“Using the CRS Concept for Plastic Pipe Design Applications”

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ABSTRACT

The CRS (Categorized Required Strength) concept was developed within the ISO pressure rating system to provide more flexibility to the design engineer. One of the major uses of CRS is to provide a design basis of 100 years for plastic piping applications. With the CRS concept plastic pipe can now have a design basis or design life of 100 years and be considered equivalent to other piping materials, such as steel or iron pipe, which claim a 100-year design life. Another major application for the CRS concept is to pressure rate plastic pipe at the actual use temperature. This can be useful for high temperature applications or in areas that have a low ground temperature. The design engineer can determine the appropriate conditions for the plastic pipe application, and design accordingly. In this paper, we will review the CRS concept, how it is validated within ISO 9080, how it is determined within ISO 12162, what its limitations are, and finally, how it is used in typical plastic piping applications to make plastic pipe more cost competitive with metal pipe. The Plastics Pipes Institute (PPI) publishes CRS values in its public listing of TR-4, which is available on the PPI website – www.plasticpipe.org. We will also describe an actual field installation where a gas company had planned to use steel pipe for operation at 160 psig. Because of the CRS concept and use of the PE 100 material’s CRS value of 11.2 MPa at 14°C, the gas company was able to use 4” SDR 11 pipe operating at 160 psig. The gas company saved money by using PE pipe instead of steel pipe due to lower installation costs. In addition, the gas company will continue to have cost savings because there is no need for cathodic protection, no maintenance, and no concerns about corrosion.

I. History of CRS

The CRS concept was first developed with ISO (International Standards Organization) because gas and water engineers felt that plastic pipe was at a disadvantage vs. other piping materials that claimed a 100-year design life. Since plastic piping materials are pressure rated using ISO 9080, which uses a 50-year design basis, they are at a disadvantage compared to those materials that use a 100-year design basis. The CRS concept was developed as a way of increasing the design basis from 50 years to 100 years for plastic pipe. In this way, they would be treated in a similar way to the 100-year design basis metal piping materials. Design engineers first developed the CRS concept within ISO/TC 138/SC 4 in the gas pipe standard for PE pipe – ISO 4437, as an annex for a new design concept. This annex is reproduced here as Appendix A. Because the CRS concept is applicable to other piping materials besides PE and other applications besides gas distribution, SC 4 members initiated a project in SC 5 for Test Methods to incorporate the CRS concept in ISO 12162. This is now an active project in SC 5.

II. Design Life vs. Service Life

HDB (hydrostatic design basis), MRS (minimum required strength) and CRS are all used to determine the pressure rating for a plastic piping material. This is how plastic pipe is designed and this is the design life or design basis of the plastic piping material. For HDB the design basis or design life is 11 years, for MRS it is 50 years, and for CRS the design life or design basis is determined by the design engineer and can be up to 100 years. The term design life is not to be confused with the term service life, which is usually intended to indicate how long plastic pipe will last in an application before failing.

Design life is the term used in designing plastic pipe and determining its pressure rating. The design life is actually the time selected for designing plastic pipe, and the stress is determined at that design lifetime. For example, Figure 1 shows the design times for HDB – 100,000 hours or 11 years, MRS – 50 years, and CRS – 100 years. These are the times selected for designing plastic pipe. The pressure rating is then determined from the value of the HDB or MRS or CRS at that design time.

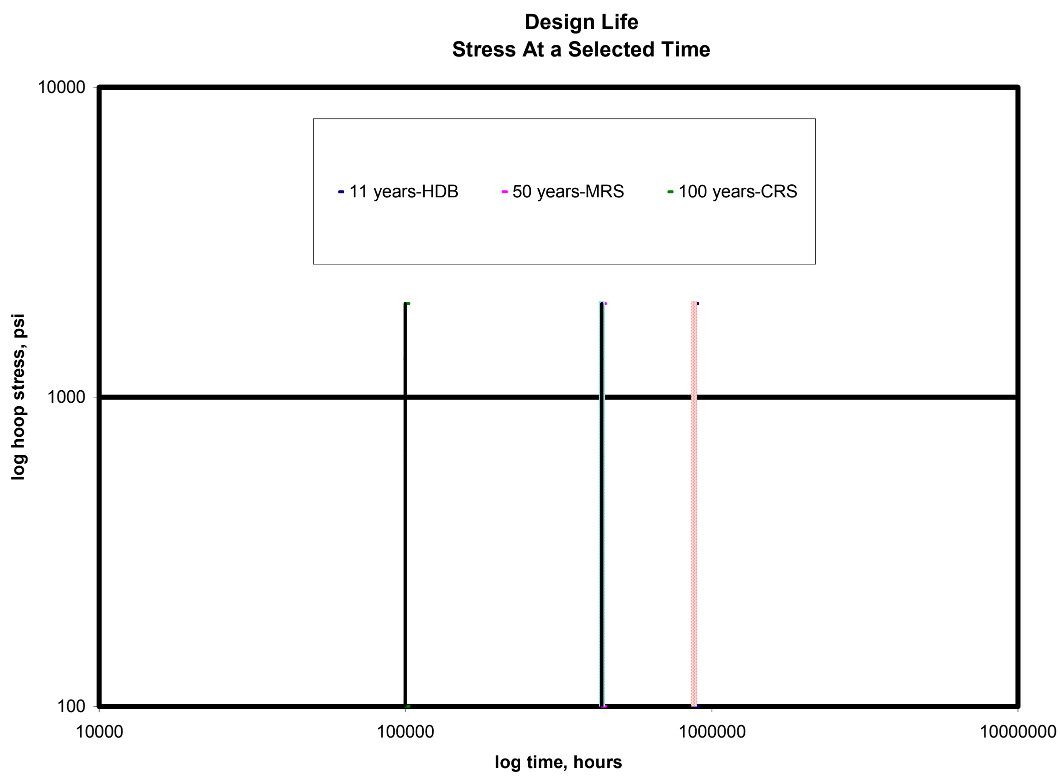

Figure 1 – Design Life

It is important to remember that the HDB is the categorized value of the stress at the extrapolated time of 11 years. It is this stress value that is used to determine the pressure rating. The MRS or CRS is the categorized value of the stress at the extrapolated time of 50 years for MRS or 100 years for CRS. It is this stress value at the extrapolated time that is used to determine the pressure rating. Thus, it is the time for extrapolation (11, 50 or 100 years) that is the design life or the basis for designing.

Service life is the term used for the life of the pipe in a particular service application. It is the time that pipe will last at a particular operating stress. In Figure 2, one can see the 500 psi stress line. The service life is the time that the pipe will survive at that particular operating stress. Service life takes into account operating variables such as, temperatures, soil loads, chemicals such as hydrocarbons or chlorine, etc.

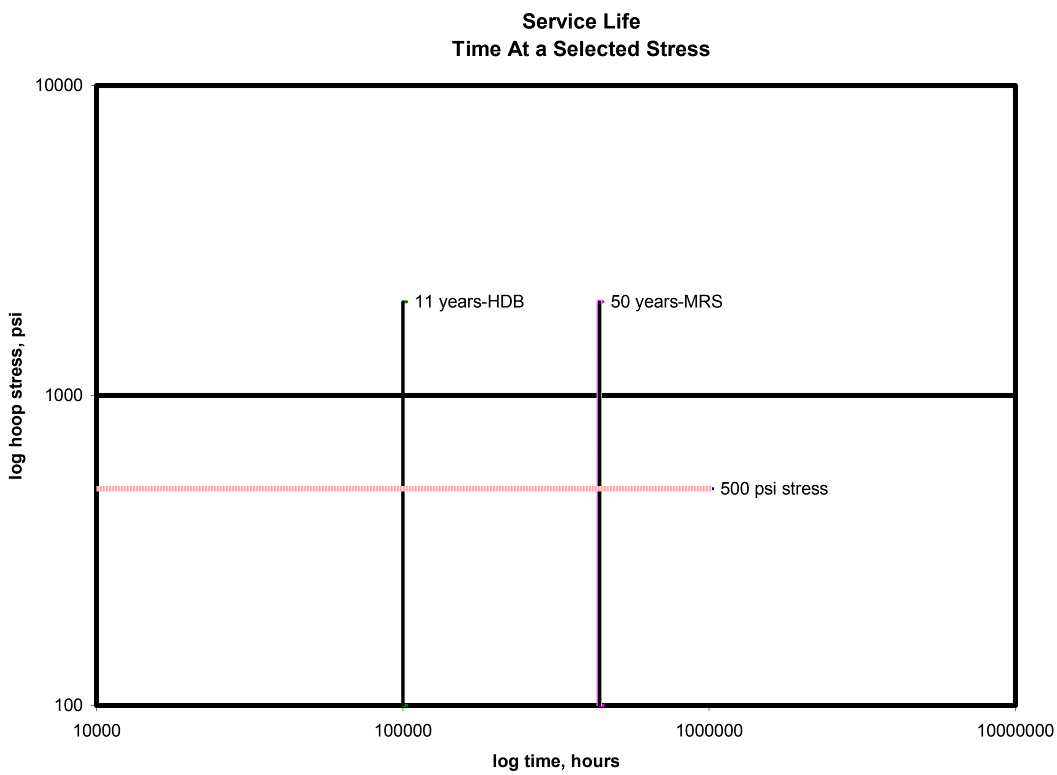

Figure 2- Service Life

When using the CRS concept, we are using it for design life as a design basis, because CRS is used to determine the pressure rating of the plastic pipe. The CRS is not used for service life.

III. CRS Validation and Determination

The Minimum Required Strength (MRS) is the categorized lower predicted limit (LPL) determined in accordance with ISO 9080 and ISO 12162. PPI lists MRS values for specific thermoplastic piping materials in TR-4. For classification purposes, the MRS is always obtained at 20°C and 50 years. This MRS value is used in the pipe material designation code, such as PE 100 or PA 160. For pressure rating calculations, the MRS may be selected by the design engineer at the desired use temperature and the desired time. At any other time/temperature condition, the MRS is then called the CRS. The MRS and CRS are determined and validated in exactly the same way using the following protocol:

Protocol for Determination of MRS and CRS

1. The data set must meet all the data requirements of ISO 9080.

2. The SEM (standard extrapolation method) software program available from Becetel is the current internationally recognized program for determination of the lower predictive limit (LPL) in accordance with ISO 9080.

3. Determine the LPL at the desired time and temperature from the SEM program calculation. The LPL must meet the extrapolation time limits of ISO 9080, which are based on the Ke extrapolation table in ISO 9080 – this information is available from the computer program. The desired time shall not exceed 100 years and the desired temperature shall not be less than 20°C below the lowest test temperature.

4. If the time is 50 years and the temperature is 20°C, the categorized value of the LPL is called the MRS in accordance with ISO 12162. For other times and/or temperatures, the categorized value of the LPL is called the CRS in accordance with ISO 12162.

The CRS concept is actually a very useful tool, and it works because ISO 9080 requires data at multiple temperatures. Therefore, the three co-efficients of the rate process method mathematical model are already known and the lower predictive limit (97.5% confidence level) or LPL can be determined at any desired time and/or any desired temperature. Once the LPL is known it is then categorized using the R10 or R20 preferred number series in accordance with ISO 12162. The categorized value at the desired time/temperature is known as the CRS, just as the categorized LPL value at 20°C/50 years is known as the MRS.

IV. CRS Limitations

Although one could extrapolate an LPL out to several hundred years, the farther you extrapolate beyond the data, the less confidence you have in the extrapolation. Therefore, ISO decided that the time limitation extrapolation for CRS values would be 100 years. In keeping with this ISO limitation, PPI will not list any CRS value in TR-4 with a time extrapolation beyond 100 years.

The other extrapolation limitation is temperature. Once you have elevated temperature stress rupture data for a plastic piping material, you could extrapolate to any desired lower temperature. Again, the farther you extrapolate beyond the data, the less confidence you have in the extrapolation. Therefore, ISO decided that the temperature limitation extrapolation for CRS values would be 20°C below the lowest temperature for which there are stress rupture data. In keeping with this ISO limitation, PPI will not list any CRS value in TR-4 with a temperature extrapolation lower than 20°C below the lowest test temperature (which is usually 20°C). In the case, the lowest extrapolation temperature would be 0°C.

V. CRS Engineering Uses

There are two ways that a design engineer would use the CRS concept – time and temperature. One way is to design the plastic piping system for a specified time period. For example, some engineers may only want the system to operate for 10 years. Some may want the system to be designed for 25 years or 75 years or 100 years. As an example, some water utilities prefer to use a piping system that has a design life or design basis of 100 years. Without the CRS system, it would not be possible for plastic piping systems to be considered for these applications. This was the case for some water piping applications in Europe where the requirement was a 100-year design basis. Some metal piping systems could meet this 100-year requirement, but plastic pipe could not. With the advent of the CRS system and its 100-year design basis, plastic pipe can now compete with metal pipe for these applications that require a 100-year design basis.

The other useful feature of the CRS concept is to design the plastic piping system for a specified temperature. Since the ISO 9080 stress rupture data are obtained at multiple temperatures and the three coefficients for the mathematical model are known, the LPL may be determined at a specified time and also at a specified temperature. In some cases, it is useful to have a pressure rating at elevated temperatures, such as hot water applications. In fact, the new ASTM product standard for polypropylene materials used in hot water applications specifically requires a CRS at the design temperature of 82°C. This was the first ASTM standard to require a CRS rating. There are several standards in Europe that specify a variety of temperatures, and use the CRS concept to arrive at these desired temperature conditions. Examples are the German DIN standards for PE piping materials – DIN 8074 and DIN 8075.

In addition to higher temperatures, the CRS concept may also be used for lower temperature applications, especially where the ground temperature is below 15°C (60°F). In this case, due to the lower temperature, the LPL value is higher and it is possible for some materials that a higher CRS category may be achievable. This is significant for applications such as gas or water distribution in areas where the average annual ground temperature is low enough that the higher CRS value is applicable. The higher CRS value will result in a higher operating pressure for a given wall thickness or a thinner wall for a given operating pressure.

VI. CRS Example

The best way to provide an example of the CRS concept at low temperatures is to compare the DR (dimension ratio) that would be required for a particular operating pressure. If we consider a gas distribution system operating at 125 psig, which is the new maximum operation pressure allowed by DOT in Part 192, we arrive at the following table:

Required DR for MOP of 125 psig

	PE3408	**PE4710**	**PE 100**	**PE100**
HDB, psi	1600	1600		
MRS/CRS, MPa			10.0	11.2 at 60°C
Design factor	0.32	0.40		
Design coefficient			2.0	2.0
Required DR for MOP of 125 psig	9	11	12.5	14

A PE 3408 material with an HDB of 1600 psi and a 0.32 design factor requires a DR of 9 to operate at 125 psig. If the PE 3408 material met all the requirements of a high performance PE material (like a PE 100), it would have a pipe material designation code of PE 4710. With the design factor of 0.4, this PE 4710 pipe would require a DR of 11 to operate at 125 psig. If the same PE 100 material were treated as a PE 100 material and pressure rated using the ISO 4437 design coefficient of 2.0, it would require a DR of 12.5 to operate at 125 psig. If this same PE 100 material was pressure rated using the ISO 4437 design coefficient of 2.0 and the average annual ground temperature was 60°F or below, we could use the CRS rating of 11.2 MPa and it would require a DR of 14 to operate at 125 psig. Obviously, as we go from DR 9 to DR 14, the wall thickness continues to decrease. This thinner wall results in lower cost for the price of the pipe as shown below for 6” pipe:

- PE 3408 DR 9 $5.05/ft
- PE 4710 DR 11 $5.00/ft
- PE 100 DR 12.5 $4.50/ft
- PE 100 DR 14 $4.10/ft
  (CRS at 60°F)

These are approximate pipe prices (FOB plant) for 6” pipe to operate at 125 psig, and will change with time. The important point to consider is the relative difference in pipe price for the various DR ratios. As you can see the pipe price for the high performance PE 4710 material is lower than its counterpart because the 0.40 design factor requires a thinner wall and less material. The pipe prices for the PE 100 material pressure rated as a PE 100 material and using the CRS value at 60°F are the lowest of all. This example shows the benefit of using the CRS concept to thin the pipe wall for a given operating pressure, which results in a larger ID and thus greater flow, results in lighter weight for the pipe and results in a lower price for the pipe. This can be a major advantage for plastic pipe, especially large diameter applications, and can result in a design engineer specifying plastic pipe instead of metal pipe.

Another example of using the low temperature CRS concept is to increase the maximum operating pressure (MOP) for a given DR or SDR. The example below shows the effect of using the CRS concept on operating pressure for a given SDR in a gas piping application.

MOP (psig) For SDR 11 Pipe

	PE 3408	PE 4710	PE 100	PE 100
HDB, psi	1600	1600		
MRS/CRS, MPa			10.0	11.2
Design factor	0.32	0.40		
Design coefficient			2.0	2.0
MOP for SDR 11, psig	100	125	145	160

A traditional PE 3408 pipe with an HDB of 1600 psi and design factor of 0.32 has a maximum operating pressure (MOP) of 100 psig. If the PE 3408 meets the requirements for a high performance PE material, then the design factor is 0.40 and the MOP increases to 125 psig. If that same material is a PE 100 and it is pressure rated as a PE 100 using a design coefficient of 2.0 for gas applications, then the MOP is 145 psig. In Europe there are several applications where PE 100 is used for the gas distribution industry and SDR 11 pipe is operated at 145 psig or 10 bars. That is why PE 100 pipe is sometimes called the 10-bar pipe. If that same PE 100 pipe is operated in an area where the average annual ground temperature is below 15°C (60°F), then the CRS concept can be used. With a CRS of 11.2 MPa, the MOP now increases to 160 psig for SDR 11 pipe.

Recently, Manitoba Hydro needed to install a 14 mile pipeline to bring natural gas to a new area. They had planned to use steel pipe because the operating pressure needed to be around 160 psig. When they heard about the new PE 100 materials and use of the CRS concept as in the example above, they decided that they could use 4" SDR 11 PE 100 pipe to achieve their desired 160 psig MOP, because their average annual ground temperature was below 14°C. PPI TR-4 lists a PE 100 material with a CRS value of 11.2 MPa at 14°C and 50 years. Use of the CRS design concept allowed this gas utility to use PE pipe instead of steel pipe and save considerable money for the installation costs, plus the PE pipe would not need cathodic protection and would not fail due to corrosion as would be the case with steel pipe.

VII. Conclusions

The CRS concept can be a very powerful tool for the design engineer. It can make plastic pipe more cost competitive with metal pipe, and can allow plastic pipe to be used in applications where otherwise other piping materials would need to be used. The CRS concept can be used in applications where a design engineer requires a 75 year or 100 year design basis, or it can be used for a 10 year or 25 year design basis. The CRS concept can also be used in applications where temperature is a design parameter. For example, in hot water piping applications, the polypropylene ASTM standard requires the CRS concept for its design temperature of 82°C. We have also shown examples where the CRS concept can increase the pressure rating for a plastic piping material at lower temperatures. It was this use of the CRS concept that allowed a gas utility to use PE pipe instead of steel pipe in their gas distribution system.

In this paper we have described the CRS concept, its history, how it is calculated and validated, and how it is used for design applications. We have also discussed its limitations with respect to time and temperature extrapolations. Finally, we have provided examples of how the CRS concept is used by a design engineer in plastic piping applications. For additional information, please contact Dr. Gene Palermo – www.plasticspipe.com.

Appendix A

ISO 4437

Annex D
Alternative Design Approach

D.1 General

The standard for PE gas pipes ISO 4437 specifies the physical properties of buried PE pipes for the supply of gaseous fuels. It lays down dimensional requirements and maximum operating pressures related to the overall service (design) coefficient and operating temperatures.

Guidance is given regarding the calculation of pipe design stress σ_S and pipe SDR and wall thickness. The MRS of the pipe material (determined at 20 °C and 50 years in water using ISO 9080) is divided by the overall service (design) coefficient C to determine the pipe design stress σ_S.

i.e. $$\sigma_S = \frac{MRS}{C}$$

For gas systems a minimum C value of 2,0 is allocated in ISO 4437 for the calculation. TC138/SC4 has discussed over several meetings possible modifications to the σ_S equation in order to reflect better the changing requirements of the gas industry. A policy paper on the subject, to be presented to ISO/TC 138, is the subject of the following paragraphs. The policy, whilst proposing changes to the existing design method, retains the well established MRS basis for the classification of PE materials in accordance with ISO 12162.

D.2 Pipe design stress σ_S

The standard ISO 12162 describes the "overall service (design) coefficient" or "C-factor". This standard details the contents of this coefficient and gives the minimum values to be used for this coefficient.

It is specified in clause 5 of this standard that the minimum coefficient is established for static water pressure at 20 ºC for 50 years, and shall take 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 ºC, 50 year and water. This influence can have either positive or negative effects;
3. Standards relating to MRS for temperatures other than 20 ºC.

Minimum values are given in table 2 of the standard.

The symbol for design stress in ISO 12162 is σ_S however the abbreviation HDS (hydrostatic design stress) has also widespread use internationally. In order to satisfy the requirements of the full international arena an alternative version is therefore suggested as a compromise i.e. σ_{HDS}.

D.3 Material strength MRS

International developments in the use of PE for gas 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 viz $CRS_{\theta,t}$ for use in pipe design calculations whilst retaining the value of $CRS_{\theta,t}$ 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 would be published as the MRS for the material in accordance with ISO 12162 as it is currently.

The $CRS_{\theta,t}$ should be equal to the value of σ_{lpl} determined and categorised for the temperature (θ) 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 categorisation of $CRS_{\theta,t}$ should be in accordance with the following series with the boundaries of categorisation as given in table D.1.

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

Table D.1: Boundaries of categorisation for $CRS_{\theta,t}$

Range of σ_{lpl} at θ and t **MPa**	**$CRS_{\theta,t}$** **MPa**
$4{,}00 \leq \sigma_{lpl} \leq 4{,}99$	4,00
$5{,}00 \leq \sigma_{lpl} \leq 6{,}29$	5,00
$6{,}30 \leq \sigma_{lpl} \leq 7{,}99$	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

D.4 The C factor

The current C factor is related to the pipe material and the anticipated installation and operating conditions. There is however no clear distinction between the relative effect on the coefficient, of material performance and application conditions. This should be corrected with individual factors introduced to separately cover material and application aspects. The proportion of the factor related to application conditions should not be considered a part of ISO 4437 where the focus should be solely on material.

In this way the material related factor C_M will be less than the value of 2,0 currently allocated in ISO 4437 and be within the experience of SC4 to determine. It reflects the properties of the components of a piping system other than those represented in the σ_{lpl} (e.g. extrusion, batch to batch variation). In this way the minimum factor should be 1,25 (the same as for water).

The application related component C_A should be left to the gas distribution 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 MOP, on the type of gas being

conveyed, etcetera. Care should be taken regarding the differences between (hydro)static 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. For natural gas it is therefore proposed that the component of C_A, related to the type of gas is 1,0 (the same as for water). For LPG gas the gas related component of C_A should be 1,1 ; 10% greater than that of natural gas, which difference is in line with values already in use by the gas industry in the ISO Codes Of Practice. The factor for manufactured gas should take into consideration the analysis of the gas with special reference to liquid hydrocarbons and should be at least 1,2. However, this component should be the subject of further discussion[1].

D.5 Design Equations

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

$$\sigma_{HDS,\theta,t} = \frac{CRS_{\theta,t}}{C_A \times C_M}$$

where

- $\sigma_{HDS,\theta,t}$ is the hydrostatic design stress for the material in contact with the fluid being transmitted at a specified temperature θ and lifetime t.
- $CRS_{\theta,t}$ is the σ_{lpl} of the material calculated for a specified temperature θ and lifetime t and suitably categorised 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 σ_{lpl} (e.g. for PE the factor C_M should be 1,25).
- C_A is the overall system design coefficient to be applied by the gas distribution engineer.

The pipe wall thickness e_n is then determined from the equations

$$e_n = \frac{d_n}{SDR}$$

and

$$SDR = \frac{20\sigma_{HDS,\theta,t}}{MOP} + 1 = \frac{20CRS_{\theta,t}}{MOP \times C_A \times C_M} + 1$$

using standardized SDR values.
Pipe diameter d_n and maximum operating pressure MOP are features of the flow requirements of the distribution system and are assumed to be set by the pipeline operator.
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 x C_M) of 2,0, the minimum value for C specified already in ISO 4437.

D.6 Concluding summary

Material related design factors are to be covered by the MRS classification according ISO 9080 and the material related coefficient C_M, which is 1,25 for PE piping systems. For

[1] In the US a derating factor is used which is equivalent to 2

greater flexibity in the use of the MRS the $CRS_{\theta,t}$ is introduced, where the temperature θ and the lifetime t may deviate from the usual values of 20 ºC and 50 years. The policy retains the well established MRS basis for the classification of PE materials in accordance with ISO 12162.

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