AHRI Guideline E
(formerly ARI Guideline E)

1997 GUIDELINE for

Fouling Factors: A Survey Of Their Application In Today's Air Conditioning And Refrigeration Industry

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IMPORTANT
SAFETY RECOMMENDATIONS

It is strongly recommended that the product be designed, constructed, assembled and installed in accordance with nationally recognized safety requirements appropriate for products covered by this guideline.

ARI, as a manufacturers' trade association, uses its best efforts to develop guidelines employing state-of-the-art and accepted industry practices. However, ARI does not certify or guarantee safety of any products, components or systems designed, tested, rated, installed or operated in accordance with these guidelines or that any tests conducted under its standards will be non-hazardous or free from risk.

Note:

This guideline supersedes ARI Guideline E-1988.

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FOULING FACTORS: A SURVEY OF THEIR APPLICATION IN TODAY'S AIR CONDITIONING AND REFRIGERATION INDUSTRY

Section 1. Purpose

1.1 *Purpose.* The purpose of this guideline is to consider the influence of fouling of heat transfer surfaces as it affects water-chilling evaporators and water-cooled condensers used in the air conditioning and refrigeration industry. Recently completed research work sponsored by ASHRAE (see B1.1 and B1.2) has shown that revisions to the fouling factors allowances for evaporators are justifiable and will be included in the latest revisions of ARI standards. This guideline also supports these revisions.**1.1.1** *Intent*. This guideline is intended for the guidance of the industry, including manufacturers, engineers, installers, contractors and users.

1.1.2 *Review and Amendment*. This guideline is subject to review and amendment as technology advances.

Section 2. Scope

2.1 *Scope.* This guideline pertains to fouling factor allowances as applied to centrifugal and rotary screw water chilling packages/positive displacement compressor water chilling packages as well as absorption water chilling and water heating packages, covered by ARI Standards 550/590 and 560 respectively.

2.1.1 *Exclusions*. This guideline does not apply to field fouling allowances as applied to water source heat pumps, covered by ARI Standards 320, 325, 330, 450 and 480.

Section 3. Definitions

3.1 *Definitions*. All terms in this document will follow the industry definitions established in the current ASHRAE *Terminology of Heating, Ventilation, Air-Conditioning and Refrigeration*, unless otherwise defined in this section.

3.2 *Fouling Factor*. The thermal resistance due to the accumulation of contaminants on the water-side of the heat transfer surface.

Section 4. Background

4.1 Water-cooled refrigerant condensers and water-chilling evaporators used in the air-conditioning and refrigeration industry are applied principally in field-installed water systems. These water systems may be closed- or open-loop systems. In general, they are subject to the accumulation of contaminants, termed "fouling," on the water-side of heat transfer surfaces. This fouling gradually increases thermal resistance and degrades overall performance of the equipment. It has been the practice in the industry to only allow for the accumulation of fouling on the water-side of the tubes. The refrigerant side does not see any fouling due to the cleanliness of the refrigerant system. The water can be on the inside or outside of the tubes depending on the design of the heat exchanger.

4.2 New heat exchangers are essentially free of water-side fouling. Fouling is understood to be progressive with time, and dependent on the quality and temperature of water used. Until recently there was very little published data predicting the rate of fouling for heat exchangers in typical air conditioning and refrigeration service. For many years, the basic reference has been the heat exchanger manual *Standards of the Tubular Exchangers Manufacturers Association*, which gives very general recommendations for a wide variety of cases. Perhaps based on this, the air conditioning industry has for decades commonly used an assumed fouling level of 0.0005 hr · ft^2°F/Btu [8.8 x 10^{-5} m^2 · °C/W] in both condensers and evaporators. In ARI Guideline E-1988, the assumed fouling allowance was reduced to 0.00025 or 2.5 x 10^{-4} hr · ft^2°F/Btu [4.4 x 10^{-5} m^2 · °C/W] based on available data at that time. Therefore in subsequent ARI standards, the level of fouling that was used in the selection of machines was 0.00025 or 2.5 x 10^{-4} hr · ft^2°F/Btu [4.4 x 10^{-5} m^2 · °C/W] for both the evaporator and the condenser.

Thus published Standard Ratings provided for increment of fouling in application (hereafter called "field fouling allowance") of 0.00025 or 2.5 x 10^{-4} hr · ft^2°F/Btu [4.4 x 10^{-5} m^2 · °C/W] above factory tested conditions. The equations used and a further explanation of the field fouling allowance is covered in Appendix C.

4.3 Water-side fouling of heat exchangers can have a significant impact on the performance of air-conditioning and refrigeration equipment. For example, a water-cooled water chilling refrigeration system operating fully loaded at temperature of 44°F [7°C] leaving chilled water, 95°F [35°C] leaving condenser water, and with clean tubes might have a saturated suction temperature of 42°F [6°C] and a saturated discharge temperature of 97°F [36 °C] (42/97°F) [6/36°C], resulting in operation at 0.60 kw/ton. If evaporator and condenser both acquire water-side fouling of 0.00025 or 2.5 x 10^{-4} hr · ft^2/Btu [4.4 x 10^{-5} m^2 · °C/W], operating conditions might be expected to move to 41/98°F [5/37°C] resulting in 0.65 kw/ton; thus increasing operating costs by 8%. The impact could be greater or less than this, depending on the type and amount of tube surface used in condenser and evaporator.

Section 5. Current Status

Several events have occurred in recent years to change the way the industry deals with fouling, as noted in the following paragraphs:

5.1 The air conditioning industry has been under pressure to improve unit efficiency and has responded with significant improvements. This has been done through improved compressors and improved heat exchangers to reduce the approach temperatures within heat exchangers. Where heat exchangers used to have 5° to 6°F [2.7° to 3.3°C] leaving temperature differences, many applications now have and 2°F [1.1°C] leaving temperature differences. With these small leaving temperature differences the field fouling allowance of 0.00025 or 2.5 x 10^{-4} hr · ft^2°F/Btu [4.4 x 10^{-5} m^2 · °C/W] is now more of the total heat transfer resistance than it was when designs were based on 5°F and 6°F [2.7°C and 3.3°C] leaving temperature differences. Due to this, the use of a field fouling allowance of 0.00025 or 2.5 x 10^{-4} hr · ft^2°F/Btu [4.4 x 10^{-5} m^2 · °C/W] can in some cases result in the selection of different equipment than if the field fouling allowance were lower. This will then result in equipment that may not be as efficient when operating with clean tubes.

5.2 As a result of a lack of fundamental data to justify the use of a field fouling allowance of 0.00025 or 2.5 x 10^{-4} hr · ft^2°F/Btu [4.4 x 10^{-5} m^2 · °C/W], a research project was undertaken by ASHRAE to evaluate water quality and its effects on fouling and to experimentally study the tube-side fouling resistance in water chiller flooded evaporators. The details of these studies are summarized in ASHRAE papers listed in Appendix B.

5.3 In the work associated with reference B1.2, several experimental tests were run with various combinations of clean water, dirty water, different tube types, and 3 ft/sec. [0.9 m/s] and 7 ft/sec. [2.1 m/s] water velocities. The results indicated that even in the worst case, the level of fouling after extended operation was less than 11.6% of the standard practice of using 0.00025 or 2.5 x 10^{-4} hr · ft^2°F/Btu [4.4 x 10^{-5} m^2 · °C/W]. This result indicates that for evaporators, the 0.00025 or 2.5 x 10^{-4} hr · ft^2°F/Btu [4.4 x 10^{-5} m^2 · °C/W] is overly conservative and is counter to the efforts to improve operating efficiency of chillers. From these results, a field fouling allowance of 0.0001 or 1.0 x 10^{-4} hr · ft^2°F/Btu [1.8 x 10^{-5} m^2 · °C/W] appears to be more appropriate for evaporators and is the recommendation of this guideline. This does not apply to condensers, as experimental data for condensers has not been developed. It is expected that the condenser would most likely have a higher fouling due to the higher temperatures of the water and the formation of biological fouling. Note that research has shown that temperature can be a strong contributor to the rate of fouling and condenser water is much warmer than evaporator water. Also cooling towers tend to have more contaminants in the water due to the loss of water due to evaporation in the tower.

5.4 ASHRAE is planning to continue fouling research on condensers, but results are now conclusive that a fouling allowance for evaporators of 0.00025 or 2.5 x 10^{-4} hr · ft^2°F/Btu [4.4 x 10^{-5} m^2 · °C/W] is overly conservative and should be reduced to the 0.0001 or 1.0 x 10^{-4} hr · ft^2°F/Btu [1.8 x 10^{-5} m^2 · °C/W] .

Section 6. Implementation

6.1 In response to the above mentioned developments, ARI began an effort to reconcile the treatment of fouling in its product standards with current knowledge and methods. By so doing, it was anticipated that old unsupported practices would be dropped and the new evaporator field fouling allowances adopted. This effort will allow for the continued improvement and optimization of air-conditioning and refrigeration equipment and the reduction in energy operating costs through proper selection of equipment.

Section 7. Conclusions

7.1 The air-conditioning and refrigeration industry will adopt the new evaporator field fouling allowance of 0.0001 or 1.0 x 10^{-4} hr · ft^2°F/Btu [1.8 x 10^{-5} m^2 · °C/W] under the assumption that closed-loop systems are used. If other systems are used then different field fouling allowances may be required.

7.2 Until further research is completed on condensers, the industry will continue to use the previous field fouling allowance of 0.00025 or 2.5×10^{-4} hr · ft^2 F/Btu [4.4×10^{-5} m^2 · °C/W].

7.3 The air conditioning and refrigeration industry should support additional ASHRAE research on fouling of condensers, leading to further improvements to the field fouling allowance.

7.4 Manufacturers, in adjusting from "as tested" performance to predicted field fouling performance, should use the calculation methods outlined in ARI Standards 450 and 480. This assumes that all factory tests will have clean tubes with no fouling.

APPENDIX A. REFERENCES - NORMATIVE

None.

APPENDIX B. REFERENCES - INFORMATIVE

B1 Listed here are standards, handbooks, and other publications which may provide useful information and background but are not considered essential. All references in this appendix are not considered as part of this guideline.

B1.1 *A Survey of Water Quality And Its Effect On Fouling In Flooded Water Chiller Evaporators* by S.I. Haider, R.L. Webb, A.K. Meitz, American Society of Heating, Refrigerating and Air-Conditioning Engineers, 1791 Tullie Circle, N.E., Atlanta, GA 30329, U.S.A.

B1.2 *An Experimental Study of Tube-Side Fouling Resistance in Water-Chilled Flooded Evaporators* by S.I. Haider, R.L. Webb, A.K. Meitz, American Society of Heating, Refrigerating and Air-Conditioning Engineers, 1791 Tullie Circle, N.E., Atlanta, GA 30329, U.S.A.

B1.3 AHRI Standard 450-93 (formerly ARI Standard 450-93), *Water-Cooled Refrigerant Condensers, Remote Type*, 1993, Air-Conditioning, Heating, and Refrigeration Institute, 2111 Wilson Boulevard, Suite 500, Arlington, VA 22201, U.S.A.

B1.4 AHRI Standard 480-95 (formerly ARI Standard 480-95), *Refrigerant-Cooled Liquid Coolers, Remote Type*, 1995, Air-Conditioning, Heating, and Refrigeration Institute, 2111 Wilson Boulevard, Suite 500, Arlington, VA 22201, U.S.A.

B1.5 AHRI Standard 550/590-97 (formerly ARI Standard 550/590-97), *Water Chilling Packages Using the Vapor Compression Cycle*, 1997, Air-Conditioning, Heating, and Refrigeration Institute, 2111 Wilson Boulevard, Suite 500, Arlington, VA 22201, U.S.A.

B1.6 AHRI Standard 560-92 (formerly ARI Standard 560-92), *Absorption Water Chilling and Water Heating Packages*, 1992, Air-Conditioning, Heating, and Refrigeration Institute, 2111 Wilson Boulevard, Suite 500, Arlington, VA 22201, U.S.A.

B1.7 AHRI Guideline E-1988 (formerly ARI Guideline E-1988), *Fouling Factors: A Survey Of Their Application In Today's Air-Conditioning And Refrigeration Industry*, 1988, Air-Conditioning, Heating, and Refrigeration Institute, 2111 Wilson Boulevard, Suite 500, Arlington, VA 22201, U.S.A.

B1.8 *Standards of the Tubular Exchangers Manufacturers Association*, Tubular Exchanger Manufacturers Association, 25 North Broadway, Tarrytown, NY 10591, U.S.A.

APPENDIX C. FIELD FOULING ALLOWANCE CALCULATION

C.1 *Rating Basis*.

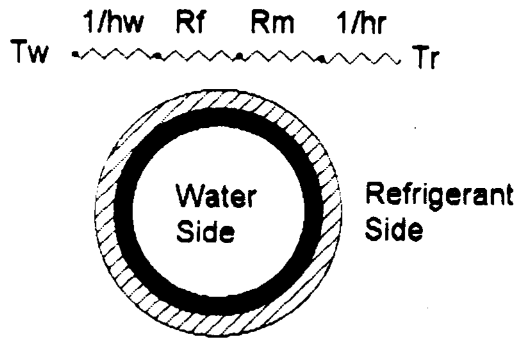
$Q = U_o A_o$ LMTD
$U_o = 1/R_o$

where:

Q = Heat transfer rate
A_o = Surface area outside, ft^2 [m^2]
LMTD = Log mean temperature difference
U_o = Overall heat transfer coefficient based on outside area
Tw = Temperature of water, °F [°C]
Tr = Temperature of refrigerant, °F [°C]
R_o = Overall thermal resistance, hr·ft^2°F/Btu [m^2 · °C/W]
Rf = Field fouling allowance, hr·ft^2°F/Btu [cm^2 · °C/W]
Rm = Tube metal resistance, hr·ft^2°F/Btu [cm^2 · °C/W]
hw = Water-side heat transfer coefficient
hr = Refrigerant heat transfer coefficient

R_o = 1/hw + Rf + Rm + 1/hrz

	Condensers	Evaporators
ARI Guideline E-1988	0.00025 or 2.5 x 10^{-4} hr·ft^2°F/Btu [4.4 x 10^{-5} m^2 · °C/W]	0.00025 or 2.5 x 10^{-4} hr·ft^2°F/Btu [4.4 x 10^{-5} m^2 · °C/W]
ARI Guideline E-1997	0.00025 or 2.5 x 10^{-4} hr·ft^2°F/Btu [4.4 x 10^{-5} m^2 · °C/W]	0.0001 or 1.0 x 10^{-4} hr·ft^2°F/Btu [1.8 x 10^{-5} m^2 · °C/W]
Note: All test fouling resistances are assumed to be clean.		


1/hw
Rf
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