Can ISO MRS and ASTM HDB Rated Materials Be Harmonized

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ABSTRACT

ISO MRS and ASTM HDB rating systems have been successfully used for more than four decades in Europe and North America. MRS differentiates well the three generations of HDPE materials by classifying them as PE63, PE80 and PE100. However, HDB classifies all three generations of HDPE as only one PE 3408. When calculating MOP, MRS uses a minimum design coefficient of C=1.25. HDB uses a maximum design factor of F=0.5. $C/(1/F) = 0.63$. In order to compare these two rating systems on the same page, design reference strength (DRS) is introduced. MRS is connected with DRS through the parameter coefficient, Cp, and HDB with DRS through the parameter factor, Fp. For a given HDPE that minimally meets ISO 9080 and ASTM D 2837, Cp and Fp are 1 and 1.53 respectively. $C_p/(1/F_p) = 1.53$. The ultimate design coefficient, $C_{ultimate} = C \times C_p = 1.25$, and ultimate design factor, $F_{ultimate} = F \times F_p = 0.77$. $C_{ultimate}/(1/F_{ultimate}) = 1.03$. This means the current MRS and HDB rating systems are equivalent and have the same design baseline. Nevertheless, since the minimum requirements in D 2837 are too low, HDB fails to differentiate HDPE materials. A detailed step-by-step analysis reveals the similarities and differences of the two rating methods. A possible revision to D 2837 to harmonize the two rating systems is given. This paper also discusses the important end-use parameters of application temperatures and design times.

1. INTRODUCTION

Pipeline transportation is one of the most efficient methods to transport liquid or gaseous materials. End use engineers design pipelines for the safe and efficient operation under a given pressure for a given design lifetime at various environmental conditions. Many factors can cause failure of a pipeline due to the complexity of the environmental interaction during the long service period. Unlike metal pipes, polyethylene (PE) pipe is chemically stable and virtually corrosion-free during the application process. However, due to creep characteristics, the hoop strength of plastic pipes is a function of constant loading times.

Numerous data have shown that the log (stress) – log (time) curve of plastic materials is essentially linear. This makes it possible to obtain the long-term hydrostatic strength (LTHS) by extrapolating to a desired time. International Standard Organization (ISO) and ASTM International have successfully developed the standard extrapolation methods. ISO uses the 50-year MRS (Minimum Required Strength) rating system [1-3,7,8]. ASTM uses the 11-year HDB (Hydrostatic Design Basis) rating system [1,4,9,10]. More than 40 years of field applications in Europe and North America have validated these two rating systems.

After the introduction of the advanced third generation bimodal high-density polyethylene (HDPE), the two rating systems began to display major differences. Table 1 lists the three generations of HDPE materials being used today. ISO 2162 standard classifies them as PE63, PE80 and PE100 respectively while ASTM standard classifies them as PE 3408 only.

Table 1. Classification of High Density Polyethylene Pipe

Genera-tion	ISO MRS Rating System			ASTM HDB Rating System			*HDB* / *MRS* %	MOP_{HDB} / MOP_{MRS} %
	Grade	MRS, MPa (Psi)	MOP, Bar (psig) C=1.25 DR=11	Grade	HDB, MPa (psi)	MOP, Bar (psig) F=0.5 DR=11		
1st	PE 63	6.3 (914)	10.1 (146)	PE 3408	11.0 (1600)	11.0 (160)	175	110
2nd	PE 80	8.0 (1160)	12.8 (186)				138	86
3rd	PE 100	10.0 (1450)	16 (232)				110	69

This paper will conduct a head-to-head comparison on these two rating systems. The major purpose is to understand the similarities and differences of MRS and HDB rating systems. This paper will discuss the on-going and emerging new material listings and standard revisions. The ultimate goal is to help harmonize these pressure-rating systems.

2. OVERVIEW OF MRS AND HDB RATING SYSTEMS

Figure 1 displays the schematic chart of the MRS and HDB rating systems. After gathering about one-year hydrostatic test data, ISO 9080 (2) or ASTM D 2837 (4) can be used to analyze the data set. D 2837 extrapolates LTHS to 11 years and then categorizes it into HDB. ISO 9080 uses the Lower Prediction Limit (LPL). LPL is the extrapolated LTHS at 50 years and 97.5% lower confidence limit (LCL). LPL is categorized into MRS in accordance to ISO 12162 (3). Note if the Stage II brittle failure occurs before 50 years or 11 years, two separate extrapolations with two slopes must be taken. By taking a design coefficient, C, the maximum operation pressure (MOP) is determined from MRS. MOP can also be calculated from HDB by taking a design factor F. If the ISO system agrees with the ASTM system, one PE material should have a similar MOP no matter which system is used.

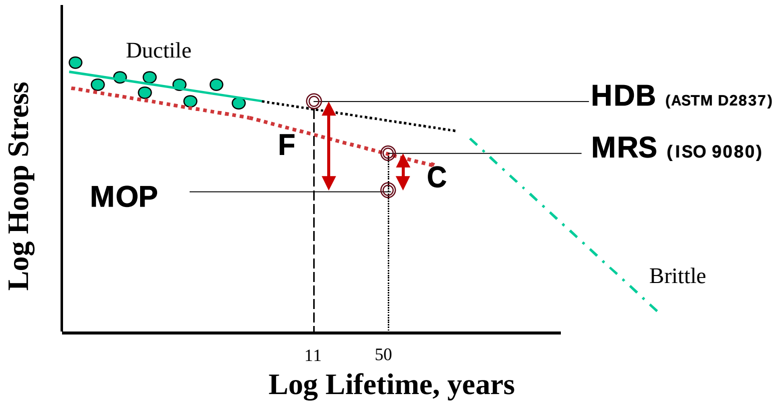

Figure 1. Schematic Chart for the MRS and HDB Rating Systems

Table 1 indicates that HDB is always higher than MRS for the three HDPE materials, ranging from 75% to 10% higher. ISO uses a minimum 1.25 of design coefficient (C) and ASTM uses a maximum 0.5 of design factor. Conceptually C is the reverse of F. The 1/F=2.0 for HDB rated materials is also higher than C=1.25 for MRS rated materials. The MOP of PE 3408 ranges from 10% higher than that of PE63 to 31% lower than that of PE100. It is interesting that the MOP of PE 3408 is about the average of PE63 and PE80, generally unimodal HDPE materials, but much lower than that of PE100, the advanced bimodal HDPE materials.

There are four key questions arising from Table 1. (1) Why is HDB always higher than MRS? (2) Why are the equivalent values of C and F so different? (3) Do the current ISO and ASTM rating systems have the same baseline in determining MOP? (4) How to revise the ASTM standard so that HDB can be used to differentiate these three generations of HDPE materials?

3. SIMILARITIES OF MRS AND HDB RATING SYSTEMS

Table 2 lists the head-to-head comparison results of the MRS and HDB rating systems. They have many similarities.

Table 2. Comparison of MRS and HDB Rating Systems

Characteristics		ISO	ASTM
Data Set	Test Method	ISO 1167	ASTM 1598
	# of Temperatures	≥ 2	1
	# of Data Points at Each Temperature	≥ 30	≥ 18
	Longest Data Point	≥ 9,000 h	≥ 10,000 h
Extrapolation	Standard Method	ISO 9080	D 2837
	Equation	3 or 4 Parameters	2 Parameter
	Time	50 years	11 years
	Confidence Level	97.5% Lower Confidence Level	50% Mean
Validation	Ductile	One step K-factor based on multi-temperature regression data	Control Point at 80°C or 90°C
	Brittle		3 Parameter Rate Process Method
Categorized MRS or HDB	Standard Method	ISO 12162	D 2837
	LPL or LTHS	LPL at 20°C, 50-y and 97.5% LCL	Mean LTHS at 23°C and 11 years
Design Coefficient or Factor		C=1.25	F=0.5

3.1. Same Testing Method: First they use the equivalent sustained pressure testing method to generate the raw data. The testing temperature, the internal pressure, the failure time and mode, characterize each raw data point. ASTM D1598 is similar to ISO 1167.

3.2. Same ISO Equation: Hoop strength is an intrinsic material property. ISO and ASTM use the same equation to convert the internal test pressures in ISO 1167 into the hoop stresses used for extrapolation.

$$\sigma = \frac{P \times (d_{e,m} - e_{y,\min})}{2 \times e_{y,\min}} = \frac{P \times (SDR - 1)}{2} \qquad (1)$$

where σ is the hoop strength, P is the internal pressure, $d_{e,m}$ is the mean outside diameter, $e_{y,m}$ is the minimum wall thickness, and the standard dimension ratio SDR = the mean outside diameter divided by the minimum wall thickness.

3.3. Same Linear Extrapolation Equation at a Given Temperature: ISO 9080 uses the 4- or 3-parameter equation. As shown in Equation (2), when the temperature is constant, they become the 2-parameter equation used by D 2837. So D 2837 extrapolation is a special case of ISO 9080 extrapolation where one temperature data set is used.

$$\log_{10} t = C_1 + \frac{C_2}{T} + C_3 \log_{10}\sigma + \frac{C_4 \log_{10}\sigma}{T} = (C_1 + \frac{C_2}{T}) + (C_3 + \frac{C_4}{T})\log_{10}\sigma = A + B\log_{10}\sigma \qquad (2)$$

3.4. Similar Validation Method: Both ISO 9080 and ASTM D 2837 require validating the extrapolation using the data points at elevated temperatures. ISO 9080 uses the K-factor method for LPL validation [2]. LTHS validation can use ISO 9080, one control point from the simplified K-factor method, or 3-parameter Rate Process Method utilizing brittle failure points, as shown in PPI TR-3 F.4 [5].

3.5. Categorized MRS and HDB: To accommodate the categorized pipe dimensions and to keep a few limited pressure rating values for the convenience of end use engineers, LPL and LTHS are categorized into MRS and HDB. LPL is rounded down to the next value in the R10 series (25% increments) as defined in ISO 3 when LPL<10 MPa or down to the next R20 series (12% increments) when LPL≥10 MPa. LTHS is categorized into HDB in accordance to Table 1 in D 2837 with 25% increments.

3.6. Same MOP Equation: After obtaining MRS and HDB, end use engineers use the same ISO equation to determine pipe SDR to meet the requirement of design operation pressure. ISO and ASTM use equation (3) to calculate MOP.

$$MOP = \frac{20 \times MRS}{C \times (SDR - 1)} \quad \text{or} \quad MOP = \frac{2 \times HDB \times F}{SDR - 1} \qquad (3)$$

where MOP is in the unit of Bar for MRS materials or psig for HDB materials, MRS is in MPa, HDB is in psi, C and F are the design coefficient and design factor, respectively.

4. DIFFERENCES OF MRS AND HDB RATING SYSTEMS

4.1. Multi-Temperature Regression vs. Single Temperature Extrapolation: From Equation (2), the slope, B, is a function of temperature. With increasing temperatures, the slope increases (B is negative). For example, one unimodal HDPE displayed B=-39 at 23°C and B=-25 at 60°C. For another bimodal HDPE, B=-63 at 23°C and B=-51 at 60°C. It is debatable as for which extrapolation is more close to the real behavior. D 2837 uses 23°C data to extrapolate 23°C LTHS without the “interference” from other temperature data. ISO 9080 uses the data set from a wide temperature range. The slope at 20°C includes some “verification” from elevated temperature data. Note the pipe application always has a temperature window. The hydrostatic test at elevated temperatures is regarded as an “accelerated” testing that is related to the long-term performance at lower temperatures. Including the elevated temperature data could virtually add very long time data points at 20°C. It allows to check if the stage II failures would occur before the extrapolated time since brittle failure points occur much sooner at elevated temperatures.

4.2. Extrapolation Time: ISO 9080 extrapolates to 50 years while ASTM D 2837 uses 11-year (100,000h) extrapolation time.

4.3. Confidence Level: ISO uses 97.5% lower confidence limit (LCL) for the extrapolation while D 2837 uses the mean value.

4.4. Minimum LPL and LTHS and the Spread: Minimum LPL is the nominal value of MRS. The minimum LTHS is 4% below the nominal HDB value.

4.5. Design Coefficient and Factor: Because MRS is different from HDB, the design coefficient C is different from design factor F, see equation (3). Although conceptually C is the reverse of F, one cannot just compare C with F without considering the difference in MRS and HDB.

5. ULTIMATE DESIGN COEFICIENT AND DESIGN FACTOR

MRS and HDB are different. C and F are also different. Before we can answer the four questions in Section 2, we must find a mutual reference so that we can compare the two rating systems on the same page.

5.1. Design Reference Strength (DRS): Assume an end-use engineer wants 50-year design lifetime for a PE pipeline. He or she wants the real hoop strength at 50 years for the pipe to be higher than the nominal categorized value that he or she is going to use to determine the MOP. If he or she tests a random pipe, they also want a 97.5% chance they will produce a data point that is above the extrapolated hoop strength at 50 years. Let us define this categorized rating from the end-use engineer as the Design Reference Strength (DRS). Table 3 lists the three key characteristics of DRS.

Table 3. Parameter Coefficient and Factor of MRS and HDB Relative to DRS

Design Reference Strength (DRS)	**ISO 9080 & ISO 12162**		**ASTM D 2837**	
	Parameter	**Cp**	**Parameter**	**Fp**
Design Lifetime: 50 year	50 Year Extrapolation	1	11 Year Extrapolation; 5.4.4.2. $\frac{LTHS_{50-year}}{LTHS_{11-year}} \geq 80\%$	1.25
Confidence Level: 97.5%	97.5 % Lower Confidence Limit	1	Mean Value 5.2.3.3 $\frac{LTHS_{97.5\% LCL,11-year}}{LTHS_{mean,11-year}} \geq 85\%$	1.18
Value: LTHS $\geq$ Nominal Pressure Rating	LPL $\geq$ MRS	1	4% Variance; Table 1 LTHS $\geq$ 96% HDB	1.04
Total Cp or Fp	**1**		**1.53**	

5.2. Parameter Coefficient, C_p, and Parameter Factor, F_p: To convert MRS and HDB into DRS, a parameter coefficient, Cp, and a parameter factor, Fp, are introduced, see Equation (4). Cp and Fp come from the differences in selected parameters during the extrapolation. The relationships among parameters are described in the standards.

$$MRS = DRS / C_p \qquad \text{or} \qquad HDB = DRS \times F_P \qquad (4)$$

First, DRS requires 50-year extrapolation. ISO 9080 uses 50-year extrapolation. D 2837 uses 11-year extrapolation. In Section 5.4.4.2 of D 2837, the standard accepts the 50-year LTHS value being 20% below that of 11-year value. For a material that marginally meets D 2837 extrapolation, the 50-year hoop strength would be 80% of the 11-year value. The corresponding Fp is 1.25. Second, DRS requires 97.5% confidence level. ISO 9080 uses the 97.5% LCL for extrapolation. D 2837 uses the mean value. In Section 5.2.3.3, D 2837 accepts the 11-year LTHS at 97.5% LCL being 15% below that of the mean value. Since D

2837 does not specify the criterion for the 50-year ratio, we take the ratio of 85% at 11 years for 50 years. Note the 50-year ratio would be lower than 85%, see Figure 1. The corresponding Fp is 1.18. Third, DRS requires the minimum hoop strength be equal to the nominal DRS value. ISO 12162 requires the minimum LPL be equal to the MRS value. In Table 1 of D 2837, it accepts LTHS 4% below the HDB value. The corresponding Fp is 1.04. The above analysis is listed in Table 3.

The purpose of a standard is to set the minimum requirements. For one material that just meets the minimum requirements of ISO 9080/12162 or D 2837, the total Cp and Fp are 1 and 1.53 respectively. This answers Question 1 in Section 2. For the worst case-scenario, HDB could be rated 53% higher than MRS.

$$\frac{HDB}{MRS} = \frac{DRS \times F_p}{DRS / C_p} = C_p \times F_p = 1.53 \qquad (5)$$

The real HDB/MRS ratio can be different from 1.53 due to three reasons. (1) Dual extrapolations are not considered. Some 1st generation PE63 HDPE have the ductile-brittle transition knee between 11-years and 50-years. D 2837 extrapolation is only for Stage I. However, ISO 9080 extrapolation includes both Stage I and Stage II. This is why the HDB/MRS ratio for PE 3408-PE63 is 175%, higher than 154%. This is also more supporting evidence that using a multi-temperature data set for extrapolation can better address the long-term performance than just using a room temperature data set. (2) The real ratios vary from the minimum ones defined in Section 5.2.3.3. and 5.4.4.2. of D 2837. (3) Categorized LPL ranges for MRS do not exactly match the categorized LTHS ranges for HDB. The degree of rounding down to MRS and HDB can be different.

5.3. Design Coefficient and Design Factor: Assuming one HDPE material meets the minimum requirements in ISO 9080 and D 2837, they should have the same MOP no matter which standard is used. From Equations (3) and (5)

$$\frac{MRS}{C} = HDB \times F \quad \text{or} \quad C_p \times C = \frac{1}{F_p \times F} \quad \text{or} \quad 1/C = 1.53 \times F \qquad (6)$$

Equation (6) can answer Question 2 in Section 2. From Equation (6), the 1/C for MRS should be 53% higher than F for HDB. Let us see what the current standards use in Table 1. MRS uses C=1.25, therefore 1/C=0.8 that is 60% higher than F=0.5 for HDB. The analysis agrees well with the application practice.

To answer Question 3 in Section 2, compare the MOP Equation (3) using the reference DRS. $C_{ultimate}$ and $F_{ultimate}$ can be compared on the same page.

$$MOP = \frac{2 \times MRS}{C \times (SDR-1)} = \frac{2 \times DRS}{C_{ultimate} \times (SDR-1)} \quad \text{or} \quad MOP = \frac{2 \times HDB \times F}{SDR-1} = \frac{2 \times DRS \times F_{ultimate}}{SDR-1} \qquad (7)$$

$$C_{ultimate} = C \times C_p \quad \text{and} \quad F_{ultimate} = F \times F_p \qquad (8)$$

As summarized in Table 4, ISO 4427 [7] uses a minimum C=1.25 for water pipe. ASTM D 3035 [9] uses a maximum F=0.5 for water pipe. The ultimate C for MRS rated materials is

1.25 (1/C=0.8). The ultimate F for HDB rated materials is 0.77 (1/F=1.30). They are essentially the same. An additional design coefficient or factor is added for gas pipe. ISO 4437[8] uses C=2.0 for gas pipe. ASTM D 2513[10] uses F=0.32 for gas pipe. The ultimate C for MRS rated materials is 2.0 (1/C=0.5). The ultimate F for HDB rated materials is 0.49 (1/F=2.04). They are essentially the same. The extra design safety factor for gas pipe on top of water pipe is 1.60:1 for MRS and 1.56:1 for HDB. They are essentially the same, indicating that the current ISO MRS rating system has the same extrapolation and design baseline as the current ASTM HDB rating system.

Table 4. Ultimate Design Coefficient and Factor

Design Coefficient and Design Factor		ISO MRS	ASTM HDB
Cp		1	
Fp			1.53
C	Water Pipe	1.25	
	Gas Pipe	2.0	
F	Water Pipe		0.5
	Gas Pipe		0.32
$C_{ultimate}$	Water Pipe	1.25	
	Gas Pipe	2.0	
$F_{ultimate}$	Water Pipe		0.77
	Gas Pipe		0.49
C (gas): C (water)		1.60:1	
1/F(gas):1/F(water)			1.56:1

6. ASTM D 2837 REVISION TO HARMONIZE MRS AND HDB

If the HDB rating system has the same baseline as the MRS rating system, why does the HDB rating system fail to differentiate HDPE materials? This is Question 4 in Section 2. To answer this question, Table 5 lists several possible case scenarios in Section 5.4.4.2, 5.2.3.3 and Table 1 of D 2837. Case 1 is the current D 2837 requirements and Case 7 is ISO 9080. Case 2 to 6 are for possible standard revisions. Fp in Case 2 to 6 is determined following the same analysis steps in Table 3. The corresponding F is determined from Fp×F=0.77, the current D 2837 design baseline. First, if one HDPE only meets Case 1, Cp=0.65 and F=0.5. It gets 0% MOP penalty. If one HDPE can meet one of the cases from 2 to 6, it can get various MOP penalties if continuing to use the current ASTM F=0.5. For example, one HDPE meeting the requirements in Case 3 has Cp=0.78. F=0.56 should be used to keep the same design baseline. If still using F=0.5, it would get 19% penalty in MOP.

Table 5. Possible ASTM D 2837 Revision to Harmonize MRS and HDB Rating Systems

Case	Standard Criteria	5.4.4.2 $\frac{LTHS_{50-year}}{LTHS_{11-year}}$	5.2.3.3 $\frac{LTHS_{97.5\%LCL,11-year}}{LTHS_{mean,11-year}}$	Table 1 $\frac{LTHS_{min}}{HDB}$	Parameter Factor, Fp	Design Factor, F	MOP Penalty if Using F=0.5
1	D 2837	80%	85%	96%	1.53	0.50	0%
2	Possible Revision	85%	90%	96%	1.36	0.56	13%
3		90%	90%	96%	1.29	0.59	18%
4		90%	90%	100%	1.23	0.62	20%
5		95%	95%	96%	1.15	0.66	32%
6		95%	95%	100%	1.11	0.69	38%
7	ISO 9080	100%	100%	100%	1	0.77	53%

Assuming there are three HDPE materials marginally meeting the requirements of Case 1, Case 3 and Case 6 respectively, the current D 2837 could not differentiate them. The three materials would have the same PE 3408 rating. If D 2837 is revised to use Case 3 requirements, the first HDPE would not be qualified for PE 3408. If D 2837 is revised to use Case 6 requirements, only the third HDPE can be qualified as PE 3408. As we lift the bar, we get better differentiation. This can explain what happened to the three generations of HDPE listed in Table 1. The bottom line is that D 2837 fails to differentiate HDPE's primarily because the requirements in Section 5.4.4.2, 5.2.3.3 and Table 1 of D 2837 are too loose.

As we discussed in Section 3.5 of this paper, another possible reason could be the 10MPa as the cut-off value to separate MRS from the R10 series to R20 series. Similarly a cut-off value of 1400psi (9.7MPa) can be introduced to HDB. LTHS is rounded down to the next value in the R10 series when LTHS<1400psi or down to the next value in the R20 series when LTHS$\geq$1400psi. This will create new classifications of 07 (1400psi HDB) and 09 (1800psi HDB) ratings. Better differentiation could be achieved.

It is worth pointing out that these possible D 2837 revisions make D 2837 more like ISO 9080, see Table 5. As we lift the bar in 5.4.4.2, 5.2.3.3 and Table 1 in D 2837, some materials will be forced to use a 50-year value and/or the 97.5% LCL value. Materials having steep slopes and large scatters would get a lower HDB. This makes D 2837 revision more difficult and complicated. **As the MRS rating system becomes dominant in the world, perhaps the most efficient and practical way to harmonize MRS and HDB rating systems is simply to adopt the ISO MRS rating system**.

7. TEMPERATURE AND TIME EFFECT

7.1. MRS Pressure Reduction Factor: MRS can be directly plugged into Equation (3) to calculate MOP for application temperatures up to 20°C. If the maximum application temperature is above 20°C, a pressure reduction factor shall be used in accordance to Table 7 in ISO 4427. 40°C is the maximum application temperature based on 20°C MRS.

ISO 4427 further differentiates MRS rated PE into Type A, Type B and Type C. If the ductile-brittle transition knee at 80°C is greater than 1 year, it is a Type A PE. If the transition knee is between ½ year and 1 year, it is a Type B PE. If it is shorter than ½ year, it is a Type C PE. Table 6 lists the pressure reduction factor for the three types of PE materials.

Table 6. Pressure Reduction Factor for MRS Rated PE Materials up to 40°C

Material	Pressure Reduction Factor at				
	20°C	25°C	30°C	35°C	40°C
Type A	1	0.93	0.87	0.80	0.74
Type B	1	0.90	0.81	0.72	0.62
Type C	1	0.82	0.65	0.47	0.30

Table 7. Temperature Design Factors for HDB Rated PE Materials up to 38°C

Maximum Operating Temperature		Temperature
°F	°C	
Up to 80	Up to 27	1
From 81 to 90	From 28 to 32	0.9
From 91 to 100	From 33 to 38	0.8

7.2. HDB Temperature Design Factor: A temperature design factor shall be used in accordance to AWWA M-55. Table 7 lists the categorized temperature design factor based on HDB at 23°C. The maximum application temperature is 38°C using 23°C HDB.

Note the differences between temperature design factor and pressure reduction factor. (1) HDB at 23°C can be directly used up to 27°C, 4°C above the extrapolation temperature. MRS can be directly used only up to the same extrapolation temperature of 20°C. (2) Two temperature design factors are used from 27°C to 38°C. The pressure reduction factor is continuous from 20°C to 40°C as given by the graphic chart in ISO 4427. (3) ASTM uses the same temperature design factor for all HDB ratings. On the contrary, ISO further differentiates the pressure reduction factors into three types of PE's with different factors.

7.3. HDB at Elevated Temperatures and CRS (θ, t): To meet elevated temperature applications, PPI has provided the listing service for HDB at elevated temperatures for many years. The policy is in PPI TR-3 [5] and the listing is in PPI TR-4 [6]. In addition to 23°C HDB listing, PPI offers the HDB listing at 140°F (60°C) and 180°F (82°C). HDB at elevated temperatures enable PE pipes to be used up to 82°C. In particular, HDB at 60°C differentiates the three generations of HDPE. PE 3408-PE100 HDPE has 1000psi HDB at 60°C. PE 3408-PE80 has 800psi HDB at 60°C. PE 3408-PE63 is not usually pressure rated or has a 630psi HDB at 60°C. D 2513 specifies 60°C HDB for gas pipe by creating CDC and CEC rating[10]. It is worth noting that unimodal medium density PE 2406 can have 1000psi HDB at 60°C, higher than 800psi HDB for unimodal high density PE 3408. This is one major reason that PE 2406 is widely used in North America for natural gas distribution.

PPI also began the MRS listing at elevated temperatures. MRS (θ, t) is MRS rating at the temperature θ and the extrapolation time t. In June 2002, CONTINUUM* DGDA-2490 NT Bimodal Polyethylene Resin from The Dow Chemical Company was listed by PPI for MRS 10 (20°C, 100y), MRS 8.0 (40°C, 50y) and MRS 6.3 (60°C, 11y). In April 2003, Hostalen® CRP100 from Basell was listed by PPI for MRS 10 (20°C, 100y) and MRS 8.0 (40°C, 100y). ISO TC 138 is introducing a new concept, CRS (θ, t), to replace MRS (θ, t). CRS (θ, t) is the Categorized Minimum Strength that is being introduced to ISO 12162. The new revision will use MRS (20°C and 50 years) for material classification purpose. End use engineers would use CRS (θ, t) to determine MOP at the application temperature of θ and design lifetime of t. This enables MRS rated PE to be used up to any listing temperatures and the listed extrapolated lifetimes.

7.4. Temperature Interpolation of LTHS and LPL: The nature of categorizations results in only a few HDB and MRS categories. The listing temperatures are also limited. However, pipe applications have a broad temperature window. It is necessary to develop a temperature interpolation equation so that the limited HDB and MRS categories can be used to calculate LTHS and LPL at other temperatures. PPI TN-18 [11] gives the temperature interpolation equation (9).

$$S_T = S_L - \frac{(S_L - S_H)\times(1/T_L - 1/T_T)}{1/T_L - 1/T_H} \qquad (9)$$

where S is LTHS, T is temperature, subscript L, T and H represents the low, interpolation and high temperature respectively. For one PE with HDB at 23°C and 60°C, the pressure rating at any temperature between 23°C and 60°C can be calculated from equation (9). LPL can also be calculated from equation (9) from two listed MRS categories. ISO 9080 can extrapolate or interpolate LPL at any temperatures provided it is validated.

7.5. Extrapolation Time: 11-year is the standard extrapolation time for HDB. D 2513 requires the linearity substantiation of LTHS at 23°C to 50 years for gas pipe. To meet the gas pipe requirement, PPI lists 23°C HDB with an asterisk to show this compliance to gas pipe application. While HDB is rated for 11 years only, CRS can be listed for any extrapolation

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times provided it is validated. PPI has listed CRS for 100-year extrapolation time for bimodal PE made by The Dow Chemical Company, ATOFINA Petrochemicals and Basell. An 11-year CRS at 60°C has also been granted for the bimodal PE from Dow.

8. SUMMARY

The head-to-head comparison has revealed that MRS and HDB rating systems have the same extrapolation and design baseline. They have been validated by many years of field applications. PE materials have been improved in past years to exceed the extrapolation requirements in D 2837 as discussed. As a result, the dramatic advances in PE resin technology cannot be reflected by HDB. End users cannot differentiate PE pipe materials and therefore can not utilize their full potential. The MRS rating system is being introduced into North America, the only region in the world that uses the HDB rating system. Perhaps the best way to harmonize MRS and HDB is to use MRS to replace HDB rather than to revise D 2837. PPI and NSF International have listed MRS. ASTM D3350 and D 2513 have recognized MRS. There are many on-going projects to introduce MRS into ASTM, AWWA and DOT standards. PE100 pipe is being used in North America following ISO standards.

The safe and efficient operation of a pipeline depends on many properties. The pressure rating is one that has been addressed in this paper. Resistances to slow crack growth (SCG), the major long-term brittle failure mode, to rapid crack propagation (RCP), the fast fractures, and the effect transported materials and environments on LTHS, the main resources to chemical-physical degradation, are not addressed due to space and time limitations.

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