

1. CT STUFFING BOX PACKERS - STRIPPER RUBBERS

v 1.8.2012

1.0. Guidance Notes

1.0.1. Aim

Questions are often raised with us as to what constitutes a suitable rubber. These notes seek to explain why and how stripper rubbers have been developed, and are still developing, and therefore give guidance on current best practice.

Benoil offers a range of stripper rubbers, the standard forms now being widely used throughout the world by both larger and smaller coiled tubing operators. Feedback on performance is always welcome and will guide further developments. Past feedback from many sources has enabled us to revise our use recommendations and it is heartening that in general Benoil rubbers have proved capable of more than we had originally allowed for. That is now reflected in these expanded notes.



1.0.2. Basic Function

The function of the stuffing box is to enable tools to be loaded into the well attached to the coil tubing. The seals in the box are designed to enable the tubing to be passed through continuously (or, as often happens, discontinuously) while exposed to the wellhead pressure. They are thus the working seal on the well during live intervention, sitting above the BOP seals. Many factors affect the suitability and performance of seals, and the circumstances of use provide an ever wider range of challenge.

1.0.3. Background

Historically, one might say, it scarcely mattered what rubber was used so long as it gave some sort of seal. Wells that are shallow, not at great temperature or pressure, not full of corrosive gases, do not present much of a problem. Nonetheless, the good wearing properties of polyurethanes commended themselves for this application so that it was chosen over, say, neoprene. But it soon became evident that as one departs from the simplest of conditions, things can go wrong.

The problem is fundamentally one of excess wear, coupled with potential chemical effects from well fluids, which can lead in the end to crumbling of rubbers, and occasionally to ejection of extruded fragments. The total loss of seal leads to escape of well fluids, with the consequent risks to task, health and environment, of spillage, spray, fire and potentially explosion.

1.0.4. Tackling the Problems

At first glance, it was perhaps not entirely evident why a particular problem arose. Often, it was an isolated event. Often, by replacement of the old rubbers by a new set, there was no further problem. That tended towards a blame culture of describing a “bad set of rubbers” or “poor rubber quality”, but while it was infrequent and curable by replacement, there was not much incentive to define any underlying problem, and still less inclination to pay for finding the solutions. But it became evident that there was an ever greater challenge to the rubber and that probably the situation might be improved by a little analysis of the problem and some experimentation.

The supply of rubbers was dominated by two major companies, Bowen and Texas Oil Tool (TOT), both now part of NOV. There were, and are, others, especially in America, but supply was quite widespread, including a company in Turkey for example. Most of the rubbers produced by most of the companies were of polyurethane, though TOT had some in other materials, such as nitrile and fluorocarbon. Benoil was itself a relative newcomer starting in 1985. It is certain that there were various discussions around the industry taking place even before then, though without a positive plan to improve rubbers in a concerted way.

BP finally decided in about 1990 that they had a significant problem in high pressure dry gas wells. Newsco (now Baker) was invited to organise trials; they used external consultants to design and build a test rig, and Benoil were involved in the design and supply of experimental rubbers. The products that resulted formed the first improved Benoil series, as referred to below.

These have been further improved upon since then. Subsequent developments have involved making the rubbers more temperature resistant for higher temperature (up to 160C) use, and, in contrast, more suitable for very low temperatures (-40C).

There is still room, and now demand, for longer life and yet higher temperature and pressure rubber products and this is the aim of current developments.

1.0.5. Analysis of the Problem

Problems arise from three sources chiefly:

- mechanical - the system of equipment whatever the rubber
- physical - the system/rubber interface
- chemical - the nature of the rubber and effects of well fluids

These interact and are not entirely independent. There is a fourth category, ever potentially present, and that is human error.

1.0.5.1. Mechanical Effects

The most obvious mechanical problem arises if the injector head and the stuffing box are less than perfectly aligned. If it is slight, it can be difficult to detect, but shows in the unilateral wearing of a rubber set. Depending on how the set is aligned in the box, it can affect both halves of a set of rubbers or just one, but virtually all the wear takes place to one side as that part of the rubber diameter is excessively stressed. In favourable cases this can be seen if the operation is interrupted at a suitable time. We are indebted to PSL (now part of Halliburton), both for samples highlighting a problem and for confirming the interpretation; in this case, the misalignment was traced to worn parts in one side of the injector head, as shown up through examination of the elastomer pads; when this was rectified, the rubbers in the stuffing box functioned normally. This kind of fault is not really cured by any modification of the rubbers; it can still occur.

Another mechanical problem may show up if tubing is rusty after a dormant period and is run in that state through the stuffing box rubbers. The abrasive nature can play havoc with rubber. This may often be only the first few hundred feet of tubing (on the outside of the reel) but it may be enough to create initial damage which allows further deterioration by other mechanisms. In the old standard rubbers of the past, this could perhaps be enough to cause rubber failure. This fault too is not cured by rubber modification, but it is ameliorated by the new rubbers. On the other hand, Exxon-Mobil recently reported some tests in which the surface roughness seemed to play only a minimal role.

Other mechanical problems may result from tubing ovality. This we have not been able to pinpoint as having an effect on rubber, but it is rather like the misalignment problem; the rubber is always under more compressive pressure in the direction in which the tubing bulges and under more distortion to seal at right angles. Tubing ovality is not apparently great enough to cause a rubber problem. Were it severe enough, there would perhaps be other major problems with the tubing. But it undoubtedly accentuates a wear problem.

The final mechanical problem is the friction problem of running the tubing, but as this is much more an effect of tubing-rubber interaction, it is considered among the physical effects.

1.0.5.2. **Physical Effects**

One could take the view that if the box was energised to something very high, say 8000psi, this would very definitely seal the rubbers around the tubing and one would not have leaks. This is not necessarily the case, however, and it was a problem with old standard rubbers which simply broke up and wore away. It is also clearly wasteful of pressure pumping capacity and injector head energy needs on the majority of wells.

The problem lies in the frictional interaction between rubber and steel. This is in two forms, dynamic and static. Static friction is particularly significant in causing initial damage to rubbers which, with older type rubbers in a dry state, could be ruinous. We know that the effect of pressurising the box is to seal the two rubber halves to each other, on to the tubing and on to the walls of the box; the rubber "grabs on" to the steel. On start up, the tubing has to overcome this static friction, which in effect pulls at the rubber; if squeezed under pressure to ensure a seal this means that the rubber is distorted in the direction of pull. Of course it is restrained by anti-extrusion rings or brass bushes which are closely fitted to the tubing, but that initial movement can pick at the rubber surface. The distortion can be maintained even by the lower dynamic friction, and the rubber wears differentially, top to bottom, giving a well-recognised funnel-shaping to the rubbers.

Such an effect is inherent. High squeezing pressures are likely to make it worse. Rusty tubing may make it worse. But it can be contained.

Lubrication - External

One obvious treatment is to ensure clean smooth tubing and lubricate it. This does give an improvement, but it is not easy (from experience) to get enough of the lubrication where it is needed. If the tubing is pre-lubricated, the rubber acts as a wiper to remove much of it before it can affect the desired interface. If the tubing is pressure lubricated, it is better - this is done in a tandem box arrangement; but it tends to lubricate only the lower box while running in or the upper while pulling out. The other rubber wears much as if it were not pressure lubricated. It also requires better than average lubricants, able to withstand high temperature; otherwise they too-readily volatilise and escape or break down and cause gumming problems.

Lubrication - Internal

An alternative solution is to lubricate the rubber internally. This is Benoil's preferred approach and what is incorporated in our current range. This proved quite problematic in itself even if the principle was clear; most of the obvious simple candidates did not actually work unless present in such quantity that they were either uneconomic and/or disruptive of the elasticity of the rubber. For example, a rubber containing PTFE was found to break apart with an appearance like shattered flint in some circumstances; graphite gave a fairly similar result. This made them worse than useless. The finally chosen and effective additive is a proprietary mixture.

The resulting rubbers have the characteristic of not binding to the steel tubing, or at least not to the same degree, which greatly reduces much of the wear problem. It therefore also has the effect of wearing more smoothly on average, which means that the rate of loss of rubber is more readily allowed for. This is particularly important in high temperature and high pressure wells, or in fast tripping which tends to generate high temperature. It is also important in deep or long reach wells. In all cases, one seeks to avoid the cost of stoppage time.

This could be important too if coil tubing were used more in mining techniques, where considerable

amounts of dust would be likely to be present in the atmosphere and could get on the surface of the coil before it was run in. If coil tubing is rusty or pitted or rough from other reasons (such as ice in the Arctic, say), it will tend to wear the rubbers faster than if it is clean and smooth. But the smooth rate of wear gives reliable operation. One user informed us he had had no significant stripper rubber problems since adopting Benoil's new rubber formulation, over several years' use; in fairness, he later had one problem run in the 12th year.

Lubrication - Complementary

It is, of course, perfectly possible to have both internal and external lubrication. Usually this can be advantageous. However, be sure to choose a lubricant which does not itself de-grade, or cause degradation of the rubbers. It must again be pointed out that diesel oil is one of the few items known to seriously swell, and so cause deterioration of, polyurethanes and must on no account be used. We found and have reported this before, but are grateful to a customer for a report which dramatically confirmed this.

1.0.5.3. Chemical Effects

It was stated earlier that effects interact. This is certainly true of the chemical and physical aspects of the rubbers used. It is true even within a rubber type.

Polyurethane

It may not be apparent to those involved with CT operations that the term polyurethane covers a very wide class of materials. There are many types and to some extent within broad limits they can be tailored to order. Some are hydrolysable and unsuitable for long term use in water, acids or alkalis, but suitable in oil. Others are resistant to such hydrolysis and oil, but less tough. Some are hard and rigid, some are rubbery, some are so soft as to be gelled liquid, some are foams, and so on. Different base chemicals can be cross-reacted and formulated in achieving desired results.

The variety is almost infinite. For this reason it is well-nigh impossible to achieve an absolutely identical result to match competitor products. Years ago when systems were simpler and there were fewer choices, they were at least more alike.

Stage 1.

When Benoil first made stripper rubbers, we chose materials which were not hydrolysable or likely to deteriorate in oil. We chose two polyurethane systems at 75A and 90A hard (our 3200 and 3100 series). Hardness is a good broad indicator of variation within a system, as well as useful in the chosen product. From the graphs of the variation of hardness with temperature (Figure 1.), one sees that the hardness of both falls slowly away to a critical point and then drops rapidly away as the compounds break down; this is a chemical breakdown of the polymer and is irreversible once beyond the critical point. The harder rubber is clearly stable to a higher temperature (about 110C) than the softer (about 90C).

Such graphs must be viewed with care and not taken out of context. Comparison with others done at different times must be particularly cautious unless there is an internal standard in the testing to show that results can be compared. One of the chief variations is time, which does not appear within the graph, but forms an important component in later comparisons.

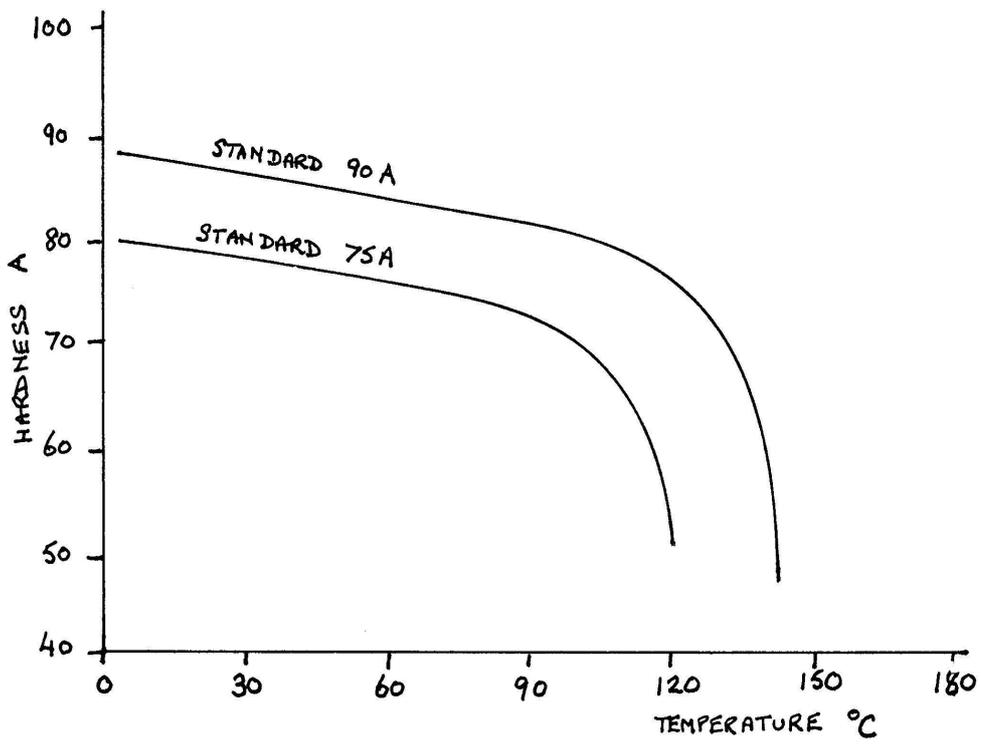


FIG 1. EFFECT OF TEMPERATURE ON HARDNESS (IN AIR)

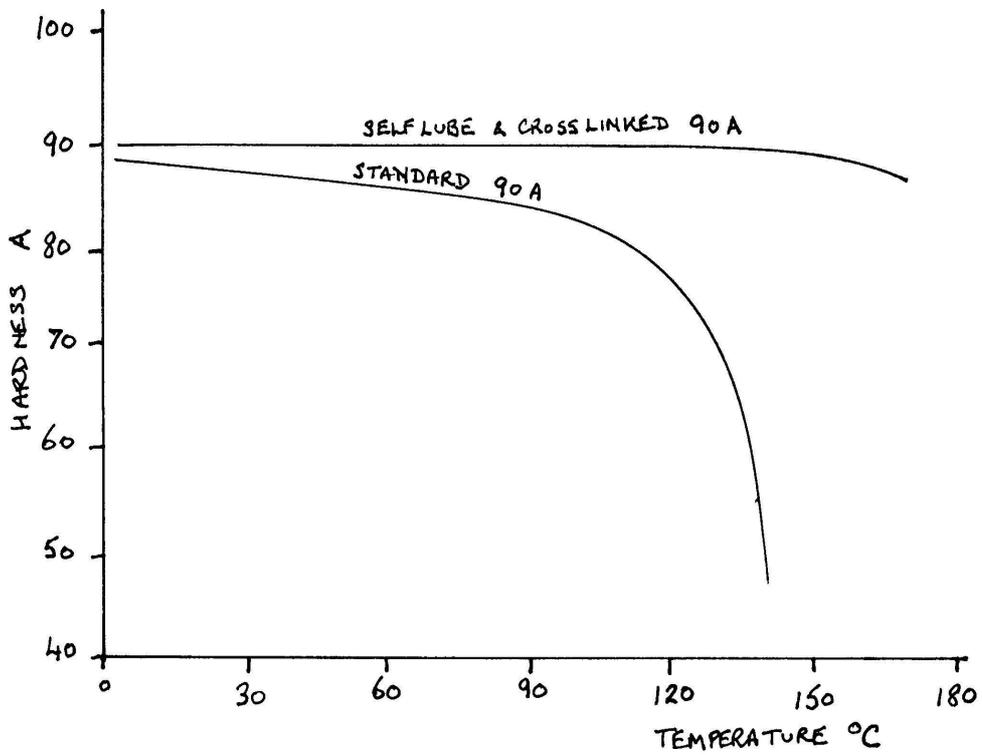


FIG 2. EFFECT OF IMPROVED POLYMER SYSTEM

Stage 2.

With the proprietary additive included (as described above under physical effects) these polymers became much smoother in their wearing behaviour. In the process they also became more stable at slightly higher temperature and pressure. Although we were looking to create this effect, we had not expected the additive alone to have this effect, so that we conclude there is almost certainly some interaction between additive and substrate, beyond a mere dispersion of the one in the other. Pressure resistance was excellent so, at this point, we established the 3400 series (95A based) products.

The 3500 series (75A based) followed as it became desirable to have a softer kind which were easier to energise for LTLP use, but with the smooth wearing characteristic.

Stage 3.

We continued developing and subsequently also modified our polymer system by deliberate additional cross-linking. This had the effect of elevating the critical point as we anticipated, while only slightly increasing the base hardness. The result is illustrated in Figure 2., in which the same 90A graph as in Figure 1. is compared with the formulation after cross-linking and addition of the self-lubricating proprietary additive. It can now be seen that the critical point is in the region of 165C, a very substantial improvement, both on the original and the intermediate result (which is not illustrated but is about 140C). Our reason for pushing up this critical point is that it clearly represents the maximum use level and makes the rubber suitable for use at high temperature as well as high pressure. This launched our 3700 series (95A), and sometime thereafter our 3600 series (90A).

The particular push for the 3700 series was again for Baker, this time in Italy, while the 3600s resulted initially from demand from Schlumberger in Germany, again for the easier energising while maintaining the wear property. The 3600s tend also to have been subsequently favoured by those who want one product to cover as much of the range as possible, and are now used by almost all the coil tubing companies from time to time.

The usefulness of the 3600 series (90A), and by analogy the other ranges, is well shown by Figure 3. The contrast with the earlier figures is that the X-axis is time and not temperature. What we plot here is in fact two separate but linked trials, which is why the reader must take (1) and (1) together, then (2) and (2), before drawing conclusions. The oven used is of the air-circulating type and so gains temperature equilibration readily, as shown by the steps in dashed line (1), when the temperature control is adjusted. It can be seen that the hardness is almost invariable until the temperature exceeds about 155C. There is a slight loss of hardness at 160C, but a significant fall off only occurs when the oven temperature is set to about 170C. Even then it takes several hours to deteriorate.

Furthermore, it must be remembered that these are samples exposed to hot air; this is not the case in a stuffing box. The hardness measurement is made in the surface, and it is clear from the browning of the samples and fume that the surface is oxidising and softening. It does not follow that the bulk is deteriorating to the same extent. When the samples are cool enough to handle and cut, it is evident that the bulk is largely unaffected by oxidation. But naturally we err on the cautious side in giving usage limits. The comparison can now be made with graphs (2), for the old standard material, in which the rate of initial temperature increase was less, but the deterioration was near immediate. This data is from the same data set used in Figure 2.. It shows the importance of not relying on one simple interpretation.

Later, we developed a cross-linked form of the 3500 series and introduced it as the 3800 series. This not only gives better wear, so that it has replaced the 3500s, but also offers a very low temperature form which should be suitable to -50C. The rubbers already give good service in Norway in cold conditions and are extensively used elsewhere.

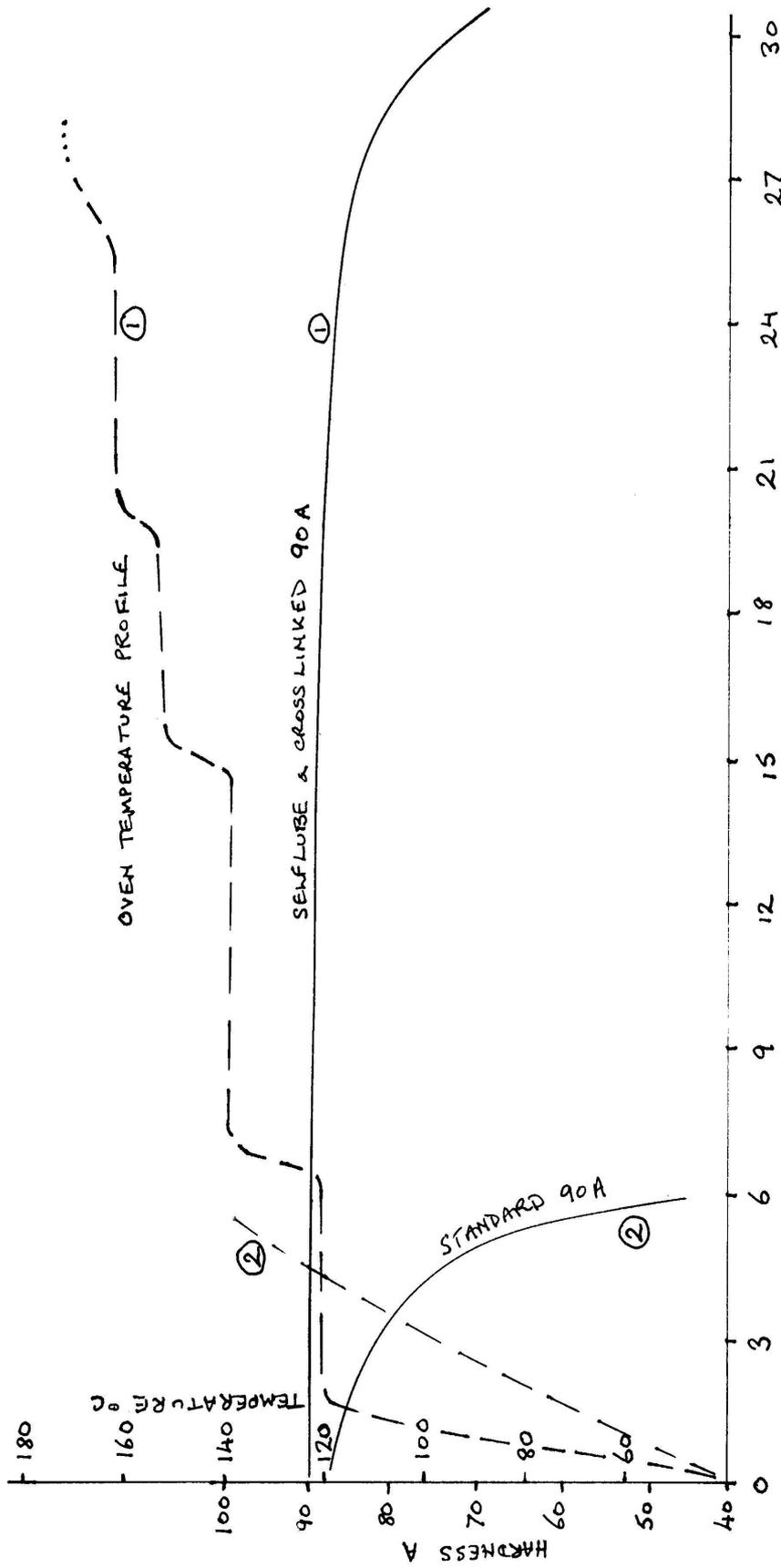


FIG. 3. EFFECT ON HARDNESS OF TIME AT HIGH TEMPERATURE [RELATE ① & ② AND ③ & ④]

Well Fluids

All the tests which we ran in our test programme were yard tests and only, therefore, with a standard atmosphere. However, we were always conscious of the possible effect of well fluids as the original BP dry gas wells contained some carbon dioxide. The first series of rubbers met their requirements by a large margin; no carbon dioxide attack has ever been reported.

While we did not specifically test for sour gas resistance, we had in fact made our selection of the raw materials for the polyurethane and the additives on the basis that this would probably be a major requirement. They are indeed resistant, as has been proved in use of thousands of rubbers without a single adverse report due to sour gas. If we may quote a Canadian in jocular mode: "In Alberta we have sulphur wells producing some oil" and our rubbers are extensively used there.

Specifically, the chosen polyurethane resists hydrolysis, which is why it resists chemical damage by carbon dioxide, hydrogen sulphide, and cement formulations.

Also we worked with a tandem pair of boxes which not only enabled one pair of rubbers to be a standard while one pair was experimental, but also meant various lubricants were tried as well. This eventually included some degraded oils, and is also why we know diesel is not a good lubricant. Though we did not attempt to inject crude oil to test for effects, we are aware that it is probable that excessive contact with certain crudes could lead to some degradation. We would particularly beware of crudes with very light aromatic fractions such as benzene, toluene and related compounds, though we have had no reports of problems. Such compounds cause swelling of polymers and, though this does not necessarily chemically degrade them, it increases the sealing pressure while softening the compound, and thus the wear rate increases.

1.0.5.4. Human Error Effects

It is not useful to dwell on these as they clearly depend on matters like well-trained and motivated staff following tested procedures in circumstances where few wells are exact repeats of another. This is beyond our present scope. But, good materials can minimise the effects of some misjudgements, so an example of this is in order. Its application to any other situation must depend on a company making its own risk assessment.

We supplied rubbers for an application using 1.75" coil tubing in relatively shallow and distinctly low pressure wells at no significant temperature. There should, in other words, have been no problem in a straightforward situation. In this case, the problem possibly lay in the very ease of the operation. The rubbers were only just closed around the pipe and barely energised. Because of the low pressure there was a leak of a small quantity of well fluids. The rubbers were indeed well worn but the through hole was so even, parallel and cylindrical that it was at first considered that incorrect 2" rubbers might have been fitted; part number markings ruled this out, however. The even wear pattern is what stopped a minor leak becoming more serious.

1.0.6. Significance of Choice

The major conclusion is that the new rubbers last much longer, even at any temperature considered suitable for the old types, and to much higher temperatures, and they wear smoothly in predictable fashion. The time factor is particularly significant because the rubber should outlast most normal coil tubing operational runs. That does not become a reason not to change them between runs!

There is an additional effect which seems to fit with field reports and usage and which might help provide selection guidance in future. It has long been noticed that the softer forms of the 3800 series (and previously 3200, 3500) are less favoured in hot countries, even by the same company and the same personnel, yet for many European jobs they are the workhorse. In hotter climates the 3600 series (previously 3100) prevails. It is thought that this is a function of ambient temperature; being so much hotter in an exposed metal box in full sun means there is less margin to the critical point and less scope for air cooling, at least by day. The 3600 series is now always recommended in such circumstances - in Venezuela, Gabon, Saudi Arabia and Singapore, for example - unless high well pressure and temperature indicate the 3700 series.

Further, the higher tropical temperatures make the harder rubbers softer, and so easier to energise,

while the softer rubbers in a cooler climate are harder and so, very broadly, equivalent to energise. As a general rule, the softer the rubber, the easier to energise but the faster it will tend to wear. The 3700 rubbers are in any case harder to energise, but come into their own for high temperature and especially high pressure applications.

Thus the ideal choice of rubber depends on the well temperature and pressure but may also reflect the ambient conditions. For example, for a given well, one might choose a harder or softer rubber depending on whether it was the middle of the Canadian summer or the depth of the Canadian winter.

1.0.7. Cost Benefits

The value of getting the selection right is the longer life and thus reduced change-out time. If the daily rate cost of an offshore rig is say £100,000/day or \$200,000/day, then the cost of a 1-2 hour change-out is around £4000-£8000 or \$8000-\$16,000. It will be much more in deepwater capital-intensive locations such as Gulf of Mexico, Shetlands, Angola and less in relatively shallow wells in land-based operations as in Texas. One might also add in lost production, or the standby cost of other deferred operations. But, however it is finalised for a given location, this is the real cost of a change-out, not the cost of a set of rubbers. To choose ones that give longer life - and our customers point out to us that ours often have 2-3 times the life of others, which can save a couple of change-outs - therefore adds substantially to overall benefit.

BP have more recently indicated to us a cost for downtime West of Shetland at £5/sec, so the above can be much too low; it should be up to £18,000 or \$30,000 per hour of downtime. As it takes about 2 hours on a changeout, this is a significant cost.

1.0.8. Design Notes

1. Sealing Face

We have considered the alternatives to flat sealing faces, which have been promoted (by other suppliers) as giving a more positive seal, evaluating various wavy and toothed interlocks. Although there is an apparent case for supposing that interlock produces a more ready seal, there appear in tests to be no actual sealing benefits over an equivalent size of flat face seal. Also, although the interlock may reduce the chance of ejection of one half when bad wear occurs, we find that a good material will not wear to give this problem anyway. It also appears that once wear starts in an interlock system, it can be actually worse on the area near the join. We therefore do not at present list or intend to list such varieties.

2. End Face

A further modification has been incorporated into some stripper rubbers; this consists of reinforcing the end faces in order to try to reduce the tendency to wear excessively, which sometimes takes place at the ends causing a funnel shape. We find that a marginal life improvement may indeed be obtained with the standard materials where these are incorrectly used, but that correctly selected and used materials perform well without need of any reinforcement.

As has been said above, it has even been known for an operator to question whether oversize rubbers had been fitted, because our 1.75" had worn in such a parallel fashion that they seemed like 2" versions.

Also, at elevated temperatures, combination materials have been known to spall apart; the bonding between different materials introduces a complication to the product. As with sealing faces, we do not at present list a range.

Feedback on use of rubbers in stuffing boxes is always welcome and any suggestions for improvement will be carefully considered.

1.0.9. Identification / Labelling / Packaging

Stock is individually labelled and marked with Benoil, a part number and a batch date.

We originally bagged products individually in black plastic as a protection against degradation by air,

moisture, heat and light. However, we have also been studying the behaviour of our polyurethane products not so protected and have shown that there is no noticeable change of condition over ten years even in greenhouse hot and moist conditions. We therefore discontinued the bagging of packer inserts, with the benefit that products are identifiable at sight.

We have sometimes been asked for a comparison of part numbers with competitor products. This is not directly possible, since to state for example that our P/N 1234 was the equivalent of Bowen's 98765 or TOT's 43210 would be inexact. Materials and construction differ, so that exact parallels are unlikely to exist. What matters is the fit in the stuffing box and the functionality of the materials.

The differing Benoil material performances as tested have been indicated above, which is why we offer choices. Colour coding completes the identification, at least within the PU ranges.

In the following lists, all packers are described with ID / OD / Length on OD. The ID corresponds to the CT diameter, and the choice of OD & L depends on the stuffing box to be used.

The common part numbers are listed for the 3600, 3700, and 3800 series. Other sizes are available on request, but they are not listed if they have never been called for or if seldom used. In each series, the part number is the same in the last two digits for the same dimensions. Earlier series did not have the same correspondence of numbers.

1.0.10. Benoil Range of Solutions

As described above, there is a range of solutions in newer materials. These are summarised by the attached following notes. We remain open to learning of any problems experienced with stuffing boxes, or of any change in materials or practice which might warrant new products from us.

In summary, the 3700 series has been created for HTHP applications; the improvement was carried forward into the softer 3800 series for LTMP applications, and an intermediate 3600 series for MTMP completes the present, active range. The 4200 series for temperatures up to 185C has now been added.

These have much better tolerance at both low (-50C/-60F) and high (160C/320F) temperatures. They do not embrittle at the upper limit so that even at excessive temperatures they do not precipitate a catastrophic breakdown. They do not show explosive decompression damage at high pressures. They are also resistant to sour gas, carbon dioxide, cement, and acids used in oilwells and methanol used in gas hydrate wells. These properties have proved so advantageous that the products have gained wide acceptance. They do not resist diesel, however.

Not all options are equally recommendable. Thus, a Bowen 4.625" box can be fitted with a 4.625" OD x 3.00" ID energiser and replaceable 3.00" OD rubbers, but it is as well fitted by our 4.625" OD series all-in-one rubbers, which offer the safety benefit of reduced leak paths; Bowen opted for the same design in their following series - our 3679 and following. The same is true of a Hydrarig 5.50" ID box, where we offer not only the energiser plus 4" OD inserts, but, particularly for the larger CT sizes, all-in-one sets of 5.50" OD rubbers. Benoil strongly recommends the use of the all-in-one types, because customer experience has proved their worth.

1.0.10.1. Present Systems

1. 3600 Series : 90A rubber with cross-linking and self-lubrication. Maximum temperature 160C.

Suitable for 20C/38F < T < 155C/310F and 1000psi < P < 5000psi
Recommended for 40C/100F < T < 150C/300F and 2000psi < P < 5000psi.
Colour code **ORANGE**

This is a wider temperature and pressure range than before.
For lower temperatures and pressures, use the 3800 series.
Generally, for extreme pressures and temperatures, use the 3700 series.
However, it remains probable that the 3600 series can be extended to higher pressures than 5000psi; they simply have not been so tested.

2. 3700 Series : 95A rubber with cross-linking and self-lubrication. Maximum temperature 165C.

These have extra wear and temperature resistance due to the harder form of the polymer. They are for applications at more extreme pressures and/or temperatures (>4500psi, >150C/F) instead of the 3600 series. They are not to be expected to be without wear if pushed to say 10,000psi or 160C/320F, but they will wear uniformly, ie safely, if evenly loaded. Because they show no tendency to brittle fracture or explosive decompression, this enables them to be run with confidence. They are, however, designed to be the wearing part of the system and should be checked often when used at extremes. They should **always** be changed between runs; anything less is a false economy in a high pressure environment.

Suitable for any T > 100C/212F and P > 3500psi,
Recommended for 150C/300F < T < 160C/ 320F
Recommended for 4500psi < P < 13,000psi
Essential for T > 150C/300F and P > 8000psi (but see also New Developments 5.)
Colour code **RED**

The upper pressure limit of 13,000psi is shown because it is known that these have been pushed to 12,600psi with remarkably little wear, and on a hot well, but it is not known how much further they might be pushed. Nor is it known by testing what the effect of simultaneous greater extremes of temperature and pressure might be. We are indebted to Baker for having taken them to 11,500psi and to Schlumberger for taking them further recently.

However, experience of use has been had in the more severe wells of both UK and Norwegian North Sea, Canada (Alberta), Venezuela, Germany, Italy, Algeria, Saudi Arabia, Kazakhstan, Indonesia and Australia, among others, and no adverse reports at all have been received.

The only drawback is that they are harder to energise. It is for this reason that some prefer to push the 3600 series a bit harder rather than switch to the 3700 series. It becomes a trade-off between slightly faster wear and ease of energising.

3. 3800 Series : 80A rubber with cross-linking and self-lubrication. Maximum temperature 150C

It is expected to serve those applications of low pressure and low temperature where it is desirable that the rubbers be relatively easy to energise. This means that it is believed suitable in VLT use (-50C/-60F) and at the same time serves a higher temperature (+150C/300F) than equivalents of the previous 3500 series; comment on low temperature experience is particularly welcome.

Suitable for any -50C/-60F < T <150C/300F and 1000psi <P < 4500psi,
Recommended for -10C/14F < T < 140C/ 285F and 1000psi < P < 4500psi
Colour code **YELLOW**

This is a relatively dramatic change on the previously recommended upper pressure limit, which was originally suggested at only 2500psi, but is based on consistent customer experience. It quite strongly supports the suggestion that the 3600 series may be similarly pushed beyond the present recommendation.

1.0.10.2. Newer Developments and Other Rubbers

1. A new series of much softer polyurethane 60A, this is designed to be more flexible to cope with rough tubing and irregular tubing, including pultrusion tubing. At present, it is tested only at low pressures, but should remain flexible and easy to energise at very low temperatures. The product includes the self-lubrication package. It should take over for the coldest conditions. It is available as the **4100 series**. Colour code **GREEN**.
2. A further series for VHT use is offered, based on a quite different material. Aflas (TM Asahi) is capable of withstanding in excess of 200C/400F, indeed up to 260C. It is not possible to incorporate the self-lubrication package in these products. Please enquire for the **3900 series**.
3. An alternative series for VHT use is also offered, based on fluorocarbon rubber. Fluorocarbon FPM (Viton TM Dupont, Fluorel TM 3M, Technoflon TM Montedison) is also capable of

withstanding 200C/400F. Please enquire for the **4300 series**.

Nitriles NBR, Hydrogenated Nitriles HNBR, and Fluorocarbons FPM are of interest as they are widely used in oilfield seals. However, when NBR and FPM were tested at high pressure, they were inclined to absorb gases and then suffer blistering and breakdown on decompression. This was a major reason for staying with polyurethanes which do not show any such effect.

4. A further alternative based on an improved silicone is also available for even higher temperatures (300C/570F). They have only been used in geothermal wells, and one has to be prepared to change the rubbers much more frequently. Though we include some self lubricating agent, wear is still much higher than for PU. These are available as the **4000 series** where no other option will suffice. There have been recent advances in silicone chemistry, which might make this area worth revisiting.
5. Recently we have found and tested a new polyurethane which will withstand (at least) 180C. This offers scope for improvement because it is only 85A-90A hard, which makes it easier to energise, and yet the higher temperature rating should enable improved temperature and pressure performance. It also accepts the lubrication agent. Samples have been satisfactorily run by Halliburton.

The basic materials may still be adjusted slightly by the manufacturer as they are novel, but we are making this available as a **4200 series**.

There are possible further developments in progress which may eventually enable us to offer even higher temperature PU products.

6. There have often been queries over **solvent resistance** of rubbers, especially where solvents are used in a down-hole process. We can now offer rubbers resistant to xylene swell for instance. Please ask. These are designated **4400 series**.

1.0.10.3. Original Systems

1. 3100 Series: De-listed. Polyurethane 90A rated to 100C/212F; shown by testing to withstand 120C/250F for a few hours. De-listed in view of the improved 3600 products; it is false economy to use old versions and rediscover old problems. This range was technically equivalent to standard products from Bowen, Chimo, or TOT.
2. 3200 Series: De-listed. Polyurethane 75A rated to 100C/212F; energises easily, but softens at higher temperature more readily than 90A. The 3800's are to be preferred.
3. 3160 Series: De-listed. Silicone 60A rated to 300C/575F, but very much lower wear resistance; these have been used successfully on a few high temperature geothermal wells. They may occasionally still be called for in exceptional circumstances, but in most cases the HT/HP forms are preferred. See 4000 series.
4. 3400 Series: De-listed. The first new upgraded standard insert. Based on 95A hard material, in red, it was recommended for T > 100C/212F and P > 3500psi, but in this it is overlapped by the 3700 series, which is now supplied, having been tested subsequently to greater extremes.
5. 3500 Series: De-listed. Based on a 75A hard, but otherwise identical, form of the same material used in the 3400 series above and easier to energise at LT/LP. The general guideline was that these were to be used usually when T < 80C/175F and P < 2500psi. This is now supplanted by the 3800 series.

<u>Benoil P/N</u>	<u>Description</u>	<u>Size of Packer (ID/OD/ L on OD)</u>
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1.1. Packers for MT/MP in Orange 90A Selflube Polymer

003613	Packer Sidedoor MTMP SL	1.00 /3.50/4.00
003614	Packer Sidedoor MTMP SL	1.25 /3.50/4.00
003615	Packer Sidedoor MTMP SL	1.50 /3.50/4.00
003616	Packer Sidedoor MTMP SL	1.75 /3.50/4.00
003617	Packer Sidedoor MTMP SL	2.00 /3.50/4.00
003618	Packer Sidedoor MTMP SL	2.375/4.00/4.00
003619	Packer MTMP SL	1.00 /4.00/4.00
003620	Packer MTMP SL	1.25 /4.00/4.00
003621	Packer MTMP SL	1.50 /4.00/4.00
003622	Packer MTMP SL	1.75 /4.00/4.00
003623	Packer MTMP SL	2.00 /4.00/4.00
003624	Packer MTMP SL	2.375/4.00/4.00
003625	Packer MTMP SL	2.875/4.00/4.00
003652	Packer MTMP SL	1.25 /5.50/4.00
003653	Packer MTMP SL	1.50 /5.50/4.00
003654	Packer MTMP SL	1.75 /5.50/4.00
003655	Packer MTMP SL	2.00 /5.50/4.00
003656	Packer MTMP SL	2.375/5.50/4.00
003657	Packer MTMP SL	2.875/5.50/4.00
003658	Packer MTMP SL & Energiser	3.50 /5.50/4.00
003659	Packer MTMP SL & Energiser	4.00 /5.50/4.00
003660	Packer MTMP SL	4.50 /5.50/4.00
003661	Packer MTMP SL	2.625 /5.50/4.00

1.2. Packers for HT/HP in Red 95A Selflube Cross-Linked Polymer

003713	Packer Sidedoor HTHP SL	1.00 /3.50/4.00
003714	Packer Sidedoor HTHP SL	1.25 /3.50/4.00
003715	Packer Sidedoor HTHP SL	1.50 /3.50/4.00
003716	Packer Sidedoor HTHP SL	1.75 /3.50/4.00
003717	Packer Sidedoor HTHP SL	2.00 /3.50/4.00
003718	Packer Sidedoor HTHP SL	2.375/4.00/4.00
003719	Packer HTHP SL	1.00 /4.00/4.00
003720	Packer HTHP SL	1.25 /4.00/4.00
003721	Packer HTHP SL	1.50 /4.00/4.00
003722	Packer HTHP SL	1.75 /4.00/4.00
003723	Packer HTHP SL	2.00 /4.00/4.00
003724	Packer HTHP SL	2.375/4.00/4.00
003725	Packer HTHP SL	2.875/4.00/4.00
003752	Packer HTHP SL	1.25 /5.50/4.00
003753	Packer HTHP SL	1.50 /5.50/4.00
003754	Packer HTHP SL	1.75 /5.50/4.00
003755	Packer HTHP SL	2.00 /5.50/4.00
003756	Packer HTHP SL	2.375/5.50/4.00
003757	Packer HTHP SL	2.875/5.50/4.00
003758	Packer HTHP SL & Energiser	3.50 /5.50/4.00
003759	Packer HTHP SL & Energiser	4.00 /5.50/4.00
003760	Packer HTHP SL	4.50 /5.50/4.00
003761	Packer HTHP SL	2.625 /5.50/4.00

<u>Benoil P/N</u>	<u>Description</u>	<u>Size of Packer (ID/OD/ L on OD)</u>
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1.3. Packers for LT/MP & VLT/MP in Yellow 80A Selflube Crosslinked Polymer

003813	Packer Sidedoor LTMP SL	1.00 /3.50/4.00
003814	Packer Sidedoor LTMP SL	1.25 /3.50/4.00
003815	Packer Sidedoor LTMP SL	1.50 /3.50/4.00
003816	Packer Sidedoor LTMP SL	1.75 /3.50/4.00
003817	Packer Sidedoor LTMP SL	2.00 /3.50/4.00
003818	Packer Sidedoor LTMP SL	2.375/4.00/4.00
003819	Packer LTMP SL	1.00 /4.00/4.00
003820	Packer LTMP SL	1.25 /4.00/4.00
003821	Packer LTMP SL	1.50 /4.00/4.00
003822	Packer LTMP SL	1.75 /4.00/4.00
003823	Packer LTMP SL	2.00 /4.00/4.00
003824	Packer LTMP SL	2.375/4.00/4.00
003825	Packer LTMP SL	2.875/4.00/4.00
003852	Packer LTMP SL	1.25 /5.50/4.00
003853	Packer LTMP SL	1.50 /5.50/4.00
003854	Packer LTMP SL	1.75 /5.50/4.00
003855	Packer LTMP SL	2.00 /5.50/4.00
003856	Packer LTMP SL	2.375/5.50/4.00
003857	Packer LTMP SL	2.875/5.50/4.00
003858	Packer LTMP SL & Energiser	3.50 /5.50/4.00
003859	Packer LTMP SL & Energiser	4.00 /5.50/4.00
003860	Packer LTMP SL	4.50 /5.50/4.00
003861	Packer LTMP SL	2.625 /5.50/4.00