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"Tightness" of Bolted Flange Connections – what does that mean ?

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ABSTRACT

Generally, sealed joints are not absolutely tight. Only a certain (finite) tightness can be reached. In this connection the following aspects are of importance:

- the demand on tightness (depending on the medium to be sealed)
- the suitability of the design of the joint for the intended application
- the gasket characteristics
- the strength and tightness proof, and
- the required assembly bolt load.

First of all, the required tightness class of a bolted flange connection has to be defined. Then the flanges, bolts and the gasket are chosen (material, dimensions).

An optimised tightening capability of the gasket in a bolted flange connection is reached by means of adequate assembly bolt load and corresponding gasket deformation. The leakage channels in the body of the gasket as well as the leakage paths between gasket surface and the flange sealing faces are closed. Depending on the required tightness and the type of medium a minimum gasket stress has to be applied during assembly. The higher the pre-deformation of the gasket during assembly the lower is the required gasket service stress for the intended tightness class. Both the required gasket stress for assembly and service condition are depending on the internal pressure and the medium to be sealed. These two gasket characteristics are to be determined by means of a leakage test.

On the basis of a calculation of the bolted flange connection the required assembly bolt or gasket load is determined and - if necessary - tightness and strength proof are carried out. Last but not least the defined assembly bolt load has to be applied with sufficient accuracy and limited scatter.

KEY WORDS: flanges, bolted flange connections, flanged joints, tightness, gasket factors, gasket characteristics, calculation, tightness proof, assembly, bolt loads

INTRODUCTION

Bolted flange connections are in use in all technical areas, e.g. for maintenance purposes. A reliable function of bolted flange connections is of importance regarding the safety of single components and whole plants - depending on the medium to be sealed (type: toxic, inflammable, explosive, radioactive; energy content: pressure, temperature), **Fig. 1**. Beside safety aspects regulations and legal decrees concerning the reduction of emissions have to be regarded. Owners and users of plants have to take into consideration economical aspects as well, e.g. costs due to loss of medium and shut downs, expenses for remedies and repair of failures, legal restrictions.

Suitable function of a bolted flange connection means sufficient tightness and strength in all service conditions. Strength is checked within the stress analysis which has to assure exclusion of mechanical failures of a bolted flange connection. In this context it should be mentioned that flanges and bolts made of tough, deformable materials do not fail in this sense during service, because excessive plastic deformation of flanges and bolts would result in leakage and a decrease of the loads before failure.

Tightness of bolted flange connections does not mean "(absolutely) tight" or "not tight". Therefore - depending on the medium to be sealed - a tightness requirement has to be defined: "What level of tightness is appropriate to the joint?"

In this paper the actually existing tightness requirements in Germany and Europe are summarised. In addition, a procedure is shown how to assure a proper function (tightness and strength proof) of bolted flange connections. These statements for bolted flange connections can be extended in some sense to other sealed joints, e.g. stuffing box packings in valves.

REGULATIONS AN LEGAL DECREES CONCERNING TIGHTNESS

For the strength proof of bolted flange connections different national and international calculation codes are available; this item is not regarded in the following.

Only a few tightness requirements do exist up to now. The German TA Luft [1] is the first regulation in this context in Europe. The target of TA Luft is to define the basis for the evaluation of air pollution (legal order according to § 48 BImSchG) in cases where toxic media or hazardous volatile air pollutants (mostly organic media) are processed. For this purpose TA Luft defines

- immission values (concentration and deposition values of a substance),
- waste gas volume and waste gas volume flow (carrier gases with solid, fluid and gaseous emissions), and
- emissions (pollution emitted by a plant).

According to TA Luft "*flange connections are only to be used in those cases where they are necessary for reasons of processing, safety or maintenance. In these cases technically tight bolted flange connections according to VDI guideline 2440 shall be used* ". The VDI guideline 2440 "Emission reduction - Mineral oil refineries" [2] demands the use of "high grade performance" sealing elements in bolted flange connections; it defines the following requirements for "high grade performance" in accordance with TA Luft: "

- *The design of the sealing system can be expected to permit normal function in the long term in the given operating conditions.*
- *The characteristic sealing values as per DIN 28090-1 or DIN EN 1591, respectively [3, 4] have to be observed when choosing and dimensioning the flange connection.*

Additionally, the VDI guideline 2440 contains some details of the "high grade performance proof" for gaskets for bolted flange connections and packings for stuffing boxes in valves. Actually, the gasket manufacturers in Germany are trying to use this "first-time test" in order to demonstrate the "general accordance to TA-Luft" of their gaskets (for use in advertisement). However, the "first-time test" for the "high grade performance" proof according to TA Luft and VDI guideline 2440 is representative only for the specific testing boundary conditions. Generally, the results are not transferable to other conditions (dimensions, additional service loads, varied assembly bolt load, ...). The target of this test is to provide data for screening of sealing elements for identical boundary conditions, and their classification.

Regarding tightening joints from a general point of view, the first two points of above citation are more important than this test described. They lead to the actual European approach that defines

(a) tightness classes and
(b) gasket factors related to these tightness classes

Both the tightness requirements and the gasket factors are used in calculations (stress analysis and tightness analysis). The key to a tightening joint with appropriate function (i.e. integrity and tightness of the joint) is the application of an integral procedure.

In the German gasket testing and quality assurance standards DIN 28090-1 [2] and DIN 28091 [6] tightness classes are introduced, and related tightness dependent gasket characteristics are defined. Tightness class $L_{0.1}$ e.g. corresponds to a leakage rate of 0.1 mg per second and unit circumference (m) of the gasket (π x mean diameter). Other tightness classes are related to the decades of the leakage rate, see **Fig. 2**. This tightness class definition was taken over by the European standardisation (prEN 13555 [5]). In a similar way the PVRC in USA defined tightness classes (T_1, T_2, ...) but the corresponding leakage rate is related to the gasket diameter. In Fig. 3 the PVRC tightness classes are recalculated and related to the circumference for comparison reasons.

On the basis of tightness classes as defined above tightness requirements for bolted flange connections and other sealing systems can be defined depending on the medium to be sealed. In the German nuclear code KTA 3211.2 [7] for the first time such a correlation between tightness classes and medium was introduced, **Fig. 3**.

FUNCTION OF A GASKET

Generally leakage of a gasket can occur due to leakage channels in the body of the gasket (inner leakage), or as a result of leakage paths at the interface of the gasket surface and the sealing faces of the flanges (interface leakage). During the assembly of a bolted flange connection the gasket is compressed, the inner leakage channels are closed, and the gasket surface is adapted to the flanges sealing faces by deformation thus reducing interface leakage paths. These effects lead to a distinct tightness depending on the level of bolt or gasket load, on the deformation and material of the gasket, see **Fig. 4**, where the results of leakage tests on different gasket types for varied gasket stresses are shown. After mounting, additional service loads - especially the internal pressure - will reduce the effective gasket stress. The higher the assembly gasket stress the lower is the required minimum service gasket stress for a defined tightness class to be met, **Fig. 5**. This demonstrates clearly the advantage of a higher pre-deformation of the gasket during assembly which allows more unloading in service.

These facts are quantitatively described by means of the gasket characteristics (DIN 28090-1 [3] and prEN 13555 [5] for floating type bolted flange connections, **Fig. 6** (left))

- minimum assembly gasket stress
- minimum service gasket stress

both related to the tightness classes. Of course both minimum required gasket stresses are depending on the internal pressure and the medium.

Besides the tightening behaviour the deformation behaviour of the gasket has to be regarded within the design of a bolted flange connection. This covers

- the limited load bearing capability of the gasket described by means of the maximum allowed gasket stress at assembly (ambient temperature) and in service (elevated temperature),
- the gaskets elastic recovery with gasket load reduction by means of the unloading modulus of elasticity, and
- the creep relaxation behaviour depending on the stiffness of the joint described by means of the creep relaxation compression set (creep factor).

The comprehensive set of gasket characteristics according to DIN 28090-1 and prEN 13555 for gaskets in floating type bolted flange connections is shown in **Fig. 7**.

For gaskets in metal-to-metal contact (MMC) type bolted flange connections, Fig. 6 (right), there are no generally acknowledged calculation codes available, consequently there are no gasket characteristics and testing standards defined. The development of the required calculation procedure and gasket standards was initiated in 2002 by CEN Technical Committee 74; the work is in progress. The basic idea of a set of gasket characteristics is shown in **Fig. 8**. With only 3 gasket factors the situation seems to be relatively simple compared to floating type bolted flange connections; in practical work, complications arise from manufacturing tolerances. Again a relation to tightness (classes) is manifested.

PARAMETERS INFLUENCING THE TIGHTNESS OF BOLTED FLANGE CONNECTIONS

In addition to the gasket characteristics described above (to be used for the design calculation) the long term behaviour of the gasket for the given service conditions must be known:

- medium resistance
- long term ageing resistance (temperature)
- corrosion resistance for the chosen flange material

The effects of medium, time and temperature are overlapping.

All loadings during assembly (forces, moments, distance and angle between flanges) and service (medium, pressure, temperature, temperature changes and distribution, additional service forces and moments, dynamic loadings,...) have to be taken into consideration, first for the selection of the constructive details of the joint and the gasket type, and then for the calculation, i.e. tightness and strength proof.

Target of the tightness proof is, first, the determination of the required assembly bolt load. It is depending on a lot of influencing parameters: gasket type, medium, internal pressure, temperature, stiffness of flanges, bolts and gasket (creep strength), additional forces and moments. Furthermore it has to be proven that the effective gasket stress is higher than the minimum one for the required tightness class in the assembly and all service conditions. Last and most important step is a controlled bolt tightening with suitable mounting tools regarding the resulting bolt load scatter in view of both tightness and strength of the joint.

FUNCTIONAL PROOF OF A BOLTED FLANGE CONNECTION

Reliable function of a bolted flange connection is given when the required tightness and strength conditions are assured [8, 9]. In order to guarantee the proper function of a bolted flange connection a targeted strategy is necessary, **Fig. 9**.

Step1: Determination of the real boundary conditions:
- medium
- tightness requirement
- strength requirement
- service loads
- depending on the type of the medium the required tightness class is defined.

Step2: Selection of suitable construction and materials:
- flanges and bolts (type, dimensions, material)
- gasket (type, dimensions, characteristics)

Step3: For the chosen construction and materials
- tightness proof (tightness class to be met) and

- strength proof (limitation of loads according to codes, safety against failure) are carried out for all service cases if necessary. If the requirements are not met constructive details have to be changed (flanges, bolts, gasket) and the proofs have to be repeated.

Step 4: Qualified and controlled mounting of the bolted flange connection taking into account the resulting bolt load scatter for the strength requirement of the bolts.

Step 5: Quality assurance and maintenance; development of a database for the quality assurance and maintenance of bolted flange connections.

CONCLUSIONS

Bolted flange connections are generally not absolutely tight; only a certain level of tightness or a distinct (finite) leakage rate can be reached. A lot of aspects are of influence on the tightness of bolted flange connections: the required tightness class (depending on the medium to be sealed), construction details of the joint, the gasket characteristics, tightness and strength proof and the assembly bolt load. Medium dependent tightness classes form the basis for realistic tightness requirements. Type tests as required e.g. by TA Luft are not valid generally but they can be used for screening purposed of sealing elements. A strategy for the assurance of the reliable function of bolted flange connections has to cover all related aspects, especially a qualified mounting and maintenance procedure.

REFERENCES

[1] First general administrative regulation to the federal immission protection law (technical guideline for clean air - TA Luft); July 24, 2002, came into force on October 1, 2002

[2] VDI guideline 2440 “Emission reduction - Mineral oil refineries”; November 2000; VDI/DIN-Handbook “Clean Air”, Vol. 3

[3] DIN 28090: 1995-09, Static gaskets for flange connections
Part 1: Characteristic values and test procedures
Part 2: Gaskets made from sheets - Special test procedures for quality assurance
Part 3: Gaskets made from sheets - Chemical resistance test procedures

[4] ENV 1591-2:2001, Flanges and their joints - Design rules for gasketed circular flange connections; Part 2: Gasket parameters

[5] prEN 13555 December 2001, Flanges and their joints - gasket parameters and test procedures relevant to the design rules for gasketed circular flange connections

[6] DIN 28091: 1995-09, Technical delivery conditions for gasket sheets
Part 1: Gasket materials - general requirements
Part 2: Fibre-based gasket materials (FA) - requirements and testing
Part 3: PTFE-based gasket materials (TF) - requirements and testing
Part 4: Expanded graphite-based gasket materials (GR) - requirements and testing

[7] KTA 3211.2 (06/92); presently under review
Pressure and activity retaining components of systems outside the primary circuit
Part 2: Design and analysis

[8] J. Bartonicek, H. Kockelmann, K.-J. Metzner and M. Schaaf, Codes for the design of flange connections, 27th MPA Seminar, October 4-5, 2001, Stuttgart, Germany

[9] J. Bartonicek, H. Kockelmann, M. Schaaf and W. Kohlpaintner, Flanged joints - function proof or monitoring of emissions?, Transactions Paper # 1732, SMIRT 16, Washinton DC, August 2001

Safety related aspects	**Economical aspects**
• Medium: toxic, inflammable, explosive, radioactive • Energy content: internal pressure, temperature • Failure of safety-related systems • Environmental pollution	• Loss of medium • Costs due to shut downs • Cost for repair • Costs for post-failure remedies • Legal restrictions

Fig. 1: Safety related and economical aspects for bolted flange connections

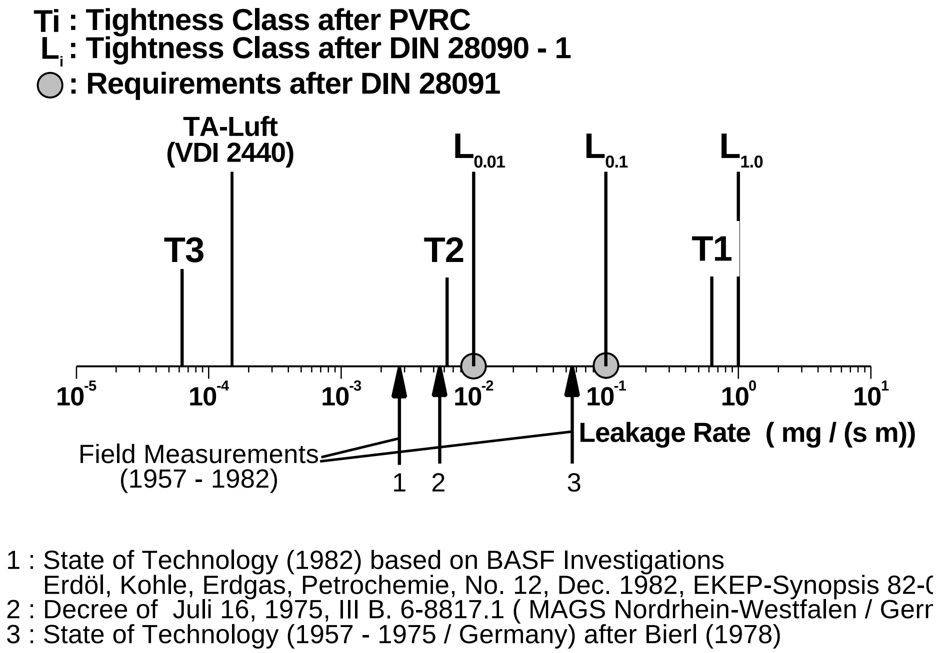

Fig. 2: Tightness classes in European and American regulations

Tightness class L [mg / (m·s)]	**Leakage rate [mg / (m·s)] (for N_2)**	**Medium**
$L_{1.0}$	1	Water without radioactivity
$L_{0.1}$	10^{-1}	Radioactive water Steam without radioactivity
$L_{0.01}$	10^{-2}	Radioactive steam

Fig. 3: Tightness classes according to KTA 3211.2 [7]

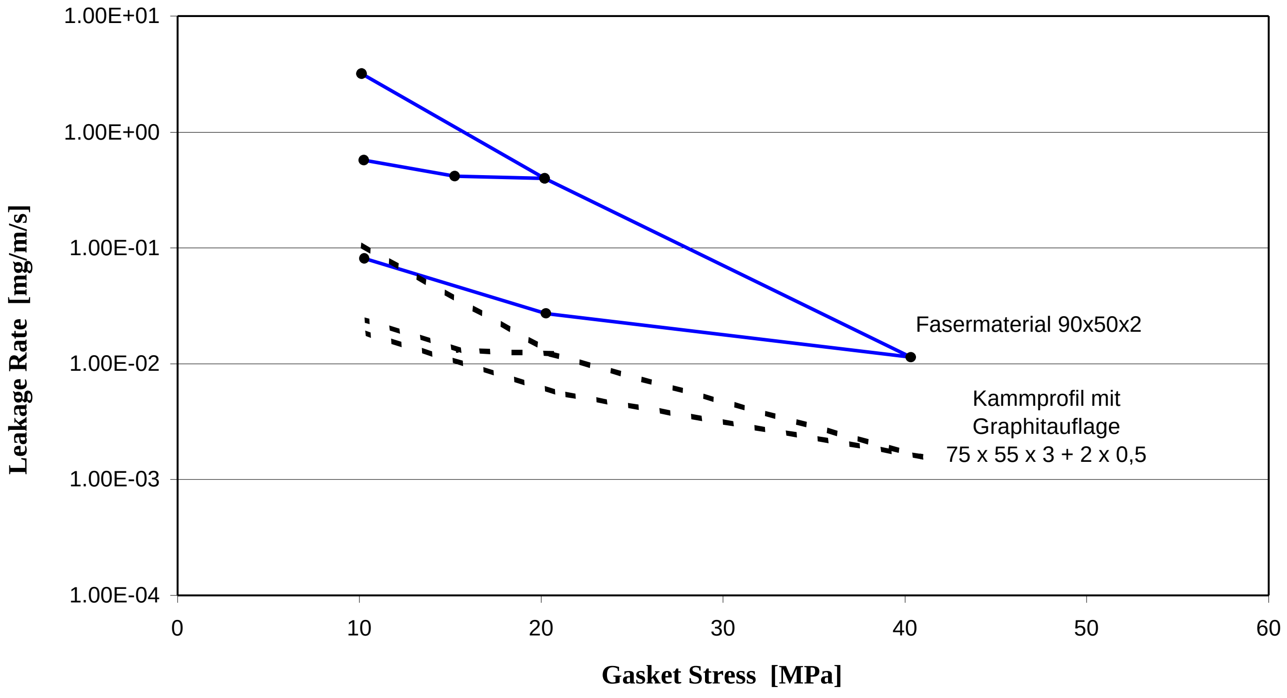

Fig. 4: Tightness behaviour of two different gasket types

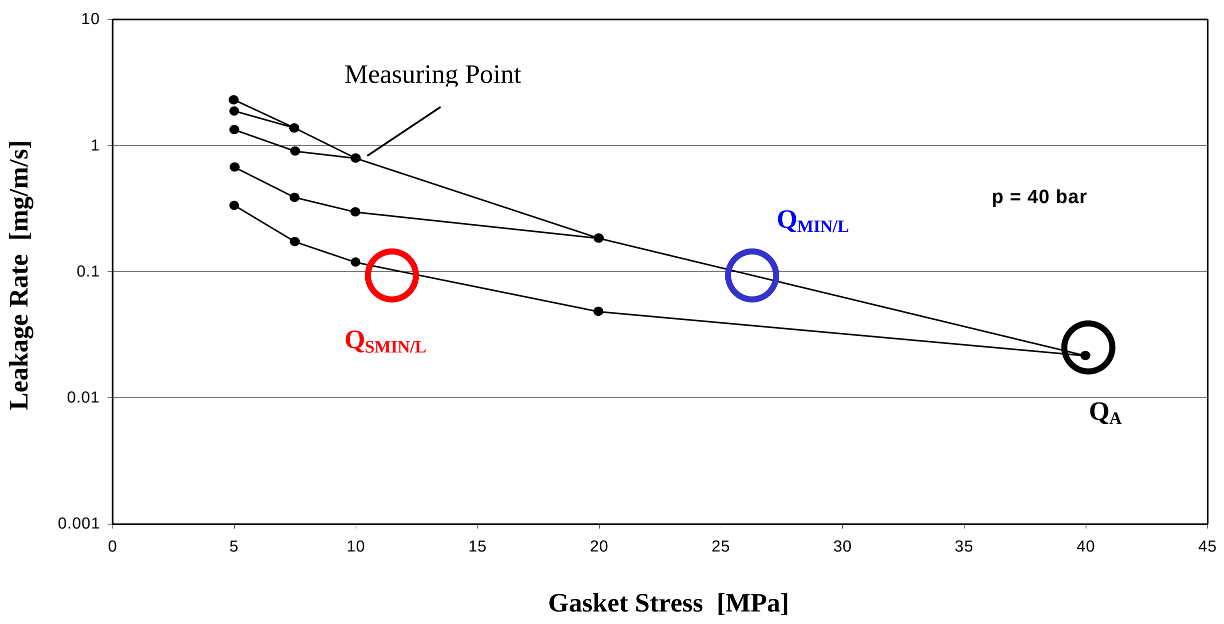

Fig. 5: Tightness related gasket characteristics $Q_{MIN/L}$ and $Q_{SMIN/L}$
(Q_A: Assembly gasket stress)

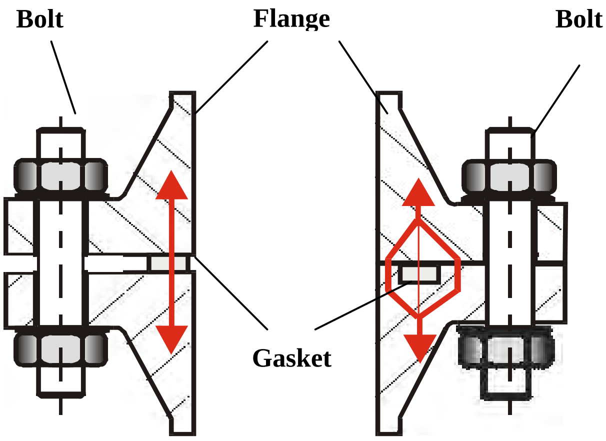

Fig. 6: Bolted flange connections of floating (left) and metal-to-metal contact type (right)

DIN 28090-1 1995	prEN 13555 2001	Definition	Target
$\sigma_{VU/L}$	$Q_{MIN} = \sigma_{VU/L}$	Minimum Assembly Gasket Stress	Optimal Seating of Gasket on Flange Faces and Closing of Inner Leakage Channels
$\sigma_{BU/L}$	$Q_{SMIN} = \sigma_{BU/L}$	Minimum Service Gasket Stress	Assurance of Technical Tightness (Limited Leakage) in Service
σ_{VO}	$Q_{SMAX} = \sigma_{VO}$	Maximum Assembly Gasket Stress	Avoidance of Excessive Plastic Deformation and/or Destruction of Gasket
σ_{BO}	$Q_{SMAX} = \sigma_{BO}$	Maximum Service Gasket Stress	Avoidance of Excessive Plastic Deformation and/or Destruction of Gasket
E_D	$E = E_0 + K_1 Q$	Unloading Modulus of Elasticity	Description of Gasket Elastic Recovery
Δh_D	$g_C \sim 1 / (1 + \text{const.}\ \Delta h_D)$	Creep Compression Set Creep Factor	Description of Gasket Creep-Relaxation Behaviour
	α_G	Thermal Expansion Coefficient	Description of Gasket Thermal Expansion

Fig. 7: Gasket characteristics for floating type bolted flange connections

Notation	Definition	Target
σ_{MMC}	Gasket Stress Required for Metal-to-Metal Contact	Assurance of Proper Function (Metal-to-Metal Contact)
$p_{MMC/L}$	Maximum Internal Pressure for Tightness Class L	Assurance of Technical Tightness (Limited Leakage) in Service
g_{MMC}	Creep-Relaxation Factor	Description of Gasket Creep-Relaxation Behaviour

Fig. 8: Gasket characteristics for metal-to-metal contact type bolted flange connections

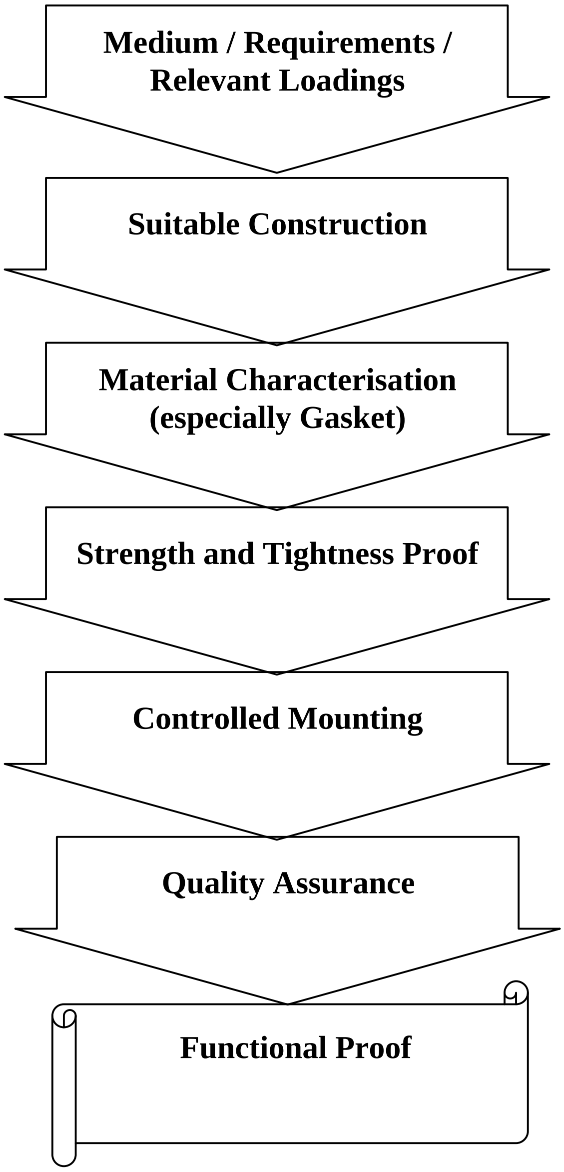

Fig. 9: Functional Proof of Gasketed Flanged Joints