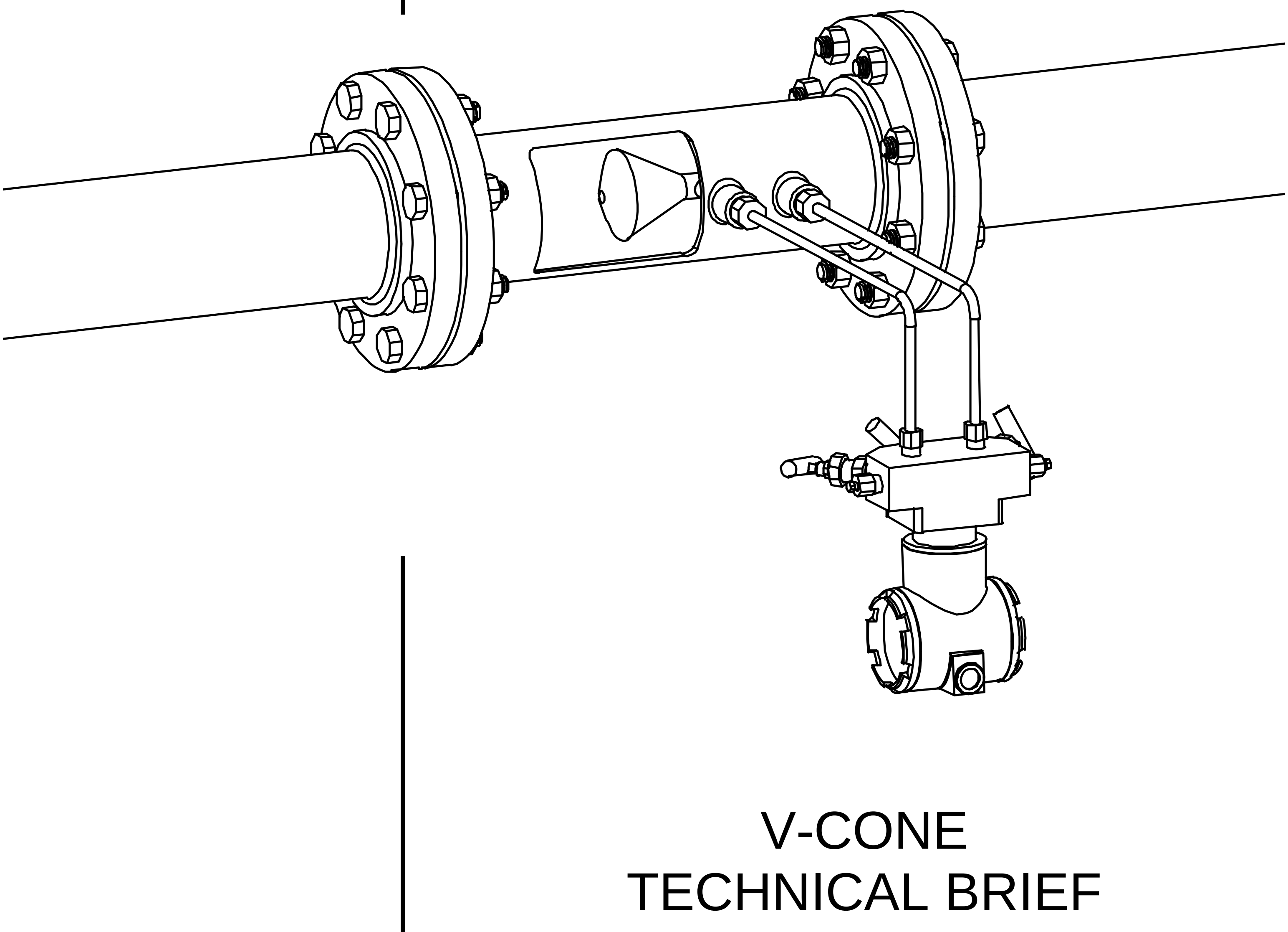
McCROMETER

Advanced
Differential
Pressure
Flowmeter
Technology

V-CONE®



V-CONE
TECHNICAL BRIEF

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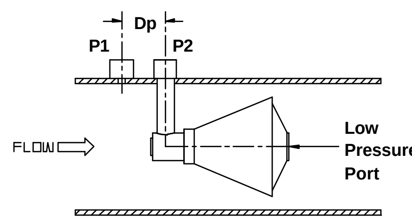
McCROMETER, INC. 3255 W. Stetson Ave., Hemet, CA 92545 PH 909-652-6811 FAX 909-652-3078 email: info@mccrometer.com

1.0 General

1.1 Introduction

The McCrometer V-Cone Flowmeter is a patented technology that accurately measures flow over a wide range of Reynolds numbers, under all kinds of conditions and for a variety of fluids. It operates on the same physical principle as other differential pressure-type flowmeters, using the theorem of conservation of energy in fluid flow through a pipe. The V-Cone's remarkable performance characteristics, however, are the result of its unique design. It features a centrally-located cone inside the tube. The cone interacts with the fluid flow, reshaping the fluid's velocity profile and creating a region of lower pressure immediately downstream of itself. The pressure difference, exhibited between the static line pressure and the low pressure created downstream of the cone, can be measured via two pressure sensing taps. One tap is placed slightly upstream of the cone, the other is located in the downstream face of the cone itself. The pressure difference can then be incorporated into a derivation of the Bernoulli equation to determine the fluid flow rate. The cone's central position in the line optimizes the velocity profile of the flow at the point of measurement, assuring highly accurate, reliable flow measurement regardless of the condition of the flow upstream of the meter.

1.2 Principles of Operation



High and Low Ports
Figure 1

The V-Cone is a differential pressure type flowmeter. Basic theories behind differential pressure type flowmeters have existed for over a century. The principal theory among these is Bernoulli's theorem for the conservation of energy in a closed pipe. This says that for a constant flow, the pressure in a pipe is inversely proportional to the square of the velocity in the pipe. Simply, the pressure decreases as the velocity increases. For instance, as the fluid approaches the V-Cone meter, it will have a pressure of P_1. As the fluid velocity increases at the constricted area of the V-Cone, the pressure drops to P_2, as shown in Figure 1. Both P_1 and P_2 are measured at the V-Cone's taps using a variety of differential pressure transducers. The Dp created by a V-Cone will increase and decrease exponentially with the flow velocity. As the constriction takes up more of the pipe cross-sectional area, more differential pressure will be created at the same flowrates. The beta ratio equals the flow area at the largest cross section of the cone (converted to an equivalent diameter) divided by the meter's inside diameter.

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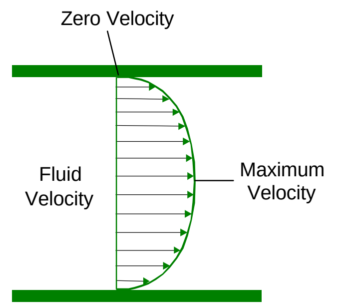
1.3 Reshaping the Velocity Profile

The V-Cone is similar to other differential pressure (Dp) meters in the equations of flow that it uses. V-Cone geometry, however, is quite different from traditional Dp meters. The V-Cone constricts the flow by positioning a cone in the center of the pipe.

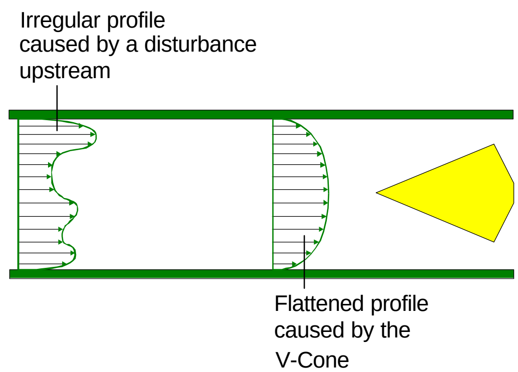
This forces the flow in the center of the pipe to flow around the cone. This geometry presents many advantages over the traditional concentric Dp meter. The actual shape of the cone has been continuously evaluated and tested for over ten years to provide the best performance under differing circumstances.

One must understand the idea of a flow profile in a pipe to understand the performance of the V-Cone. If the flow in a long pipe is not subject to any obstructions or disturbances, it is well-developed flow. If a line passes across the diameter of this well-developed flow, the velocity at each point on that line would be different. The velocity would be zero at the wall of the pipe, maximum at the center of the pipe, and zero again at the opposite wall. This is due to friction at the pipe walls that slows the fluid as it passes. Since the cone is suspended in the center of the pipe, it interacts directly with the “high velocity core” of the flow. The cone forces the high velocity core to mix with the lower velocity flows closer to the pipe walls. Other Dp meters have centrally located openings and do not interact with this high velocity core. This is an important advantage to the V-Cone at lower flowrates. As the flowrate decreases, the V-Cone continues to interact with the highest velocity in the pipe. Other Dp meters may lose their useful Dp signal at flows where the V-Cone can still produce one.



Velocity Profile
Figure 2

The pipe flow profile in actual installations is rarely ideal. There are many installations where a flowmeter exists in flow that is not well developed. Practically any changes to the piping, such as elbows, valves, reductions, expansions, pumps, and tees can disturb well-developed flow. Trying to measure disturbed flow can create a substantial problem for other flowmeter technologies. The V-Cone overcomes this by reshaping the velocity profile upstream of the cone. This is a benefit derived from the cone’s contoured shape and position in the line. As the flow approaches the cone, the flow profile “flattens” toward the shape of a well-developed profile.



Flattened Velocity Profile
Figure 3

The V-Cone can flatten the flow profile under even extreme conditions, such as single elbows or double elbows out-of-plane positioned closely upstream of the meter. This means that as different flow profiles approach the cone, there will always be a predictable flow profile at the cone. This ensures accurate measurements even in non-ideal conditions.

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2.0 Features

2.1 High Accuracy

The V-Cone primary element can be accurate to ±0.5% of reading. The level of accuracy is dependent to a degree on application parameters and secondary instrumentation.

2.2 Repeatability

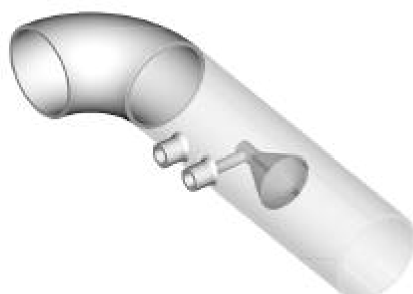
The V-Cone primary element exhibits excellent repeatability of ±0.1% or better.

2.3 Turndown

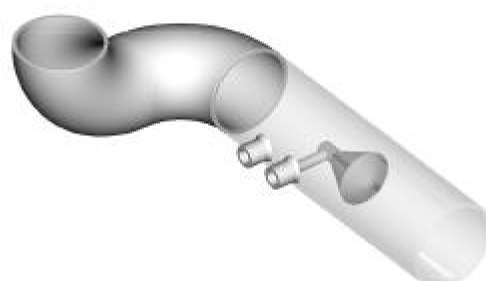
The turndown of the V-Cone can reach far beyond traditional Dp meters. A typical turndown for a V-Cone is 10 to 1. Greater turndowns are attainable. Flows with Reynolds numbers as low as 8000 will produce a linear signal. Lower Reynolds number ranges are measurable and are repeatable by applying a curve fit to the measured Dp.

2.4 Installation Requirements

Since the V-Cone can flatten the velocity profile, it can function much closer to upstream disturbances than other Dp meters. The recommended installation for the V-Cone is zero to three diameters of straight run upstream and zero to one diameters downstream. This can be a major benefit to users with larger, more expensive line sizes or users with small run lengths available. McCrometer conducted performance tests of the V-Cone downstream of a single 90° elbow and two close coupled 90° elbows out of plane. These tests show that the V-Cone can be installed adjacent to either single elbows or two elbows out of plane without sacrificing accuracy.



Single Elbow and V-Cone
Figure 4



Double Elbow and V-Cone
Figure 5

2.5 Long Term Performance

The contoured shape of the cone constricts the flow without impacting it against an abrupt surface. A boundary layer forms along the cone and directs the fluid away from the beta edge. This means the beta edge will not be as subject to the usual wear by unclean fluids. The beta ratio will then remain unchanged and the calibration of the meter will be accurate for a much longer time.

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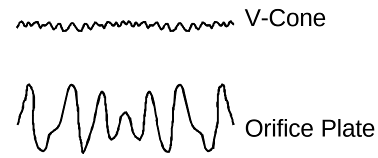
2.6 Signal Stability



Signal Stability
Figure 6

Every Dp meter has a "signal bounce". This means that even in steady flow, the signal generated by the primary element will fluctuate a certain amount. On a typical orifice plate, the vortices that form just after the plate are long. These long vortices create a high amplitude, low frequency signal from the orifice plate. This could disturb the Dp readings from the meter. The V-Cone forms very short vortices as the flow passes the cone. These short vortices create a low amplitude, high frequency signal. This translates into a signal with high stability from the V-Cone. Representative signals from a V-Cone and from a typical orifice plate are shown in figure 6.

2.7 Low Permanent Pressure Loss

Without the impact of an abrupt surface, the permanent pressure loss is lower than a typical orifice plate meter. Also, the signal stability of the V-Cone allows the recommended full scale Dp signal to be lower for the V-Cone than other Dp meters. This will lower the permanent pressure loss.

2.8 Sizing

The unique geometry of the V-Cone allows for a wide range of beta ratios. Standard beta ratios range from 0.45, 0.55, 0.65, 0.75, and 0.85.

2.9 No Areas of Stagnation

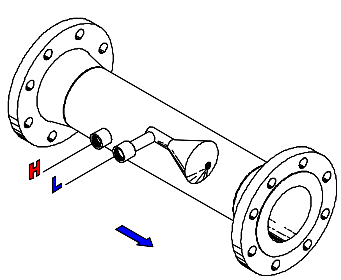
The "swept through" design of the cone does not allow for areas of stagnation where debris, condensation or particles from the fluid could accumulate.

2.10 Mixing

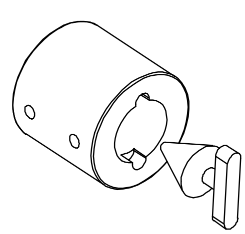
The short vortices described above mix the fluid thoroughly just downstream of the cone. The V-Cone is currently in many applications as a static mixer where instant and complete mixing are necessary.

2.11 Three Models

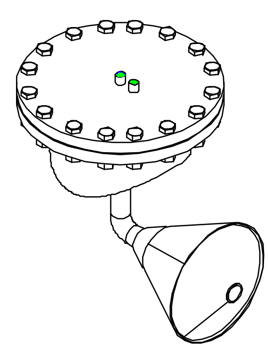
McCrometer offers three types of V-Cone primary elements, the precision tube V-Cone, the Wafer-Cone™ and the insertion top-plate V-Cone. Precision tube V-Cones range in line sizes from ½" to 72" and larger; Wafer-Cones range from 1/2" to 6"; and insertion top-plate V-Cones range in line size from 6" to 72" and larger.



Precision Tube V-Cone
Figure 7



Wafer-Cone
Figure 8



Insertion Top-plate V-Cone
Figure 9

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3.0 The V-Cone Flow Meas. System

3.1 Application Data

The customer must provide application parameters so that the appropriate V-Cone flowmeter may be selected. McCrometer has an extensive meter performance database of fluid properties which can be utilized for sizing purposes.

3.2 General Calculations

Nomenclature:

ΔP	differential pressure (Dp)	inWC
D	inside diameter	inches
d	cone diameter	inches
β	beta ratio	.
k	isentropic exponent	.
k_1	flow constant	.
k_2	Y factor constants	.
k_3	Y factor constants	
G_C	gravitational cons. (32.2)	f/s^2
C_F	flowmeter coefficient	.
Y	gas expansion factor	.
ρ	flowing density	lb/ft^3

P	operating pressure	psia
T	operating temperature	Rankine
Z	gas compressibility	.
S_F	operating specific grav.	.
S_{STP}	specific grav. at STP	.
ρ_{water}	water density (62.3663)	lb/ft^3
P_b	base pressure	psia
T_b	base temperature	Rankine
Z_b	base gas compressibility	.
Y_{sizing}	Y factor from sizing	.
ΔP_{sizing}	Dp from sizing	inWC
P_{sizing}	pressure from sizing	psia

3.2.1	Differential Pressure	$\Delta P = P_H - P_L$	ΔP units are inWC
3.2.2	Flowmeter Coefficient	Derived from calibration or from historical data.	Located on sizing and calibration reports.
3.2.3	V-Cone beta ratio	$b = \frac{\sqrt{D^2 - d^2}}{D}$	b from sizing report
3.2.4	Flow Constant	$k_1 = \frac{p}{576}\sqrt{2G_c}\,\frac{D^2 b^2}{\sqrt{1-b^4}}C_F$	k_1 from sizing report

3.3 Calculations for Liquids

3.3.1	Density	$r = S_F\, r_{water}$	
3.3.2	flowrate conversion	$GPM = 448.8\ ACFS$	
3.3.3	Flowrate	$ACFS = k_1\sqrt{\frac{5.197\ \Delta P}{r}}$	

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3.4 Calculations for Compressible Fluids (gases and vapors)

3.4.1	Y gas expansion factor correction for ΔP and pressure.	$Y=\sqrt{\dfrac{\left[\left(1-b^{4}\right)\times\dfrac{k}{k-1}\times R^{\frac{2}{k}}\times\left(1-R^{\frac{k-1}{k}}\right)\right]}{\left[\left(1-\left(b^{4}\times R^{\frac{2}{k}}\right)\right)\times(1-R)\right]}}$ $R=1-\left(\dfrac{\Delta P}{27.7\ P}\right)$	k Isentropic Exponent is located on the sizing report.
3.4.2	gas density	$r\ (\text{lb/ft}^3)=2.6988\dfrac{S_{STP}\ P}{Z\ T}$	
3.4.3	Flowrate	$ACFS=k_1\ Y\sqrt{\dfrac{5.197\ \Delta P}{r}}$	
3.4.4	flowrate conversion	$SCFS=ACFS\left(\dfrac{P\ T_b\ Z_b}{P_b\ T\ Z}\right)$	converts actual flow to standard flow

3.5 Simplified Formulas for Y - Gas Expansion Factor

3.5.1	Y expansion factor correction for ΔP and pressure.	$Y=1-\left[\dfrac{1-Y_{Sizing}}{Y_{Sizing}}\right]\dfrac{P_{sizing}\ \Delta P}{P\ \Delta P_{sizing}}$	ΔP and ΔP_{sizing} must be in the same units, P and P_{sizing} must be in the same units
3.5.2	Y gas expansion factor correction for ΔP only.	$Y=1-\Delta P\ k_2$	k_2 from sizing report, ΔP units must be the same as on the sizing report
3.5.3	Y expansion factor correction for ΔP and pressure.	$Y=1-\dfrac{\Delta P}{P}k_3$	k_3 from sizing report, ΔP and P units must be in the same units as on the sizing report

In the equations above k_2 and k_3 were calculated using the isentropic exponent corresponding to the operating temperature on the sizing report, therefore corrections for isentropic exponent changes are not incorporated. If this isn't acceptable then equation 3.4.1 should be used.

3.6 Application Sizing

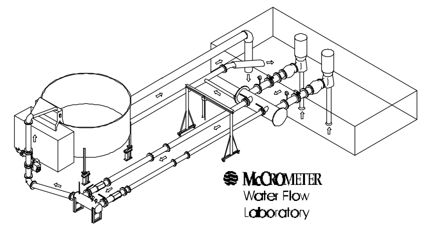
Each V-Cone is tailored to its specific application. Before manufacturing, every V-Cone will have a "sizing" completed according to the physical parameters of the application. The computer generated sizing uses application data as a basis to predict the V-Cone's performance. Full scale DP (typically 50 inches of water at full scale), working flow range, expected accuracy, and predicted pressure loss are determined by the sizing. The sizing recommends the beta ratio that best meets the application requirements.

3.7 Calibrations

Precision tube and wafer flowmeters less than 18" diameter are calibrated in one or more of the following McCrometer calibration facilities:

Calibration Facility	*Size Range*	*Calibration Facility*	*Size Range*
Water 40k lb Gravimetric	3" to 16"	Water 1.5k lb Gravimetric	up to 4"
Water 5k lb Gravimetric	up to 6"	Air 80 cfm	up to 2"

McCrometer recommends that every V-Cone meter be calibrated. A calibration is required when the application requires the best accuracy. Insertion top-plate style flowmeters can be calibrated as an option. If an actual calibration is not requested, the coefficient for the meter can be estimated. Data collected over years of independent testing allows for an accurate estimate of the meter's C_f . For V-Cones intended for use in a compressible fluid with high accuracy requirements, McCrometer recommends calibration in a compressible fluid.



Calibration Facility 40k Gravimetric
Figure 10

3.8 Materials of Construction

All materials used on V-Cone flowmeters are certified. Materials furnished to McCrometer include a certified material test report (CMTR) from the original material manufacturer. The test reports include material composition and applicable material grades. Upon request copies of the material test reports can be supplied to our customers.

3.9 Valve Manifolds

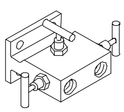
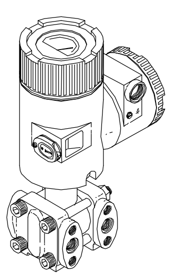


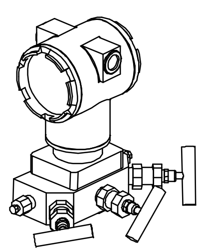
Figure 11

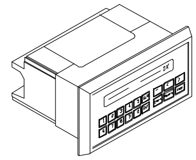
McCrometer recommends a three valve or five valve manifold as part of a V-Cone flow measurement system. Manifolds allow for in-line transmitter calibrations, isolation of the transmitter from the transmission lines without depressurizing the line and in-line purging of transmission lines.

3.10 Secondary and Tertiary Instrumentation

A differential pressure transmitter generally measures the differential pressure signal from the primary element. Once the signal is measured, the transmitter generates an electronic signal that is then interpreted by a flow monitor or other process control system. For compressible fluids, line pressure and temperature measurements are sometimes required. McCrometer offers the following flow measurement instrumentation: differential pressure transmitters, flow computers, and pressure and temperature sensors for mass flow measurement. All can be calibrated and programmed at the factory.


Typical Dp Trans.
Figure 12


Typical Dp Trans.
Figure 13


Flow Computer
Figure 14

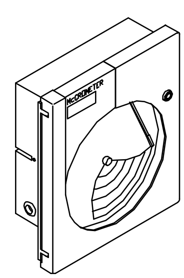


Chart Recorder
Figure 15

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MANUFACTURER'S WARRANTY

This Warranty shall apply to and be limited to the original purchaser consumer of any McCrometer product. Meters or instruments defective because of faulty material or workmanship will be repaired or replaced, at the option of McCrometer, Inc., free of charge, FOB the factory in Hemet, California, within a period of one (1) year from the date of delivery.

Repairs or modifications by others than McCrometer, Inc. or their authorized representatives shall render this Warranty null and void in the event that factory examination reveals that such repair or modification was detrimental to the meter or instrument. Any deviations from the factory calibration require notification in writing to McCrometer, Inc. of such recalibrations or this warranty shall be voided.

In case of a claim under this Warranty, the claimant is instructed to contact McCrometer, Inc. 3255 West Stetson Ave., Hemet, California 92545, and to provide an identification or description of the meter or instrument, the date of delivery, and the nature of the problem.

The Warranty provided above is the only warranty made by McCrometer, Inc. with respect to its products or any parts thereof and is made expressly in lieu of any other warranties, by course of dealing, usages of trade or otherwise, expressed or implied, including but not limited to any implied warranties of fitness for any particular purpose or of merchantability under the uniform commercial code. It is agreed this warranty is in lieu of and buyer hereby waives all other warranties, guarantees or liabilities arising by law or otherwise. Seller shall not incur any other obligations or liabilities or be liable to buyer, or any customer of buyer for any anticipated or lost profits, incidental or consequential damages, or any other losses or expenses incurred by reason of the purchase, installation, repair, use or misuse by buyer or third parties of its products (including any parts repaired or replaced); and seller does not authorize any person to assume for seller any other liability in connection with the products or parts thereof. This Warranty cannot be extended, altered or varied except by a written instrument signed by seller and buyer.

This Warranty gives you specific legal rights, and you may also have other rights which vary from state to state.

McCrometer, Inc. reserves the right to make improvements and repairs on product components which are beyond the warranty period at the manufacturer's option and expense, without obligation to renew the expired warranty on the components or on the entire unit. Due to the rapid advancement of meter design technology, McCrometer, Inc. reserves the right to make improvements in design and material without prior notice to the trade.

All sales and all agreements in relation to sales shall be deemed made at the manufacturer's place of business in Hemet, California and any dispute arising from any sale or agreement shall be interpreted under the laws of the State of California.

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√CONE ®

OTHER McCROMETER PRODUCTS INCLUDE:

Mc ® Propeller Liquid Flowmeters

√CONE ® Differential Pressure Flowmeter

Wafer-Cone™ Differential Pressure Flowmeter

SK ® Variable Area Meters

MX ® Magnetic Flowmeters

Electronic Instrumentation for Remote Display and Control

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Canadian Patent 1325113 European Patent 0277121 Japan patent 1,858,116 Other U.S. and Foreign patents pending

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