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LOW TEMPERATURE SEALING CAPABILITY OF O-RINGS: THE RELATIONSHIP BETWEEN LABORATORY TESTS AND SERVICE PERFORMANCE

A technical paper
presented by
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High Performance Sealing Technology

generally not clear to the reader, who simply seeks a value with which to compare elastomers that meet the other performance criteria from various manufacturers. He or she will normally assume that the minimum operating temperature quoted represents the lowest temperature at which elastomer components will seal in all situations, unless caveats suggest otherwise.

Whilst applicable in other areas, the focus of this paper is on elastomers typically used in Oil and Gas applications, the most popular materials of which are HNBR (hydrogenated nitrile) and FKM (fluoroelastomer). A selection of low temperature claims for elastomers based on similar polymers designed for use at low temperatures from a number of manufacturers appears in Fig. 2. The reader will note that claims from the seal manufacturers are in some cases beyond that of the polymer manufacturers on which these materials will be based.

Manufacturer	Polymer	Low temp claim, Deg C	Test method	Nominal hardness of compound (Shore A/IRHD)
Polymer mfr A	FKM / low temp, 64%F	-31	TR10	70
Polymer mfr B	FKM / low temp, 64%F	-31	TR10	65
Polymer mfr C	FKM / low temp, 64%F	-30	TR10	70
Polymer mfr E	HNBR Low temp, some unsat., 17 to 20% ACN content	-36	TR10	Not known
	HNBR Low temp, 'fully' sat, 17 to 20% ACN content	-36	TR10	Not known
Polymer mfr F	HNBR Low temp, some unsat., 19.5 to 22.5% ACN Content	-35	TR10	Not known
	HNBR Low temp, 'fully' sat., 19.5 to 22.5% ACN Content	-35	TR10	Not known
Seal mfr A	Low temp HNBR	-40	Not specified	70
	Low temp HNBR	-40	Not specified	80
	Low temp FKM	-30	Not specified	75
	Low temp FKM	-37	Not specified	90
Seal mfr B	Low temp HNBR	-37	Not specified	90
	Low temp HNBR	-40	Not specified	80
	Low temp HNBR	-40	Not specified	70
	Low temp HNBR	-40	Not specified	80
	Low temp HNBR	-40	Not specified	70
	Low temp HNBR	-37	Not specified	90
	Low temp FKM	-40	Not specified	60
	Low temp FKM	-37	Not specified	75
Seal mfr C	Low temp HNBR	-40	ISO 812, Type B ASTM D2137, Method A	70
	Low temp HNBR	-40	Not brittle after 3 mins at -40C	60
	Low temp FKM	-40	Not specified	75
	Low temp FKM	-40	Not specified	75
Seal mfr D	Low temp HNBR	-40	Not brittle after 3 mins at -40C	70
	Low temp HNBR	-40	Not brittle after 3 mins at -40C	
	Low temp FKM	-40	Not specified	75
	Low temp FKM	-40 static -30 dynamic	Not specified	85

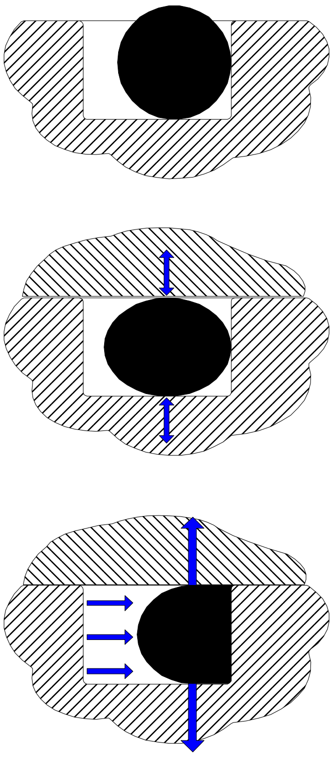
Fig. 2: A comparison of low temperature claims made by polymer and seal manufacturers.

How do these low temperature claims relate to actual service performance?

O-RINGS: MECHANICS OF SEALING

Toroidal seals rely on an initial 'squeeze' which provides a sealing force between the contact faces. Pressure within the system further activates the seal, and increases the sealing force by that of the system pressure. The initial sealing force created by the squeeze on the seal, and maintained by the residual stress within it takes the overall sealing force above that of the system pressure. It is this balance of forces that forms the seal.

Fig 3, Balance of forces in an O-ring



- O-Ring in housing
- Initial compression generates reactive forces (sealing stress)
- System pressure increases forces and sealing stress within the seal.

Whilst the seal is energised by the system pressure, the residual stress within the elastomer is critical to maintain a sealing force above the pressure being contained. Excessive stress relaxation over time caused by physical and chemical changes to the seal material, will inevitably compromise its ability to function. At low temperatures, the residual sealing force can also reduce to a point where the system will fail.

FACTORS INFLUENCING LOW TEMPERATURE FLEXIBILITY OF ELASTOMERS

i) Molecular structure

In simple terms elastomers are based on rubber polymers made up of long chain molecules randomly arranged in coils which have been chemically cross-linked to form a three dimensional structure. Within their normal operating temperatures, the molecules will be free to rotate and the individual chain segments will remain flexible. As the temperature is decreased, the ability of the molecules to rotate is reduced as they move closer together. The glass transition temperature (or Tg) of an elastomer represents the temperature at which it 'freezes' though is not yet brittle. Chain mobility is restricted, and the elastomer starts to crystallise, becoming 'leathery' and unresponsive. The brittle point normally sits a few degrees below the Tg, though the distance between the Tg and brittle point can vary significantly between polymer types. The temperature at which the elastomer crystallises is predominantly influenced by its chemical structure. Introducing 'irregular' monomers reduces the tendency to crystallise, and as a consequence improves the flexibility of the polymer at low temperatures. The molecular structure of a rubber polymer has by far the greatest influence on the low temperature flexibility of the fully compounded elastomer, however other ingredients in the formulation can lower the Tg by a few degrees.

ii) Influence of compounding additives

With FKM, little can be done to change the Tg with regards to additives, though as with all elastomer types, lowering the hardness and/or the modulus can reduce the Tg typically by between 1 and 3°C. Perhaps the greates t compounding influence is the selective use of plasticisers in NBR's (nitrile) and HNBR's. The maximum gain in low temperature flexibility by the addition of for example DOS (dioctyl sebacate), will be in the region of 8℃ below the capabilities of the unplasticised polymer. This must be tempered with a reduction in physical properties, and selective use of fillers can help the compounder achieve a more acceptable balance. A plasticizer loading of 10phr is a typical compromise.

It must be emphasised that if the elastomer is subjected to high temperatures, some of the plasticisers may be lost dependant on their volatility. Fig. 4 examines the comparative volatile loss of five plasticisers at 180℃ (and 10phr loading); the maximum operating temperature suggested by at least one manufacturer, and then re-examines their low temperature properties in Fig. 5.

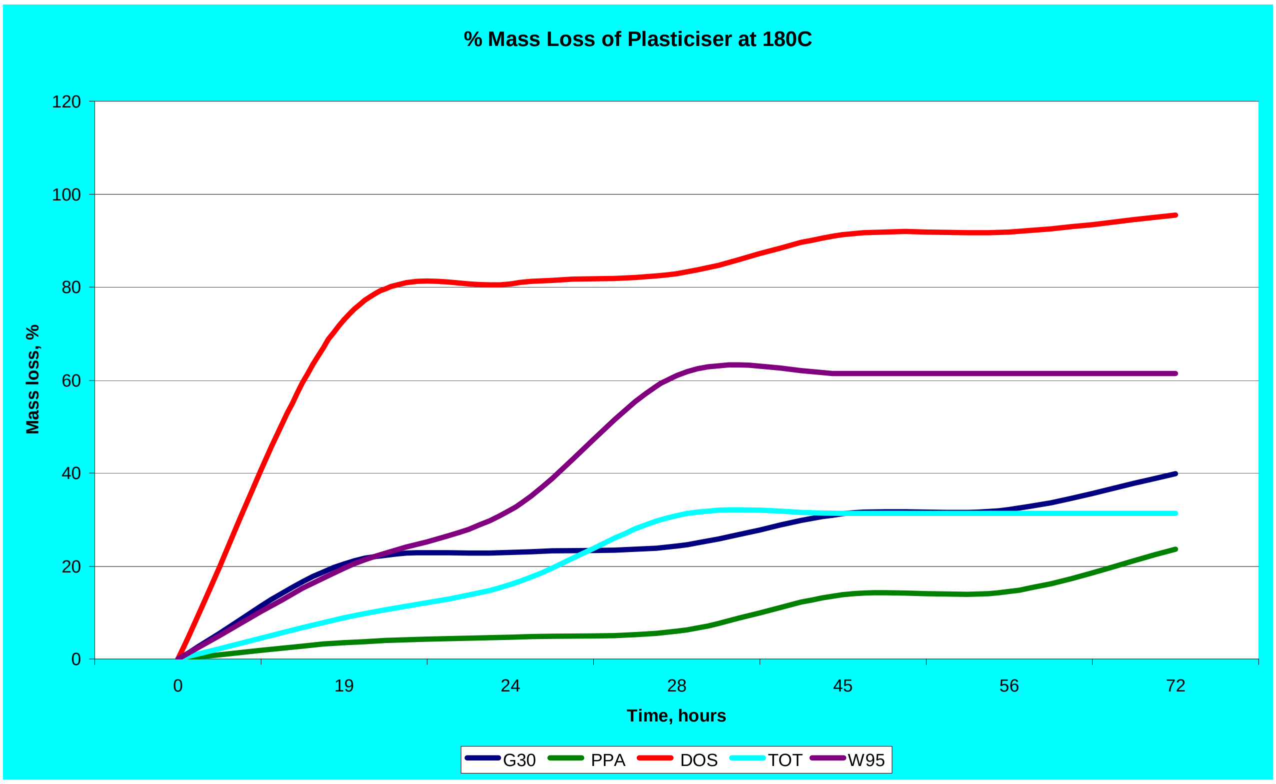


Fig.4, Volatile loss at max operating temperature.

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