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A general approach for quantifying the heat-ageing of gaskets

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ABSTRACT

A recurrent concern in the design of packaging for the transportation of radioactive material is to determine the elastomeric gaskets life at high temperature. Most gasket suppliers specify maximum allowable temperatures during “continuous service” and “peak service” (such as “200°C in continuous service” or “250°C in peak”) but they do not specify the definition of “continuous” or “peak” service, what are the acceptance criteria and how these maximum temperatures are determined. Based on this type of data, it is difficult to assess the acceptability of a gasket submitted to fluctuating temperatures.

COGEMA LOGISTICS has launched a test program on the different rubber grades used on its casks to determine, for different temperature levels (e.g. 200°C, 210°C,…, 250°C…), the maximum seal life based on clearly defined criteria. The goal is to establish, for each rubber grade, the seal life versus temperature curve. These curves can be used to know if a gasket exposed to <u>any specified temperature profile</u> can guarantee the leaktightness. The principle of the method is to calculate a sum of “elementary damage rates” on the temperature profile (split up into elementary time intervals) and to compare this sum (the “global damage rate”) to a “maximum permissible damage rate”. If the global damage rate is lower than the maximum permissible damage rate, the leaktightness of the packaging can be guaranteed for the given temperature profile.

1. ISSUE

The determination of the elastomeric gaskets seal life at high temperature is a recurrent issue in the design and safety analysis of packaging for the transportation of radioactive material.

The gasket suppliers give some data but these ones are imprecise. For example, their technical datasheets specify maximum allowable temperatures during “continuous service” and “peak service” but they do not specify the definition of “continuous” or “peak” service, what are the acceptance criteria and how these maximum temperatures are determined.

Also, some publications deal with the evolution of the mechanical characteristics at high temperature over time of the elastomers used for the manufacturing of gaskets. The problem in this case is that it is difficult to link the mechanical characteristics to the gasket capacity to guarantee the leaktightness.

This is the reason why COGEMA LOGISTICS has developed a method for the assessment of the seal efficiency of the elastomeric gaskets used on its casks. This paper deals with the development of this method. A test program using this method has been launched to determine the seal life of EPDM gaskets used on COGEMA LOGISTICS packages.

2. BENCHMARKING

2.1. Heat-ageing methods commonly used

Methods to determine the life of mechanical parts are commonly used in the industry (particularly in the nuclear industry).

For example, a lot of studies are performed to know the evolution at high temperature of the mechanical characteristics (yield strength, ultimate strength…) of various materials over the time.

The principle of this type of study is to do accelerated heat-ageing tests. The idea is to expose the tested material at higher temperatures than the temperature in service and to study the evolution of the mechanical characteristics over time (for short periods). Creep laws allow the extrapolation of the results of these short tests at high temperature to lower temperatures over longer periods. Curves giving the evolution of different mechanical characteristics over time at different temperatures are available in several construction codes or standards. If not, specific tests can be performed to plot this type of curve.

The designer can check if the mechanical characteristics he is looking for at a given temperature after a determined duration are compatible with the data plotted on these curves.

2.2. Heat-ageing methods currently used for the elastomeric gaskets

Some publications deal with heat-ageing studies on elastomeric gaskets. In general, the methods used are issued from the methods presented above. In general, these methods consider the evolution of the mechanical characteristics at high temperature over time of the elastomer used for the manufacturing of the gasket.

The following characteristics are generally studied :

- the tensile strength,
- the strain at break,
- the hardness,
- the elasticity modulus at 50% / 100% / 150% / 200%…,
- the compression set,
- the density.

For these evaluations, the goal is to study the evolution of these mechanical characteristics at higher temperatures than the temperatures met in service by the gasket and to extrapolate the results at lower temperatures for longer periods with classical ageing laws (Arrhenius law for example).

2.3. Issue of the classical elastomeric gaskets heat-ageing methods

The problem in the case of heat-ageing studies on elastomeric gaskets is that it is difficult to link the mechanical characteristics to the property which we are interested in which is the leaktightness.

Indeed, the link between the evolution of the tensile strength or of the compression set (for example) and the evolution of the leak rate is a difficult matter.

If the tensile strength of an elastomer decreases from 15 MPa to 5 MPa during an accelerated heat-ageing test, from which value can we consider that a gasket manufactured with this elastomer will not be able to guarantee the leaktightness ? (10 MPa ? 7 MPa ?). Perhaps, this mechanical characteristic does not have any influence on the leaktightness and it is mainly the compression set which has got a major influence on the leaktightness. And even in this case, the problem is the same : from which value of compression set does a leakage appears on a gasket : 70%, 80%, 90% ?

Consequently, it is not completely relevant to study the evolution of mechanical characteristics during heat-ageing tests to study the seal life of elastomeric gaskets at high temperature.

This type of method is easily applicable to cases where the characteristic studied during the test is the characteristic we are looking for in the final application. For example, if an application requires a given tensile strength after a certain time at a determined temperature, it is relevant to study the evolution of this characteristic over time at different temperatures (but not really in cases where the leaktightness is studied).

This is the reason why COGEMA LOGISTICS bases its safety justifications on tests performed on gaskets fitted on test rigs to study directly the property we are interested in, which is the leaktightness. This method involves measuring the evolution of the leak rate at a certain temperature to determine the seal life at this temperature. Thus, it requires testing gaskets fitted on test rigs and not only test specimens.

3. GENERAL PROCEDURE

COGEMA LOGISTICS has started a series of tests on the different grades of EPDM gaskets used on its casks.

The idea of the tests is to measure every day at a given temperature the leak rate of gaskets fitted on test rigs until reaching the leak rate criteria.

The goal of these tests is to determine, for each grade of gasket used by COGEMA LOGISTICS, a curve giving the seal life versus the temperature (the temperature being maintained at a steady value). This curve is built step by step, for different temperatures evenly spaced (every 10°C for example).

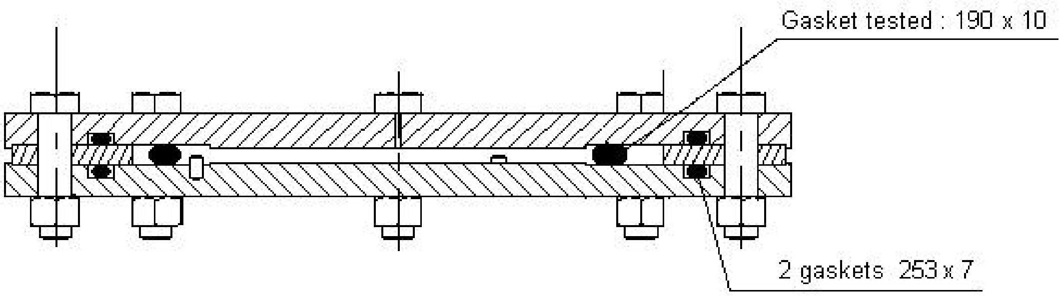
4. PRELIMINARY HEAT-AGEING TESTS PERFORMED

4.1. Test assembly

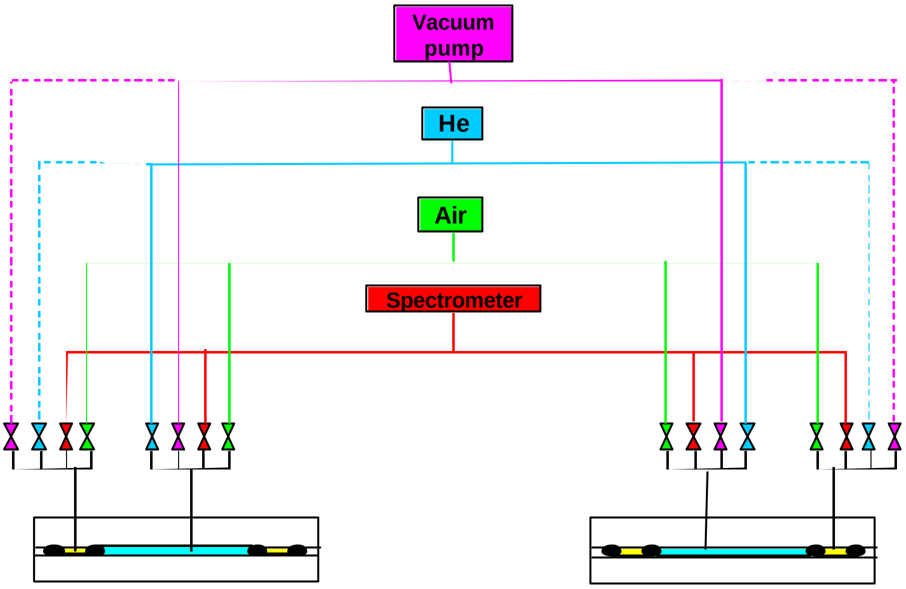
The test assembly consists of :

- two identical test rigs where the gaskets tested are fitted (for test replication),
- a set of electrovalves controlled by a computer to perform the leak tests.

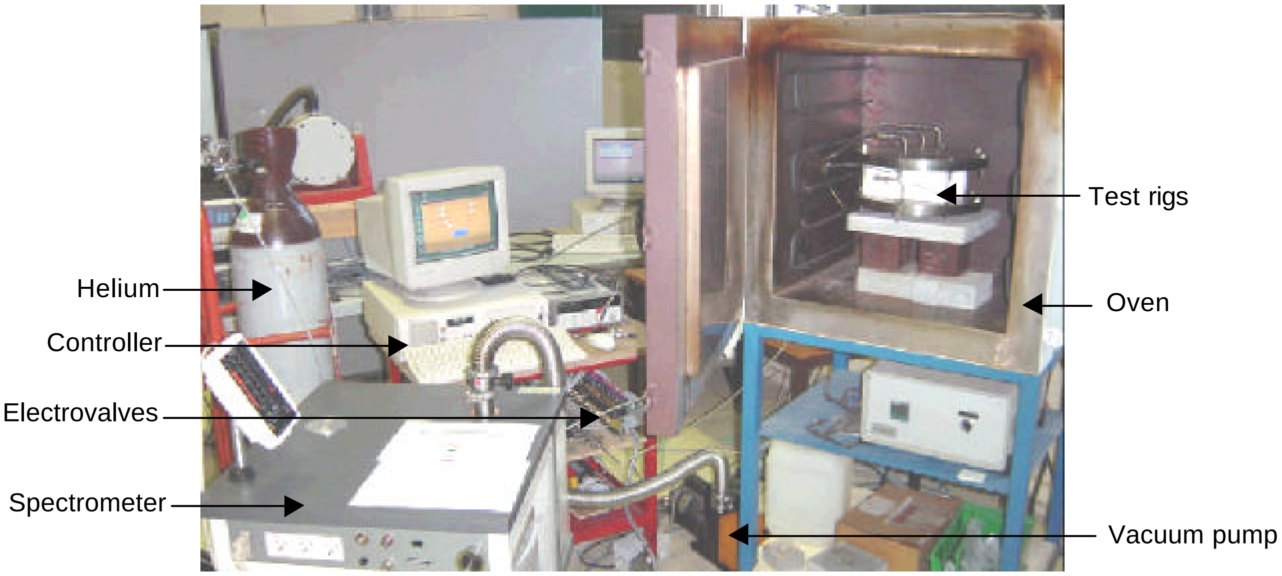
The two test rigs are made up of two flat flanges (no grooves) separated by a spacer to adjust the compression rate (for these tests, the gasket nominal compression rates were 30%). The gaskets tested had the following nominal dimensions : 190 x 10 mm. A drawing of these test rigs is given below :



The electrovalves allow to connect the interspace or the center of one of the two test rigs to the following devices : a spectrometer, a vaccum pump, a helium bottle, a compressed air bottle.



A picture of the test assembly is given below :



4.2. Tests results

COGEMA LOGISTICS has completed a first set of tests at high temperature on EPDM gaskets fitted on the test rig described above.

These tests have been carried out at 250°C for two weeks. The leak rate was measured every day.

After two weeks at 250°C, the gaskets tested were still leaktight which is surprising for EPDM gaskets at this temperature (according to the data commonly available in the literature, a seal life of only few days was expected).

Thus, it has been decided to stop the tests. The test rigs have been cooled to the ambient temperature and taken apart. It was quite difficult to take the rigs apart because of a phenomenon of sticking between the gaskets and the flanges. As expected, the gaskets tested were very damaged (no elastic recovery, structure completely vitrified). However, the gasket surface in contact with the flanges (where the sticking occurred) was not damaged (smooth surface, no cracks). These tests showed that the EPDM gaskets tested were still leaktight after two weeks at 250°C not because of the preservation of good mechanical characteristics (these mechanical characteristics (compression set, tensile strength, hardness…) were seriously affected) but only because of the phenomenon of sticking between the gaskets and the flanges.

Thus, it appears that this type of test does not produce the expected results (the determination of a seal life at a certain level of temperature). Indeed, even if this kind of results is interesting to appreciate the existing margins in accident conditions, we are looking for a seal life which can be used for safety justifications in accident conditions but also in normal conditions. Thus, we are looking for a seal life with the gasket maintained in “good condition” and not to a seal life with a gasket completely damaged, the leaktightness being maintained by a phenomenon of sticking : the leaktightness must be due only to the preservation of good mechanical characteristics.

5. QUALIFIED TEST METHOD

5.1. Improved test procedure

Considering the previous test results, the procedure and the test assembly have been modified to avoid any sticking of the gaskets.

The improved procedure involves separating/reassembling the flanges before each leak test to avoid any sticking between the gasket and the flanges.

With this procedure, the leaktightness cannot be maintained by a sticking between the flanges and the gasket but only by the sufficient mechanical characteristics of the gasket. If the gasket has lost its properties (elastic recovery, cracks…), a leak will necessarily appear after this operation of separating/reassembling of the flanges.

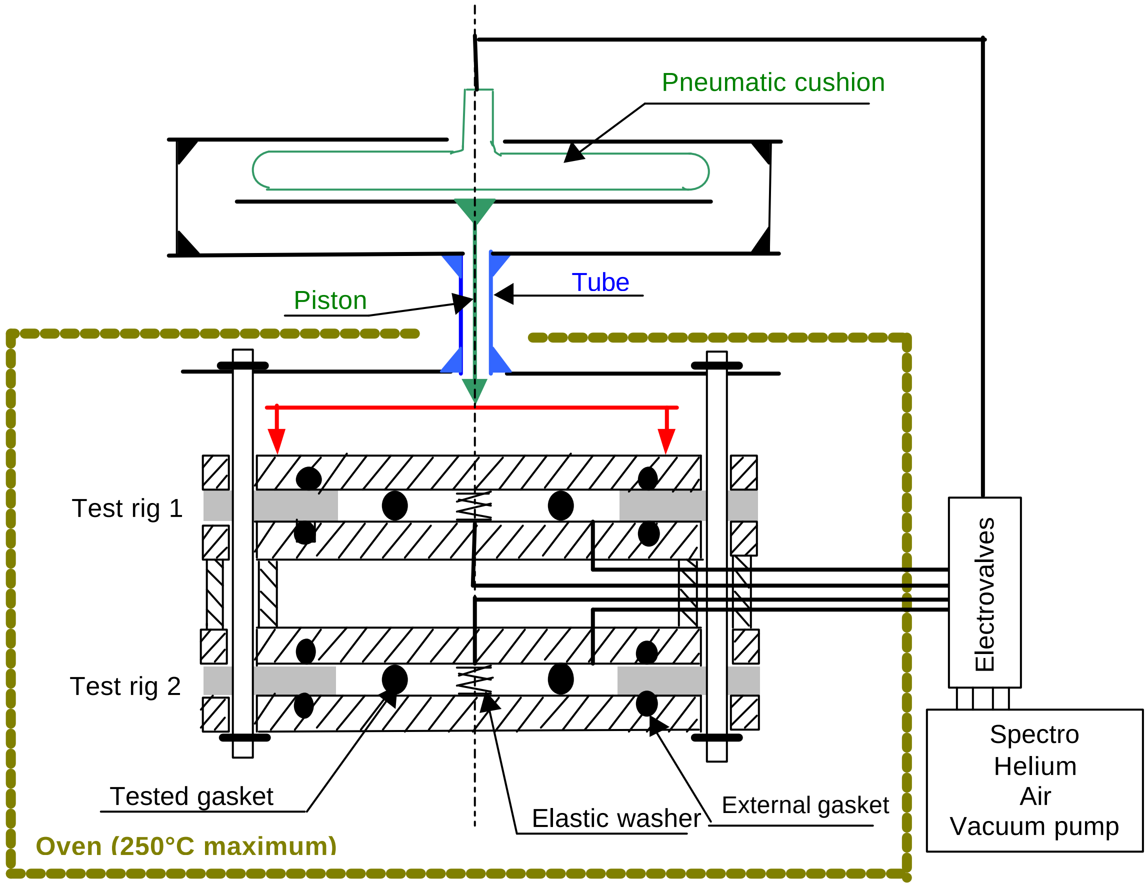
5.2. Improved test assembly

The test assembly has been modified to be able to separate the flanges.

Elastic washers have been added between the flanges of the two test rigs and a system of pneumatic cushion (placed outside of the oven) is used to separate and to tighten the flanges.

The separating/reassembling of the flanges is done automatically just before the leak test (which is also performed automatically).

A sketch of this improved test assembly is shown below (two test rigs are tested simultaneously for test replication) :



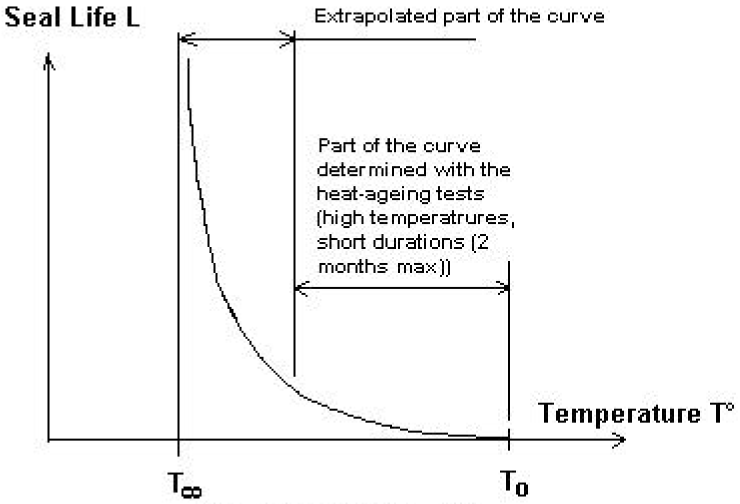
5.3. Tests results

Heat-ageing tests on EPDM gaskets with this new test assembly are under way. They will allow to plot a seal life versus temperature curve for this type of gasket. The following paragraph explains the methodology employed to use these results for COGEMA LOGISTICS applications.

6. METHODOLOGY

6.1. General description

The seal life versus temperature curve has a shape as shown on the figure below :

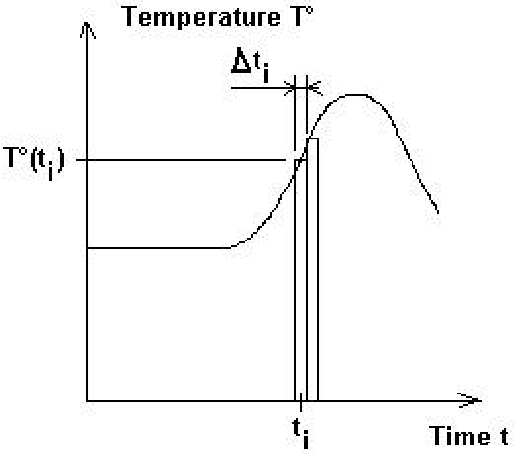


Seal life curve : L=f(T°)

where :

- L : seal life at the temperature T°,
- T_0 : temperature where the gasket seal life is equal to zero,
- T_∞ : temperature where the gasket seal life is “infinite” (which corresponds to the temperature where it can be considered that no heat-ageing occurs).

With this type of curve, it is possible to know, for any temperature profile, if a gasket is able to guarantee the containment. For example, we can consider the following temperature profile (which can correspond to the succession of normal and accident conditions of transport) :



Example of temperature profile : T°=f(t)

The idea is to calculate the gasket “total damage rate” on the given temperature profile. This total damage rate is calculated with a method similar to the methods used in fatigue (Wöhler curves) or creep studies.

The temperature profile is split into elementary time intervals ?t_i (where ones the temperature can be considered as constant and equal to T°(t_i)). The “elementary damage rate” on the interval ?t_i is equal to ?t_i divided by the gasket seal life at the temperature T°(t_i). The “total damage rate” is equal to the sum of the “elementary damage rates” :

$$DR(t)=\sum_{0}^{t}\frac{\Delta t_i}{L(T^\circ(t_i))}$$

where :

- DR(t) : total damage rate at the instant t,
- ?t_i : duration of the elementary interval at the instant t_i,
- T°(t_i) : temperature at the time t_i,
- L (T°) : seal life at the temperature T°.

If the total damage rate calculated is lower than 1, the leaktightness is guaranteed.

6.2. Application to COGEMA LOGISTICS justifications

For every COGEMA LOGISTICS package, thermal calculations are done to know the temperatures to which the gaskets are exposed in the following two configurations :

- in normal conditions (calculation of the maximum reachable temperature in normal conditions),
- in accident conditions (30 minutes fire at 800°C,…) : determination of the temperature profile on the gaskets.

With the (seal life versus temperature) curve, it is possible to know, <u>for any temperature profile</u>, if a gasket is able to guarantee the leaktightness.

<u>For example</u>, if the heat-ageing test results (and their extrapolation to lower temperatures and longer seal lives) are the following ones :

Temperature in steady state	**Seal life**	**Determination**
160°C	20 years	Arrhenius extrapolation
170°C	2 years	Arrhenius extrapolation
190°C	2 months	Tests
200°C	2 weeks	Tests
210°C	2 days	Tests

According to the method detailed in paragraph 6.1, a gasket exposed to a temperature of 170°C during one year will have reached 50% of its seal life (or maximum permissible damage rate).

After this heat-ageing, it can be exposed to accident conditions of 1 week at 200°C, which do add a damage rate of 50% (according to the regulations, the consequences, in terms of activity release, must be analysed on a duration of 1 week).

According to the same principle, after this one year heat-ageing at 170°C, this gasket can also be exposed to a half-day at 210°C and 6.5 days at 190°C (total of 1 week), the damage rate in this case being equal to :

$$0.5+\frac{0.5}{2}+\frac{6.5}{60}=0.86$$

If the gasket is exposed for one year to a temperature of 160°C instead of 170°C, the accident conditions can be more severe for the same total damage rate (in comparison with the previous case). For example : 1.5 day at 210°C, followed by 5.5 days at 190°C, for a total damage rate of :

$$\frac{1}{20}+\frac{1.5}{2}+\frac{5.5}{60}\approx 0.86$$

This method can be applied to any temperature profile (not just for a succession of steady states), as explained in paragraph 6.1 (temperature profile split into several elementary time intervals).

Consequently, with this method, it is possible to know, for any temperature profile, <u>if a gasket can be exposed to the superposition of a one-year heat ageing (maximum transport duration) and a determined accident profile</u>.

7. CONCLUSION

Contrary to a lot of studies relative to the studying of the elastomeric gaskets life, the method developed by COGEMA LOGISTICS is not based on the analysis of the evolution of the elastomer mechanical characteristics at high temperature over time. The COGEMA LOGISTICS method consists in measuring the leak rate on different gaskets which are exposed to different temperatures. The seal life is determined when the leak rate criteria is reached. Consequently, the property studied during the tests is really the criteria which we are interested in (the leak rate).

COGEMA LOGISTICS has started to perform heat-ageing tests with this method. They will allow to determine, for each elastomer grade used by COGEMA LOGISTICS, a curve giving the seal life versus the gasket temperature. With this curve, it is possible to calculate, for the different COGEMA LOGISTICS packages, the gasket “total damage rate” throughout its life. This “total damage rate” is equal to a sum of “elementary damage rates” calculated on small time intervals. To guarantee the gasket leaktightness, the “total damage rate” must be lower than a “maximum permissible damage rate” (which is equal to 1).

This quantitative method developed by COGEMA LOGISTICS will allow a better knowledge of the damage suffered by the gaskets and thus, of the safety margins. The final goal is the improvement of the COGEMA LOGISTICS packages performance (increase of the heat load for example) and a better flexibility in safety justifications.