A MATERIALS AND EQUIPMENT REVIEW OF SELECTED U.S. GEOTHERMAL DISTRICT HEATING SYSTEMS

Kevin D. Rafferty, P.E.
Geo-Heat Center, Oregon Institute of Technology
Klamath Falls, OR 97601

ABSTRACT

Geothermal district heating systems are now quite common in the western U.S. A recent survey identified a total of 17 such systems. The performance of materials and equipment in 13 of these systems is reviewed in this paper. Specific areas covered include: production facilities, central plants, distribution, customer connection, metering and disposal. Those areas: characterized by the highest incidence of problems include: production well pumps, customer branch piping and energy metering.

INTRODUCTION

Most of the systems included in this review have logged a minium of five years operating experience. As such, they have encountered many of the problems likely to occur as a result of fluid chemistry and initial design. Table 1 presents an introduction to the systems included in report.

As indicated, these systems are located generally in the western U.S., and particularly concentrated in the states of Nevada, California, Idaho and Oregon.

All of the systems have experienced equipment problems of one sort or another. Difficulties tend to be associated with one of the following areas: production facilities, central plants, distribution, customer connections, metering and disposal. Each of these areas is discussed in detail below.

Production Facilities

There is great variation in the depth and temperature of production wells employed for these systems. Depth ranges from only 275 feet at Pagosa Springs to 3,030 ft at the Capital Mall in Boise. Temperatures of 138 to 218ºF are employed. With one exception (Pagosa Springs), all of the projects employ pumps to produce the geothermal fluid. Several systems previously were able to operate for some of the year on the artesian head generated by the well. At present, however, only the two Elko, NV projects and Pagosa Springs system have this capability.

Production well pumps, in general, have been the source of much system downtime. Specifically, difficulties have centered around shaft and bearing failures in lineshaft pumps. Two types of lineshaft pumps have typically been employed in geothermal applications: enclosed lineshaft and open lineshaft. Of these, the open shaft has been more subject to failure. In this design, the shaft and bearings are lubricated by the fluid flowing up the pump column. As a result, these components are exposed to the geothermal fluid. Shaft materials of both carbon and stainless steel have experienced failure in this application along with bearing materials of bronze and various elastomers (rubber).

The nature of the failure of these components has been attributed to a variety of modes; however, two causes are most common:

1. Deterioration of the bronze bearings as a result of fluids containing hydrogen sulphide, and
2. "Dry" running of the top bearings (those above the static water level) at start up.

This latter effect may be particularly important in view of the relative success of water lubricated pumps in artesian wells. The Boise City, Boise Capital Mall and Elko Heat Company systems have all operated water-lubricated pumps successfully and all have artesian wells. The water levels in these wells are of sufficient height to maintain the bearings in a fully-lubricated state, thus avoiding "dry" running.

Table 1. Information Summary - Systems Reviewed

System and Location	Years Operated	Resource Temp. ^{O}F	Peak Flow (gpm)	Feet of Pipe
Oregon Institute of Technology (OIT), Klamath Falls, OR	26	192	980	7,300
Klamath Falls City, Klamath Falls, OR	5	218	1,000	14,000
Susanville DOE, Susanville, CA	5	174	700	19,000
Susanville HUD, Susanville, CA	4	155	300	10,000
San Bernardino Water District, San Bernardino, CA	5	138	3,700	35,000
Pagosa Springs, Pagosa Springs, CO	6	140	600	15,000
New Mexico State University (NMSU), Las Cruces, NM	6	142	230	N/A
Boise City, Boise, ID	5	170	4,000	37,000
Boise Warm Springs Water District (BWSWD), Boise, ID	100	176	1,600	11,300
Boise Capital Mall, Boise, ID	6	169	750	6,000
Elko County School District (ECSD), Elko, NV	2	190	290	11,300
Elko Heat Company, Elko, NV	6	170	650	15,500
Warren Property, Reno, NV	6	210	710	26,500

The most successful shaft and bearing arrangement for direct-use wells has been the enclosed shaft, oil-lubricated design. This system isolates the shaft and bearings from the geothermal fluid and maintains the lubrication on a constant basis. One system (Susanville) experimented with a water-lubricated enclosed lineshaft arrangement initially; however, after several failures, oil-lubricated models were installed (Templeton, 1988).

Of the 11 systems reviewed which use lineshaft pumps, eight use oil-lubricated designs. The Oregon Institute of Technology (OIT) system has successfully operated such pumps in 192^{o}F, 800 TDS fluid for as long as 15 years without major overhaul.

The pumps (bowl assemblies) themselves have proven more reliable than the lineshaft/bearing portion of the system. Few failures of the bowl assembly have been experienced. The only system to experience numerous, recent failures of the pump was New Mexico State University (NMSU). This is due to the production of large quantities of sand in that location. The OIT system experienced several failures of the bowl assembly in the early years of operation. This was reportedly due to impellers becoming detached from the shaft (Wiltrout, 1988). A change was made to keyed rather than collet connections (impellers-to-shaft) and no further problems were encountered.

Regardless of the type of lineshaft design (oil- or water-lubricated), the bearings in the bowl assembly are water lubricated. Of interest is the fact that leaded red bronze bearings, while the source of numerous failures (as lineshaft bearings) in open lineshaft pumps, have demonstrated good performance in bowl assembly bearings.

The most successful design for production well pumps in direct-use systems includes: enclosed lineshaft, oil-lubricated equipment with bowl assemblies consisting of leaded red bronze bearings, stainless steel shaft, keyed impeller connections and enameled cast iron impellers.

Submersible pumps were employed in only one of the systems reviewed (NMSU). Numerous failures occurred and such pumps are no longer used.

Other pump problems of note include headshaft seal failures in Boise and deterioration of threaded pump column connections at NMSU.

All of the original pumps in the Boise Capital Mall and Boise City systems included teflon packing in the headshaft seal. Several incidents of shaft scoring occurred and the teflon was replaced with graphite impregnated material (Osgood, 1988).

The NMSU operators have experienced ongoing problems with corrosion of carbon steel components in the system. One area in which this has been of greatest concern is threaded connections on well pump columns. Several solutions have been attempted including various coatings and the use of flanged rather than threaded connections. These efforts have been partially successful; however, carbon steel components continue to fail due to corrosion (Lockwood, 1988).

As indicated in Table 2, many of the systems employ variable-speed drives of one type or another to regulate well pump output. The two most common are fluid couplings and variable frequency drives. The fluid coupling is a mechanical device installed between the electric motor and pump shaft. It is a relatively simple device which can generally be serviced by the local pump contractor. The only problem experienced by users of this equipment is periodic replacement of the thrust bearings.

Variable frequency drives are more energy efficient than fluid couplings. This efficiency, however, comes at the expense of much greater sophistication. Some operators have found it useful to purchase the optional self-diagnostic packages and factory operator training available from certain manufacturers (Fisher, 1988).

The remaining production facility problems relate mainly to controls and system design.

The Susanville Department of Energy (DOE) system was originally designed as a pumped storage system. The well produced into a large storage tank. From here, a booster pump supplied water to the system. Higher than normal energy use (the booster pump was designed for peak system flow and throttled to control its output) and level control problems resulted in the redesign to a variable-speed well pump feeding directly into the system.

Table 2. Production Facility Information Summary

Facility	No. Of Well Pumps in System	Pump Type	Lube	Artesian	Variable-Speed Drive	Frequency of Well Pump Failures Early	Recent
Oregon Institute of Technology	3	ELS	Oil	No	FC	High	None
Klamath Falls City	2	ELS	Oil	No	FC	None	None
Susanville DOE	1	ELS	Oil	No	VFD	High	None
Susanville HUD	1	ELS	Oil	No	VFD	High	None
San Bernardino	2	ELS	Oil	Yes	VFD	None	None
Pagosa Springs	0	–	–	Yes	None	None	None
New Mexico State University	1	ELS	Oil	No	None	High	Mod
Boise City	3	OLS	Water	Yes	None	High	None
Boise Warm Springs Water District	2	ELS	Oil	Yes	None	Mod	Mod
Boise Capital Mall	1	OLS	Water	Yes	MSM	None	High
Elko County School District	1	Surface	–	Yes	VFD	None	None
Elko Heat Company	1	OLS	Water	Yes	None	None	None
Warren Property	2	ELS	Oil	No	None	High	None

ELS - Enclosed Lineshaft; OLS - Open Lineshaft
VFD - Variable Frequency Drive; FC - Fluid Coupling
MSM - Multi-Speed Motor; MOD - Moderate

The OIT system also includes a wellhead tank. The three production wells produce into the tank which then feeds the campus system by gravity. The tank, which is vented to atmosphere permits oxygen to enter the system. This substantially increased the corrosion rate on the largely steel distribution system. In recent years, much of the distribution system has been converted to fiberglass piping. The tank remains vented to atmosphere.

The Boise City system regulates flow to its distribution system by cycling its three production pumps. In addition, a large pneumatic valve throttles the flow in response to supply line pressure. A number of problems surfaced with this design. Initially, pressure surges were experienced as different pumps were cycled on and off. Subsequent modifications included the installation of pressure relief valves and removal of stages from pumps to allow for closer matching of head at certain flows. Finally, the main throttling valve, designed for the system peak flow (4,000 gpm), was somewhat oversized for the actual flow during initial operations. This resulted in "hunting" of the valve and system pressure variation. Control modifications which effectively reduced valve travel by 50% successfully addressed this situation (Turner, 1988).

Central Mechanical Plant

Central mechanical plants are included in five of the systems reviewed for this project. The central mechanical plant contains the main heat exchangers, circulating pumps, expansion tanks and controls for systems which employ closed-type distribution systems. Closed systems are those in which the geothermal fluid does not flow through the distribution system to the customers. A closed loop is used to deliver the heat.

The equipment in these facilities has been quite successful with respect to fluid compatibility. No corrosion related failures have been reported.

Piping within mechanical plants consists of all steel in three of the systems, all copper in one and all fiberglass (epoxy adhesive joint) in the remaining plant. Isolation heat exchangers, in all cases, are constructed of 316 stainless steel plates and nitrile (Buna-N) gaskets. Control valves are typically of iron body, flanged construction with stainless steel trim.

Although no corrosion related problems have occurred, operational problems have surfaced.

The Klamath Falls system had difficulty with a pressure sustaining valve on the geothermal injection line. This valve, designed to regulate the peak system flow (800 gpm) exhibited erratic operation at the low flow under which the system was operated. Controls for the valve were disconnected and a manual valve is operated to perform this function (Colahan, 1988).

Similarly, the Pagosa Springs system is operated manually though it is extensively instrumented with sensors and motorized valves for automatic operation. The low load imposed on the system is such that manual control resulted in more stable operation.

The Elko County School District (ECSD) system also experienced problems with very low load operation. The unstable operation which occurred under these conditions was not possible to address through manual means since the system was designed to operate unattended. As a result, a small, low-load heat exchanger was installed. Controls were modified such that the two main heat exchangers were out of the loop at low flows and supply water temperature was controlled only through the small heat exchanger (Vietti, 1988).

Distribution System

Distribution networks for these systems fall into two general designs: open and closed. As discussed in the Central Plant section, the closed-type distribution system includes central heat exchangers; while, the open system delivers the geothermal fluid directly to the customer. This is an important distinction since the open type design exposes the entire distribution system to the geothermal fluid.

As indicated in Table 3, a wide variety of piping materials has been applied to geothermal district heating systems. Of these, the most common is

Table 3. Distribution Systems Equipment and Materials Summary

System	Distribution Type	Geo. Pipe	Non-Geo. Pipe	Customer Branch Line	Isolation Valves
OIT	Open	FG, STL	–	STL	G. BF
Klamath Falls	Closed	STL	FG, STL	STL, CU	G
Susanville DOE	Open	AC, FG, PB	–	FG, PB, STL	BF
Susanville HUD	Open	PB	–	PB	–
San Bernardino	Open	AC, DI, PVC	–	STL, CU	G
Pagosa Springs	Closed	AC	AC	STL, CU	G, BF
New Mexico State University	Closed	AC	AC	STL, CU	G, BF
Boise City	Open	AC, FG	–	STL	BF
BWSWD	Open	AC, STL	–	STL	G
Boise Capital Mal	Open	STL, AC	–	STL	BF
Elko County School District	Closed	AC, STL	STL	STL	BF
Elko Heat Company	Open	AC	–	STL, SS	G
Warren Property	Closed	STL, CU	STL, FG	CU	G

FG - Fiberglass
PB - Polybutylene
PVC - Poly Vinyl Chloride
SS - Stainless Steel (304)

STL - Steel
DI - Ductile Iron
G - Gate

AC - Asbestos Cement
CU - Copper
BF - Butterfly

Open - No Central Heat Exchangers, Geothermal fluid delivered directly to customers
Closed - Central Heat Exchanger

asbestos cement. This material, frequently used in municipal water systems, is familiar to installers, relatively low cost, designed in such a way as to eliminate the need for expansion compensation devices and, as a non-metallic, is impervious to corrosion. Unfortunately, health related concerns regarding the asbestos content of this material have, for practical purposes, eliminated it from consideration for new projects. An important task for the future will be the identification of a substitute material capable of replicating the practical and economic advantages of AC pipe.

The San Bernardino system, which has to date employed largely pre-insulated AC pipe, recently installed a new extension using pre-insulated ductile iron piping which they manufacture themselves. Another system anticipating expansion is considering a fiberglass product which incorporates threaded connections (Mickelson, 1988).

Fiberglass piping has been used successfully in several systems. At Oregon Institute of Technology, the original direct-buried steel piping was replaced with fiberglass piping after about 15 years. The original field installed asphalt coating, used to protect the pipe and insulation from moisture, failed and permitted exterior corrosion of the pipe to occur. The replacement fiberglass piping employed epoxy adhesive joints and was installed largely in concrete tunnels.

The Klamath Falls City system experienced a failure of the fiberglass portion of their system (7,000 lf).

Interestingly, this failure occurred not in piping exposed to the geothermal fluid, but on the closed loop portion of the system. The piping system employed a "key lock" type joining system. This connection method consisted of a bell and spigot arrangement with a flexible "key" to lock the join together. When assembled, a groove on the male portion of the fitting aligned with a groove in the female portion of the fitting. A flexible key was inserted into these grooves to lock the connection axially. The failure involved the epoxy, used at the factory, to attach the grooved rings to each section of pipe. This epoxy failed allowing the connection to slip and ultimately leak. The piping itself experienced no failure.

Ductile iron was originally selected for replacement of the fiberglass. Consideration is also being given to retaining the fiberglass piping and repairing only the piping connections.

Aside from fiberglass and AC, the two remaining types of piping in common use for main lines are steel and polybutylene.

Steel has been used successfully in both the Klamath Falls system and Boise Capital Mall system for the conveyance of geothermal fluid. In addition, it is used in the ECSD, Klamath Falls and Warren Property systems on closed distribution loops. In both the Klamath Falls and Capital Mall systems, this piping is installed primarily in concrete tunnels and building mechanical spaces in order to permit access.

The Boise Warm Springs Water District (BWSWD) system used a wrought iron alloy pipe for approximately 50 years. This pipe was removed during the system upgrade in 1982 (Griffiths, 1988).

Polybutylene was used successfully in the Susanville HUD system. This piping, in sizes of 2 to 8 in. has been in service for five years and has not required any repair. The entire system was assembled using thermal fusion connections.

Although the experience with various types of main line piping has been generally good, problems have occurred in some systems with such items as valves and temperature crossovers.

Two types of valves have been employed for isolation duty on these systems: gate and butterfly. Gate valves are the most common. These valves, in many cases, have experienced stem leakage and seizure. In addition, they tend not to be capable of 100% shut off after several years in service (Lattin, 1988). As a result, two system operators have switched to resilient seated gate valves for new construction.

Butterfly-type valves appear to be better suited to geothermal applications. The rotary motion (rather than reciprocating) is less prone to leakage. In addition, the resilient lining protects the valve body from exposure to the geothermal fluid. Most geothermal applications employ seats and "O" rings of EPDM, and shafts and discs of 316 stainless steel in butterfly valves.

Only one system has thus far experienced problems with these valves. The Boise City system employed butterfly valves at various points around the system for temperature maintenance duty. These valves, installed between the supply and waste collection piping, were designed to divert a small flow of hot water to waste in order to maintain adequate supply temperature in the distribution system. In some valves, the resilient seat distorted in such a way as to cause an increase in resistance to movement of the disk. This resistance required the operator to apply more torque to open and close the valve. As a result, the geared operator on some valves failed.

These valves were replaced with automatic temperature activated valves which were installed in concrete valve boxes. Each valve station also included a water meter for monitoring of flows. These installations solved the problems with the direct-buried manual valves and resulted in significantly reduced system flow requirements.

Customer Connections

The customer connection is the physical link between the building heating loop and the district system. In general, this connection contains isolation valves, metering (volume or energy), temperature and pressure instrumentation, and in some cases, a heat exchanger and/or temperature limiting valve. The components included in the customer connections vary according to district system type (open or closed) and sophistication.

The simplicity of the customer connections in most systems has resulted in few if any problems for most operators.

Customer branch lines, however, have been the source of some problems. In the Susanville HUD system, field insulated polybutylene lines were used for all customers. Compression-type fittings were used to join this piping. After startup, numerous leaks developed at these connections. It was later discovered that the fittings incorporated acetal components which were not recommended for use in continuously recirculating hot water systems. These fittings were replaced with brass and stainless steel components, and the leakage was eliminated (Templeton, 1988).

Exterior corrosion of steel service lines has occurred in a large extent in both the Elko Heat Company and the Boise City systems. The operators of these systems have taken two different approaches to the problem.

At Elko, type 304 stainless steel piping with welded connections is used for branch lines for new installations. Although considerably more expensive than carbon steel, corrosion problems have been completely eliminated (Lattin, 1988).

At Boise, several solutions have been applied. These involve the use of fusion bonded epoxy coating on all ferrous components to be directly buried in the soil, high-potential magnesium anodes with test stations and selected backfill material (Turner, 1988).

Metering

Most district heating systems which serve more than a few customers, must employ some means for apportioning costs. In addition, many systems install wellhead meters to track total production rates. In the systems reviewed for this report, both the equipment employed and the results obtained vary widely.

Wellhead metering is used in eight of the systems. All of these are of the volume type, measuring total gallons supplied. As indicated in Table 4, a variety of meter types are used. Only two of the systems report difficulties with this instrumentation. The OIT system's paddlewheel-type insertion meter was installed just downstream of a number of fittings. As a result, accuracy is questionable.

The original turbine meter at the Boise City System # 2 well failed after a short period of operation. The turbine wheel from this meter was discovered lodged in the piping at the system disposal point some 14,000 feet away. The turbine meter was replaced with a magnetic flow meter. In addition, piping modifications were made to accommodate a sufficient straight length of piping upstream of the meter.

The turbine meter installed at the BWSWD production facilities has been in service for approximately 35 years. In that time, it has been rebuilt at the factory on only two occasions.

Customer metering is used on all but one of the systems. Meter output is of one of two types: volume or energy. In general, volume metering has been less trouble prone than energy metering.

Volume meters are considerably less complex than energy meters, and hence, their greater reliability. Volume metering provides an incentive for customers to minimize flow requirements since billing rates are generally indexed to a specific ΔT. Customers who design their systems for higher ΔT (lower flow rate) increase their savings and help minimize district system flow requirements. Three of the systems use turbine meters for volume metering.

One system (BWSWD) uses orifice plates for metering purposes. A constant pressure is maintained in the supply system and as a result, various orifice sizes can be used to regulate customer flow rates. Of course, the orifice plate method controls only the peak flow rate and does not address the total gallons used. This method does not provide the incentive to minimize use as discussed above.

Energy metering has been demonstrated to be a useful technique or a persistent problem depending upon the system in question.

In Susanville, most of the problems have been traced to poor installation practices. Meters were installed in orientations not recommended by the manufacturer (such as horizontal meters in vertical position). Over-sizing of the flow meter portion of the instrumentation also appears to be a problem there.

Table 4. Metering Summary

System	Wellhead Metering	Type	Experience	Customer Metering	Type	Experience
OIT	Yes	1. IPW	Fair	None	–	–
Klamath Falls	None	–	–	Yes	Energy	Good
Susanville DOE	Yes	Orifice	Good	Yes	Energy	Poor
Susanville HUD	None	–	–	Yes	Energy	Poor
San Bernardino	Yes	1. IPW	Good	Yes	Energy	Good
Pagosa Springs	None	–	–	Yes	Energy	Fair
New Mexico State University	Yes	Turbine	Good	Yes	Volume/ Turbine	Good
Boise City	Yes	Turbine/ Magnetic	Poor/ Good	Yes	Volume/ Turbine	Good
BWSWD	Yes	Turbine	Good	Yes	Volume/ Orifice	Good
Boise Capital Mall	Yes	–	–	–	–	–
Elko County School District	None	–	–	Yes	Energy	Good
Elko Heat Company	Yes	Ultrasonic	Good	Yes	Volume/ Turbine	Good
Warren Property	None	--	–	Yes	Energy	Fair

1. IPW - Insertion Paddle Wheel

The results at Susanville suggest that it is equally important to consider the average and minimum flow rates in addition to the peak flow rate when sizing these meters. This is particularly true for space heating applications.

At the Warren Property system in Reno, installation practices again have given rise to problems. In this case, the meters were installed in small concrete valve boxes at the edge of each property. These valve boxes tend to accumulate water particularly during the spring and summer months. This water penetrates the electronic integrating circuits and renders the display unreadable or in some cases, the entire unit inoperable. In the drier locations of the system, however, these meters have performed well.

One experience which seems to be common to most operations using battery operated energy meters is that the “5-year” batteries seem to consistently last only 2-3 years. As a result, some systems favor AC power sources for the meters, or have switched to the less expensive 1-year batteries.

Disposal

Most operating systems currently use some type of surface disposal, though four employ injection wells. Of note is the fact that half (4) of those currently disposing on the surface are planning for or are in the construction phase of injection wells. This movement toward injection is a result primarily of regulatory issues.

The Susanville systems have been operated for several years under temporary surface disposal permits. During this time, attempts have been made to complete an injection well which would be capable of serving both systems. One existing well was found to be incorrectly completed and two subsequent wells drilled for injection were incapable of accepting a sufficient flow. The motivation for injection is regulatory pressure from the local water quality control board.

In Klamath Falls and Boise, extensive geothermal development has resulted in measurable reservoir declines. This is particularly true in Boise where wells which previously flowed artesian no longer do so. As a result, system operators are working diligently toward injection.

In both cases, regulatory pressure again plays an important role. At Klamath Falls, a city ordinance requires that all wells currently discharging to the surface cease to do so by 1990. In Boise, no specific regulations have been enacted; however, the State Department of Water Resources is closely monitoring the situation and has hired an outside consultant to evaluate the reservoir.

The OIT system is currently in the testing phase on their 2,000-ft injection well. As indicated in Table 5, the success of the well as an injector is still in question. Initial pump tests have not been encouraging.

For those systems currently operating injection wells, few problems have been encountered.

The Capital Mall system experienced some minor pressure fluctuations on startup. These were traced to the main throttling valve on the outlet of the injection pumps. Adjustments to the valve controller successfully addressed this problem.

The three other systems with injection wells do not require injection pumps and have had no problems (Austin, 1988).

For the systems using surface disposal, the only common problem relates to pressure sustaining

Table 5. Disposal Data

System	Type of Disposal	Repository	Planning Injection	Injection Well Under Construction	No. of Unsuccessful Inj. Wells
OIT	Surface	Lake	Yes	Yes	1 ?
Klamath Falls	Injection	–	–	–	0
Susanville DOE	Surface	Drain Ditch	Yes	Yes	3
Susanville HUD	Surface	Drain Ditch	Yes	Yes	
San Bernardino	Surface	River	No	No	0
Pagosa Springs	Surface	River	No	No	0
New Mexico State University	Injection	–	–	–	1
Boise City	Surface	River	Yes	No	0
Boise Warm Springs Water District	Surface	Storm/Sanit. Sewer Irrig. Canal	No	No	0
Boise Capital Mall	Injection	–	–	–	0
Elko County School District	Surface	Irrigation	No	No	0
Elko Heat Company	Surface	Pond & River	No	No	0
Warren Property	Injection	–	–	–	0

valves. These valves used to maintain a minimum back pressure on the system, have failed at four sites. The failures are generally related to embrittlement of valve diaphrams. Periodic monitoring and replacement has been successful in reducing the problem. Standard Buna-N material has demonstrated the shortest life. Ethylene propylene diene monomer (EPDM) offers improved performance and fluroelastomer superior performance.

CONCLUSION

The systems reviewed in the course of this work have all experienced materials and/or equipment problems to some degree. For the most part, however, these difficulties have been overcome and the systems serve as a reliable energy source for their customers.

The experience gained from the combined 182 years of operation of these systems allows one to describe conceptually, the ideal geothermal district heating system from a materials and equipment perspective. In summary, this system would consist of:

- Production well pumps of the enclosed lineshaft, oil-lubricated design with bowl assemblies containing enameled cast iron impellers with keyed shaft connections, leaded red brass bearings and stainless steel shafts.
- Production pumps equipped with a variable-speed drive (preferably a multi-speed motor or variable frequency drive).
- Production pumps feeding directly into the main production line (no wellhead storage tank).
- Open-type distribution system with asbestos cement piping (or some similar substitute).
- Butterfly valves (EPDM/316 SS trim).
- Automatic temperature activated valves for crossovers if used.
- Customer branch lines of non-metallic material.
- Volume metering for billing purposes.
- Surface disposal if regulatory authorities permit.

REFERENCES

Austin, J., 1988. Oral communication, CH_2M-Hill, Boise, ID.

Colahan, K., 1988. Oral communication, City of Klamath Falls, Klamath Falls, OR.

Fisher, K., 1988. Oral communication, San Bernardino City Water District, San Bernardino, CA.

Lattin, M., 1988. Oral communication, Kennedy/Jenks/Chilton Engineers, Elko, NV.

Lockwood, O., 1988. Oral communication, New Mexico State University, Physical Plant, Las Cruces, NM.

Mickelson, L., 1988. Oral communication, City of Boise, Public Works, Boise, ID.

Osgood, L., 1988. Oral communication, State of Idaho, Department of Public Works, Boise, ID.

Templeton, L., 1988. Oral communication, City of Susanville, Susanville, CA.

Turner, D., 1988. Oral communication, City of Boise, Department of Public Works, Boise, ID.

Wiltrout, R., 1988. Oral communication, Oregon Institute of Technology, Physical Plant, Klamath Falls, OR.