RESULTS OF INVESTIGATIONS OF FAILURES OF GEOTHERMAL DIRECT-USE WELL PUMPS

Prepared for:

U.S. Department of Energy
Contract No.: DE-FG07-90ID 13049 A007

By:

Gene Culver

Geo-Heat Center
Oregon Institute of Technology
Klamath Falls, OR

December 1994

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

DISCLAIMER STATEMENT

This report was prepared with the support of the U.S. Department of Energy (DOE Grant No. DE-FG07-90ID 13040). Any opinions, findings, conclusions, or recommendations expressed herein are those of the author(s) and do not necessarily reflect the view of DOE.

ABSTRACT

Failures of 13 geothermal direct-use well pumps were investigated and information obtained about an additional 5 pumps that have been in service up to 23 years, but have not failed. Pumps with extra long lateral and variable-speed drives had the highest correlation with reduced time in service. There appears to be at least circumstantial evidence that recirculation may be a cause of reduced pump life. If recirculation is a cause of pump failures, pump specifiers will need to be more aware of minimum flow conditions as well as maximum flow conditions when specifying pumps. Over-sizing pumps and the tendency to specify pumps with high flow and low Net Positive Suction Head (NPSH) could lead to increased problems with recirculation.

INTRODUCTION

Over the years since 1978, the Geo-Heat Center has been asked for advice on new pump installations and replacement installations. For at least half that time, the advice was based on experience with pumps on the Oregon Institute of Technology campus since it was the only modern large geothermal direct-use installation, and of course, the Center is located on the campus. Some information on this system was readily available. The other large system, the Warm Springs Water District in Boise, Idaho, was nearly 100 years old; but, we had limited contact with them.

Most, if not all, geothermal well pump problems seemed readily solved. Typical problems were worn impellers due to lack of adequate bowl lateral, broken column lineshafts due to bearing failures and hard starts, coupling failures due to hard starts, and excessive longitudinal loads, etc. In most cases, we recommended all or part of the following.

1. Variable-speed drives to eliminate hard starts and also reduce pumping costs in variable load situations (space heating).

2. Enclosed lineshaft with oil lubrication to eliminate bearing contact with geothermal fluid and provide better lubrication to column bearings.

3. Careful consideration of thrust loading and thermal expansion timing differences between column and shaft to assure adequate lateral allowances in bowls and impellers.

4. Maximum diameter shafting for column and pump. Maximum diameter will provide 10 - 15% increase in bearing surface area in shaft sizes usually used in direct-use pumps.

5. Keyed and colletted impeller to shaft connections at temperatures over about 160°F. (This suggestion was not as widely accepted as the others.)

Over the years through new installations and replacement of failed pumps, most of the suggestions were followed. There was a period of several years when no pump failures that could be attributed to the above were reported and we thought the problems were largely resolved.

Then about 3-1/2 years ago, new pump problems began to be reported. These were not generally attributable to the above, but appeared to be bearing and other failures in the pumps themselves as opposed to column bearings. The Geo-Heat Center initiated a study of pump failures documenting as much information as was readily available in an effort to provide information for better pump application. Pump information was obtained on an "as available" basis. The following case histories are probably the best way to describe the conditions.

PUMP FAILURES

Oregon Institute of Technology

The OIT space heating system was started in 1964 and was not without problems during its first years of operation. There was little experience with pumping geothermal water to rely on and it was a learn-as-you-go situation.

Written records are very sketchy; but based on recollections, the three original pumps were basically irrigation or municipal well water pumps with direct-coupled motors, open lineshaft with rubber bearings and standard lateral pumps with bronze bearings and impellers. The wellhead and motors were in pits or cellars below ground level. The three wells vary in depth and productivity, so each pump was slightly different. The wells are within about 400 ft of each other and produce from the same aquifer. Water temperature is the same in all three--192°F.

Problems experienced were broken lineshafts probably due to swelling of the rubber column bearings and seizing on the lineshaft. Teflon bearings were tried; but, they also apparently swelled and problems continued. This was aggravated by the direct-coupled hard starts. Motors overheated probably due to lineshaft bearings swelling (increasing motor loading) and lack of ventilation in the wellhead pits. Pump impellers loosened on the shaft due to differential expansion of the bronze impellers and stainless steel colletts and shaft. (Bronze expands at approximately twice the expansion rate of stainless steel). Bronze lineshaft bearings were tried; but, the geothermal water apparently corroded them and lineshaft bearing problems continued. Because of the lack of lateral in the bowls, pumps that had been shut off required preheating by pumping water from another well into the idle well to thermally equilibrate the entire column and shaft. This was time consuming and probably thermal equilibrium was not always reached, resulting in impeller and bowl wear.

In 1969 and 1970, a program of upgrading the pumping system was initiated. The wellheads were raised above ground level and enclosed in well ventilated well houses. Variable-speed fluid couplings were installed. New pumps with oil-lubricated enclosed lineshaft and bronze bearings with extra lateral bowls and impellers (up to about 4 inches), and keyed colletted impellers were installed. Pumps were set 40 ft below previous setting to increase water vapor pressure at the pump suction.

<u>OIT Production Well #5</u>
Layne Bowler 10 in. diameter type RL 12 stage
Serial number 26530 (?)
Setting depth: 440 ft
Pumping level: 350 ft @ 550 gpm (estimated)
Installed March 1970

The pump was pulled, disassembled and inspected on-site June 1979 for scheduled maintenance. All pump bowls and impellers were ok--installed new pump bearings and reassembled pump. Column bearings were ok; but, two sections of column showed outside corrosion and were replaced.

In July 1989, the pump was pulled, disassembled and inspected for scheduled maintenance. The tail (bottom) bearing and two bearings up were worn. The pump was overhauled including new pump bearings and impellers. The pump shaft and bowls were reused. Also new were 46 lineshaft bearings, 30 10 ft-column pipes (12 were reused), and one oil tube support spider.

This pump had been in service for 19 years and 5 months, with one minor overhaul, when it was pulled in 1989. Luckily it was pulled and inspected since wear would have progressed up the pump after the lower bearings were worn. In another year, more or less, the bearings, impellers and bowls would probably have been worn to the point where replacement of the entire pump would have been required. As it was, only the impellers and bowl bearings were replaced saving considerable expense.

August 1994--For several months, it had been felt that #5 pump flow was diminished and getting worse. The pump was pulled. The pump was not personally inspected by the author; but, photographs were obtained.

As can be seen from the photographs, failure was initiated in the lower end. The suction case bearing (tail bearing), bearing case and even the supporting ribs are gone. A small amount of one the ribs can be seen in the suction case (Figure 1). Also in Figure 1 are what was remaining of the first stage impeller, pieces of bearings, and the bottom cap of the suction case bearing. Figure 2 shows that the first intermediate- stage bearing support is worn through to the waterways, and the 2nd-stage impeller skirt and part of the shroud are worn away. The 10th- and 11th-stage bearings and impellers (Figure 3) still show wear, but far less than the lower stages.

Figure 1. OIT #5 suction case, 1st bowl and impeller.

Figure 2. OIT #5 suction case, 1st and 2nd bowls, and 2nd and 3rd impellers.

Figure 3. OIT #5 10th and 11th bowls, and impellers

This pump had been in the well almost exactly five years and was still operating, but at reduced flow rate. Although the lower end was completely gone and obviously banging around inside what remains of the lower bowls, the pump noise at the surface was normal except for some wear in the variable-speed drive thrust bearing, which could be heard and located using a stethoscope.

It is important to note that OIT has 3 wells which are alternately pumped. Two wells produce about the same amount and are alternated during the winter when heating loads are high, and in summer to run the absorption chiller. The third well has lower productivity and is used during spring and fall, and exercised occasionally during winter.

There are no written records of when each pump is run. Maintenance personnel just try to balance the run times by recollection and changing on a fairly regular basis.

When pulled and overhauled in 1989, the actual run time was probably greater than 6 years. When pulled in 1994, actual run time was probably about 2-1/2 years.

OIT Production Well #2

Aurora	7-in. diameter	type 50-VTP-RM	35 stage

Serial number: V79-04554
Setting depth: 560 ft
Pumping level: 510 ft @ 130 gpm (estimated)

As with the other OIT wells, #2 was refurbished during the early 1970s. This included extending the casing and raising the pump motor out of the cellar, changing from open lineshaft to enclosed oil-lubricated shaft, new extra long lateral bowls and impellers, and adding Nelson Liquid Drive for variable-speed control.

The new pump installed in July 1974 was an Aurora 50-VTP-7RM-35 hung on 560 feet of 5 in. x 2 in. x 1-3/16 in. column, tube and shaft. The 35-stage pump is rated at 130 gpm @ 637 ft Total Dynamic Head (TDH) @ 1680 rpm. Pump bearings are standard leaded tin bronze. Lateral is 4.2 inches. Well #2 is about 400 ft from wells #5 and #6, and produces from the same 192°F water strata, but at lower production. Pumping submergence is believed to be about 50 ft at 130 gpm.

This pump has not been pulled since its installation in 1974, and is still running apparently smoothly. Actual run time is unknown since run times are not logged; but, it is estimated to be greater than 6 years equivalent. It is used as a backup pump, for low-load conditions in spring and fall, and sometimes for medium-load conditions in conjunction with #6.

OIT Production Well #6

Aurora	8-in. diameter	type RH	26 stage

Serial number: D29347
Setting depth: 600 ft
Pumping level: 550 ft @ 350 gpm (estimated)

The pump in OIT Well #6 was installed in March 1971. It is an Aurora 3 RH with 26 stages and inter-stages between 9 and 10, and between 18 and 19. The pump is rated at 350 gpm

@ 650 TDH @ 1720 rpm and has 4.2 inches of lateral. The pump was hung on 600 ft of 6 in. x 2-1/2 in. x 1-1/2 in. column, enclosing tube and shaft. In June 1988, the pump was pulled and refurbished with new pump bearings and impellers, and the column was extended to 650 ft. The pump repairman remembered that the three lower bearings and impellers were worn with wear decreasing up the pump, and that bearing and impeller wear near the top was nil. All the original bowls and shaft were reused. The Nelson Liquid Drive thrust bearings were replaced in 1974, 1977 and again when the pump was refurbished in 1988. As of October 1994, the pump sounds smooth; but, the output had decreased to 215 gpm, measured during a 6-hr flow test in July 1994. There is no flow meter to check the flow on a regular basis.

Pump #6 is used less than #5, but more than #2. It is estimated that actual rotating time is 6 - 7 years with speed and flow rate varying with campus heating load. The pump is sometimes used in conjunction with #2 during which time the speed and output of both pumps would be reduced during days when the campus heating load is low.

Calistoga Bottled Water

A new well was drilled to provide water for bottling, bottle washing and cleanup. The well produces water at about 250°F of good quality "mineral spring" water. A 6-inch vertical open lineshaft pump was set at 240 ft in an 8-inch casing. The pump ran essentially continuously to supply water for a three-shift operation. Static water level was at or near the surface after shut down for a few hours for maintenance in the plant.

<u>Symptoms</u>

After only 2 1/2 months, a "noticeable" vibration was occurring at the pump. The pump was pulled and lineshaft bearings and shaft wear was apparent at 100 ft, and at 160 ft. All other column bearings, shaft and the pump itself were reported to be in useable condition. Worn bearings and shaft sections were replaced, and the assembly reinstalled (Lynn, 1989).

After another 2 months, vibration was noted again and the pump pulled, column bearings and shaft at 100 ft and 160 ft were replaced and re-installed. Vibration was noted again after only 6 weeks and on pulling the pump, wear was noted in the same areas.

At this point, a conference was held attended by company engineers and managers, the driller (who was also the pump installer), and a Geo-Heat Center representative. Drillers logs were examined and changes of formation noted at about the bearing failure depths. The driller's daily log, not previously supplied, noted "rough drilling" at the same depths. Although the driller insisted the hole was straight and plumb as evidenced by the fact the pump went down the hole very easily, it was decided to plumb bob the hole using the method suggested by Roscoe Moss Company (Engineers Manual for Water Well Design 1985).

The results of the plumb bob run indicated a dog leg of about 3 inches at 110 ft and another at 85 compass degrees from the first at 150 ft of about 3 inches.

Conclusions

Although the lineshaft pump went in the hole easily, it was apparent the well was crooked. A submersible pump was installed and has been operating for about five years (as of December 1994).

The driller's logs indicated changes from lava to sandy clay, and back into lava in about 10 - 15 ft in the areas where bearing problems were noted. It is probable that the top of the lava flows had been breciated and somewhat cobbled due to initial cooling and later weathering. This condition could have caused the rotary bit to deviate and would not have been noticed at the surface. Drilling a straight hole under such conditions is difficult. About all that can be done is to plumb bob the hole and if crooked, ream the hole to accept casing large enough to permit the pump to hang straight. This of course increases the cost of the well and many drillers and owners simply hope the well is straight.

Merle West Medical Center

The Medical Center was converted from natural gas to geothermal heating in November 1976. The system was patterned somewhat after the OIT system which had operated satisfactorily for about seven years after the modifications. The major difference was that the pump discharged to a tank and was level controlled in an on/off mode. The well is about 600 ft from the OIT wells and produces from the same aquifer.

The pump was:

> Layne Bowler, 10 in. diameter, 14 stage, enclosed oil-lubricated lineshaft with bronze bearings and impellers, set at 550 ft. Extra long lateral of 4 in. was provided. Drive was 100-hp through a Nelson Liquid Drive. Rated flow was 500 gpm and pumping level should have been 350 ft based on pump testing. During normal operation, the pump cycled about four times per hour in response to the level controller and was on about 20% of the time.

On August 11, 1979, loss of pumping capacity was noted and the pump was pulled August 29, 1979. Disassembly and inspection revealed the keys from stages 1 and 14 were missing, and it appeared that one key had passed through several stages and damaged the impellers and bowl vanes.

Stages 3 and 13 were sent to Radian Corp. (Anliker, 1981), who were then involved in corrosion/erosion analyses for USDOE, for analysis. A summary of their results was:

> "The pump materials were essentially as specified. Bearings and impellers were ASTM B584 C83800 and the shaft was 316 stainless steel. Pump bowls were ASTM A48 Class 20 rather than the Class 35 specified; but, the lower strength material did not appear to be detrimental for this application. No signs of corrosion were detected on the pump bowls, collets or keys.

The impellers showed mechanical damage (presumably from the key passing through) and slight erosion/corrosion. The amount of erosion/corrosion would not be significant for much longer periods of service than this pump had experienced. No dealloying of impellers was detected. Surface analysis indicated major amounts of magnetite and silicon on bowls and impellers with trace amounts of other constituents of the geothermal fluid.

The bowl bearings showed broad, shallow pits about 0.005 in. deep covering 13% to 17% of the bearing surface, resulting from attack by a sulfur species, probably hydrogen sulfide.

The pump had been in the well about 24,400 hours, experienced about 97,600 start-stop cycles, and about 4,880 rotating hours (Lienau, 1984).

A new replacement bowl assembly and the original column, lineshaft and lineshaft bearings were installed." (Anliker, 1981)

January 1985--New bowl assembly installed. There are no recorded details of why. At that time, the control system was redesigned to provide constant turning of the pump. When no flow was required to the tank, the Nelson Liquid Drive slowed the pump to maintain water level in the pump column at or near ground surface, but provide no flow.

October 1987--Pump produced essentially zero flow. Flow had been diminishing for some time.

Inspection showed wear had progressed from the bottom stage up. Only bits and pieces of bearing could be found, and had black thin uniform coating which could be scratched with knife but not fingernail. Impeller skirts of most impellers were gone, and there was extensive wear to impeller vanes and shrouds on lower impellers. Bowl bearing wear had varied from nearly eliminating cast iron bearing seats in lower bowls (Figure 4) to portions of bearings remaining in the upper bearings (Figure 5), the shaft was worn and had copper colored areas at bearing locations (Figure 6).

Figure 4. MWMC 1st through 4th bowls and impellers.

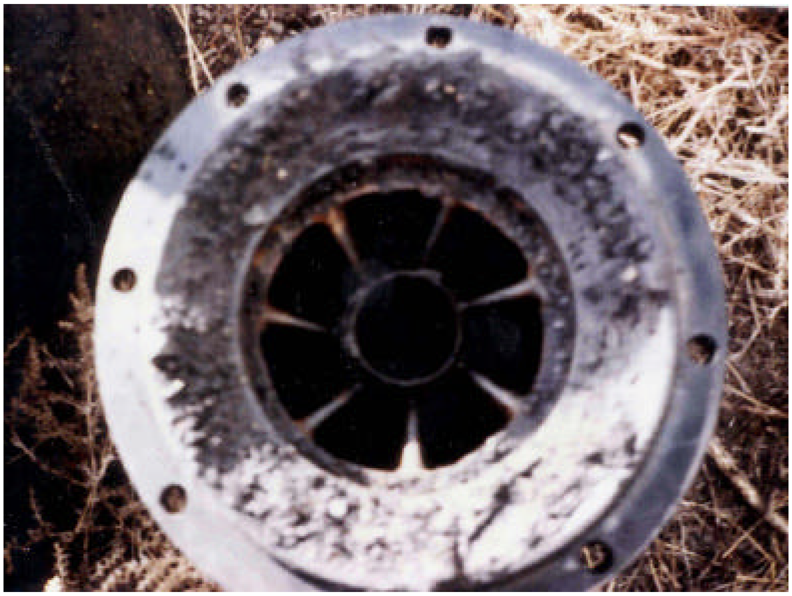


Figure 5. MWMC 13th bowl.

Figure 6. MWMC 1st stage impeller and discolored shaft.

The cause of this failure seems obvious. When running under no flow conditions, the power required to maintain the water column at near ground level is dissipated in the pump. Water in the pump soon is flashed to steam providing no lubrication. The bottom bowl, having the least pressure in it (pumping level head), experiences flashing first and flashing progresses up the pump.

December 1987--New Peerless bowl assembly installed. Assembly essentially the same as Aurora--Vertiline. Aurora had ceased manufacture of extended lateral hot water pumps due to lack of large number of sales. At this time, the wellhead was modified to dump water back in the casing. When the level control in the tank is not calling for water, pump speed is maintained to provide about 40 gpm of flow through the pump which is dumped back to the well, thus providing some level of cooling to the pump.

April 1990--A decrease in flow was noted which had been slowly increasing with time. The pump was pulled and the rebuilt Aurora from previous use installed.

It is reported that inspection noted lower and middle bearings and impeller skirts worn. Top bearings worn, but not bad (Campbell, 1990).

March 18, 1994--Twisted off head shaft just below Nelson Liquid Drive. Reported that drive had blown seals. Bowls were locked up. No report on bowls condition as of December 1994.

College of Southern Idaho

<u>Pump</u>

American Turbine, Model 11 H 110, 3 stage 1200 gpm, 189 TDH @ 1760 rpm. Pump setting 220 ft, 8-inch column, water lubricated column bearings on 10-ft centers.

Pump bowls, impellers and bearings were specified as zinc-less bronze due to poor experience with zinc alloy bronzes in valves and fittings.

The pump is variable frequency controlled. The well is artesian, but won't handle high loads on artesian flow only. Pump tested at 50% speed--441 gpm with 20 ft pumping level. At 100% speed, 1174 gpm and 11 psi at surface with 121 ft pumping level.

Maximum temperature 98^{o}F. Total dissolved solids 260 parts per million.

Pump installed late September 1992, failed December 1993 with about 200 hours run-time.

<u>Symptoms</u>

Pump vibrated during initial start up at 25 - 40% of full speed. The variable frequency control was set to run through that speed range quickly and to block out continued operation at those speeds. Vibration was not noticeable at 50% speed and above.

Pump slowly pumped less and less, vibration got worse and worse. Complete failure December 1993.

<u>Inspection</u>

Pump was not inspected by Geo-Heat Center personnel.

Initial inspection by Funk Irrigation showed top bearings worn most tapering off to tail bearing. Bowls and impeller worn, pump shaft broken. Column bearings ok.

Pump was shipped back to American Turbine for failure analysis.

Telephone conference July 1, 1993, with Dan Buetner, CSI maintenance supervisor, reported pump had been inspected by American Turbine and an independent pump consultant. Both concluded problem was due to improper installation--an alignment problem. It has not been confirmed whether the pump was or was not test run at manufacturer, but probably not.

<u>Conclusions</u>

This pump should never have been allowed to stay in hole after vibration was noted at initial start up.

The pump was completely rebuilt by American Turbine and the two bottom column section threads were cut off, the column machined and re-threaded. The pump has been reinstalled and is running very smooth as of December 1994. Apparently, the column pipe or at least the bottom one or two sections had been machined and threaded at a slight angle causing bearing wear and vibration of the shaft leading to fatigue failure of the shaft.

Ross Colahan, Paisley, Oregon

<u>Pump</u>

Worthington 8 in., 5 stage, semi-open, keyed impellers. Pump was used and reportedly newly rebuilt when purchased--as is, where is. No data on model or serial numbers. Pump was used to pump water to pond for cooling to be used for irrigation. On/off operation. Temperature 234°F.

<u>Symptoms</u>

Reduced flow and noisy. No record of run hours or number of cycles.

<u>Inspection</u>

Shaft broken at second impeller thrust ring. Thrust ring gone--probably pumped through. Second impeller and bowl very badly worn resulting from missing thrust ring. Other impellers and bowls badly worn apparently from lack of lateral and poor lateral adjustment. Bowl bearings badly worn.

<u>Conclusions</u>

This pump had a rough life. Lateral was worn and it was impossible to measure its intended length, but probably was about 3/8 inch to 1/2 inch. In order to operate the pump each time it was started it was run several minutes, shut off, the lateral adjusted, run several more minutes, shut off, lateral adjusted and this repeated until it seemed the pump did not severely load the motor. A very poor practice. It resulted in wear at both top and bottom of impellers and matching bowl surfaces. The broken shaft was probably the result of starting when the impellers were bound.

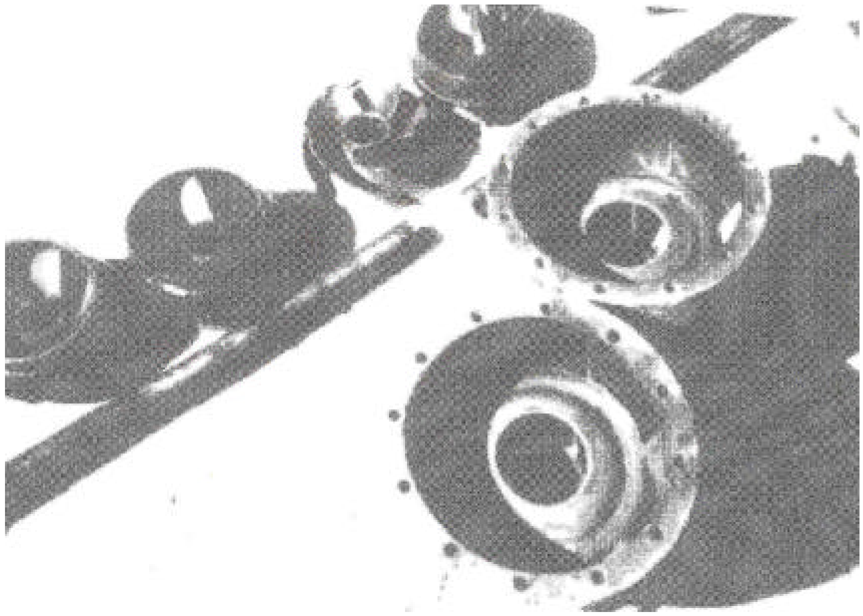


Figure 7. Ross Colahan pump 230 ft, 1-1/2 year operation, shaft broken at impeller thrust ring groove.

The pump is not beyond repair. It is planned to re-machine the bowls to provide more lateral and cleanup bowl/impeller skirt mating area, install impellers with longer and larger diameter skirts to match machining and to install silicon carbide bearings.

No report of operation as of December 1994.

Susanville District Heating System Well - Susan #1

<u>Pump</u>

Ingersol Rand, 10 NK bowls, H impeller 7.28 inch diameter, 8 stage, 1-1/2 inch stainless steel shaft. Bowls and impellers cast iron. 800 gpm @ 243 ft head. Pump bearings nitrile rubber.

The pump was set at 140 ft. Static water level is 15 ft and pumping level at 800 gpm estimated at 100 ft. Pumping temperature 174°F. The district heating system has never realized full build out, so pumping rate probably never exceeded 350 - 400 gpm. A variable frequency drive controls pumping rate to match requirements.

The pump column is enclosed lineshaft oil-lubricated with 2-1/2-inch tube and 1-1/2-inch shaft with bronze bearings on 5 ft centers.

Symptoms

According to pump installer, this pump was "tight" at installation. Shaft was difficult to turn by hand and lateral difficult to adjust. Lateral was adjusted to top, then backed off, according to manufacturer's specifications. Motor current was initially high, but reduced to normal after several hours run in.

This pump operated more or less satisfactorily for approximately 16 months--February 92 - June 93. After a power failure in early June 1993, the pump could not be restarted. Drive motor stalled, lateral could not be adjusted either up or down, and the drive shaft could not be turned with a pipe wrench.

A factory-rebuilt pump was installed using the same column, lineshaft and lineshaft bearings. The column bearings reportedly showed very little wear.

On June 18, 1993, the pump was briefly inspected in the Tri-County Pump yard near Susanville. An antectodal history (above) was obtained from Tri-County owner Larry Cravey. The pump was subsequently shipped to Hays Pumps in Anderson, CA, for disassembly and inspection.

On June 29, 1993, the pump was disassembled at Hays Pumps with a Geo-Heat Center staff member witnessing. Prior to disassembly, the pump shaft could not be turned and there was no lateral movement.

Inspection Results

When the Center staff member arrived, the pump was on a pump stand with the tail (inlet) and head (outlet) sections removed and not apparent. Presumably, these had been reused in the installation of the replacement pump. The tail bearings area looked to be in new condition--scratching with a fingernail could not detect any wear in the bearing area. At the headshaft bearing location, there was slight detectable wear around approximately 120 degrees of the pump shaft. This later was dial indicated and found to be 0.004 inch.

Disassembly proceeded normally after the first collet was loosened. Initially the top impeller could not be driven off the collet. It was decided to try disassembly from the bottom up; but, the collet could not be driven up inside the impeller. Heat was used on the bottom impeller with no better results after a number of hits with the slider. At that point, it was noted that the top collet had loosened in the top impeller and was disassembled. Disassembly proceeded normally from top down. Each impeller and bowl was visually inspected for wear as they were disassembled. The third from bottom impeller was noted to have a crack in its hub which extended to the outer end of the vane, but did not extend to the skirt. There was no rotation or lateral movement until the second from bottom impeller was loosened from its collet.

Bowls and matching skirts were measured after disassembly. All clearances were 0.010± 0.001 inch (within new specs), including #3 with the cracked hub.

Shaft run out was dial indicated at 0.002 - 0.003 inch except at the discharge bearing as noted above. Bearing wear areas were shiny, but could not be detected by fingernail. Rubber bearings appeared to be in like-new condition. Machining marks could be seen on both bowls and impellers indicating there had been no lateral wear. Bowls and impellers were shiny for about 5/16 inch indicating where impellers had been running; but, this was not detectable by fingernail or micrometer.

During disassembly, a black flaky material was noted in the bowls--probably iron sulfide--it broke down to a very fine power when rubbed between fingers. Each bowl had about the amount that could be picked up by scraping with two fingers--less than 1/8 teaspoon--some in the bowl itself and some in the bowl/skirt running area.

All normal and abnormal wearing surfaces were in new- or near-new condition. There were no indications of seizure. Hays pump engineers felt that the black flaky material may have settled into the 0.010 clearance between the impeller skirts and bowls, and bound the pump, similar to sand binding a well pump screen to remove it. Particles found in the bowl/skirt area were smaller than those in the bowl itself--perhaps crushed while driving impellers off the collet?

No serial number could be found on the pump.

<u>Past history of Susan #1 pumps</u>.

A sketchy, but more complete history of pumping in Susan # 1 was obtained from the city of Susanville records.

Ingersol bowls (duplicates of the ones inspected) were installed in November 1986. The pump ran until August 1989. Off due to power outage--wouldn't restart that day. Next day restarted--ran till September 16, 1989. Pump off September 17 (off due to power outage), wouldn't re-start. Next day with 3 hours of repeated starting and motor heaters stopping it, pump ran until February 14, 1992, when pump went off and would not restart. Pump had approximately 5-1/3 years of operation. February 15, 1992, pulled pump and changed bowls (to the ones inspected)--installed and started, but with high current draw. February 17, 1992, pump off but restarted with high current draw. Pump ran until June 8, 1993, approximately 16 months. June 10, 1994, installed factory-rebuilt bowls, started, ran and checked lateral adjustment. Shut off because of very low district heating load during summer--only domestic hot water and customers have backup. Attempted start September 21, 1993, after several attempts with motor stalling each time, pulled pump. September 22, 1993, pump out and could be turned by hand. A rebuilt pump with bronze bearings was installed in September 1993, before the Geo-Heat Center was informed of the last pump seizure and inspection could be arranged.

<u>Conclusions</u>

The pump inspected probably had a minor alignment problem between the pump itself and pump outlet or the column as indicated by the 120^{o} wear on headshaft. The pump outlet with its bearing and the column were not available for inspection since they had been reinstalled.

The fact that the inspected pump ran for approximately 16 months with no detectable wear in the main bearings or shaft, indicates that non-metallic bearing material may be useful. Pump seizures after some time in the well indicate that either the bearing clearances are too small or that the compound used swells more than estimated. Two identical pumps had the same symptoms. Since the last pump could not be turned with wrenches while in the well, but could be turned by hand after cooling, indicates the particular compound used swells on heating more than allowed for.

Hayes Pumps engineers have become interested in the problems and have contacted rubber manufacturers. They reported by telephone April 22, 1994, that the nitrile rubber compound used should be suitable at temperatures up to 200°F. However if there is even small amounts of oil present, the service temperature drops to about 100°F. Since the pump has an oil-lubricated lineshaft, it is possible for small amounts of oil to be pumped.

Hayes engineers are consulting with B. F. Goodrich Rubber Co. on the problem.

Modoc High School - Alturas, California - Well #AL 1

<u>Pump</u>

Worthington, BL 12, 11 stage, 9 impellers 5.81 in. trim, 2 impellers 5.13 in. trim, @ 1760 rpm, 80 gpm 170°F with 347 TDH. Enclosed lineshaft pressure oil lubricated. Pump setting 320 ft. Serial number C51591.

Total lateral 11/16 in. after machining extra 1/4 inch.

Bearing material specified was bronze ASTM B271 Alloy 932 - Cu 83%, Sn 7%, Pb 7%, Zn 3% centrifugally cast. Bowls and impellers cast iron.

Pump installed by Modoc Pump Co., Cedarville, CA. Interview indicated no installation problems--no hang up, well straight, pump and column could be easily rotated by hand when at setting depth. Normal start up--no excessive current draw on motor. No vibrations noted; although, it is unclear what the rpm ranges were. Pump is run on variable-frequency drive and has bypass back to well to provide recommended flow through pump when heating system is calling for minimum heat.

<u>Symptoms</u>

Pump was installed in March 1990 and ran satisfactorily through remainder of school year. Pump was run intermittently to provide hot water for showers during summer. The following school year, the pump seemed ok; but, by January of 1992, flow at given rpm was notably reduced and in order to maintain heat for school, rpm was increased. By May, flow was significantly reduced and pump was "noisy." Pump was pulled in June 1992. Approximately 20 months of satisfactory service had been achieved.

Inspection

A Geo-Heat Center staff member was on-site for pump tear down.

The lower bearing in the oil tube was badly worn--hourglass shaped. There were only bits and pieces of bowl bearings except for the tail bearing which was worn but still intact. Starting at the top, the first impeller skirt was worn completely away; 2nd, 3rd and 4th impeller skirts were worn but still attached; 5th and 6th skirts were completely gone; 7th worn but attached; 8th completely gone; and 9th, 10th and 11th skirts were there. The 11th or bottom impeller and bowl showed the least wear. Lateral had been correct as evidenced by no wear on top of impellers and machining marks visible on bottoms. An identification number was readable on the bottom impeller.

Figure 8. Left to right bottom: oil tube brg., top impeller, top bowl, and 2nd impeller from top.

Figure 9. Top bowl, 2nd impeller, 2nd bowl, 3rd impeller, 3rd bowl, and missing bearing remains.

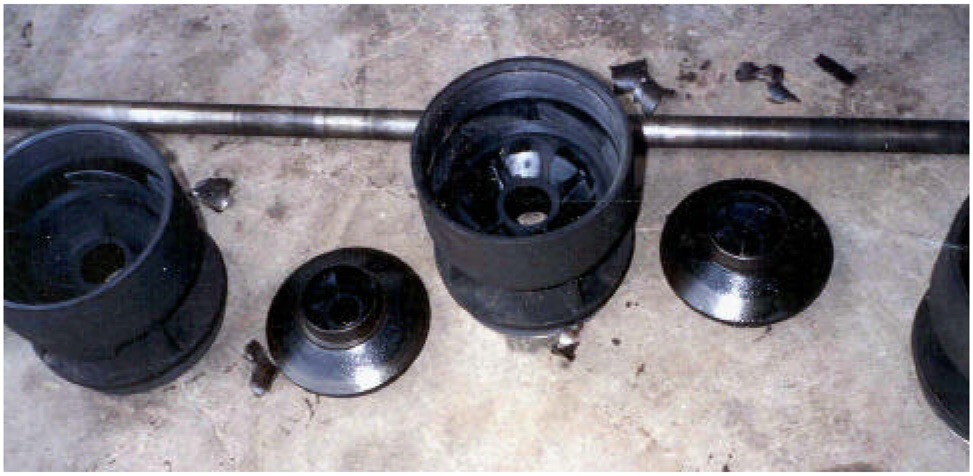


Figure 10. 3rd bowl, 4th impeller, 4th bowl, and 5th impeller.

Figure 11. 4th impeller, 4th bowl, 5th impeller, and 5th bowl.

Figure 12. 5th impeller, 5th bowl, 6th impeller, and 6th bowl.

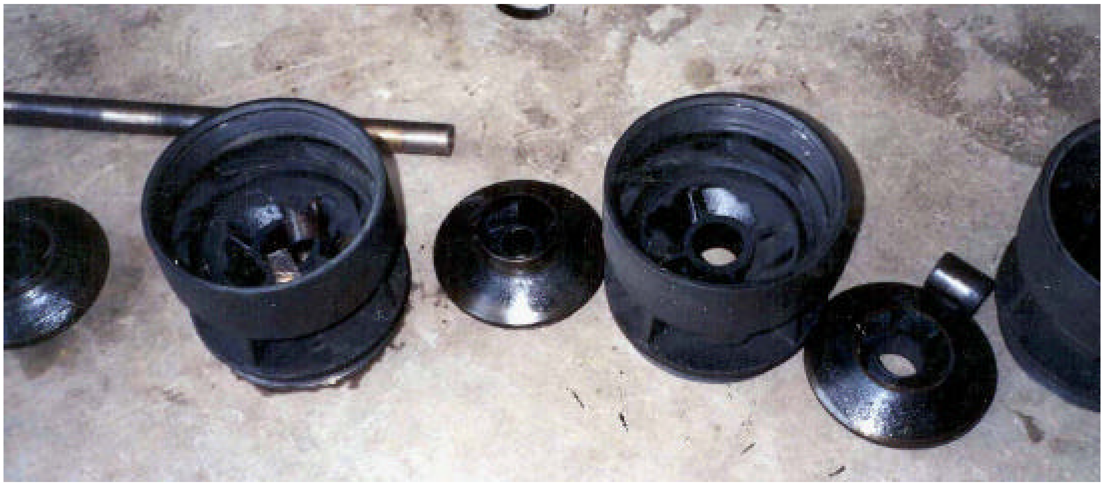


Figure 13. 9th, 10th and 11th impellers and bowls.

Impeller and bowl vanes appeared in as cast condition indicating no sand pumping, cavitation or recirculation problems.

The stainless steel pump shaft was in surprisingly good condition. There was visible wear at the bearing areas; but, the wear was even indicating the shaft was straight. Apparently, the impellers were acting as bearings during the later stages of pump life. Shaft run out was less than 0.003 inches over entire length with no excessively high or low areas.

Conclusions

Nothing specific. The alternating nature of wear suggests a critical speed problem or impellers out of balance. It's impossible to determine the initial cause. It is possible the rotating parts were initially out of balance; but, this is usually detected during impeller balancing at the manufacturer. However, if the manufacturer was not aware the pump would be operated on a variable-frequency drive, parts may not have been tested through the entire operating speed ranges.

One of the bearings may have prematurely worn allowing vibration to start--which would be self-perpetuating.

During a discussion of this pump with ex-pump designer/trouble shooter for a major pump manufacturer, now a private pump consultant, it was noted that top bearing problems have been caused by insufficient oil tube tension either through lack of tension during initial installation or due to alternating on/off operation and the resulting thermal expansion (personal communication, Jack Frost, 1994).

The bearing material is higher in tin content and lower in zinc than most bearings which should make it less susceptible to dezincification noted in some geothermal components.

Anonymous

The owner of this installation prefers to remain anonymous at least until the problem is solved and any potential conflicts resolved.

The application is space heating utilizing a 10-stage, 6-inch vertical turbine pump set at 90 ft. Temperature is 172°F with 77 gpm flow at 121 ft head at peak design conditions. Static water level is 5 ft 6 in. The column is open lineshaft with nitrile rubber cutlass type bearings and stainless steel sleeves with 10 ft spacing on a 1-inch diameter shaft. Pump speed is varied by a variable frequency drive in response to pump discharge pressure which in turn is controlled by valves at the various heating units. Pump speed varies between about 900 and 1760 rpm.

The pump, column, motor, drive and speed range were all specified by the engineer as to make, model and materials with no exceptions or substitutes.

Symptoms

After installation of the pump and initial run in at full speed, the pump installer set the speed limits on the variable frequency drive. The variable frequency control is in a basement mechanical room about 50 ft from the well and pump. The installer noted that during speed up from about 1300 rpm to about 1600 rpm, there were "noises" in the piping. He attributed it to water hammer, since the system valves had not been balanced.

During balancing of the system, the HVAC contractor also noted noises in the piping. He suspected the pump was sucking air and called the pump installer. An air line to check water level was installed, the pump ran at full speed several hours with no noise and pumping water level well above Net Positive Suction Head (NPSH) requirements.

The system ran for 1 week when the stuffing box at the discharge head started leaking and could not be stopped. The pump was pulled and inspection revealed the stuffing box, top column bronze bearing and the next two rubber bearings were worn and their stainless steel sleeves loose on the shaft.

New bearings and stuffing box were installed and the system started again. It ran for 10 days when noise and vibrations required shutdown.

Disassembly revealed stuffing box worn, all lineshaft bearings worn and top bowl bearings worn elliptical.

Conclusions

The pump installer discovered the problem. After such short operation times, he went through the basic pump and column selection procedure, and discovered that the shaft would be in the critical speed 2nd harmonic range between 1400 rpm and 1600 rpm. Since this all happened between Christmas and mid-February, it is likely the pump ran at critical 2nd harmonic speed much of the time.

Probably one of the problems in this project is lack of communication. It is not unusual to find an HVAC engineer who is not familiar with downhole turbine pumps; however, the redundancy in the purchasing system may have caught the problem had the full system design and operation been communicated. It appears that the regional pump representative, the pump manufacturer and the pump installer did not know the pump system was to be variable speed drive. Had they known, someone probably would have checked for critical speed through the speed range specified.

SUCCESSFUL PUMPS

In addition to finding and examining failed pumps, some successful pumps or pumps that have run for longer times than "normal" were located and information on their construction obtained.

Naef Well, Susanville, CA

The Naef well is used to supply geothermal water for space and domestic water heating at 155°F to the Housing and Urban Development (HUD) portion of the geothermal district heating system. The original pertinent pump specs were:

Well temperature	158°F
Flow	300 gpm @ 160 ft head
Static level	46 ft
Setting	160 ft
Design pumping level	146 ft
Size	7 inch (Peerless 7HXB)
Hp	20
Lubrication	Enclosed lineshaft, fresh water lub. column, geothermal water lub bowls.
Bearings	Nitrile rubber

The original pump failed after less than one year of service. The column was changed to oil-lubricated bronze bearings and bowl assembly rebuilt with bronze (SAE 64) bearings. At that time, the column was lengthened to 220 ft. The rebuilt pump was put in service in March 1985 and currently has 9 years, 8 months of service.

Both the Naef well and Susan #1 produce from the same aquifer; although, Susan #1 is about 20°F hotter, and both reportedly have 0.5 mg/l of H_2S.

The system has experienced only about one-third of its design potential build out. The pump has a pressure actuated variable speed control; so, it is assumed flow is about 100 gpm and pumping level is about 79 ft providing about 150 ft of submergence at the pump suction.

The pump is reported to be of standard design (i.e., no extra lateral and colletted impellers); although, records can not be found to verify this. Standard design seems appropriate since the static level is only 46 ft and temperature 158°F, so differential expansion would not be a problem.

Wineagle Binary Plant - Near Susanville, CA

This is not a direct use, but a binary electric power generating plant. It is included because the temperature, peak flow and chemistry are similar to some of the failed direct use pumps.

Temperature	231°F
Flow	600 gpm
Pumping setting	140 ft to top of bowls
Static water level	Artesian to surface
Pumps level	55 ft
Lubrication	Enclosed lineshaft oil lub; geothermal water bowl bearings
Size	10 inch (Ingersol-Rand)

This is a standard bowl assembly with keyed impellers. The high temperature requires keyed impellers, and the high static and pumping levels permit standard bowls (i.e., no extra lateral).

No information on H_2S levels in the well could be found--but the effluent from the plant is monitored regularly to comply with surface discharge permits. H_2S levels in the discharge are in the tens of parts per billion. Some of the H_2S is undoubtedly removed by reaction with components in the system and there are several opportunities for escape ahead of the monitor sampling point, so H_2S levels are probably in the 100 parts per billion range--enough to cause some reaction with copper in the bronze bearings.

The pump was installed in late 1986, went into production in early 1987 and has operated continuously except for power outages since then. The pump is running smooth and currently has approximately 8 years of run time. Although there are no written records readily available to confirm it since the pump has keyed-impellers, it probably has the maximum size shaft and bearings which will reduce the load per unit area on the bearing surfaces.

Klamath County Road Department Shops, Klamath Falls, OR

This pump is used to supply 128°F geothermal water for space heating truck, heavy equipment and auto repair shop areas; offices and storage. Little recorded information is available due to losses and change of ownership of the pump company that installed the pump. The best information available is:

Temperature	128°F
Peak flow rate	120 gpm
Pump setting	165 ft
Static water level	6 ft

Pump	8 inch Johnston - variable speed drive
Lubrication	Enclosed lineshaft oil lub; pump geothermal water lub. Bronze bearings both pump and lineshaft.

There is no record of a pump test with water levels measured; but, the drillers log indicates air lift of 200+ gpm. Pumping level is estimated to be less than 100 ft providing more than 65 ft submergence.

The pump is a standard pump (i.e., no extra lateral with standard colletted impellers). Considering pump setting, temperature and static level, this would be acceptable.

There are no water chemistry records; but, there is a very slight smell of H_2S comparable to other wells in the Klamath Falls area.

It is believed the pump was installed in late 1983 and began space heating operations in early 1984. The pump has never been pulled and seems to be running very smooth. Installed life to date is over 10 years with 7+ years of rotating life. The pump is turned on in early fall and off in late spring. System design, and to a greater extent, actual operation preclude much flow control. Maintenance personnel report the pump runs essentially at full speed with little well head pressure increase all the time.

Klamath Union High School

The KUHS pump is a standard "off the shelf" cold water pump with no special materials or construction.

Temperature	165°F
Flow	500 gpm
Static level	11 ft
Setting	about 90 ft
Pumping level	20 ft
Size	10 inch, 5 stage
Lubrication	water open lineshaft
Bearings	bronze

This pump is in an ex-artesian area of the geothermal resource. The well has not flowed for some years, but is a good producer with little drawdown. The pump is turned on in the fall when school starts and off the following spring. Most of the head is due to over 1200 ft of piping to and from the heat exchangers in the school, and elevation difference between the well and school. Actual TDH is unknown. There are no flow or pressure instruments at the pump.

The pump has in excess of 12 years of satisfactory operation.

DISCUSSION

It should be noted that this projects intent was to, if possible, determine modes of pump failures or at least document them as accurately, as readily possible, and not to provide or even suggest, methods to prevent failures. That is for the pump manufacturers to do.

Since it was apparent that pump failures were due to bearing failures, the most widely discussed failures in geothermal pumps (i.e., corrosion, temperature and lubrication) were initially investigated. Information on bearing materials, clearances, length and diameter (load per unit area), pumped fluid temperatures, and pumped fluid chemistry were gathered on the failed pumps.

BEARING MATERIALS

With the exception of the rubber bearings in Susan #1 pumps, Susanville District Heating System, all the pumps had bronze bearings. Several bronze alloys are used with variation in copper of 81 to 86%, lead 5 to 7%, tin 3 to 5%, and zinc 5 to 9%. Since copper is subject to corrosion by hydrogen sulfide which is present in all the geothermal fluids pumped, it was initially suspected the use of bronze bearings would be a contributing factor to early failures. Although this may be true since all the bearings inspected had black fairly tightly adhering material believed to be copper sulfide (Cu_2S) on all surfaces, no gross corrosion was noted. Although most of the bearings inspected were either missing or badly worn, those that were still in fair condition were smooth and not pitted as detectable by naked eye and fingernails.

Bronze appears to be capable of providing at least acceptable life as evidenced by the Wineagle pump at 7+ years which is pumping the hottest and highest H_2S laden fluids, and Klamath Union High School and OIT #2 pumps at 12 and 23 years respectively in their wells.

BEARING SIZES

Information on bearing sizes (length, diameter and clearances) was obtained with the thought that differences in clearances might effect rates of flow through the bearing, therefore lubrication and cooling. Length and diameter would effect load per unit area.

Bearing length and diameter for comparable pumping duties are very similar across pump manufacturers. For the common pump sizes encountered (nominal 6, 8 and 10 inches) bearing lengths are about 5 inches and diameters 1 inch to 1 1/2 inches. For keyed impellers shaft, bearing sizes are increased because of increased stresses at keyways which may account for slightly better life of some of the early pumps. The increased diameter for keyed shafts decreases load/unit area about 15%.

Bearing clearances vary between manufacturers ranging from about 0.005 in. to about 0.008 in.

Pumps specifically manufactured for pumping temperatures 150 - 220^{o}F may have bearing clearances increased 0.001 - 0.003 in. For this report no correlation between bearing clearances and pump life could be noted.

Nearly all pump bowls can be machined to obtain extra lateral to accommodate shaft stretch and some thermal expansion differences. During telephone conversations with pump design engineers, they stressed that bearing length must not be reduced to gain a little more extra lateral. This could be done by field shop modifications. Extra long lateral beyond that recommended by the manufacturer requires special castings for both the bowls and impellers.

TEMPERATURE

Pumped fluid temperature does not seem to have as great an influence on pump life as had been originally expected. While the lower temperature pumps (Klamath County Shops, Naef and Klamath Union High School) have the longest rotating lives. The hottest pump, Wineagle at 231^{o}F, is approaching them. The Colahan and bottling company pumps can't be considered since they had other specific identifiable problems.

EXTRA LATERAL

During the initial part of this investigation, extra lateral and variable speed control were not considered as contributing to shortened pump life--in fact, they were considered attributes providing longer life as well as reduced pumping costs. Then as data on successful pumps began to be collected and added to Table 1, it became apparent that there was a high correlation between extra lateral, variable speed and shorter pump life. Whether they actually contribute to shortened life, or short life is an artifact of some other characteristic, is at this time unknown.

Extra long lateral, which is the total axial movement of the impellers within the bowl, may contribute to early bearing failures as explained below.

In a standard pump (Figure 14), the high fluid velocity at the impeller vane tips is slowed and converted to increased pressure as the fluid passes through the bowl waterways. The higher pressure at the next stage inlet area tends to force fluid down through the bearing providing lubrication and some flow for cooling. Additionally, the rotation of the top end of the impeller acts as a slinger pulling fluid away from the bearing lower end and to the impeller edge where the fluid joins the flow into the next bowl.

In an extra long lateral pump (Figure 15), there is a larger volume of fluid between the top of the impeller and vane tips, and the bowl water way inlets. When the distance between the impeller and next stage bowl waterway is several inches (as it could be in deep high temperature pumps), there must be considerable turbulence and resulting pressure increase between the impeller and bowl waterways, therefore reducing the pressure of the next impeller eye. Additionally, the impeller top

TABLE 1. Summary of Pumps Investigated.

Name	Variable Speed	Extra Lateral	Bearing Material	Pump Setting	Pumping Level	Temp. °F	Average Rotating Life/Years	Comments
OIT #2	Yes	Yes	Brz.	560 ft	510 ft	192	6+ so far	Operated OK since new (1971) in same water conditions as other OIT pumps.
OIT #5 (July 1989)	Yes	Yes	Brz.	440 ft	350 ft	192	6+	Bowls had been in service 24+ years. Bearings replaced about every 6 years.
OIT #5 (August 1994)	Yes	Yes	Brz.	440 ft	350 ft	192	2 1/2	Lower 7 bowls and impellers worn beyond repair. Upper bowls and impellers worn. Lower bearing completely gone and shaft worn into bowl bearing housing. Upper bearings still in place but worn.
OIT #6	Yes	Yes	Brz.	600 ft	550 ft	192	6+ so far	Bowls in service 23+ years. Bearings and impellers replaced after 17 years.
Susanville (all in same well)								
Pump #1	Yes	Yes	Rubber	140 ft	~70 ft	174	5 1/2	Bowls, bearings and impellers looked like new. Rubber bearings had swelled.
Pump #2	Yes	Yes	Rubber	140 ft	~70 ft	174	16 mos.	
Pump #3	Yes	Yes	Rubber	140 ft	~70 ft	174	a few hrs.	
Naef	Yes	No	Brz.	160 ft	146 ft	158	9+ so far	No failure, not inspected. Pump is run at about 2/3 flow during heating season.
Klamath County Shops	Yes	No	Brz.	165 ft	65± ft	128	10+ so far	No failure, not inspected. Pump is run at nearly full speed all the time during heating season.
Wineagle	No	No	Brz.	140 ft	85± ft	231	7+ so far	No failure, not inspected. Pump is always run at full speed and very near best efficiency.
Merle West Medical Center	Yes	Yes	Brz.	550 ft	300 ft	192	4	Bearings and impellers worn at 4 - 5 year intervals. Bowls sometimes re-machinable.
Modoc High School	Yes	Yes	Brz.	320 ft	varies 25 - 280 ft	170	2 1/2	Strange wear pattern. Cause unknown. Possible imbalance of impellers.
Colahan	No	No	Brz.	230 ft	?	230	1 - 2	Not good example - poor engineering.
Bottling	No	No	Brz.	240 ft	55 ft	249	1 - 3 mos.	Pump ok. Crooked well caused column brg. failure.
CSI	Yes	No	Brz.	220 ft	100± ft		1	Improper alignment of lower column caused pump vibrations and failure. Possible critical speed problems?
Klamath Union High School	No	No	Brz.	~90 ft	20 ft	165	12+ so far	This pump is in an ex-artesian area and has a shallow (~90 ft) pump setting. The pump is turned on in fall and off in spring. No failure. Not inspected.
Anonymous (Klamath Falls)	Yes	No	Brz.	90 ft	55 ft`	172	10 days	Operated in shaft critical speed range.

is now a considerable distance from the bearing lower end reducing the slinging action at the lower end of the bearing. These two factors should result in decreased flow through the bearings.

Anything further than suggesting this may be a possible factor contributing to failure is beyond the scope of this report. No references to these actions/reactions was found in the literature.

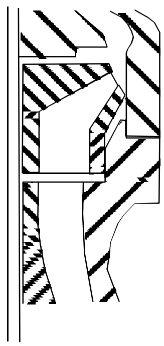


Figure 14. "Standard" pump at operating condition.

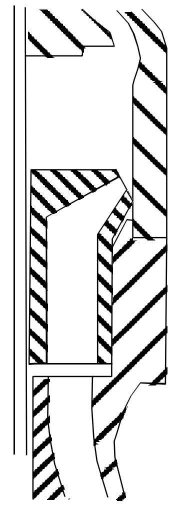


Figure 15. Extra long lateral pump at operating condition.

RECIRCULATION AND VARIABLE SPEED

Internal recirculation (Figure 16) is a phenomenon occurring in all centrifugal pumps at certain reduced flows. This results in flow reversals in both the suction and discharge areas of the impeller. The result of these reversals is the formation of vortices creating low pressure and the formation of vapor bubbles in these areas. The subsequent collapse of these bubbles results in greatly increased vibration and pressure pulsations, and erosion of impeller vanes similar to cavitation caused by insufficient net positive suction head (NPSH), but on the hidden high-pressure side of the vanes instead of the low-pressure side.

The phenomenon was first explained in about 1971 in a limited circulation paper, but not more widely published until 1981. Even today, the phenomenon is not understood or taken into account by many pump distributors, installers and engineers who frequently specify pumps for direct-use applications. This is probably due to a large extent to the fact that recirculation has not been considered important or observed in pumps below about 100 hp. It seems possible, however, that it could occur in a typical direct-use pump and result in premature failures.

Recirculation is initiated at some percentage of best efficiency flow Q, and is increased at lower flows. Recirculation occurs at a higher percentage of flow in pumps with higher suction specific speeds S_S

(lower required NPSH and larger impeller eye diameters) and is excaberated with higher head per stage and larger capacities.

where: S_s = Suctionn Specific Speed
Q = Flow (gpm)
NPSH = Net Posiive Suction Head (ft)

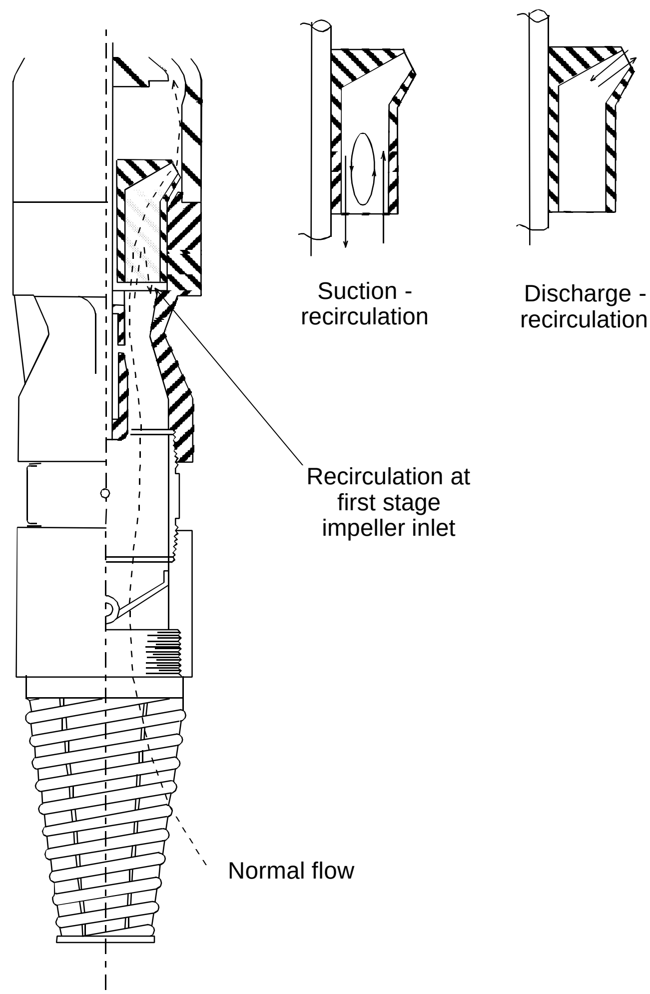
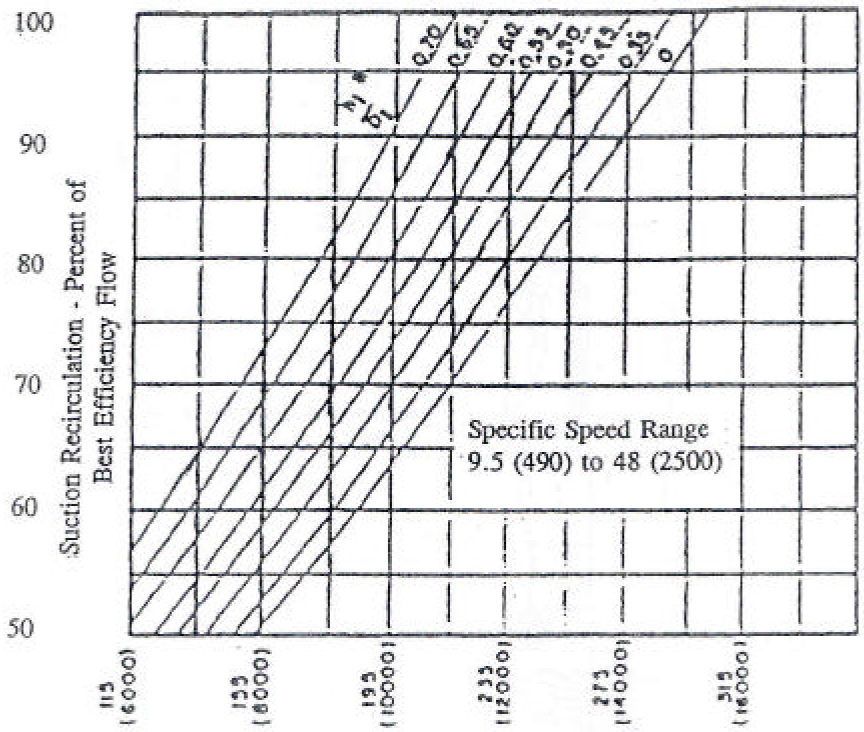


Figure 16. Suction and discharge recirculation.

In 1981, W. H. Fraser published a paper (Fraser, 1981) presenting a mathematical analysis of the flow at which recirculation is initiated based on the geometry of the impeller; and graphs (Figures 17 and 18) that can be useful in initial selection and application of pumps and when details of the impeller design are unknown.

Although so far as is known, recirculation cavitation damage has not been noted on direct-use pumps; it may be that vibrations caused by recirculation are causing bearing failures and the problem is being attributed to bearing problems. The OIT pumps seem to provide at least circumstantial evidence of this.



Suction Specific Speed - Ss at Best Efficiency Flow
Single Suction or One Side of Double Suction

h1 - Shaft or impeller hub diameter
d1 - Impeller eye diameter

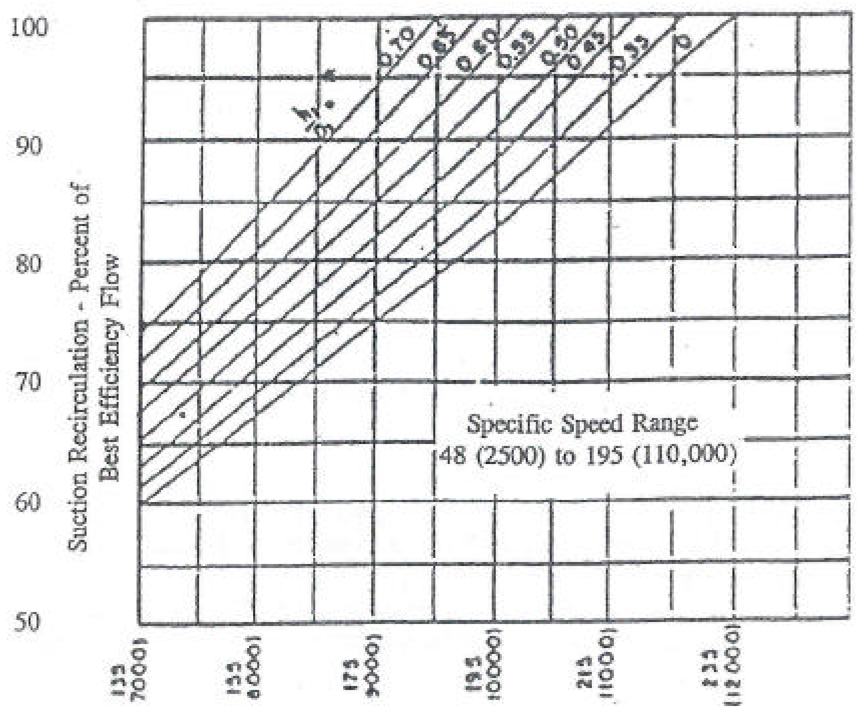
1. For pumps rated at 2500 gpm or less, the suction recirculation values can be reduced by 50 percent for continuous operation and by 75 percent for intermittent operation.

2. For hydrocarbons, the suction recirculation values can be reduced by 60 percent for continuous operation and by 75 percent for intermittent operation.

Figure 17. Recirculation as a function of specific speed and the hub-to-eye diameter ratio.

OIT #5 well is the best producer of the three campus wells. The last pump (which was replaced in November 1994) had its best efficiency at 557 gpm and 464 ft, Total Dynamic Head (TDH) at 1770 rpm and Net Positive Suction Head Required (NPSHR) was 10.1, specific speed 2700 and suction specific speed 7380. Static water level is 320 ft, well specific capacity 18.3 gpm/ft and temperature 192°F. The pump was set to 453 ft at the first stage impeller eye. The pump rpm is controlled by a

Nelson liquid drive sensing pressure at the discharge head. During cold weather when the campus heating system is calling for a lot of heat, pressure at the discharge head was about 12 - 15 psi and pump flow was high. During warmer periods and when classrooms are full, flow is decreased and pressure is limited to 30 psi by the Nelson drive. During the warmer periods, flow averages about 125 gpm and may decrease to 40 -50 gpm for some time.



Suction Specific Speed - Ss at Best Efficiency Flow
Single Suction or One Side of Double Suction

h1 - Shaft or impeller hub diameter
d1 - Impeller eye diameter

3. For pumps rated at 2500 gpm or less, the suction recirculation values can be reduced by 50 percent for continuous operation and by 75 percent for intermittent operation.

4. For hydrocarbons, the suction recirculation values can be reduced by 60 percent for continuous operation and by 75 percent for intermittent operation.

Figure 18. Recirculation as a function of specific speed and the hub-to-eye diameter ratio.

At 125 gpm, the pump had 58 ft/stage or 696 ft of head available--however, the head required was only:

$$TDH = swl + drawdown + surface\ head = 320 + 6.3 + (30*2.307) = 396\ ft$$

neglecting minor amounts for column and discharge friction heads.

The Nelson drive would slow the pump to:

$$New\ speed\ =(\frac{new\ \ head}{old\ \ head})^{1/2} *old\ \ speed$$

$$=(\frac{396}{464})^{1/2} *1770\ \ =1635\ \ rpm$$

and

$$Best\ \ efficiency\ \ flow\ \ =\frac{new\ \ speed}{old\ \ speed} *old\ \ flow$$

$$=\frac{1635}{1770} *557\ \ =515\ \ gpm.$$

Suction specific speeds (S_S) at 1637 rpm, needed to enter the curves in Figures 17 and 18, is not available from manufacturers curves--nor is NPSH which can be used to calculate S_S. NPSH can be estimated using the pump affinity laws. Some pump engineers prefer the square of the speed ratio; others the 1.5 power. In this case:

$$NPSH=10.\ 1 *(\frac{1635}{1770})^{2} =8.\ 97\ ft$$

$$NPSH=10.\ 1 *(\frac{1635}{1770})^{1.\ 5} =8.\ 79\ ft$$

Selecting 8.79 ft as a compromise

$$S_S at\ \ 1635\ \ =1635\ \ \sqrt{515} / 8.\ 79^{3/4} =7,\ 268$$

Entering Figure 18 at S_S = 7000 and h1/D1 = .44 (h1/d1 obtained from manufacturers information), we find recirculation will initiate at about 50% of 515 gpm or 257 gpm. Reducing that by 50% per note 1 of these curves, we find that the pump may be operating at dangerous, but perhaps not critical flows for perhaps half its rotating life.

The question is: can such operation result in vibrations which in turn cause bearing failure, but yet not be evidenced by erosion of impeller vane surfaces as noted in other cases of recirculation? Discussions with pump engineers suggest it may be possible, perhaps probable, that recirculation is a contributing factor.

There is some additional evidence to support the conclusion that it might.

It has been reported, but not documented, that bearing wear in pumps that have been reconditioned and in pumps beyond repair that wear seems to be worse in the lower stages--where recirculation would be more likely.

In particular at OIT and to some extent at adjoining Merle West Medical Center, pump life has been decreasing over time. At both facilities, old equipment and controls have been slowly replaced by newer equipment and controls that reduce required flow rates--which could lead to additional rotating time at recirculation flows.

Early on at OIT and Merle West it was discovered that deeper setting of pumps seemed to result in less bearing wear. This could be the result of increased NPSH available reducing bubble formation and collapse.

Although the rubber bearings in the Susanville pumps swell the impeller and bowl mating surfaces are in surprisingly good condition. Could the rubber bearings be absorbing vibrations due to recirculation?

SUGGESTIONS

Clearly more work needs to be done, particularly documentation of operating conditions and of failures.

If recirculation is in fact a cause of pump failures, pump specifiers will need to be ever more aware of minimum flow conditions as well as maximum flow conditions usually used to specify pumps. In space heating applications, the tendency to apply safety margins in calculating heat loads, specifying equipment, sizing for maximum buildout, etc., should be carefully considered. All these factors are multiplied and result in pumps being significantly oversized for actual operating conditions.

Oversizing pumps, and the tendency to specify pumps with high flow and low NPSH because those are normally attributes of "good" pumps, could lead to increased problems with recirculation.

REFERENCES

Anliker, D. M. and Ellis, P. F. Component analysis report, Radian Corp., 1981.

Campbell, L. Interstate Pump Co., Klamath Falls, OR. Personal communication, April 1990.

Fraser, W. F. "Recirculation in Centrifugal Pumps", Winter Annual Meeting of ASME, November 1981.

Lienau, P. J. "Direct-Use Downhole Pumps", Geo-Heat Center Quarterly Bulletin, Vol. 8, No. 3, 1984.

Lynn, M. Plant manager, Calistoga Bottling Co., March 1989.