

**Recommended Design  
Factors and Design  
Coefficients for  
Thermoplastic Pressure Pipe  
TR-9/2002**



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## **FOREWORD**

This report was developed and published with the technical help and financial support of the members of the PPI (Plastics Pipe Institute, Inc.). The members have shown their interest in quality products by assisting independent standards-making and user organizations in the development of standards, and also by developing reports on an industry-wide basis to help engineers, code officials, specifying groups, and users.

The purpose of this technical report is to provide important information available to PPI on design factors and design coefficients recommended for thermoplastic pressure piping applications. These recommendations are based on discussions with several internationally recognized technical experts in the plastic pipe industry. More detailed information on its purpose and use is provided in the document itself.

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# Recommended Design Factors and Design Coefficients for Thermoplastic Pressure Pipe

## 1.0 GENERAL INTRODUCTION

This Technical Report provides a summary of industry recommended design factors (DF) used with the Hydrostatic Design Basis (HDB) determined in accordance with ASTM D 2837, and recommended design coefficients (C) used with the Minimum Required Strength (MRS) determined in accordance with ISO 9080 and ISO 12162. To avoid confusion, we are using the standard definitions and terms in this report that are recognized internationally in ASTM and ISO documents.

These design factors and design coefficients differ because of the conventions by which HDB and MRS are determined. Therefore, one should not use a design factor (DF) with MRS or a design coefficient (C) with HDB.

Other PPI Technical Reports that are concerned with pressure applications of thermoplastic pipe material are PPI TR-4, "PPI Listing of HDB, SDB, PDB and MRS Ratings for Thermoplastic Piping Materials or Pipe", and PPI TR-3, "Policies and Procedures for Developing HDB, PDB, SDB and MRS Ratings for Thermoplastic Piping Materials or Pipe".

These recommended design factors and design coefficients have been developed on the basis of several years of international field experience, engineering tests, investigations, and safety considerations. Experience to date indicates that they are conservative within the limits for which they are recommended. However, no guarantee or warranty can be assumed regarding their application and use. Under some conditions, such as cyclic pressure applications or applications where the consequences of failure are heightened, a more conservative (i.e., smaller DF or larger C) should be applied.

## 2.0 STANDARD TERMINOLOGY

### 2.1 HDB Method

**Long-Term Hydrostatic Strength (LTHS)** - the hoop stress that when applied continuously, will cause failure of the pipe at 100,000 hours (11.43 years). This is the intercept of the stress regression line with the 100,000-h coordinate as defined in ASTM D 2837. Note –The typical condition uses water as the pressurizing fluid at 23°C (73°F).

**Hydrostatic Design Basis (HDB)** – one of a series of established stress values specified in Test Method D 2837 "Standard Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials" for a plastic compound obtained by categorizing the LTHS determined in accordance with Test Method D 2837. HDB refers to the categorized LTHS in the circumferential, or hoop direction, for a given set of end

use conditions. Established HDB's are listed in PPI TR-4.

**Design Factor (DF)** - a number less than 1.00 that takes into consideration the variables and degree of safety involved in a properly installed thermoplastic pressure piping installation. For purposes of this document, a service design factor recommended for use with an HDB category is designated **DF<sub>s</sub>**.

**Hydrostatic Design Stress (HDS)** – the estimated maximum tensile stress (psi) in the wall of the pipe in the circumferential orientation due to internal hydrostatic pressure that can be continuously applied with a high degree of certainty that failure of the pipe will not occur.

$$\text{HDS} = \text{HDB} \times \text{DF}$$

**HDB Pressure Rating (PR<sub>HDB</sub>)** - the estimated maximum pressure (psig) that the medium in the pipe can exert continuously with a high degree of certainty that failure of the pipe will not occur.

$$\text{PR}_{\text{HDB}} = \frac{2 (\text{HDB}) (\text{DF})}{\text{DR}-1} = \frac{2 (\text{HDS})}{\text{DR}-1}$$

## **2.2 MRS Method**

**Lower Predictive Limit (LPL)** – a pipe material's 97.5% lower confidence level of the extrapolated value (typically at 20°C and 50 years) obtained in accordance with ISO 9080 "Determination of the long-term hydrostatic strength of thermoplastics materials in pipe form by extrapolation".

**Minimum Required Strength (MRS)** - the categorized lower predictive limit (LPL) of the ISO 9080 long-term strength at 20°C and 50 years as defined in ISO 12162, "Thermoplastic materials for pipes and fittings for pressure applications – Classification and designation – Overall service (design) coefficient.

**Design Coefficient (C)** - a number greater than 1.00 that takes into consideration the variables and degree of safety involved in a properly installed thermoplastic pressure piping installation. For purposes of this document, a service design coefficient recommended for use with an MRS category is designated **C<sub>s</sub>**.

**Hydrostatic Design Stress (HDS)** – the estimated maximum tensile stress (psi) in the wall of the pipe in the circumferential orientation due to internal hydrostatic pressure that can be continuously applied with a high degree of certainty that failure of the pipe will not occur.

$$\underline{\text{HDS}} = \frac{\text{MRS}}{\text{C}}$$

**MRS Pressure Rating ( $PR_{MRS}$ )** - the estimated maximum pressure (bar) that the medium in the pipe can exert continuously with a high degree of certainty that failure of the pipe will not occur.

$$PR_{MRS} = \frac{20 (MRS)}{(DR-1) C}$$

### **3.0 SIGNIFICANCE**

A design factor or design coefficient is intended to make allowance for two general groups of conditions. The first group considers manufacturing and testing variables; specifically, normal variations in the material, manufacture, dimensions, and in the evaluation procedures (ASTM D 2837 and D 1598, for example). Experience to date indicates that the variation due to this group of conditions is usually within plus or minus ten percent. The second group considers installation, chemical environment (both inside and outside the piping), temperature, hazard involved, life expectancy desired, and the degree of reliability selected. If the temperature of use and/or the chemical environment differs from that associated with the long-term stress rating, an additional chemical design factor ( $DF_C$ ) is used. If anticipated handling and installation procedures may adversely affect the material, the service design factor (or design coefficient) should be reduced (increased) to account for these effects.

### **4.0 THE HDB APPROACH**

#### **A. Introduction to HDB**

The Hydrostatic Design Basis (HDB) is the categorized long-term hydrostatic strength (LTHS) determined in accordance with ASTM D 2837. General ASTM thermoplastic pipe specifications use the HDB at 73°F (23°C) to establish dimensions and maximum operating pressures. PPI lists HDB's and maximum recommended HDS's for specific thermoplastic piping materials in TR-4. The service design factor used to obtain these HDS values is 0.50, which is the service design factor for water.

$$HDS = HDB \times 0.5$$

#### **B. Service Design Factor**

Product standards or codes for specific applications or jurisdictions may require more conservative service design factors ( $DF_S$ ) reflecting additional design or safety considerations. A governmental agency, a trade association or standards writing group may establish the service design factor. As an example, in the United States the Department of Transportation has assigned a service design factor of 0.32 for all plastic pipe used in natural gas applications. These regulations may result in requiring that an actual pressure rating being marked on the pipe (e.g., ASTM D 2241 and AWWA C

900) or it may require a pressure rating code letter be marked on the piping (e.g., ASTM D 2513).

Some of the accepted industry maximum service design factors are given in Table 1.

**TABLE 1 - MAXIMUM RECOMMENDED SERVICE DESIGN FACTORS FOR USE WITH HDB-RATED MATERIALS**

| <b><u>SERVICE APPLICATION</u></b> | <b><u>THERMOPLASTIC PIPING MATERIAL</u></b> | <b><u>MAXIMUM SERVICE DESIGN FACTOR for HDB</u></b> |
|-----------------------------------|---|---|
|                                   |   | <b>DF<sub>s</sub></b>                               |
| Water                             | PE and other approved materials             | 0.50  |
|                                   | PVC distribution pipe                       | 0.40  |
|                                   | PVC transmission pipe                       | 0.50  |
| Fuel Gas Distribution (USA)       | All approved materials                      | 0.32  |
| Fuel Gas Distribution (Canada)    | All approved materials                      | 0.40  |
| Dry natural gas                   | All approved materials                      | 0.50  |

### **C. Temperature Effect**

PPI publishes HDB values in TR-4 at 73°F (23°C) and also at other selected elevated temperatures (120°F, 140°F, etc.). Where recommended by the manufacturer, the HDB at this elevated temperature is used with the appropriate service design factor and without the need for a temperature design factor. This is the preferred method to account for elevated temperature because it is more accurate.

$$HDS_{(140^{\circ}F)} = [HDB_{(140^{\circ}F)}] (DF_s)$$

For service temperatures between 73°F and the elevated temperature at which the pipe manufacturer has established an HDB, the user may arithmetically interpolate the HDB at his service temperature (T) to determine the appropriate pressure rating:

$$HDS_{(T)} = [HDB \text{ (interpolated between two temperatures)}] (DF_s)$$

PPI has published a temperature interpolation policy in TN-18, “Long-Term Strength (LTHS) By Temperature Interpolation”. This policy is also included in TR-3.

If the service temperature exceeds the maximum established HDB for a material, the manufacturer should be consulted to obtain an appropriate recommended temperature design factor ( $DF_T$ ):

$$HDS_T = [HDB_{(73^\circ F)}] (DF_S) (DF_T)$$

Where a recommendation is not available from the manufacturer, conservative values, such as those in Table 2 for PVC, may be used. These PVC values for  $DF_T$  are consistent with AWWA C900 and C905. Temperature design factors should only be used when an established HDB is not available at the desired temperature.

**TABLE 2 - Maximum Recommended TEMPERATURE DESIGN FACTORS**

| <u>Service Temperature</u><br><u>(°F)</u> | <u>Service Temperature</u><br><u>(°C)</u> | <u>Temperature Design</u><br><u>Factor (<math>DF_T</math>)</u><br><u>For PVC</u> |
|---|---|--|
| 80  | 27  | 0.88   |
| 90  | 32  | 0.75   |
| 100                                       | 38  | 0.62   |
| 120                                       | 49  | 0.40   |
| 130                                       | 55  | 0.30   |
| 140                                       | 60  | 0.22   |

With liquid hydrocarbons and other chemicals, temperature can have a disproportional effect on the long-term performance of the pipe. No general chemical design factor for elevated temperature service can be established and each case should be designed on its own merit.

#### **D. Chemical Effects**

Because of the wide differences in chemical resistance of various thermoplastic piping materials, specific attention should be given to the effect of the transported medium fluid on the piping. Experience has shown that the effects of air, water, natural gas, and neutral salt solutions on the long-term stress rating are relatively insignificant with presently used thermoplastic pressure piping materials. However, other fluids may have a significant effect on the long-term strength of thermoplastics pipe materials. The design engineer must consider these effects. In these cases, use of a chemical design factor ( $DF_C$ ) is appropriate. Table 3 gives, as an example, maximum recommended chemical design factors for three thermoplastic materials when continuously exposed to

liquid hydrocarbons.

**Table 3 - Maximum Recommended Chemical Design Factors for Continuous Liquid Hydrocarbon Exposure**

| <b>Pipe Material</b>        | <b>Chemical Design Factor (DF<sub>C</sub>)</b> |
|-----------------------------|--|
| PA – polyamide              | 1.00   |
| PE – polyethylene           | 0.50   |
| PVC – poly (vinyl chloride) | 0.50   |

### **E. Overall Design Factor/Pressure Rating**

Multiple design factors (service, temperature, chemical, others) may be necessary for certain applications. For example, one may apply a service design factor (DF<sub>S</sub>) for a specific application and a temperature design factor (DF<sub>T</sub>). One could also apply a chemical design factor (DF<sub>C</sub>) if that piping is used in the presence of a chemical environment that lowers the long-term stress capacity of the material (see PPI TR-19 and TR-22). The overall design factor (DF) is the product of all these design factors:

$$DF = (DF_S) (DF_T) (DF_C)$$

Pressure ratings (PR) are calculated from the dimension ratio of the pipe (DR), the material's hydrostatic design basis (HDB), and the overall design factor (DF):

$$PR \text{ (psig)} = \frac{2 \text{ (HDB) (DF)}}{(DR - 1)}$$

## **5.0 THE MRS APPROACH**

### **A. Introduction to MRS**

The Minimum Required Strength (MRS) is the categorized long-term hydrostatic strength determined in accordance with ISO 9080 and ISO 12162. PPI lists MRS's for specific thermoplastic piping materials in TR-4. For classification purposes, the MRS is obtained at 20°C and 50 years. For pressure rating calculations, the MRS may be obtained at the desired use temperature and the desired time.

### **B. Design Coefficient**

The standard ISO 12162 describes the "overall service (design) coefficient" or "C-factor" and details the contents of this coefficient and gives the minimum values to be used for this coefficient. The minimum coefficient is established for static water pressure at 20 °C for 50 years, and takes into account the following considerations:

1. Additional stress and other unquantifiable effects which are considered to arise in the application;
2. Influence of temperature, time and environment inside or outside of the pipe, if different from 20 °C, 50 year and water. This influence can have either positive or negative effects;
3. Standards relating to MRS for temperatures other than 20 °C.

The C coefficient is related to the pipe material and the anticipated installation and operating conditions. It should be corrected with individual factors introduced to separately cover material and application aspects. The material related coefficient ( $C_M$ ) reflects the properties of the components of a piping system other than those represented in the  $\sigma_{pl}$  (e.g. extrusion, batch to batch variation).

The application related coefficient ( $C_A$ ) is left to the design engineer to incorporate via appropriate design codes (e.g. ISO 10839) and national regulations and should be dependent on the location of the pipeline, the operating pressure, on the type of gas being conveyed, etc. Care should be taken regarding the differences between hydrostatic and dynamic loading.

Internal fluids such as gases and aggressive condensates when absorbed may have the effect of reducing the material strength upon which the design stress is based; the influence of gas being much less severe than condensate.

The industry accepted minimum material design coefficients ( $C_M$ ) are provided in ISO 12162 and are reproduced in Table 4.

**TABLE 4 - MINIMUM RECOMMENDED MATERIAL DESIGN COEFFICIENTS  
FOR USE WITH MRS-RATED MATERIALS**

| <b><u>THERMOPLASTIC PIPING<br/>MATERIAL</u></b> | <b><u>MINIMUM MATERIAL<br/>DESIGN COEFFICIENT<br/>FOR MRS</u></b> |
|---|---|
|   | <b>(C<sub>M</sub>)</b>  |
| PB  | 1.25  |
| PE  | 1.25  |
| PEX   | 1.25  |
| PP copolymer                                    | 1.25  |
| PP homopolymer                                  | 1.6   |
| PVC-HI  | 1.4   |
| PVC-U   | 1.6   |
| PVC-C   | 1.6   |
| PVDF copolymer                                  | 1.4   |
| PVDF homopolymer                                | 1.6   |

**. C. Temperature Effect**

International developments in the use of plastic pipe systems are more and more focused on operating conditions that deviate substantially from the well established 20 °C temperature and 50 years design life parameters that form the basis of the determination of MRS. Greater flexibility is needed in dealing with requirements that depart from the standard 20 °C and 50 years. This could be achieved by the introduction of a universal function of the MRS parameter -  $MRS_{\theta,t}$  for use in pipe design calculations while retaining the value of  $MRS_{\theta,t}$  at 20 °C in water and 50 years as the usual basis for classification of material type e.g. PE 80 or PE 100. The 20 °C/50 year value is published as the MRS for the material in accordance with ISO 12162. The  $MRS_{\theta,t}$  is the value of  $\sigma_{lpl}$  determined and categorized for the temperature ( $\theta$ ) and required lifetime (t) in water in accordance with ISO 9080 using the 3 or 4 coefficient stress rupture/time equation. This differs from the historical approach where de-rating coefficients acting on the MRS are used to establish the effect of temperature only on the strength of the pipe material.

The categorization of  $MRS_{\theta,t}$  is in accordance with the following series with the boundaries of categorization as given in Table 5.

- R20 series for  $MRS_{\theta,t} \geq 10$  MPa
- R10 series for  $MRS_{\theta,t} < 10$  MPa

**Table 5: Boundaries of categorization for  $MRS_{\theta,t}$**

| Range of $\sigma_{lpl}$ at $\theta$ and $t$<br>MPa | $MRS_{\theta,t}$<br>MPa |
|--|-------------------------|
| $6,30 \leq \sigma_{lpl} \leq 7,99$                 | 6,30                    |
| $8,00 \leq \sigma_{lpl} \leq 9,99$                 | 8,00                    |
| $10,00 \leq \sigma_{lpl} \leq 11,19$               | 10,00                   |
| $11,20 \leq \sigma_{lpl} \leq 12,49$               | 11,20                   |
| $12,50 \leq \sigma_{lpl} \leq 13,99$               | 12,50                   |

PPI publishes MRS values in TR-4 at 68°F (20°C), which is the temperature used for classification purposes. PPI also publishes MRS values at other selected elevated temperatures (40°C, 60°C etc.). These are known as the  $MRS_{\theta,t}$  where  $\theta$  is the selected temperature and  $t$  is the selected time. These  $MRS_{\theta,t}$  values are used for design calculations. Where recommended by the manufacturer, the MRS at this elevated temperature is used with the appropriate service design coefficient and without the need for a temperature design coefficient.

#### D. Overall Design Coefficient/Pressure Rating

The design stress equation inclusive of the above features may be written as follows:

$$\sigma_{HDS,\theta,t} = \frac{MRS_{\theta,t}}{C_A \leftarrow C_M}$$

where:

- $\sigma_{HDS,\theta,t}$  is the hydrostatic design stress for the material in contact with the fluid being transmitted at a specified temperature  $\theta$  and lifetime  $t$ .
- $MRS_{\theta,t}$  is the  $\sigma_{lpl}$  of the material calculated for a specified temperature  $\theta$  and lifetime  $t$  and suitably categorized from data produced in water in accordance with ISO 9080.
- $C_M$  reflects the material related properties of the components of a piping system, other than those represented in the  $\sigma_{lpl}$  (e.g. for PE the factor  $C_M$  should be 1.25).
- $C_A$  is the system design coefficient to be applied by the application design engineer.

For example, a value of  $C_A$  of 1.6 when applied in conjunction with the  $C_M$  value for natural gas of 1.25 would give an overall factor ( $C_A \times C_M$ ) of 2.0, the minimum value for  $C$  specified already in ISO 4437.

For greater flexibility in the use of the MRS the  $MRS_{\theta,t}$  is introduced, where the temperature  $\theta$  and the lifetime  $t$  may differentiate from the usual values of 20 °C and 50 years. This policy retains the well-established MRS basis for the classification of PE

materials in accordance with ISO 12162.

Application related design coefficients, which are covered in  $C_A$ , are left to the design engineer and should be specified in the relevant Codes Of Practice.

Pressure ratings (PR) are calculated from the dimension ratio of the pipe (DR), the material's Minimum Required Strength (MRS), and the overall design coefficient (C):

$$PR \text{ (bar)} = \frac{20 \text{ (MRS)}}{(DR - 1)(C)}$$

## **6.0 CONCLUSION**

This PPI Technical Report provides information on use of the HDB and appropriate design factor to arrive at a pipe pressure rating. It also provides information on the use of the MRS and appropriate design coefficient to arrive at a pressure rating.

HDB and MRS are different methods for predicting material performance, and it is possible for the calculated pressure rating to be different if both methods are used for the same material.

Pipe made from a plastic piping material should perform the same whether that material is HDB-rated or MRS-rated. The prediction method has no effect on actual material performance.