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Short Communication

Bursting pressure of mild steel cylindrical vessels

T. Aseer Brabin [a], T. Christopher [b], B. Nageswara Rao [c,*]

[a] Faculty of Mechanical Engineering, C.S.I. Institute of Technology, Thovalai 629 302, India
[b] Faculty of Mechanical Engineering, Government College of Engineering, Tirunelveli 627 007, India
[c] Structural Analysis and Testing Group, Vikram Sarabhai Space Centre, Trivandrum 695 022, India

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ABSTRACT

An accurate prediction of the burst pressure of cylindrical vessels is very important in the engineering design for the oil and gas industry. Some of the existing predictive equations are examined utilizing test data on different steel vessels. Faupel's bursting pressure formula is found to be simple and reliable in predicting the burst strength of thick and thin-walled steel cylindrical vessels.

1. Introduction

Being inexpensive and possessing high plasticity, toughness as well as good weldablity, mild steels have become the main production materials of pressure vessels such as tower reactors and exchangers or chemical equipment. The burst pressure evaluation of vessels has formed the subject of a large number of researchers to improve design precision for utilizing the maximum strength of the material.

Christopher et al. [1] examined failure data on various pressure vessels and compared the frequently used theories for validation and further use in the design of aerospace pressure vessels. Zheng and Lei [2] conducted several bursting experiments on mild steel cylindrical vessels and found inconsistency in Faupel's bursting pressure formula. Law and Bowie [3] compared several burst pressure formulae with test results of high yield-to-tensile strength ratio line pipes. Guven [4] investigated the failure pressures of thick and thin-walled copper and brass cylindrical vessels considering the Voce hardening law and plastic orthotropic effects. Zhu and Leis [5] made theoretical and numerical predictions of the burst pressure of pipes or pipelines. Since the Tresca yield theory provides a lower bound to burst pressure and the von Mises yield theory provides an upper bound, the average shear stress yield (ASSY) theory was developed for isotropic materials to improve the prediction of burst pressure. Since commercial finite element codes adopt the von Mises yield criterion and the associated flow rule as the default plasticity model for isotropic hardening metals, only the von Mises-based burst pressure of pipes can be determined using these FEA codes [6–9].

Of several formulae for calculating the burst pressure of vessels, the Faupel formula is the most popular. Based on hundreds of bursting experiments on pressure vessels made of Q235-D and 20R (1020) mild steels and after statistically analyzing the data, Zheng and Lei [2] stated that the Faupel formula had some errors. They modified the formula using the data and demonstrated its validity through comparison of test data on mild steel pressure vessels having different diameters and shell thickness. Motivated by the work of the above-mentioned researchers, this paper examines the applicability of Faupel's bursting pressure formula by considering test results of mild steel cylindrical vessels.

2. Burst pressure estimates of cylindrical pressure vessels

For power-law hardening materials, three different theoretical solutions for the burst pressure (P_b) of thin-walled pipes can be expressed in the general form [5]

$$P_b = \left(\frac{C_{ZL}}{2}\right)^{n+1} \frac{4t_i}{D_m}\sigma_{ult} \quad (1)$$

* Corresponding author. Tel.: +91 471 2565836; fax: +91 471 2564184.
E-mail address: bnrao52@rediffmail.com (B. Nageswara Rao).

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Table 1
Comparison of failure pressure estimates with test results [3] of thin-walled end-capped steel pipes.

	X42 ex-mill	X65 aged	X70 aged	X80 ex-mill	X80 aged
Geometric details and material properties					
Outer diameter, D_o (mm)	355.65	273.14	457.20	356.90	356.17
Thickness, t_i (mm)	6.41	7.10	9.97	6.96	6.91
Ultimate tensile strength, σ_{ult} (MPa)	471	662	700	677	684
0.2% proof stress or yield strength, σ_{ys} (MPa)	321	587	637	568	640
Strain hardening exponent, n (Equation (3))	0.1415	0.0646	0.0554	0.0826	0.0445
Failure pressure, P_b (MPa) estimates and test data					
Test [3]	15.75	36.33	30.53	27.44	27.80
Tresca yield theory (Equation (1))	15.67	33.79	30.03	25.43	26.24
von Mises theory (Equation (1))	18.47	39.38	34.96	29.72	30.50
ASSY theory (Equation (1))	17.06	36.58	32.49	27.57	28.37
Svensson's formula (Equation (5))	17.82	38.58	34.29	29.02	29.93
Faupel's formula (Equation (6))	17.94	40.28	35.75	30.29	31.13
Modified Faupel's formula (Equation (9))	16.42	38.85	34.72	28.82	30.47

where t_i is the initial wall thickness; $D_m = \frac{1}{2}(D_o + D_i)$, is the mean of the inner (D_i) and outer (D_o) diameters; C_{ZL} is a yield theory-dependent constant having values

$$\begin{aligned} C_{ZL} &= 1 \quad \text{for the Tresca Theory} \\ &= \frac{2}{\sqrt{3}} \text{ for the von Mises theory} \\ &= \frac{1}{2} + \frac{1}{\sqrt{3}} \text{ for the average shear stress yield (ASSY) theory} \end{aligned} \tag{2}$$

σ_{ult} is the ultimate tensile strength of the material; and n is the strain-hardening exponent (usually in the range 0–0.3 for most pipeline steels) expressed in the form

$$n = 0.224\left(\frac{\sigma_{ult}}{\sigma_{ys}} - 1\right)^{0.604} \tag{3}$$

σ_{ys} is the 0.2% proof stress or yield strength of the material.

Subhananda Rao et al. [10] have obtained the burst pressure of thin-walled rocket motor cases as

$$P_b = \frac{4}{\left(\sqrt{3}\right)^{n+1}} \frac{t_i}{D_i} \sigma_{ult}, \tag{4}$$

which is same as that derived in a different way by Durban and Kubi [11] and Marin and Sharma [12]. Replacing the inner diameter (D_i) by mean diameter (D_m) in equation (4), one can obtain the failure pressure of equation (1) for the von Mises theory. Other formulae frequently used to evaluate the failure pressure of cylindrical vessels are:

Svensson [13]:

$$P_b = \sigma_{ult}\left(\frac{0.25}{n + 0.227}\right)\left(\frac{e}{n}\right)^n \ln\left(\frac{D_o}{D_i}\right) \tag{5}$$

Faupel [14]:

$$P_b = \frac{2}{\sqrt{3}}\sigma_{ys}\left(2 - \frac{\sigma_{ys}}{\sigma_{ult}}\right)\ln\left(\frac{D_o}{D_i}\right) \tag{6}$$

For relatively thin-walled vessels, a modified Svensson's formula is suggested in [8] by writing $\ln(\frac{D_o}{D_i}) \approx \frac{2t_i}{D_i}$ in equation (5). Equation (6) has been obtained using the ratio, $\frac{\sigma_{ys}}{\sigma_{ult}} : (1 - \frac{\sigma_{ys}}{\sigma_{ult}})$ to interpolate between the lowest and highest bursting pressures of the vessels (viz., $P_{\min}$ and $P_{\max}$) defined below.

$$P_{\min} = \frac{2}{\sqrt{3}}\sigma_{ys}\ln\left(\frac{D_o}{D_i}\right) \tag{7}$$

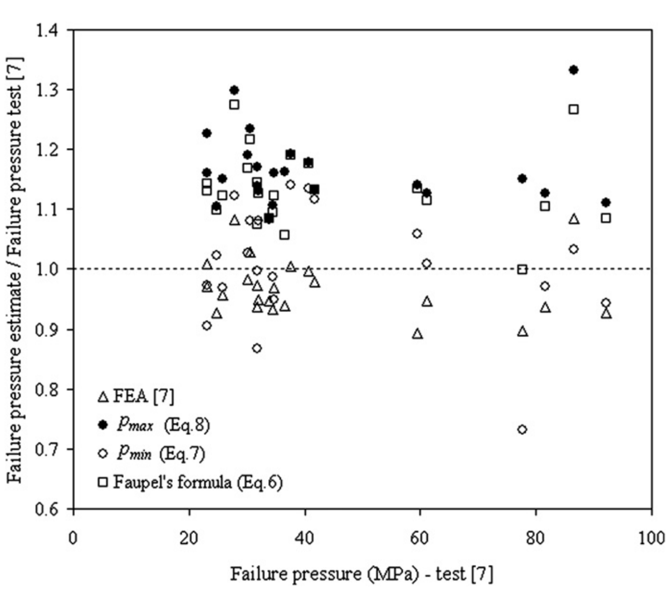

Fig. 1. Comparison of the burst pressure estimates from the Faupel's formula and FEA of Huang et al. [7] with test data.

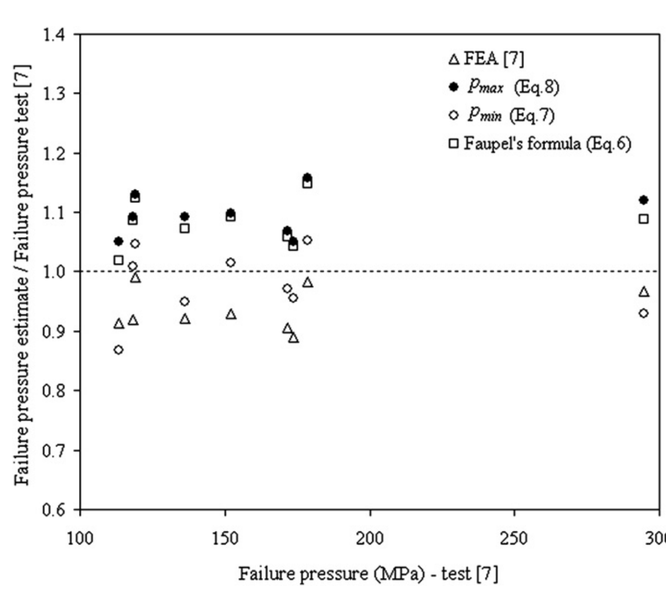

Fig. 2. Comparison of the burst pressure estimates from the Faupel's formula and FEA of Huang et al. [7] with test data.