An Alternative Method for Dimensioning of Line Pipe for Pipeline Projects

1 Preamble
Secured gas supply, safe and reliable operating assets whilst targeting expenses on cost-saving level let actors on the market facing the challenge of a balancing act with applying safest possible technology on the one hand and cost-efficiency on the other.

Over the years a massive improvement of knowledge and fast growing development of new technologies took place. Understanding the influence and multidimensional interdependencies of relevant factors and conditions (e.g. manufacturing process, material properties, construction techniques, environmental conditions, physical behavior for example static and dynamic loads, temperature and pressure distribution a.s.o.) keep the industry to improve procedures, products and services. Technological and methodological development inhere an iterative process integrating both, improvement based on known and proven rules as well as to scrutinize such rules. Based on this philosophy, a new approach for line pipe dimensioning will be presented hereinafter, which has been evaluated as safe, scientific and technically sound, and with economical positive results.

2 An Alternative Method for Dimensioning of Line Pipe
In the course of project planning for one of the largest onshore gas pipeline within Europe questions were raised if alternative technical approaches and design parameters could be applied which in terms of dimensioning provide parity for the same high-level state of safety, although deviating from common regimes like EN 1594 in conjunction with DVGW, which are applied in Germany.

Considering the principles of line pipe supply terms, line pipe as ‘delivery item’ will normally have higher actual yield strength limits and higher wallthicknesses than the required minimum standard values to be guaranteed, which are stipulated by applicable standards, regimes and design practical use. So, there is a potential which can be technically assessed and – by applying in line pipe order requisitions and specifications – could be used for design and dimensioning of line pipe for a high pressure onshore gas pipeline. Thus, an optimum of pipeline dimensioning as well as enhancement of the admissible utilization of material parameters of can be achieved whereas maintaining the same high safety level as when strictly adhere to the written rules and standards.
3 Background
In Germany, the law governing electricity and gas supply (German Energy Law – EnWG) of 24th April 1998, last revised on 20.05.2003, constitutes the legal basis for construction and operation of high pressure gas pipelines. Furthermore, the Ordinance Regulating High Pressure Gas Pipelines (GasHL-VO, 17th December 1974, last revised 12th December 1996) prescribes a deterministic safety philosophy to be adhered in Germany. Within this ordinance, safety-related quality and organizational requirements are regulated, to which the subjected system or device have to comply with. Only this compliance constitutes an adequate prevention of risks in value judgements of the legislator. The general requirements for high pressure gas pipelines are set in § 3 of above ordinance; and within Appendix § 3 para. 1, it is more precisely stated, that high pressure gas pipelines must be constructed and operated according to the “state-of-the-art”.

The respective “state-of-the-art“ implies compliance with the requirements set by the German Technical and Scientific Association for Gas and Water (DVGW e.V.) and by the latest standards, rules and regulations. If the same or even higher safety will be warranted otherwise by alternative or other ways, deviating from conventional approaches are allowable.

The above named Ordinance Regulating High Pressure Gas Pipelines, § 3 and Appendix § 3 para. 1, specifying requirements for high pressure gas pipelines and related facilities do adress rules and prescriptions concerning
- Construction
- Commissioning and Initial Operation
- Operation (surveillance and inspection by the operator and monitoring possibilities on the part of the competent authority)

As initially mentioned, the herein described alternative method is related to one of the largest onshore gas pipeline within Europe. During planning period for subject pipeline project there had to be clarified under which conditions a method for line pipe dimensioning could be applied which is based on actual “as-fabricated“ dimensions and strength behavior of the line pipe, and therefore is deviating from a strict adherence to EN1594 and DVGW Code of Practice G 463.

Choosing this alternative way for line pipe dimensioning means to adopt an approach with some significant supplements to commonly used standard EN 1594 regarding minimum requirements.

Conventional dimensioning of line pipe has to apply EN 1594 in conjunction with DVGW Code of Practice G 463, using following formula:

\[ T = \frac{DP \times D}{20 \times fo \times R_t} \]

whereas:
- \( T \) minimum wall thickness [mm]
- \( DP \) design pressure [bar]
- \( D \) nominal outer diameter [mm]
- \( fo \) efficiency / grade of utilization (e.g. buried pipeline sections outside stations ≤ 0,625)
- \( R_t \) yield point at 0.5% total strain / ultimate elongation (specified minimum value) [N/mm²];
  \( R_{t0.5}(\theta) \) at Design Temperature;
  \( R_{t0.5} \) at Ambient Temperature
Furthermore, as additional basic prerequisite, the minimum parameter for line pipe regarding their manufacturing are prescribed within the Manufacturer Standard DIN/EN 10208-2, which states higher and more stringent requirements on pipe, particularly with regard to tolerances of ordered wall thickness, with regard to the yield ratio, the elongation at break and the impact strength. These values and parameters are the main mechanical-technological material properties with direct impact on line pipe dimensioning and safety.

As mentioned before, line pipe as 'delivery item' will normally have higher actual yield strength limits and higher wall thicknesses than stated by the minimum technical requirements; as a logical consequence for optimized wall thickness determination, the pipe material’s strength parameters are within the focus of examination.

4 Yield Ratio
The yield ratio reflects the relation between yield strength and tensile strength, i.e. the relation between allowable operating constant load and the maximum load shortly before pipe failure. Therefore, the yield ratio represents a safety margin between admissible operating load conditions and pipe failure. According to DIN/EN 10208-2, for high-quality pipeline steel L 485 MB this ratio value should not exceed maximum 0.9, i.e. should be better than 0.9.

5 Ordered wallthickness
During the plate manufacturing processes, manufacturers are nowadays able to produce with rolling tolerances at measures much lower than required as per applicable standards and rules. This means, the required minimum values for wall thickness are higher than those of the actual manufactured pipes, whereas, of course, the wall thickness will be subject to proper QA/QC during the manufacturing process. This includes regularly measurements, monitoring, recording and verification by a Third Party Inspection and any exceeding limits, i.e. produced wall thickness falling below the minimum threshold value will be timely detected.

So, for line pipe ordering, the order requisitions shall specify that rolling tolerances during plate manufacturing must be minimized to be as low as feasible for a modern plate and/or pipe manufacturer.

6 Elongation at break
The required minimum elongation to be specified within pipe order requisitions shall be above the one as stated within DIN/EN 10208-2 in order to make allowance for additional contingency in case of damage to buried pipeline.

Furthermore, it is recommended for evaluation of material's deformation behavior within the multiaxial stress state, to determine its uniform elongation. This approach will enable to assess the total deformation behavior of the utilized pipe.
7 Impact strength
It is recommended to increase the requirements for impact strength value above to those stated in DIN/EN 10208-2 in order to establish best possible resistance to crack formation and longitudinal cracks.

8 Pipe Manufacturer
Each of the potential pipe manufacturers shall undergo an audit to verify conformity with the higher requirements not only at random tests but are able to manufacture constantly at the required high-quality level.

9 Resistant strength - strength values $R_t \cdot s$ (known as ‘$K \cdot s$’)
Determination of the used pipe material’s yield strength ($R_t$) shall be conducted by regularly taking specimen during pipe manufacturing. It should be considered to go for production lot of quantity enabling to record a sufficient number of test results and which provides statistically sound results, whereas all occurring heats have to be taken into account.

Comprehensive statistical verification according to ‘Gauss’ shall assure that adherence on the strength values of all pipes of a production lot is being maintained as follows: the average ($X$) of all strength values of a production lot, minus 2 x standard deviation ($2 \cdot s$) shall be higher than the specified minimum yield strength value ($R_t$); i.e. $R_t < (X - 2 \cdot s)$

Therefore, availability and application of a ‘Gaussian Distribution’ ensures that minimum 97.5% of all pipes have the requested strength properties.

10 Determination of a Theoretically Feasible Design Pressure of a New HP Gas Pipeline
Mathematical determination of an upgraded allowable design pressure is based on the actual values and material properties as per Inspection Certificates and their ‘Gaussian Distribution Curve’ of wall thickness ($s$), yield strength ($R_t$), tensile strength, breaking elongation, uniform elongation and impact strength.

To prove that the statistical results of the determined new design pressure are valid for all pipes, those will be subject to a stress test according to VdTÜV 1060. Completed pipeline sections will be defined in accordance with requirements by „Stress-Test-Verfahren“ (VdTÜV 1060), i.e. in terms of limited test section volume, section length, altitude (high point & low point), etc.

The maximum stress test pressure shall be determined by using the pipes’ actual material values ($R_t \cdot s$) as well as taking into account the tensile specimen’s position and shape. These values shall be evaluated under a statistical aspect.
For stress testing, at the test section’s high point there shall be a test pressure achieved, which is 85% of the actual maximum value ‘K ∙ s’ or which corresponds to the maximum statistical ‘K ∙ s’ value. There has to be paid attention that the pipe with the minimum ‘K ∙ s‘ value will not be exposed to an inadmissible pressure level; such pipe shall be assumed to be at the test section’s low point.

As verification that during the stress testing the pipeline had been exposed to loads which extent is being required and methodical sufficient, there may be – if required – circumferential strain measurements at pre-defined locations to be performed and analysed.

11 Geometric Survey
To verify that no unacceptable pipe deformation will be caused due to partial reduction of strength or any unnoticed wallthickness reduction, a caliper inspection survey will be performed on the new high pressure gas pipeline. Such inadmissible deformation are e.g. dents, ovalities, enlarged diameter which have a negative impact on the pipeline’s integrity and therefore have affects on the maximum allowable operating pressure (design pressure). Only such geometric inspection tools and technologies will be applied which have been examined and approved according to VdTÜV 1069. It should be aspired to apply an enhanced measurement accuracy especially for detecting deviations in diameter. For accurate detection and measurement of deformations, the caliper inspection tool has to be calibrated in accordance with pre-defined acceptable values of deformation, e.g for dents, ovalities and enlarged diameter. Such threshold values or threshold limits for inadmissible deformations will be defined by Independent Authorized Experts in relation to material, diameter, and wallthickness before the caliper survey will be performed.
12 MOP upgrading – determination of new future design pressure
On the basis of the aforementioned prerequisites and conditions as well the test pressure level achieved with stress testing methodology, a new allowable design pressure can be determined - of course, by considering the necessary safety factor. Furthermore, the multiaxial (triaxial) stress state within all pipes has to be taken into account for such determination of upgraded design pressure. This should be adhered to, because the admissible yield strength which is utilized according to the technical “state-of-the-art” is the minimum yield strength value as defined within EN/DIN 10208-2, which constitutes a minimum value to be guaranteed. Such minimum yield strength value to be guaranteed is being determined by tensile testing and is falling considerably below the value of the actual yield strength.

The mechanical properties verified by tensile tests represent an uniaxial stress state, whereas and the actual load conditions within a pipe achieved by hydrostatic testing, represent a multiaxial stress state. This difference between uniaxial stress state of the tension specimen and the actual multiaxial stress state of the pipe wall is to be regarded when determining the new future design pressure as described above.

13 Conclusion
Application of this approach and methodology enables to increase the allowable design pressure by approx. 3 – 8 % to the dimensioning methodology according to commonly used regimes. Utilization of said methodology on the pipeline project referred to in the beginning, savings of 20.000 tons pipe steel led to significant financial savings in the range of several millions of Euros.