



## **5.7. Fouling**

The contamination of a surface (fouling) on which a liquid is boiling can produce unexpected results. For instance, on smooth surfaces having few nucleation sites the initial surface contamination can increase the number of nucleation sites and increase the boiling coefficient sufficiently to overcome the thermal resistance of the fouling layer. However, this effect is dependent upon a number of special conditions and exists only during the initial stages of fouling. Later as the fouling layer builds up, its thermal resistance will reduce the overall coefficient and heat flux.

The strong dependence of the nucleate boiling coefficient on the film temperature difference can magnify the influence of a fouling coefficient when the overall temperature difference is fixed. This effect is the same regardless of the source of the increased resistance, be it fouling, change in tube wall coefficient due to change in thickness or thermal conductivity, or changes in the heating medium coefficient. However, at constant flux the increase in overall temperature difference due to an increased resistance is the normal expected value of just an additional  $\Delta T$  of the fouling layer.

At a constant overall temperature difference any change in fouling, wall, or heating medium resistances will change the temperature distribution and result in a change in the boiling coefficient. Usually a trial and error calculation is required; however, in Figure 5.33 we have a generalized graphical solution. Here equation 5.8 is rearranged to

$$q = [A^* F(P)]^{3.33} \Delta T^{3.33} = B \Delta T^{3.33} \quad (5.62)$$

In Figure 5.33 we plot  $q/B$  versus  $\Delta T$  with curves of  $R_o B$  as parameters where  $R_o$  is the total of all resistances other than the boiling resistance. The curve  $R_o B = 0$  represents the boiling curve. The following examples illustrate the use of this figure. For the examples we will use  $B = 2$  and  $\Delta T = 15$ .

(a) If there are no other resistances then  $R_o B = 0$  and the flux is  $q = 8250 \times 2 = 16,500$  and  $h_b = 1100$ .

(b) If a resistance of 0.001 were added then  $R_o B = 0.001 \times 2 = 0.002$  and at  $\Delta T = 15$ ,  $q = 2250 \times 2 = 4500$ . At this flux,  $q/B = 2250$ , we find from curve  $R_o B = 0$  that the boiling film  $\Delta T$  is 10 thus the boiling coefficient,  $h_b$ , was reduced to 450. To have maintained the same flux as in (a), that is  $q/B = 8250$ , we find from curve  $R_o B = 0.002$  that the temperature difference would have to be 31.5.

(c) Suppose the resistance of 0.001 in (b) represented the wall and heating medium resistances in the clean condition. Now suppose an additional resistance of 0.001 was added due to fouling, change of tube material, or a different heating medium coefficient. Now  $R_o B = (0.001 + 0.001) \times 2 = 0.004$ . From the figure at  $\Delta T = 15$  we find the flux would now be  $q = 1500 \times 2 = 3000$  and that the boiling film  $\Delta T = 9$  (from  $R_o B = 0$  curve).

Fouling coefficients as currently used are vague and unreliable. The purpose of a fouling coefficient is to permit operation of the equipment for a reasonable length of time before shutting down and cleaning. However, the time interval associated with a fouling coefficient is unspecified and the term reasonable depends upon circumstances. For instance, in crystallizing evaporators a shut down once a shift or once a day for washing out the evaporators is reasonable but in a reboiler where polymerization fouls the tubes and requires a physical cleaning such cycles are unreasonable while a several month cleaning cycle should include evaluating the costs of cleaning, lost production, and cost of exchanger surface to determine the optimum cycle. Unfortunately present knowledge of fouling is insufficient to permit a



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prediction of fouling rates and even a basic understanding of the effect of velocity, temperatures, or compositions on fouling rates is lacking. For additional information see references (63) through (67).

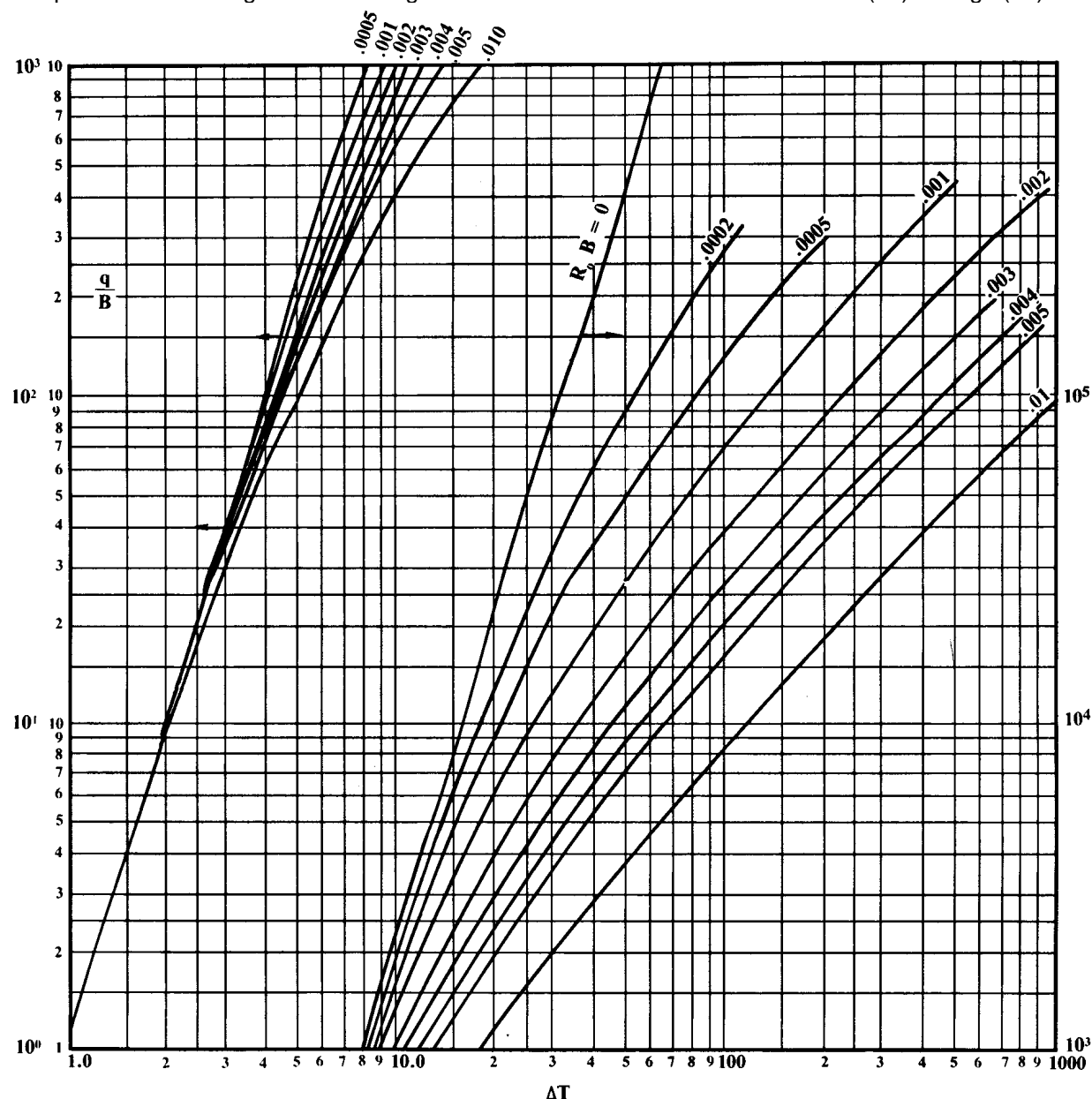


Fig. 5.33 Effect of other resistances on the nucleate boiling curve.

Fouling under boiling conditions could be different than fouling under convective heat transfer and depends upon the type of boiling. For instance, in the early transition and film boiling regimes, B-C portion of the boiling curve in Figure 5. 1, fouling can be very rapid due to the alternate wetting and drying of the surface. There is little published data on fouling in vaporizers and most values lack documentation as to



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the operating conditions and cycle time. However, the following values can be used as a guide to making a guess of the values to use in your designs.

## Boiling Side

Cl-C8 normal hydrocarbons	0 - 0.001 °F ft <sup>2</sup> hr/Btu
Heavier normal hydrocarbons	0.001-0.003
Diolefins and polymerizing hydrocarbons	0.003-0.005

## Heating Side

Condensing steam	0-0.0005
Condensing organics	0.0005-0.001
Sensible heating, organic liquids	0.0005-0.002

Also the TEMA standards (68) can be consulted for further values.

Excessive conservatism for fouling allowances may result in oversizing the reboiler such that under clean or initial operation problems may arise in control of the boil up, problems in condensate removal because of low pressure, economic penalties for unnecessary surface, the possibility that reduced circulation may permit more rapid fouling, and for a fixed  $\Delta T$  that the film boiling region might be reached.

Therefore, it is best to make realistic estimates of the fouling avoiding over-conservatism and to evaluate the performance of the reboiler under the full range of operating conditions (from reduced production when clean to full production when fouled).

Fouling rates are affected by the type of boiling surface. For instance, low-finned tubes have performed well in fouling conditions (69, 70). These articles report instances where the substitution of low-finned tubes for plain tubes resulted in lower rates of fouling and reduced cleaning times.