Inflatable Packers for Grouting

11/10/00

Introduction

Inflatable packers are frequently used for grout injection in geotechnical applications for structural reinforcement and/or water-proofing of foundations, tunnels and mines. The two main methods are single packer grouting, where grout is injected into the ground below a single inflated packer and double packer grouting, usually in combination with a Tube à Manchette or grouting sleeve. Each of these is reviewed here.

Whether using single or double packers, both grouting methods rely on the use of inflatable packers for efficient and reliable sealing of the borehole. We will consider the general criteria of importance in selecting and using inflatable packers before moving on to the specifics of each method.

The basic types

Cross-sections through two typical inflatable packers are shown in Figures 1 and 2. Figure 1 shows a fixed end packer and Figure 2 shows a moving end style packer. As can be seen from the drawings, a fixed end packer remains the same length as it is inflated whereas the moving end style shortens on inflation by an amount depending on the amount of inflation.

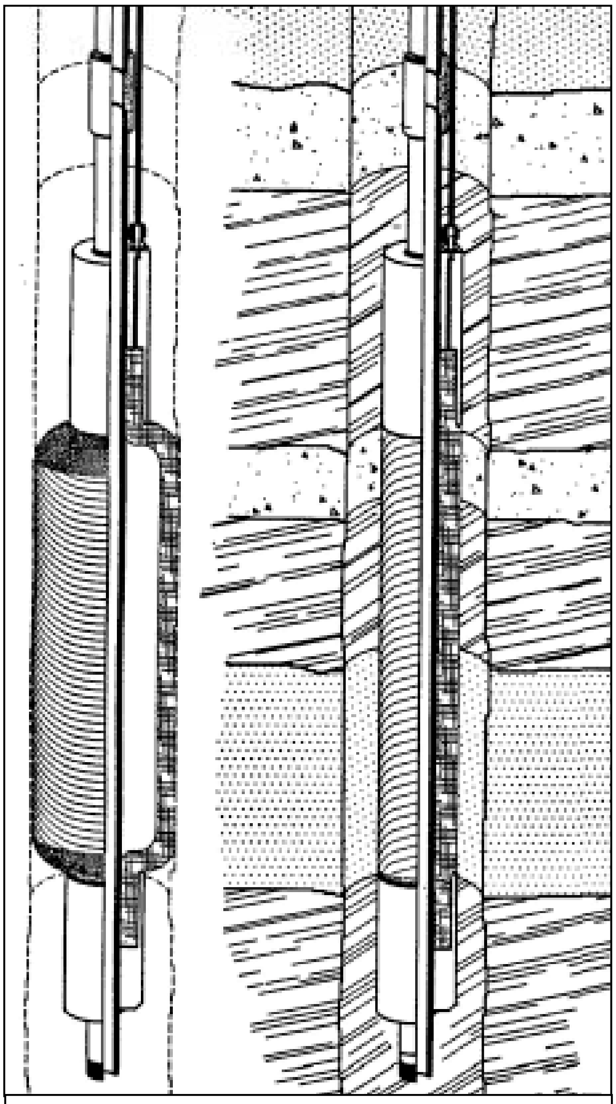

Figure 1 - Fixed end inflatable packer

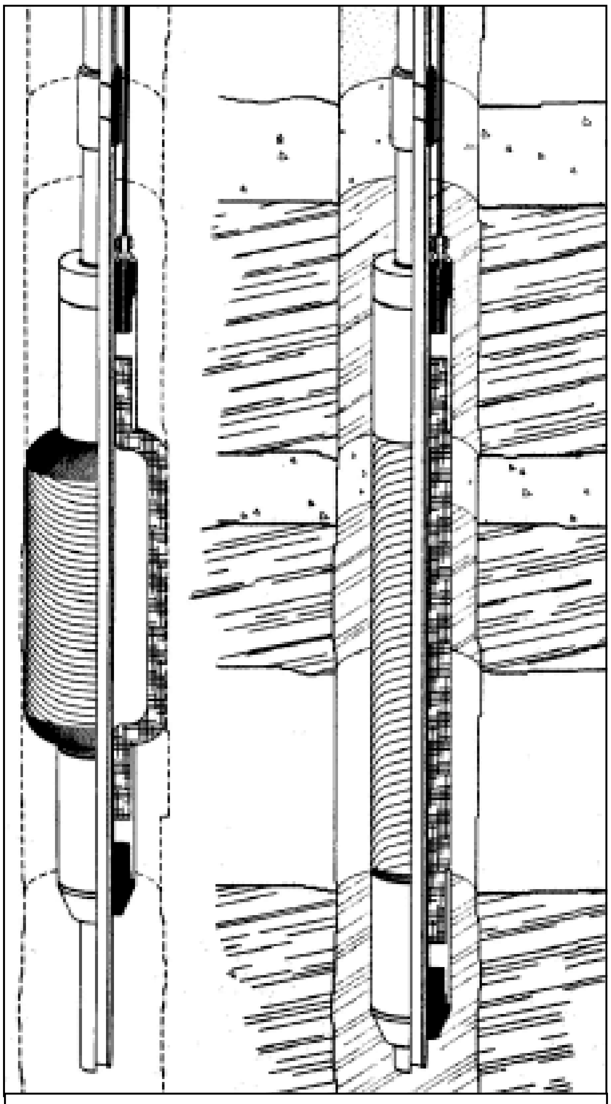

Figure 2 - Moving end inflatable packer

Generally, in competent formations at grouting pressures below 500 psi (35 bar), the fixed end design is preferred. The main reason for this is that when the moving end packer inflates the central mandrel is progressively exposed as the end slides upwards. This exposed portion is potentially subject to damage by the grout being pumped into the borehole.

In the double packer configuration this is even more important since the two packers are linked, usually, by a small bore tube which has to be spiraled around the center pipe to allow the lower end of the top packer to move relative to the top end of the bottom packer. In this case, both the exposed portion of pipe for the top packer and the spiraled tube are potentially open to damage. Conversely, in a fixed end design double packer, there's no relative movement of the packer ends in the straddle zone. This facilitates the use of flush OD pipe that incorporates an integral inflation line (for the lower packer) in the straddle zone (see Figure 5) thus eliminating both potential damage points. It also minimizes the grout contained between the packers thus minimizing the likelihood of being stuck after packer deflation.

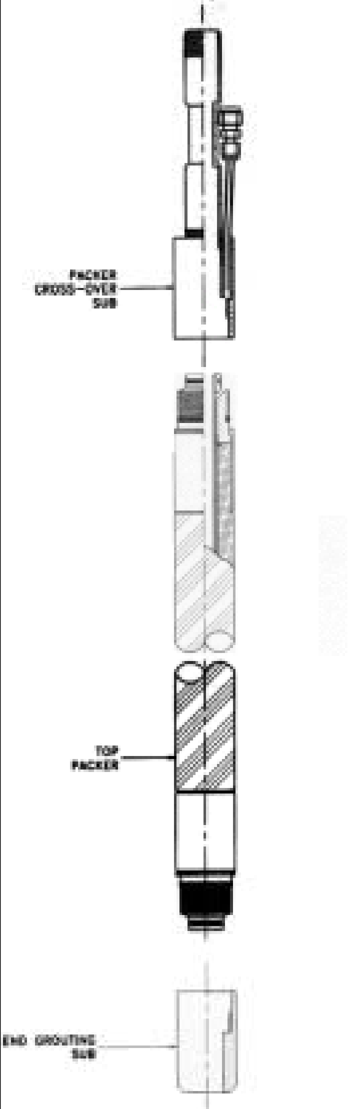

Figure 3 - Single, fixed end grouting packer

Inflation fluid

Another major consideration is the choice of inflation fluid. Most inflatable packer manufacturers recommend inflation with water for grouting applications whenever possible. Generally the only time it's not possible is in a dry hole or where the water table is too low. In these circumstances the column of water in the inflation tube is too great to allow complete deflation of the packer. Even then, use of special deflation valves (usually requiring running two inflation tubes) makes use of water inflation possible.

The reason water inflation is preferred is that a water inflated packer after establishing an initial seal will remain inflated up to the burst pressure of the packer owing to the incompressibility of the water. In contrast a gas inflated packer can only provide a seal if the gas pressure is maintained at a level above the sum of the sealing and grouting pressures. Leaks, relaxation, soil movement, excess grouting pressure, etc can all lead to bypass of a gas inflated packer without the operator's knowledge. If grout pumps around and sits above the packer for any length of time, the packer will become difficult or impossible to retrieve.

In fact, any liquid will provide the same inflation benefits as water and in sub-zero temperatures other liquids or water/anti-freeze solutions must be used. Where possible however, water is the preferred liquid since it's non-polluting, readily available and will not damage the rubber. (Note that most grouting packers are made of natural or SBR rubber and thus are not suitable for oil inflation.)

The major drawback with using water for inflation is that deflation is slower than when using gas and it may be more inconvenient to operate a manual inflation pump in some circumstances.

Where gas inflation is used, the gases preferred are compressed air or nitrogen. Under no circumstances should oxygen be used as it may cause explosive failure of the packer. Other gases should be checked with the packer manufacturer for compatibility with their elastomers.

Gas inflation pressures, as already mentioned, are of critical importance and must be carefully calculated and monitored during grouting operations. For any particular application, the minimum inflation pressure required (in units of kPa), as read on a surface pressure gauge, can be calculated as follows:

Minimum gas inflate pressure = (Pressure to inflate to hole diameter) + (sealing pressure advised by manufacturer) + (maximum grouting pressure)

Note that the “maximum grouting pressure” is the pressure at the packer, not the surface pressure. This is determined as follows:

Maximum grout Pressure = (depth to packer (m) x 10 x S.G. of grout) + (surface grouting pressure) - (Packer depth below water (m) x 10)

The above calculations assume all units to be in kPa. If using psi, multiply the depth in feet by 0.43 to get the head pressure in psi. If using bar, multiply the depth in metres by 0.1 to get the head pressure in bar. The pressure to inflate the packer to the hole diameter is normally given by the manufacturer but should be checked on site before starting grouting operations. If the sealing pressure (really a safety factor to assure adequate sealing) is not provided by the manufacturer a figure of around 10-20% of the maximum grouting pressure should be used.

Another prime consideration with gas inflation is the safety aspect of dealing with high pressure gas. A gas inflated packer is basically a bomb and should be treated as such. If ruptured it has the potential to do lethal damage – we have seen the center pipe from such a packer driven through the engine block of a truck! Under no circumstances should gas be used to test inflate packers free-in-air. Test inflations should always be conducted in a pipe with adequate protection to personnel against potential injury by projectiles ejected from the pipe should the packer fail.

Inflation Controls

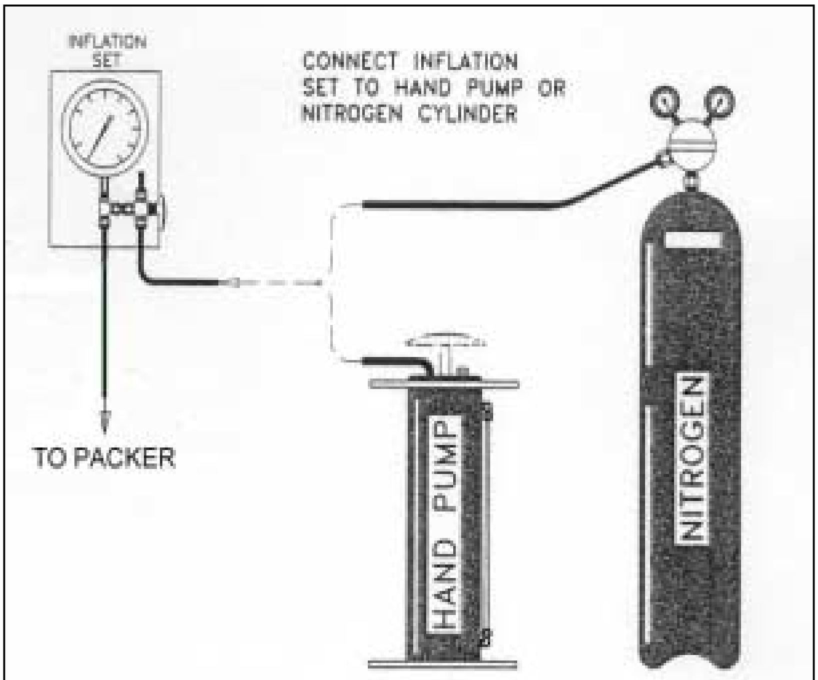

Figure 4 - Inflation control & monitoring system

Regardless of the type of packer or the inflation method it is critically important to have an inflation system that provides sufficient control and monitoring functions. The assembly shown in Figure 4 (or an equivalent set-up) is considered to be the minimum for safe, efficient operation. The system basically requires: a pressure source; an isolation valve; a vent valve; a pressure gauge; suitable hose/tube to connect to the packer and the between the other items. (Figure 4’s assembly combines the isolation and vent valves into one 3-way ball valve for more compact packaging.)

Using this type of inflation control and monitoring assembly ensures that, for example:

- the pressure gauge cannot be accidentally isolated from the packers and so always indicates packer pressure.
- The pressure source is independently isolated from the packer. This is of great importance with gas regulators since they can easily be set at very high pressures or not be properly shut down. (In fact, the temptation is to leave the regulated gas sully connected to the packer at pressure which may lead to packer over-expansion and sub-sequent failure.)
- The separate vent valve (or vent function) ensures the packer can be safely vented for deflation.
- Being small, self contained and portable (if provided with suitable hose lengths), the gauge set can be moved to the most convenient location to control and monitor the packer during inflation & grouting operations.

Clearly, all components used in the inflation control system must be of adequate pressure rating. In the case of gas inflation, if operating deep in a water filled hole the surface gas pressure may easily be over 1000 psi (70 bar) and adequate precautions are required. The pressure gauge should be chosen such that the maximum inflation pressure lies in the middle third of the gauge's scale. Pressure gauges are delicate instruments that require careful treatment and regular calibration to ensure their reliable operation.

Inflating the packers

Once the packers have been chosen along with a suitable inflation fluid and an inflation control and monitoring system it's time to connect it all up and trial inflate the packer/s. If gas inflating, trial inflations should only be performed in a pipe of adequate strength and with appropriate safety precautions. If inflating with a fluid, trial inflations may be performed free-in-air but are probably more usefully done in a pipe as per the gas inflated packers.

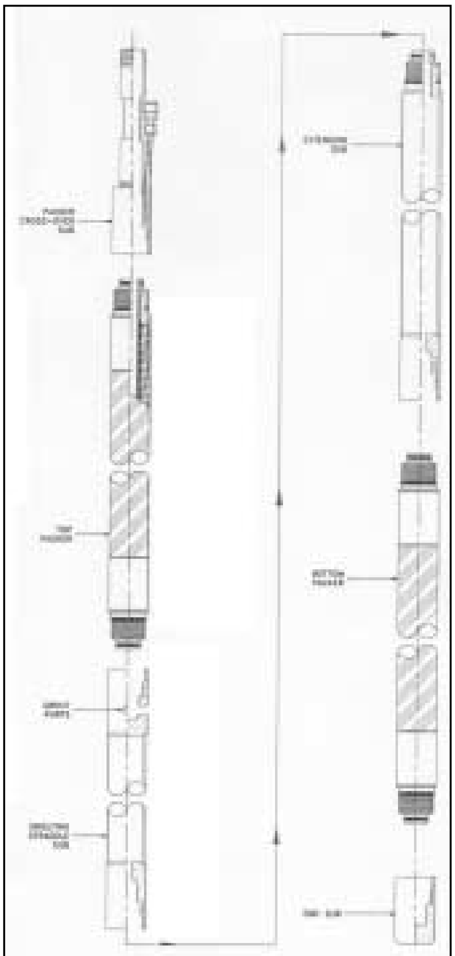

Figure 5 - Double, fixed end packer components

Trial inflation allows the operator to check for system performance and leaks. Specifically, the operator should be checking inflation pressure to firm contact with the test pipe wall and packer integrity at the maximum in-hole pressure. Note that the latter may be considerably less than the surface inflation pressure for a gas inflated packer owing to the fact for a surface inflation there's no "depth below water" term in the inflation pressure calculation. This may mean that a separate pressure test with the packer disconnected is warranted to assure the inflation system.

It is best to perform trial inflations with the full length of inflation tube that will be run in the hole with the packer. This allows the operator to time inflation and deflation, get an indication of pumping pressures during different stages of inflation and, for a liquid inflated packer, primes both the packer and the inflation tube.

The general characteristic of packers whether inflated with liquid or gas is that the bulk of the inflation volume is placed into the packer at relatively low pressure and it is only the last little bit of volume that is placed at increasingly higher pressures. Charting inflation pressure against time leads to a curve showing low, steady pressure increase over an extended period followed by a rapid pressure increase (after wall contact is achieved) in a relatively very short time. This characteristic takes some getting used to and operators should be encouraged to use the trial inflations to accustom themselves to the pressures, volumes and times involved.

Deploying the packer

The usual deployment methods are via rigid pipe or via hose. The later is quicker but provides limited depth control, no packer hold-down capacity and limited support for inflation tubes. It is also depth limited by the self-supporting capacity of the hose and it's connection to the packer for which reason a safety wire is sometimes used along with the hose. Depth limitations may also be due to the handling capacity of the hose raising and lowering system which is frequently manual.

Using a rigid pipe for running the packers offers good depth control, good support for inflation tubes and some hold-down capacity. However it generally requires a mechanized system (drill rig or crane) to handle the rods due to their length and weight and thus is much slower and more cumbersome.

Concerning hold-down capacity, this is related to the inflatable packer's ability to anchor itself in the borehole against the up-lift force generated by the differential grouting pressure. It has been calculated that for normal grouting situations, where the L/D ratio (packer contact length to hole diameter ratio) is 10 or more the packer should be self-anchoring against all differential pressures up to burst. If the L/D ratio is less than 10, whether or not the packer is self-anchoring would depend on the specifics of the application. Advice should be sought from the packer supplier in these circumstances.

Single packer grouting

This is the method most often used and the downhole equipment required is as illustrated in Figures 1, 2 & 3. The technique is extremely simple in that the packer is lowered into the borehole, inflated to the required pressure and grout is pumped in under pressure below the packer. If multiple levels are to be grouted, then the lower level is treated first, the packer is deflated, moved up-hole to the next level, re-inflated and grout is pumped with this process being repeated as required.

Throughout the grouting process, the packer inflation pressure should be monitored to ensure that it is adequate to seal against the grout injection pressure. If inflating with water, the packer inflation pressure should automatically respond to the grout injection pressure and may, in fact, be used to monitor injection in some circumstances.

Double packer grouting

As mentioned previously double packer grouting is normally limited to the so-called TAM pressure grouting technique. Using a Tube à Manchette (TAM) system offers an efficient, cost effective means of grouting for foundations, tunnels and mines. This system is based around the TAM which basically consists of a length of pipe with small holes drilled around the circumference and at equal intervals along the length of the pipe. Each set of holes is covered by a rubber sleeve (or manchette), which allows the whole arrangement to act as a series of one-way valves. That is, flow out through the holes is permitted by expansion of the rubber sleeve but flow in the opposite direction is prevented by the sleeve collapsing onto the pipe.

During grouting operations, each of the TAM valves is accessed individually by a set of inflatable packers which are run inside the TAM pipe and inflated so that they straddle the valve.

The actual sequence of operations normally consists of two or more separate stages of grouting as illustrated in Figure 6. In the first stage (A) the TAM is installed in a predrilled hole and in (B) is grouted in place using a light "sleeve" grout or a gravel packing for low pressure applications. This operation being required to seal the Tam into the borehole and to prevent flow of grout, under pressure, up the borehole/TAM interface.

In the actual pressure grouting phase, the level to be grouted is isolated with the straddle packers which are run on a separate string inside the TAM (C). The sleeve grout around the valve is fractured by pumping water under high pressure down the packer string and out through the isolated valve. Grout is then pumped in through this valve up to the permissible maximum injection pressure or volume (D). This process is repeated at subsequent valve levels normally proceeding from the bottom up.

Optimum treatment may require more stages of grouting in which further fracture and grouting processes are performed at some or all of the valves. The process may in fact be repeated for as long as the TAM remains accessible and sufficient pressure may be applied to fracture the previously placed grout.

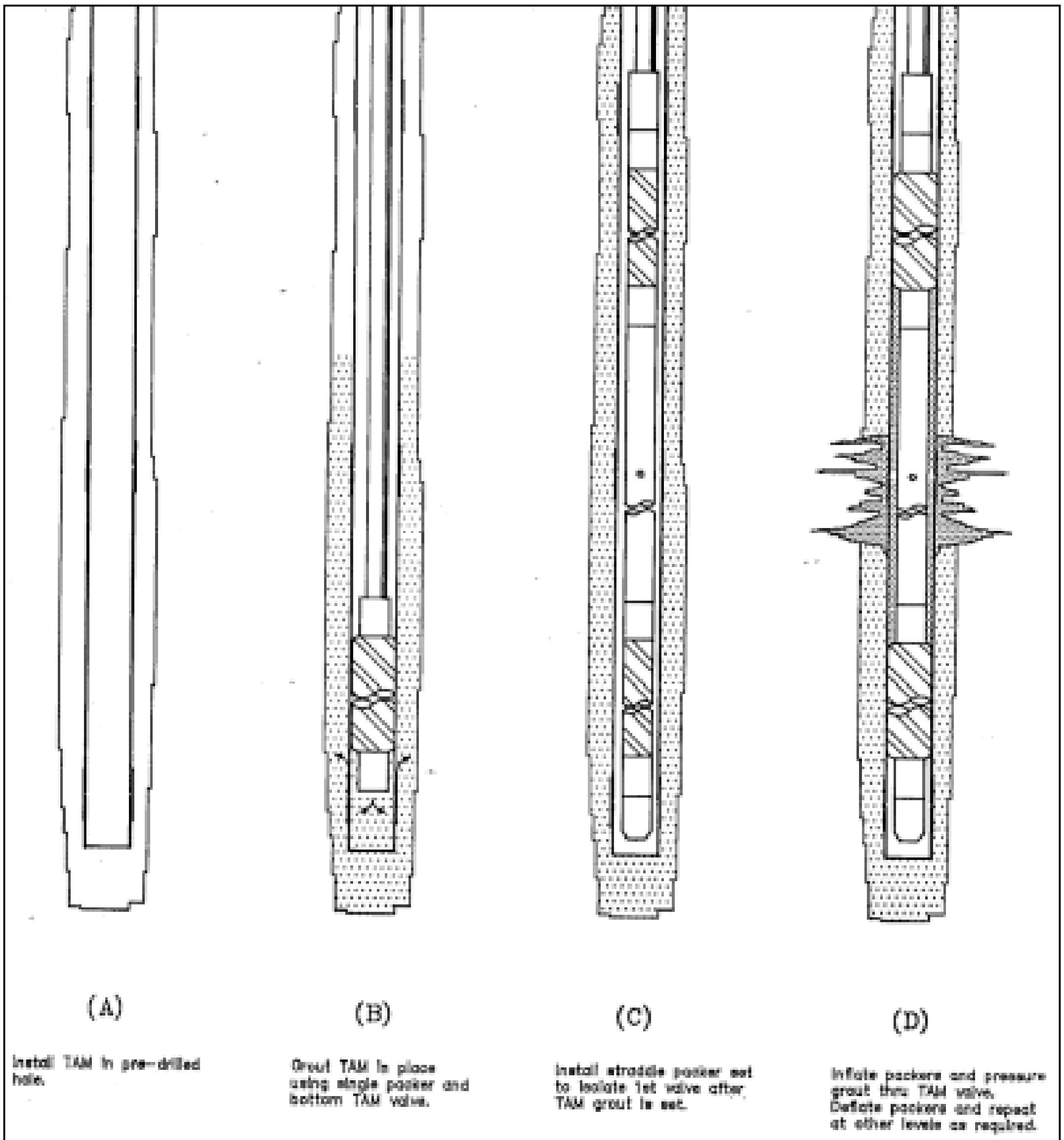

Figure 6 - TAM pressure grouting stages

Packer damage and service life

Packer damage during grouting operations is generally due to one of the following factors:

- Over-expansion – caused by inflating in too large a borehole or a washed out section of the hole or, occasionally, in a yielding soil such as weak clay.
- Rubber cutting – caused by any sharp object in the borehole, eg end of casing or a casing joint or sharply fractured rock.
- Over-pressurisation – packers are rated for specific pressures in specific diameter holes and over-pressurisation normally is caused by using the packer's pressure rating in one hole as the rating in a much larger hole. Always refer to manufacturer's diameter vs pressure rating charts before deciding on an inflation pressure.
- Moving a packer when it's still partially inflated can damage it either by excessive wear against the hole wall or by pulling the steel ends off the rubber, either partially or completely.
- Grout contamination of a sliding end packer mandrel can prevent the packer end from sliding and/or damage the sliding end seals.
- Deterioration of the rubber in packers due to direct sunlight or high temperature conditions or solvents exposure.
- Inflating natural (or SBR) rubber packers with oil will cause excessive swelling and associated softening of the rubber.
- Long term inflation with gas (though rarely a criteria in grouting operations) often causes rubber blistering and delamination after the packer is removed from the borehole as gas which has been absorbed into the rubber under pressure is desorbed and collects in pockets formed within the packer reinforcement carcass.

Barring failure due to one or more of the causes outlined above and assuming that the packers are well maintained and adequately stored between uses, and when used are used in accordance with the guidelines given in this article, then inflatable packers should provide long term reliable service for grouting operations. There is no intrinsic reason why many hundreds of grouting operations may not be performed with a single packer. When such service life is not realized it is frequently due to one or more of the factors highlighted above which stem from inadequate operator knowledge and training. It is hoped that articles of this nature will serve to remedy the first of these detriments and that, with such knowledge available, contractors will ensure that their operators are appropriately trained.

By C.J. Rowe – Managing Director, Inflatable Packers International