THE PITOMETER AND ITS USES IN WATER WORKS OPERATION

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1921
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A THESIS

PRESENTED BY

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TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

CIVIL ENGINEER

JUNE 2, 1921

APPROVED:

ILLINOIS INSTITUTE OF TECHNOLOGY
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The successful operation of a water works system requires a thorough knowledge of what becomes of all of the water that enters the system. The history of the water from the suction end of the pump to the ultimate consumer is an indication of the efficiency of the system. This history can be briefly stated in a few words. First the water enters the suction end of the pump and part of it fails to go into the discharge system on account of pump slippage. After entering the discharge system part is lost through leaks, open blow-offs and illegitimate use. In metered districts the remainder passes through the consumers' meters and part is unpaid for due to meter slippage. In unmetered districts the consumer is inclined to look upon the water as a free commodity and consequently is inclined to be careless in regard to its use, with the result that on account of leaky plumbing or wilful waste he consumes an amount in excess of what is really needed. The determination of all of these losses and cutting them down to a minimum should be the aim of all water works managers.

In addition to the determination of the disposition of the water a knowledge of how it is distributed is also of prime importance. The maintenance of proper pressures requires that the
distribution mains must be of a certain size and so located as to properly and economically distribute this pressure. The extra demand that is made on the discharge system during fires must also be taken care of by intelligent design of feeder and distribution mains. Not only must the design be right, but proper care must be exercised to see that all valves are open or the purpose of a main may be defeated. In the succeeding pages we will discuss methods of carrying on investigations that will make it possible to ascertain the condition of a distribution system as well as obtain data to be used in the design of additions to the system.

METERS

The investigation of a distribution system consists essentially of determining the volume of water passing through the mains at various points in the system. This necessitates the use of some kind of a meter or measuring device. The installation of disc, plunger, or other types of meters requiring the cutting of the pipes on four, six, and eight inch mains, would not only require the expenditure of an enormous sum of money, but would also require considerable maintenance work and would be apt to interfere with the free flow of water. The installation of any of these types of meters on mains from twelve inches to thirty-six inches in diameter would be entirely impracticable.
It is possible to measure some flows in some mains by closing a line valve and bypassing the water through a small meter. This method of flow measurement is unsatisfactory for high velocities because of the fact that pressure lost through the meter introduces an unusual condition which might materially affect the results of the survey. The solution of the problem of metering the mains lies in the use of some type of meter that will be portable, will not interfere with the flow, can be adapted to all sizes of pipes, will be cheap, will be easily maintained, and will give accurate results. The one meter that fulfills all of these requirements is the Pitometer. The use of the Pitometer requires no cutting of the mains, but only the installation of the ordinary one inch corporation cock used for service connections. The remainder of the outfit necessary to flow determination consists of a rod meter, a U-tube, and a recording Pitometer, all of which are easily moved from place to place and can be used on any size of pipe. The accompanying photograph shows the Pitometer manufactured by the Municipal Supply Company of Chicago. In the photograph the rod is shown connected to a twelve inch pipe that has been broken upon to show the method of connection. The manometer and recording pitometer are both shown connected to the rod. A calibrating rod for the measurement of the diameter is also shown.
THEORY AND OPERATION

The Pitometer Rod consists essentially of two orifices, two brass tubes passing through a sleeve, and a stuffing box for connection to the main. The rod is connected to a manometer by rubber tubes for portable use, or by piping for permanent installation. The actual operation of making observations consists in first connecting the two tubes on the rod to a manometer half full of mercury or carbon tetra-chloride, as shown in the photograph. The stuffing box is then attached to a one inch corporation cock and the cock opened. The rod can then be pushed into the main and the orifices lined up parallel to the line of the pipe. By moving the rod up or down in the stuffing box the orifices can be set in any position across the diameter of the pipe.

The impact of the water on the up-stream orifices transmits an additional pressure at this point because of the velocity of the water. This additional pressure varies with the velocity of the water in the same ration that the velocity of a body falling in vacuum bears to the distance travelled, and is represented by the formula

\[ v^2 = 2gh \]

h in this case representing the additional pressure on the up-stream orifice. This increment of pressure is measured by the
liquid column in the manometer. A calibration constant C must be introduced; this constant has been arrived at by the various Pitometer manufacturers by making observations in pipes where the velocity was known or by moving pitometer rod at a known velocity in still water. It varies from .73 to .84 with different types of rods having the down-stream orifices in different positions with respect to the flow. The formula then becomes

\[ V = C \cdot 2gh \]

The head \( h \) indicated on the manometer = \( H(s-1) \) where \( H \) is the deflection of the liquid in the manometer in Feet and \( s \) the specific gravity of the liquid. The term in parenthesis becomes \( s-1 \) because of the fact that the liquid column is balanced by the additional head plus the water column (specific gravity = 1) on the low side of the tube, or

\[ h + Hx1 = Hxs \]
\[ h = H(s-1) \]

The formula then is

\[ V = C \cdot 2gH(s-1) \]

From this formula tables giving the value of \( V \) for various values of \( H \) in inches are prepared for different values of \( s \). Combinations of carbon tetra-chloride and benzine are mixed to give specific gravities from 1.25 to 1.50, and mixtures of bromoform and benzine for gravities from 2.00 to 2.50. For higher velocities mercury is used.
TRAVERSING

Before the mean velocity can be determined it is necessary to determine the coefficient of the pipe. In order to determine this coefficient it is necessary to determine the velocities at various points across the diameter of the pipe. This process is called "Traversing the Pipe". In explaining this part of the operation we will consider the traverse shown on Plate-I. The rod is first inserted in the main with the orifices touching the bottom of the pipe, and an observation made on the manometer to determine the velocity at this point. In this case the deflection of 1.60 sp.gr. liquid was 6 inches which indicates a velocity of 3.684 feet per second. The rod was then pulled part way out until the orifices were 3 inches from the bottom of the pipe, the location of the orifices being determined by graduations on the side of the Pitometer rod. The manometer observations are made at this point and the operation repeated until velocities have been determined at 12 points across the diameter. The traversing is then repeated beginning at the top of the pipe and making observations at points midway between those used in the first traverse. This gives twenty-four points in the curve. At frequent intervals during traversing the reading at the center should be repeated because any change in center velocity during traversing would result in an erronius curve.
For most accurate work this is repeated on two diameters at right angles to one another, the average of the pipe coefficients for each traverse being used as the pipe coefficient. Having plotted the velocities as shown on Plate-I the pipe is divided into annular rings having nearly equal areas, and the volume flowing in each ring determined from its area and the mean of the two velocities shown in the traverse in that particular ring. See table on Plate-I.

Plate-II shows two traverses made on a 36 inch main. These are typical traverses and were very carefully made as rating tests on two centrifugal pumps were made from observations at this point. Plate-III shows traverses made on 30 inch discharge pipes. In these cases the taps were located near bends and check valves thus causing a departure from the usual parabola-like curve. In spite of this irregularity the coefficients determined from these traverses were checked by observations made at these points and at the points whose traverses are shown on Plate-II. During one test the flow indicated on the 30 inch pipe was 21,102,600 G.P.D. and the same flow on the 36 inch was 21,067,200 G.D.P. an error of .17%.

The main is then calipered by means of a special calibrating rod (see photograph) and the exact diameter obtained. We now have the pipe coefficient and the area, and by measuring center
**Plate I**

**Traverse of Vertical Diameter, 36” Main In Oglesby Ave. at 68th St.**

<table>
<thead>
<tr>
<th>Ring</th>
<th>Vel.</th>
<th>Edge 1</th>
<th>Edge 2</th>
<th>Edge 3</th>
<th>Edge 4</th>
<th>Edge 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3.68</td>
<td>3.30</td>
<td>3.95</td>
<td>3.30</td>
<td>3.68</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>4.70</td>
<td>4.50</td>
<td>4.93</td>
<td>4.50</td>
<td>4.70</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>5.03</td>
<td>5.03</td>
<td>5.03</td>
<td>5.03</td>
<td>5.03</td>
<td></td>
</tr>
</tbody>
</table>

**Center Velocity**

<table>
<thead>
<tr>
<th>Diameter</th>
<th>Ring Area</th>
<th>Diff. In Area</th>
<th>Velocities</th>
<th>Mean Velocity</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>36</td>
<td>31.0685</td>
<td>5.2444</td>
<td>1.8821</td>
<td>3.68</td>
<td>3.815</td>
</tr>
<tr>
<td>A</td>
<td>25.3488</td>
<td>1.9226</td>
<td>4.43</td>
<td>4.43</td>
<td>4.441</td>
</tr>
<tr>
<td>B</td>
<td>18.1767</td>
<td>1.6417</td>
<td>4.70</td>
<td>4.70</td>
<td>4.709</td>
</tr>
<tr>
<td>C</td>
<td>12.5000</td>
<td>1.7617</td>
<td>5.03</td>
<td>5.03</td>
<td>5.030</td>
</tr>
</tbody>
</table>

**Total Volume**

**Mean Velocity**

\[
\text{Mean Velocity} = \frac{31.6469}{7.0685} = 4.477 \text{ ft. per sec.}
\]

**Pipe Coefficient**

\[
\text{Pipe Coefficient} = \frac{\text{Mean Velocity}}{\text{Center Velocity}} = \frac{4.477}{5.085} = 0.8804
\]

*Traverse by L.F. Wolfe*
TRaverse of 36' Main in Oglesby Ave.
6 ft. West of East line of Oglesby Ave.
23 ft. North of South line of 68th St.

Vertical Traverse

Horizontal Traverse

Coef. 0.88

Avg. Coef. 0.885

Deflections in inches

Sp.Gr. 1.80

Plate II
velocities and substituting in the formula

\[ Q = CAV \]

the volume of water can be computed. The discussion of the various kinds of surveys that are made in water works operation will be taken up in the following order—pump slip tests, additions to system, fire flow tests, closed valve tests, leak tests.

**PUMP SLIP TESTS**

The starting point in the pumping station design is the determination of the volume of water it will be necessary to deliver. This fact is recognized by all engineers and pumping stations are designed accordingly. Great care is taken to install efficient engines, modern coal and ash handling equipment, condensers, and so forth, to the end that the cost of delivering water will be as low as possible. Frequent tests are made on the steam end of the pumps to see that they are operating at their highest efficiency. There seems to be a tendency, however, to overlook the performance of the water end of the pump, although this performance is what determines whether or not the station is fulfilling its purpose. The maintenance of the high efficiency aimed at in station design can only be attained by constant care of the water end of the pumps. There is no pump made whose parts will last forever. Consequently, it is reasonable to suppose that the amount of slip in a pump will become greater with age.
It is also a fact that the pump's valves may become loose or damaged in such a way as to remain open at all times, thus causing a large slip. It is necessary, therefore, to make frequent tests on the discharge of a pump to determine the amount of slip. This is done by installing a Pitometer on the discharge line and comparing the volume of water discharged to the plunger displacement of the pump. If a valve should become dislodged or broken a test of this kind will indicate this condition at once and proper measures can be taken to repair the damaged part. The writer recalls a pump having 1,000 valves with a loss of one valve resulted in a slip of 25%. Without a test this pump might have run indefinitely delivering only a part of what was required of it. Pitometers should also be installed on centrifugal pumps as the impeller may become worn or broken and the efficiency reduced without any outward indication. A centrifugal pump tested by the writer showed a discharge of 9,000,000 gallons per day, whereas its rating curve indicated that it should deliver 20,000,000 gallons per day. When the pump was opened it was found that the impeller was damaged by a baffle plate that had become loose and lodged in such a position that it gradually wore away the blades.

ADDITIONAL FEEDER MAINS

The necessity for additional feeder mains in any
district is first evidenced, as a rule, by a lack of pressure in the district in question. If the engineer in charge of distribution waits for this lack of pressure to indicate the need of new feeders he is not rendering proper service to the consumers, as they are then required to endure a period of low pressure until a new main is installed. Instead of waiting for this low pressure to indicate the necessity of new mains a survey of the existing mains combined with a knowledge of the future requirements would indicate the need of new feeders as well as what size they should be and also where located. This survey consists in determining at what velocities the mains are working for the purpose of - not only finding out what the existing consumption is - but also to determine how much additional supply they can deliver without excessive pressure losses. Here again the Pitometer comes into play for determining the velocities in all of the mains in the territory in question. From the velocities determined in this survey, pressure losses along the mains, both under existing as well as future conditions, can be determined. This investigation of velocities may indicate any of the following conditions that can only be determined by such a test: - The feeders may be large enough, but the distribution mains may not be capable of developing the full capacity of the feeder; the distribution mains may be large enough, but the feeder may be working at such a velocity as to result in excessive pressure losses; a valve on a feeder main may be closed or partially closed.
Having obtained the above information the matter of design
of new mains becomes a mathematical problem covering veloci-
ties, pressures, and main areas, and leaves out any guess work
as to what existing mains are doing or what they will be
required to do under increased demand.

FIRE FLOW TESTS

An exact knowledge of the amount of water available
for fire protection at any point in a city is of the utmost
importance, for while under ordinary conditions the distribution
system may supply sufficient water a proper pressure for domestic
and ordinary uses, nevertheless the mains may fail to deliver
sufficient water to handle the requirements in case of fire.
The National Board of Fire Underwriters have laid down certain
requirements as to the amount of water that should be available
for the fire protection in various kinds of localities. So many
conditions affect the flow from fire hydrants that it is almost
impossible to compute what the discharge actually is. Consequently
the logical thing to do is to actually measure the available
supply. The conduct of a fire flow investigation is simply a
matter of opening all the hydrants available for the protection
of the building in question, (the fire underwriters consider only
those hydrants within 600 feet of the fire as available), and
reading Pitometers on the mains that supply these hydrants. The
quantities so measured will show how much is available for fire
fighting purposes, and if insufficient supply is shown steps can be taken to reinforce the supply, either by installing additional hydrants or mains, as the results might indicate. Pitot tube observations are sometimes made on hydrant nozzles in conducting fire flow tests but the results are not as accurate as those obtained by pitometers on the mains.

CLOSED VALVES

While careful supervision of valve operations and the use of some form of records of these operations tends to reduce the probability of a valve being left closed, nevertheless anyone who has handled this kind of work knows that it is possible to entirely overlook a valve that has been closed, or if it is operated after having been closed it may be only partially opened. The result is that the effectiveness of the main is either entirely nullified or at least reduced. Pressure surveys will often indicate the fact that a feeder valve has been left closed, but if the valve is only partially closed the resultant loss of pressure might easily be confused with the expected pressure loss due to velocity in the mains. Again the valve might be so located as to have no particular effect on the pressures under normal flow conditions, but when the demand becomes larger on account of fires or other causes, the fact that the valve is closed may be disastrous. In either case if Pitometers had
been read on the main the fact that the valve was closed would show a reduced velocity. If the pressure drop in any section were greater than the measured velocity would give using the formula

\[ \text{Friction loss } = \frac{f v^2}{d g} \]

it would be evident that the pipe was obstructed and the trouble could then be located.

LEAK TESTS

Leaks in water mains very often represent a large part of the total water pumped into any system. How large this leakage may be can only be determined by a systematic survey of the distribution system. Very often this investigation will unearth a single leak, which when stopped will easily pay for the cost of the survey as well as the cost of repairs. There have been numerous instances where blowoffs have been left open and discharging directly into a sewer, that would never have been discovered if a Pitometer test on this particular main had not been made. Again there are cases where abandoned service pipes run wide open and the water finds its way to the sewer without appearing on the surface. These and other leaks, such as joint leaks, leaks due to electrolysis, and unlawful connections to mains, cannot be estimated, but can only be determined by actual measurement.

We will endeavor to follow through in detail the
method of survey for leak determination in a system of mains, such as is shown on the attached map.

In order to ascertain the amount of leakage in the twenty-four inch main ABC the flow is measured at A and B when all connections between these points are shut off. The amount of leakage in the section is then represented by the difference between the volumes measured at A and at B. If it is found that this is excessive, the velocity may be measured at some point, such as D, and the difference in rate of flow between A and D and D and B would indicate in which section the leak lay. This can be repeated until the leak is pinned down to a section small enough to be stopped and the leak stopped.

It is next desired to determine the amount of leakage in the districts between 103rd Street and 107th Street, Torrence Avenue and Bensley Avenue. The valves one to seven are closed and the entire district supplied through valve 8 and a Pitometer installed on the main at this point. Readings at this point will indicate the total consumption in the district under investigation. If this quantity is measured at about 2 A.M. it is reasonable to suppose that it represents the leakage in the mains as well as the leakage and wastage in the premises. If this amount is found to be excessive valve 20 is closed and the reading repeated. The difference between this reading and the original indicates the quantity of water flowing into Calhoun Avenue between 103rd and 104th Streets. Valve 20 is then opened and valve 21 closed.
Observations made while this valve is down will show how much water is flowing into Hoxie Avenue between 103rd and 104th Streets. Closing valves 22 and 24 and observing the difference in consumption will indicate how much water is being used in the section. By repeating this operation the flow into each section is determined. We will assume that the excessive flow has been traced to Section 22-24. The next step is to inspect the premises along these streets and see that all plumbing leakage is stopped. After this has been done the remainder represents the amount of leakage in the main and services. In order to still further locate the leak the main may be cut and capped at X and the test repeated to determine whether the leak is in Section 22-X or 24-X. This process may be repeated if found necessary.

Very often after a leak is found to be in a certain block the exact location of the leak may be determined by use of aquaphones or other leak detectors now on the market.

While the above discussion deals with some of the more important uses of the Pitometer, in general it can be used for measurement of velocity in any closed pipe, either under a positive head, no head, or a suction head. Its accuracy, which is in the neighborhood of two percent, compares favorably with the accuracy of any other water measuring device. One Pitometer rod can be used for all sizes of pipe from four
inches to sixty inches and the whole apparatus easily transported from place to place and installed at very little cost. Its usefulness cannot be over estimated, as the data obtained by the use of this instrument will determine the quality of service that is rendered by a water works. It reduces the losses of water to a minimum and makes it possible for the engineer to intelligently design future extensions and provide proper fire protection. In a word, it is the instrument by which the pulse of the water works system is felt and its troubles diagnosed.