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PIPE LINE GROUTING - WHAT ENGINEERS AND CONTRACTORS NEED TO KNOW TO MAKE IT WORK

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ABSTRACT: Pipe line grouting has often been the victim of a poor reputation. A number of utility owners have had bad experiences in attempting to stop or impede the infiltration of clean water into their sewer lines by grouting the pipe joints and laterals. The goal of any sewer rehabilitation is to ensure the proper longevity of the work. Failures that occur within months or even a couple of years after completion of the rehabilitation work are not an acceptable option.

Grouting, in theory, has been a cost-effective method of sealing pipe joints and can be a very viable technology for structurally-sound pipes. However, many municipalities have attempted grouting in the past and been underwhelmed by its performance, especially as a longer term solution to infiltration and to pipe stabiliztion. These past failures of grouting are primarily attributable to technical issues, some of which are largely unknown to engineers specifying the work or by the contractors who perform the grouting work.

Grouting failure is caused by a number of issues, and this paper focuses on how to avoid them by designing grouting projects with longevity in mind. Topics include:

- Additives and their affect on grout performance.
- Design life of grout.
- Additional considerations to the ASTM model specifications.
- Pipe appropriateness.
- Impact of roots.
- Grout base material ratio and groundwater dilution.
- Setting gel time based on pipe size, pumping rates, packer void space, and project goals.
- Recommended application rates.
- Temperature affects on grout gel time.
- How to bid the work to ensure successful results.
- Field test procedures.
- Contractor qualifications.
- What an inspector needs to look for when overseeing the work.

1. INTRODUCTION

Chemical grouts have been in use for over 50 years. The intent of chemical grouting in sewer systems is primarily two fold. First, to to stop infiltration (and often more importantly, rainfall derived infiltration) and, occationally,exfiltration; and second, to stabilize the pipe bedding so that structural failures, resulting from the loss of fines into the pipe through leaking joints, do not occur or become exacerbated.

Grouting is simple, quick and relatively inexpensive compared to other rehabilitation technologies. Its main limitation is that it cannot repair broken pipes, as other rehabiliation methods such as pipe lining can. It is highly effective, however, on structurally sound pipes that are admitting groundwater through the joints. Targeted pipes are most often clay pipes, which, properly installed, seem to last forever, but, unfortunately, whose jointing materials in the past were not so long lasting. When a utility has identified leaking but otherwise generally structurally sound sewer pipes and manholes, grouting is a feasible option, both as a moderately long term rehabiliation solution and as part of the arsenal in enhance operation and maintenance procedures for preventing pipe failure and extending pipe life.

Most leaks in sewer systems are through pipe joints, manholes, service connections, and service laterals. This is true of structurally sound as well as structurally flawed /failed pipe. To work properly and for the long haul, grout should not simply fill existing defects and open pipe joints; it needs to be pumped under pressure through the defects and joints and into the surround soil/pipe bedding where they gel with the pie bedding to form a gel-soil matrix that both stabilizes the pipe bedding and provides a waterstop around the pipe defect or joint. This flexible but cohesive gel-soil matrix blocks groundwater (or more proberly, trenchwater, prevents further loss of pipe bedding or surround soil into the pipe, and providing longer-lasting pipe support.

2. GROUT TYPES AND ADMIXTURES

There are three commercially available types of grout for sealing sewer infrastructure with particular emphasis on pipe joints. Acrylamide, acrylate, and urethane gels used in sewer rehabilitation all have the ability to interact with water, are non-soluble, are resistant to normal sewage flows, are generally heavier than water, are non-biodegradable after “gelation”, and are flexible (not brittle) after curing.

A number of additives are available to enhance or modify the properties of the grout mix. Additives can increase mix viscosity, density, strength, and appearance. The purpose of these additives is shown in Table 1. The use of these additives needs to be considered during the design phase to account for both the intent of the grouting and the conditions under which the grout work is conducted.

Table 1 – Additives to Grout Mixtures

Additive	Purpose
Latex Additive (or equal)	Increase physical properties of grout and reduces potential shrinkage, adds white coloration to cured grout
2, 6, Dichlorobenxonitrile (Dichlobenil)	Root growth inhibitor (does not kill roots)
Ethylene Glycol	Reduce freezing temperature of grout and reduces potential dehydration of cured grout
Dye (Green for clay, red for PVC)	Colors normally clear acrylamide/acrylate gel
Potassium Ferricyanide (KFe)	Extends gel time for acrylamide/acrylate gel

3. DESIGN LIFE OF GROUT

One of the key questions in grouting revolves around the effective life of grout. Grout manufacturers refer to stories of grouted pipe that were excavated 25 years later to reveal sound, watertight soil-gel matrix rings around the pipe joints, and laboratory data reported indicate the acrylimide and acrylate type gels, under the right conditions, can last much longer. However, chemical grouts are subject to drying and cracking so it is important that grout constantly stays wet or humid. This means soils that desicate are not usually good places to use chemical grouts. However, it is not necessary to submerge the soil-gel matrix to keep it resilient. One rule of thumb is that so long as the grass lives, the grout lives.

How long the grout performs is another matter. While it may continue to perform its pipe bedding stabilization responsibilities for decades, most utilities want to rely on grout for its water stoppage abilities, and to do that, the soil-gel matrix must be thick enough, resilient enough, and 'sticky' enough to cling to the pipe joint as the surround soil column settles and moves (both naturally and from adjacent other utility movement/constrution) and as the pipe itself flexes (both from temperature flucations and from bedding settlement). It is this combination of grout installation effectiveness and pipe-soil fluctuations over time that determine the longevity of pipe line grouting as an infiltration stopper. While we can't much control the pipe-soil fluctuations, we can affect the longevity of the grouting by influencing its effectiveness during design and construction.

Most agree that grouting won't last as long as a newly installed pipe. In order to perform equal life-cycle costs, many engineers and utilities have generally settled on a 10- to 15-year life cycle for grouting. There basis for this is simplistic and not very scientific, but neverless logical : If lining lasts 50 years, then grouting must be less long lived.

However, at less than a one-sixth of the cost of replacement and one-fourth of the cost of cured-in-place pipe lining, this pipe line grouting is easy, more cost-effective, quickly reduces I&I flows, and stabilizes the structural condition of the pipeline. If a line has structural damage, grouting alone is not enough. If there is only one defect in a pipe segment, it is often cost-effective to install a cured-in-place point repair (CIPPR) to address the structural defect and then follow that up with a grouting approach.

On the other hand, if a line segment requires more than one CIPPR or if it has a high criticality rating (i.e., in front of a hospital, behind City Hall, etc.), cured-in-place pipe (CIPP) lining or other longer-term rehabilitation methodologies may be preferable.

From a management perspective, it is critical that the level of service be selected to properly determine if grouting is an appropriate rehabilitation technology. For instance, if a utility selects a life cycle of 50 years, a properly designed and installed CIPP may last 50 years with a one-time capital investment. However, grouting may be more attractive if the pipe structurally sound and **if** the utility is willing to come back every 10-15 years and regrout joints. This is a critical and often overlooked aspect of the decision making process during the evaluation of grouting as a rehabilitation technology.

4. DESIGNING FOR LONGEVITY

Specifications

ASTM Standards have been released on packer injection grouting in the last decade. These standards help to establish sound practices and consistency for grouting. Currently there are ASTM Standard Practices for chemical grouting to seal sewer mains (ASTM F2304-03), manholes (ASTM F2414-04) and lateral connections and lines (ASTM 2454-05), covering the three main applications of chemical grouting.

However, there are a number of things that an Engineer should specify that are not clearly addressed by the ASTM standards and that affect the longevity and effectiveness of chemical grouting. These include:

- Specific percentage of base material (e.g., acrylamide or acrylate) in grout mixture
- Verification that the 2 psi drop allowed by ASTM F2454 for lateral testing is acceptable
- Calculation of the volume of annular space between the packer and host pipe
- Requirements regarding strict control of gel time due to the many influences
- Pre-construction submittal requirements

- Contractual payment mechanisms to “incentivize” grouting
- Prequalification of potential contractors

Pipe Appropriateness

Structural soundness of the pipe is not the only criteria. Grouting can not be accomplished if the packer cannot be seated. It takes a sound pipe wall on both sides of the joint or lateral connection to properly seat the packer. The pipe surface must be relatively smooth and should be cleaned. Some pipe materials, such as iron or concrete, are subject to tuberculation and pitting that make obtaining proper seating of packer extremely difficult.

The bulk of time needed to perform grouting is tied up in the setup of the equipment. Once the equipment is properly set up, the grouting process is fairly quick. Therefore, large offset joints and transitions in pipe size (an important consideration in laterals) must also be examined carefully and disclosed (when possible) to the Contractor prior to grouting. Side by side laterals cannot be sealed if the length of sound pipe between the laterals is less than 6 inches. Protruding laterals should be cut back within 5/8” prior to sealing. Any impediments that can be highlighted to the Contractor prior to setup will ensure a smoother project for all parties.

Laterals themselves pose problems. Cleaning of the laterals and removal of roots in the absence of cleanouts can be problematic. The use of a lateral launching cleaning device is recommended.

(Logiball, Inc., Used by Permission)
Figure 6 – Lateral Launching Cleaning Device

Roots

Many studies of damaged sewer lines reveal that root intrusion is a common operation and maintenance problem. Vapor leaks at the top of an otherwise water-tight joint will encourage microscopic growth. As cells multiply, roots grow rapidly. Nourished by the sewage flowing within the line, roots will quickly grow into the sewer. Cutting out the roots alone does not solve the problem because they generally grow back thicker and stronger than before. If root growth is heavy, the joint space may be filled with root material, preventing grout from penetrating the joint. Cutting the roots may result in much of the root material being pulled out of the joint, in which case using grout with a root growth inhibitor additive can be effective. However, in order to maximize the effectiveness of grouting, chemical root treatment should be applied approximately six months prior to grouting to cause the root masses in the joints to die and slough off.

Percentage of Base Material

The ASTM standards set 10% as the minimum amount of acrylamide or acrylate in the final mix. The percentage can be increased to increase strength or reduce the effects of dilution from water. The minimum percentage of base material used to be 12% (55 pound bags of acrylamide used to be common, but newer shipping rules have reduced the bag size to 50 pounds). A higher percentage (i.e., 12%) of base material is recommended in all situations, and is demanded in situations where groundwater surrounds the pipe and when longer gel times are used.

Determination of Gel Times

Gel time is the most critical component of a successful grouting project. Gel time is the time it takes for the grout to catalyze from liquid form to gelatinous form. Gel times should be set to ensure that the grout moves through the open pipe joint and into the surrounding soil before hardening, thus forming a soil-grout matrix around the pipe joint and sealing it from future groundwater infiltration. Even if the correct grout mixture is selected, if the grout gels too quickly, it cannot be forced through the pipe joint and into the surrounding soil. This can result in a layer of grout just on the surface of the joint which results in a positive air test but lacks the intended soil-gel ring surrounding the pipe. This is what engineers often refer to as "veneering" the joint.

Conversely, if the grout does not gel quickly enough, it may not form into a strong, watertight collar around the outside of the pipe joint without pumping excessive amounts of grout or before being diluted by groundwater. From an engineering perspective, pumping too much grout is preferred over veneering the joint.

Gel time of acrylamide or acrylate gels can be controlled by changing the ratios of the catalyst to the grout mixture. If long gel times are needed (especially when working with high temperatures), additives such as Potassium Ferricyanide (KFe) can be used to extend gel time. For urethane gels, the proportion of water to urethane will modify the gel time.

For mainline sewer pipe joint sealing and sealing laterals connected to manholes by traditional low void packers, gel times should normally be set between 30 and 40 seconds. This gel time should be modified based on the volume of the void in the packer.

Calculation of Annular Space Between Packer and Host Pipe

In order to calculate gel times, it is important to understand the correlation between gel time, pumping rate, and amount of grout needed to seal the joints or lateral connections. Most contractors when working in smaller diameter pipes (e.g., 24" or less) use low void mainline packers with void spaces as small as ¼ gallon. With typical pumping rates of 3 to 4 gallons per minute (gpm), the ¼ gallon void space will not make much of a difference. However, if the void is large, if the pumping rate is impeded, or if the gel time is relatively fast, this may impact getting adequate amounts of grout through the joints into the surrounding soil and resulting in a veneered joint.

Packer equipment manufacturers will know the approximate void space in the main line packer. For lateral packers, either from the sewer main or push packers from manholes, the void will vary based on the length of the lateral being grouted. The effective volume of grout used for rehabilitation is the total volume pumped less the void volume of the packer chamber.

Prior to grouting, the Contractor should submit calculations of the expected annular space between the packer and the lateral pipe for approval. This will aid the Engineer in setting the appropriate gel time. For example, for lateral tap connection sealing for laterals directly connected to the mainline sewer and for lateral pipe joints sealing for laterals directly connected to manholes, one way to calculate gel times is the following:

$$Gel\ Time = \left(\frac{\{Volume\ of\ Annular\ Space\ (gal)\} + \{PipeDiameter(inch)/4\}}{Pumping\ Rate\,(gpm)} \right) \left(\frac{60\,\text{sec}}{1\,\text{min}} \right) \ (\pm 5\ \text{seconds})$$

Another way to determine the volume of annular space is by using an above-ground setup. The volume of the packer chamber is measured in the above ground lateral and pipe connection set up by simulating the actual sealing, using water only, and measuring the quantity of water necessary to fill up the void area.

Influences on Gel Time

The gel time of grouts can also be significantly influenced by the grout temperature, the pH of the grout solution, the amount of oxygen dissolved in the grout solution. In addition, gel time can be influenced by contact with certain metals, by exposure to ultraviolet rays from sunlight, or by the presence of certain mineral salts in the water used to make the grout solution.

The gel time obtained from a given mix should be verified and modified accordingly in the field. Tests of gel time under ambient conditions using the actual water which will be mixed with the grout are recommended.

One of the greatest and most difficult to manage influences on gel time is changes in temperature. For typical grout used in sewer joint sealing, manufacturers state that gel times can be doubled (or halved) for every 10°F change in temperature. The gel times decrease with an increase in temperature and vice versa.

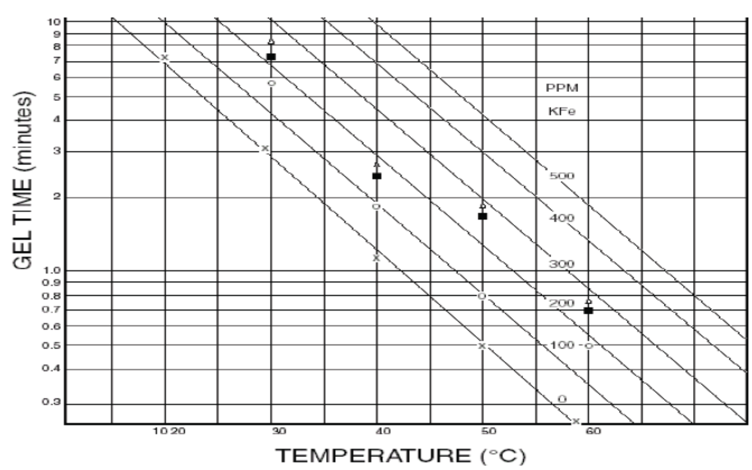

Figure 7 – Gel Time Changes With Temperature

This is especially problematic in summer months. For example, if the grout components are mixed at 7:00 a.m. when the ambient temperature is 60°F and the water pulled from a nearby hydrant is 50°F, the temperature of the grout components may be 55°F when the above ground gel test is performed. By the late afternoon when the ambient temperature is 95°F, if the grout tanks are not temperature controlled (most grout trucks do not have temperature-controlled tanks or even temperature monitors), the temperature of grout components may have increased by almost 40°F to 95°F. This can lead to dramatic gel time decreases.

Since the packer and some of the hoses are in a sewer environment that is often much cooler (normally 50-60°F) and not subject to dramatic temperature swings, one can argue that the temperature of the grout components at the packer may be cooled by down by the time it is injected. However, from Table 2, even if the grout components have cooled to only 75°F, the gel time still is not even close to the intended 40 seconds.

Table 2 – Gel Time Decreases with Increasing Temperature

Temperature	Gel Time
55°F	40 seconds
65°F	20 seconds
75°F	10 seconds
85°F	5 seconds

Many contractors are not aware of the sensitivity of gel time to temperature. In many instances, contractors will just dilute the mixture with water to extend gel time. However, this results in an even lower percentage of base material with weaker physical properties. Even using an additive such as KFe that lengthens gel time does not reduce the affects of temperature on gel time.
Strict monitoring of temperatures and, if possible, temperature control of the grout tanks should be specified and enforced on all grouting projects.

In addition, there are a number of other influences on gel time. These influences should be carefully considered for each specific project area when determining the gel time.

Table 3 – Other Influences on Gel Time

Influences	Affect	Control
pH	In general, as the pH of the grout solution drops, gel time will increase. The use of highly alkaline or acidic water will significantly influence the gel time.	Use water with known and controlled pH.
Presence of Entrained Oxygen in the Solution	Oxygen entrained and dissolved during vigorous mixing of the solutions will increase gel time	Allow mixture to settle before testing gel time
Contact with Certain Metals	Metals such as iron and copper have an unpredictable effect on the gel time	Utilize plastic or stainless steel tanks
Ultraviolet Rays	Ultraviolet rays also initiate gelation	Keep all components out of direct sunlight. Utilize equipment that protects against ultraviolet light
Presence of Groundwater in Grouting Zone	The set time will be 2 to 4 times longer if the grout is diluted in the grout zone with an equal volume (100% dilution) of water	Adjust specified gel times to account for expected amount of groundwater (e.g., seasonal influences, wet-weather events)

Specifying Price of Grout

One key component of a successful grouting program is to ensure that the joints that fail the testing or come close to failing the testing be grouted with as much grout as possible. The cost of the grout is not so important in the overall sealing cost and should not be a limiting factor as the cost of grout itself is a relatively small percentage of the total project cost. The only possible measurement of a satisfactory seal is the pumping to an agreed upon refusal pressure.

One way to ensure that the contractor pumps sufficient grout is to fix the price of grout in the bidding documents. The price should be set about 20% higher than the actual cost of the grout (be sure to include the cost of shipping and handling). By fixing the price of grout (rather than letting bidders low-ball the price of grout and high-price the cost of testing or injecting), this incentivizes the contractor to inject as much grout as possible. Payment by the gallon of effective grout shall be an incentive to pump enough grout.

Another additional conservative method of incentivizing grouting is to also fix the price of grouting a joint, if grouting is a separate pay item from testing. Again, this levels the playing field among the various bidders and, if the price is fixed such that the contractor makes a profit, eliminates the temptation for a contractor to not grout a joint in favor of productivity.

Pull Back Testing

A large percentage of the contractor's cost in grouting is in the time to setup up grouting operations at a particular sewer line segment. Therefore, additional testing after completion of grouting and before a breakdown of the equipment is a relatively inexpensive requirement. At the completion of the sewer line segment (i.e., manhole to manhole), the contractor should conduct joint grouting verification testing of grouted joints and laterals for quality control purposes on 5% of the grouted main line joints (minimum of two repaired joints) or 25% of the grouted lateral taps (minimum of one lateral tap). This can be referred to as pull-back testing, since the equipment has to be pulled back to the initial setup manhole anyway. Within a sewer line segment, if any joints, lateral taps fail the retest after sealing, all joints and laterals should be retested, as applicable, in the sewer line segment.

Warranty Testing

Conducting warranty testing prior to termination of the Contract can be a low-cost method to verify the grouting was performed correctly and to ensure peace of mind. If the contractual mechanisms and contracting community can manage longer-duration contracts and maintain performance bonds, warranty testing 1.5 to 2 years after completion of grouting is recommended, normally during seasonally high groundwater conditions. This provides verification that the grouted joints continue to be watertight, that root growth inhibitors continue to be effective, and that joints that previously passed testing did not falsely pass the tests during the initial work. Warranty testing can also reveal if joints that were not grouted may now be failing due to increased hydrostatic pressure.

Since reinspecting and retesting all the work is cost-prohibitive, warranty testing should be performed on all of the joints in 15% of the pipe segments and laterals rehabilitated. If more than 10% of the warranty tested joints fail, test an additional 15% of the pipe segments. If more than 10% of the second group of warranty tested joints fail, test 100% of the joints in the remaining untested pipe segments at no additional compensation

Pre-Construction Submittal Requirements

If a utility decides to give potential contractors a choice in type of grout (e.g., acrylamide versus acrylate), it is important that the type of grout be submitted along with the delivery equipment planned for injection of the grout. All parties will be properly informed of the proper grout mixture ratios, additives being used, MSDS sheets to ensure worker safety, and equipment operating procedures. Also, if the price of grout has been fixed to incentivize grouting, only low void packers with minimal annular space should be used. If lateral grouting is being specified, the Contractor should submit the volume annular space between the lateral tap connection packer and host pipe in order to properly set the gel time for lateral grouting, as described above.

Post-Construction Submittal Requirements

Upon completion of grouting each reach, the Contractor should submit to ENGINEER a report showing the following data for each joint tested and/or grouted or attempted to be grouted.

1. Location of the pipeline segment.
2. Time and date.
3. Ambient Outside Temperature.
4. Location of each joint tested (i.e., Stationing).
5. Location of any joints not tested and the reason for not testing.
6. Grout mixture formation, including additives and catalyst mixture formulation and proportion of each. Include procedure for adjusting grout mixture for variations in ambient temperatures and changes of temperature of grout through hoses exposed to the atmosphere.
7. Pumping pressure and duration of test.
8. Test pressure achieved and the duration of test maintained for each joint passing the air test.
9. Grout tank temperatures.
10. Gel time and time last verified.
11. Quantity of grout (if applicable) used to seal the joint.
12. Post-grout pressure test results.
13. Regrouting and retesting giving above data as required.
14. Recording cross-reference index.

5. FIELD CONTROLS AND INSPECTION

Beyond the specfications, a key component of a successful grouting project is having an inspector that is qualified to observe grouting activities and make judgement call regarding the efficacy of the work. The inspector must be aware of what is required to install grout properly, and how he or she might be misled during the installation process. For example, if a packer pressure gauge is not calibrated correctly, the inspector cannot know the true condition of a joint. Therefore, the Contract Documents should specify an above-ground pressure test of each packer at the beginning of each work shift and at other random times, in accordance with the ASTM Standards. The inspector should be familiar with these tests and should watch the test gauge each time the packer is deflated to make sure the gauge returns to zero. If it doesn't, the operation must be stopped until the gauge is properly calibrated.

Another example would be verifying the amount of grout pumped. Many contractors do not have a true flow meter on their equipment, so often times the number of pump displacement strokes can be counted to determine the amount of grout pumped. Traditional acrylamide and acrylate grout components are normally set at a 1:1 ratio, so the inspector should verify that the levels in the tanks match at all times. If unequal levels are noted in the tanks, the packer should be pulled from the sewer and a pump test should be performed.

Root Inhibitor Additive

Dichlobenil becomes a suspended solid when mixed in a grout solution. To avoid settlement, continuous mixing is recommended. However, excessive oxygen entrainment in the grout tanks will influence gel times. A trained inspector will be able to balance these requirements and be able to hold the contractor to the specifications accordingly.

Testing Gel Times

The inspector should also verify the gel time of the grout. After the temperature of the grout tanks are recorded, and the grout mixture is allowed to settle, grout should be injected into a small container directly from the packer above ground. The traditional cup test at the tanks is a good indicator of gel times, but measuring the gel time at the packer ensures that the grout has passed through the hundreds of feet of hoses as it would in the actual sewer itself.

At the beginning of each day, when new batches of grout are mixed, when grout additives are modified to change gel times, at the beginning of any new pipe segment or manhole, and whenever the temperature in the tanks and hoses have changed by more than 10°F from the previous gel test, the specifications and the inspector should require a grout gel test to determine the grout mixture gel time.

Defining "Refusal"

An inspector should be familiar with the term "refusal". As the mixed chemical grout has flowed throughout the void space in the packer and through any joint failure into the surrounding soil, the grout has gelled and formed a cohesive seal stopping further grout flow. Therefore, the rise in void pressure shows a "refusal" to pumping more grout into the void area. Under pumping conditions, the void pressure will slowly rise above groundwater pressure as grout is forced into the void and out into the surrounding soil. As pumping continues past the gel set time (the gel set time will usually be extended as a result of groundwater dilution), a point is reached at which the void pressure rapidly spikes an additional 8 to 12 psi above the prior void pressure in a short pumping period of 1 to 5 s. This is considered the "point of refusal," and grout pumps are stopped and the grout should be allowed gel the additional gel time before deflating the packer. Some blowby (grout squeezing past the packer ends, as most packers ends are generally rated at 10 psi) may occur and is allowable past the packer end seals at this "point of refusal."

After the packer ends are deflated, the inspector should verify that the void pressure meter should zero psi. If it does not read zero psi, grout may be on the pressure port and the equipment must be cleaned of residual grout or other equipment repairs/adjustments may be needed to produce accurate void pressure readings. A quick burst of air is often effective clean the pressure port on the packer.

The inspector should also verify that upon completion of the injection, the packer deflated and moved at least one packer length in either direction to break away the ring of gel formed by the packer void. If the ring of gel does not break away, this ring must be broken away by other means (e.g., by jetting the sewer) before the verification that the grouting was successful.

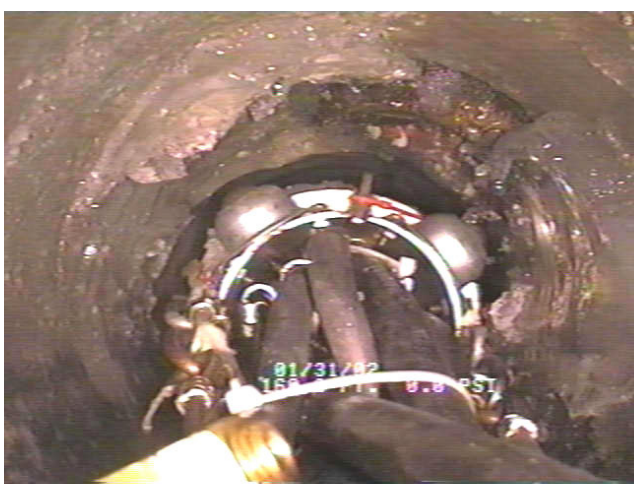

Figure 8 – Gel Ring After Packer Deflation

Once the gel ring is broken away, the packer should then be repositioned over the joint, the packer ends inflated, and the joint retested at a pressure equal to the initial test pressure. If the joint or lateral tap fails this air test, the grouting procedure must be repeated. The test after sealing will be fool-proof only if the inside grout plugging the crevice is removed. This is especially problematic with lateral grouting, as the inner surface of the lateral is often completely covered with grout.

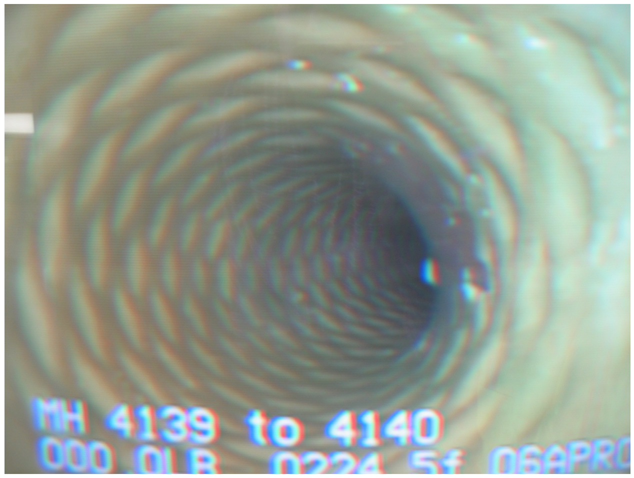

Figure 9 – Photo of Inside of Lateral Immediately After Grouting

Stage Grouting

If the grout is pumped into the void and surrounding soil and a void pressure point of refusal is not reached when pumping typical grout quantities (i.e., ¼ to ½ gallon per inch-diameter of pipe,) or when the grout flows outside the pipe from one crevice to another before gelling, then this condition usually indicates an excessively porous soil, washed out soil pockets or voids outside the pipe, extreme dilution and washing away of the grout in the soil as a result of extreme groundwater flow rates outside the pipe, or extremely influenced gel times. These conditions may be overcome by staging the grout and building a soil sealed grout wall outside the sewer line. Staging are repetitive cycles of pumping and curing carried out until refusal conditions can be reached. When using stage grouting, the applicator must avoid sealing the inner surface of the pipe from the inside (i.e., veneering) before building up a durable impermeable wall or ring outside the pipe. The intervals between the pump strokes must be shorter than the gel time. Before staging is attempted, the inspector should be notified and approval obtained due to the potentially large volumes of grout utilized in this technique. The inspector should be familiar with stage grouting in order to make the determination that the grout consumption is too high and stop subsequent attempts to seal the joint(s).

CONCLUSIONS

The nation's sewer pipelines have now become an urgent national concern. Restoring or replacing this aging buried infrastructure will represent by far the largest capital investment for most municipal utilities in the coming decades. Years of under funding have forced utility owners into a reactive management style, with most operational resources allocated to emergency response and repair. Meanwhile, sewers that have not exhibited problems continue to age and, if left unchanged, will become the operational and structural problems of the future.

Given this state, it is becoming increasingly critical that monies for rehabilitation efforts are used judiciously. Many utility owners have poor past experiences and justified reasons for discounting the effectiveness of grouting. But grouting of structurally sound pipes and manholes is one of the most cost effective means of reducing infiltration and inflow, *if it is done correctly*. Selection of the appropriate pipes and manholes, developing contract documents that add incentive for the contractor (e.g., fixing the price of grout) and provide the checks (e.g., warranty inspections) to make him grout conservatively, and having a resident project representative that understands the technology (e.g., gel times and their many influences) and what to watch for are all key components to a grouting project. Just as critical are the long-term life-cycle approach to rehabilitation and the understanding that grouting *programs* are needed prior to making decisions on grouting. From an engineering perspective, if specified conservatively, performed by an incentivized contractor, and observed by a qualified and trained inspector, there is no reason why grouting cannot be one of the most efficient and cost-effective methods in any I/I program.

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