Meter Weights & Measures Reference

Engineering Data

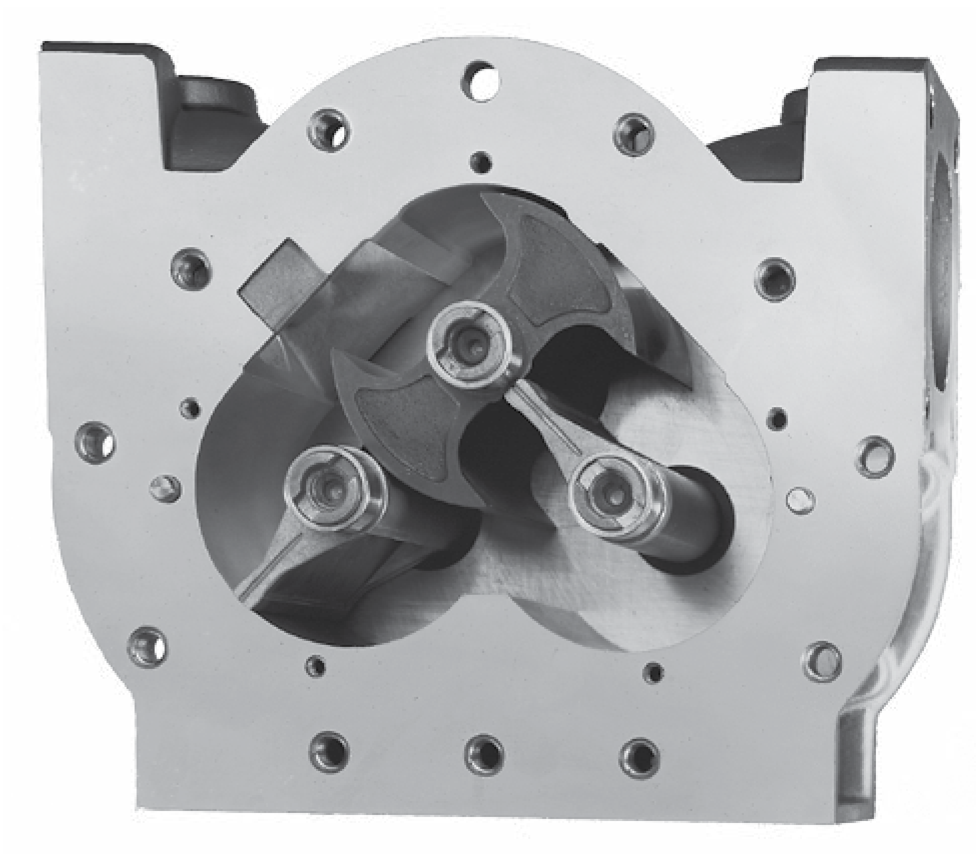


TABLE OF CONTENTS

Publication Updates and Translations

The most current English versions of all Liquid Controls publications are available on our web site, **www.lcmeter.com**. It is the responsibility of the local distributor to provide the most current version of LC manuals, instructions, and specification sheets in the required language of the country, or the language of the end user to which the products are shipping. If there are questions about the language of any LC manuals, instructions, or specification sheets, please contact your local distributor.

FOREWORD

The purpose of this discussion is to promote better understanding in several areas related to metering systems and their use. One such area is the established tolerances that are applied to the measurement accuracy of metering systems. Another is the inclination on the part of the user or installer to ignore certain basic requirements resulting in system performance that is deficient in some respects. We have noticed also a loose usage of certain words or terms. To promote better understanding between the manufacturer, the user, the installer, and the regulatory official, we will discuss some of these subjects.

It has been customary over the years to talk about - or to quote - figures for “meter accuracy”. We believe that it is appropriate to discuss this and other terms or phrases so that a better understanding may be reached whenever meter performance is discussed.

It can be misleading to make a statement of meter accuracy without specifying the type of test involved. A series of tests made, at a constant flow rate and with other conditions fairly constant, is a test for repeatability. A series of tests under varying flow rates would develop the characteristic curve of the metering system showing apparent meter accuracy at the various flow rates.

Meters do an outstanding job of measuring liquid volume while the liquid is in motion. Meters have been doing this so successfully and for such a long period of time that it is taken for granted. The recent attempts to set up specifications and standards for “In-motion” weighing, have brought out the difficulties of determining the weight of moving objects. This should emphasize the progress that has been made in liquid metering.

A most important point is that it is practically impossible to determine the accuracy or inaccuracy of the meter only. Even in a scientific testing laboratory there are other items involved in making a test for accuracy. These could include the piping system, the pump or pressure source, valves in the system, the prover or standard of comparison, the liquid being measured, and in a gravity truck installation, - the receiving system. All can affect the apparent results - as we shall see.

After considerable effort, the meter manufacturers have been able to promote the idea of consideration of the complete Metering System when discussing accuracy or the overall performance. So far, this has consisted mostly of studying the system after the installation is made and is operating. The time is fast approaching when more consideration must be given to the various elements of the system before the installation is made. The recommendations of the Meter Manufacturer should be obtained and should be followed in planning or using a liquid metering system.

Editorial Note

The Meter Manual was developed under the auspices of the Meter Manufacturers Technical Committee (MMTC) and published in 1976. This was a collaborative effort of Liquid Controls Corporation and five (5) other member companies with support from seven (7) Associate Members. This was to promote better understanding of metering systems and their use.

Since 1976, changes have occurred in the MMTC, which is now identified as the Meter Manufacturers Association (MMA), with regard to participation of member companies, Measurement Sector Weights and Measurers officials and their relationship.

Acceptance Test
Originally intended to be a test of the measuring device only, under carefully controlled conditions with expert operators, to determine that the device will comply and with the requirements for approval, for sale in a state requiring such approval.

Accessories (Auxiliary Equipment)
Items used with a measuring device to facilitate the use of the information obtained from it. Also, items furnished to improve its performance, such as strainers, air eliminators, valves, etc.

Accumulative
A term applied to indicating elements or recording elements to describe the fact that they are not resettable to a zero indication in normal use.

Accuracy
Freedom from error, usually expressed in percentage.

Accuracy Curve
A graph or plotted curve showing the performance characteristics of a measuring device. The information plotted is the amount of error at the rates of flow between the minimum and maximum rated capacity of the device.

Adjuster
A ratio changing device which is used to obtain agreement between the indicated and/or recorded volume and the actual volume measured. The ratio may be either continuously variable or variable in increments.

Air Eliminator (Air Release) (Vapor Eliminator)
A device installed upstream of the measuring device to avoid measuring air or vapor. Air or vapor measured with liquid will result in registering a volume larger than the liquid volume.

Air Separator
A device of the air eliminator type designed to include the capability of separating air or vapor intimately mixed with the liquid. It may include one or more air eliminator mechanisms and usually incorporates a greater volume or other means for achieving separation.

Air (Vapor) Control System
An arrangement of various elements intended to assist the air eliminatoror air separator by stopping or reducing flow of liquid when air or vapor is detected. May have various trade names.

Ambient Temperature
Literally, this is the temperature of the surroundings. It is usually used to denote the temperature of the atmosphere in a given location at a specific time.

Analog Device
A device in which the indicated quantity is a constantly changing amount which indicates directly the amount being measured. An example is the pointer on a clock or a continuous motion type indicator. In reading this for the delivered quantity, it may be necessary to estimate the fractional units.

Auxiliary Equipment
See Accessories.

Back Pressure Valve
A device intended to maintain a desired minimum upstream pressure.

Bubble Point
The conditions of temperature and pressure under which a liquid will begin to form vapor.

Calibration
The process or procedure of setting or bringing a meter or a prover into agreement with an established standard.

Change Gears
A gear train located between the meter and the indicating and recording elements usually used to provide registration by the counter in the desired units of measurement. Also used to bring the registration closer to true value. These gears may be located in the meter or be part of a subassembly between the meter and the indicating elements.

Check Valve (Non-return Valve)
A device designed to prevent a reversal of flow of liquid.

Clingage
The liquid film that adheres to the inside surface of a container after it has been emptied.

Coefficient of Expansion
A number usually expressed as a decimal that indicates the change of volume per unit of volume per degree of temperature change.

Counter (Register)
A device which indicates a quantity related to the volume measured by the meter.

Synonyms in parentheses

Deactivate
To stop normal activity.

Delivery, Over
Delivery, Under
The terms, over-delivery and under-delivery, are commonly used to indicate the kind of mearuring error that is experienced. Under-delivery indicates that the counter is registering a greater volume than is delivered by the meter, and over-delivery indicates that the meter is delivering more than is registered on the counter.

Density, Relative
The relative desity t_1/t_2 of a solid or liquid substance is defined as the ratio of the mass of a given volume of the substance at a temperature t_1 to the mass of an equal volume of pure water at a temperature t_2 (this term replaces the normal term “specific gravity”).

Differential Pressure Valve
A device designed to maintain the total pressure in a system at a desired pressure higher than the vapor pressure of the liquid when being metered.

Digital Device
A device in which the indication of the measured quantity changes by finite increments which may be units, fractions or decimals.

Digital Signal
Transmitted information that takes the form of a series of individual distinct signals. These are commonly called pulses.

Drainage Time
The drainage time for test measures and provers shall be 10 seconds for a capacity of 10 gallons or less, and 30 seconds for capacities exceeding 10 gallons. Necessary to achieve uniform clingage film.

Error
The difference between the indicated value and the true value.

Flow Limiting Device (Flow Control)
A device installed in the system to prevent the rate of flow through the meter from exceeding the desired maximum flow rate.

Flow Meter
Commonly used to describe a liquid measuring device which indicates the rate of flow in terms of velocity or as units of volume per unit of time.

Flow Range
The minimum and maximum flow rates established by the manufacturer to provide the maximum meter performance and accuracy with long life. If exceeded, accuracy or meter life may be adversely affected.

Flow Rate (Rate of Flow)
The rate of flow of liquid expressed in volume or mass units per unit of time.

Gravity, API
A Measure of the specific gravity of a liquid hydrocarbon as indicated by a hydrometer having a scale graduated in degrees API.

Gravity, Specific
See Density, Relative.

High Vapor Pressure Liquid
A liquid which must be maintained in a closed system because it will boil or form vapor above 70° F and 15 P.S.I.

Inferential Meter
A liquid measuring device in which the primary sensing element measures the rate of flow and the volume indication is “inferred” since the liquid velocity through a given area does permit conversion to volume.

Laminar Flow
Liquid flow in which the liquid elements travel along relatively straight parallel paths.

Synonyms in parentheses

Low Vapor Pressure Liquid
A liquid which at atmospheric pressure and temperature can be maintained in an open system without boiling.

Master Meter
A meter used as a reference for testing other working meters.

Meniscus
The curved surface at the end of a liquid column.

Non-return Valve (Check Valve)
A device designed to prevent a reversal of flow.

Normal Test
A test made at the maximum discharge rate that may be anticipated under normal conditions of installation. (If equipped with an automatic temperature compensator, the meter should be tested with the temperature compensator deactivated.)

This is a test for basic meter accuracy and is essentially a test for repeatability, presuming that the meter has been adjusted to give as close to zero error as possible.

Positive Displacement Meter
A meter in which the primary sensing element separates the liquid into measured segments of known volume providing a shaft motion or other signal that can be used for indicating the volume delivered.

Preset Device
An indicating device that can be preset for a desired quantity which will stop the flow automatically, or provide a signal when the preselected quantity of liquid has been metered or “delivered”.

Pressure Loss (Pressure Drop) (Loss of Head) (Differential Pressure)
The difference in pressure between the inlet and outlet of a device while operating.

Prover (Proving Tank) Volumetric Type
A closed or open vessel designed especially for accurate determination of the volume of a liquid delivered into or out of it during a meter run. The volume of liquid is either observed from the liquid level in a gage proving glass or is known from previous calibration of a fixed-volume vessel. The volume is greater than ten gallons. (See Test Measure)

Recording Element
A device designed to print the volume metered on a ticket, slip tape, or card.

Reference Standard
A volumetric measure that has been verified to “contain” or to “deliver” a known volume, and which is used for establishing the volume of field and working standards.

Register (Counter)
A device which indicates the quantity measured by the meter.

Registration, Over
Registration, Under
The terms, over-registration and under-registration, are commonly used to indicate the kind of measuring error that is experienced. Over-registration indicates the counter is registering a greater volume than is delivered by the meter, and under-registration indicated that the meter is delivering more than is registered on the counter.

Repeatability
A measure of the deviation of a series of test results from their mean value, all determinations being carried out under identical conditions.

Special Test
Any test other than a “Normal” test. A special test is defined as a test “to develop the operating characteristics of a liquid measuring device and any special elements and accessories attached to or associated with the device”.

Split Compartment Test
A test applied to a truck mounted metering system which simulates the conditions encountered in actual operation when one truck compartment is emptied during a delivery and the delivery is completed from another compartment.

Strainer (Filter)
A device equipped with a porous medium or wire mesh element to prevent particles of foreign material from passing through a meter.

DEFINITIONS

Swirl Plate
A plate or baffle installed in or near the outlet connection of a storage container to reduce or prevent formation of a vortex.

Test Measure
Vessels designed especially for the precision measurement of liquid having verified capacities of 1, 5 or 10 gallons. These are usually certified for accuracy of measurement by the National Bureau of Standards.

Tolerance
The amount of error that will be allowed. It is a plus or minus value.

Torque Load
The power required of the meter for driving accessory equipment such as counters, printers, etc.

True Value
The theoretically correct amount. In every day use it is represented by the Standard being used for comparison.

Turbulent Flow
Flow in a pipeline is turbulent when the liquid elements no longer travel along straight parallel paths. This usually occurs when the Reynolds Number is well above 2,000.

Vapor Eliminator (Vapor Release)
A device installed upstream of the measuring device to avoid measuring air and/or vapor.

Vortex
The swirling motion of liquid often encountered as it enters the outlet opening of a container. The tendency of a vortex to form depends upon many details of the container construction. Since the swirling liquid can form around a central column of air or vapor, the flow area is reduced. This restricts the rate of flow and often results in carrying considerable quantities of air or vapor with the liquid.

Some of these definitions may differ slightly from the same terms defined elsewhere. We feel that the language shown is more applicable to the points to be discussed in this document.

LIQUID CONTROLS®

There are various words and terms used in discussing meter accuracy that are related to each other, but which do not necessarily mean the same thing to all people. They may be used incorrectly and thus, convey false information. The purpose of this discussion is to promote an understanding of the terminology commonly used so that there may be mutual understanding when meter accuracy is discussed.

To help differentiate between these terms, let us consider a marksman shooting at a target. Let us presume that he has mounted the gun in a solidly mounted holding vise so that any errors found will not be due to the operator. The grouping of the shots in Figure 1 indicate that the gun is very precise and that it is adjusted for a minimum of error. It is both accurate and precise. Utmost precision would result in a single hole through which all of the ten bullets passed. This discussion does not require such precision. The grouping of the shots in Figure 2 indicate that the gun is precise but that it is not accurate. The results show a bias that could be due to several reasons. It could be very well that the bias is due to a maladjustment of the gun sights. In this case it should be possible to correct the results so that they are similar to those shown in Figure 1.

After the sights have been adjusted to provide performance equivalent to that shown in Figure 1, the gun might be retested under the same mounting arrangement and the results shown in Figure 3 might be obtained. In this test a bias is again evident. We might presume that a wind was blowing from left to right, and this is a logical explanation for the bias obtained. Presumably, this bias can be eliminated by adjustment of the sights for windage. This correction will only be valid, however, if the wind remains constant in velocity and in direction.

Let us presume, now, that the mounting arrangement is not used and the marksman will hold and fire the gun. With the sights adjusted and a correction made for windage, the results should be comparable to Figure 1, if his hand is steady and if his eyesight is good. An unsteady hand or difficulty in seeing both sights and the target simultaneously might give the results shown in Figure 4. This is known as “scatter” and illustrates the results that might be obtained with an accurate and precise instrument where one part of the system prevents the full capabilities of the instrument from being achieved.

We often speak of accuracy as a tangible quality of a device. By definition, accuracy is “freedom from error”. The error, or inaccuracy, would be the difference between the volume delivered to a prover, or standard measure, and the volume registered by the meter as a specific rate of flow. If the prover or standard measure shows the delivery to be 100.00 gallons, and if the meter registers 100.00 gallons, the meter has zero error or is accurate at that particular flow rate. This sounds like a logical conclusion, but it is true only if (1) the prover or standard measure is accurate, (2) if the liquid volume did not change after it was metered and before the prover volume was read due to a change in temperature, evaporation or valve leakage, and (3) if the operation was performed correctly.

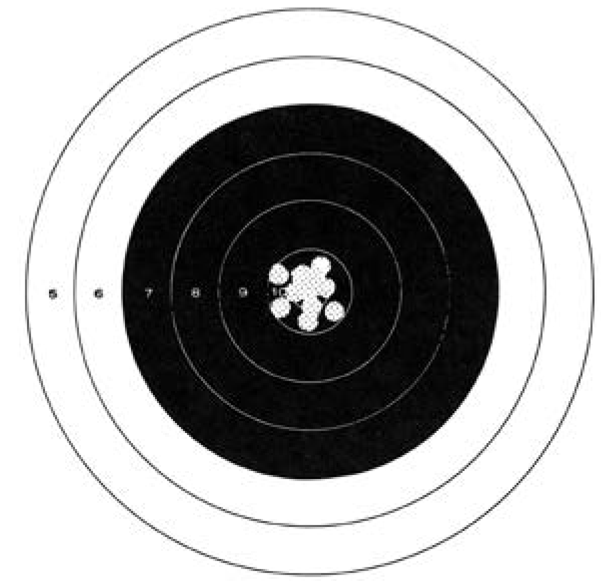


Figure 1
PRECISION WITH ACCURACY

Figure 2
PRECISE BUT NOT ACCURATE

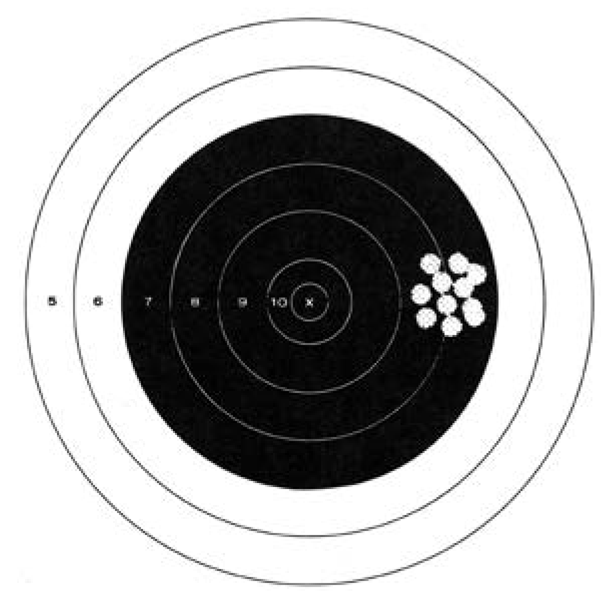


Figure 3
PRECISE BUT NOT ACCURATE

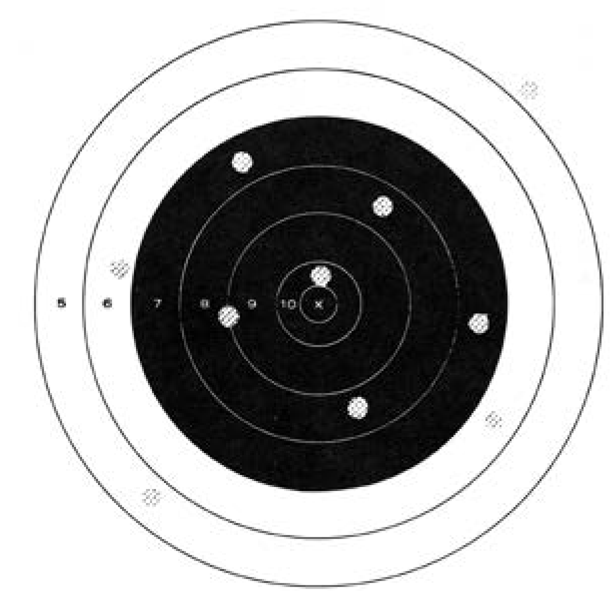


Figure 4
“SCATTER”

The prover by definition is a measurement reference standard, and yet prover accuracy can logically be questioned. Provers will change in volume due to rust, scale, dirt collection or because of mechanical deformation. The prover is usually a sturdy receiving vessel that has been carefully verified to hold a specified volume with provision for reading the actual volume within 5/1,000 of 1% (0.00005) by an experienced observer. This is accomplished by using a reduced diameter neck on the prover fitted with a gage glass and a calibrated scale for reading the liquid level in the prover.

Even if a prover is in excellent condition, the original verification of its volume must include an uncertainty. The numerical value of this uncertainty is dependent on the uncertainty of the standard measure that is used for verifying the prover volume.

A prover or test measure that has been verified by the National Institute of Standards and Technology will be verified to contain a specific volume with a states “estimated uncertainty” of plus or minus some quantity (cubic inches or fractional gallons) of the order of approximately 0.02%. This means that the volume may be exactly as specified, or it may be greater or less by an amount no greater than the estimated uncertainty. There is no known way at the present time of economically determining the volume more precisely. It should be noted that the figures quoted apply only to test measures or provers verified by NIST.

If a 5-gallon test measure verified (e.g., by NIST) to have an estimated uncertainty of 0.02% (or 0.001 gallons) is used to verify the volume of a 50-gallon prover, for example, let us examine the uncertainty of the result. To begin with, the 5-gallon measure will be used ten times to build up to the required 50 gallons. Thus, whatever error it has will occur ten times—it has no chance to be randomized out—and could lead to an error of 10 times 0.001 gallons = 0.01 gallons. As a percentage error, this turns out to be 100(0.01)/50% = 0.02%. To this we must add 10 measuring operations. If we assume these errors are bounded (e.g., a 3-standard deviation limit) by 0.02% or 0.001 gallons, then these random error limits combine as:

$$\sqrt{(0.001)2 + (0.001)2 — —+ (0.001)2} \text{ gallons} =$$

$$(\sqrt{10})\ 0.001 \text{ gallons} = 0.003 \text{ gallons}$$

This corresponds to 100(0.003)/50% = 0.006%.

The total uncertainty on the 50-gallon measure would be the sum; namely, 0.01+0.003=0.013 gallons, which corresponds to 100(0.013)/50%=0.026%

If this 50 gallon measure is then used to verify a 1,000 gallon capacity measure, then the uncertainty would be 20(uncertainty of 50 gallon measure) + (the random error limit for each transfer) $\sqrt{20}$.

If we assume the error limits for a transfer are 0.05% or (0.0005)(50) gallon = 0.025 gallons, then we get

$$20(0.013) + \sqrt{20}(0.025) = 0.037\%.$$

Thus, we find that a 1,000-gallon measure verified with a 50-gallon measure would have an estimated uncertainty of 0.037% if the verification were performed by experienced NIST personnel. Since the third-generation verifications are not performed by NIST, but by possibly less experienced personnel, it is safe to state that very few third-generation verifications can be expected to have a maximum uncertainty of 0.04% or less.

We have described the possible error in the calibration of the prover for two reasons. One is that if more than one prover is in use in an area or in an operation, their errors can add up to a constant meter error that would be difficult to isolate. Obviously, if there were only one prover, and if everyone agreed on a value for the volume it held, it would make no difference whether that volume was correct or not. The second reason is that good measurement practice requires that the gage or reference standard being used to check a device must have a tolerance no greater than 25% of the tolerance to be applied to the device. Looking at this another way, a 4-inch loading rack meter that is to be tested into a 1,000-gallon prover for the first time, would have applied to it under Handbook 44, an “acceptance tolerance” of 262 cubic inches in the 1,000-gallon delivery. This is approximately 0.11% which would mean that the prover must have a maximum uncertainty of no more than 0.03%. It is impossible at the present time to verify the volume of a 1,000 gallon prover with that degree of certainty.

There can be a change in the volume of the prover, particularly if the liquid delivered into the prover is considerably warmer or colder than 60°F. The prover shell will expand or contract if the temperature is above or below this base temperature, and the prover will be larger or smaller. The prover volume is established for a base temperature of 60°F. The amount of change in volume is quite small per degree of temperature, but at 40°F or at 80°F a mild steel prover verified for 60°F will have a volume change of 0.0372%.

Tolerance

Tolerance is the limits of allowable error or departure from true performance or value (NIST Handbook 44). Saying this another way, it is the amount of inaccuracy that will be tolerated. Theory of tolerances is explained in Handbook 44 as “tolerance values are so fixed that the permissible errors are sufficiently small that there is no serious injury to either the buyer or the seller of commodities, yet not so small as to make manufacturing or maintenance costs of equipment disproportionately high”.

Handbook 44 specifies the tolerance values for “Normal” tests and for “Special” tests.

The “Normal” test is at the maximum rate of flow normally obtained in the installation. This is basically a test for repeatability, since the Handbook also specifies that the meter should be adjusted as close to zero error as practicable. It also prohibits adjusting a meter to take advantage of the specified tolerance.

The “Special Test” is any test other than a “Normal Test”. A “Special Test” may be made to develop the operating characteristics of a liquid-measuring device and any special elements, and/or accessories attached to or associated with the device.

The tolerance value in Handbook 44 were very carefully selected. Generally speaking, they have provided workable guidelines for the meter manufacturer, the user, and the Weights and Measures official.

As mentioned before, certain tolerance values should be reconsidered since they do not meet the mathematical requirements for establishing the tolerance on a device. It should be quite obvious that an overall tolerance for a measurement system must be greater than the largest tolerance of an item used in the system. We would like to repeat:

1. The reference standard must not have a tolerance greater than 25% of the tolerance assigned to the device under test.
2, The tolerance applied to a measuring system must be based on proper combination of the uncertainties of the various components of the system. Any efforts to establish a tolerance for the system smaller than permitted by these two rules can only result in inequity or downright deception of those depending on the tolerance for accuracy of measurement.

Coefficient of Expansion

The change in prover dimensions previously described would be based on the coefficient of thermal expansion of mild steel. API provides tables for correcting the prover volume. All petroleum based liquids also expand or contract as the temperature increases or decreases. The coefficient of thermal expansion, per degree, is much greater for petroleum products than it is for metals. This coefficient is expressed as a decimal. Approximate figures are .00045 for #2 fuel oil, .0005 for kerosene, .0006 for gasoline and .0017 for liquid propane. From this we can say that a change in temperature of gasoline of two degrees F will cause a change in volume of 12/100 of 1% or more than 1/10 of 1%—which is the acceptance tolerance for a “Normal” test.

The possibility of a change in volume due to temperature change will not be a problem if the liquid temperature does not change after the liquid was measured by the meter and until the volume is read in the prover neck. It would be reasonable to expect very little change in liquid temperature if the ambient temperature is similar to the temperature of the liquid in storage. If there is a wide difference between the liquid in storage and the air temperature outside, the amount of heat added to or taken from the liquid will depend on several factors. These might be the presence of sun or shade, rain, wind or snow, and especially the time required to fill the prover. To insure accurate results, means must be provided for accurately determining the liquid temperature at or near the meter and in the prover. With this information, the volume of the prover can be corrected for any deviation from 60°F, and the volume of the liquid can be corrected if a change in temperature occurred after it passed through the meter.

NIST will verify the volume of test measures and will furnish a “Report of Calibration” which will carry the notation that the measure has been calibrated “to contain” or “to deliver” a specified volume. Test measures of 10-gallon capacity and smaller are routinely calibrated gravimetrically and the “Report of Calibration” will show the volume when used either as a “To Contain” or as a “To Deliver” measure. It is important to understand this distinction and to use the proper reported value when the test measure is used. Manufacturers of test measures normally indicate “Delivers” or “Contains” on the gage scale plate of the measures.

A test measure verified “to contain” a specified quantity must be wiped clean inside after each use. There must be no film of liquid clinging to the inner surface when the measure is used for receiving liquid.

A measure that is calibrated “to deliver” a specified volume is verified after a film of liquid has been established on the inner surface. This “clingage” film thus is part of the dimensions of the measure, and the measure should not be used without establishing this film of liquid.

This distinction has been overlooked at times in the past, and test measures that were verified “to contain” a certain volume have been used as test measures calibrated “to deliver”. Any provers calibrated with such test measures would be in error by the amount of the clingage film.

All volumetric provers and test measures should be calibrated and verified to “deliver” the specified volume. It must, therefore, hold the delivered volume plus an additional volume that will cling to the inside surface when it is emptied. This “clingage” will vary with the prover shape, the inner surface roughness, the viscosity of the liquid, temperature, and the time allowed for the clingage film to drain. The prover shape and surface are fixed for any one prover. The temperature is 60°F when it is checked. The viscosity of water is fairly constant, so the remaining variable is the drain time. This should be a fixed interval between the time that the full flow out of the prover has stopped and the time when the outlet is closed. Any reasonable period may be used. The recommended time is thirty seconds.

This drain time, once it is established, must be observed when the prover is calibrated or checked and should be used by the operator each time the prover is used. The drain time thus becomes part of the prover calibration, and as such, should be shown on the prover. If this drain time is not known for an existing prover, it may be established the next time that the prover is checked.

Since the amount of clingage remaining in the prover directly affects the volume of the prover, it is very important that the conditions during draining be the same each time the prover is used. It should be understood that if the prover is emptied one time with a high capacity pump, even with the established drain time, there will be more clingage than if the prover is emptied at a lower rate of flow. The additional time required for pumping out the prover will allow, in effect, more time for clingage film to drain away.

Testing Procedure

The primary rule in testing meters is that the tests shall be made under the same operating conditions that will apply under normal use of the meter. For example, if a loading-rack meter is normally used with a long down-spout that is submerged most of the time, it should not be tested with a short sport that will create splashing. For the same reason, a meter installed with facilities for the bottom loading of trucks should not be tested by top loading into an open neck volumetric prover. The difference in loss due to evaporation will create an error which would be removed by adjusting the meter. This would result in a permanent meter error in normal usage.

The meter testing procedure should be carefully spelled out and should be carefully followed for every test. This may be based on the Examination Procedure Outlines prepared by the National Institute of Standards and Technology—Office of Weights and Measures, numbers 21 through 27. These outline a standard test procedure and may be used as a basis for establishing a routine test procedure. They do not include instructions for determining liquid temperatures in the meter and in the prover. These should be added and corrections made when there is a difference in the two temperatures. The temperature of the liquid in the prover should be the average of the reading of three thermometers located at different levels within the prover. The temperature of the liquid as it is metered would be the average reading during the delivery, of a thermometer located in the line adjacent to the meter.

The Weights and Measures official has every right to expect that in a group of meters, those that are not adjusted for zero error will be fairly equally divided in showing over-registration and under-registration. Any group of meters in which most of them are over-registering indicate an intentional bias. There is no reason why meters cannot be adjusted to an error of less than 1/10 of 1%; the number of them adjusted on the plus side should be roughly equal to those adjusted on the minus side.

Handbook 44 also provides for a tolerance on “Special” tests. This is defined as any test other than a normal test. Basically, it is a test to develop the operating characteristics of the meter which would include a slow flow test. It might also include a test of the air elimination system. On truck mounted meters, this is known as a split compartment test. The results of these tests will depend a great deal upon the characteristics of the installation and of the liquid being measured. In this respect, the entire system is being tested during a special test.

Repeatability

Repeatability is the ability of the meter to give measurement indications that are in close agreement with each other when measuring a standard volume at a specific flow rate. If the measurement indications are in close agreement, but are not the same as the standard volume, the meter adjusting mechanism should be changed to reduce the error to as near zero as possible. This would be a “normal test” and the normal test tolerances would apply. The tolerance that is applied to a normal test is a plus or minus tolerance. You will note that we stress adjusting the meter to obtain as nearly zero error as practicable.

The Liquid

The liquid being measured is probably one of the most unpredictable parts of the metering system. We have already discussed the characteristic of some liquids to change in volume with a change in temperature. There is also a change in volume with a change in pressure, but this is a comparatively small amount compared to the change due to temperature variation.

Some liquids are corrosive, and some may have an undesirable effect on the materials of construction, particularly the materials used for gaskets and seals.

While some liquids may have the ability to furnish lubrication for the bearings of the meter, others may have practically no lubricating value. Examples of the latter are gasoline or LPG.

Some liquids have a tendency to foam when mixed with air, and in some cases a great deal of time is required to separate the air from the liquid.

The viscosity of the liquid can have a considerable effect on the measurement. This is true not only of the measurement by the meter, but of the performance of the prover used to verify the meter accuracy. When the prover is emptied, the liquid film that remains on the inner surfaces naturally occupies some of the prover volume. The amount of this "clingage" will vary with viscosity of the liquid. Since viscosity affects the speed with which the liquid will drain from the inner surfaces, this clingage film is related to the time allowed for draining. This viscosity of some liquids varies widely with variations in temperature. Therefore, this particular characteristic is also temperature dependent and should be taken into consideration.

Metering LPG or NH_3

LPG and NH_3 are both high vapor pressure liquids. Liquids of this type tend to vaporize easily and successful meter operation will depend on the care exercised to prevent this from happening.

Certain materials of construction may be used in LPG meters that are not suitable for use with NH_3. The installation requirements and the method of operation are quite similar for the two liquids.

In order to prevent vaporization of the liquid, certain rules should be observed in designing, fabricating and operating LPG and NH_3 meter installations. They are:

1. The piping from the storage tank to the pump inlet should be at least one pipe size larger than the pipe size of the pump inlet. Any valves, strainers or other fittings in the inlet piping system should be similarly sized. During operation the pressure at the pump inlet must be equal to or greater than the vapor pressure of the product.
2. All shut-off valves should be full-bore ball type or a similar free-flow type.
3. An external pump bypass (pressure relief. line from the pump outlet to the storage tank should be provided. This should include a pressure relief valve set to permit circulation through this line at a pressure that is about 25 PSI lower than the pump bypass relief valve setting. This is to prevent recirculation within the pump which may cause heating and formation of vapor.
4. The piping system from the pump to the meter should be the same pipe size as the pump outlet. Shut-off valves should be the ball type or an equally free-flow type. A minimum number of elbows and fittings should be employed.
5. Safety valves or pressure relief valves should be included in the installation so that any section of the installation that might be isolated when valves are closed will be protected.
6. There must be provision for determining product temperature as it passes through the meter. The thermometer used should have no less than one graduation per degree F—preferably five.
7. NIST Handbook 99 describes the procedures and tests to be followed in proving meters operating on these products.

LPG is flammable when mixed with air and the same safety precautions should be observed that would be used in handling a liquid such as gasoline. Dangerous concentrations of LPG may not be readily detected. Therefore, adequate ventilation is a primary requirement.

NH_3 is poisonous and can irritate the nose, throat and eyes. Ordinarily the penetrating odor will give adequate warning.

We have discussed elsewhere the change in volume of liquids with a change in temperature. LPG has a higher coefficient of expansion than other petroleum liquids. A change in liquid temperature of 1°F will result in a change in volume of 0.17%. Due to this characteristic, it is quite common to use Automatic Temperature Compensator on LPG meters used in the delivery of LPG to consumers. This arrangement automatically converts the volume delivered by the meter to the volume that this would represent at 60°F.

In general the recommendations for installing and operating meters are covered in relevant sections of the API Manual of Petroleum Measurement Standards. There are some specific points that are important enough to warrant repeating for further emphasis. The ability of a metering system to perform as required is almost entirely dependent on the installation details and the operating procedure. Preventing the measurement of air or vapor will be discussed separately. Since the amount of air or vapor present is entirely due to the installation details, this particular point must be carefully considered in designing the installation.

Perhaps the most important period in the life of a metering system is the first few hours or few days of operation. There are three problems that can occur during this period, and all of them can be avoided by simple precautions during the start of operation. They are:

1. excessive speed of operation due to air or vapor in the system.
2. the presence of foreign material (dirt, rust, welding slag, etc.).
3. the presence of water.

A new installation is sometimes placed in operation simply by turning on the pumps without first filling the lines with liquid. This will push the air or vapor in the lines ahead of the incoming liquid at a far greater rate than any air eliminator equipment can handle. As a consequence, some of this air or vapor will be measured, and the meter will operate at many times the RPM that it will have in normal operation. This alone can result in considerable damage to the meter.

What usually happens is that the meter operates for a short period at this high rate of rotation, and when the liquid finally enters the meter it is instantly slowed to a much slower rate of rotation. This can be equally damaging.

New installations are chronically the source of foreign material of various kinds. This may be anything from rust and scale, to welding beads, slag, or even sand and gravel. No meter is designed to handle liquids containing these materials and the installation should include adequate strainer equipment to prevent such material from reaching the meter. During the period of initial operation, the strainer should be inspected frequently to determine the amount of material being collected. If this is not done, it is possible that the collected material will load up or rupture the strainer basket or filtering medium, allowing the collected materials to enter the meter.

Except for meters specifically designed to measure water, no water should be allowed to enter any meters.

Where it is the practice to test lines, storage tanks or truck tank compartments with water, it is imperative that the water be completely removed from the system through a connection that will prevent it from reaching the meter.

Meters are tested at the factory to determine their operating characteristics. Obviously, they cannot be tested on the individual liquid that they may be required to measure. It is, therefore, imperative that the meter be tested after installation under the operating conditions that will normally exist. As will be discussed elsewhere, the accuracy of the system will depend on the facilities provided for determining accuracy. A proving facility, then is an important item to be considered when planning or designing an installation.

A common question that is asked when a prover is to be included in an installation involves the recommended size of the prover. It has been customary in the past to recommend a prover volume that would permit at least 1 ½ minutes of operation at the maximum rate of flow obtainable but with a volume equal to two minutes of operation preferred. The intention here was to minimize operator error and meter error due to the variation in rate of flow in starting up and in stopping the delivery into the prover.

This possible error due to starting up and slowing down the meter has concerned meter users for a long time. There is really very little reason to be concerned, since it is relatively easy to establish the amount of this error.

Presuming that the procedure for starting up and for stopping the flow into the prover is standardized and repeatable, and presuming also that the viscosity of the liquid will not change during a test run, the amount of error can be established by starting and stopping twice during the delivery instead of just once. The first step would be to establish a figure for the system accuracy by making several test runs in the usual manner, with one start up and one shut down during the proving run. When the system accuracy has been established within required limits for this method of operation, test runs could be made in which the flow is stopped and started up again at the mid-point of the prover. The difference in the results between this type of test and the previously established results are an indication of the error involved in start up and stopping the meter once during a test run.

Viscous Liquids

Positive displacement meters can measure liquids of all viscosities. As a general rule, if the liquid can be pumped—it can be metered.

Some designs require differing arrangements and if the liquid is heated, this may require special treatment. The recommendations of the meter manufacturer should be obtained and followed. This general subject is covered in detail in API MPMS.

Air Elimination

Since any air, vapor or gas included in the flowing liquid will be measured by the meter, an erroneous registration will be obtained unless steps are taken to prevent it from being measured. The obvious solution to this problem is to prevent the air, gas or vapor from being included in the flowing streams in the first place. A sizeable percentage of metering installations that exhibit measurement problems because of air or vapor could have been trouble-free if a little thought had been given to the proper design before installation was made.

Many times these problems are created by attempts to cut corners or reduce the cost of the installation by specifying inadequate facilities. An installation in which it is unlikely that air or vapor will be delivered with the liquid may require no air elimination equipment, or in some cases minimal equipment.

TERMINAL AIR ELIMINATION

Modern loading terminals are usually excellent examples of minimal need for air elimination equipment. With the use of centrifugal pumps, above ground storage, flooded suction and low level cut-offs, there is practically no chance that air or vapor will be pumped with the liquid. If the system includes swing check valves so that the liquid cannot flow out of the higher portions of the system back into storage, the system will remain full after it is filled initially.

A system that is kept constantly under pump pressure will not have the possibility of vapor forming under normal conditions of operation.

At one time many installations used the lines between storage and the loading rack for delivering the product to the storage tank. This usually meant that at the end of an incoming delivery these lines would be filled with air. This air would be pushed ahead of the liquid when the next metered delivery was started. This creates a very severe air problem which may require rather expensive air eliminator equipment. In some installations, it may well be that complete elimination of air or vapor may be impossible due to the operating conditions.

One of the most common causes of air or vapor in the lines is the draining back to storage of liquid from high points in the system. As mentioned above, check valves must be included to prevent this, but the success of the installation will depend on the ability of the check valves to accomplish this. Periodic inspection is a necessity to insure that they are, in fact, able to do this job.

Once in a while the source of air or vapor will be a pressure reducing valve in the system. This is usually required due to the high pressure of the pumps being used, and if this pressure is high enough, the control valve will be required to throttle severely to maintain the desired downstream pressure. On most volatile liquids, such as gasoline, this can result in “wire drawing”, or the formation of vapor at the valve seat due to the severe pressure drop being created in the valve.

If it is necessary to reduce the pressure, a much more satisfactory method would be to do it at the pump installation. The pump installation outlet pressure can be regulated by a suitable bypass arrangement which will carry some portion of the pump output back to the inlet side of the pump.

In designing a terminal installation, the method of withdrawing liquid from the storage tank should be studied very carefully to avoid any possibility of a vortex forming at the storage tank outlet connection which might induce air or vapor into the flowing stream. Anti-swirl or low-level cut-off devices should be included.

TRUCK AIR ELIMINATION

The metered, power operated, delivery truck represents a complete metering system in one package, almost independent of any outside influence. It is not quite independent, however, since the operator has control of the truck engine and the valves in the system.

Here is an ideal example of where the best method for air elimination would be to prevent the introduction of air or vapor into the flowing stream. It is also a good example of the type of installation where often little or no thought is given by the designer of the installation to accomplishing this end. An example is the ability to prevent the formation of a vortex by using properly designed baffle plates in a pump truck, or by using properly designed outlet sumps in a gravity truck. For the very small amount of extra cost that might be involved in designing the compartment outlets properly, the amount of air that would be encountered in an installation could be reduced about 50%.

Gravity trucks present a particularly poor picture of the overall approach to engineering the installation so as to obtain the best accuracy. The demand is constantly for higher and higher rates of flow, and larger and larger meters are being provided to increase the rate of flow by lowering the pressure loss through the meter. The truck design, however, has not kept pace and the supply lines to the meter are still the same size. This means that the meter will be “starved” as often as not, depending upon the negative head on the outlet side of the meter.

If the negative head is greater than the positive head on the meter, this can result in the formation of vapor within the meter at the point where the negative head reduces the pressure to the point where vapor can form. This point of “flashing” will vary depending upon the amount of negative head and the amount of positive head, and the amount of restriction preventing adequate flow into the meter.

Gravity trucks also usually include one or more compartments where the line between the compartment and the meter or valve manifold is long and has very little slope. Many times the last 20 or 30 gallons out of one of these compartments will trickle out at a very slow rate of flow.

Meters intended for use on pump trucks and on gravity trucks are available with various air eliminator systems which do a very creditable job in handling the problems discussed here. This is no assurance, however, that they will always do so. Any air separator, air eliminator, or air or vapor control system will be able to handle certain specified operating conditions. If these conditions are exceeded, some air or vapor may be measured. It must be recognized that there will be a point beyond which it is not possible to design mechanical equipment that will be able to compensate for errors in design or in execution, that are made in planning or installing a metering system.

Power operated truck meters should be proved under operating conditions similar to those that will be encountered in normal operation. It has been shown that a variation in apparent meter delivery can be obtained when delivering to a prover below ground level as compared to delivery to a prover above ground level. One of the contributing factors here was the condition of the hose nozzle.

Chart (A) shows what might be a typical series of meter tests over a period of four years and seven months. We have presumed that no adjustment was required until the fourth month of the fourth year. At that point the meter accuracy was approaching the upper limit and the meter was adjusted closer to zero error as shown for that month. From the data shown, this would be interpreted as an adjustment required due to change in accuracy resulting from normal wear. If subsequent adjustment changes are needed at more frequent intervals, or if the meter becomes noticeably noisy in operation, it should be removed from service for inspection and overhaul.

Curve (B) illustrates the type of information that would be difficult to obtain from data by any other method of handling. This chart shows that the meter was found to have an accuracy of plus 3/10 of 1% when tested during the ninth month. This is outside the control limits, and the meter was adjusted closer to zero error. It is quite noticeable that the following monthly tests showed a gradual change in meter accuracy toward a minus percentage finally being outside the control limits in the second month of the second year. It was again adjusted closer to zero error and showed a continuing trend toward a minus percentage for the following two months. At that time the meter performance stabilized, showing no further variations that would be considered abnormal.

A possible cause of the change in accuracy between the eighth and ninth months of the first year might be the introduction of foreign material or dirt into the system. This would change the meter operating characteristics, causing a change in meter accuracy. If this change in accuracy is corrected by a change in meter adjustment with no other action being taken, the meter will eventually return to its previous operating condition, or nearly so, with a return to approximately the previous accuracy. This is obviously what happened in this instance. After keeping control charts such as this for a period of time, the operator will soon be able to recognize when it would be better to look for the reason for a change in accuracy, rather than to try to adjust for it.

Curve (C) illustrates a somewhat similar occurrence which would have a different explanation. You will note that the meter was under control at the time of the test in the sixth month of the third year. When tested in the seventh month, however, it was out of control on the minus percentage side. It was adjusted closer to zero error and then the meter was sealed. When tested in the eighth month, the meter was found to be out of control on the plus percentage side by an amount equal to the previous error, and it was necessary to readjust closer to zero error.

Since the previous test records and those following showed no pattern of information, we must presume that this particular change in the seventh month of the third year was due to some temporary occurrence. We can guess at what may have happened, but without additional evidence we cannot be sure. A change in accuracy toward a minus percentage can be due to measurement of air. It can also be caused by leaking valves in the proving equipment, or it could be due to operator error.

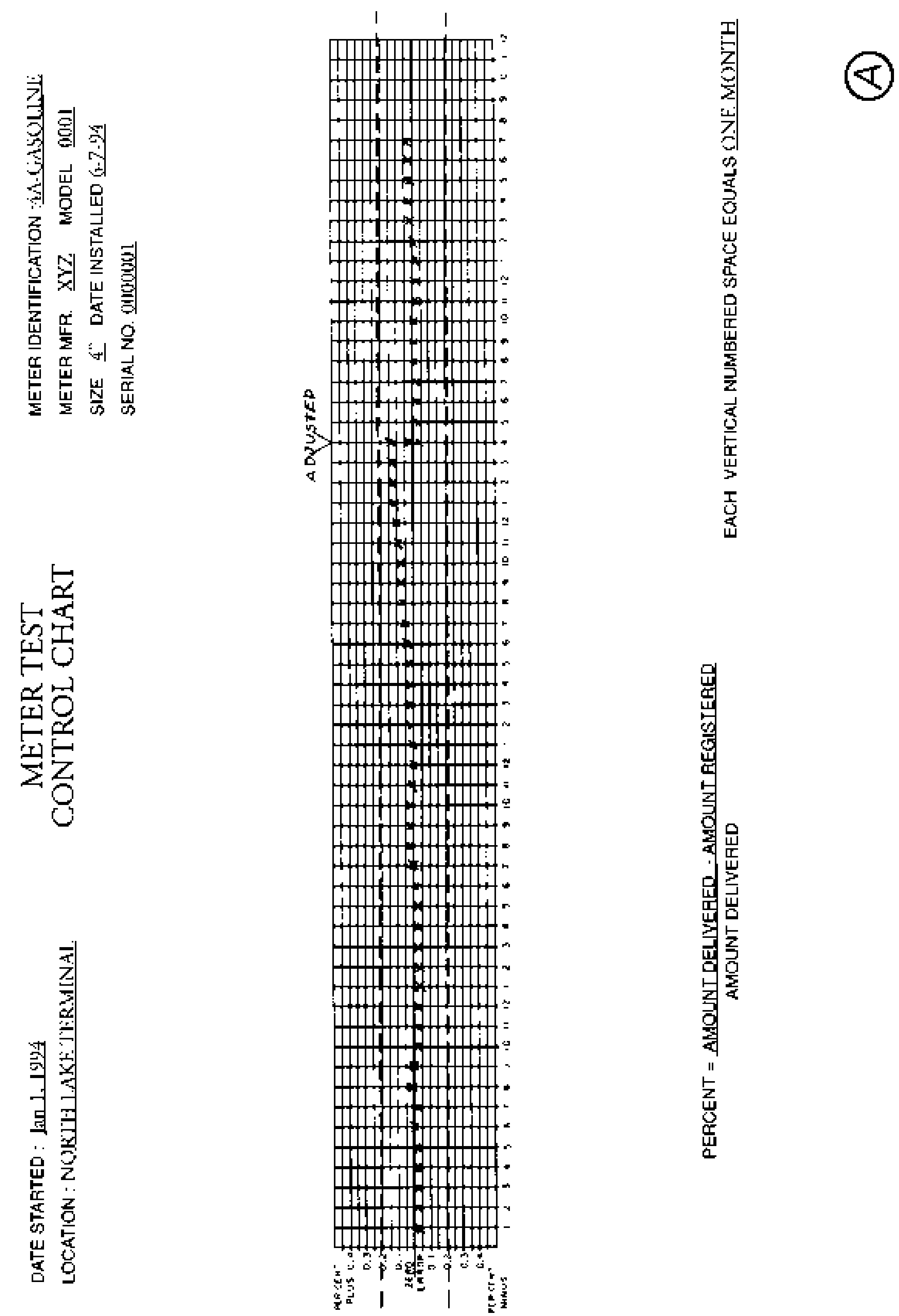
Chart (D) is included to show more dramatically the advantages of control chart records over the use of a computer with these devices. A computer would have to accept the fact that the device is within the control limits and would be in no position to make any comment other than that. The chart, however, shows that while the results do fall within the control limits, there is good reason to suspect that some part of the system could be improved. These erratic results could be due to meter error, of course, but they could also be due to proving equipment errors or operational errors, or a combination of these. Even if a computer could be programmed to analyze data such as this for possible reasons, the chart system has a much better chance of pointing to the probable source of such variations.

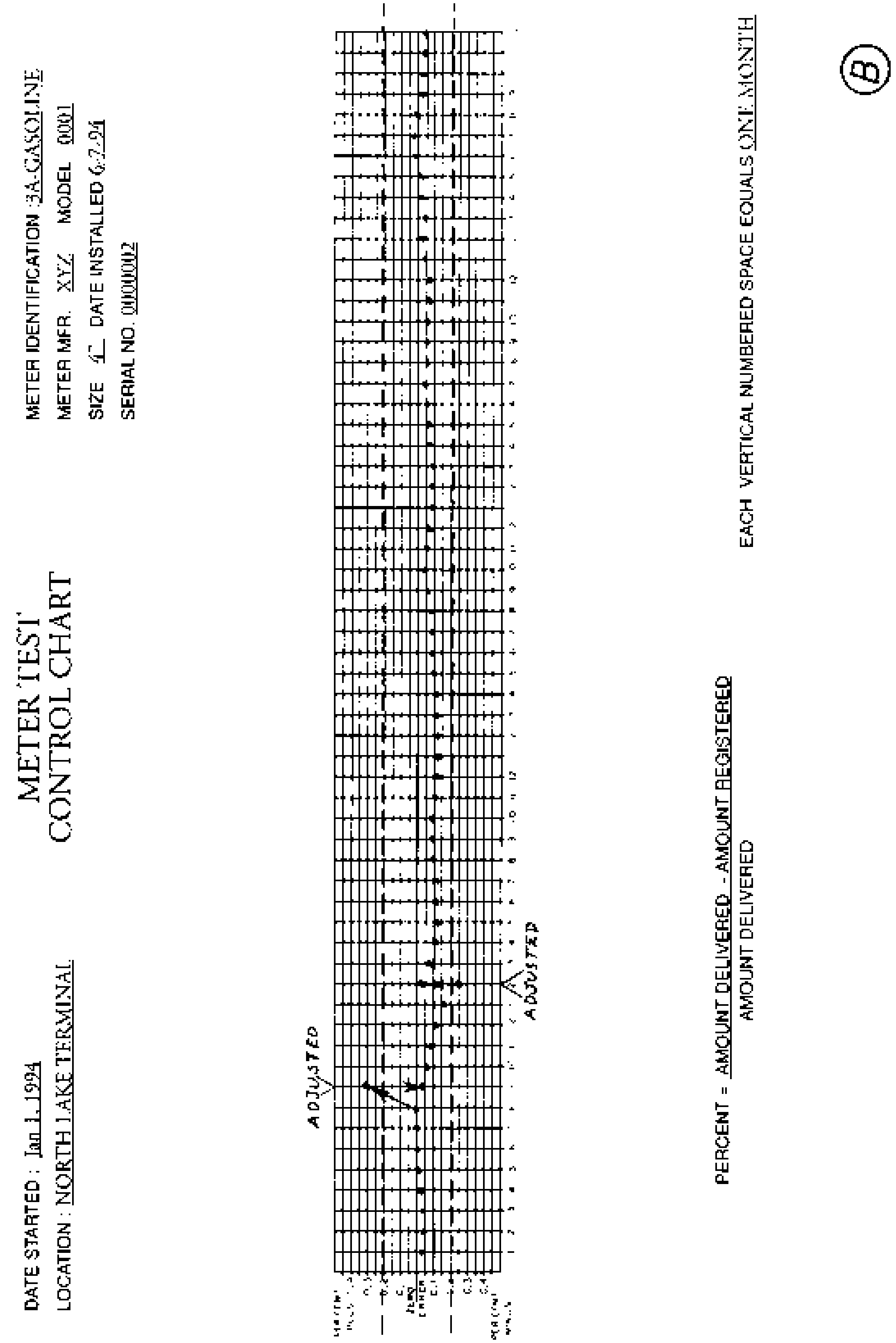
For example, if the data recorded on all four of these charts was obtained by the same operator using the same proving equipment, then Charts, A, B and C would indicate that the variation noticed on Chart D is not due to the proving equipment or the operator.

This presumes that the installation is identical in each case. If there is a difference for the tests recorded on Chart D, then it should be thoroughly investigated to determine whether or not it could cause the variation. This could be a different connection for pumping off the prover or a change in the system valving, leaking valves, or the use of different facilities for pumping off the prover.

Here is a device “within control limits”, yet it could be closer to zero error considering the results obtained form other devices at the same location.

METER TEST CONTROL CHARTS




METER TEST CONTROL CHART
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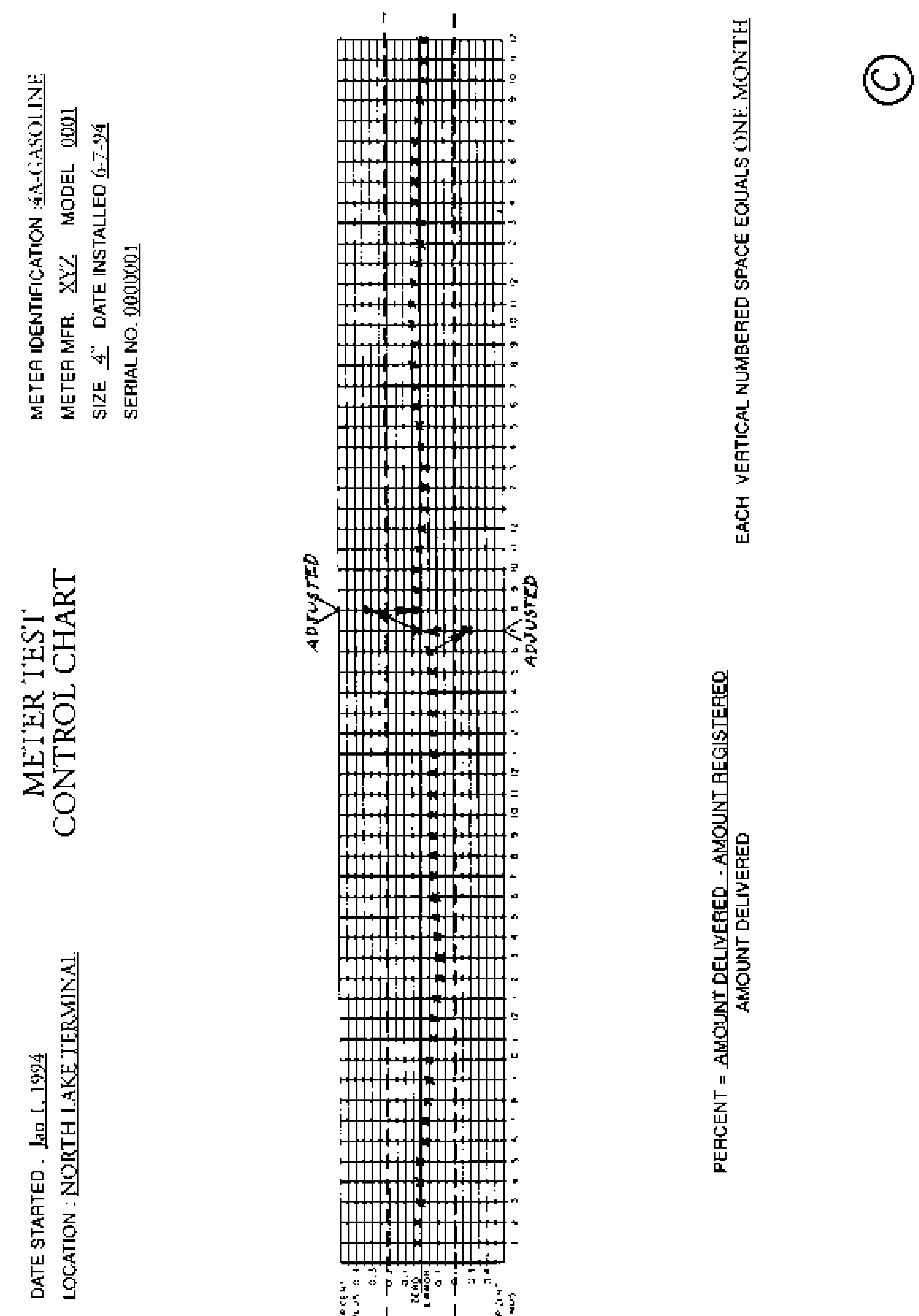
LOCATION: NORTH LAKE TERMINAL
METER IDENTIFICATION 3A-GASOLINE
METER MFR. XYZ MODEL 0001
SIZE 4" DATE INSTALLED 6-7-94
SERIAL NO. 0000002
ADJUSTED
ADJUSTED
PERCENT = AMOUNT DELIVERED - AMOUNT REGISTERED / AMOUNT DELIVERED
EACH VERTICAL NUMBERED SPACE EQUALS ONE MONTH
B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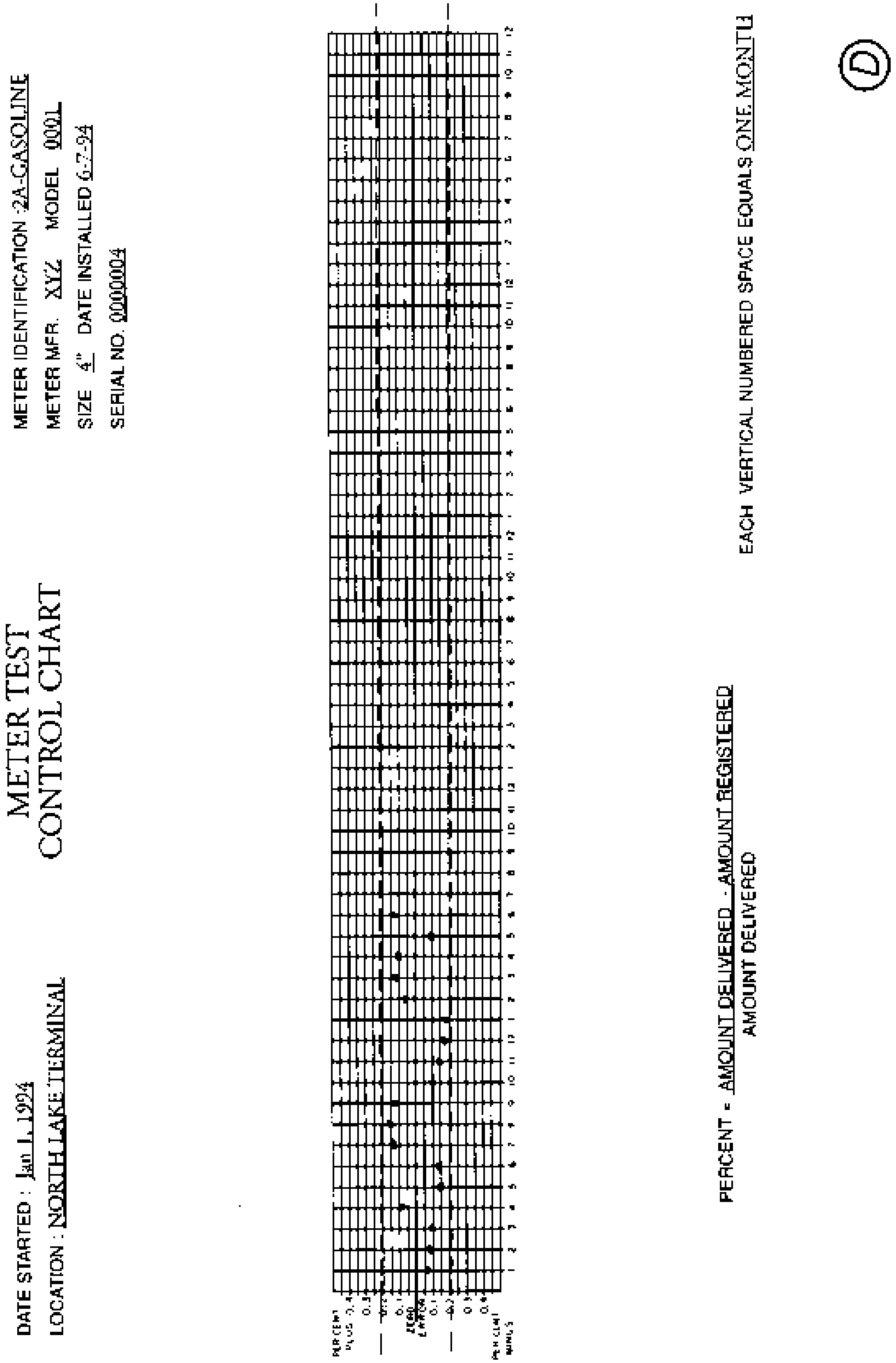
C



We have attempted to define terms and to explain some of the requirements for accurate measurement so that the meter user and the regulatory official might better understand what is needed to obtain accurate liquid measurement. As we have mentioned before, the meter is always associated with other components of an installation. In meter accuracy tests the most variable of these components is the operator.

Consider for a moment the example that we discussed of the target shooter. In Figure 4 we show how an accurate and precise instrument might give scattered results in the hands of an operator who is unable to achieve precision or accuracy.

One of the popular reactions to apparent meter inaccuracy is to advocate “reduction of tolerances”. This is obviously based on the presumption that the error is due to the meter only, and that it can be corrected by changing the applicable tolerance.

There will be operators with the skill and experience enabling them to achieve better meter test results than can be obtained by the average operator. Quite often it is these skilled individuals who can see no reason why meter tolerances might not be reduced. Regulations written around the skill or ability of a small number of technicians is not going to change the skill or ability of the large bulk of operators who will be enforcing the regulations.

This particular point was very conclusively established in a report to the 38th National Conference on Weights and Measures by W.J. Youden and M.W. Jensen. It would be difficult to improve on the presentation they gave at the 1953 meeting. This contained in Miscellaneous Publication 209, U.S. Department of Commerce, National Institute for Standards and Technology.

Another report to the 37th National Conference on Weights and Measures was by W.A. Kerlin in 1952. It is titled “Testing of Vehicle Tank Meters”. This also discusses the effect of the “human equation” as well as some of the other factors affecting meter testing, such as temperature, nozzle velocity, etc. This report is contained in Miscellaneous Publication 206, U.S. Department of Commerce, NIST.

In most meter installations the meter is operated at the rate of flow provided by the other components of the system. An accuracy test at this maximum rate of flow, once the meter has been adjusted for minimum error, is essentially a test for repeatability. We are, in effect, determining the precision of the system.

If the meter is tested at other rates of flow, we are then developing the characteristic curve of the meter which shows what can be expected at any flow rate within the rated operating range of the meter. The results obtained will naturally be affected by the precision of the system or the lack of precision.

This accuracy curve is characteristic of any particular meter and does not materially change during the life of the meter. The allowable limits for this accuracy curve are established by the “special test” tolerance of Handbook 44.

This special test tolerance has been in existence since Handbook 44 was first adopted. All of the meters in commercial usage have had to comply with this tolerance. Any reduction in the “special test” tolerance would automatically make some portion of the meters now in use unable to comply with the new tolerance. The percentage would depend on the amount by which the tolerance is reduced. This would essentially require replacement of this portion of meters already in service.

There is no question that a metering installation can give accurate measurement. We hope that this discussion has brought home the point that the way to achieve accuracy of measurement is by eliminating the variables and the errors that have existed in the past. This may mean better control of the installation design, more intelligent use of the facilities, or education of the operator, installer, or regulatory official. If this discussion has encouraged or started this education, then we consider that it has been successful. The Meter Manufacturers' Technical Committee would welcome any opportunity to discuss any subject related to liquid metering in order to achieve some of the above goals.

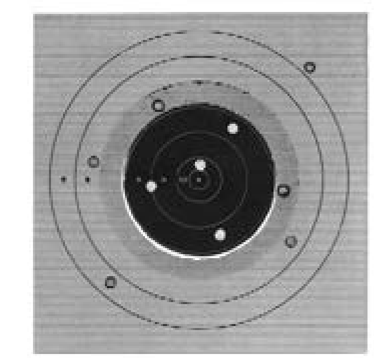


Figure 5

REDUCED TOLERANCE

Figure 5 shows what might result if we were to attempt to improve the results shown in Figure 4 by “reducing the tolerance”. We will only accept shots that are placed within a circle one-half the diameter of the target shown. We have changed nothing else. The instrument is as precise and as accurate as is necessary. The variable in the system is still present, therefore, the results cannot be any different. We will now have only four of the ten shots that are acceptable.

If the first four shots happen to be those within the new tolerance limits, we might convince ourselves that we have improved the system accuracy by taking this action. It is just as likely, however, that the first four shots would not be in that area and we could waste considerable time attempting various adjustments to bring the results within the required limits. Instead of making an improvement, these adjustments could very well result in a less accurate device.

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