IRRIGATION TRAINING AND RESEARCH CENTER

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Irrigation Training and Research Center

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## TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Published Studies</td>
<td>1</td>
</tr>
<tr>
<td>General</td>
<td>2</td>
</tr>
<tr>
<td>Reduce the volume of water pumped per year</td>
<td>3</td>
</tr>
<tr>
<td>Reduce the total pressure required from the pump</td>
<td>4</td>
</tr>
<tr>
<td>Reduction of friction losses in and around the pump assembly</td>
<td>4</td>
</tr>
<tr>
<td>Reduce pressure requirements in the irrigation system (downstream of the pump)</td>
<td>6</td>
</tr>
<tr>
<td>Reduce other pump power requirements</td>
<td>12</td>
</tr>
<tr>
<td>Improve the efficiency of the motor</td>
<td>15</td>
</tr>
<tr>
<td>Improve basic understanding and hydraulics</td>
<td>15</td>
</tr>
<tr>
<td>Improve the bowl and impeller efficiencies</td>
<td>17</td>
</tr>
<tr>
<td>Attainable bowl/impeller efficiencies</td>
<td>17</td>
</tr>
<tr>
<td>Coat the impeller/volute/bowl for smoothness</td>
<td>18</td>
</tr>
<tr>
<td>Underfiling and streamlining</td>
<td>21</td>
</tr>
<tr>
<td>Wear rings</td>
<td>22</td>
</tr>
<tr>
<td>Dynamically balancing of impellers (for vibrations)</td>
<td>24</td>
</tr>
<tr>
<td>Maintain a high pumping plant efficiency</td>
<td>25</td>
</tr>
<tr>
<td>Oil drip rate and oilers for vertical turbine pumps</td>
<td>25</td>
</tr>
<tr>
<td>Wear on impeller and bowls</td>
<td>29</td>
</tr>
</tbody>
</table>
IRRIGATION SYSTEM COMPONENTS AND POTENTIALS FOR ENERGY CONSERVATION

Published Studies
There are numerous papers and promotional materials that claim that electricity consumption is reduced by converting to drip/micro irrigation. However, in most cases drip/micro irrigation requires a pump, whereas with most surface irrigation no pumps are required. Although each site can be different, in general electric energy consumption for pumping increases when drip/micro is used for irrigation.

A previous study by ITRC\(^1\) for PIER also noted that electricity consumption in California will grow significantly as more farmers convert to drip/micro irrigation.

Only one research paper was found that specifically addressed the irrigation system view of component energy requirements\(^2\). The conclusions of Trout and Gartung, based in large part on ITRC-collected data, were:

Micro-irrigation emitters require only 7 - 20 psi. Cleaning and delivering the water to the emitters on flat fields typically requires an additional 15 psi. A survey of 312 California micro-irrigation systems showed that 60% of the systems exceed these pressures, and 25% exceed by over 10 psi. Pressure could be reduced by an average of 15 psi in 60% of the systems. Pressure was lost at the filter station, in the distribution system, at pressure regulators, in the lateral inlets, and at the emitters. Higher pressure is required to irrigate undulating land. Reducing system pressure by 15 psi in a system could save about $25 per acre per year in electricity costs, and reducing pressure by 15 psi for 60% of the 1.7 million acres of micro-irrigation in California would save 220 Gigawatt-hrs/yr of energy and 90 Megawatts of peak load. (Trout and Gartung 2002)

The recommendations of Trout and Gartung were:

1. Economically evaluate the best pipe sizes for distribution systems.
2. Use pressure regulators or PC emitters only where the benefits in initial costs, water distribution uniformity and system operation are greater than the energy costs.
3. Design filter backflush systems that do not limit system pressures.
4. Use lateral inlet fittings (ball valves, hose screens, spaghetti tubing) that cause little (<0.5 psi) pressure loss.
5. Use booster pumps or variable frequency drives when a pumping plant must operate over a range of pressures or flow rates.

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The author of this report notes the following regarding the Trout and Gartung recommendations:

- The benefits of economic pipe sizing are well known in academia. However, a true economic pipe sizing procedure is complex, is not commonly done, and is typically of relatively minor importance.
- New PC emitters now available (since 2002) offer the potential for very low pressure systems, rather than otherwise.
- Stage 3b of this contract addressed filter backflush problems. It is of major importance.
- The importance of using large fittings with low pressure losses is also well known in academia, but often not well understood in the field by designers.
- Variable frequency drives are very strongly recommended in this report, for more reasons than listed by Trout and Gartung.

The energy indexing of irrigation/pumping system components is provided in the sections below. The indexing format is intended to give the reader and utilities a broad, system-wide view of electricity savings potentials in agricultural irrigation systems. Many options are mentioned and discarded. The most promising actions are summarized at the end of this Stage.

**General**

On-site electricity conservation in irrigation can be accomplished through the following general steps:

1. Reduce the volume of water pumped per year
2. Reduce the total pressure required from the pump
3. Reduce other pump power requirements
4. Improve the efficiency of the motor
5. Improve some basic understanding and hydraulics
6. Improve the efficiency of the bowl/impeller assembly of the pump
7. Maintain a high pumping plant efficiency

The primary focus of the agricultural energy conservation programs of the utilities has been to improve the efficiency of the pumping plant. In general, the electric utilities have provided or subsidized pump testing, along with some form of rebate for replacement or repair of pumps.

There are, of course, other irrigation-related aspects of energy conservation. For example, the manufacturing process for nitrogen fertilizer is very energy intensive. Therefore, avoiding leaching of nitrogen fertilizer is an important energy consideration. But this report focuses on on-site electricity conservation in the field.
Reduce the volume of water pumped per year

There is a large appeal to designing energy conservation programs that focus on reducing irrigation applications. There have been various utility-sponsored programs created to accomplish this for at least 25 years. They have focused on one of two aspects:

1. **Improve the uniformity of water application in a field.** This is logical, because if all plants receive about the same amount of water, there is no need to over-irrigate on the average to provide enough water for the drier spots. There have been two primary utility programs to improve uniformity:

   a. **Subsidize the installation of drip irrigation systems.** While a properly designed and maintained drip/micro system is inherently capable of (and indeed does accomplish, on the average) applying water with a higher uniformity than other irrigation methods, there are two problems with this type of program:
      i. There are typically no specifications required for drip/micro irrigation systems that must be met in order to receive a rebate.
      ii. In general, drip/micro irrigation systems increase kWh per year that is consumed – even accounting for energy needed for conveyance to the site.

   b. **Pay for field evaluation of the uniformity of existing irrigation systems.** ITRC, with funding from California Dept. of Water Resources, has developed widely used and standardized procedures to evaluation the Distribution Uniformity of irrigation water for most agricultural irrigation systems. Over the past 20 years, there has been a gradual improvement in Distribution Uniformity of drip/micro systems. This is likely due to a heightened awareness of Distribution Uniformity among farmers, manufacturers, and irrigation dealers.

2. **Improve irrigation scheduling.** The idea is that if farmers have better control of their irrigation systems, plus more pertinent knowledge, they would irrigate fewer hours per year. These programs generally have involved one or more of the following components:

   a. **Installation of a flow meter if one does not exist.**
   b. **Provide irrigation scheduling services, in terms of:**
      i. Subsidizing the payment to a commercial irrigation scheduling company.
      ii. Providing information on crop evapotranspiration via the local irrigation district or some other entity.
      iii. Paying for soil moisture sensors, possibly even with remote monitoring.
      iv. Encouraging farmers to use regulated deficit irrigation

It is the opinion of the author, based on over thirty years of experience in irrigation scheduling and observation of numerous such programs, that these programs are helpful in a variety of ways but likely result in minimal energy savings. The reasons are:

a. Quite often good irrigation scheduling will detect under-irrigation and the need for more (not less) water applied.

b. Soil moisture sensor programs have been in existence for perhaps 50 years, and they are nothing new. Sustained water savings are difficult to document over many years.

c. Many crops are already irrigated with regulated deficits. Assumptions of potential water savings often ignore the existing widespread deficit irrigation of wine grapes, processing tomatoes, cotton, pistachios, and other major crops.
Ultimately, the day-to-day irrigation decisions are typically more complex than one might think when envisioning a water conservation program. Daily irrigation decisions must consider labor, irrigation district inflexibility, spraying of crops, and many other factors. Irrigators and irrigation foremen usually only see risk when someone recommends changes, so changes occur gradually. Over the long haul, there is no doubt that improved irrigation scheduling programs and good flow measurement are necessary tools for achieving high irrigation efficiency without under-irrigation. But broad, positive, quick energy reducing benefits are elusive and are typically assumed rather than documented.

**Reduce the total pressure required from the pump**
This item can be divided into several major components:

1. Reduce any friction losses in and around the pump assembly.
2. Reduce friction losses in irrigation system components.
3. Only deliver as much pressure as is needed, through the use of variable frequency drive controls.

**Reduction of friction losses in and around the pump assembly**
There are several variable friction components for a well pump. These components must be selected when the pump is designed. The first three items are well known to pump companies:

1. Discharge head losses. Discharge head losses are relatively small (typically less than 0.7 ft), and the size of the discharge head is generally determined by the size of the column pipe.
2. Fittings at the discharge of the pipe. The friction characteristics of these fittings are well known.
3. The diameter of the column pipe. All well pump books contain tables for friction loss.

While the three components above are well known, the economics of selecting larger (less pressure loss) components are not well understood or used. **Table 1** illustrates the importance of economic selection that includes knowledge of hours per year pumped, interest rate (assumed to be 6%), years life of investment (assumed 10 years), and power cost (assumed $.15/kWh)

<table>
<thead>
<tr>
<th>Column Diameter Choice</th>
<th>1000</th>
<th>1500</th>
<th>2000</th>
<th>2500</th>
<th>3000</th>
<th>4000</th>
</tr>
</thead>
<tbody>
<tr>
<td>8” vs. 10”</td>
<td>1025</td>
<td>887</td>
<td><strong>800</strong></td>
<td>750</td>
<td>695</td>
<td>631</td>
</tr>
<tr>
<td>10” vs. 12”</td>
<td>1870</td>
<td>1620</td>
<td>1440</td>
<td>1335</td>
<td>1275</td>
<td>1130</td>
</tr>
</tbody>
</table>

**Table 1** shows that with 2000 hours/year of pumping, at a flow rate of **800** GPM there is no economic benefit to using either an 8” or 10” column diameter. However, any flow between 800 and 1400 GPM should use a 10” column diameter. At 1441 GPM, a 12” diameter is more economical than a 10” diameter column pipe.

There is no simple rule regarding the appropriate column pipe diameter, based on the bowl diameter. A typical bowl assembly is often offered with at least 3 standard options for column pipe connections. Furthermore, a 12” bowl may be designed for 800 GPM or for 1200 GPM.
The next two items are not well understood or recognized.

4. Entrance losses in well pumps, primarily due to entrance screens. This is rarely considered, but it should be often. Standard mild steel entrance screens can become almost completely fouled, which not only increases the pressure requirement of the pump, but also eliminates proper hydraulic entrance conditions into the first impellers – lowering pump efficiency.

5. Coating of the inside of the column pipe to reduce friction. A variety of coatings exist, and smooth pipe materials such as stainless steel are available. One of the biggest problems is avoiding pinhole cracks that will accelerate local corrosion and cause flaking of the coating.

If the drawdown (Initial water level in well – Final pumping water level in well) can be minimized, the pump does not need to provide as much pressure. The three most important human-impacted variables that influence the drawdown are:

1. The quality and cleanliness of the well screen. Screens cost money up front. Holes poked in well casing are cheap, but a good screen has numerous initial and long-term advantages that save power in the long run. These advantages include:
   o They allow for good development of a well (see below).
   o They have a large percentage of open area – easily 3-4 times as much as inexpensive slots or holes in casing. This means there is less head loss between the aquifer and the well (meaning less drawdown), and the lower velocities also help minimize corrosion and chemical blockage.
   o Good materials do not corrode. Corrosion blocks the entry of water into the well, increasing the TDH and decreasing the yield (flow rate).

2. Proper development of the well after it is initially drilled. Development is the process of cleaning out the soil immediately around the well screen to allow for free flow of water into the well (and thereby decreasing drawdown). Proper drawdown involves a lot more than just “overpumping” (the common practice), which just improves the opening of already-
clean zones. Well development procedures are well described in the book “Groundwater and Wells” by the Johnson Division of Driscoll.

3. Cleaning of a fouled well screen. The fouling can be caused by any number of factors such as calcium carbonate, iron bacteria, or rust.

The economic and energy impacts of the factors above are summarized in Table 2.

<table>
<thead>
<tr>
<th>Action</th>
<th>Likely difference in Total Dynamic Head (Pressure) - feet</th>
<th>Is this already common practice?</th>
<th>Opportunity for success in adoption and energy savings if targeted by utilities (1 = very poor; 10 = excellent)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Larger discharge head</td>
<td>0.30</td>
<td>N</td>
<td>1</td>
<td>Already understood; Computation tool might help</td>
</tr>
<tr>
<td>Larger pipe fittings</td>
<td>0.5 – 10</td>
<td>Y</td>
<td>4</td>
<td>Need simple calculation tool</td>
</tr>
<tr>
<td>Large column diameter</td>
<td>5 – 30</td>
<td>N</td>
<td>8</td>
<td>Need awareness and simple rebate. Minimal expense; high benefit</td>
</tr>
<tr>
<td>Good pump entrance screen</td>
<td>0 - 15</td>
<td>N</td>
<td>10</td>
<td>Need better documentation. Very site specific and must be targeted. Falls under maintenance.</td>
</tr>
<tr>
<td>Column pipe coating (powder coating)</td>
<td>1 – 9</td>
<td>N</td>
<td>5</td>
<td>Coating must be high quality, or it will crack and corrode</td>
</tr>
<tr>
<td>Good well screen</td>
<td>2 – 40</td>
<td>N</td>
<td>4</td>
<td>Difficult to predict benefits in advance</td>
</tr>
<tr>
<td>Proper well development</td>
<td>1 – 10</td>
<td>N</td>
<td>8</td>
<td>Relatively simple to achieve</td>
</tr>
<tr>
<td>Screen cleaning</td>
<td>2 – 40</td>
<td>Variable</td>
<td>4</td>
<td>Need better documentation. Very site specific and must be targeted. Falls under maintenance.</td>
</tr>
</tbody>
</table>

Reduce pressure requirements in the irrigation system (downstream of the pump)

There are two initial points to be made regarding this possibility:

1. It should be obvious that reducing pressure requirements of the irrigation system itself can potentially conserve energy. However, reducing the pressure requirement of the irrigation system, without changing the pump to match the new pressure requirement, may result in no electricity savings.

2. The only utility rebate program that ITRC is aware of that has directly rewarded farmers for pressure reduction is related to “low pressure nozzles”. These are discussed in the Sprinkler Component section.

Surface Irrigation Components

Surface irrigation (furrows, border strips, and basins) typically have very little pumping requirement, although there are exceptions when long conveyance pipelines are used. The major savings related to surface irrigation would in concept occur via improving irrigation
efficiency – thereby reducing the electricity needed to pump the water to field (e.g., California Aqueduct, Delta-Mendota Canal, well pumps).

However, water contractors that receive water from the California Aqueduct and the Delta Mendota Canal have limited water allocations. Therefore, if water applications are reduced on one field, they will be increased on other fields – the volume is limited and therefore will not be reduced overall if efficiency is improved on one field.

For well pumps, the savings is more direct. If 50% less water is pumped, there is a 50% reduction in electricity (not including additional electricity requirements to improve the irrigation efficiency).

The ways to improve irrigation efficiency with surface irrigation are well documented by Burt\(^3\) and many others. Summarized, the two modifications that are most useful in California are:

1. Reduce the length of the basins, border strips, or furrows.
2. Install a tailwater return system (which, by its nature, requires a pump).

The difficulty with surface irrigation improvements in California is that it is challenging to make good estimates of the water (and therefore the energy) that will be conserved. Quite often, there are no records of actual water deliveries to individual fields. Also, field evaluations only give limited information with inexperienced evaluators, because the nature of water advance and infiltration varies greatly throughout the season. Furthermore, irrigation efficiency estimates must include excellent computations of the efficiency of individual irrigation events.

**Sprinkler Components**

Within the sprinkler industry, there have been two primary items that have been promoted for reduced pressure requirements:

1. Use of low pressure sprinklers on center pivots and linear moves. This is now standard practice in the industry. The older, high pressure (50 – 60 psi) sprinklers have almost been completely replaced by relatively lower pressure sprinklers (10 – 20 psi). The newer low pressure sprinklers have additional benefits such as better distribution uniformity and less wind drift. The major manufacturers of the low pressure sprinklers are Nelson Irrigation (www.nelsonirrigation.com) and Senninger Irrigation (www.senninger.com), both of which are US companies.

2. Use of “low pressure nozzles” on hand move sprinklers and side roll (wheel line) sprinklers. These have been included in various electric utility rebate programs, but they have some significant disadvantages in terms of larger droplets which tend to crust the soil surface, and a lower pressure uniformity among sprinklers throughout the sprinkler system. When one considers the disadvantages of converting a higher pressure nozzle to a low pressure nozzle, especially without also changing the pump at the same time, it is questionable whether there is an overall energy savings.

Other standard options such as using larger pipelines are applicable to all methods of irrigation, including sprinkler irrigation.

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There are a variety of measures that can be used to improve distribution uniformity of the water application. Although they have the holistic benefit of improving crop yield, they may or may not have an impact on electrical consumption. The most simple and cost effective such component is the use of pre-set pressure regulators under every sprinkler in hand move and side roll sprinkler systems.

**Drip/Micro Irrigation Components**

The terms “drip irrigation”, “microirrigation”, and “trickle irrigation” can be synonymous although they can refer to the design of the final emission device. These systems are often referred to as “low pressure systems”, although a typical California pump discharge pressure is about 40 – 45 psi on flat ground (even though the emitter may need 6-12 psi pressure). A detailed explanation of options and designs can be found in (Burt, C.M. and S. W. Styles. 2011. Drip and Micro Irrigation and Management. ITRC. Cal Poly. San Luis Obispo).

The study by Trout and Gartung, written 10 years ago, highlighted several important topics. Certainly, if typical emitters only need 6-12 psi of pressure, one must question why typical drip system pump discharge pressures average about 45 psi on flat ground. Further discussion is provided here, with specific recommendations.

The figure below is a conceptual sketch of a drip/micro irrigation system with key components.

**Figure 3: Drip/micro irrigation system schematic.**

To minimize pressure requirements at the pump discharge, one must consider the pressure requirements for water to flow through each of these components.

1. **Control valves near the filter.** All control valves have friction loss, but there are significant differences between various sizes and models. There is very little new knowledge here, and some excellent control valves exist for this location.
2. Filters. This is one component that has significant room for improvement. Therefore, ITRC conducted a major study of media filter performance as part of this contract. The large pressure loss that is built into drip and micro irrigation systems for filters is not needed if the correct filters are used. The major factors are:
   a. Some filters, such as the various internal-wand-cleaning screen filters, and various disc filters, require 35 psi minimum to properly backflush.
   b. Media filters (most common type) are often thought to require 35 psi to backflush. The ITRC filter study (Appendix 3A) shows this is not a universal requirement.

Because the filter backflush pressure requirement is so large, there is typically no reason for designers to select low pressure loss valves and fittings within the irrigation system. In other words, items #3-6 below are not very important unless the proper filter is selected.

3. Control/pressure regulation valves within the distribution system, and at the heads of tapes and hoses. Depending upon the model and design, there can be significant pressure savings if valves are carefully selected. There are two types of pressure regulation valves:
   a. Pilot-operated valves. These are usually 2” or larger in diameter, and are used at the heads of manifolds, especially with tape systems. There is a major, little known hydraulic fact about many of these valves: if the downstream pressure is 8 psi (typical for drip tape), there may be a 10 psi loss across the valve for a flow of 100 GPM. But if the downstream pressure is 20 psi, there may only be a 2 psi loss across the valve for a flow of 100 GPM. The manufacturers publish the 2 psi value, not the 8 psi. Irrigation designers do not know which valves have these characteristics, or that they even have them. Designers do know that they need a substantial “safety factor” of extra psi for the pump to take care of things like this.
   b. Pre-set pressure regulators. These pressure regulators are typically used at the heads of hoses in hilly terrain. They can have large (3-6 psi) friction losses across them when wide open.

4. Fittings on hose risers can be small and have appreciable friction loss. There is no standard in the industry for these fittings, and the friction loss of the various assemblies that are used is not well known.

5. Drip hose/tape hydraulics. These are fairly well understood. All the major manufacturers have good hydraulics programs that they provide to irrigation designers. ITRC has a similar program for education that is used by many designers. They all perform the same functions – the uniformity of water discharge, friction, pressure requirements, etc. are automatically computed if one inputs the slope, hose diameter, emitter specifications, etc.

6. Emitters and microsprayers and microsprinklers. These are the final emission devices. Many of the designs have not changed for many years. For discussion, there are two basic types of emission devices: Those with fixed holes, and those with some type of pressure compensating (PC) ability that requires some type of flexible diaphragm inside the emission device. There are some very interesting possibilities at this level, such as:
   a. Standard, fixed hole/path emitters must have a minimum pressure of 6-12 psi just to maintain good uniformity of discharge along the hoses and between hoses. When there is elevation variation, a higher optimum average pressure is needed to maintain good uniformity.
   b. Pressure compensating (PC) devices have the interesting possibilities:
There are very few PC emitters (discharging somewhere between 0.5 and 1.0 Gallons/hour) that can operate very well at pressures as low as 4 or 5 psi. This means that at a wide range of pressures, say between 4 and 35 psi, the flow rate is almost identical. Especially for hilly terrain, this feature can offer substantial (at least 10 psi) pressure reduction benefits.

Microsprinklers are emission devices which have a stream of water (e.g., 15 Gallons/hr) that is rotated to provide a large amount of ground coverage. The most popular PC microsprinklers do not work well until the pressure at the microsprinkler is about 25 psi. ITRC was unable to locate any commercially available low pressure PC microsprinklers.

Microsprayers are emission devices with relatively large flows (e.g., 15 Gallons/hr) that discharge from a nozzle, hit a fixed plate, and then spray out with multiple jet patterns. Bowsmith Industries (Exeter, CA) recently developed a PC microsprayer that begins to function well at relatively low pressures (8 psi). As with PC emitters, this is important for hilly terrain.

Rebate Programs for Drip/Micro Irrigation. Drip/micro irrigation rebate programs offer substantial holistic potential benefits in terms of improved fertilizer efficiency and increased yield. These two items can produce more crop per drop of fertilizer and water consumed. Such rebate programs might require numerous specific features such as the correct flow rate, appropriate air vents, good fertilizer injectors, certain thicknesses of tape, and so on. But perhaps more importantly, the following key performance results should be specified:

1. The new system Distribution Uniformity, as measured with the Cal Poly ITRC drip/micro irrigation evaluation procedures, must be greater than 0.92
2. The pump discharge pressure shall be no greater than the following:
   a. For tape systems: 23 psi, plus the difference in elevation between the highest point in the field and the pump discharge.
   b. For emitter and micro-spray systems: 27 psi, plus the difference in elevation between the highest point in the field and pump discharge.

The values are obtained using readily attainable pressure losses, as shown in Table 3.

<table>
<thead>
<tr>
<th>Item</th>
<th>Pressure required for different systems</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tape</td>
</tr>
<tr>
<td>Emitter</td>
<td>6</td>
</tr>
<tr>
<td>Hose/tape</td>
<td>3</td>
</tr>
<tr>
<td>Fittings, valve losses</td>
<td>2.5</td>
</tr>
<tr>
<td>PVC main and manifold</td>
<td>3.5</td>
</tr>
<tr>
<td>Filter</td>
<td>5</td>
</tr>
<tr>
<td>Control valves, check</td>
<td>3</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>23</strong></td>
</tr>
</tbody>
</table>
Perhaps there could be a $200/acre rebate for new systems meeting the pressure and uniformity criteria, plus an additional $40/acre rebate for every psi reduction below the total listed above.

**Pressure Reduction with VFDs.** Variable frequency drive (VFD) controllers for irrigation pump motors may have the greatest potential for immediate power savings. There are numerous reasons to promote VFDs on both well pumps and booster pumps. These include:

1. Designers must always over-design pumps. Farmers do not complain if they have too much pressure; but they definitely complain if they do not have enough. The uncertainties with pump design are:
   a. As mentioned above in the discussion regarding drip/micro irrigation, designers always include a “safety factor” of at least 5 psi in a design - whether needed or not.
   b. Published pump curves often do not exactly match what does into a field.
   c. The pressures from irrigation district pipeline turnouts vary over time, and may not even be known by the designer.
   d. Well water levels vary from year-to-year, and from Spring to Fall. These variations can easily be 50 feet.

2. Irrigation systems do not require a constant pressure. In general, irrigation systems have multiple blocks that are sequences. These blocks have varying elevations and sizes, each with unique pressure requirements.

In summary, given the two items above, VFDs allow designers to over-design the pump to meet uncertainties and occasional extreme conditions, without having continuous power wastage due to an over-designed pump.

There are three other substantial benefits derived from the use of VFDs, although they do not in themselves reduce electricity consumption (kWh). These benefits are:

3. Water hammer and subsequent damage to the pump and irrigation system are reduced because of the slow start and slow stop capabilities of VFD-equipped pumps.

4. Farmers are much more likely to adopt time-of-use pumping practices with well pumps. This is because the slow starting of well pumps, as opposed to 100% speed starting (with subsequent very high flow rates), can have a drastic impact on the life of wells. Many farmers will not start or stop well pumps during the irrigation season because they are afraid the starts and stops will damage their wells.

5. The slow start minimizes large but temporary current loads on the electric utility grid.

Given that VFD controllers can provide substantial energy-related benefits with agricultural irrigation pumps, any rebate program for VFDs should contain minimum requirements for the purchase of VFD controllers, covering the following features:

1. Efficiency. Inefficient VFDs create excess heat which requires significant air conditioning power to dissipate.
2. Temperature rating.
4. Form of the simulated sine wave.
5. Audible noise.
6. Length of power cords that can be used. Some low quality VFD units can only have a cable of about 20 feet long between them and the motor.
7. Means of cooling the VFD.
8. Allowable voltage variation between legs.

Reduce other pump power requirements
The primary “other” components in pumps are the bearings. There are two types of bearings that interest most pump people:

1. “Thrust bearings”, which are located in the motor. These are designed to allow the shaft and rotor to rotate while experiencing downthrust from the weight of the shaft and the dynamic thrust of the impellers. Thrust bearing power requirements can be computed, but are often assumed to equal 0.5% of the brake horsepower requirement of the impeller/shaft. Other than having good maintenance (proper lubrication) and balancing, thrust bearings are not a major item to consider in reducing electric energy requirements for pumps.

2. Mechanical friction in line shafts. This can be appreciable. The values typically range from about 1.0 to 2.0 brake horsepower per 100 feet of shaft, when new. If there is poor lubrication or wear on the line shaft bearings, the horsepower requirement increases.
In general, deep well irrigation pumps have historically had redwood or bronze oil lubricated bearings enclosed in an oil tube that surrounds the bearings and lineshaft. Bronze bearings are almost the universal choice by pump repair companies in California and manufacturers.

Nevertheless, ITRC thinks that it would be worthwhile to examine the merits of new material for oil lubricated bearings. Taking a typical 300’ pump length in California, the present bronze bearings need about 3-6 horsepower to overcome mechanical friction when new. As they get older, they wear not only themselves but also the lineshaft. New materials should be able to reduce the friction in half, as well as provide longer wear. This appears to be a relatively simple way to save power. Vesconite, which is described below for water-lubricated bearings, is not suitable for oil lubricated bearings because the temperature must be kept below 60 deg. C. There is not enough oil passing through the bearings to maintain this temperature – especially at startup of a deep well turbine.

Although rubber water lubricated (“product” lubricated) bearings are available for vertical lineshaft turbines, they have historically suffered damage if the pumping water level is quite
Irrigation System Components and Potentials for Energy Conservation

www.itrc.org/reports/components.htm

ITRC Report No. R 11-003

Irrigation Training and Research Center

14

deep; the shaft spins on dry rubber bearings for a long time before water arrives to lubricate them. Similarly, for large flow rate vertical pumps used by irrigation districts to lift water from canals or rivers, there is often a problem with silt. Therefore, even if the bearings will not be dry for an appreciable time, the silt in the lubricating water can wear out the bearings, and increase the line shaft friction over time.

Horizontal irrigation centrifugal pumps typically have water-lubricated “packing”, as seen in the figure below. A recommended packing material is graphite impregnated, such as John Crane® 1340 graphite acrylic. The packing is typically tightened to allow about 2-3 drips/second, which minimizes mechanical friction.

**Figure 6: Packing cutaway view – horizontal centrifugal irrigation pump.**

A number of synthetic bearing materials have been introduced to reduce mechanical friction and to overcome problems of lubrication wear and friction with product (i.e., water) lubricated lineshafts. They are not used on oil lubricated lineshafts because they are not sufficiently cooled, and because some of the materials are incompatible with oil. Several of the major materials for water lubricated bearings are listed below:

a. Graphalloy®. This is a self-lubricating graphite/metal alloy used for bearings. It is claimed to be non-galling, corrosion resistant, and dimensionally stable, and is sold for both vertical and horizontal pumps.

b. Thordon SXL®. These bearings also are sold on the basis of having low friction, impact tolerance, and self-lubricating qualities.

c. Vesconite®. Vesconite is a specialized thermoplastic made from internally lubricated polymers that has been available since the 1960’s. It has no water swell, does not delaminate, remains hard in water, has a low friction, and gives many times the life of phosphor bronze, and easily machined. Because of these characteristics, it has become popular with some vertical pump manufacturers, and in many pump repair shops in California.

d. Duramax OEM Cutless® industrial bearings.
Improve the efficiency of the motor
The electric utilities have had rebate programs for many years for using high efficiency motors. However, the benefit is likely not as great now as several years ago. The motor efficiency standards for “standard” motors have improved to the point that the efficiency of some “high efficiency” or “premium” motors is the no better than that of “standard” motors.

Perhaps one area for improvement would be to use slightly better insulation classes for motor windings. The choice of insulation depends on the maximum expected windings temperature. If the expected temperature is close to one insulation class it is better to select the next higher insulation class for the motor winding.

A typical inverter duty hollow shaft motor for an irrigation well pump will have an insulation class of “F”. As seen in the table below, an insulation class of “H” would reduce the importance of keeping the motor cool.

<table>
<thead>
<tr>
<th>Insulation Class</th>
<th>Temperature Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>105° C</td>
</tr>
<tr>
<td>B</td>
<td>130° C</td>
</tr>
<tr>
<td>F</td>
<td>155° C</td>
</tr>
<tr>
<td>H</td>
<td>180° C</td>
</tr>
</tbody>
</table>

Improve basic understanding and hydraulics
The following two items are rather basic, but need attention.

Obtain a pump curve. This may seem only logical, but in many areas of California it is unusual that the farmer is supplied with a pump performance curve that shows the relationship between flow, pressure, and efficiency – plus the design operating point. Any rebate program should insist that farmer receive a pump curve.

Improve the entrance conditions on booster and short-coupled vertical pumps (vertical pumps in sumps rather than in wells). ANSI/HI 9.8-1998, Pump Intake Design (from the Hydraulic Institute Standards) provides great detail about proper inlet design for pumps. A distorted velocity profile entering the suction side of pumps can contribute to excessive noise, cavitation, and uneven loading of internal bearings. The exact effect of poor entrance conditions on pump efficiency is not known, but anecdotal experience indicates that the impact can be rather severe – such as 5-10 percent drop in efficiency.

For short-coupled vertical pumps, the ANSI standards are fairly straight-forward to follow. Pump dealers, however, rarely attempt to follow more than minimum guidelines from the ANSI standards with agricultural irrigation pumps. ANSI standards are well known to consulting engineers working for irrigation districts.

The best opportunity for significant and simple modification of inlet conditions comes with horizontal booster pumps. The figures below show “typical” installations for booster pumps, all of which have elbows close to the inlet of the pump.
Most pump dealers understand the need for long, straight (6 – 10 diameters) sections of pipe upstream of flow meters. But that knowledge is rarely applied to the installation of the inlet piping for booster pumps. In part, this is likely because pump installers do not know the specific, quantitative effect of inlet conditions on efficiency. In part, it is likely due to the need to have short pipes just so the installation fits within allowable boundaries.

Within the past few years, there has been increased promotion by flow meter companies of new “flow conditioning” equipment that can be placed in front of propeller flow meters. This flow conditioning equipment accomplishes two things in a short pipe section:

1. It minimizes or eliminates swirling of the water.
2. It straightens out the velocity profile so that it is concentric about the center of the pipe.

Elbow flow conditioners can be installed upstream from critical equipment requiring a swirl-free, repeatable, and symmetric velocity profile

The same concepts could be applied to a simple rebate program. Companies such as VORTAB offer special inserts and pipe sections that provide excellent entrance conditions to pumps with limited space.
Improve the bowl and impeller efficiencies

Attainable bowl/impeller efficiencies

The figure below illustrates generally attainable efficiency levels of centrifugal pumps at the best efficiency point, with the maximum diameter impeller when pumping clear water. Well pumps fall under the category of “vertical turbine bowl” (the uppermost curve); most booster pumps fall under the “end suction ANSI” (the third from the top curve) category.

Figure 8: Optimum generally attainable efficiency for bowl/impeller assemblies of industrial class, of high quality. ((Figure 1.75C in HI Centrifugal Pump Design and Application – 2000)

Most well pumps in California range from about 500 GPM to 2000 GPM, as seen in Figure 9. Therefore, maximum potential efficiencies of bowl/impeller assemblies range from about 82% to 86% on well pumps. Attainable improvements in efficiency must therefore use such numbers as the “base efficiency values”. For the discussions below of various options, a base efficiency value of 84% will be assumed.

Improvements of efficiency due to specific actions are not additive. Although the compounding mathematical effect of independent actions can be computed, there may be physical interactions when multiple actions are implemented to improve efficiency. The discussions below consider the actions individually.
Coat the impeller/volute/bowl for smoothness

The Hydraulic Institute provided an estimate of the benefit of improved smoothness in the figure below in 2000, but this figure has been removed from the most recent Hydraulic Institute Pump Standards.

The specific speed of an impeller is defined as:

$$\text{Specific Speed} = \frac{(n \times \text{GPM}^{0.5})}{\text{Feet}^{0.75}}$$

Where

- $n$ = RPM of the pump
- Feet = the head per impeller stage

A typical specific speed for a typical California agricultural well pump is 3000.
Figure 10 shows less than 0.5 percent efficiency benefit from smoothing of impellers and bowls for typical agricultural well pumps. But interviews with manufacturers and smooth compound vendors indicate that improving smoothness will give several percentage points of efficiency improvement if impellers and/or bowls are smoothed.

The general rules for smoothing of impellers appear to be:

1. Impellers smaller than 16” or 18” in diameter are typically not smoothed by applying an epoxy-type coating. The impeller waterways are too narrow, which makes it too difficult to uniformly apply epoxy coatings, and the small openings can also plug. This means that epoxy coating is suitable for typical on-farm pumps (both vertical and horizontal). However, epoxy coatings should be reserved for re-conditioning impellers, rather than for new impellers.

2. There is a large difference in new impeller qualities among various manufacturers. High quality manufacturers, on a standard basis, employ good casting designs and have swirl machines on site to polish impellers. They place the newly cast impellers in a bath of abrasive material and spin the impellers to polish the impeller passages. They also hand polish impellers if efficiency is critical. Other manufacturers, particularly targeting the agricultural pumping market, do not have the equipment or technology to properly polish
Irrigation System Components and Potentials for Energy Conservation

The smoothing of pump bowls is somewhat different from smoothing of impellers.

1. Historically, the major pump manufacturers used porcelain enamel on their bowls. But this is now rare because:
   a. Most of the castings now come from overseas, often lacking porcelain enamel coating facilities.
   b. There is a movement to have NSF 61 approved coatings, and evidently porcelain enamel cannot meet the requirements for this stamp of approval.

2. Interestingly, many of the published efficiency curves were based on the old porcelain enamel lining, which was very smooth. If spray on epoxies is used, there are evidently 1-2 efficiency points lost compared to published curves. But with fusion bonded epoxy coating (see 3M Scotchkote 124 description below), the efficiencies will be as good as with porcelain enamel.

3. Based on interviews with pump dealers and manufacturers, it appears that the compounds below are the most popular smoothing applications for bowls and column pipes. They are listed below with a few pertinent comments.
   o Belzona. There are about 60 different types of this hydrophobic coating. It appears to be primarily used on reconditioning projects.
      • Belzona personnel travel to the job site and decide correct type of Belzona to use
      • Coating is applied on site, stays stuck very well, may chip if dinged, but will not peel; chips stays localized.
      • Apparently this has a long life – one pump coated in the 1960’s was claimed to be in excellent condition in 2007, but the details are not known.
      • Material self-levels itself when being applied, producing a very smooth finish.
   o Powder coating with 3M Scotchkote 134 Fusion Bonded Epoxy Coating. This appears to be the “standard” that other products attempt to meet, and is common on new bowls.
      • This is a one-part, heat curable, thermosetting epoxy coating, which is one of the most popular “powder coatings” used by manufacturers of pumps.
      • It is NSF approved for potable water.
      • The epoxy is applied to pre-heated steel as a dry powder which melts and cures to a uniform coating thickness. It can be electrostatically applied to unheated metal parts and subsequently cured by baking. No primer is required.
      • The coated material must be able to withstand 400-deg temperature
   o Flash chrome is a very thin layering. It does not obstruct waterways, and fills holes in bronze. It is reputed to last a long time, and also reduces sand wear.
   o Glass lining. Glass coating is only for the bowl – not a coating for the impeller. Glass lining is often recommended for smaller bowls (less than 18” diameter), as opposed to various epoxy materials.

In summary, new bowl assemblies for pumps with large hours of operation should be specified to have fusion bonded epoxy coatings, or glass linings. The estimated improvement in
efficiency is 1-2%. The cost for a typical agricultural vertical pump bowl (10” – 14”) would be about $500 - $650/stage, and about $300 for a horizontal pump. The economics on a horizontal pump, which has only one stage, are much more attractive than for vertical pumps with multiple stages.

**Underfiling and streamlining**

The exact details of these procedures, and whether they are desirable, should be left to the discretion of the manufacturer. However, it is recommended that any new pump should be specified to have no obvious burrs on the machined surfaces of the impellers or bowls.

- Both procedures involve filing burrs on the machined vane of the impeller.
- **Streamlining** entails filing the opposite side of the impeller than underfiling
- Both underfiling and streamlining will improve efficiency and will aid in maintaining operating consistency. This occurs mainly due to reduced shock losses at the exit of the impeller. Due to the steeper discharge angle, the location of the BEP will also move out to a higher flow rate.
- The exact technique and/or angles that manufacturers use to underfile is somewhat of a 'trade secret'.
- Thinner blades have higher efficiencies, but they have less life span.

**Figure 11:** Thin part towards the bottom of the vane on the upper right photo has the correct thickness. The upper burrs (appearing as a thicker vane) need to be filed off.

![Figure 11: Thin part towards the bottom of the vane on the upper right photo has the correct thickness. The upper burrs (appearing as a thicker vane) need to be filed off.](image)

**Figure 12:** Machined impellers. The one on the left has been underfiled, and the one on the right still has burrs on it.

![Figure 12: Machined impellers. The one on the left has been underfiled, and the one on the right still has burrs on it.](image)
Wear rings
Impellers are centered in the pump casing (volute or bowl) with bearings. There must be a small clearance (not a bearing) between the impeller and the pump casing to allow the impeller to rotate freely. Some wear or erosion will occur at the point where the impeller and the pump casing nearly come into contact. This wear is due to the erosion caused by liquid and particulates flowing through this tight clearance from the high pressure side to the low pressure side. As the clearances become larger due to wear and the rate of leakage increases, the pump efficiency drops. This is illustrated in Figure 13.

Figure 13: Estimated efficiency decrease due to increased wear ring clearance. (Figure 1.78B in HI Centrifugal Pump Design and Application – 2000)

This location of the close tolerance section is illustrated below for a horizontal end suction pump, as seen by the designation of “wearing rings”.
The wear rings shown in Figure 14 special replaceable rings that are attached to the pump impeller. With vertical pumps, they are usually attached to the bowl itself, although sometimes they are also found on the impellers. Vertical turbine pumps can have wear rings on both the top and bottom of the impeller, although they are most common on the suction (bottom) side.

The idea of using wear rings is that if the close-tolerance surfaces are replaceable, they can be replaced periodically over the life of the pump without the more costly replacement of the impeller or casing.

Interviews with manufacturers and pump dealer/repair companies showed very conflicting sentiments regarding the use of wear rings. Some have strong feelings against wear rings, using the following arguments:

1. If the water is clean with no abrasives, installing wear rings is a complete waste of money.
2. By the time the wear rings have worn down to a noticeable extent, the bowl and impeller have also been worn down and need replacement.

On the other hand, it common for engineers to specify wear rings on new installations. Even here, there are differences in opinion as to what hardness the materials should have. Some manufacturers promote wear rings that are softer than the impeller materials; others promote wear rings that are harder than impeller materials. Others promote the use of hard materials.
for both of the wear surfaces. It seems most logical to use hard materials on both wear surfaces, but to avoid materials that will gall, such as stainless steel.

**Figure 15: Fully machined impeller. Wear ring goes where arrow is pointing, on the inlet side. Ring is stationary, so it is pressed into the bowl or volute, and rubs on the impeller.**

The cost to add double rings to a single stage of 10” – 12” vertical turbine will cost $100 - $300 for bronze materials, and $600 - $900 for harder materials.

*Dynamically balancing of impellers (for vibrations)*

Dynamic balancing of impellers is no different from dynamic balancing of car tires. Balancing should be to better than ISO 1940 Grade G 6.3 specs. The balancing is typically done by grinding small amounts of material from the heavy side of the impeller.

**Figure 16: Dynamic Impeller Balancing Equipment. Photo courtesy Hines Industries, Ann Arbor, MI.**
Maintain a high pumping plant efficiency
Devices/techniques that will help maintain low energy consumption:

1. Prevention of pump impeller/bowl wear
   a. New impeller materials
   b. Special linings
2. Prevention of bearing wear
   a. New oiler designs
   b. Special bearings and lubricant systems

Oil drip rate and oilers for vertical turbine pumps
Perhaps 70% of sudden failures of deep well vertical turbine pumps are caused by improper lubrication of motor bearings and lineshaft bearing problems. Use of newer bearing materials for water lubricated lineshaft bearings is discussed below. But most deep well pumps in agriculture have oil lubricated lineshaft bearings. There are three outstanding issues with the oil lubrication:

1. Most people do not know the proper drip rate.
2. The oil reservoirs are too small, so they may run out of oil before they are refilled.
3. Hardware that is sold does not provide for a constant drip rate over time.

Proper oil drip rate. Christensen (a division of Layne Christensen Co.) provides the following advice in its Deep Well Turbine Pumps manual:

<table>
<thead>
<tr>
<th>Shaft Diameter (inches)</th>
<th>Basic Drops per minute</th>
<th>Additional Drops per Minute per 100 ft. setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>.75 – 1.19</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>1.50 – 1.68</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>1.94 – 2.43</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>2.68 and larger</td>
<td>12</td>
<td>5</td>
</tr>
</tbody>
</table>

Size of oil reservoir. A gallon of oil (size of many standard oil reservoirs) holds about 150,000 drops. This corresponds to about a 2 day to 2 week supply of oil in a typical one gallon oil reservoir. ITRC recommends using a reservoir holding a minimum of about 4 gallon.

Maintaining a constant oil drip rate. Oil drip rates change over time for three reasons:

- The level of the oil in the reservoir drops, decreasing the pressure on the adjusting valve.
- The temperature of the oil reservoir drops, decreasing the viscosity.
- The adjusting valve, or its entrance, becomes plugged.
A design by ITRC, shown in the following figure, overcomes all of these problems by:

- Raising the oil reservoir several feet above the adjusting valve. Therefore, a change in the oil level in the reservoir itself only represents a small percentage change in the total pressure on the valve.
- Some of the pumped water is circulated around the oil tube, immediately above the adjusting valve. This maintains a fairly constant oil temperature, regardless of air temperatures.
- The size of the oil reservoir is 4-5 gallons, so it does not need to be refilled as frequently as conventional oil reservoirs.
- The bottom of the oil reservoir is drainable, so sludge and contaminants and water can be removed easily.
- The intake pipe to the flow adjusting valve is located several inches above the floor of the reservoir, to minimize the chance of contaminants entering the adjusting valve.

Figure 17: ITRC well pump oiler
Lubricant types. Christensen recommends the following lubricants for pumps. Soy oil is also available for lineshaft lubrication.

**Table 6: Recommended pump lubricants**
(from Christensen Pumps O&M Manual Deep Well Turbine Pumps)

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Recommended Standard Industrial Lubricants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chevron Texaco Corp.</td>
<td>Chevron Ultri-Plex Grease EP2</td>
</tr>
<tr>
<td></td>
<td>Texaco *Regal EP 32</td>
</tr>
<tr>
<td>CITGO Petroleum Corp.</td>
<td>Mystik Oil &amp; Grease</td>
</tr>
<tr>
<td></td>
<td>Mystik JT-S Grease (S-494)</td>
</tr>
<tr>
<td></td>
<td>Premium Lithium EP2</td>
</tr>
<tr>
<td></td>
<td>Lyondell Lubricants</td>
</tr>
<tr>
<td></td>
<td>Litholine HEP Grease</td>
</tr>
<tr>
<td>Fiske Brothers Refining Co.</td>
<td>Lubriplate</td>
</tr>
<tr>
<td></td>
<td>130AA Grease</td>
</tr>
<tr>
<td>Exxon Mobil Corp.</td>
<td>Mobilux Grease EP2</td>
</tr>
<tr>
<td></td>
<td>Exxon *Nuto H Hydraulic Oil 32</td>
</tr>
<tr>
<td></td>
<td>Ladok EP 2</td>
</tr>
<tr>
<td>76 Lubricants Co.</td>
<td>76 Lubricants</td>
</tr>
<tr>
<td></td>
<td>Multiplex EP Grease 2</td>
</tr>
<tr>
<td>Shell Oil</td>
<td>Shell</td>
</tr>
<tr>
<td></td>
<td>Alvania EP Grease 2</td>
</tr>
</tbody>
</table>

*Note: In front of the oil grade means it is suitable for sub zero (F) temperature service.*

**Table 7: Recommended food machinery lubricants**

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Recommended Food Machinery Lubricants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chevron Texaco Corp.</td>
<td>Chevron #FM Grease EP2</td>
</tr>
<tr>
<td></td>
<td>Texaco #Cygnus Grease 2</td>
</tr>
<tr>
<td>CITGO Petroleum Corp.</td>
<td>Mystik FG Grease (S-607)</td>
</tr>
<tr>
<td></td>
<td>#Mystik TG 2 Grease (5607)</td>
</tr>
<tr>
<td></td>
<td>#Clariant FG HEP Grease</td>
</tr>
<tr>
<td></td>
<td>Lyondell Lubricants</td>
</tr>
<tr>
<td></td>
<td>Ideal FG 2 Grease</td>
</tr>
<tr>
<td>Fiske Brothers Refining Co.</td>
<td>Lubriplate</td>
</tr>
<tr>
<td></td>
<td>FM: 1 Grease</td>
</tr>
<tr>
<td>Exxon Mobil Corp.</td>
<td>Mobilux Grease PM103</td>
</tr>
<tr>
<td></td>
<td>Exxon Foodrex FG 1</td>
</tr>
<tr>
<td>76 Lubricants Co.</td>
<td>76 Lubricants</td>
</tr>
<tr>
<td></td>
<td>76 Pure FM Grease</td>
</tr>
</tbody>
</table>

*Note: 1. In front of the oil grade means it is suitable for sub zero (F) service. 2. Food machinery lubricants meet USDA H-1 requirements and FDA document 21 CFR 178.3570. In addition, # in front of the product name means it is NSF 61 registered products.*
Lower discharge bearing. Mixed and axial flow pumps have a “lower discharge bearing” located immediately above the bowl assembly. Even if the other bearings are oil lubricated, this bearing is product lubricated. It is common practice to run a grease line from the surface down to this bearing on axial and mixed flow pumps because of their short setting and the fact that they are in sumps rather than in confined wells. The figure below shows a mixed flow pump being assembled with such a fitting.

**Figure 18: Grease fitting to lubricate the discharge bearing of a mixed flow pump**

Bowl Sump Bearing. Some low-lift (axial or mixed flow) vertical pumps have a bearing on the inlet bell itself. These are also grease lubricated in very sandy conditions. Vesconite bearings could also be used. The figure below shows a grease tube that supplies the bearing.

**Figure 19: Grease tube to lubricate the bowl sump bearing**
Wear on impeller and bowls

There are three types of wear that one may find on impellers:

1. Corrosion
2. Sand erosion
3. Cavitation

Cavitation problems can be solved with a proper pump and inlet design, so it is not discussed further in this section. It is interesting to note that a material that is resistant to cavitation may be poorly suited for sand wear resistance. Corrosion and sand wear problems can be minimized if the proper impeller and bowl materials are used, which is discussed below.

ITRC was unable to find any information regarding how pump performance degrades over time with sand wear with various materials and sand concentrations. ITRC is currently performing research on impeller/bowl sand wear, and corresponding pump performance. That research resulted from this PIER grant.

The table below provides some information regarding sand wear on different alloys.

### Table 7: Typical impeller-tumbler wear data for ferrous alloys

<table>
<thead>
<tr>
<th>Alloy and designation</th>
<th>Chemical composition</th>
<th>Hardness (BHN)</th>
<th>Volume loss (mm³/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>304 SS</td>
<td>18.9Cr-2.4Mn-8.0Ni-0.4Si-0.3Mo-0.3Cu</td>
<td>153</td>
<td>104.7</td>
</tr>
<tr>
<td>Gall Tough a, b</td>
<td>0.1C-16.3Cr-5.5Mn-5.2Ni-3.5Si-0.1Mo-0.1Cu-0.1N</td>
<td>184</td>
<td>83.1</td>
</tr>
<tr>
<td>13% Mn Steel</td>
<td>1.1C-0.4Cr-12.8Mn-0.2Ni-0.4Si</td>
<td>201</td>
<td>78.2</td>
</tr>
<tr>
<td>ASTM A514</td>
<td>0.2C-0.5Cr-1.4Mn-0.2Ni-0.3Si-0.2Mo-0.4Cu</td>
<td>269</td>
<td>94.7</td>
</tr>
<tr>
<td>18-18Plus a, b</td>
<td>0.1C-17.4Cr-17.7Mn-0.4Ni-0.5Si-1.0Mo-1.0Cu-0.5N</td>
<td>315</td>
<td>90.5</td>
</tr>
<tr>
<td>REM 500</td>
<td>0.3C-1.1Cr-0.6Mn-0.3Si-0.2Mo</td>
<td>495</td>
<td>91.3</td>
</tr>
<tr>
<td>AISI 4340</td>
<td>0.4C-0.8Cr-0.7Mn-0.18Ni-0.3Si0 1Mo</td>
<td>515</td>
<td>89.7</td>
</tr>
<tr>
<td>HT-6a</td>
<td>0.3C-19.6Cr-0.1V-7.2Fe (bal Ni)</td>
<td>597</td>
<td>188.2</td>
</tr>
<tr>
<td>D2 tool steel</td>
<td>1.6C-13.7Cr-0.5Mn-0.2Ni-0.4Si-0.8Mo-0.8V</td>
<td>608</td>
<td>69.5</td>
</tr>
<tr>
<td>White cast iron</td>
<td>3.2C-15.3Cr-0.8Mn-0.5Ni-0.4Si-1.0Mo</td>
<td>698</td>
<td>67.1</td>
</tr>
<tr>
<td>CHW-45</td>
<td>2.1C-5.4Cr-0.2Ni-1.5Mo-1.1V</td>
<td>709</td>
<td>106.6</td>
</tr>
<tr>
<td>AISI 1060</td>
<td>0.8C-0.4Mn</td>
<td>716</td>
<td>63.9</td>
</tr>
<tr>
<td>MS-5A</td>
<td>0.9C-15.2Cr-5.4Ni-3.8Mo-4.8C0-0.1V</td>
<td>772</td>
<td>109.4</td>
</tr>
<tr>
<td>CM b</td>
<td>2.3C-11.1Cr-0.2Ni-2.8Mo-0.1V</td>
<td>891</td>
<td>73.3</td>
</tr>
<tr>
<td>C b</td>
<td>2.7C-2.9C-0.2Ni-3.1Mo-0.1V</td>
<td>999</td>
<td>46.3</td>
</tr>
</tbody>
</table>

*The Gall Tough a, b and the 18-18 Plus a, b are nitrogen-containing stainless steels produced by the Carpenter Technology.

*b These materials are the Ferro-Tic a, b line of TiC reinforced composites produced by Alloy Technology International (HT-6A is a Ni-based matrix, while the others are Fe-based).*
Relative prices of various materials are given in the table below. A “typical” agricultural irrigation well pump impeller in California will weigh about 25 pounds.

**Table 8: Relative prices of various impeller materials**

<table>
<thead>
<tr>
<th>Material</th>
<th>$/lb in 2010</th>
<th>Cost difference for a 25 lb impeller</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast Iron</td>
<td>1.95</td>
<td></td>
</tr>
<tr>
<td>Ductile Iron 65-45-12</td>
<td>3.54</td>
<td></td>
</tr>
<tr>
<td>Ductile Iron 100-70-03</td>
<td>2.96</td>
<td></td>
</tr>
<tr>
<td>Bronze</td>
<td>9.01</td>
<td>0</td>
</tr>
<tr>
<td>316 Stainless Steel</td>
<td>7.50</td>
<td>-38.</td>
</tr>
<tr>
<td>CD4MCU Stainless Steel</td>
<td>10.51</td>
<td>+38.</td>
</tr>
<tr>
<td>Super Duplex Stainless</td>
<td>22.82</td>
<td>+345.</td>
</tr>
<tr>
<td>(v. high chrome)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Evidently, most published pump curves, unless stated otherwise, are based on some type of bronze as the impeller material. SAE 40 red brass, SAE 63 zincless bronze, silicon bronze, aluminum bronze, or Ni-Al-bronze all have about the same smoothness, which means no difference in the efficiency of the impeller (not bowl). All of the iron materials (cast iron, ductile iron, and Ni-Resist) all have a much rougher finish. Therefore, unless they are carefully polished, they will typically have 1-2 percentage points drop in efficiency compared to published data. Stainless steels have the same roughness problem, but they have an additional challenge in that the castings come out a bit smaller than with other materials, so the actual head and flow are a bit lower than published if the manufacturer is not a top-end manufacturer who publishes special curves or modifies the casting process.

As prices of materials have come closer, there is less cost difference between materials. Therefore, some companies are switching to standard stainless steel impellers. Many people believe that if there is a sand problem a hard iron should be selected over any bronze alloy (such as aluminum bronze).

Corrosion is not a major factor in most of California, with the exception of some areas near the ocean. **Table 9** provides information regarding common pump component materials and their resistance to corrosion.
Table 9: Relative corrosion of various materials available for use in pumps.

<table>
<thead>
<tr>
<th>Material</th>
<th>No Corrosion</th>
<th>Increasing to</th>
</tr>
</thead>
<tbody>
<tr>
<td>59% Ni-Cr-Mo Alloy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Titanium</td>
<td>&lt; 1 (25)</td>
<td>&lt; 10 (255)</td>
</tr>
<tr>
<td>70/30 Cu-Ni Alloy (Fe 0.5%)</td>
<td>&lt; 2 (51)</td>
<td>&gt; 5 (127)</td>
</tr>
<tr>
<td>90/10 Cu-Ni Alloy (Fe 1.5%)</td>
<td>&lt; 2 (51)</td>
<td>&gt; 5 (127)</td>
</tr>
<tr>
<td>Aluminium Brass</td>
<td>&lt; 3 (76)</td>
<td>&gt; 5 (127)</td>
</tr>
<tr>
<td>Admiralty Brass</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Steel (127-255 g/m²)</td>
<td>10-20 (255-510)</td>
<td>20-30 (510-760)</td>
</tr>
<tr>
<td>Ni-Cu Alloy 400</td>
<td>&lt; 1 (25)</td>
<td></td>
</tr>
<tr>
<td>70/30 Cu-Ni Alloy (Fe 5%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stainless Steel Type 316</td>
<td>&lt; 1 (25)</td>
<td></td>
</tr>
<tr>
<td>Stainless Steel Type 304</td>
<td>xx</td>
<td>&lt; 1 (25)</td>
</tr>
<tr>
<td>Ni-Cr Alloys</td>
<td>xx</td>
<td>&lt; 1 (25)</td>
</tr>
<tr>
<td>Nickel</td>
<td>x</td>
<td>&lt; 1 (25)</td>
</tr>
<tr>
<td>Ni-Al Bronze</td>
<td>x</td>
<td>&lt; 10 (255)</td>
</tr>
<tr>
<td>Ni-Al-Mn Bronze</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gunmetal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Austenitic Nickel Cast Iron</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mn Bronze</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NOTE: Approximate corrosion rates are given by the figures on the bars and expressed in units/hr as mils/yr (microns/yr).

SOURCE: (INCO) International Nickel Company
NIT Publication 12007 [Copper-Nickel Alloys - Properties and Applications (12007) Published by Copper Development Association, in co-operation with the Nickel Development Institute, 1982.]
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