Various Questions on Swelling Seal application and use Ref: RP/2014 Engineering. Feb -002

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A High level Look at the effects of well conditions and operational factors of the performance of 2nd Generations elastomers and Products developed and supplied in OBLIQUE swelling seal systems. Author R.W.Hibberd - Ruma Products BV Holland 2014

The Effects of well mechanics and operations on the performance of our Q-Spectrum Elastomers

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Pre-Amble

Customers and potential customers often have questions and concerns regarding the use of and the way elastomers and seals work or have been designed and developed. What factor is important for them and what is less important. To answer a few of these points the following document has been created.

Acid and H2S resistance

Acid Resistance

Acid resistance of the base elastomer is technical not an issue, the base elastomer if correctly developed does not react with acids. There were problems experienced and published in SPE papers by Aramco in the past on Acid effects on swelling elastomers. These problems were the result of well acid stimulation reacting with elastomers that swell but were due to the swell induction medium being used being SAP (Super Absorbent Polymer). Because it is possible that the suppliers of some swelling seals do not create their own elastomers, or even manufacture their own products, that they do not always have available or have supplied to them the full elastomer technical background so do not always know of the effects of well fluids on the elastomers. This means that neither they nor their customers were aware of the fact that SAP breaks down in a pH environment lower than about pH 4 and higher than a pH of about 9-10 nor even that SAP potentially decays at temperatures above 90-100 C. Ruma as the designer of its own compounds know the ingredients and tests these compounds in the lab to ensure Acid and the other more commonly used well chemicals are not a problem with the elastomer.

Compounds which contain other ingredients can show differing results on Acid testing, some have an increased swell rate, other slow down or will crimp slightly depending upon how much they were swollen at the time of acid being pumped. However once the acid has passed they will revert to their previous swelling state and show no permanent damage. SAP however once affected is effectively destroyed and will never recover. For further details we refer to the acid test as described in Appendix I.

H2S resistance

H2S affects the swelling elastomers in two ways, as it is often dissolved in the production water (potentially also with CO2) the water is reasonably acidic. Therefore the effects mentioned above can be expected on SAP containing elastomers. The second way it can affects the swelling elastomer is that H2S reacts with elastomers that have been vulcanised using Sulphur as the vulcanisation agent. Oblique Q-Spectrum coloured elastomers do not and have not been vulcanised with Sulphur. They are a second generation elastomer and utilise a more advanced and own alternate technology.

In none of the Q-Spectrum elastomer range in normal use is either acid or H2S a problem. Although it is always wise with any elastomer to check with the supplier to ensure it is fully compatible with any intended fluids or stimulation fluids on a well

Cool Down

To understand the effect of potential cool down in a swelling seal system you first need to have an understanding of the effect of warming up on that system. In a system with both tubing and swelling seals the first thing that happens is that the tubular diameter and length increases due to thermal expansion, the elastomer also undergoes a similar effect, it will be bigger and longer. Hydrostatic pressure can also have an effect on both of these components. At temperature the seal swells and then seals the hole, locking the length change of the tubular into the system. Any cooling on the system will have the greatest effect on the shortening of the tubular versus the warm situation.

We model the effects of temperature and Hydrostatic on the seal assembly as a part of our geothermal work, (see attachment.) The effects of temperature on the OD is minimal even when not taking the effect of diameter increase caused by Tubing ballooning into account on the seal. The greatest effect is that of tubing shortening due to cooling. This shortening has an effect on the loading of the swelling seal which manifests itself in an increased loading on the BONDING between the elastomer and the pipe. It must be remembered that the effects of changing the length due to heating the cooling is almost impossible to simulate in a test setup if the ends or one end of the OCTG where the swelling seal are attached to the test set up body.

As a manufacturer of industrial rollers (up to 3 meter diameter and 8 meter lengths) where sheet metals are being transported at elevated temperatures as well as high speed bonding is the most crucial part of this process. The bonding process developed for swelling seal has been created to reflect this high demand and is a crucial part of the system. Bonding is however specific for the elastomer type and sort as well as the metallurgy of the base pipe. 13Cr has another bonding requirement to that of 4140, when testing this has to be born in mind, this is another variable possible that needs to be considered.

Water swell is different to Oil swelling and high temperature bonding is different to low temperature. Failure to develop a good bonding quality will result in the elastomer releasing under load. As in welding the bonding should be stronger than the elastomer.

As in the above statement for Acid and H_2S the suppliers should be aware of what bonding is and how it works. The result of incorrect or poor quality bonding or poor application can be critical and a nonchalant view on its significance must not be taken.

Equipment Temperature Rating

Temperature rating for equipment is a complex rating as a number of different factors are involved resulting often in different ratings applying. In elastomers there are a number of crucial temperature points.

Glass Transition Point

This is a temperature where the normally flexible elastomer suddenly changes to being a hard and very brittle structure. For swelling elastomers the base elastomer family determines the exact temperature this occurs, commonly this is at a value of -15 to -25 Celsius. However the elastomer can be designed to supress this to as low as -50 Celsius. However if this is done the maximum temperature this base elastomer can have is then often ALSO moved down The swelling seals may be stored at this or even lower temperatures but may not be used. Storage needs to be carefully conducted as the brittle elastomer can easily be shattered if it is mechanically shocked. At temperatures higher that this the Activation Energy is either constant or increases and it may then be used in a well. For these extreme low arctic type temperatures the packing and protective material must also capable of working at these conditions.

However the operating range of the swelling function of the elastomer is separate from this. The elastomer has been designed to start swelling at a triggering temperature where below this point swelling hardly occurs. This lower temperature is tightly tied to the salinity of the brine for water swelling. For a lot of applications 60 Celsius can be seen as the lower operating temperature of the swelling mechanism, however if correctly designed this could be as low as 5-10 Celsius. However this is usually for a low salinity brine often in the 0-5% range. At higher salinities swelling if it occurs at all is very slow.

The higher temperature range is then the actual maximum range that the base elastomer (not swelling) can be operated at. This maximum has a lot to do with the ageing of the elastomer, the Arrhenius Equation is often used to determine the effects of temperature upon aging (shelf life). This varies according to the elastomer family with the more common elastomer types limited to around 125 Celsius and for the NBR and HNBR class in the order of less than 170 Celsius.

As with the low temperature swelling, the high temperature maximum swelling range is heavily influenced by the fluid salinity and is commonly in the 15-20% range. Fluid salinities lower than this can and often do result in a too rapid a swell and either hang up in the well or sometimes in extreme cases can result in seal destruction. As mentioned previously the bonding is here also crucial, the bonding should also be chosen to suit the temperature range, incorrect bonding potentially will result in the bonding aging and failing.

On Oil swelling elastomers a lower temperature limit of around 40 Celsius is often the case, under this swelling can be extremely slow and of such a small physical value so as effectively to be negligible. At the high temperature end the risk is that above 135 Celsius the elastomer will start to dissolve away too quickly.

Equipment Pressure Rating

Pressure rating of Swell seals is problematic to define. In a mechanical packer the rating is determined by the myriad of individual component that constitute the body of the seal as well as the sealing element. It is worth noting that the sealing element is commonly 8-12 inches long even in very high pressure ratings.

For swelling seals the basic pressure rating is determined by the OCTG rating being used (bear in mind that the specifications given by the OCTG manufacturers is related to 20 Celsius so needs to be corrected for things such a yield reduction due to temperature). The seal itself has a very different rating and this is heavily dependent upon two factors, how central is the seal in the hole and how little the washout in the hole is, and this is also often determined by the mechanics of the reservoir rock (porosity etc). In a hole with a casing the latter is not important. However what is important is how the system is being tested and exactly what the procedure for this is, as well as the characteristics of the fluid being used. For water swelling seals two different things need to be understood and applied in the testing. The seal swells by a diffusion gradient being created between the inside of the elastomer and the fluid outside of the elastomer. In a water swelling elastomer temperature and salinity determine the rate and absolute swell of the elastomer. Absolute swell is the amount of swell that occurs against time for that situation. Irrespective of how thick the elastomer is it will never swell more than this amount in a certain time.

Example: A 10 mm thick sample swells 5mm in X days. If it were 20 mm thick it would still only swell this same 5 mm. So it is vital not to talk about % seal swell in an application in this example in the first the swell is 50% and in the second it is only 25%. However the swell is still the same amount. There is however a difference between how much the seal is required to swell to bridge the space and how much swell an elastomer can generate. Compare this to a balloon where one has a heavy hard wall and the other a light thin soft wall. The one balloon can be inflated a huge amount the other barely. This is important because the amount of swelling of the seal is NOT a function of the swelling ingredients but of the base elastomer mechanics (which are part of the elastomer design). In the balloon example the swelling ingredients can be compared to the air pressure used to inflate the balloon.

In the actual swelling, sweet water is being extracted from the system brine and enters the elastomer causing it to swell. If distilled water were to be used the diffusion gradient would be at its maximum for that water and elastomer temperature combination. As the salinity of the brine is increased the diffusion gradient actually decreases and with it the swell rate and absolute swell too. This occurs because the salt dissolved in the brine also tries to hold onto the solute water in the brine and releases it only to a superior force to itself. As sweet water is removed from the brine the brine concentration increases exerting a higher holding force on the water reducing the diffusion gradient between it and the swell inducing ingredients in the elastomer.

Secondary to this as the temperature increases so does the diffusion gradient. So in a sweet water application an elastomer would swell slower at 20 Celsius than the same water and elastomer combination at 100 Celsius.

This all has to be born in mind when testing a swelling seal. If it is being tested with a brine, the salinity of the brine will change as the sweet-water is being extracted from the brine and pulled into the elastomer. This has to be taken into account with pressure tests, otherwise the risk is being taken that the elastomer has NOT swollen as much as it was believed to have with the obvious effect on the results. System fluid Volume is therefore crucial, as is the orientation of the pressure test cell. The brine salinity change results in density change which can produce a density gradient in both sample pots and cells, this influences the results. *Note: the cleanliness of the test system is also crucial the presence of chemicals from previous tests and or the presence of simple things like antifreeze and corrosion inhibitors can dramatically affect the results so care is required.*

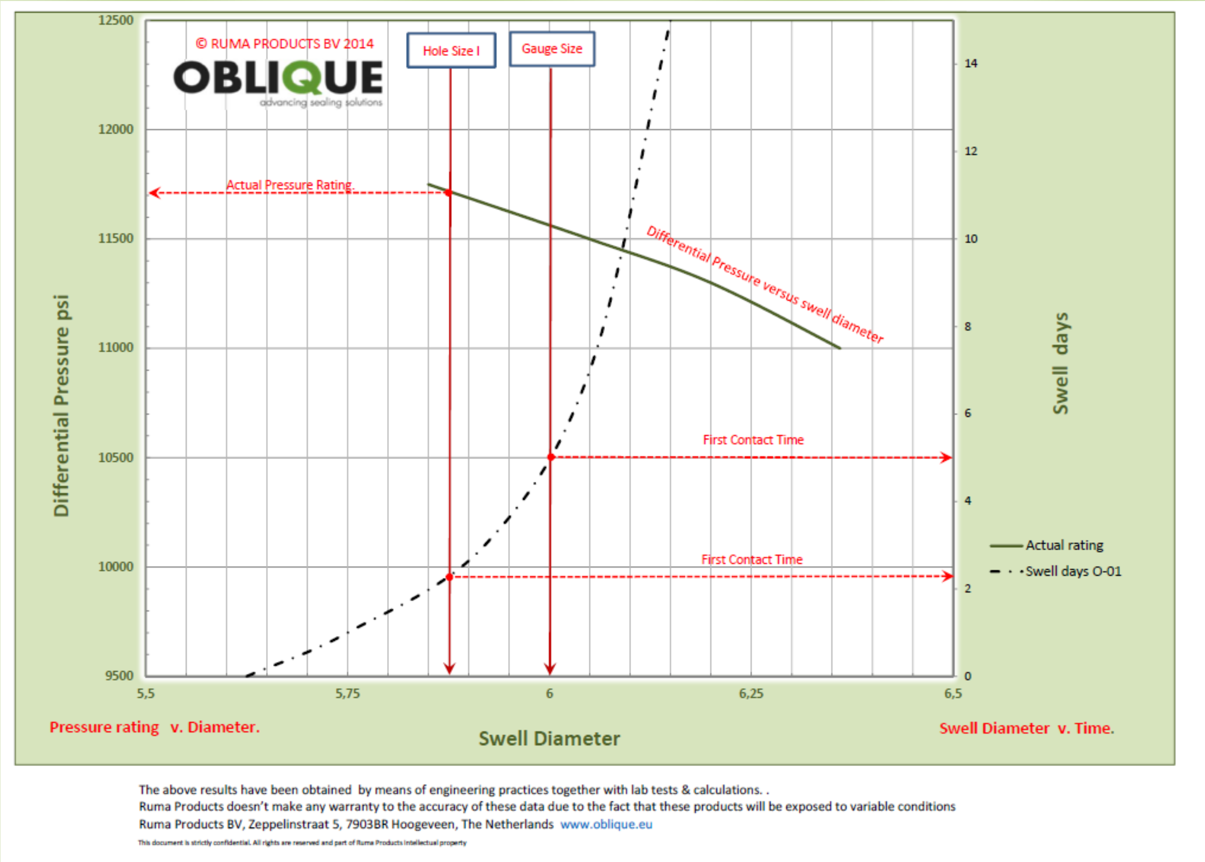
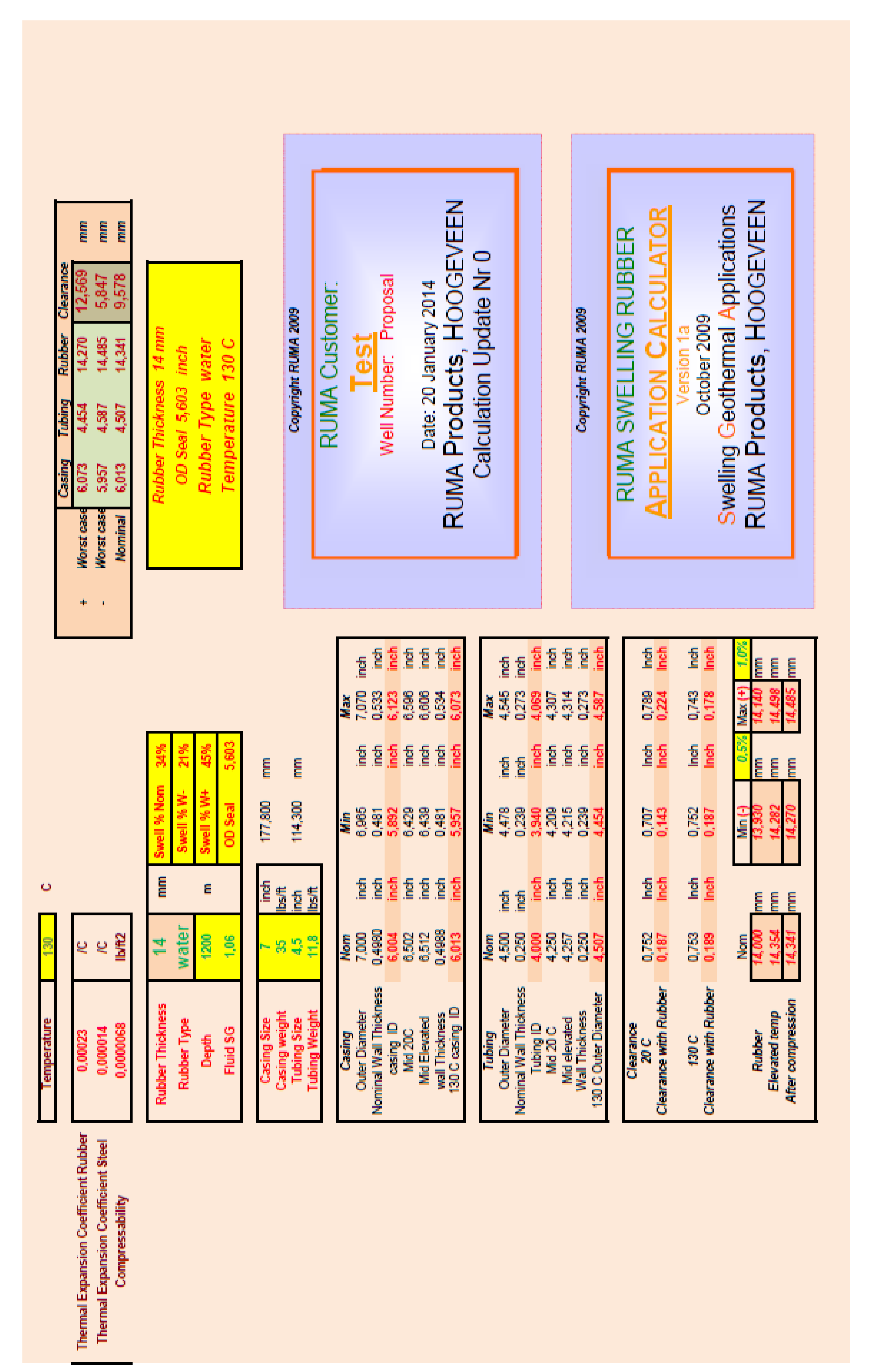


Fig. Performance curves

The above graph is an illustration of the Oblique swelling elastomer performance curve. As with all swelling elastomers the change in geometry alters the performance curve as a function of Pi as well as the results of the change in flux due to the seal inner and outer radius of curvature.

Effects of Temperature on Bonded seal systems



Temperature	130	C

Thermal Expansion Coefficient Rubber	0,00023	/C
Thermal Expansion Coefficient Steel	0,000014	/C
Compressability	0,0000068	lb/ft2

Rubber Thickness	14	mm	Swell % Nom	34%
Rubber Type	water		Swell % W-	21%
Depth	1200	m	Swell % W+	45%
Fluid SG	1,06		OD Seal	5,603

Casing Size	7	inch	177,800	mm
Casing weight	35	lbs/ft		
Tubing Size	4,5	inch	114,300	mm
Tubing Weight	11,8	lbs/ft		

Casing	Nom		Min		Max	
Outer Diameter	7,000	inch	6,965	inch	7,070	inch
Nominal Wall Thickness	0,4980	inch	0,481	inch	0,533	inch
casing ID	6,004	inch	5,892	inch	6,123	inch
Mid 20C	6,502	inch	6,429	inch	6,596	inch
Mid Elevated	6,512	inch	6,439	inch	6,606	inch
wall Thickness	0,4988	inch	0,481	inch	0,534	inch
130 C casing ID	6,013	inch	5,957	inch	6,073	inch

Tubing	Nom		Min		Max	
Outer Diameter	4,500	inch	4,478	inch	4,545	inch
Nominal Wall Thickness	0,250	inch	0,239	inch	0,273	inch
Tubing ID	4,000	inch	3,940	inch	4,069	inch
Mid 20 C	4,250	inch	4,209	inch	4,307	inch
Mid elevated	4,257	inch	4,215	inch	4,314	inch
Wall Thickness	0,250	inch	0,239	inch	0,273	inch
130 C Outer Diameter	4,507	inch	4,454	inch	4,587	inch

Clearance						
20 C	0,752	Inch	0,707	Inch	0,789	Inch
Clearance with Rubber	0,187	Inch	0,143	Inch	0,224	Inch
130 C	0,753	Inch	0,752	Inch	0,743	Inch
Clearance with Rubber	0,189	Inch	0,187	Inch	0,178	Inch

	Nom		Min (-)	0,5%	Max (+)	1,0%
Rubber	14,000	mm	13,930	mm	14,140	mm
Elevated temp	14,354	mm	14,282	mm	14,498	mm
After compression	14,341	mm	14,270	mm	14,485	mm

		Casing	Tubing	Rubber	Clearance	
+	Worst case	6,073	4,454	14,270	12,569	mm
-	Worst case	5,957	4,587	14,485	5,847	mm
	Nominal	6,013	4,507	14,341	9,578	mm

Rubber Thickness 14 mm
OD Seal 5,603 inch
Rubber Type water
Temperature 130 C

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RUMA Customer:
Test
Well Number: Proposal
Date: 20 January 2014
RUMA Products, HOOGEVEEN
Calculation Update Nr 0

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RUMA SWELLING RUBBER
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3.0 Authorisation

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Appendix I

TEST DATA EFFECT OF ACID ON ELASTOMERS (X1 AND X2)

Below graph and table show the effect on elastomers X1 and X2 after the test fluid is changed from salt to acid (CHOOH).

Compound X1

This one shows huge swell in 0.5% NaCl to over 1000% and after change to acid the elastomer collapses completely.

Compound X2

This one swells about 150% in 20% salt at 80°C and after changing to acid shows an increase in swell to over 800% with a decrease to 750% in time.

To go from 800% to 750% the elastomer takes approx. 100 days

Note: The acid has not been replaced/refreshed during the test period.

Time 1 (days)	X1 in 0,5%NaCl	X2 in 20% NaCl	X1 in 20% CHOOH	X2 in 20% CHOOH
0,0	0	0		
1,0	212,5	51,65		
3,0	651,5	100,7		
7,0	1013	154,8	1013	154,8
14,0			442,5	829,4
21,0			404,2	883,3
28,0			364,2	859,4
35,0			360	823,2
42,0			316,5	797,8
49,0			288,9	793,2
63,0			228,3	777,2
95,0			166,3	772,1
121,0			143,1	755,3
149,0			124,0	756,8