Designation: D8002 – 15$^{\varepsilon 1}$

Standard Test Method for Modified Fouling Index (MFI-0.45) of Water[1]

This standard is issued under the fixed designation D8002; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

ε[1] NOTE—Note 12 was editorially corrected in June 2016.

1. Scope

1.1 This test method covers the determination of the modified fouling index (MFI) of water measured at constant pressure. This test can be used to indicate the fouling potential of reverse osmosis/nanofiltration (RO/NF) feed water due particulate matter and is applicable to low and high turbidity waters. Since the size, shape, and nature of particulate matter in water may vary, this test method is not an absolute measurement of the quantity of particulate matter.

1.2 This test method is not applicable for reagent-grade water Types I, II, and III of Specification D1193 or effluents from most reverse osmosis and ultra-filtration systems.

1.3 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D1129 Terminology Relating to Water

D1193 Specification for Reagent Water

D2777 Practice for Determination of Precision and Bias of Applicable Test Methods of Committee D19 on Water

D3370 Practices for Sampling Water from Closed Conduits

D4189 Test Method for Silt Density Index (SDI) of Water

D6161 Terminology Used for Microfiltration, Ultrafiltration, Nanofiltration and Reverse Osmosis Membrane Processes

D7726 Guide for The Use of Various Turbidimeter Technologies for Measurement of Turbidity in Water

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms used in this standard, refer to Terminologies D1129 and D6161.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *modified fouling index, MFI-0.45, n*—index calculated from the development of filtration velocity through a 0.45-µm membrane filter. **D2777**

4. Summary of Test Method

4.1 Water is passed through a 0.45-µm membrane filter at constant pressure of 200 kPa and the development of the rate of filtration is measured continuously.

4.2 The MFI is calculated from the obtained data of flow versus time at constant pressure and temperature.

5. Significance and Use

5.1 This test method is an alternative for the silt density index (SDI) method (Test Method D4189) with the aim to overcome inaccuracies related to a nonlinear relation with the fouling potential due to particulate matter concentration, absence of temperature correction, support pad, and time.

5.2 The MFI-0.45 can serve as a useful indication of the quantity of particulate matter.

5.3 The MFI-0.45 can be used to determine effectiveness of various processes such as filtration or clarification used to remove particulate matter.

5.4 The MFI-0.45 has empirically been correlated with fouling tendency of some water treatment equipment such as reverse osmosis (RO) devices.

6. Apparatus

6.1 *MFI Assembly*—As described in Fig. 1 and Fig. 2, wetted parts should be made of high-quality stainless or plastic to prevent contamination by corrosion products. Do not use reactive materials such as carbon steel, galvanized steel, cast iron, and copper alloys. Suitable filter holders, designed to withstand an operational gage pressure of 350 kPa, can be

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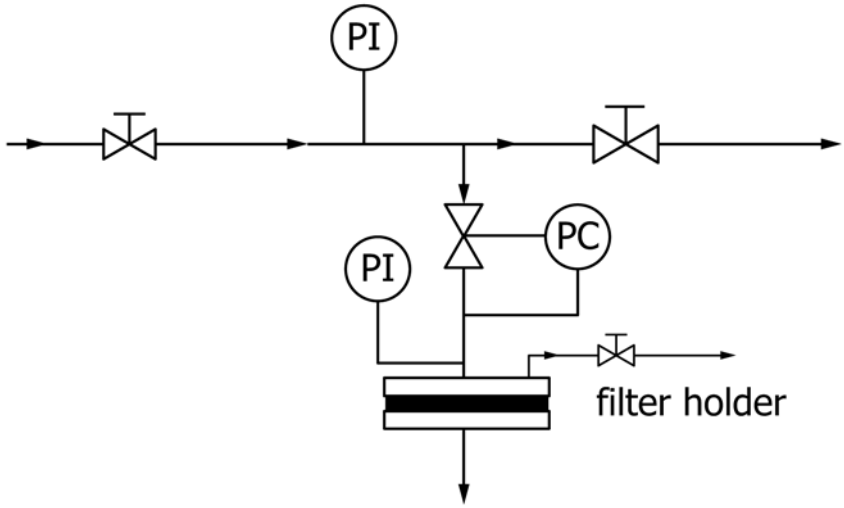
[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.



NOTE 1—PI is pressure indicator; PC is pressure controller.

FIG. 1 Apparatus for Measuring MFI at Constant Pressure with a Pump

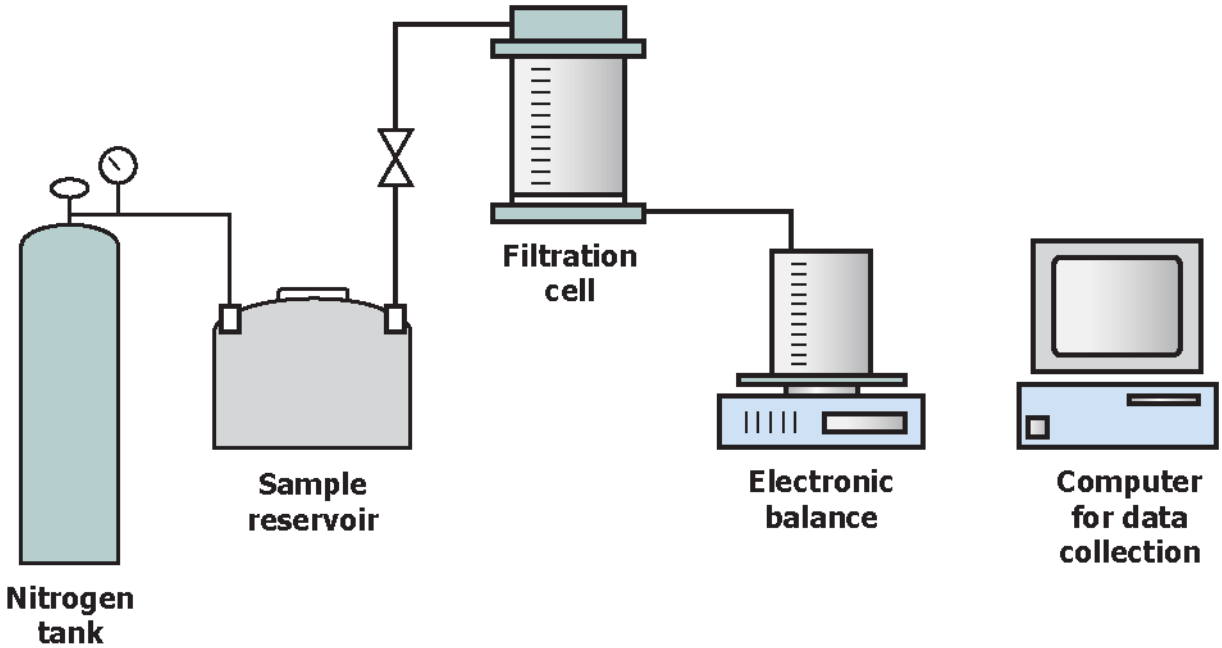


FIG. 2 Representative Apparatus for Measuring MFI at Constant Pressure with a Pressure Vessel

obtained from suppliers of membrane filters. The filter holder should be equipped with a device releasing air.

6.2 *Membrane Filter:*

6.2.1 *Membrane,* white hydrophilic, mixed cellulose nitrate (50–75 %) and mixed cellulose acetate (MCE).

6.2.2 *Replaceable Highly Porous Foam Support Pad,* to be placed on the bottom of the filter holder.

6.2.3 *Mean Pore Size,* 0.45 µm.

6.2.4 *Diameter,* 47 mm.

6.2.5 *Thickness,* 115 to 180 µm.

6.2.6 *Pure Water Flow,* 25 to 50 s/500 mL.

6.2.7 *Pressure Difference across Membrane Filter,* 200 kPa.

6.2.8 *Bubble Point,* 179 to 248 kPa.

6.2.9 Use only filters that are packaged in the same orientation.

6.3 *Thermometer or Sensor Suitable for Measuring Temperature of the Water Sample,* capable of being read or registered ±1°C.

6.4 Electronic flow meter or mass balance.

6.5 Computer or data-collecting and processing device.

7. Procedure

7.1 Assemble apparatus as shown in Fig. 1 and Fig. 2 including flow-measuring devices (electronic flow meter or mass balance) and set the pressure regulator at 200 kPa.

7.2 Before installing the membrane filter, flush the water to be tested through the apparatus to remove contaminants. For sampling, follow the procedure given in Practices D3370. Discrete samples can be used with appropriate pressurizing apparatus such as a pump or an air/nitrogen pressurized vessel.

NOTE 1—The pump should be of such a design that grinding flocs will not occur or be minimal.

NOTE 2—Ensure that the sample to be tested is not super saturated with air or nitrogen.

7.3 Measure the temperature of the water.

7.4 Open the membrane filter holder and place a 0.45-µm membrane filter (47 mm in diameter) on the support plate of the holder. A replaceable foam support pad needs to be placed on the support plate of the holder. Handle the membrane filter only with dull tweezers to avoid puncturing. Avoid touching the membrane filter with fingers.

NOTE 3—Record the manufacturer of the membrane filter and manufacturer's identification for the membrane filter.

7.5 Make sure the O-ring is in good condition and properly placed.

7.6 Replace the top of the half of the filter holder and close loosely.

7.7 Bleed out air by opening the pressure relieve valve and open the small air relieve valve on top of the filter holder.

NOTE 4—Apparatus making use of membranes of smaller diameters might use a disposable membrane incorporated in a filter holder. These disposables should be equipped with an air relieve device.

7.8 Close the relieve valve and start recording flow (and preferably pressure as well). Run the test for 30 to 60 min depending on the rate of flow decline.

NOTE 5—The initial flow should be within 10 % of the flow recorded with nonplugging reference water. This water can be obtained by filtering distilled water through a 0.2-µm pore size membrane filter.

NOTE 6—If the initial flow is more than 10 % higher than with reference water, the filter might be cracked and a new filter should be used.

NOTE 7—The pressure shall remain at 200 ± 2 kPa throughout the test.

NOTE 8—In many cases, especially when dealing with raw water, the fouling rate will plug the filters very quickly, for example, in a matter of a few minutes. A recommended time interval for data acquisition is a minimum of every 30 s.

7.9 After completing the test, the membrane filter may be retained for future reference.

8. Calculation

8.1 In this test, fouling of a flat-sheet membrane in dead-end filtration at a constant transmembrane pressure is considered to take place in three steps: (*1*) pore blocking, (*2*) formation of an incompressible gel/cake, and (*3*) gel compression or increasing rejection or both as a result of narrowing pores in gel.

8.2 During the gel filtration period, there exists a linear relation between resistance (here expressed as reciprocal flow rate at standard conditions) and cumulative filtered water volume (V), for which the slope (b) describes the fouling tendency of a given water (Eq 1 and Eq 2).

$$\frac{t}{V} = \frac{1}{Q_{avg}} = \frac{\eta R_m}{\Delta P A} + \frac{\eta I}{2\Delta P A^2} V \tag{1}$$

$$b = \frac{\eta \cdot I}{2 \cdot \Delta P \cdot A^2} = \frac{\frac{dt}{dV}}{dV} \tag{2}$$

where:

t = filtration time, s,
V = cumulative filtrate volume, L,
Q_{avg} = average flow rate, t/V,
η = water viscosity, Ns/m^2,
I = fouling index, l/m^2,
R_m = membrane resistance, l/m,
ΔP = applied transmembrane pressure, N/m^2, and
A = membrane surface area, m^2.

8.3 The gradient of the line (b) has been defined as the MFI, as an index of the fouling potential of a feed water containing particles for the fixed reference values of ΔP_0 (200 kPa), η ($\eta_{20°C}$), and A_0 (13.8×10^{-4} m^2 equivalent to 47-mm diameter membrane filter). The term, I, represents the fouling index for the propensity of particles in water to form a layer with hydraulic resistance:

$$\text{MFI} = \frac{\eta_{20°C} \cdot I}{2 \cdot \Delta P_0 \cdot A_0^2} \tag{3}$$

NOTE 9—MFI is expressed in units of s/L^2. By doing this, the results will be in the same order of magnitude of SDI in the range 2 to 3.

8.4 In conducting the MFI test, the MFI can be determined from the gradient (b, $\frac{\frac{dt}{dV}}{dV}$) of the linear region of minimum slope determined in (a plot of) t/V versus V. Normalizing this slope to standard conditions of temperature (T_{corr}), pressure (P_{corr}), and membrane area (A_{corr}) yields MFI as shown in Eq 4. The MFI can also be determined from a plot of gradient over time where gel filtration is observed as a minimum or stable MFI value depending on the length of cake filtration.

$$\text{MFI} = \left(\frac{\eta_{20°C}}{\eta_T}\right) \cdot \left(\frac{\Delta P}{\Delta P_0}\right) \cdot \left(\frac{A}{A_0}\right)^2 \cdot \frac{d\frac{t}{V}}{dV} = (T_{corr}) \cdot (P_{corr}) \cdot (A_{corr}) \cdot \frac{d\frac{t}{V}}{dV} \tag{4}$$

NOTE 10—An alternative method for calculating MFI is based on the basic equation:

$$\frac{dt}{dV} = \frac{1}{Q} = \frac{\eta R_m}{\Delta P A} + \frac{\eta I}{\Delta P A^2} V \tag{5}$$

The calculated slope is two times higher than in the standard procedure; consequently, in calculating MFI, this factor has to be taken into account. This approach has the advantage that possible errors in time and flow at the start of the test will not have an influence on the calculated slope in course of the test. However, a highly accurate pressure regulator and flow measurement device are needed to obtain desired highly accurate MFI values.

NOTE 11—The MFI was initially developed using 0.45 and 0.05-µm membrane referred to as MFI-0.45 and MFI-0.05. Later on, the MFI-UF method was developed at constant pressure.

9. Report

9.1 Report the following information:

9.1.1 The MFI, with a subscript indicating the total elapsed flow time (T) in minutes,

9.1.2 The water temperature before and after the test, and

9.1.3 The manufacturer of the 0.45-µm membrane filter used for the test as well the manufacturer's identification for the membrane filter.

10. Precision, Bias, and Quality Control

10.1 The MFI test outcome is not a concentration or equivalent concentration; although some basic items are useful and achievable in the MFI (0.45) test, this does not mean that full QC measures typically associated with laboratory analytical measurements will be sufficient for use with the MFI. The MFI gives the fouling potential of the sample for RO/NF membrane systems, and the use of a standard foulant is not useful since RO/NF membranes are not/never exposed to such a foulant. The fouling potential might change over time (for example, in a couple of hours). Consequently many laboratory-based statistical tests are not useful in practice. Usually a very limited numbers of samples are tested in a series.

10.2 The filtration curve plotted as t/V versus V and dt/dV versus V show usually a part that is linear suggesting that gel/cake filtration without compression occurs. However, testing at a different pressure shows a clear pressure dependency and still shows the linear relationships. Theory confirms this observation. Consequently, it is recommended not to deviate from the indicated transmembrane pressure of 200 kPa.

10.3 Substantial differences have been observed in MFI values between membranes of different manufacturers. The reasons for these observations are: differences in pore size, pore size distribution, surface porosity, shape of the pores, and membrane material. Far fewer differences have been observed between membranes of the same manufacturer and between different batches. Empirical correction/normalization can be achieved by determining the correlation between initial normalized permeability (flux) and MFI. This correcting factor is most likely specific for a certain type of membrane of a specific manufacturer and dependent on the type of water; as a consequence, the correction factor (if required) should be accomplished with natural water and locally.

NOTE 12—Typically, the higher the normalized permeability/clean water flux, the lower the MFI.

10.4 *Bias*—The bias of this test method cannot be determined because the test method is based upon waters of choice, which may differ with each source, as provided for in Practice D2777.

10.5 It is the user's responsibility to ensure the validity the test method for waters of untested matrices.

10.6 The accuracy and reproducibility depends further on the accuracy of the pressure regulators applied.

10.7 In practice, MFI measurements are not performed in duplicate; rather, the measurements are performed one or two times per shift or automatically with equipment.

10.8 Conducting a test with blank water is useful to verify whether or not the equipment releases particulate matter, for example, corrosion products, which may result in a higher MFI values. A test with pure water (for example, reverse osmosis permeate or distillate) at least during initial of equipment use and thereafter once a month is recommended. A test with artificially prepared seawater is useful if said application is for seawater purposes. In this case, pure water with sodium chloride of a concentration equivalent to the seawater to be tested can be used. Both blank test should give a MFI (0.45) value below 0.1 s/L^2.

10.9 In practice, the MFI test is a very basic, robust and stable test. Calibration and calibration verification will not be required as the equipment used for the MFI (0.45) test is simple and follows a basic procedure. The MFI target from membrane manufacturer lower or equal to 1 s/L^2 is equivalent to SDI target (lower or equal 3 % per min).

10.10 The quality (reproducibility, accuracy, correctness) of the obtained MFI values depend on several parameters (for example, pressure indicator, pressure controller, flowmeter or mass balance). In addition, the quality of the membrane filters used also impacts quality control; consequently, the pores size and pore size distribution are important. This aspect is more or less covered by the requirement for pure water flow namely 25–50 seconds per 500 ml. This is the same as for SDI (Test Method D4189). Should a calibration with a standard be required, 1 mg/L of formazinein deionized distilled water willproduce a MFI of 15 s/L^2. It gives a linear relation between MFI and Formazine concentration up to at least MFI 250 s/L^2. Formazine solutions are "standardized" by Guide D7726. Formazine is commercially available on the market. Solutions up 4000 NTU are available (1 NTU = 1 mg Formazine/L).

11. Keywords

11.1 fouling; membranes; modified fouling index; water