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SCIENTIA NOBILITAT
BRAZILIAN JOURNAL OF PETROLEUM AND GAS
Journal Homepage: www.portalabpg.org.br/bjpg
A publication of the
ABPG
BRAZILIAN ASSOCIATION OF R&D IN PETROLEUM AND GAS

COMPARATIVE STUDY OF THE MINIMUM THICKNESS OF NATURAL GAS DISTRIBUTION TUBES FOCUSING ON LOCATED PLASTICIZATION

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Received: 16.05.2020 / Revised: 20.07.2020 / Accepted: 03.08.2020 / Published on line: 06.10.2020

ABSTRACT

Natural gas distribution systems traditionally rely on the use of carbon steel pipes. As with the engineering of other mechanical components, specific standards for the design of these components and accessories must be applied appropriately for each corresponding project. For the specific case of transmission networks and distribution of piped natural gas, one should use as reference the Brazilian code NBR-12712 - Systems design of fuel gas transmission and distribution. Among the various items covered by this code, the sub-item that provides guidelines to calculate the minimum thickness of the pipe for a given design pressure deserves special attention. The present work, therefore, makes a comparative analysis between the wall thicknesses defined by the mentioned standard, the wall thicknesses used in certain operational situations, and the wall thicknesses corresponding to the limit yield and plasticization conditions of the material considered. The present study also reviews the operational data of the COMPAGAS distribution network - the company responsible for the distribution of piped natural gas in the state of Paraná, Brazil.

KEYWORDS

natural gas network; plasticity; NBR-12712

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doi:10.5419/bjpg2020-0014

1. INTRODUCTION

Piped natural gas distribution systems customarily use carbon steel pipes to transport and distribute gas within the system. Mechanical systems follow a design based on specific project standards, codes or recommendations. In this process, designers focus on meeting safety guidelines, in addition to following all other parameters involved in the conventional design process. In the context of the design of a network distribution for piped natural gas, there are several parameters or items to be considered in the establishment of safety, viability, and cost-effectiveness of the project. The NBR-12712 code – Design of fuel gas transmission and distribution systems **(ABNT, 2002)**, which corresponds to an adapted translation of the American standard ANSI B31.8 **(ASME, 2000)** is a reference in the establishment of these parameters. Within this standard, one of the items to be considered corresponds to the determination of a minimum wall thickness for the pipe under analysis, which depends directly on the design pressure of the gas to be distributed. The present work, therefore, makes a comparative analysis between the wall thicknesses defined by the mentioned standard, the wall thicknesses used in certain operational situations, and the wall thicknesses corresponding to the limit yield and plasticization conditions of the material considered. For this purpose, operational data from the COMPAGAS distribution network, the company responsible for the distribution of natural gas in the state of Paraná, Southern Brazil, were considered to establish parameters compatible with real situations of gas distribution and supply.

2. NOMENCLATURE

a	external pipe radius
b	internal pipe radius
c	intermediate pipe radius
D_e	outer diameter of pipe
D_i	inner diameter of the duct
E	joint efficiency factor
F	design factor
k	yield stress from *Tresca*
p	pressure
p_e	external pressure
p_{EP}	pressure in the elastic-plastic regime
p_i	internal pressure
p_{ult}	maximum pressure in the condition of plasticization of the material
p_{yield}	maximum pressure at the limit of yield stress
r	generic radius duct
SF_{12712}	safety factor in relation to the code 12712
SF_{ult}	safety factor relative to the pressure in the condition of plasticization of the material
S_y	yield stress from code NBR 12712
SF_{yield}	safety factor relative to the pressure in the condition of yield stress of the material
t	the duct wall thickness
t_{min}	minimum thickness
t_{rig}	minimum rigidity thickness
T	temperature factor
σ_R	radial stress
σ_θ	tangential stress
ν	coefficient of *Poisson*

3. THEORETICAL CONCEPTS

Pipes for fluid distribution, in a general context, can be subject to both internal and external pressures. Likewise, their mathematical equations can be affected by the conditions of thin or thick-walled ducts. In the first case, this assumption is valid when the relationship between wall thickness and inner radius of the pipe is lower than the relationship (1/20). However, the possibility of fine or thin walls is just a simplification of the overall equation valid for the thick pipes considered, for this reason we use the following general and more complete equation.

According **Shigley et al. (2004)**, a cylindrical pipe subjected to a combination of internal and external pressures in a state of plane stress shows a distribution of radial and tangential stresses, as shown in Figure 1. The values of these tensions depend directly on the pipe rays and can be set in the elastic range of material, according to the *Lamé* equations in the form:

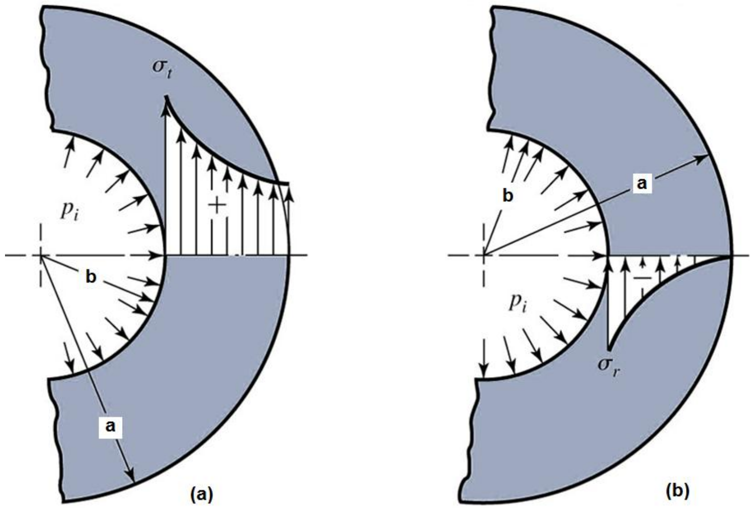

Figure 1. Stress distribution, (a) tangential and (b) radial, in a cylindrical pipe (adapted from **Shigley et al., 2004**).

$$\sigma_R = -\frac{1}{2}(p_i + p_e) + \frac{p_i - p_e}{2(1-(a/b)^2)}\left[1 + \left(\frac{a}{b}\right)^2 - 2\left(\frac{a}{r}\right)^2\right] \quad (1)$$

$$\sigma_\theta = -\frac{1}{2}(p_i + p_e) + \frac{p_i - p_e}{2(1-(a/b)^2)}\left[1 + \left(\frac{a}{b}\right)^2 + 2\left(\frac{a}{r}\right)^2\right] \quad (2)$$

For the condition of zero external pressure, Equations (1) and (2) simplify to:

$$\sigma_R = -\frac{p}{(b/a)^2 - 1}\left[\frac{b^2}{r^2} - 1\right] \quad (3)$$

$$\sigma_\theta = \frac{p}{(b/a)^2 - 1}\left[\frac{b^2}{r^2} + 1\right] \quad (4)$$

3.1 Initial pressure of yield stress

The maximum pressure can be regarded as the elastic limit condition. It corresponds to the pressure that satisfies certain criteria under a specific yield stress. Consequently, the criterion of *Tresca* is assumed and the equality between the tension components in the system and the corresponding yield stress limit are in the form (according **Lubliner (2008)**:

$$\sigma_R{}^2 - \sigma_R\sigma_\theta + \sigma_\theta{}^2 = 3k^2 \quad (5)$$

where parameter (k) corresponds to yield strength of the pipe material.

The substitution of Equations (3) and (4) in Equation (5), also allows us to define a specific ratio as a function of the maximum pressure corresponding to the elastic limit. Such pressure, referred to as (p_{yield}), may be defined by:

$$p_{yield} = k\frac{1 - \left(\frac{b}{a}\right)^2}{\sqrt{1 + \frac{1}{3}\left(\frac{b}{a}\right)^4}} \quad (6)$$

3.2 Regime elastic-plastic

When the internal to acting-pressure value exceeds the yield stress (p_{yield}), a localized plasticity appears along the pipe, extending it from (r = a) until a generic radius (r = c), restricting the elastic section to the condition: (c < r < b). In such circumstances, the corresponding stresses are defined by:

$$\sigma_R = -\frac{p}{\left(\frac{b}{c}\right)^2 - 1}\left[\frac{b^2}{r^2} - 1\right] \quad (7)$$

$$\sigma_\theta = -\frac{p}{\left(\frac{b}{c}\right)^2 - 1}\left[\frac{b^2}{r^2} + 1\right] \quad (8)$$

In these circumstances, *Tresca*'s formulation becomes valid based on the relationship:

$$\sigma_\theta - \sigma_R = 2k \quad (9)$$

By replacing the equations corresponding to radial and tangential stresses in Equation (9), a specific relationship of the acting pressure is obtained in the elasto-plastic condition of the material. Such pressure, called (p_{EP}), is now defined by:

$$p_{EP} = k\left(1-\left(\frac{c}{b}\right)^2 + \ln\left(\frac{c}{a}\right)^2\right) \qquad (10)$$

In these circumstances, note that (r = c).

3.3 Maximum pressure - material plasticization condition

The generalized plasticization along the pipe wall thickness occurs for the condition (r = c = b). This condition can be represented by an ultimate or limit pressure, which can be obtained from Equation (10) in the form:

$$p_{ult} = kln\left(\frac{b}{a}\right)^2 \qquad (11)$$

To apply Equation (11), it becomes necessary, however, to perform a check in terms of its validity condition. Such check depends on the pipe's end conditions and it is done by applying a balance equation in the longitudinal direction of the pipe. This deduction can be checked from the bibliographies referenced in this work. Mathematically, in the case of a state stress level, we have:

$$\frac{p}{2k} \le \frac{(1-\nu)(1-(a/b)^2)}{1-2\nu-(a/b)^2} \qquad (12)$$

where the parameter (ν) is the *Poisson* coefficient.

4. DISTRIBUTION SYSTEM COMPAGAS

The COMPAGAS corresponds to the state company responsible for the distribution of natural gas in the State of Paraná, Brazil. The company has about 22 years of operation and has a network of, approximately, 900 km of carbon steel pipes and HDPE located in over 12 different municipalities. The present study considered carbon steel pipes, proposing the assessment of their plasticity in relation to the material of the pipe.

COMPAGAS has pipes with nominal diameters ranging from 4 to 10 in, operating at nominal pressures of 4, 7, 17, and 35 bar. Table 1 shows geometric features, operating pressure ranges, and data concerning the material considered (in this case, carbon steel API 5L GR.B).

5. WALL THICKNESS ACCORDING TO CODE NBR-12712

The standard NBR-12712 - Design of fuel gas transmission and distribution systems **(ABNT, 2002)** - contemplates all aspects and considerations about the design and construction of piped natural gas transmission and distribution networks. To determine the wall thickness of the pipe, item 7.1 of said standard includes detailed information about the minimum thickness calculated from the specific equation reproduced below (t_{min}), as well as minimum thickness values to be applied due to the condition required rigidity for a given pipe (t_{rig}). Table 2 reproduces the abovementioned values.

$$t = \frac{pD_e}{2S_yFET} \qquad (13)$$

This equation is observed in addition to the presence of specific factors of design, more specifically, design factor (F), joint efficiency factor (E), and temperature factor (T). Aiming at harmonizing the final results, these factors are considered equal to one in this work.

Table 1. General parameters of COMPAGAS' distribution networks.

Nominal diameter [in]	Wall thickness [mm]	Outside diameter [mm]	Internal diameter [mm]	Yield stress [MPa]
4	6.02	114.30	102.26	241.00
6	4.80	168.30	158.70	241.00
8	4.80	219.10	209.50	241.00
10	6.40	273.10	260.30	241.00

Table 2. Minimum values of duct wall thickness according to NBR-12712.

Nominal diameter [in]	Outside diameter [mm]	Operating pressure reference [bar]	t_{min} [mm]	t_{rig} [mm]
4	114.30	35.00	0.830	4.00
6	168.30	35.00	1.222	4.80
8	219.10	35.00	1.591	4.80
10	273.10	35.00	1.983	4.80

Table 3. Pressure flow and final pressure to the range of nominal diameters adopted by COMPAGAS.

Nominal diameter [in]	Wall thickness [mm]	Maximum pressure [bar]	SF_{12712}
4	6.02	253.87	7.25
6	4.80	137.47	3.93
8	4.80	105.60	3.02
10	6.40	112.96	3.23

6. SECURITY COEFFICIENTS INVOLVED

The final analysis to be carried out in the present study depends on available operational data (working pressure and wall thicknesses considered for each duct), as well as limiting pressures in terms of yield stress and generalized plasticization of the pipe material. Thus, first, considering only the parameters of the NBR-12712 code, we obtain the results shown in Table 3, where:

a) the maximum pressure calculated was obtained from Equation (13);

b) the design factors (F, E, and T) were considered equal to the unit;

c) the safety factors were defined from the maximum operating pressure, 35 bar.

Repeating the calculations, now in the limit condition of the yield stress of the material, the results are obtained and tabulated in Table 4, where:

a) the pressure in the limit condition of the material yield stress was obtained from Equation (6);

b) the safety factors were defined from the maximum operating pressure, 35 bar;

c) Equation (12) is met for all diameter ranges considered (assuming a Poisson's coefficient of 0.3).

To finish the comparative analysis, the calculations were repeated in the generalized plasticization condition, leaving the results shown in Table 5, where:

a) the pressure corresponding to generalized plasticization was obtained from Equation (11);

Table 4. Safety coefficients of COMPAGAS pipes, in the limit condition of the material yield stress.

Nominal diameter [in]	Wall thickness [mm]	p_{yield} [bar]	SF_{yield}
4	6.02	436.62	12.47
6	4.80	237.61	6.79
8	4.80	182.68	5.21
10	6.40	195.37	5.58

Table 5. Safety coefficients of COMPAGAS pipes, in the condition of generalized plasticization of the material.

Nominal diameter [in]	p_{ult} [MPa]	SF_{ult}
4	536.50	15.33
6	283.10	8.09
8	215.96	6.17
10	231.38	6.61

b) the safety factors were defined from the maximum operating pressure, 35 bar;

c) Equation (12) is met for all diameter ranges considered (assuming a Poisson's coefficient of 0.3).

7. CONCLUDING REMARKS

The present work aims to demonstrate the existing safety coefficient when using a specific project code, more precisely, the safety coefficient contemplated by the NBR 12712 code in the minimum wall thickness for a natural gas distribution pipe channeled. The present study considered as a reference the geometric parameters in terms of diameters and thicknesses used in an existing distribution network covering a reasonable network extension and, consequently, having a good number of end customers involved, as well as their corresponding operating pressures. To complete our study, we used the data available on API 5L Gr.B carbon steel, a material that is commonly used by a good number of natural gas distribution companies in Brazil (Figure 2). The results obtained demonstrate that there is a good safety margin in operational terms, as well as an excellent safety margin when considering the pressures designated, in this work, as yield and ultimate pressures. Such pressures correspond to the limit conditions for the elastic regime and for the generalized plasticization of the pipe. It becomes evident that intermediate values between these pressures correspond to a condition of the elasto-plastic regime of the pipe. Emphasis should also be given to the additional design factors provided for in the NBR 12712 standard equation, considered equal to the unit in this work. In practical terms, if applied, it would further favor the issue of security involved in terms of determining wall thicknesses. Finally, emphasis should be given in the context of the mandatory use of the referenced standard for the purposes of designing and operating the corresponding distribution networks. The values presented in this

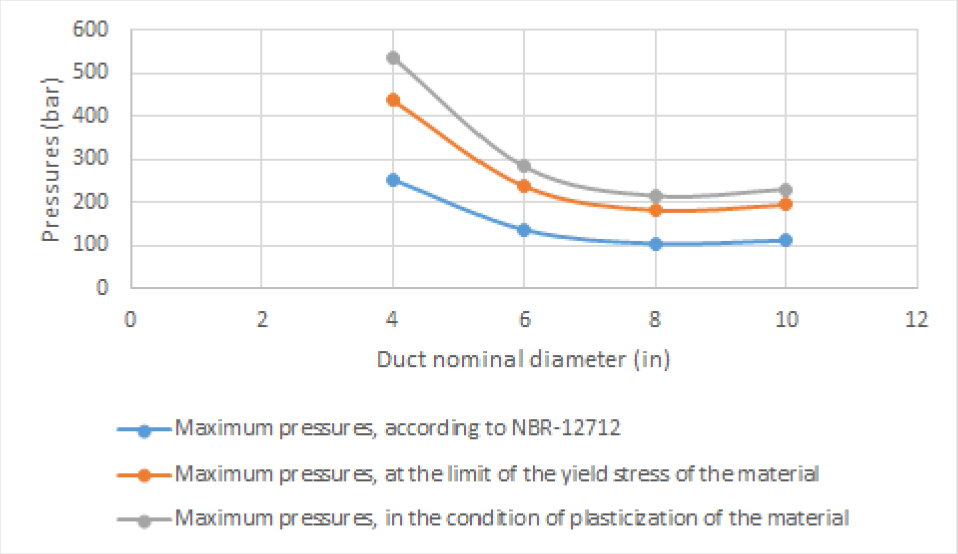

Figure 2. Pressure graphs.

work serve only for comparison and peace of mind to the designers involved with the subject at hand. The results presented in the present work do not justify their application in any projects that are yet to be developed.

8. REFERENCES

ABNT, NBR 12712. Projeto de Sistemas de Transmissão e Distribuição de Gás Combustível. Rio de Janeiro-RJ, 2002 (in Portuguese).

ASME, ASME B31.8 – Gas Transmission and Distribution Piping Systems. Houston- TX, 2000.

Lubliner, J. **Plasticity Theory**. New York: Dover Publications Inc., 2008.

Shigley, J., Mischke, C., Brow, T. **Standard Handbook of Machine Design**. 3rd Edition. United States: McGraw-Hill, 2004.