European Sealing Association e.V.

Effect of temperature on bolted flange assemblies

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Bolted flange assemblies are widely used to connect different elements of pressure vessels and pipelines that carry process media at temperatures varying from cryogenic to more than 1000°C.

High temperature and thermal transitions have long been identified as playing a major role in the tightness of bolted flange assemblies. Tightness failure due to thermal effects can be encountered even if the assembled components (flanges, bolts and gaskets) are within their rating limits and not undergoing any mechanical failure.

Process temperatures are expected to rise in the future with a demand for an improvement in efficiency of chemical processes driving this. Therefore components such as gaskets will also have to be able to withstand this increase.

Also designers (and end-users) will have to be able to understand the impact of increased temperature on the whole of their system.

Characterization of the temperature effect on bolted assembly has always been and still remains an important issue for designers and end-users as it involves complex physical laws. The temperature directly impacts all the different elements of the bolted assemblies.

The impact can be split into 2 different perspectives:

1. The modification of the gasket properties;
2. The modification of the bolts / flanges elastic interactions.

Modification of the gaskets properties under temperature

One of the most important effects of temperature on gaskets is the influence on creep / relaxation which can be considered as a delayed response (in time) to a mechanical action.

- Creep is a loss of gasket thickness under a constant load over time. It is the principal temperature effect on PTFE based gasket;
- Relaxation is a loss of gasket stress at constant compression/gasket thickness over time. It is the principal temperature effect on gaskets with a metal/metal contact.

The temperature plays an important role in creep and relaxation as it increases both phenomena. A gasket suffering from significant creep and/or relaxation can offer a proper seal at bolt-up, but after a given period of time, the load between the gasket and the mating flanges can decrease below the required one to achieve a correct seal.

Creep and relaxation are not taken into consideration into traditional "Taylor Forge" calculation such as ASME / CODAP / standard EN13445 methods. In the new flange design procedure EN1591 and gasket parameters and test procedure EN13555, a factor – the Pqr – has been introduced to characterize the effect on the imposed load of the relaxation of the gasket between the completion of bolt up and after long term experience of the service temperature.

Another temperature effect is the oxidization of graphite based gaskets. Oxidization of graphite is a function of graphite quality, media, temperature and time of exposure. A gasket that has proved effective on a flange for a given period of time should so be carefully checked for oxidation before being left in service for a longer period.

Calendered fiber gaskets are also affected but in a different manner. At elevated temperature the elastomeric binder can further vulcanise, which embrittles the gasket and reduces the maximum stress it can withstand.

Finally, the temperature will also alter characteristics of the gaskets such as the sealing properties, compression/elastic recovery and the maximum allowable stress.

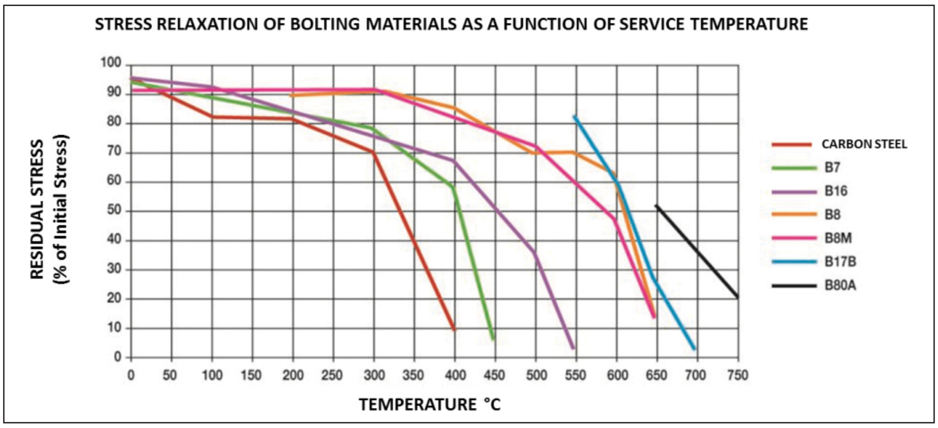
High quality gasket manufacturers are currently able to supply EN 13555 parameters that can help designers and end users to take into account the effect of temperature on gasket sealing.

Modification of bolts/flanges elastic interactions

As well as gaskets, bolts and flanges will suffer from the increase in temperature. Focusing on thermally induced changes in bolts, an easy analysis generally done is the analysis of elastic modulus evolution at temperature. The bolt acts as a spring and temperature reduces the elastic modulus of material, the clamp force modification can be firstly approached as a ratio of the elastic modulus

$$E_{temperature}/E_{ambient}.$$

If it can be seen as a good start, creep of the bolt and elasticity/flexibility of the whole assembly lead to a more complex situation.



The creep of bolting can be seen in the graph below showing the residual stress in different common bolting material after 1000hr of exposure to different temperatures.

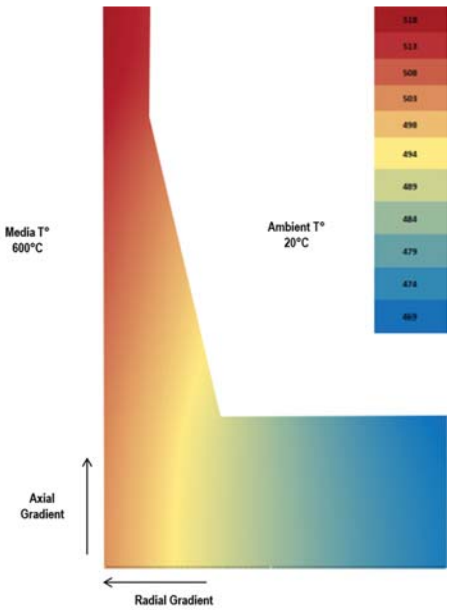
The insulation of flanges closures should be carefully checked and designed bearing in mind high temperature, in order to limit loss of clamp load.

The flange will also undergo significant modification because of thermal effects. Due to its general geometry the flange can be seen as a cooling fin of a pipe/vessel introducing an axial and radial thermal gradient within the assembly which will act oppositely one to the other. If the flanges and the bolts are made of the same type of material – or with material having similar thermal expansion coefficients, we can summarize the impact as below:

- The radial gradient: It will cause differential axial dilatation. Due to its direct contact with the media, the inner edge of the flange will expand more than the outer edge and the bolting, inducing an increase in bolt and gaskets stress.
- The axial gradient: It will cause differential radial dilatation. As the pipe is thinner that the flange itself, it radially expands more than the flange inducing a rotational moment onto the flange ring that decrease bolt load and thus gasket load.

These gradients, observed in steady state situation, are emphasized and magnified in cyclic situations such as plant start-up/stop or dynamic process situations.

If the bolt and flange are made with dissymmetric material like carbon steel and stainless steel, a more dramatic effect can be encountered.



Again, effects of temperature on bolts and flanges assembly are not addressed by the traditional "Taylor Forge" calculation, other than the impact on the material stress limit. EN1591 has made significant improvement introducing assessment of differential axial thermal expansion between the bolts and the flanges. As an example, in the French code – CODAP – the differential axial thermal expansion is not addressed and said to be negligible if:

1. The temperature difference between the flange and the bolt is within 50°C ;
2. The difference in thermal expansion coefficient of the different components of the bolt joint doesn't exceed 10% if the vessel design temperature is above 120°C.

Substantial radial or circumferential thermal gradient can make it even more difficult to achieve a proper seal. Such effect can be seen on large pumps/valves where the media flow is not axisymmetric, or in a tube sheet heat exchanger where different temperatures between the channel and the shell can lead to dissimilar radial expansion and so induce shear on the gaskets.

Testing, such as the R.A.S.T -Radial Shear Tightness Test, has been developed in order to mimic the radial shearing effects that the gasket needs to withstand in a heat exchanger. It has been shown that shear can have a dramatic effect on some gaskets, such as metal jacketed gaskets.

In summary, temperature has an important influence on the tightness of flange assemblies and should be carefully considered by end users and designers.

If thermal analysis in bolted joints has made significant progress during the last decade, the complexity of these calculations requires a lot of time and effort to properly assess its full impact. Careful choice of high quality, well designed gaskets and reputable manufacturers is so essential in order to obtain leak free, high temperature, gasketed joints.

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