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ASPECTS OF ADAPTATION OF FLANGE JOINTS FOR MODERN LOW-CARBON ENERGETICS

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Abstract: *This study investigates the possible need for flange joint design adaptation when dealing with hydrogen. The study focuses on the comparison of flange joint design with two different leakage rates representing the need for higher tightness due to the leak-prone nature of hydrogen molecules. The model calculation following the European standard EN 1591-1 based on an industrial flange joint in a natural gas pipeline outlines the impact of changing tightness class on load ratios for bolts, gasket and flanges. While the operation remains safe in the specific case studied, the findings underscore the need for careful consideration in flange joint design when switching to natural gas hydrogen blends or pure hydrogen, ensuring both the safety and reliability of the processes in modern low-carbon energetics.*

Keywords: Flange joint tightness, hydrogen, gasket suitable for hydrogen.

1. Introduction

Bolted flange joints are widely used across various industries, particularly in situations where joint dismantling is necessary for example due to periodical maintenance. The reliability of flange joints is vital to ensure the safety and reliability of the entire process or system. One of the consequences of an improper design and subsequent failed flange joint is the leakage of operating media posing a significant impact on the environment and also personnel safety. Therefore, high demands are placed on the joints not only to withstand pressure and other mechanical and thermal loads safely but also to maintain sufficient tightness to avoid potentially dangerous leaks. The design and evaluation of bolted flange joints according to European standard EN 1591-1 (The Czech Office for Standards, Metrology and Testing [OSMT], 2015) enable the leakage rate estimation based on gasket test data according to standard EN 13555 (Czech Standardization Agency [CSA], 2021).

2. Discussion of engineering aspects of hydrogen utilization

With the increasing emphasis on sustainable energy sources and mitigating carbon emissions to achieve the 2050 carbon neutrality commitment, hydrogen is widely researched as a clean source of energy. Hydrogen can be used as fuel or an energy carrier and storage. However, the utilization of hydrogen presents unique challenges including hydrogen damage mechanisms (hydrogen-induced cracking, hydrogen embrittlement, hydrogen blistering), changes in equipment operating conditions and also the need for higher equipment tightness as hydrogen molecules are extremely small and therefore susceptible to higher rates of leaking. Proper design of flange joint with regard to its tightness becomes imperative as hydrogen

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is odourless, colourless, tasteless and flammable and potentially explosive. Hydrogen leaks are especially dangerous indoors, in a poorly ventilated spaces, where the gas cannot be quickly diluted into a non-flammable concentration.

This study focuses on the comparison of two versions of the same flange joint – one designed with a lower Tightness Class and the other one designed with a stricter Tightness Class representing the need for higher tightness when dealing with hydrogen. The typical design of a bolted flange joint with two weld-neck flanges with raised face and flat gasket is shown in Fig. 1. This topic was inspired by a high number of scientific articles exploring the possibility of using existing natural gas pipeline network to transport natural gas hydrogen blends or pure hydrogen. However, most of these articles are general and lack specific details such as flange joints. The general consensus is that blends up to about 20 vol. % of hydrogen should not have a significant impact on the pipeline (Erdener et al., 2023). This appears to be confirmed by a research project in Germany, where 20 % hydrogen blend was transported in the natural gas grid to regular households with no significant technical issues or leaks (Dörr et al., 2023).

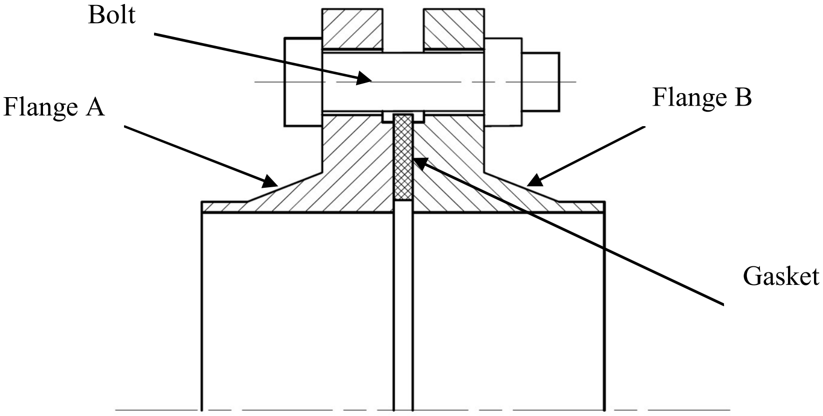

Fig. 1: Sketch of a typical bolted flange joint with a flat gasket.

2.1. Design of flange joints with leakage rate estimate

The calculation method outlined in European standard EN 1591-1 (OSMT, 2015) satisfies both leak tightness and strength criteria of flange joint design. If a selected leakage rate is to be achieved, the gasket properties have to be assumed from test results performed according to European standard EN 13555 (CSA, 2021) with helium as the operating medium. The calculation involves an elastic analysis of the load and deformation response between bolts, flanges and gasket, considering potential plasticity of gasket material during assembly. This calculation method considers both internal and external loads and loading of the flange joint must be axisymmetric as must be the geometry. Other assumptions on which the mechanical model is based in this calculation method include: only circumferential stress and strain in the flange ring is considered and gasket–flange contact is an annular area. This method does not take bolt bending into account.

Annex I of EN 1591-1 (OSMT, 2015) outlines the procedure for leakage rate conversion from reference (test) to actual operating conditions. However, this procedure cannot be used to determine the actual on-site leakage rate due to the incomplete understanding of leakage mechanisms. Therefore, this annex only provides a summary of the general correlations and should be considered indicative only if used. Therefore, this calculation would not be performed.

2.2. Gaskets suitable for hydrogen utilization

The material of the selected gasket must be chemically resistant to hydrogen. Gasket manufacturers usually conduct a series of additional tests to prove chemical resistance. For long-term leak tightness in a hydrogen environment, gasket materials based on elastomers or PTFE are not suitable due to elastomer embrittlement over time and the time-dependent creep of PTFE as reported by SGL Carbon GmbH (2022). These gasket materials show significant increase in leakage over time. However, gaskets from flexible graphite do not demonstrate this kind of behavior and leakage rate remains constant over time as shown in Fig. 2.

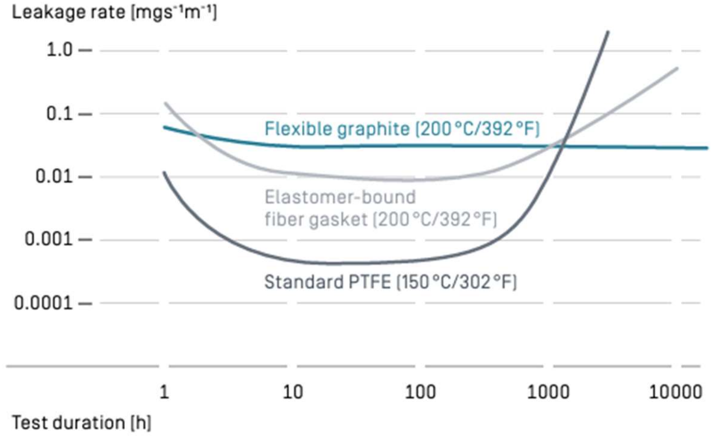

Fig. 2: Leakage rate over time of different gasket materials (SGL Carbon GmbH, 2022).

3. Model calculation of the hydrogen effect on the design of flange joint tightness

The model calculation is based on an industrial flange joint used to incorporate a flow meter into a pipeline transporting natural gas for combustion in a furnace. The flange joint consists of two similar DN100 PN16 weld-neck flanges as given in EN 1092-1 (Czech Standardization Agency [CSA], 2019) with tongue/groove flange facings. The minimum required gasket surface pressure at assembly $Q_{\min(L)}$ and minimum required gasket surface pressure in subsequent service conditions $Q_{S\min(L)}$ for Sigraflex Universal PRO gasket for Tightness Classes $L_{0.01}$ and $L_{0.001}$ are shown in Tab. 1, where Q_A is gasket surface pressure at assembly prior to unloading.

L	$Q_{\min(L)}$	$Q_{S\min(L)}$ $[MPa]$			
$[mg/(s \cdot m)]$	$[MPa]$	$Q_A = 20\,MPa$	$Q_A = 30\,MPa$	$Q_A = 40\,MPa$	$Q_A = 60\,MPa$
0.01	11	5	5	5	5
0.001	27	-	18	9	5

Tab. 1: Minimum required gasket surface pressure for different tightness classes, valid for PN16 (16 bar) (Münster University of Applied Sciences, 2019).

Materials used for flanges and bolts are P250GH and C45E, respectively. Assessment of the suitability of these materials for hydrogen operation was not the subject of this work. The service conditions are given in Tab. 2.

	Assembly	**Hydraulic test**	**Operating conditions**
Pressure [MPa]	0	2.288	1.6
Temperature [°C]	20	20	50
Axial force [N]	0	0	0
Bending moment [N.m]	0	0	0
Radial force [N]	0	0	0
Torsional moment [N.m]	0	0	0

Tab. 2: Service conditions.

Both calculations were based on the minimum required pressure limits. The required bolt force is 80 kN and 150 kN respectively for the two tightness classes. The resulting load ratios are given in Tab. 3.

		Assembly	Hydraulic test	Operating conditions
Bolts	$L_{0.01}$	27.2 %	13.9 %	19.4 %
	$L_{0.001}$	51.1 %	27.9 %	41.0 %
Gasket	$L_{0.01}$	10.9 %	2.5 %	3.3 %
	$L_{0.001}$	20.5 %	9.0 %	10.1 %
Flange	$L_{0.01}$	20.1 %	14.3 %	18.6 %
	$L_{0.001}$	37.7 %	26.4 %	36.7 %

Tab. 3: Flange joint load ratios.

The change in tightness class resulted in higher load ratios for bolts, gasket and flange. As none of the load ratios exceed 100 %, the operation of the flange joint is still safe after the tightness change. However, this model calculation highlights the possibility of a load ratio exceeding 100 % due to the higher minimum force required for a higher tightness class. In that case, the replacement of the flanges could be needed to withstand higher mechanical load.

4. Conclusions

This study describes the possible need for flange joint design adaptation in connection to modern low-carbon energetics, focusing on hydrogen and the challenges connected to switching to natural gas hydrogen blends in the existing natural gas pipeline network. The comparison of two flange joint designs, differing in leakage rates, serves as a practical example of adapting engineering solutions to the specific demands of hydrogen applications such as the need for higher tightness of process equipment. With a lower allowable leakage rate, the load ratios of bolts, gasket and flanges are higher due to the higher required gasket surface pressure.

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