Figure 6 reveals that due to the pipe load interaction with its surrounding, the stresses vary along the pipe length and its circumference, as well as its thickness. Using eqns (6) and (12), along with eqn (17) one can conclude that the maximum compressive hoop stress produced at the pipe crown is 0.22 MPa. This corresponds to 4.7% difference between the results obtained through finite element model and those predicted by equations. Any logical increase in ground cementitious cover thickness did not seem to have a considerable effect on pipe stresses. Moreover, due to arching effect, increasing the traffic load did not seem to have a considerable impact on pipe stresses at a depth of 120 cm (Figure 7).

Since other stresses are also present in the pipe, one has to consider their summation in terms of von Mises stress expressed by the following equation.

$$\sigma_{\text{von}} = \left[ \frac{\left(\sigma_1-\sigma_2\right)^2 + \left(\sigma_2-\sigma_3\right)^2 + \left(\sigma_1-\sigma_3\right)^2}{2} \right]^{1/2}$$

(22)

here, $\sigma_1$, $\sigma_2$, and $\sigma_3$ are the principal stresses. Obviously, the pipe experiences this stress as a whole and it must be this value which is used in real design. According to Figure 8, based on H20 loading condition, the maximum von Mises stress at the pipe crown is 0.206 MPa. This corresponds to a 1.9% difference in stress value obtained through the equations and that predicted by finite element model. This validates the accuracy of the proposed finite element model. According to Figure 8, at a point 90° away from the pipe crown, the maximum von Mises stress is about 0.25 MPa. Due to the vast variation of stresses along the pipe circumference, eqns (3) through (17) which only represent the state of stress at a point (namely the pipe crown) do not lead to correct results at all locations. Consequently, any calculations for maximum

### Table 3. Physical properties of the pipe surrounding soil layers.

<table>
<thead>
<tr>
<th></th>
<th>Trench soil (MPa)</th>
<th>Surrounding soil (MPa)</th>
<th>Subgrade soil (MPa)</th>
<th>Pavement (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elastic modulus</td>
<td>6.40</td>
<td>15.0</td>
<td>140</td>
<td>27560</td>
</tr>
<tr>
<td>Poisson's ratio</td>
<td>0.35</td>
<td>0.35</td>
<td>0.35</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2800</td>
</tr>
<tr>
<td>Pavement (MPa)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cementitious (rigid)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asphalt (flexible)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Physical properties of the pipe surrounding soil layers.

![Figure 6. Variation of $S_x$ along the MDPE pipe length and circumference.](image)

![Figure 7. Effect of traffic load on MDPE pipe stresses at a depth of 120 cm.](image)
Figure 8. Variation of von Mises stress along the MDPE pipe length and its circumference.

pipe stress (based on these equations) may lead to faulty results. Comparison of the results reveals that the foregoing equations underestimate the maximum stress in the pipe by 0.04 MPa. This corresponds to 19% difference compared to the actual value of 0.25 MPa. Use of a flexible pavement (asphalt) led to higher values of stresses at the pipe crown. Table 4 compares these results for loading conditions given in Figures 6 or 8.

Higher value of stress at the pipe crown for the asphalt cover is due to weaker arching effect of asphalt compared to a cementitious pavement. Eqn (15) accounts for pavement rigidity, while in eqn (12) (which is used for a flexible pavement, namely asphalt) the properties of the cover and its thickness are neglected as if the ground cover (pavement) is not present. Consequently, one would expect less accurate results obtained through eqn (12), as compared to those of eqn (15). This leads to higher differences in the results, obtained for an asphalt pavement.

Table 4. Comparison of the results obtained through finite element models and those predicted by equations.

<table>
<thead>
<tr>
<th>Ground cover</th>
<th>Existing equations</th>
<th>Finite element model</th>
<th>Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cementitious</td>
<td>0.21</td>
<td>0.22</td>
<td>4.7</td>
</tr>
<tr>
<td>Asphalt</td>
<td>0.53</td>
<td>0.46</td>
<td>13.2</td>
</tr>
</tbody>
</table>

As stated earlier, the maximum allowable percent deflection is 3% in a flexible pipe, such as MDPE, with SDR = 11. To check this issue, horizontal pipe deflection is plotted in Figure 9. According to this figure, maximum horizontal deflection in the pipe is $0.286 \times 10^{-4}$ m. For a pipe with an outside diameter of 90 mm, wall thickness is 8.2 mm and SDR = 11. This corresponds to an inside diameter of 73.6 mm. Hence, according to eqn (21) percent deflection for

Table 5. Comparison of the results obtained through finite element models and those predicted by equations for a buried MDPE gas pipe with an internal pressure of 4 bars.

<table>
<thead>
<tr>
<th>Ground cover</th>
<th>Existing equations</th>
<th>Finite element model</th>
<th>Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe crown</td>
<td>1.80</td>
<td>1.28</td>
<td>28.8</td>
</tr>
<tr>
<td>Pipe bottom</td>
<td>1.47</td>
<td>2.50</td>
<td>70.0</td>
</tr>
</tbody>
</table>

Figure 9. Plot of horizontal deflection $U_x$ within the MDPE gas pipe.
As stated earlier, due to seasonal changes, the ground surface temperature variation in Ahvaz, at a depth of 120 cm, is about 22°C. Hence, a buried pipe and its socket can experience a temperature variation of 22°C during a year. This problem imposes additional stresses on to the pipe. A plot of von Mises stress in the pipe (and its socket) due to a temperature rise of 30°C is shown in Figure 10. Here, the surrounding soil has been removed and the pipe and its socket are sectioned for more clarity. One can easily observe the stress concentrations in both components due to presence of the socket. The maximum value of these stresses happens to be in the pipe.

To design for long life period (50 years) and include the viscoelastic behaviour of the pipe, maximum values of the resulted stresses in the pipe and its socket are compared to their corresponding values of which are based on their MRS values. According to eqn (18), \( \sigma_s \) is obtained by dividing MRS values by \( C \). Here, \( C \) is assumed to be equal to 2. MRS values of PE80 and PE100 are given on Table 2 for various working temperatures.

Figure 11 shows the variation of maximum von Mises stress in the pipe for various temperature changes. For further comparison, the MRS values of PE80 for a 50 years life time period at different temperatures are superimposed. According to Figure 11, a MDPE gas pipes buried at a depth of 120 cm, can well sustain a temperature drop (or rise) of almost 15°C while other loads (such as H20 traffic load and internal gas pressure of 4 bars) are present, providing the pipe temperature does not exceed beyond 30°C.

<table>
<thead>
<tr>
<th></th>
<th>( \Delta T = 0^\circ )</th>
<th>( \Delta T = 10^\circ )</th>
<th>( \Delta T = 20^\circ )</th>
<th>( \Delta T = 30^\circ )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma_{\text{max}} ) socket (MPa)</td>
<td>1.8</td>
<td>2.1</td>
<td>2.7</td>
<td>4.5</td>
</tr>
<tr>
<td>( \sigma_{\text{max}} ) pipe (MPa)</td>
<td>2.3</td>
<td>2.6</td>
<td>4.0</td>
<td>5.4</td>
</tr>
<tr>
<td>( \sigma_{\text{max}} ) socket (MPa)</td>
<td>2.10</td>
<td>3.80</td>
<td>5.80</td>
<td>7.78</td>
</tr>
<tr>
<td>( \sigma_{\text{max}} ) pipe (MPa)</td>
<td>2.3</td>
<td>3.0</td>
<td>4.6</td>
<td>6.1</td>
</tr>
</tbody>
</table>

Table 6. Variation of maximum von Mises stresses both in a MDPE gas pipe and its socket at two different pipe diameters.

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Figure 10. Variation of von Mises stress for a buried MDPE pipe subjected to a temperature rise of 30°C.

As stated earlier, due to seasonal changes, the ground surface temperature variation in Ahvaz, at a depth of 120 cm, is about 22°C. Hence, a buried pipe and its socket can experience a temperature variation of 22°C during a year. This problem imposes additional stresses on to the pipe. A plot of von Mises stress in the pipe (and its socket) due to a temperature rise of 30°C is shown in Figure 10. Here, the surrounding soil has been removed and the pipe and its socket are sectioned for more clarity. One can easily observe the stress concentrations in both components due to presence of the socket. The maximum value of these stresses happens to be in the pipe.

To design for long life period (50 years) and include the viscoelastic behaviour of the pipe, maximum values of the resulted stresses in the pipe and its socket are compared to their corresponding values of which are based on their MRS values. According to eqn (18), \( \sigma_s \) is obtained by dividing MRS values by \( C \). Here, \( C \) is assumed to be equal to 2. MRS values of PE80 and PE100 are given on Table 2 for various working temperatures.

Figure 11 shows the variation of maximum von Mises stress in the pipe for various temperature changes. For further comparison, the MRS values of PE80 for a 50 years life time period at different temperatures are superimposed. According to Figure 11, a MDPE gas pipes buried at a depth of 120 cm, can well sustain a temperature drop (or rise) of almost 15°C while other loads (such as H20 traffic load and internal gas pressure of 4 bars) are present, providing the pipe temperature does not exceed beyond 30°C.

<table>
<thead>
<tr>
<th></th>
<th>( \Delta T = 0^\circ )</th>
<th>( \Delta T = 10^\circ )</th>
<th>( \Delta T = 20^\circ )</th>
<th>( \Delta T = 30^\circ )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma_{\text{max}} ) socket (MPa)</td>
<td>1.8</td>
<td>2.1</td>
<td>2.7</td>
<td>4.5</td>
</tr>
<tr>
<td>( \sigma_{\text{max}} ) pipe (MPa)</td>
<td>2.3</td>
<td>2.6</td>
<td>4.0</td>
<td>5.4</td>
</tr>
<tr>
<td>( \sigma_{\text{max}} ) socket (MPa)</td>
<td>2.10</td>
<td>3.80</td>
<td>5.80</td>
<td>7.78</td>
</tr>
<tr>
<td>( \sigma_{\text{max}} ) pipe (MPa)</td>
<td>2.3</td>
<td>3.0</td>
<td>4.6</td>
<td>6.1</td>
</tr>
</tbody>
</table>

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Table 6. Variation of maximum von Mises stresses both in a MDPE gas pipe and its socket at two different pipe diameters.
This is because the maximum von Mises stress produced in the pipe wall does not exceed the limiting value of $\sigma_s$ for 50 years service life at this working temperature. In other words, assuming installation has occurred in winter in a place such as Ahvaz, then the pipe working temperature at a depth of 120 cm would be 13°C (Figure 2). Due to seasonal temperature changes, this magnitude can raise to higher values. As far as the soil temperature does not exceed the value of 28°C (13 + 15 = 28), the maximum stress produced in the pipe does not exceed its limiting value at this new temperature. For any further rise in pipe wall temperature (or the surrounding soil), additional remedies, such as the use of expansion joints or laying techniques must be employed to relieve any excessive stressed produced beyond the limiting value of $\sigma_s$.

Figure 12 shows variation of maximum von Mises stress in the socket for the same loading condition. According to Figure 12, compared to a MDPE pipe, PE100 socket (HDPE) is more sensitive to a temperature drop. The values of $\sigma_s$ for a 50 year service life are also superimposed for further comparison. As it was realized, the socket can well sustain a temperature rise (or drop) of 15°C due to the seasonal temperature change. Of course, in real pipe installation, other remedies such as expansion joints may be used to relief some of these stresses.

Holding SDR as a constant, a change in pipe diameter seemed to affect the pipe and socket stresses, especially at higher temperature variations. The results on MDPE pipe (and its socket) are shown in Table 7.

### Table 7. Variation of maximum von Mises stresses both in a MDPE gas pipe and its socket at different burial depths.

<table>
<thead>
<tr>
<th>Pipe depth (cm)</th>
<th>$\Delta T_{\text{rise}} = 0^\circ C$</th>
<th>$\Delta T_{\text{rise}} = 30^\circ C$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$[\sigma_{\text{von, max}}]_{\text{socket}}$ (MPa)</td>
<td>$[\sigma_{\text{von, max}}]_{\text{pipe}}$ (MPa)</td>
</tr>
<tr>
<td>120</td>
<td>2.1</td>
<td>2.3</td>
</tr>
<tr>
<td>90</td>
<td>2.3</td>
<td>2.5</td>
</tr>
<tr>
<td>60</td>
<td>2.6</td>
<td>2.9</td>
</tr>
</tbody>
</table>
Table 6. Due to soil arching effect, for a specific temperature drop, changing the pipe depth did not seem to have a considerable effect on the maximum von Mises stresses developed in either component, provided the variation was not high. The results for a 90 mm pipe diameter are shown in Table 7. Similar results were obtained for other pipe diameters. To prevent over stressing in design and account for viscoelasticity, these values must be compared to their limiting values of $\sigma_s$ obtained from the MRS values.

### CONCLUSION

Stress variations in a buried MDPE gas pipe and its socket (PE100) were fully investigated in a hot climate region (city of Ahvaz in southwest Iran), to determine the applicability of MDPE piping in gas transportation in such areas. The optimum burial depth was found to be 120 cm, while the maximum ground surface temperature (for a hot summer day) at this depth was calculated to be 35°C. Similar temperature in a winter day was 13°C. To check the integrity and validity of the finite element model, eqns (1)-(17) at the first step, H20 loading, as well as, soil column weight were imposed on the pipe and the following conclusions are reached:

1. The calculated stresses through finite element models and those predicted by the equations agree well at pipe crown. Based on the results deduced from finite element models, the stress varies at all points along and around the pipe circumference, which its magnitude differs considerably from those predicted at the pipe crown. This is due to comprehensive soil-pipe interaction which has not been taken into consideration in the above equations. Since eqns (1)-(17) assume a uniform radial stress throughout the pipe, then, any attempt on their use for maximum stress calculation may lead to faulty results. In presence of other loadings (such as internal pressure, temperature variation, etc.) this effect is exaggerated. In such cases, finite element method appears to be an excellent substitute for any stress calculations in such pipes (and their socket) according to the new loading conditions.

2. Due to arching effect, traffic load does not seem to alter much the pipe stresses provided the burial depth is not too shallow.

3. Changing the ground cover from asphalt to cementitious did not seem to have a considerable effect on maximum stress produced in MDPE pipe buried 120 cm deep.

4. A HDPE socket (PE100) seems to be more sensitive to a temperature drop compared to that of a MDPE pipe.

5. Due to the nature of loading, PE100 seems to be more sensitive to a temperature drop compared to that of a temperature rise of the same magnitude.

6. Changing pipe diameter, indeed affects the resulting stresses, provided the value of SDR remains constant. This factor seems to be more pronounced at higher temperature variations.

7. In presence of all loadings (soil column weight, traffic loads, soil pipe interaction, stress concentrations due to a local discontinuity in pipe geometry (such as a socket, and seasonal temperature variations in a hot climate area), MDPE gas pipe and its socket (PE100) can well sustain the induced stresses based on a 50 year service life, provided the resulting stresses do not exceed their limiting value of $\sigma_s$.

8. Using the guidelines given in this research and those cited in the standards and procedures available on MDPE pipe installation, from stress point of view, MDPE pipe and its HDPE socket (PE100), can be used for gas transportation in hot climates of south of Iran.

### ACKNOWLEDGEMENTS

This research was funded by south-west regional branch of Iran Gas Company in Ahvaz, Khouzestan. The authors wish to thank both the Iran Gas Company and Shahid Chamran University officials for their kind support.

### SYMBOLS AND ABBREVIATIONS

- $A$ Difference between maximum and minimum temperatures for the working period assumed
- $A_c$ Contact area
- $B_D$ Trench width at pipe crown
C  Design coefficient  \[\Delta T\]  Pipe temperature change
CD Load coefficient  \[\Delta x\]  Pipe horizontal deflection
CH Load coefficient  \[\phi\]  Internal soil friction angle
D Pipe outside diameter (mm)  \[\nu\]  Poisson’s ratio
Di Pipe inside diameter  \[\sigma\]  Thermal stress in the pipe
E’ Pavement modulus  \[\sigma_c\]  Pipe compressive stress
E’ Embedment soil modulus  \[\sigma_{i(1,2,3)}\]  Principal stresses in the pipe
Ep Pipe elastic modulus  

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USA, 2007.


