FILTRAMETER – a continuous online monitor of filter effectiveness

James T. Farley, P.E.
Houston, TX

Successful injection of water into the subsurface for recovery of oil requires the cost-effective maintenance of adequate water quality. Based upon on-site testing (1), chemical and mechanical means are tailored to achieve the desired water quality. Once the full-scale facility is in place, monitoring is necessary to detect facility malfunctions and prevent injection well damage. Often the primary cause of wellbore damage is waterborne solids; therefore, water is filtered prior to injection. For years, manual methods (2) have been used to measure the effectiveness of commercial filters. More recently, turbidity meters were employed to monitor suspended particles. Presently, a continuous online meter provides an alternate method to monitor primary filter effluent. The concept, design and development of this patented automated meter (3) are the subject of this paper.

The purpose of the meter is to monitor the effectiveness of a commercial primary filter. A cartridge filter of known degree of filtration is the central part of the meter for monitoring water quality with respect to suspended particles. Typically, the holder of the monitor filter element is located at a point downstream of the primary filter that is being monitored. Sensors of flow rate and differential pressure send signals to the microprocessor of the meter that calculates the transmissibility of the monitor filter element. Thus changes in transmissibility reflect the quality of primary filter effluent.

Depending upon the water quality being observed microprocessor logic manipulates steps of the meter and sends signals to display, control, and alarm.

A tangible additional benefit of this meter, in comparison to optical turbidity meters, is determination of reagents to remove the solids. The flushing step of the meter reveals the response of the monitor filter element to solids removal by flushing agent or agents: acids, oxidant or mutual solvent. Meter response can help with design of full-scale chemical treatment of injection wells that have inadvertently been damaged by solids.

Meter Description

The meter is essentially a cartridge filter holder and element with upstream and downstream pressure transducers. Downstream of the holder is a flow-rate sensor that sends a signal to a programmable logic controller (PLC) that uses the signals from the pressure transducer also in calculations that are to be discussed later. Depending upon the microprocessor logic, effluent is back flowed, a reagent is flushed through the filter element to restore flow before monitoring is continued.

The meter operates at ambient conditions: monitoring pressure to a maximum of 75 psig and a maximum temperature of 100°F. Flow rate through the monitor filter ranges from a minimum of 1.0 gpm to a maximum of 35 gpm. The differential pressure across the filter element has a maximum limit of 80 psid. A photo of the meter is shown in Figure 1.

The components are mainly PVC except for a few stainless steel fitting that come into contact with corrosive fluids: injection water, produced water, seawater, and acids. The signals from the sensors of flow rate and pressure are sent to the microprocessor that calculates the quality of the primary filter effluent. The calculations are made continuously, recorded and displayed on the meter or transmitted to another location for analysis. More about data evaluation is presented in the next section.

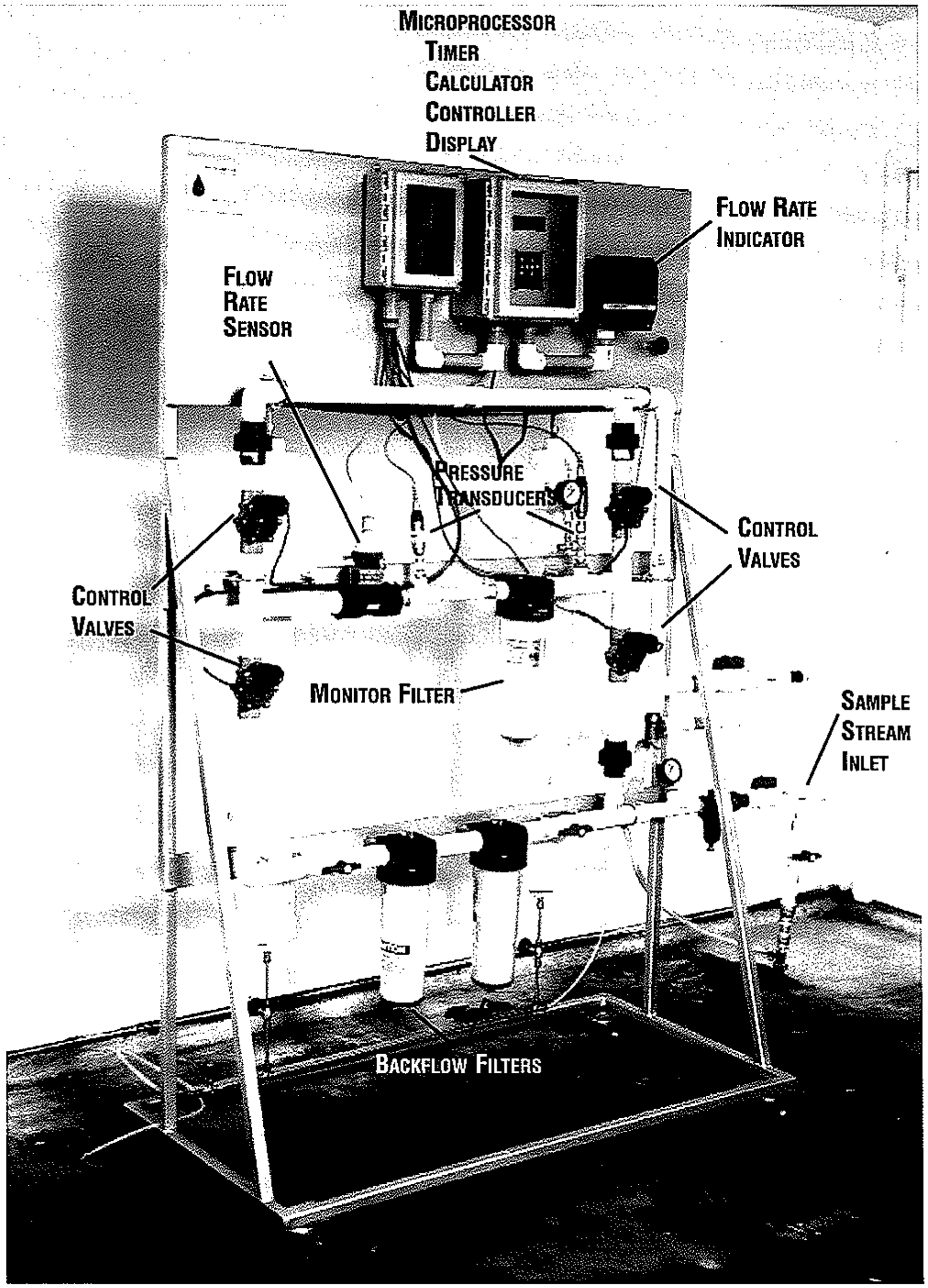


FIGURE 1 FILTRAMETER: continuous online monitor of solids

Basic Functions

The basic steps of the meter are to monitor the water quality, to backflow contaminants from the monitor element or to flush contaminants from the element using acids, oxidant or mutual solvent. Monitoring consists of calculating the transmissibility of the monitor filter as effluent from the primary filter passes through the element. Transmissibility, T, is defined by the following equation (4):

$$\mathbf{T = Q/DP^{1/2}}$$

where:

Q = flow rate, gpm

DP = differential pressure across the filter element, psid.

In order to dampen possible swings in transmissibility caused by abrupt changes in water pressure and to observe trends in overall water quality, filtration ratio was defined as follows:

$$\mathbf{FR = T/T_0}$$

where:

T = transmissibility

T_0 = original transmissibility.

The slope, FE, of the FR versus t plot indicates the effectiveness of the primary filter at removal of suspended particles from the effluent.

$$\mathbf{FE = (FR_i - FR_{i-1})/(t_i - t_{i-1})}$$

where:

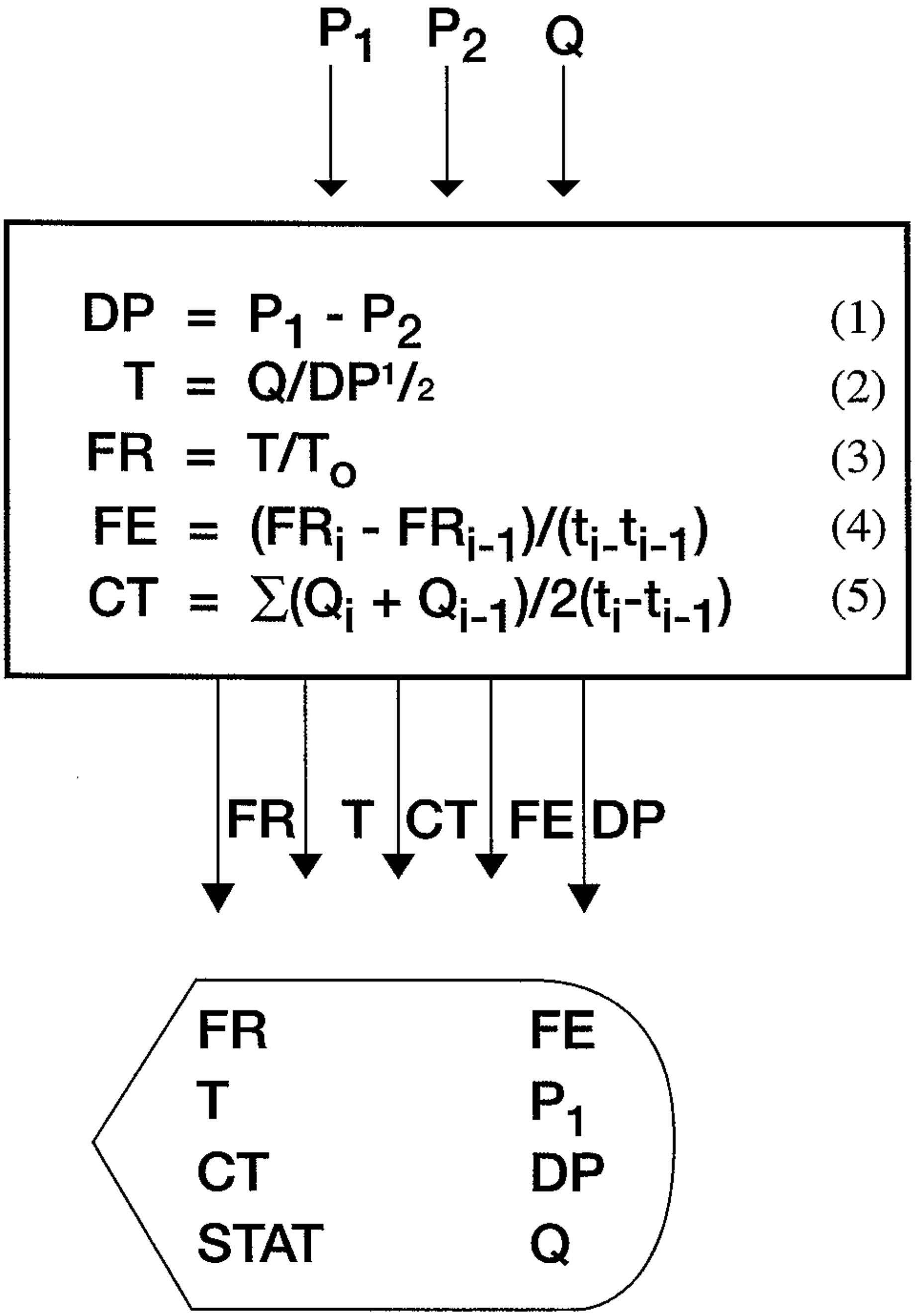
FE = filter effectiveness, min^{-1}

t = time, min

All of the equations used in the microprocessor are presented in Figure 2.

The concept of monitoring water quality using FR and FE enables the setting of limits and bounds on water quality measurement before alarms, manipulations and controls are executed by the meter, more explanation follows in the next section.

Programmed computer logic that utilizes the real time calculated value of filtration ratio, FR, is illustrated in Figure 3. Filter effectiveness, FE, the magnitude and direction is tested to determine quality and controls the meter functions: monitor or backflow. These steps may be over ridden by the keypad on the controller/microprocessor. For instance, the operator may wish to restore FR to a value of 1.0 by backflowing the meter. If backflowing does not return the transmissibility of the meter element to its original value (FR = 1.0), the operator may manually flush the element with a flush fluid contained in vessels that are part of the meter.



$$DP = P_1 - P_2 \quad (1)$$

$$T = Q/DP^{1/2} \quad (2)$$

$$FR = T/T_o \quad (3)$$

$$FE = (FR_i - FR_{i-1})/(t_i - t_{i-1}) \quad (4)$$

$$CT = \sum(Q_i + Q_{i-1})/2(t_i - t_{i-1}) \quad (5)$$

Figure 2 Equations for FILTRAMETER calculations and display.

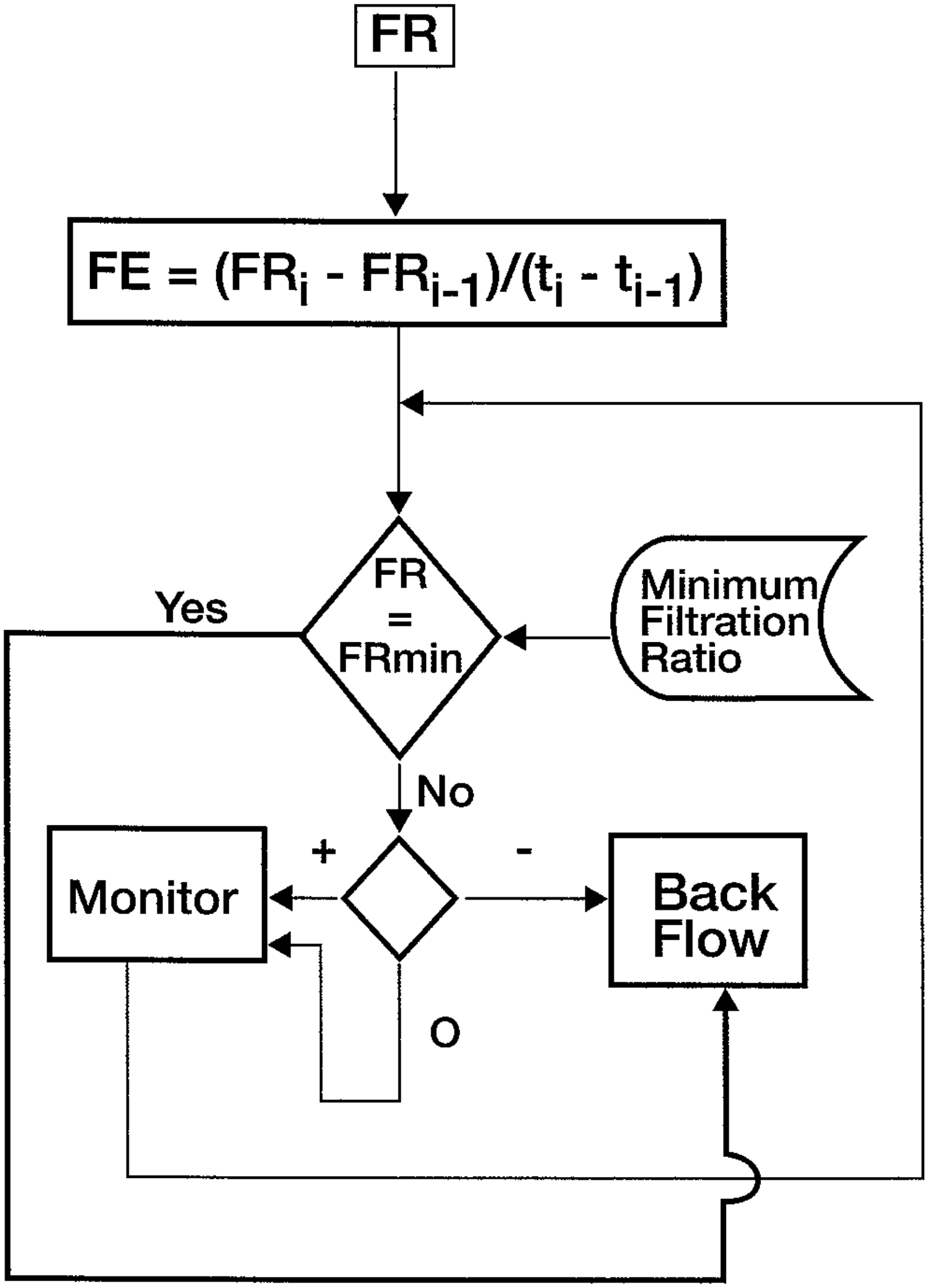


Figure 3 Flowchart of basic logic of FILTRAMETER control.

Preliminary Laboratory Tests

Preliminary laboratory tests of the meter were conducted on Houston tap water. It was available and convenient and relatively consistent in quality from day to day. The hardness of the water was 70 mg/l as calcium carbonate. Because of its low concentration of suspended particles, less than 1.0 mg/l, the limits of impact of low suspended particles on filter effectiveness could be determined. Altering the quality of the tap water was simulated by dynamically changing the degree of filtration of the online primary filter upstream of the meter. The results of a typical test conducted at 70°F operating temperature; 45 psig, flowing pressure; and 15 gpm, flow rate are given in Figure 4.

The desired degree of filtration needed to protect a formation from particle damage was set at 2.0 microns. Then a 2.0-micron filter element is used in the monitor filter to determine the effectiveness of the primary filter at removing particles greater than 2.0 microns. For the sake of this laboratory simulation of primary filtration, the degree of filtration of the primary filter is initially selected to be 2.0 microns. During the period that the 2.0-micron primary filter is in place, the transmissibility of the element of the monitor filter is unchanged and filtration ratio stays at 1.0. Likewise, for the same period, 0 to 120 minutes, the primary filter is effective, FE = 0, which indicates that the primary filter is effective.

When the primary filtration is selected to be coarser than monitor filter degree of filtration particles larger than 2.0 microns but less than 5.0 microns impinge upon the

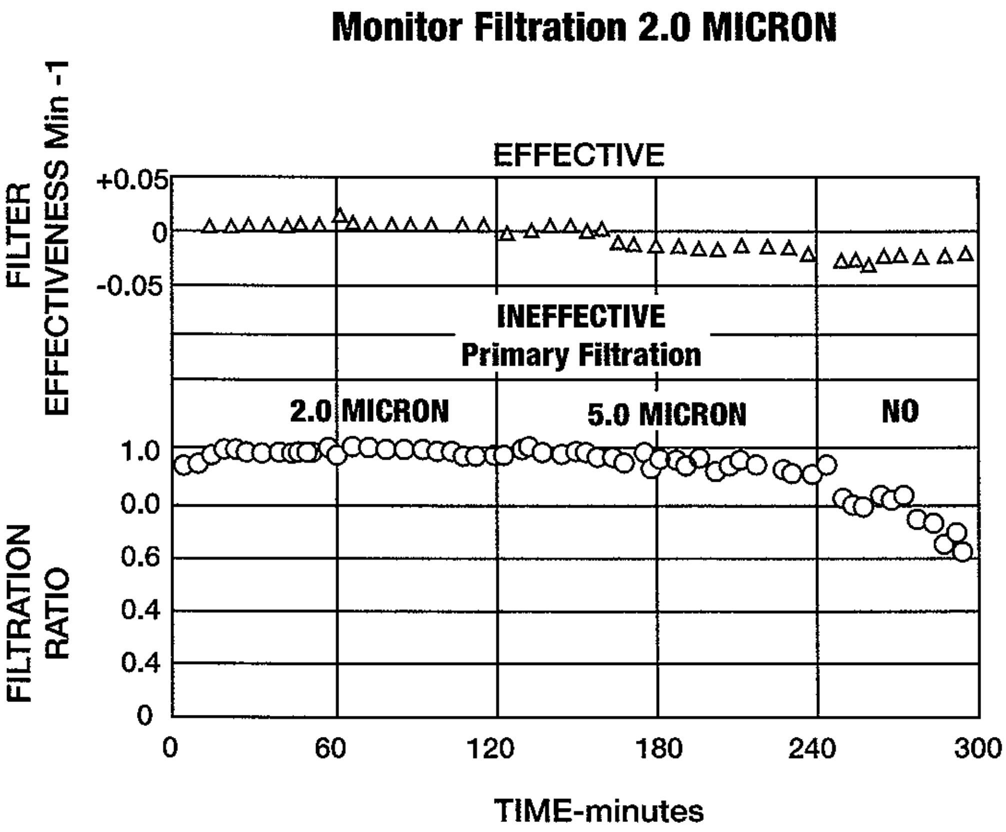


Figure 4 FILTRAMETER response to changes in primary filtration

monitor filter that responds to the poorer quality of water. When the 5.0-micron primary filter is in place, from 120 to 240 minutes, the filtration ratio declines from 1.0 to 0.9, a loss of 10%. Similarly, the filter effectiveness value turned negative and that is indicative of a lesser degree of filtration being achieved by the prefilter with respect to the 2.0-micron monitor filter. In actual practice, a 10% decline in filtration ratio would be correlated with a similar decline in permeability observed during on-site core-flow tests or full-scale injectivity test. Correlation and interpretation of meter results is essential for cost-effective management and operation of pretreatment system.

Finally, no filtration is given during the last period of the test. The time from 240 to 300 minutes simulates bypass of particles through the primary filter. This is the time when all of the solids in the tap water impinge upon the 2.0-micron monitor filter. During the hour, filtration rate declined from 0.9 to 0.6 or an additional loss of 30% in transmissibility from its original value. Typically, the minimum value set for the programmable logic controller (PLC) of the meter would have activated the alarm at a set point of 0.75. The backflow procedure of the meter could be activated automatically or overridden by the operator. The operator could manually flush the monitor filter with fluid to determine the nature of the contaminant.

Monitor Filter Blinding

A possible limitation to monitoring water quality using a filter element is the "blinding" of the meter. Blinding is the term given to describe the gradual change in the transmissibility of the monitor filter element caused by buildup of fine particles. This accumulation of particles within the interstices of the filter element results in greater decline in filtration ratio than for a new filter element. This phenomenon is exhibited in Figure 5. Note, the monitor filter has been measuring filtration ratio for 300 minutes. Taking up where Figure 4 left off, filtration ratio, FR, starts at 0.6 because of poor water quality that was simulated by prior coarser filtration than the 2.0-micron monitor filter, 5.0-micron monitor filter from 120 to 240 minutes and no filtration from 240 to 300 minutes. This simulates a 30% decline in monitor filter transmissibility over a 180-minute period. The gradual decline in filtration ratio, while primary filtration of 2.0 microns was restored indicates a lessening in filter effectiveness. That is probably not the case; rather, the 2.0-micron monitor filter is likely partially fouled with particles. Small particles that pass through the 2.0-micron primary filter now impinge upon the 2.0-micron monitor filter that has been in service for 5 hours and subjected to poor quality water. Though this is an impediment to measurement of the exact degree of filtration that the primary filter is maintaining, blinding can be less of a handicap when determining filter effectiveness during water monitoring for subsurface injection.

In the case of waterflooding, the monitor filter is analogous to the subsurface formation. The changes in water quality over the duration of injection impact the meter; as well as, the injector. Wellbore damage is a cumulative response to poor water quality; therefore,

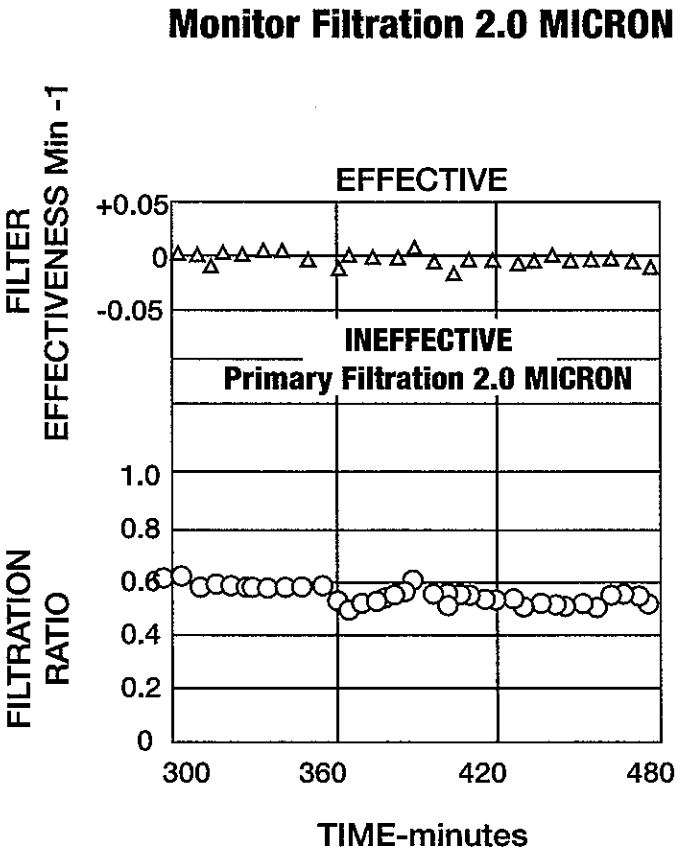


Figure 5 "Blinding" alters FILTRAMETER sensitivity to small particles.

the injector becomes more sensitive as more and more particle buildup in the perforations or the interstices of the formation. Just as the injector becomes more sensitive; so too, the meter becomes more sensitive and the meter becomes an early warning device for anticipating injection well impairment.

The effect of blinding can be overcome by chemical removal of contaminates from the monitor filter element. Likewise, the stimulation of a formation can be assessed during the reagent flush of the blinded meter. Thus two objectives are achieved by flushing the monitor filter that has been contaminated during monitoring: 1) filter element transmissibility is restored for further monitoring and 2) injection well restoration is indicated using a stimulant such as the flushing agent.

Choosing a Flushing Agent

The choice of flushing agent largely depends upon the composition of the predominate solid that accumulates in the monitor filter. The causes of particle accumulation are many. They range from blow-by of solids through the primary filter during time of high differential pressure to precipitation of solids during malfunction of chemical feed pumps. The flushing agents that correspond to various particles/droplets are as follows:

Flushing Agent	Particle/Droplet
Hydrochloric acid	Calcium carbonate
Citric acid	Iron carbonate
Ehylene diamine tetractic acid	Calcium sulfate
Hydrochloric-hydrofluoric acid	Hydrous aluminosilicates
Hydrofluoric acid	Silica
Sodium hypochlorite	Micro-organisms
Ethylene glycol monobutyl ether	Oil

It is possible that more than one type of particle may blind the monitor filter; therefore, the meter has multiple vessels that are filled with various agents for flushing the monitor filter element. The selection of the best flushing agent or sequence of agents depends upon the response of the monitor filter to the flushing. Such an investigation follows.

It is obvious from preliminary tests that there is a contaminant in the water that is impinging on the monitor filter when the water is not being filtered to 2.0 microns: the degree of the monitor filter. Since the concentration of suspended solids in the Houston tap water is less than 1.0 mg/l, and the dissolved solids concentration is 70.1 mg/l as calcium carbonate, the potential for minute scaling is there. Possibly scaling is blinding the monitor filter when primary filtration is greater than 2.0 microns.

A test was conducted to determine the response of the monitor filter to flushing with hydrochloric acid, a reactant with calcium carbonate scale. Taking up where the test of the monitor filter blinding stopped, a 480 minutes into monitoring, the FR stabilized at approximately 0.5 (see Figure 6). After flowing for 30 minutes with both primary filter and monitor filter at 2.0-micron filtration, 3.5 wt % hydrochloric acid was injected at a rate of 0.15 gpm into the inlet of the monitor filter that the primary filtered water rate was reduced to 5.0 gpm. Since the dilution of acid to water was approximately 1 to 40, the resulting hydrochloric acid concentration entering the monitor filter was 0.875 wt %. Even at this low concentration of acid, FR increased from 0.5 to 0.7 after 15 minutes during which time all of the 2.5 gallons of hydrochloric acid were injected at the inlet to the monitor filter. Probably, FR could have been restored totally to 1.0 had there been more acid or a higher concentration of acid been in the flush fluid vessels. After 525 minutes, the FR stabilized at 0.7 for another 45 minutes. The test demonstrated the potential of using a flush fluid to restore the sensitivity of the monitor filter element and a like stimulation to improve the injectivity of a water injection well.

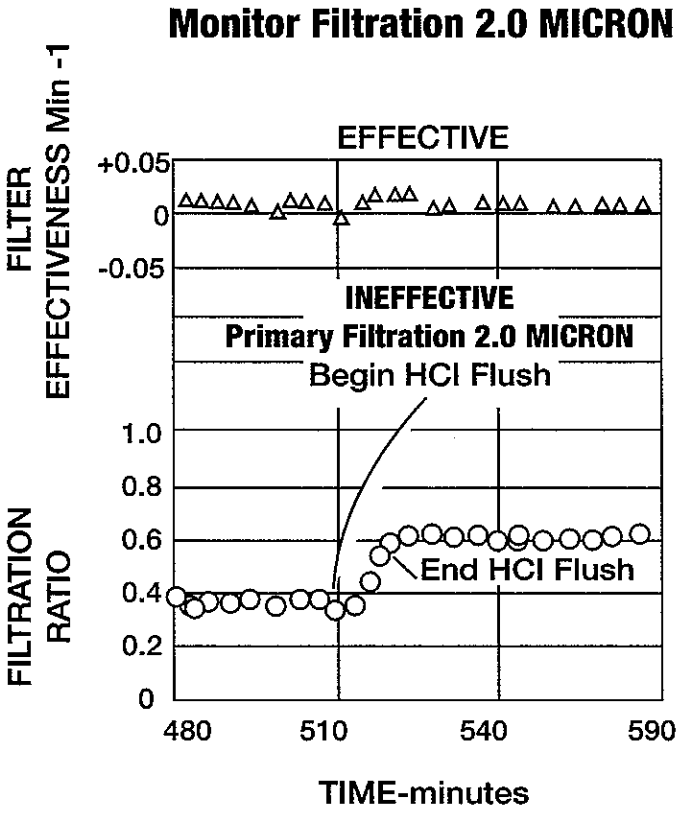


Figure 6 FILTRAMETER demonstrates response to flushing agent.

Future Tests

In the future, tests are designed to evaluate the concept and to apply the meter in a field setting on real oilfield water and equipment. The feasibility of monitoring and controlling a primary filter in actual operation must be demonstrated. Further, application of the meter in the areas of prediction of water injection well response to: 1) particle damage and 2) damage removal. The affect warrants the remedy.

Tests will consist of: 1) onsite core flow tests to determine the desired degree of filtration needed to sustain adequate water quality, 2) tests on the meter settings to maintain the filtration that is required, and 3) well injectivity tests to correlate well injection with monitored water quality. The suite of tests is designed to determine the relationship between the monitor filter settings for quality water and actual water injectivity of the well.

Though the solids in water and the formation into which the water is being injected are specific for each case, once the degree of filtration is set, the meter can measure the water quality. Application of the meter response to prediction of well impairment will test the basic premise that the monitor filter element is a metaphor for the subsurface formation. Presently, only a fiber element has been tested and field tests may indicate other media must be investigated. These are the objectives of the onsite test program, as well as, to illustrate an economical, logical method of monitoring water quality and for tailoring the meter to specific pretreatment facility requirements.

Summary

The feasibility of the FILTRAMETER monitoring filter effectiveness has been demonstrated in the laboratory. A second-generation prototype has been built for oilfield use and trials are proposed to further evaluate this new technology. The FILTRAMETER is not only capable of monitoring and controlling primary filters; it has potential for assisting in the design of stimulation treatments for water injection wells.

References

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APPENDIX A

Meter Status

Status	Function
B	Backflow effluent
F	Flush fluid
M	Monitor
S	Stop flow