PRACTICAL CONSIDERATIONS FOR PUMP BASEPLATES, GROUTING AND FOUNDATIONS

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ABSTRACT

For pumps, most attention is directed at their hydraulic, mechanical/rotating/sealing, and metallurgical aspects. Another area of concern is the structural integrity of the pump support. Key elements of this are the baseplate, grouting and foundation. Failure to attain good end results in these areas can cause vibration, distortion, misalignment, and sealing problems with a pump which is otherwise good.

API 610 now includes several worthwhile requirements and options, helpful to anyone concerned with achieving sound pump support. Some of the API 610 items will be repeated here, but further details will be presented of "What can go wrong, and how can this be avoided?" As in most work, knowing what to expect and being prepared for it, can offer control of the situation.

INTRODUCTION

For the past twenty to thirty years, most API 610 [1] pumps have used welded steel baseplates. These have high resistance to thermal and mechanical shock, as compared to the cast iron baseplates used previously, but are generally less rigid. For the most part, the pump manufacturers have concentrated their efforts on the pump itself, and have given less attention to the baseplate—often subcontracting its design and fabrication to outside shops. The result has been a great variety of designs and fabrications, many of them inadequate, and a few vastly overdone. Several years ago API 610 addressed this situation to a degree, but left some areas which could benefit from further elaboration.

The pump foundation is the responsibility of the pump vendor, engineering consultant or contractor, or pump purchaser. Without proper engineering standards or guidelines, inadequately designed foundations can result. Several suggestions for avoiding common foundation problems are included herein.

The grout occupies the space between the baseplate and foundation. Properly chosen and installed, it gives even support, with adequate resistance to mechanical, thermal and chemical influences. Several aspects of grouting which can affect the success or failure of the installation will be described. Non-grouted pumps and baseplates, designed to "float" with the piping, are sometimes used, but these will not be covered.

A pump having most of the undesirable baseplate, grout, and foundation features likely to result from the foregoing practices is shown in Figure 1.

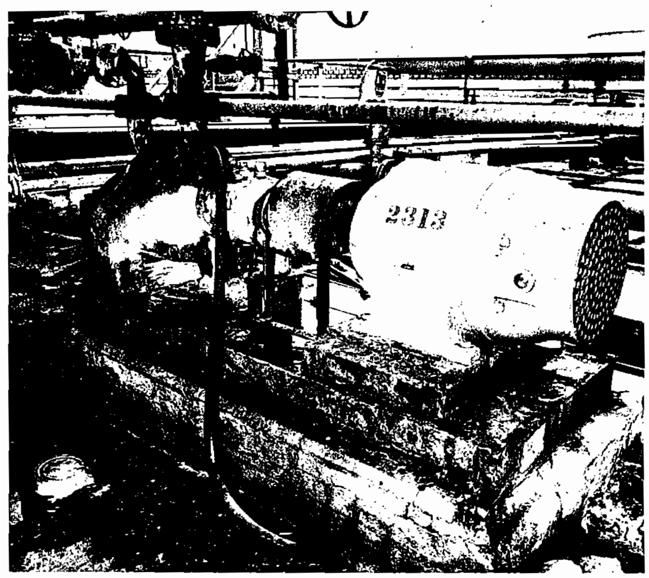

Figure 1. Pump with Severely Corroded Baseplate, and Cracked and Spalled Grout and Foundation.

COMMON DIFFICULTIES, AND SUGGESTIONS FOR THEIR AVOIDANCE

Foundation—Inadequate Size

Occasionally, the foundation mass will prove insufficient for stability, resulting in an insufficient damping ability. To be assured of having adequate foundation mass, a rule of thumb calls for three times the machine weight for rotating machines, and five times the machine weight for reciprocating machines assuming 150 lb/ft^3 for reinforced concrete. If soft soil conditions are present, spread footings should be considered. A flexible isolation joint between the foundation and the pavement slab can be helpful in avoiding undesired vibration transmission between adjacent foundations.

A common deficiency in pump foundation design is the insufficient extension of its perimeter beyond the outline of the pump baseplate. This can cause difficulties in leveling and grouting. Foundation extension three inches beyond the baseplate perimeter is recommended.

Foundation—Inadequate Strength

• Soupy concrete mix. This is easy to pour, so is often preferred by those doing the pouring. It can, however, be excessively weak and subject to shrinkage cracking. The mix should be workable, but not soupy, giving at least 2500 psi compressive strength when tested following a 28-day cure. It should not have shrinkage cracks.

• Absent, insufficient, or poorly placed reinforcing steel. With few or no rebars, concrete pouring is easier, particularly with a non-soupy mix. The end result can be poor, however, with insufficient strength and resistance to cracking. In addition to proper engineering design of the rebar size and layout, care should be taken to ensure at least two inches concrete cover, to resist spalling.

• Inadequate testing, inspection, and field follow-up. The best designs fail if the executions are faulty. Taking pour samples for later testing (and making all concerned aware of this) helps dull the temptation to add excessive water to the mix. The actual rebar layout should be inspected for design compliance *before* the pour is made, for obvious reasons. A minimum three day wet cure is desirable, although additives and/or plastic sheeting are sometimes used instead, for moisture retention. Regardless of method, responsible follow-up is essential, to be sure that what is called for really does get done.

Baseplate—Common Problems and Suggested Solutions

Mr. Murphy, the well known legislator, must have had some experience with pump baseplates which helped him to formulate his famous law. For something so uncomplicated at first glance, a surprising number of things can be done wrong, and often are.

Baseplate excessively flexible. This should be less of a problem now that API 610 includes some stiffness criteria. Section 3.3.1.8 makes provisions for an optional heavy-duty baseplate. Older baseplates being removed and reinstalled may benefit from additional bracing and remachining of mounting surfaces. Another point to watch is shipping and in-plant transportation of baseplates. Electric motors are usually much heavier than the pumps they drive. For this reason, it is good to have motors over 100 hp shipped unmounted, to avoid baseplate distortion caused by the motor weight acting on the ungrouted baseplate.

Welding stresses not relieved, leading to distortion in service. For welded steel baseplates, which most of them are nowadays, request oven stress relieving after welding and before final machining of the pad surfaces, and before any protective coating is applied. This will help avoid distortion due to gradual in-service stress relief.

High strength machine-to-pedestal hold-down bolts, such as SAE Grade 5 or 8. These are all right as replacements, but should not be used as original equipment in which their high strength is taken advantage of in determining bolt size and/or quantity. Sooner or later, somebody in the field will substitute one or more Grade 2 mild steel bolt(s), which will be vulnerable to overstressing.

Inadequate shim thickness beneath driver feet. API 610 calls for 1/16 or 1/8 in shim thickness beneath driver feet. It is better to specify 3/16 in. It is often necessary to remove more than 1/8 in of shims, but seldom necessary to remove 3/16 in. This is due to factors such as pump pedestals that get cocked down toward the driver, and "common" or "floating" spare pumps and drivers that have slightly different foot-to-shaft-centerline dimensions than the originals. use a 3/16 in shim space—you may not need it, but if you do, you will be glad it is there.

Inadequate bolt-to-hole clearance, impeding horizontal alignment movement. Specify a minimum of 1/8 in annular clearance between full-size (not undercut) SAE Grade 2 bolts and their boltholes, after the driver has been aligned to the pump at the factory. Once satisfactory running alignment has been achieved in the field, install two number eight taper dowel pins at the pump, for easy return of the pump to its pedestal, to a "nearly aligned" position. Use an anti-seize compound when installing these pins. An exception would apply for a row of numerous identical pumps with a "floating spare." Here, doweling is useless. The driver should not be doweled, since this will normally require some movement for aligning it to the pump each time the latter is reinstalled following shop repair. Three pairs of foot/pad punch marks can be used, instead.

Square corners on baseplate flanges. These can be safety hazards during handling prior to installation. Specify rounded flange corners with approximately two inch radius.

Sensitive to corrosion—poor or no surface preparation, followed by a coat of "standard" shop primer applied over rust and mill scale. Surface protection should be specified, for the dual purpose of corrosion protection and for a good grout bonding surface. One good system is an inorganic zinc silicate coating, applied immediately after sandblasting to white metal per SSPC SP-5. This leaves a rough, dull surface, with the coating having a molecular bond to the metal, and works well with both inorganic and epoxy grouts. By contrast, for use with epoxy grouts, API 610 calls for precoating grouting surfaces with "a catalyzed epoxy primer applied to degreased white metal." This seems rather dubious. Most epoxy coatings cure with a smooth, glazed, and sometimes waxy finish. This is *not* a good grout bonding surface unless it is first roughened our sandblasted. Also, the degreasing requirement implies that the white metal has sat around for a while, collecting grease, oil, and perhaps rust. It is better to do the coating immediately following the sandblasting, to minimize oxidation and other contamination. Degreasing would then not be required.

Difficult access for grouting—insufficient or poorly placed filling holes and vent holes (Figure 2). Preferably, one four inch grout filling hole should be provided at the center of each

Figure 2. Large Baseplate Underside, as Received. Grout filling and vent holes are lacking in some sections, and not ideally placed in others. Generally, it is best to have one 4 in filling hole at the center of each bulkhead section, with one 1/2 in vent hole near each corner of the section.

bulkhead section, with one 1/2 in vent hole near each corner of the section. This allows controlled grout placement, and verification that each section is filled with grout. API 610 now covers this requirement pretty well, and also specifies a raised lip and metallic covers for the grout filling holes, as protection against liquids. Nothing is said about similar protection for the smaller but more numerous vent holes. A more practical approach is to omit the lips and covers—doing nothing further if epoxy grout is used, and applying a protective coating to inorganic grout at exposed areas. More details on such coatings will be given later.

No provision for leveling. Vertical leveling screws should be specified. Shims and wedges should be avoided. If left in place after grouting, these may cause "hard spots" rather than the uniform support desired from the grout. Also, they may allow moisture penetration, followed by corrosion and grout spalling. If they are to be removed after grouting, this requires their isolation from the main grout pour with extra forming, followed by a secondary grout pour after the main pour has hardened. The extra labor and time for this are neither desirable nor necessary. API 610 now mentions optional leveling screws and their layout, but does not specify their size. For most baseplates, 3/4 in-10NC square head setscrews, six inches long, resting on 1 in × 1 in × 1/8 in stainless steel bearing plates will work well.

Machine mounting pads not flat, parallel, and coplanar. API 610 now covers this adequately, but it should still be carefully checked to avoid problems (Figure 3).

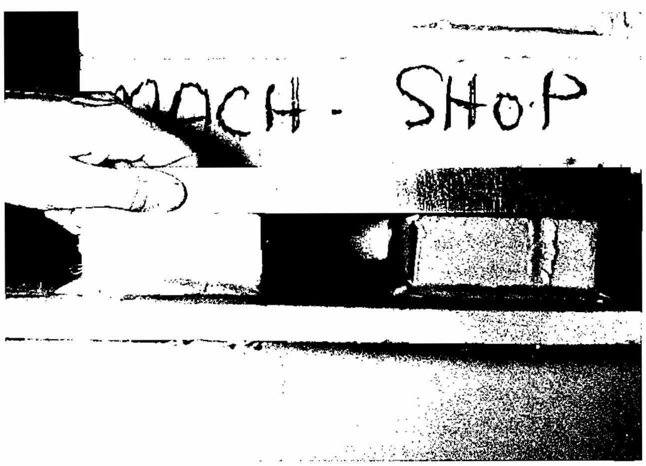

Figure 3. Pump Baseplate with Visible Tilt in Mounting Pad Surface.

Drain system not well designed. API 610 now calls for either a drain pan (center drain) or a perimeter drain rim. The drain pan is preferable to the drain rim, because the latter interferes with the leveling screws. A sloped center drain, either flat or dropped, will work, but the flat design is easier to grout. A poorly designed center drain baseplate having an open-top frame, which promotes trash accumulation is shown in Figure 4. A simpler design that avoids this problem is presented in Figure 5.

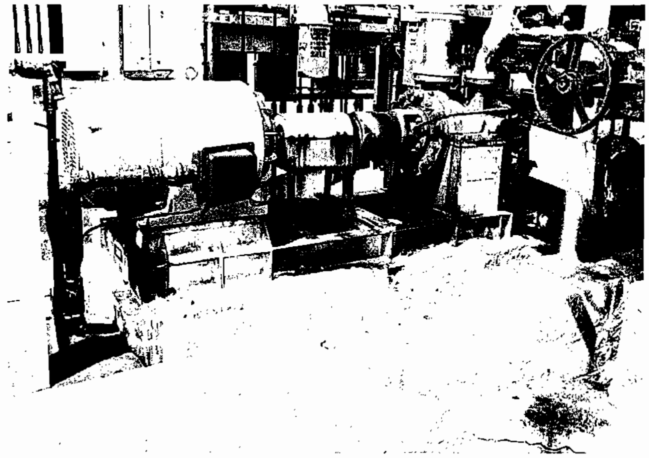

Figure 4. Open-Top Frame Design for Pump Baseplate. This design promotes trash accumulation, and should be avoided.

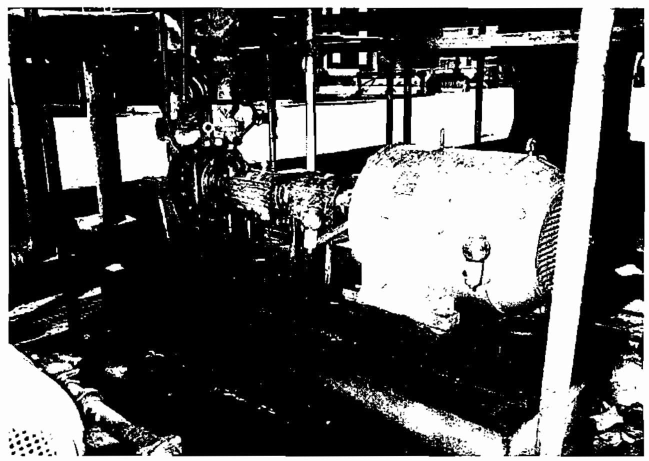

Figure 5. Simple Baseplate Design with Sloping Flat Center Drain. This design avoids the trash-collecting tendencies of that shown in Figure 4.

Alignment jackscrews and/or lugs of inadequate strength, corrodable, and placed so as to interfere with the installation or removal of the machine element and/or its shims. API 610 calls for alignment jackscrews for drive elements of 100 hp and higher. This is an area which can benefit from a close examination of individual installation requirements. At times, as with an axially long boiler feed pump, it may be worthwhile to have alignment jackscrews at the pump rather than or in addition to those at the driver. In the majority of cases, jackscrews can be omitted at electric motors, if adequate access is available to allow the use of a soft-face deadblow hammer. This is a surprisingly accurate method for making horizontal alignment moves, without damaging the motor. It will work even on large motors of several thousand horsepower and weighing several tons. For motors 500 hp and larger, it is worthwhile to ask for API 610's optional two inch minimum clearance beneath the motor center at each end of the motor. This will permit the use of hydraulic jacks for lifting, or a pair of alignment positioners for easy adjustment in any direction, vertical and horizontal [2]. For turbine drivers, alignment jackscrews are nearly always worth having. Jackscrews and their mounting lugs should be resistant to corrosion, and sized to avoid bending or breaking in use. Five-eights inch screws in 2 in × 3/4 in lugs are strong enough for most installations. Zinc plating protects against corrosion at low cost, but 316L stainless steel may do it longer. If the lugs are installed by welding, they should be placed to allow access for machine and shim installation and removal. If this is not feasible, they should be attached by drilling, tapping, and bolting.

Inadequate review drawings. Request detailed baseplate review drawings, not merely outline drawings, and examine them carefuly to ensure compliance with design specifications.

Inadequate inspectio)follow-up. Inspect the baseplates when they arrive. This includes tilting them and looking at their undersides. Despite best efforts at specifying what is wanted and reviewing the drawings, compliance may be incomplete. Most of the desired features such as grout filling and vent holes, leveling screws, corrosion protection, etc., can be retrofitted onsite or in a nearby shop. In some cases a cost adjustment can then be obtained from the pump vendor.

Baseplate Features—Costs

Many of the baseplate features cited are free for the asking. Other cost little, particularly if several pumps are being ordered at the same time from the same vendor. For a baseplate with all applicable features, figure that two percent to three percent will be added to the pump plus driver cost, versus getting a bare-bones baseplate. For pumps in the range of 100 hp to 800 hp, bought singly or in small lots, this would add an average of $450 to $600. This is small compared to the cost of possible installation and maintenance delays, and distortion-vibration-related premature pump failures, caused by less than optimum baseplates [3]. As to how common such problems are, statistics are not readily available. During 15 years of machinery work in three plants, however, such situations were encountered by the author about a dozen times, sometimes with multiple pump installations.

Grouting—Common Problems and Suggested Solutions

The responsibility for seeing that grouting is done properly has long been avoided by many engineers. The mechanical engineer thinks of grout as an extension of the foundation, which obviously means it should be handled by the civil engineer. The civil engineer considers it a stiffening medium for the pump baseplate, obviously a machine part and therefore in the province of the mechanical engineer. As a result, grouting is often left to chance, and ends up being done haphazardly, by poorly qualified people. Several consultants have built profitable businesses based on correcting the grouting mistakes of others. It is better to do the grouting right the first time, and not really all that difficult.

In a broad sense, the way to be assured of a good grout job, as with most tasks, is to determine the job requirements, plan ahead using some intelligent forethought, and provide competent supervision to assure that the job is done properly. By contrast, grout jobs that just "happen" seldom turn out well.

Proceeding from the general to the specific, grouting phases and potential problems fall into several categories, as follows:

Pre-grouting

Material choice
Procurement and storage
Site preparation
Basic planning and logistics
Contingency planning and logistics

Grouting

Proportioning and mixing
Placement
Sampling

Post-grouting

Withdrawing leveling screws and sealing the holes
Testing samples
Curing
Protective coating

The foregoing subjects will now be elaborated on in more detail.

Material choice. Consideration should be given to physical properties, ease of use, and cost. In a broad sense, the choice is between organics (usually epoxies) and inorganics (portland cement/sand/water plus anti-shrink and cure-acceleration additives). Some people use epoxy for everything, because epoxy is "good." While having good strength and chemical resistance, epoxy can creep undesirably at elevated temperatures (above 150°F for some common epoxies, although special grades are available that withstand higher temperatures). It also gets rather expensive if large volumes are needed. In most cases, it pays to use a pre-mixed commercial nonmetallic inorganic grout instead, if grout volume will exceed six cubic feet, and if epoxy is not needed for impact or chemical resistance. At this break point, the ease of epoxy use is overcome by the money to be saved with a good inorganic grout, which justifies using the more complicated inorganic grout procedure to achieve this saving. More specifically, a typical epoxy grout costs $90/ft^3$, versus a typical good nonmetallic inorganic grout at $36/ft^3$, or a 2-1/2 times multiplier for epoxy versus inorganic cost. On the small to medium sized pump baseplate requiring six cubic feet of grout, the saving with inorganic grout comes to $324. On a pump of 500 hp, 1750 cpm, which would typically require 32 ft^3 of grout, the saving would be $1728. On a plant construction or modification project with numerous pumps, savings of $50,000 to $1000000 would not be unusual. Chosen and used properly, a good inorganic grout can, for most applications, be as satisfactory as epoxy, with the twin advantages of lower cost and higher temperature capability (500°F to 1000°F upper limit). A word of caution—avoid inorganics that are gypsum based. These are subject to degradation from water exposure. Also, avoid grouts with metallic additives; these can expand uncontrollably over long periods, breaking anchor bolts and causing repeated misalignment. Do not plan on saving money by mixing a "homemade" grout from cement, sand, and water. This will invariably be inferior to a good commercial pre-mixed grout. If flowable enough for easy placement, it will be weak and subject to shrinkage cracking. If stiff enough for adequate strength and shrinkage resistance, it will be difficult to place without leaving voids.

Finally, choose a grout whose cure time is neither too fast to allow its proper placement, nor so slow that it delays the job excessively.

Procurement and storage. Buy the grout material from a reliable supplier, who uses good indoor warehousing facilities. Inspect it upon arrival for signs of deterioration. Store it indoors, away from roof leaks. Provide for onsite short term storage under shelter or a tarp.

Site preparation. Chip laitance (weak top layer) of the foundation to remove one-half inch to one inch and reach sound

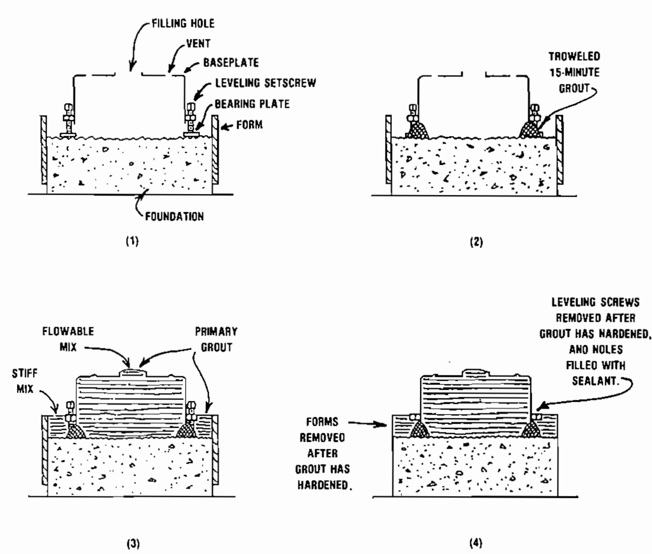

Figure 6. Sequence Illustrations Showing a Pump Baseplate Grouting Procedure Which Has Proven Successfuly on Many Jobs. More details can be found 4. A simple hand-operated topping pump (Figure 7) is used to force-fill the last inch or so at the top, until grout comes through all vent holes.

concrete. Obtain a source of oil-free air, and blow off dust. Cover chipped foundation with a tarp to prevent oil spills from reaching the concrete. Locate a nearby source of uncontaminated fresh water, if inorganic grout will be used. If the area is congested, decide where the mixing will be done, and decide the path and transport method for moving the mixture to the placement site.

Basic and contingency planning and logistics. Obtain, adapt, or compose a complete procedure. This should include a list of required materials, equipment, and personnel, and a sequential stepwise procedure for forming, waving forms and leveling screws, grout material proportioning, mixing, placement, sampling, testing, curing, leveling screw removal and hole sealing, and protective coating. Industrial hygience precautions should be included, especially if epoxy grout will be used. Such procedures and supporting information are found in the literature [4, 5, 6]. A procedure that has worked successfully on many pump baseplate grout jobs is shown in Figure 6. A simple grout topping pump, which can be made from about $5 worth of 4 in plastic pipe, wood, and polyethylene foam, in about an hour is depicted in Figure 7. This pump can be washed and re-used after an inorganic grout job, but should be discarded after an epoxy job. It is used initially as a standpipe, to aid gravity flow of the grout. When this flow becomes slow, as the cavity nears the filled conditions, the piston is used to force the grout into the remaining space until it comes out through the vent holes.

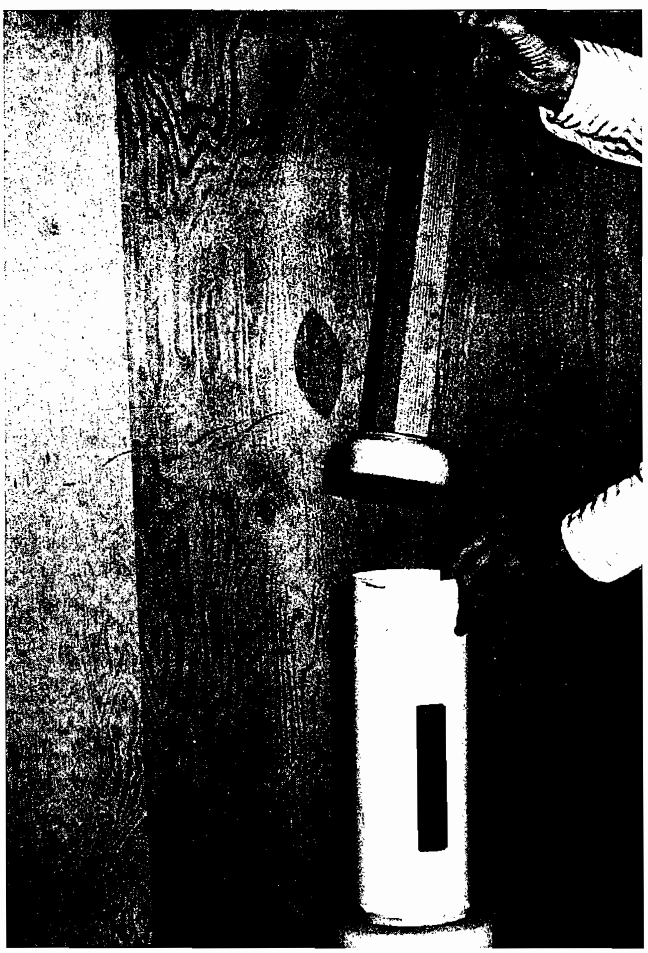

Figure 7. Simple Topping Pump. In the early part of the job, the pump barrel is useful as a standpipe to promote gravity flow of the grout. When this flow becomes slow, the piston is used to force grout into the upper portion of the baseplate cavity, and out to the corners where it comes through the vent holes.

Other useful items include the following:

- 1 ½ gallon cylindrical tins with wire bail handles, squashed to form a pouring spout, for transferring grout from mixing wheelbarrow to baseplate cavity.
- Rubber laboratory stoppers, for plugging vent holes selectively.
- Wood covers with lead weights to do the same with the filling holes.
- Small pointed mason's trowels.
- Mason's hoes for mixing.
- Chewing gum, to plug wheelbarrow leaks prior to mixing the first batch of grout.
- Two inch triple test cube mold.
- Measuring containers with marked levels. Small (six to ten gallon) steel garbage pails work well for this purpose.
- Quantity of cube or tube ice, if using inorganic grout in hot weather.
- Steam hose, if grouting in cold weather.
- Tarp shelter material if grouting must proceed during inclement weather.

Hold a meeting a day or more ahead of the job, and agree on who will be responsible for what. The middle of a grout job, with part of the grout placed and curing, is not a convenient time to discover that something essential is missing, or some procedural step needs lengthy debate. Include contingency plans in the meeting agenda, such as how the job will be handled (or postponed) in the event of inclement weather. Make it clear that once the job starts, it will continue without interruption until completion. Any restroom or meal breaks will be staggered so as to leave a majority of personnel onsite and working through the job.

Resist the temptation to order transit-mix grout from an outside source. This relinquishes control to others, and makes end results less certain. Also, many of the better grouts become fully mixed in a matter of minutes, and further mixing or transit delay allows partial cure prior to placement—an undesirable situation. On major projects, with many pumps to be grouted, a better solution is to use an onsite double-carriage open-top planetary mixer, transferring the grout with a pneumatic diaphragm pump and hoses [5].

Proportioning and mixing. Follow the agreed-upon instructions. If using an unfamiliar grout material, it is wise to have done an experimental mixing-bowl trial prior to the real job, to verify the exact proportions needed to achieve a grout consistency that is neither too stiff nor too runny for proper placement. Such a trial is also useful for verifying cure times and compressive strengths. For epoxy grouts, be sure to mix resin and catalyst, then add *aggregate* to the *liquid* mix. Do not add *liquid* to *aggregate—this* makes a mess!

Placement. Keep in mind the basic objective—to completely fill the cavity. This means putting the grout in, and causing it to flow across each bulkhead section and out each vent hole. Use of a topping pump, weighted covers, and stoppers can accomplish this quite well. Avoid delays or interruptions once the placement begins, to prevent premature setup of grout in a partially-filled cavity, blocking the flow of grout to unfilled regions.

Sampling and testing. Take two inch cube samples during the job, and break them at three, seven and 14 or 28 days, to check the grout compressive strength. Good inorganic grouts should reach 2500 psi (pumped) or 4000 psi (manually placed) after three days, often doubling these strengths in two to four weeks. Less than 1500 psi may require re-doing the job if loading is concentrated. Epoxies will generally attain higher strengths in shorter periods. On some jobs, the baseplate, foundation, and grout are vastly in excess of what is needed for strength and rigidity, simply because of the geometry of the pump and baseplate versus horsepower and cpm rotating speed. Certain screw and progressing cavity pumps fall into this category. In such cases, grout sampling may be omitted, since just about any mix will work, and grout strength is not very critical. For any job in which normal grout strength is required, however, sampling and testing should be done. This is easy to do, inexpensive, and quite mind-relieving.

Withdrawing leveling screws and sealing their holes. This can be done a day or two after the grouting. Holes can be filled with grout mix or with liquid epoxy, or with wadded paper towels topped in the last inch by RTV silicone rubber or other commercial sealant.

Curing. Allow cure time as specified by the grout manufacturer's instructions. Three days is the minimum time for most grouts. For inorganic grouts, keep water-saturated sacks in place for three days minimum.

Protective coating. It is usually desirable to apply a protective coating to finished inorganic grout, including filling and vent holes, and all foundations, regardless of grout type, following the grouting. If possible, wait 28 days, but if the machine must be run before that, reduce the waiting time as necessary. The coating protects against oil soaking and chemical attack, particularly at the grout/foundation interface. Various coatings can be used, depending on the anticipated fluid exposure. For acids, butyl rubber and silicone rubber (of a type that does not use acetic acid as a curing agent) work well. For typical hydrocarbon pumps, epoxy-acetone followed by polysulfide rubber makes a good combination. Bloch and Geitner have a procedure [4].

Dry-pack Grouting

Dry-pack grouting deserves mention, even though it is not normally used for pump baseplates. Bloch and Geitner include a detailed procedure for this. Dry packing is ideal for skid or rail bases, with easy access and shallow cavities that can be blocked on the blind side, for ramming. Many lobe-type blowers and some screw compressors have such skid bases. Dry packing eliminates the need for external forms, and can give amazingly high compressive strengths with inorganic grouts—on the order of 14,000 psi after two weeks. Some epoxies are also formulated for dry packing. After doing the dry packing under the load bearing sections of the skid, a "cosmetic" grout can be troweled around the outside. Sometimes, readymix concrete is then poured into the inside open box section to eliminate trash, water, and oil accumulation space.

CONCLUSIONS

Pump baseplates, foundations, and grouting are often given insufficient attention as compared to the pump proper, driver, coupling, piping and pipe supports, and instrumentation. A chain is as strong as its weakest link—and a weak link beneath the pump can cause trouble just as surely as one at or above it.

The solution is to give proper attention to the necessary details, and be willing to spend a relatively small but well-directed amount of money and time in their pursuit. Leaving matters to chance, or to vendors and contractors bidding competitively on loose specifications, will usually give a poor end result. Assignment of a responsible engineer at the beginning of the project, not the day before the grouting, is desirable. The engineer should plan, coordinate, and provide hands-on supervision—to make the job go according to plan. This includes having the flexibility to modify the plan in case of unforeseen contingencies, without compromising job integrity.

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