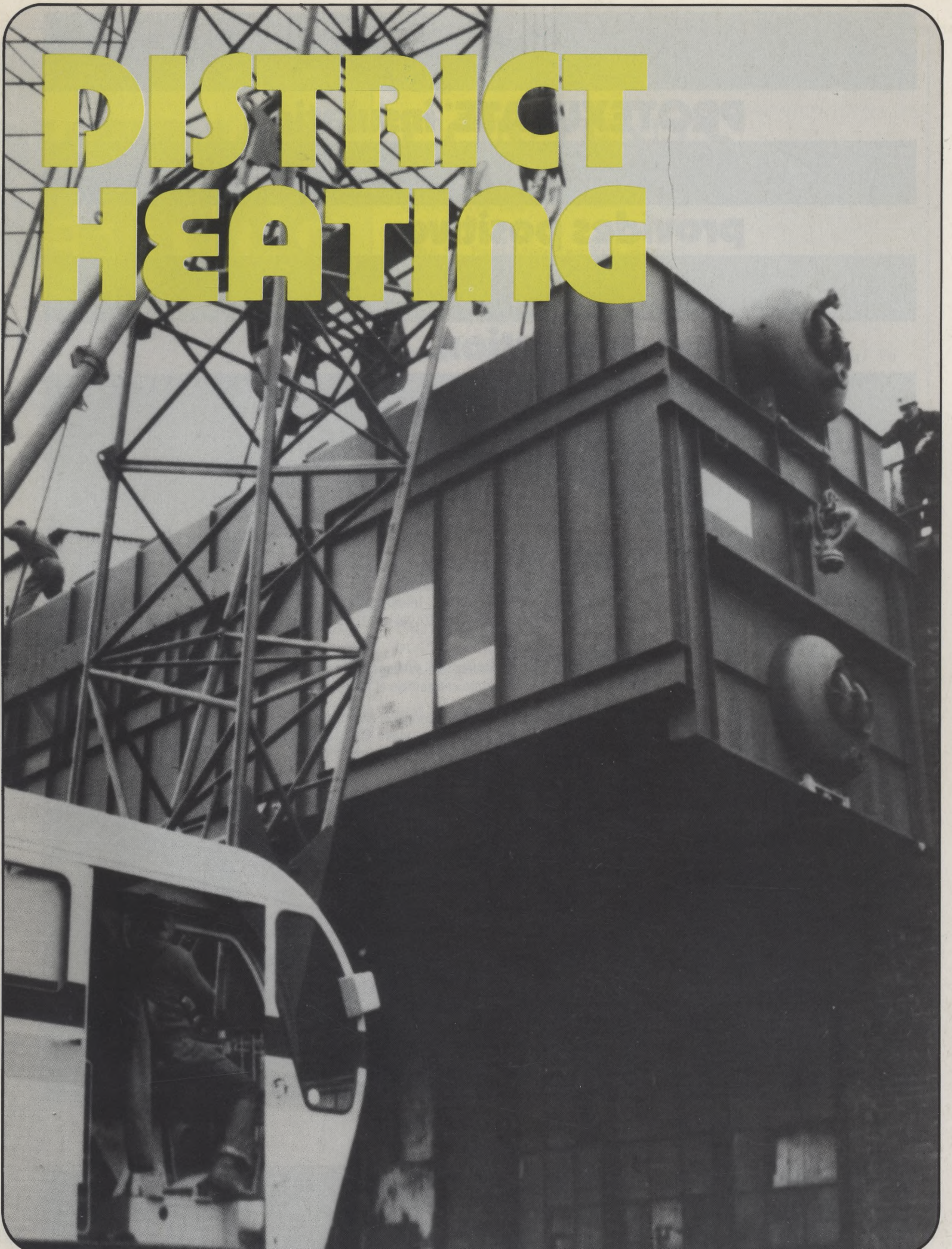
DISTRICT HEATING



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The St. Paul Metering Experience

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Introduction

Being a pioneer, the District Heating Development Company has faced many problems. One of these was the accurate and equitable billing of customers for heat energy consumed. This case history outlines the requirements of the downtown St. Paul Heating System and explains in detail how the individual components of the BTU System combine to meet those requirements.

The St. Paul downtown hot water district heating system is similar to every other district heating network in function. The District Heating Development Company (hereafter referred to as DHDC), supplies hot water to each customer's heat exchanger and then bills for energy consumption. In simplified form, and before the installation of heat meters, the system at each customer site appears as follows. DHDC was responsible for the installation of the supply and return piping into the building and the shutoff valves. DHDC also provided the customers with a BTU meter system.

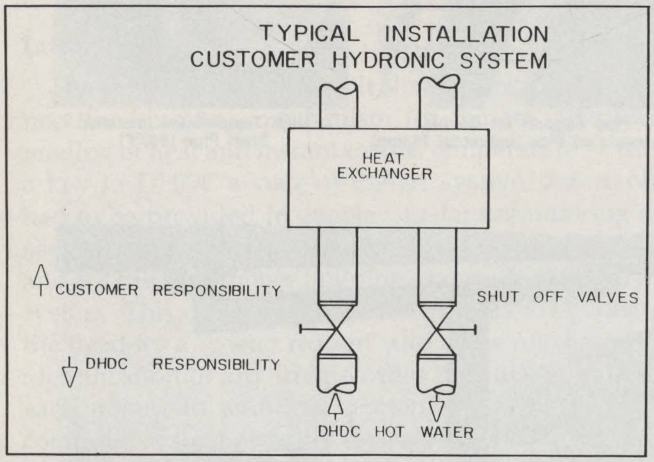

Figure 1

The actual DHDC system parameters include maximum pressures of 250 PSIG and maximum temperatures of 250°F. Summer supply temperatures are usually about 190°F, while winter supply temperatures are generally 220°F. Return temperature is to remain below 160°F or the customer incurs a penalty. Pipe sizes at the customer sites range from ¾″ for very small energy consumers to 6″ for large consumers such as hospitals and industries.

In addition to space heating in the winter, this system is also used to provide heat for domestic hot water. Hence, even in the summer, the hot water system is not completely shut down. This parameter dictates the large meter ranges required for this system.

System Requirements

The preceding system environment outlined some specific requirements of the BTU meter. Condensed and categorized they include accuracy, rangeabilty and interfaces.

Accuracy

The heat meter accuracy requirement was originally specified in two pieces, volumetric flow measurement accuracy and heat flow accuracy.

The graphical interpretation of volumetric flow measurement accuracy has been reproduced here from the original specifications. Again, it is independent of heat flow accuracy and a table of Q_n (nominal flow rates) was provided to enable the use of this one accuracy curve for all meter sizes.[1]

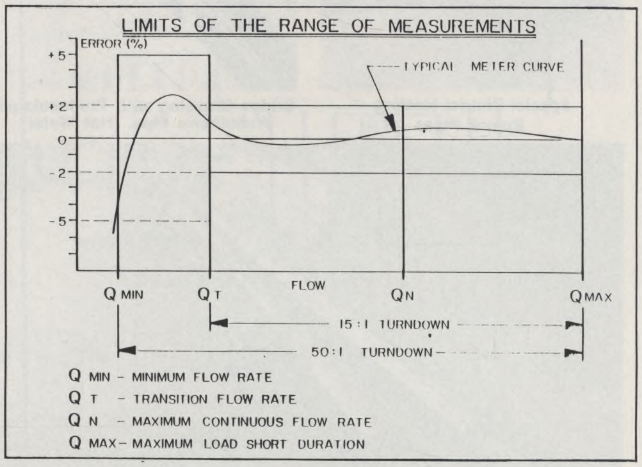

Figure 2

Heat flow measurement accuracy was stated independent of errors in the measurement of volumetric flow. Accuracy was specified according to differential temperature in the following table.[2]

Table 1 indicated a definite preference for accurate heat energy measurement. It implied the use of the integral heat transfer equation $Q = \int \dot{m} \, (h_2 - h_1) \, dt$, rather than the popular constant specific heat approximation BTUs $= C_p \int \dot{m} \, \Delta T \, dt$.[3]

TABLE 1

Accuracy of Measurement

T (°C)	Accuracy With enthalpy and density correction %	Accuracy Without enthalpy and density correction %
$5 < T \leq 15$	±2	± 4
$15 < T \leq 30$	± 1	± 2
$30 < T \leq T_n$	± 0.5	± 1

Where,

Q = heat energy delivered
$\dot{m}$ = mass flow rate
h = enthalpy of the liquid
C_p = constant specific heat
ΔT = differential temperature

Rangeability

Rangeability requirements included a minimum meter turndown of 50:1.[1] This turndown was stated as relating to the limits of the range of measurements figure (Figure 2) in the following manner:

Table 2

Range of Measurements
$Q_{min} \leq 0.04\ Q_n$
$Q_L \leq 0.14\ Q_n$
$Q_{max}\ 2\ Q_n$

Interfaces

The simple specification "It shall be possible to connect the counting mechanism for remote computer reading of heat and instantaneous temperature,"[4] was a key to DHDC's state-of-the-art system. Interfaces had to be provided to enable constant monitoring of each site from a remote location at the power plant and by the customer's building energy management system. This continuous monitoring was to eliminate the need for a "meter reader" and allow for the rapid identification of any irregularities in the operation of each meter. In addition to monitoring, the DHDC computer system provides the time variable for energy rate use to effectively provide the function of demand meters. By polling the meters at set time intervals, the rate of energy use for each customer can be obtained.

Heat Meters

Every hot water energy meter package must always consist of the following components: one flow meter, two temperature sensors (one on the supply line and one on the return) and an integrating device to calculate energy consumption. Superimposing those components on Figure 1 created the following typical installation.

Each component, flow meter, temperature sensors, and integrator will now be discussed as each relates to the DHDC energy measurement device.

Flow Meter

The equation for heat flow energy is $Q = \int \dot{m}\,(h_2 - h_1)\,dt$, therefore, the measurement of mass flow ($\dot{m}$) obviously is very important. Many primary flow measurement devices are available to accomplish flow measurement. However a turbine meter was selected for its rangeability, accuracy and reliability.

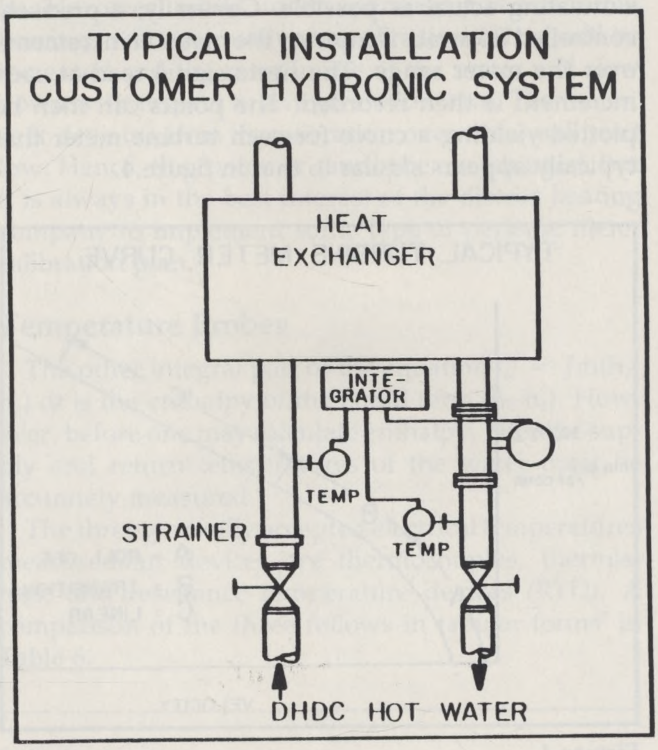

Figure 3

Method of Operation

By design, turbine meters require some method of determining rotor blade position. In the early years of turbine meters this was accomplished exclusively through the use of mechanical linkages. However, the electrical sensors now available enable much more reliable performance due to the elimination of many moving parts.

Although RF and capacitance pickups occasionally appear, the use of an electromagnetic field is by far the most common method to sense rotor blade position for turbine meters. The signal off the magnetic coil is sinusoidal in nature and generally expressed as pulses per second (hertz). It is generated by the rotor blade breaking the magnetic field and creating a voltage spike.

Rangeability

Turbine meters have long been noted for their wide readable range (turndown). Manufacturers advertise turndowns ranging from 10:1 to 100:1. Recall that the original meter specification (Figure 2) included a minimum 50:1 turndown.

Accuracy

Meter turndown is independent of accuracy. It is merely the variable flow range over which a meter is capable of giving a reading. However, accuracy over the range is extremely important. To achieve the highest degree of accuracy, each turbine meter should be individually calibrated under conditions as closely simulating actual as possible. Generally, a precisely controlled flow rate is input to the meter at increments over the meter range. The hertz signal read at each increment is then recorded. The points can then be plotted yielding a curve for each turbine meter that typically appears similar to that in figure 4.

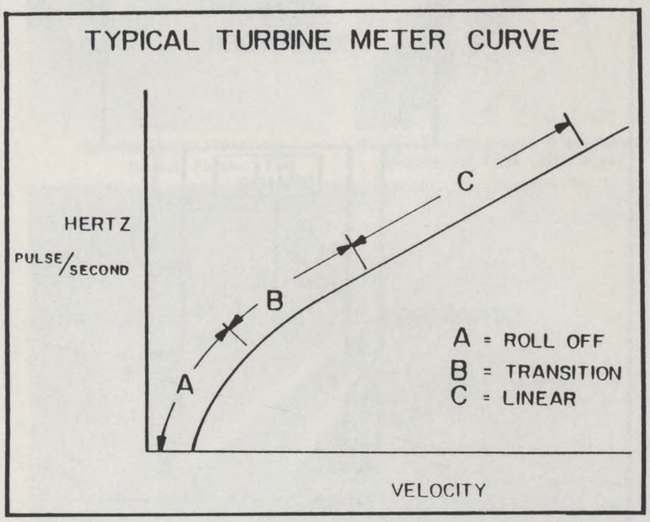

Figure 4

Note the linear range indicated on the graph. Most manufacturers state linearities of ±1% of reading or better within this range.

Another key to turbine meter performance is repeatability or always obtaining the same reading under the same conditions. Within the linear range, repeatability is generally stated from ±0.10% to ±0.25% depending on the manufacturer.

Regardless of manufacturer, all turbine meters in water service should behave similarly to Figure 4. The transition zone is the area of the curve where bearing drag and fluid viscosity begin to have a noticeable effect on the turbine meter rotor. Linearity becomes poorer in this zone, and repeatability becomes slightly more erratic. However, repeatability remains roughly in the ±1% range.

The final, low flow zone is the "roll off" area. If a turbine meter had no mass and no bearing drag, then this "roll off" would not appear and the linear range would extend through the origin.

However, in the real world it does take a certain minimal amount of kinetic energy to start the rotor turning. Since kinetic energy is generally expressed as pV^2 where p = density and v = velocity, a minimal velocity must be achieved before a turbine meter begins to read. In water, this point is often below ½ foot per second and can be in the range of ¼ foot per second.

Repeatability in the roll off zone is not particularly good. It is typically in the 5-10% range and can be even worse. Because of the erratic behavior at low kinetic energy levels, it is recommended that one avoid selecting a turbine meter that is to operate continuously in the roll off zone.

The roll off zone generally begins after a 50:1 turndown. For example, EMCO 2" turbine meters are specified as illustrated in Figure 5.

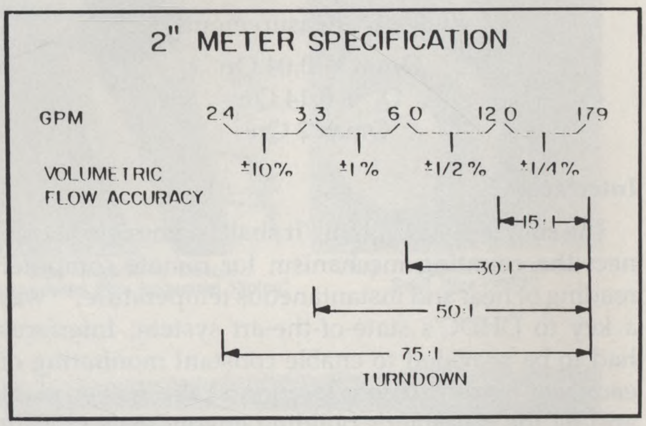

Figure 5

Turbine meter accuracy is always stated as a percentage of point or as a percentage of reading. Both terms have identical meanings. For example, suppose the linear range of a hypothetical turbine meter exists from 5 GPM to 100 GPM. (The 20:1 turndown implied here is not at all unreasonable.) If a manufacturer makes the statement that the turbine meter will be accurate to ±1% or reading the following accuracy is implied (see Table 4).

Hence, the customer would be receiving "free" energy as the differential pressure generated by the orifice plate would be too small to read at those low flow rates. Also, since accuracy was stated as ±1% of full scale, the orifice plate accuracy would never be better than ±1 1 GPM. In tabular form (see Table 5).

Point accuracy is often confused with the full scale accuracy quoted for differential pressure devices. If,

Table 4

Turbine Meter Accuracy

Flow Rate	**Potential reading Error in GPM**	**Accuracy at the rate**
100 GPM	±1 GPM	±1%
50 GPM	±0.5 GPM	±1%
25 GPM	±0.25 GPM	±1%
5 GPM	±0.25 GPM	±1%

Table 5

Orifice Plate Accuracy

Flow Rate	**Potential Reading Error in GPM**	**Accuracy at the rate**
100 GPM	±1 GPM	±1%
50 GPM	±1 GPM	±2%
25 GPM	±1 GPM	±4%
5 GPM	No reading	No reading

for example, an orifice plate were used for the same 5-100 GPM application, several degrees of accuracy and rangeability would be lost.

First of all, it is common knowledge that orifice plates have a turndown generally limited to 4:1. Thus, the lower end of the turbine meter linear range, 5-25 GPM, would not be read at all.

The full scale versus point accuracy argument holds for all differential pressure devices such as averaging pitot tubes and venturi nozzles. Some of these differential pressure devices do have larger ranges than orifice plates. For example, the standard turndown quoted by a manufacturer of pitot tubes is 7:1.

Reliability

Reliability of meters used for custody transfer (billing purposes) has always been a problem. One must be able to prove that the custody transfer meter will not result in a customer being overcharged even after a long period of service.

To prove that there is no possibility of overcharging, look at the mechanical design of a turbine meter. When the meter is new, it is generally calibrated in water. The bearings and the shaft that fits into them are as close to perfect frictionless operation as they can ever be. However, while under operation it is a fact that bearings will eventually wear. Frictional drag will be increased and the rotor inside of the meter will slow down with respect to any given flow rate. The meter, as it deviates from its calibration over time, will read low. Hence, the customer cannot be overcharged, but it is always in the best interest of the district heating company to implement some type of periodic meter calibration plan.

Temperature Probes

The other integral part of the equation $Q = \int \dot{m}(h_2-h_1)\,dt$ is the enthalpy of the liquid term (h_2-h_1). However, before one may calculate enthalpy, both the supply and return temperatures of the water must be accurately measured.

The three generally accepted electrical temperatures measurement devices are thermocouples, thermistors, and resistance temperature devices (RTD). A comparison of the three follows in tabular forms[5] in Table 6.

Table 6

Temperature Transducers

	Thermocouple	**Thermistors**	**Platinum RTD**
Service Range	500 −3000°F	Up to 6000°F	−320-1800°F
Sensitivity	10-50 Micro volts/°C	100-1000 ohms/°C	0.2-10 ohms/°C
Repeatability	2-15°F	0.2-2°	0.05-0.01°F
Linearity	Excellent	Poor	Excellent
Unique Feature	Largest Range Highest Temperature	Greatest Sensivity	Best Accuracy over A Wide Range. Very Stable.

Integrator

The final element of the BTU meter system is the electronics package. An integrator had to be developed to provide state-of-the-art calculations of heat energy consumption.

With the availability of low cost microprocessors, the achievement of using enthalpy of the liquid rather than simply differential temperature was realized. Therefore, for the DHDC system the actual equation $Q = \int \dot{m} (h_2 - h_1)\, dt$ is utilized.

The first term $\dot{m}$ (mass flow) was broken down into the component equation $\dot{m} = p\,AV$, where p = density, A = pipe cross-sectional area and V = average fluid velocity.[6] The first term, density of the liquid, fluctuates slightly with changes in temperature. Hence, in an effort to keep the mass flow calculation as accurate as possible, a water density algorithum was developed to calculate density of the water. In the case of the DHDC integrators, the density is updated every four seconds.

Since area is a constant, the measurement of velocity was the only other controllable variable. It was given a thorough scrutiny as it relates to turbine meters only because they had already been selected for their rangeability.

The hypothesis was that if the turbine meter measurement could be made dependent on repeatability rather than linearity then better accuracy could be achieved. Also, larger turndowns could be realized because one would no longer be restricted to the linear range.

To achieve this, each turbine meter was calibrated individually within its meter body at six points that extend down into the non-linear range of the meters. An EPROM was then burned with the six point calibration for each particular meter and the microprocessor at each meter location sets up a segmented curve of those points. Typically, it would look something like this:

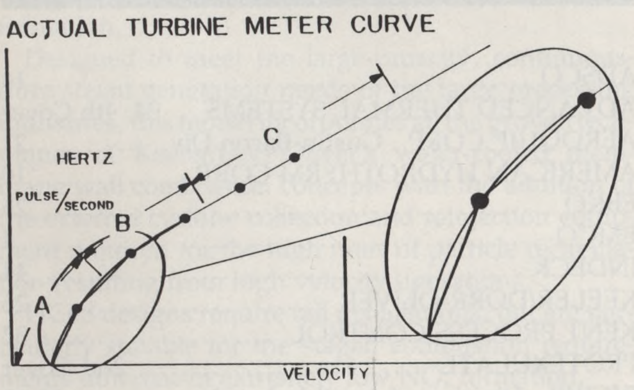

Figure 6

Note the similarity to Figure 4. The segmented curve follows the actual meter calibration. Hence, the accuracy of the flow meters became dependent on repeatability rather than linearity and the readable range extended to a range often in excess of 75:1.

Fault Detection

Flow meters are often regarded as "black boxes" by the general public. They are attached to or inserted into a pipe and they give a reading. In custody transfer applications that reading is generally law until it markedly changes. Then generally the meter is removed and an estimated bill is provided for the previous month and for the month during the repair. However, instantaneous fault detections can greatly shorten meter down time and hence, estimated billing time. For example, the DHDC microprocessor integrators constantly monitor the operation of each flow meter, the temperature probes and themselves. If any of these components malfunction, an LED is lighted on the integrator signaling the problem. This feature provides peace of mind to the customer and provides evidence of a correctly functioning meter for the District Heating Company if a tenant questions the validity of a bill. Simple visual inspection of the integrator will indicate any malfunction in the recent past.

Interfaces

One step ahead of a "meter reader" is use of computer interfaces for the constant polling of the meters. It enables the collection and desemination of information from each meter location and includes such vital information as temperature and flow rates in addition to instantaneous fault detection. As previously mentioned, all meter locations on the DHDC system are constantly monitored through the use of RS232C outputs from each integrator.

Conclusion

State-of-the-art BTU meter accuracy was the goal of DHDC. It was to this end that all components were designed. However, theoretical and real world conditions sometimes differ. Hence, several real world problems were encountered and solved by DHDC. The two most common ones follow.

Apparently because of their rush to connect to the system, several customers put off completing all of the work on the piping between the strainer and the meter (Figure 3) until after the line was in service. A common scenario was the hot tapping of instruments into the lines after the service had begun. At those locations and in several others where line flushing was not done per specification, solids in the line ruined turbine meters. DHDC now requires a strainer directly upstream of the meter.

The contractual agreement with each customer included a clause stating that the customer shall provide 110 AC power for the BTU meters. Neither Engineering Measurements Company (the BTU meter manufacturer) nor the District Heating Development Company foresaw the possibility of power supply surges of the magnitude experienced at several locations as most of the customers had rather new buildings. However, after a short period of service it became evident that AC line filters were a necessity. Filters were retrofitted to the first few integrators and then made standard for the remainder of the electronics.

DHDC worked through those problems encountered with the BTU meters over the first few months of operation. Now, the District Heating Development Company has a truly showcase system.

References

1. Henningson, Durham & Richardson, Inc., *Specifications for St. Paul District Heating System Heat Metering* (Minneapolis, Minnesota, April 1983), pp. 13640-13.
2. Ibid., pp. 13640-16.
3. J. P. Holman, *Heat Transfer*, (McGraw-Hill, 1976), p. 204.
4. Henningson, Durham & Richardson, Inc., *Specifications for St. Paul District Heating System Heat Metering*, (Minneapolis, Minnesota, April 1983), pps. 13640-16.
5. Source: Sales literature of various transducer manufacturers and American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., *ASHRAE Handbook of Fundamentals*, 1976), p. F-198.
6. John Vennard and Robert Street, *Elementary Fluid Mechanics*, (John Wiley and Sons, 1975) pp. 108-110.

Zallea's Drawings and Engineering Data Acquired by Pathway

Pathway Bellows has acquired all of the Zallea drawings and engineering data and is now able to provide equivalent expansion joint designs to replace or refurbish existing Zallea Expansion Joints. Pathway will continue to supply the high quality and engineering expertise that Zallea had provided to its customers for many years.

All previous Zallea order information as well as the engineering drawings and calculations are readily available to provide the back-up information necessary to replace any Zallea installation. Simply provide Pathway with an order or drawing number, and a quotation for the replacement expansion joint or other system component will be provided quickly. For further information, please write or call: Pathway's Customer Service Department, P.O. Box 1526, El Cajon, CA 92022-1526 (619) 440-1300.

Barnes & Jones Introduces Conversion for Disc Traps

Barnes & Jones' new Disc Trap Conversion converts a disc trap into an energy-saving thermostatic trap *without disturbing piping*. The conversion is a small lightweight thermostatic trap which "piggybacks" onto a disc trap body after removal of the disc and cap. No re-sizing or re-piping is required. The old disc trap body remains on line as a piece of pipe. The Barnes & Jones Disc Trap Conversion is available for all major makes and models of disc traps. It takes *ten minutes* to convert to the new B & J unit versus one hour or more to re-trap.

Steam Time

Editor's Note: Our thanks to Edgar A. Center of Falmouth, MA who shares our enthusiasm for steam as one of the versitile methods of the transmission of energy. This is a street clock in Vancouver, B.C. powered by *steam* and is located on the corner of Water and Cambie Streets.

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