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A TRANSITION FROM STEAM TO HOT WATER:

VIRGINIA, MINNESOTA

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I. Introduction

During the 1980-81 heating season, a new district heating main went into service in Virginia, Minnesota to serve the north side of this large municipal district heating system. While normally not a unique event, this new main represents the first phase of a long range program which could ultimately result in a change in the thermal transport media for this system from steam to hot water. This 5,620 feet of new main from the municipally-owned, cogeneration power plant plant consists of two direct buried lines which will initially deliver steam to the north side, but which ultimately will function as a water delivery-and-return pair when the segment is converted to hot water. Before discussing the design features of the new main and the economic advantage which accrue initially as a steam line and ultimately as a hot water delivery and return system, the history of the system and the rationale for decisions made in the past and for the ultimate conversion of the system to hot water in the future will be discussed.

The City of Virginia (population 12,500) is located on the eastern end of the Mesabi Iron Range in northern Minnesota (Exhibit 1). The annual degree days are in the 10,000 to 11,000 range which makes the Virginia system a good study for district heating. The City, through its Department of Public Utilities, owns and operates the electric, water, gas, and district heating systems serving consumers generally located within the City. The major physical plant serving the electric and district heating system consists of a steam electric generating plant (Exhibit 2) with coal-fired boilers, an electric distribution system, and one of the largest district heating systems serving individual residential consumers as well as commercial and industrial consumers. The power plant operates on a cogeneration cycle, defined as the sequential use of energy from a single fuel source. The heat energy in the fuel is converted to steam which is used sequentially to generate electric energy with the steam turbine and then to supply heating and process thermal loads after the steam is extracted or exhausted from the turbines.

II. Historical Perspective

Electric service was initiated in Virginia in 1892 and the utility was acquired by the City in 1913 (Exhibit 3). The district heating system began in 1919, and originally operated at a steam pressure of 10 psig. The steam was produced in low pressure boilers burning mill slashings from what was then the largest white pine lumber mill in the country. After the lumber mill was shut down, steam for the district heating system was extracted from condensing-extraction steam turbine generators installed in the power plant during the period 1922-1937, and exhausted from a 5,000 KW back pressure turbine generator installed in 1949. As the district heating system grew, the 10 psig operating steam pressure became inadequate, and, except for that portion of the system serving the business district close to the plant, the system pressure was increased to 50 psig.

The electric load grew concurrently with the district heating load and it was economical to install two high pressure, condensing-extraction turbine generators in 1952 and 1970, respectively, each designed for steam extraction at 50 psig to supply the the district heating system. The prime steam and electric generating facilities in the plant are capable of producing 38,600 KW gross electric output concurrently with delivering 270,000 lbs per hour of steam to the district heating system. This district heating steam and a large portion of the electric requirements are capable of being produced on a cogeneration cycle during the heating season. The balance of the electric system energy requirements during the warmer months are either generated on the condensing cycle or purchased as economy energy from Minnesota Power Company.

The entire district heating system is shown on Exhibit 4. The system serves the downtown area and large portions of the residential areas consisting of a total of about 3,200 customers, of which about 2,400 are residential consumers. There are approximately 105,000 feet of steam main of various construction types including split tile, tunnel, buried with granular or insulating concrete insulation, and prefabricated designs. Major problems facing the district heating utility in 1978 provided the impetus for studies on the future planning for the system (Exhibit 5). These problems are reviewed in the following paragraphs.

III. Problems and Solutions

The growth of the district heating load on the north side of the system, coupled with the small steam main delivering steam to the area, resulted in an unacceptable pressure drop during the heating season. The extraction steam at 50 psig pressure was not adequate to supply the north side; and high pressure steam supplied from the steam header through a pressure reducing station was necessary to supply the north side load. The advantage of using the cogeneration cycle to supply about one-third of the district heating load during 5 months each year was lost.

Much of the system is old and inefficient as evidenced by the losses in the system. The 1979-1980 operating statistics show annual steam delivered to the system of 801,204,000 lbs and corresponding sales of 522,665,000 lbs, resulting in steam losses of about 35%. The system is kept hot the year around which contributes to a high percentage loss as radiation losses are somewhat independent of ambient air temperature. Although some of the losses may be attributed to leaks and and metering error, the principal cause is radiation loss due to deterioration of the insulation. Evaluating the district heating system efficiency on the basis of heat delivered to the consumer versus the heat delivered into the system less heat returned shows an efficiency of 55%.

The district heating system has no condensate return system which is a current economic disadvantage considering the high costs of energy, and the costs of producing the large quantity of treated boiler feedwater makeup. The low fuel cost and unsophisticated boiler feedwater treatment required at the inception of the system, and during most of the time since, has discouraged the spending of money for the installation and maintenance of a return system; and successive system extensions followed this original philosophy. The last system expansion occurred about 22 years ago. The lack of a return system resulted in sewering the condensate from the 801,204,000 lbs of steam delivered into the system during the year and over 96 million gallons of condensate was lost. The heat lost was accounted for in system efficiency calculations; but the estimated cost of treating a like amount of boiler feedwater makeup represents an additional $45,000 cost in 1980 dollars.

The Public Utility Commission of Virginia decided to address the north side steam supply problems first (Exhibit 6), and in 1978 authorized HDR to make a study of this problem. About this time, the Scandanavian concept of using hot water as the thermal transport media was introduced in Minnesota largely through the efforts of the Minnesota Energy Agency, and the Public Utility Commission of Virginia authorized the study to include this alternative. An extensive study of this alternative was undertaken including a trip to Sweden by HDR staff to discuss the concept with Swedish engineers and utility system operators. The hot water system offers competitive (Exhibits 7, 8, 9, and 10) capital costs, excellent distribution system efficiencies, ease of transmitting thermal energy long distances, and lower maintenance costs. With a 90% efficient hot water distribtuion system, the loss incurred in delivering the thermal equivalent of 522,665,000 lbs of steam to consumers would be reduced by approximately 358,000 x 10^6 Btu compared to the existing system; this energy saving could be marketed. The value of this loss reduction expressed in terms of lower plant fuel costs would be about $492,000 after allowance for the cogeneration cycle and a coal cost of $2.00 per 10^6 Btu.

Based on these studies, the Commission decided that the ultimate conversion of the entire system to hot water could be advantageous, and that the design of the new main to the north side (Exhibit 11) should not preclude the conversion of these mains to hot water at some future time. The first hot water implementation phase was decided to be the conversion of the north side of the district heating system to hot water with the concurrent installation of ciruclating pumps and steam-to-water heat exchangers at the power plant. As the advantages of the hot water transport media are confirmed by experience in Virginia, the balance of the system would be converted within a time table dictated by a combination of factors such as load growth, replacement requirements, and funding constraints.

IV. Design, Construction, and Operations

The route for the new main does not follow the existing eight-inch main, but circles the south and west side of Silver Lake (Exhibit 11) to pick up potential loads of the Mesabi Community College, an area of town referred to as the Lakeview Addition, and other area loads. Furthermore, this route was relatively unobstructed with respect to existing buried utilities. A problem was encountered in the park area along the south side of the lake. The old white pine lumber mill which was the original source of fuel for the system had been located here; and the soil consists of wood wastes for a depth of 10-15 feet. The unstable soil made it necessary to support the main on piling across this area. About one-third of the total length installed was supported in this way.

Of the 5,620 feet of main, the 2,900 feet from the generating plant to the manhole east of the Mesabi Community College is a dual 14-inch line, with the remaining 2,720 feet being a pair of 12-inch lines. The new main is designed for initial operation on 50 psig steam and for future operation transporting hot water at 280° F to the load and 230° F return under maximum load conditions. Normally, the supply and return water temperatures would be about 250° F and 150° F, respectively. However, the north side has predominantly older residences with steam heating systems. The hotter water is necessary to generate low pressure steam on those customers' premises who elect to perpetuate these heating systems and thereby avoid the high cost of installing new warm air or hot water heating systems. It is anticipated new homes built in the area will be equipped with modern heating facilities capable of using hot water. The new mains are designed for a hot water capacity of 4,000 gpm at a maximum of 280° F, and operating pressures up to 100 psig.

Two methods of installing the mains were investigated. The box tunnel concept (Exhibit 12) was considered which uses either poured-in-place concrete or a combination of poured-in-place and precast concrete envelope with the mains supported and insulated separately within this envelope. This design provides excellent protection for the system if the manholes and the tunnel are properly drained.

The alternate system investigated is a prefabricated steel conduit system that is drainable, dryable, and testable (Exhibit 13). The system consists of a separately insulated main installed within a steel conduit, which is direct buried. Cathodic protection is installed for corrosion protection of the steel conduit.

The prefabricated steel conduit system with cathodic protection was selected because:

a) Current manufacturing techniques and methods indicate a long life for the system provided proper installation procedures are followed;

b) Limited construction season favored the shorter installation time for this system; and

c) Less excavation costs would be incurred.

Material selected for the main was ASTM A-53, Grade B, seamless standard weight steel pipe with butt welded fittings.

Where the conduit is supported on piling, a study was made to determine the economic balance between conduit wall thickness and spacing between pile bents. Approximately 2,000 feet of the dual 14-inch pipe/24-inch conduit has conduit wall thickness up to 3/8 inch to span the supporting pile bents. A cross section of the conduit and piping where the main crosses the poor soil is shown in Exhibit 14. The 24-inch diameter outer pipe conduit is constructed of 6 gauge, smooth wall, carbon steel pipe, sandblasted clean to an NACE near-white finish and coated with catalyzed epoxy. The interior surface received a six mil coating. The exterior surface received a multiple application of epoxy with a layer of glass fabric mesh interposed under pressure at even thickness to assure stability and provide a total thickness of 20 mils minimum.

The system was supplied in standard sections of approximately 39 feet in length with special lengths as necessary to close between anchor points. Field closures were made with sleeves of the same material and thickness as the conduit. Closures were welded into place and coated with compatible epoxy specially suited for field application. The main is insulated with preformed fiberglass insulation having a maximum K factor of .24 at a mean temeprature of 75° F and a minimum density of 5 lbs per cubic foot. The insulation is installed in two layers with all joints staggered to minimize heat loss. The outer layer was provided with an all-purpose A&J jacket secured additionally with 1/2-inch wide by 32-gauge stainless steel bands spaced on 18-inch centers maximum. The total insulation thickness is four inches, leaving a nominal one-inch air gap between outer covering and inner wall of the conduit.

The main is supported at approximately the original grade across the poor soil area (Exhibit 15) and covered with a low level berm which does not harm the aesthetics of this park area. Several meetings were held with City officials and interested citizens on the environmental aspects of this design before the route was finally approved.

The prefabricated conduit system requires a fine concrete aggregate equal to ASTM -C-33 for bedding and surrounding material to provide maximum protection for the epoxy coating. Readily available taconite tailings were found by the soil consultant to be a sutiable substitute for washed sand, and at a significant cost reduction (Exhibit 16).

Compensation for expansion is provided by externally pressurized, bellows type expansion joints (Exhibit 17). The conventional bellows expansion joint is internally pressurized with the expansion rate of each convolution controlled by an equalizing ring. The joint used on this project is pressurized externally and the tendency to squirm is all but eliminated. Expansion joints are constructed of carbon steel, except for the bellows which are made of ASTM B-168 INCO 600 for maximum corrosion protection. The joints were specified to provide up to 14 inches of expansion for an interval of 400 feet of pipe run. Each joint is fitted with one-inch drain and 1/2-inch vent connections. The drain connections are used to trap condensate, thus saving the cost of installing scale pockets on the mains. The vent connections are plugged for future use when the changeover to hot water is implemented.

The high groundwater area along the south end of Silver Lake prompted the elimination of two full manholes in this area and direct burial of eight expansion joints. Typical designs of expansion joint installations in manholes and buried expansion joints are presented on Exhibit 18. Space constraints and poor soil conditions requiring support pilings influenced the selection of expansion joints over expansion loops, except for the difficult crossing of culverts which drain Silver Lake where an expansion loop was installed (Exhibit 19). Special field closure sleeves were welded to the adjacent pipe conduit on either end of each expansion joint after insulation was applied. The field closures were then epoxy coated in the same manner as normal field joints in the conduit system. Condensate traps were located in 36-inch diameter concrete pipe manholes installed adjacent to the pipe line.

Steam traps are installed to accommodate initial steam operation; and trap discharge piping is Type L hard copper with soldered fittings. The traps are located in the manholes and discharge to the nearest sewer. The small quantity of condensate trapped from the lines does not justify the cost of returning the condensate to the power plant. During the period when the new mains are handling steam, the dual lines offer backup to one another should one be taken out of service for any reason. An isolating valve is installed on each line prior to exiting the power plant. Isolating and bypass valves installed in Manhole No. 6 to permit crossing over from one line to another at this point offer added flexibility. All valves four inches and larger are 150 lb class, cast steel, weld end gate valves. These valves were purchased directly by the Utility prior to bidding for installation of the system. This procedure was initiated for purchase of valves and expansion joints as to assure that long delivery items would be available during the relativley short period between bidding and construction of the project.

Standard manhole configurations were used except at turns and for special valving requirements (Exhibit 20). Mains are offset to one side for personnel access and to prevent moisture from the manway from impinging on the mains below. Manholes are constructed of cast-in-place reinforced concrete. Each manhole has a floor drain with backwater valve and piping to sewer.

The construction cost of the approximately 5,620 feet of new dual main was $2,789,000, exclusive of the cost of in-plant piping changes. The cost of the new main was about $496.00 per foot. The cost of the mains would have been less if designed for initial operation on hot water directly. This would have enabled design supply and return temperatures to be 250° F and 150° F, respectively. The cost estimate for the total project was $3,570,000 and the five bids received ranged from $2.9 million to $3.3 million. The project was financed by the issuance of general obligation-revenue public utility bonds and a $600,000 grant from the Iron Range Resource and Rehabilitation Board. The bonds were sold on September 10, 1980 for a net interest rate of 6.959%. The issue was rated Aa by Moody.

The new line (Exhibit 21) went into operation in October, 1980. The pressure drop problem to the north side was solved and the area was supplied with 50 psig extraction steam during the entire ensuing heating season. The Virginia Regional Medical Center, located on Virginia's north side, used the steam for its laundry, sterilizing, and heating needs, and did not operate its gas and oil-fired boilers during the heating season. Utility personnel estimate that the fuel savings accruing to this more efficient operation to have been approximately $200,000 to $225,000.

The Mesabi Community College load of about 7,500 pounds per hour was added to the new main which added income to the district heating utility and conserved critical fossil fuels burned in the college plant. A dual line for ultimate conversion to hot water was installed to serve the college.

An example of improvements realized by the operation of this new line is shown in Exhibit 22. For consecutive Februarys, the steam sales and the level of generated and purchased electrical energy were about the same. The total energy required to be input into the system was about 22,664 x 10^6 Btu less in the 1980-81 heating season than in the previous year. Being able to take greater advantage of the cogeneration cycle, and with a new distribution system to reduce the losses, and with the capability to provide for growth, places the Virginia heating utility in a good position for the future. Planning is underway for additional system improvements in other areas of town.

V. Lakeview Addition District Heating

Additional loads for a district heating system can be developed by installing the mains to serve limited portions of the ultimate service area and installing small boilers near the load to supply the necessary thermal energy. These satellite systems are established according to a plan for integration into the principal system when it is constructed. All facilities are designed for incorporation into the ultimate district heating system, and a flow of revenue is developed early to assist in financing the total project. As the satellite systems are connected to the growing principal system, the small boilers are moved to new satellite areas being established.

A similar method was evaluated in converting the Virginia district heating system from steam to hot water. Instead of boilers, however, the satellite areas would be served by steam-to-hot water heat exchangers served from the present steam system. When the load served by a particular steam main is substantially converted to hot water in this manner, this entire circuit including the main from the power plant is converted to hot water, and the satellite heat exchangers are relocated for the development and/or conversion of another segment of the system. It is anticipated that the north side of the Virginia system served by the new steam/hot water main will be converted in this manner.

With the construction of the new main areas of the City which previously did not have access to district heating were made available. One substantial new load secured for the district heating system was the Mesabi Community College previously discussed. In addition, a residential development known as the Lakeview Addition (Exhibit 23) petitioned the Utility for district heating service and provided a good opportunity to establish the initial satellite system. The Lakeview Addition includes 37 existing residences, all of which were polled in questionnaires for information on present heating facilities. All of the 30 responses indicated oil fuel with 21 residences having warm air furnaces and nine with hot water boilers. The furnace input range is from 80,000 Btuh to 130,000 Btuh.

A satellite hot water system to serve Lakeview is shown on Exhibit 24. The total cost estimate was $311,207 of which $188,882 covered the steam line and the satellite converter and pumping station; and $122,325 was the estimate for the construction of the hot water distribution system in this neighborhood. The policy of the Utility requires district heating extensions to be paid by the customer. Contributed funds are anticipated which would pay for the steam line and converter station; but the hot water main cost would be assessed $3,306 per lot. A special study was also made of the cost of converting the equipment on a customer's premises to utilize hot water. A schematic of a typical conversion is presented on Exhibit 25. The estimated cost for the conversion and the service line on the customer premisis is $3,908 for a warm air furnace, and $2,607 for a hot water boiler (Exhibit 26). The Department of Public Utilities offered to finance customer costs over a ten-year period at 9% interest.

A cost comparison between thermal energy via the hot water system, including payments on the cost of conversion, versus the cost of oil for space heating and electric energy for water heating is presented on Exhibit 27. The comparative energy cost trends used in this study are as follows:

Thermal Energy.	+ 10% per year
Electric Energy for Water Heating . . .	+ 10% per year
No. 2 Fuel Oil for Home Heating	+ 14% per year for 5 years + 10-11% per year thereafter

The forecast of No. 2 fuel oil cost is based on projections of the Minnesota Energy Agency and reflect escalation due to price decontrol during the initial five years. The estimated annual costs are higher for the first one or two years as shown on Exhibit 27; but the difference favoring district heating increases dramatically as the cost of No. 2 fuel oil escalates.

The use of steam rather than hot water as the thermal transport media to serve Lakeview was also studied. The estimated cost of the steam system is slightly higher ($318,000 vs. $311,207). The customer's estimated cost of conversion using steam is $608 lower with a warm air furnace and $963 higher with a hot water boiler installation, compared to conversion for a hot water distribution system. An advantage of converting to hot water initially is to prevent a double conversion, first to steam, and then to hot water when the north side system is converted from steam to hot water. Furthermore, the conversion and pumping station can be moved to another satellite system location and would have a salvage value.

The Lakeview project (Exhibit 28) is on hold at the present time awaiting a commitment of contributed funds from a state governmental unit which starts a new fiscal year and funding plan on July 1, and final approval by the residents of the Lakeview Addition.

VI. Conclusion

The City of Virginia (Exhibit 29) has made a commitment to continue its 62-year record of service in district heating. Facing a significant capital improvement program associated with its distribution system, and with concurrent opportunities to increase the overall system operating efficiency, the Department of Public Utilities looked down the road many years. Planning studies indicated that long-term dollar savings were possible with a conversion to a modern hot water district heating system. In addition, the increased efficiency brings about the potential for meeting additional load growth without added generating capacity. This paper has presented a discussion of the first step - sometimes the hardest one to take.

The City of Virginia has been, and continues to be, an active promoter of district heating. Mr. Ed Kozan, Superintendent of the Department of Public Utilities, and Mr. Dave Rubenstein of the Virginia City Council, are regular participants in efforts to explain the benefits and difficulties associated with district heating systems. They have been involved at local, state, regional, and federal levels with trade groups, government agencies, and congressional delegations. District heating will continue in Virginia, Minnesota. Hopefully, some of the experiences of the Virginia Department of Public Utilities will be of interest to other existing district heating utilities, and to those cities and towns contemplating district heating for their communities.