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ANALYSIS OF BOILING ON A FIN

by Y. Y. Hsu

Lewis Research Center

Cleveland, Ohio

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ABSTRACT

A simplified method of calculation is proposed to determine the performance of a fin exposed to various modes of boiling. The heat-transfer coefficients of boiling were approximated by segments of simple n^{th} power functions of superheat. These functions provide the analytical solution of the temperature gradient in the fin as a function of temperature. Results compare favorably with those obtained from a small-increment numerical solution. Three examples are given to illustrate the application of fin concept to boiling heat-transfer processes.

ANALYSIS OF BOILING ON A FIN

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SUMMARY

The heat-transfer process with boiling on a fin cannot be treated in the conventional manner of assuming a constant heat-transfer coefficient. This report proposes a simplified method for determining fin performance. The heat-transfer coefficients in various boiling regions are approximated by various n^{th} power functions of superheat. The results yield the temperature gradient as a function of temperature surplus, fin width, and thermal conductivity of the fin. Computed results for boiling freon and isopropanol on a fin compare favorably with those obtained from a small-increment numerical solution.

Three examples are given to illustrate the application of the fin concept to boiling heat-transfer processes. One case shows that the cladding of a nuclear fuel rod with a spline-shaped jacket would provide a much wider operating range of temperature before the onset of burnout. In the second case, the spiral insert in a boiler channel is treated as a fin for determining the proper geometry to eliminate the nonboiling region in the central section. The third case estimates the end loss of a heating tube, the end of which was considered as a fin.

INTRODUCTION

In the conventional treatment of fin problems, the heat-transfer coefficient is usually assumed constant. Such an assumption might be legitimate for single-phase convection, but it may cause significant error when the fin is being cooled by a boiling two-phase flow in which the heat-transfer coefficient is strongly dependent on the local temperature surplus (difference of wall temperature and liquid bulk temperature).

In the literature, numerous papers have been published that treat the problems of a fin with the heat-transfer coefficient as a function of distance from the tip (or base). An excellent review is given in reference 1. However, for boiling on a fin, the heat-transfer coefficient is a function of temperature instead of location and thus presents a new class of problems, to which only a few studies have been devoted. Haley and Westwater (ref. 1) present experimental results of boiling on fins, together with an analysis based on numerical solutions. Boiling on a fin has also been studied by Cumo, et al. (ref. 2), who use a relaxation method to obtain numerical solutions. Reference 3 provided a small amount of experimental information about incipience of boiling on a fin and also proposes equations to determine the temperature profile when the fin is partially cooled by nucleate and transition boiling. In the analysis of reference 3, the boiling curve was represented by segments of simple power functions, which made possible the expression of the heat-transfer performances of a fin in closed-form equations. This approach enables a quick assessment of fin performance. On the other hand, reference 1 used a more exact but tedious small-increment numerical method. The analytical results of reference 3 compare favorably with those computed in reference 1. The practical application of the fin concept was reported in reference 4 in which fins (called Vapotrons) were used to avoid the burnout condition of fuel rods.

The purpose of this report is to extend the method proposed in reference 3, which was mainly for nucleate boiling, to the cases where all the boiling modes - film boiling, transition boiling, and nucleate boiling - and convection coexist on the same fin. Thus, the method is extended to a more general situation with a broader temperature range, and part of these results compared with those obtained by Haley and Westwater (ref. 1). For the present study, only isolated straight fins (i.e., cylindrical or rectangular fins of constant cross section) are considered. For illustration, examples of the practical application of the proposed method to boiling on a fin are cited.

SYMBOLS

a	parameter used in Gaussian curve (eq. (12))
b	half-width or half-radius of fin
c	constant
h	heat-transfer coefficient
k	thermal conductivity
L	length of fin
m	$\sqrt{h/kb}$
n	index parameter in eq. (2)
q	heat flux
T	temperature

x coordinate in fig. 3, distance from fin tip

η fin effectiveness

θ temperature surplus of fin surface above bulk temperature

θ' temperature gradient, $d\theta/dx$

Subscripts:

b base

j j^{th} section

sat saturation

wall wall

* reference

1 tip of fin

ANALYSIS

Postulation of Model

The following assumptions are commonly used for the analysis of heat transfer from a straight fin and are applicable herein:

(1) The fin is so thin that only one-dimensional heat conduction is involved. (Note that this assumption may be the most vulnerable one since, under boiling conditions, the temperature gradient in the transverse direction may not be negligible.)

(2) The physical properties of the fin are constant.

(3) The tip of the fin is cooled by fluid with a constant heat-transfer coefficient. In the special case (where either h or the tip area is small), the end loss can be assumed negligible.

(4) The hydrodynamic effect due to the presence of the fin is negligible.

(5) The base temperature of the fin is assumed to be constant.

Additional assumptions particularly germane to this study are:

(6) The fin is cooled by various modes of heat transfer. The local heat-transfer coefficients are assumed to be the same function of the local temperature surplus θ as would be expected from a heater of uniform temperature. For example, for the case of pool boiling, the boiling curve (heat-transfer coefficient h against temperature differential θ) obtained from a pool-boiling experiment applies. This assumption was used in reference 1 and found to be valid.

(7) The boiling curve of $h(\theta)$ is approximated by segments of curves in the form of $h \propto (\theta)^n$. The boiling curve for a log-log plot of h against θ is thus approximated by segments of straight lines with n-values equal to the slope of each line. For example, the boiling curves for isopropanol and freon are shown in figures 1 and 2, and the curve-fitting parameters are given in table I. These curves are obtained from reference 1.

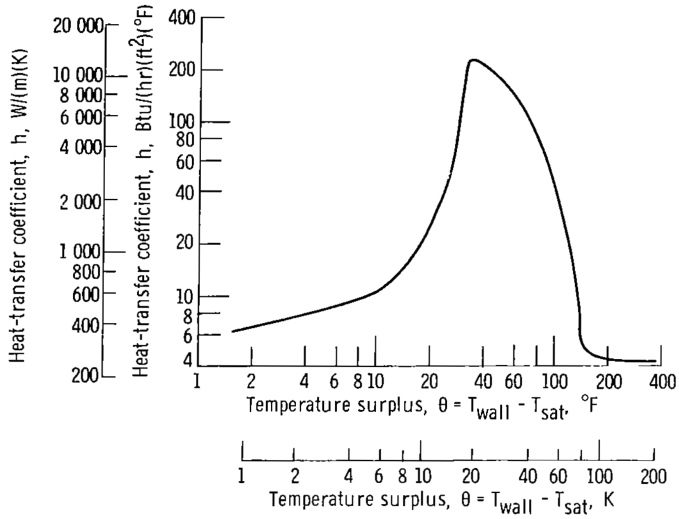


Figure 1. - Boiling curve of isopropanol (from ref. 1).

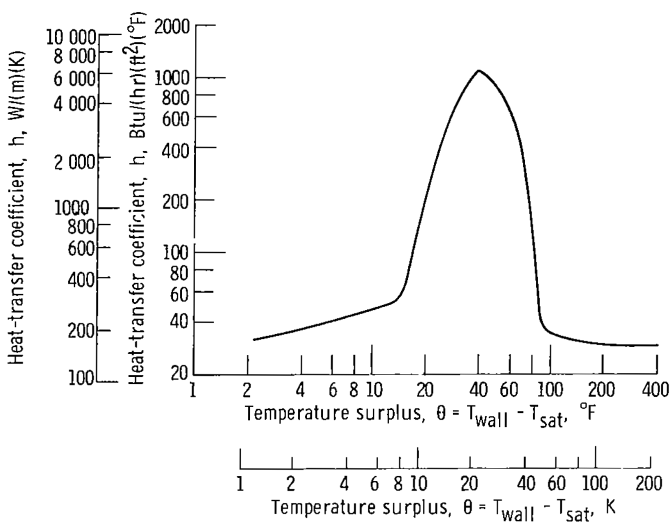


Figure 2. - Boiling curve of freon (from ref. 1).

(8) A fin is postulated as consisting of several sections joined in series. Each section is cooled by one mode of boiling that corresponds to one segment of the boiling curve; that is, for each section, the heat-transfer coefficient can be expressed as proportional

TABLE I. - PARAMETERS FOR APPROXIMATION

Temperature range of each segment				Heat-transfer coefficient at j^{th} section, h_j		Index parameter in eq. (2), n_j
Temperature surplus at joint j, θ_j		Temperature surplus at joint j + 1, θ_{j+1}		Btu/(hr)(ft^2)($^{\circ}$F)	W/(m^2)(K)	
$^{\circ}$F	K	$^{\circ}$F	K			
Isopropanol						
25	13.9	35	19.4	300	1 700	5
35	19.4	100	55.6	3000	17 000	-1.75
100	55.6	150	83.3	500	2 840	-6
150	83.3	1000	555.6	44	250	0
Freon						
15	8.33	25	13.9	60	340	4.1
25	13.9	42	23.3	500	2 840	1.8
42	23.3	70	38.9	1250	7 100	-2.22
70	38.9	105	58.3	352	2 000	-6.6
105	58.3	1000	555.6	30	170	0

to the temperature surplus θ raised to a unique power n. For the continuity of temperature and heat flux, the temperature and temperature gradient in two adjoining sections are required to match at the junction. The model is shown in figure 3.

Basic Equations

The basic equation for one-dimensional heat conduction in a fin is

$$\frac{d^2\theta}{dx^2} = \frac{h(\theta)}{kb}\theta \tag{1}$$

where b is the half-width for a rectangular straight fin or is the half-radius for a cylindrical fin, x is the distance from the tip, and θ is the temperature surplus.

For the j^{th} section of the fin, the value of the heat-transfer coefficient is expressed as

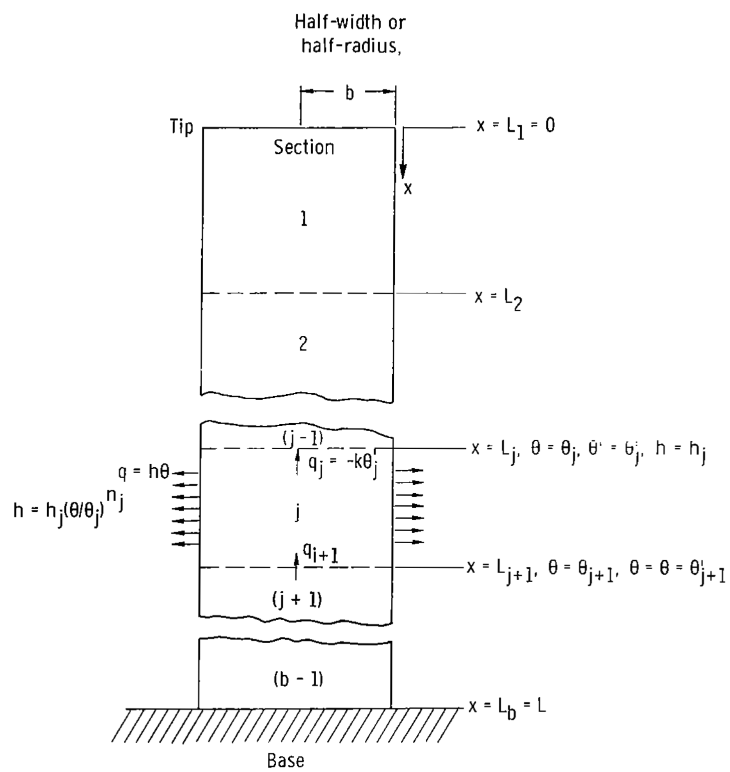


Figure 3. - Model for fin cooled by boiling

$$h = h_j \left(\frac{\theta}{\theta_j}\right)^{n_j} \qquad j = 1, 2, 3, \ldots b \tag{2}$$

where h_j is the heat-transfer coefficient at θ_j, which is the temperature at the junction between the j^{th} and $(j+1)^{th}$ sections.

The boundary conditions are

$$\theta = \theta_j \qquad \text{at } x = L_j \tag{3}$$

$$\theta' = \theta'_j \qquad \text{at } x = L_j \tag{4}$$

with the special boundary condition

$$\theta' = \theta'_1 = 0 \qquad \text{at } x = 0 \tag{5}$$

for the assumption that no heat is transferred from the tip end of the fin. (Note that this restriction is not alsays necessary and can be replaced by $\theta_1' = c$ at $x = 0$ if the end effect is not negligible.)

The combination of equations (1) and (2) results in

$$\frac{d^2\theta}{dx^2} = m_j^2 \frac{1}{\theta_j^{n_j}} (\theta)^{n_j+1} \tag{6}$$

where

$$\frac{h_j}{kb} = m_j^2$$

Multiplying both sides of equation (6) by $2(d\theta/dx)$ yields

$$2 \frac{d\theta}{dx} \frac{d^2\theta}{dx^2} = \frac{2m_j^2}{\theta_j^{n_j}} \theta^{n_j+1} \frac{d\theta}{dx}$$

or

$$\frac{d}{dx} (\theta'^2) = \frac{2}{n_j + 2} \frac{m_j^2}{\theta_j^{n_j}} \left(\frac{d\theta^{n_j+2}}{dx}\right) \tag{7}$$

Integrating equation (7) from $x = L_j$, $\theta = \theta_j$, and $\theta' = \theta_j'$ to x, θ, and θ' results in

$$\theta'^2 - \theta_j'^2 = \frac{2m_j^2}{n_j + 2} \frac{1}{\theta_j^{n_j}} \left(\theta^{n_j+2} - \theta_j^{n_j+2}\right) = \frac{2m_j^2\theta_j^2}{n_j + 2} \left[\left(\frac{\theta}{\theta_j}\right)^{n_j+2} - 1\right] \tag{8}$$

$$\theta' = \left\{\frac{2}{n_j + 2} m_j^2\theta_j^2 \left[\left(\frac{\theta}{\theta_j}\right)^{n_j+2} - 1\right] + \theta_j'^2\right\}^{1/2} \tag{9a}$$

which is the same as equation (6) of reference 3. Equation (9a), can also be written as a series of equations. For example, the temperature gradient at, for example, the fourth intersection would be

$$\theta_4' = \left\{ \frac{2}{n_3 + 2} (m_3\theta_3)^2 \left[\left(\frac{\theta_4}{\theta_3} \right)^{n_3+2} - 1 \right] + \theta_3'^2 \right\}^{1/2}$$

with

$$\theta_3' = \left\{ \frac{2}{n_2 + 2} (m_2\theta_2)^2 \left[\left(\frac{\theta_3}{\theta_2} \right)^{n_2+2} - 1 \right] + \theta_2'^2 \right\}^{1/2}$$

with

$$\theta_2' = \left\{ \frac{2}{n_1 + 2} (m_1\theta_1)^2 \left[\left(\frac{\theta_2}{\theta_1} \right)^{n_1+2} - 1 \right] + 0 \right\}^{1/2} \tag{9b}$$

Therefore, the temperature gradient (and heat flux) at the base of the fin can easily be determined once the base temperature surplus θ_b and the tip temperature surplus θ_1 are specified.

The length of the fin required for a given set of tip and base temperatures can be determined as

$$L_b = \int_{\theta_1}^{\theta_b} \frac{d\theta}{\theta'} = \int_{\theta_1}^{\theta_b} \frac{d\theta}{\left\{ \frac{2}{n_j + 2} (m_j\theta_j)^2 \left[\left(\frac{\theta}{\theta_j} \right)^{n_j+2} - 1 \right] + \theta_j'^2 \right\}^{1/2}} \tag{10}$$

The integration in equation (10) can be performed either numerically or graphically.

If the fin length L_b and base temperature θ_b are given and the base heat flux is unknown, then a short trial-and-error iteration is necessary to determine the tip temperature that would give the right fin length from equation (10).

In some cases, the boiling curve can be fitted by segments of a Gaussian curve in the form of

$$h = h_* \, e^{-a(\theta-\theta_*)^2} \tag{11}$$

Where h_* is the heat-transfer coefficient at the reference temperature θ_*, and a is a curve-fitting parameter. Combination of equations (1) and (11) results in

$$\frac{d^2\theta}{dx^2} = \frac{h_*}{kb} \, e^{-a(\theta-\theta_*)^2} \, \theta \tag{12}$$

Multiplying equation (12) by $d\theta/dx$ and solving the resulting differential equation with the same boundary conditions given by equations (3) to (5) yield

$$\frac{d\theta}{dx} = \left\{\frac{h_*}{akb}\left[-e^{-a(\theta-\theta_*)^2} + e^{-a(\theta_j-\theta_*)^2}\right]\right.$$

$$\left. + \frac{h_*}{kb}\,\theta_*\sqrt{\frac{\pi}{a}}\left(\mathrm{erf}\left[\sqrt{a}\,(\theta - \theta_*)\right] - \mathrm{erf}\left[\sqrt{a}\,(\theta_j - \theta_*)\right]\right) + \left(\frac{d\theta}{dx_j}\right)^2\right\}^{1/2} \tag{13}$$

The length of the fin is determined by

$$L_{j+1} - L_j = \int_{\theta_j}^{\theta_{j+1}} \frac{d\theta}{\left(\frac{d\theta}{dx}\right)} \tag{14}$$

RESULTS AND DISCUSSION

Equations (9a) and (10) should be checked against existing data to test the proposed method. In reference 1, both experimental data and analytical results based on a numerical computation were presented for isopropanol and freon (trichloro-trifloro-ethane) on copper rods 1/8-inch in radius. These results were presented in the form of the temperature gradient at the fin base as a function of the base temperature surplus with the fin length as a parameter (ref. 1). Corresponding results are calculated herein by use of the present method. The parameters used in the simple power-function approximation for the boiling curves of isopropanol and freon, as shown in figures 1 and 2, are given in table I. Other pertinent parameters used for copper are b = 1/16 inch (0.159 cm) and k = 220 Btu per hour per foot per $^{\circ}$F (381 W/(m)(K)). The bulk of the fluid was assumed to be at the saturation temperature, which made the temperature surplus equal to the superheat. Equation (9a) gives the relation between the temperature gradient and the base temperature for given tip and base temperatures, as shown in figure 4. The corresponding fin length for a given set of tip and base temperature can be calculated from equation (10). Typical curves are shown in figure 5. Note that in both figures 4 and 5 the modes of boiling at the base are also indicated. A comparison of the present method with that of reference 1 was made possible by presenting the results from equation (9a) (θ_b' as function of θ_b and θ_1) and equation (10) (L_b as function of θ_b and θ_1) in the form of the temperature gradient as a function of the base temperature with the fin length as a parameter $\theta_b'(\theta_b, L)$. The conversion scheme for this comparison follows:

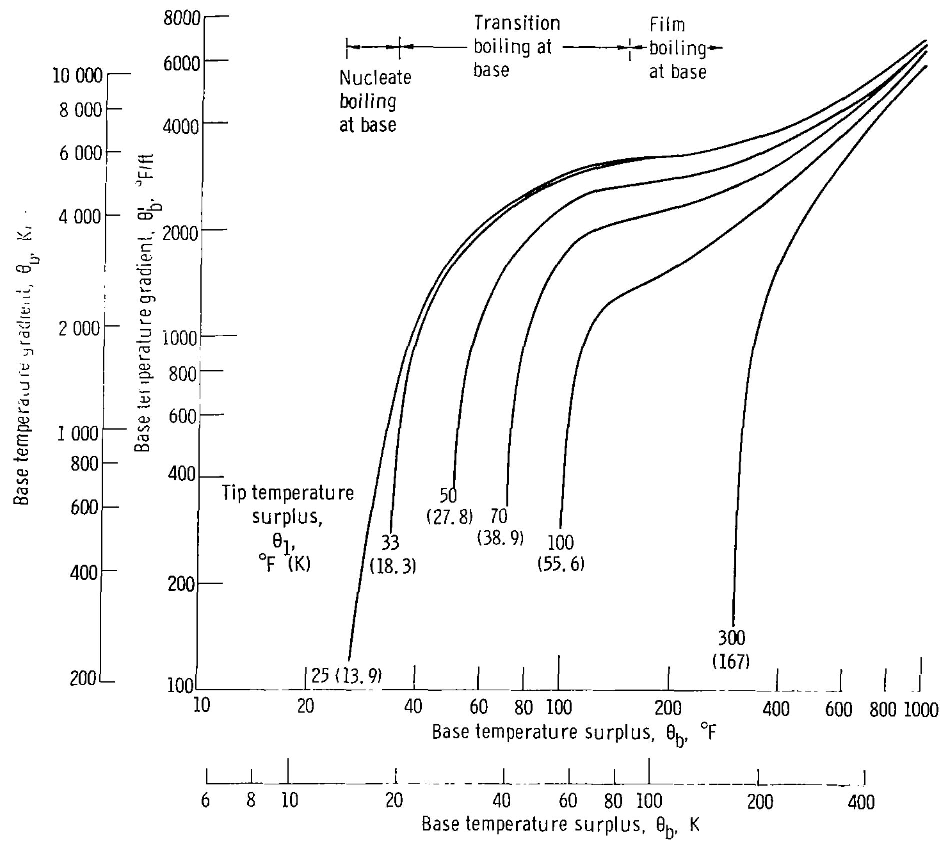


Figure 4. - Typical curves for dependence of base temperature gradient on base temperature surplus with tip temperature surplus as parameter and isopropanol as fluid.

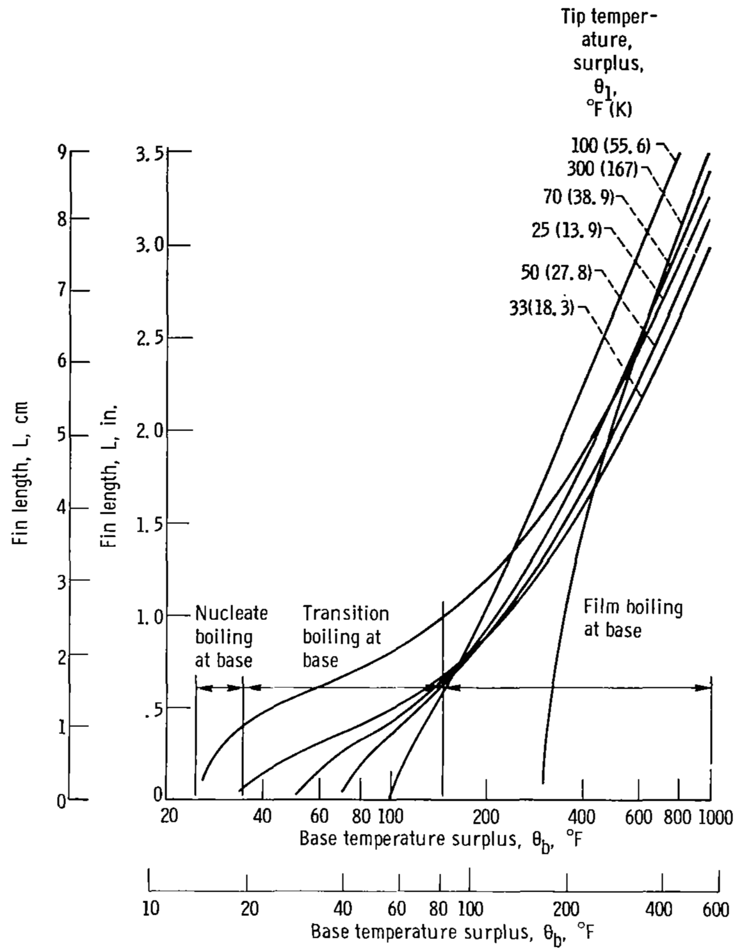


Figure 5. - Typical curves of fin length as function of base temperature surplus with tip temperature surplus as parameter and isopropanol as fluid.

(1) The base temperature surplus for various tip temperatures was read for a given length from curves similar to those in figure 5.

(2) For the same group of base temperature surpluses, the corresponding base temperature gradients for the respective tip temperatures were read from curves similar to those in figure 4.

(3) These corresponding pairs of base temperature gradients and base temperature surpluses all belong to one given length parameter.

The whole conversion operation is equivalent to eliminating the tip temperature θ_1 between equations (9a) and (10) to give a function $\theta_b'(\theta_b, L)$. The plot thus constructed is the same as that of reference 1. The plots for isopropanol and freon are shown in figures 6 and 7, respectively. In these two figures, the solid lines calculated from equations (9a) and (10) are compared with the dashed curve obtained in reference 1 by use

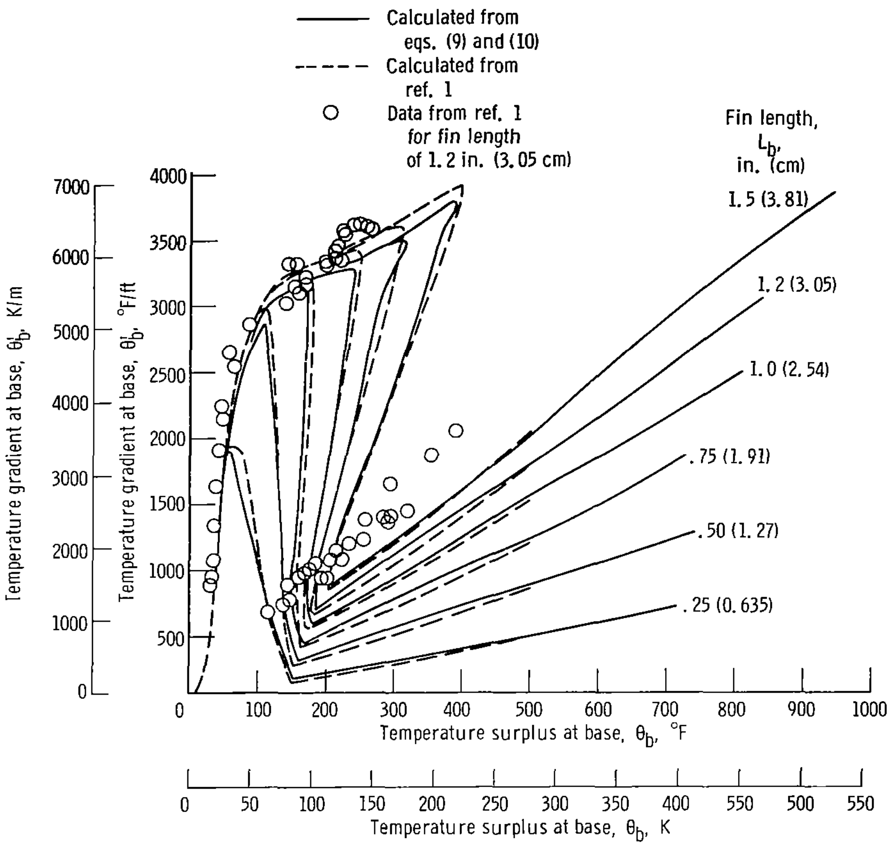


Figure 6. - Temperature gradient at base as function of base temperature surplus for various fin lengths. Isopropanol used as fluid.

of the more exact numerical method. As can be seen, the agreement between the two methods is quite satisfactory, and the present method offers a simpler and easier way of assessing the fin performance than does the numerical method of reference 1.

The experimental data of reference 1 are represented in figures 6 and 7 by the circular symbols. Both analytical curves appear to underpredict the temperature gradient in the region of high temperature surplus by about 30 percent. The discrepancy may be attributed to two reasons:

(1) Enhancement of the heat-transfer coefficient in the film boiling zone occurred because of agitation imparted by the neighboring nucleate and transition boiling zones. (This reason was the one advanced in ref. 1 to explain the discrepancy.)

(2) Assumption (1) in the basic model might not be valid under the boiling conditions. However, this second reason could be discounted by the fact that the agreement between experimental and analytical results is better in the lower temperature surplus region where the heat flux is higher and the departure from the assumption of one-dimensional conduction is expected to be more serious.

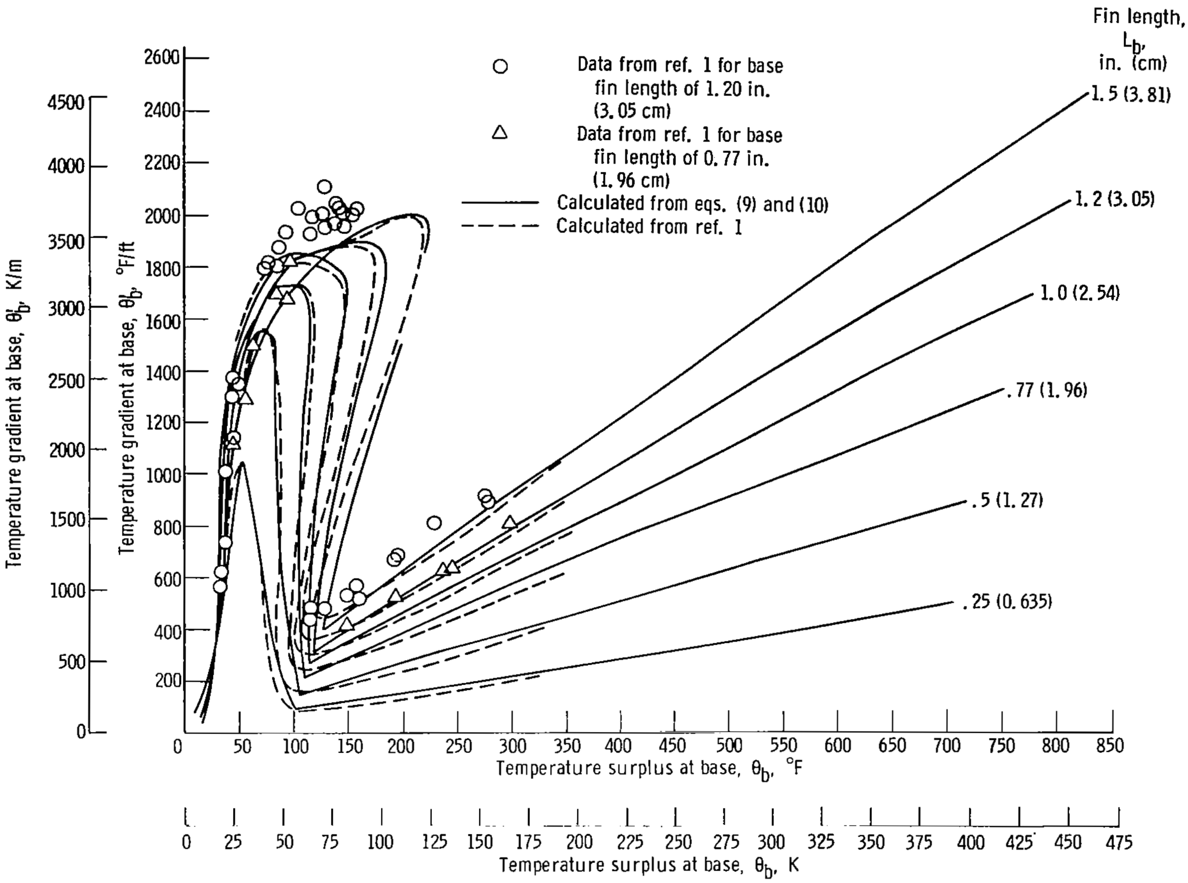


Figure 7. - Temperature gradient at base as function of base temperature surplus for various fin lengths. Freon used as fluid.

No calculation was performed with the use of equations (13) and (14) because the boiling curves of freon and isopropanol could not be well fitted by Gaussian curves.

Reference 1 still presents a more accurate method of determining performance because no approximate expression or curve fitting of the heat-transfer coefficient is involved. However, the present method has the flexibility of providing answers with various degrees of accuracy and simplicity. If a high-speed computer is available, the boiling curve can be fitted with many segments of n^{th} power curves, and the result can be as accurate as the exact solution. On the other hand, simple, quick estimations can be achieved by approximating the boiling curve with only two or three segments of n^{th} power curves. Thus, the present method is adaptable to either a high-speed computer calculation or a hand computation, depending on the degree of accuracy required and the availability of resources.

The fin performance is commonly expressed in the form of fin effectiveness $\eta = (k\theta_b' b)/(h\theta_b L)$. For the present case of boiling on a fin, such an expression yields

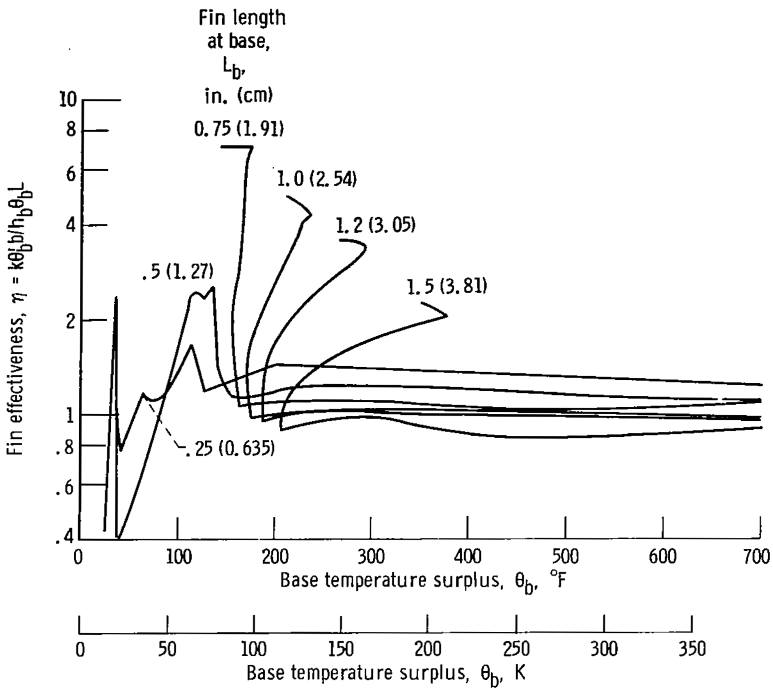


Figure 8. - Typical plots of fin effectiveness as function of base temperature surface and fin length for isopropanol. Half-radius of fin, 1/16 inch (0.159 cm).

irregular curves of η against θ_b. A typical result is shown in figure 8. The seemingly erratic result is obtained because both the $\theta_b'(\theta_b)$ curves of figures 6 and 7 and the $h(\theta_b)$ curves of figures 1 and 2 are N-shaped with the minimum and maximum for θ_b' and h located at different values of θ_b. Therefore, the parameter η, which is the quotient of θ_b' and h, should exhibit two maximums and two minimums. An interesting lesson learned from such an exercise is that a seemingly senseless result could be generated by a set of logical rules. In any event, it appears that the normal definition of fin effectiveness is not an adequate parameter for fin performance when boiling is involved.

EXAMPLES OF PRACTICAL APPLICATION OF CONCEPT OF BOILING ON A FIN TO ENGINEERING PROBLEMS

As the concept of boiling on a fin is rather novel, an illustration of the practical application of such a concept might be of interest. The description of each system is over simplified and focused only on the aspect that is pertinent to the application of the fin concept.

Example 1: Cooling of a Nuclear Fuel Rod

For a nuclear fuel rod to operate satisfactorily, an important requirement is that heat be removed at a high rate, usually at boiling conditions. Thus, the important limit is to keep the rod temperature below the so-called burnout temperature (ref. 4). Otherwise, once the critical ΔT, usually of the order of 30 K, is passed, the surface temperature will rise to a range of thousands of degrees and cause physical burnout. A range of 30 K is quite narrow for practical operation. However, the rod could be fitted with fins that extend radially (fig. 9). In such a configuration, although the root of the fin is covered by a vapor blanket, heat can still be dissipated through nucleate boiling near the fin tip. Thus, while the base temperature of the fin is higher than that of the heating element without a fin, the range of operating temperatures with a positive slope of $dq/d\theta$ is greatly broadened, (e.g., in fig. 6, the operational range of the positive slope is extended from $\theta_b = 35^\circ$ F (19.4 K) for a bare tube to $\theta_b = 240^\circ$ F (133 K) for the case of a 1-in. (2.54-cm) fin). Of course, besides a broader operation temperature the traditional advantage exists of the fin dissipating more heat because of the presence of more surface.

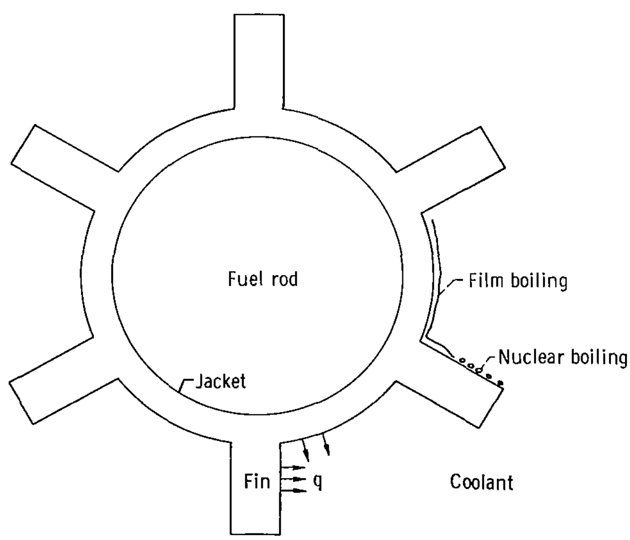


Figure 9. - Configuration of nuclear fuel rod with finned jacket.

Example 2: Heat-Transfer Characteristics of a Spiral Insert in a Heating Tube

In the boiler of a power plant, a spiral insert is sometimes installed to promote heat

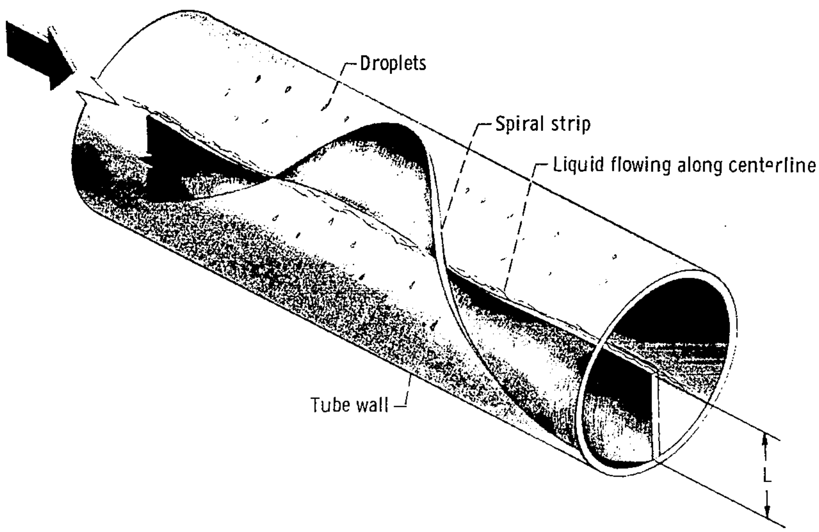


Figure 10. - Configuration of boiling two-phase flow channel with spiral-tape insert.

transfer and to ensure complete evaporation of liquid by throwing droplets on the heating surface. This configuration is illustrated in figure 10. If the insert protrudes too far into the flow, an undesirable feature is that liquid tends to collect at the tip of the insert and to trickle downstream along the centerline. If the insert is now viewed as a fin, one way to prevent the collection of liquid at the tip is to ensure that the temperature of the whole fin be higher than that of the incipient boiling, so that liquid can be evaporated. As an illustration, suppose that liquid potassium is to be evaporated in the boiler and that the heat-transfer coefficient of boiling potassium can be approximated by the following equations:

Nucleate boiling:

$$\frac{h}{h_1} = \left(\frac{\theta}{\theta_1}\right)^3$$

for $10^\circ\ F < \theta < 30^\circ\ F$ ($5.56\ K < \theta < 16.7\ K$)

$$\theta_1 = 10^\circ\ F\ (5.56\ K)$$

$$h_1 = 10^3\ Btu/(hr)(ft^2)(^\circ F)\ (5680\ W/(m^2)(K))$$

Transition boiling:

$$\frac{h}{h_2} = \left(\frac{\theta}{\theta_2}\right)^{-3.3}$$

for 30° F $< \theta < 75^{\circ}$ F (16.7 K $< \theta <$ 41.6 K)

$$\theta_2 = 30^{\circ}\text{ F (16.7 K)}$$

$$h_2 = 2.7\times10^{4}\text{ Btu/(hr)(ft}^2)(^{\circ}\text{F) (1.53}\times10^{5}\text{ W/(m}^2\text{)(K))}$$

Film boiling:

$$\frac{h}{h_3} = \left(\frac{\theta}{\theta_3}\right)^{0}$$

for $\theta > 75^{\circ}$ F ($\theta >$ 41.6 K)

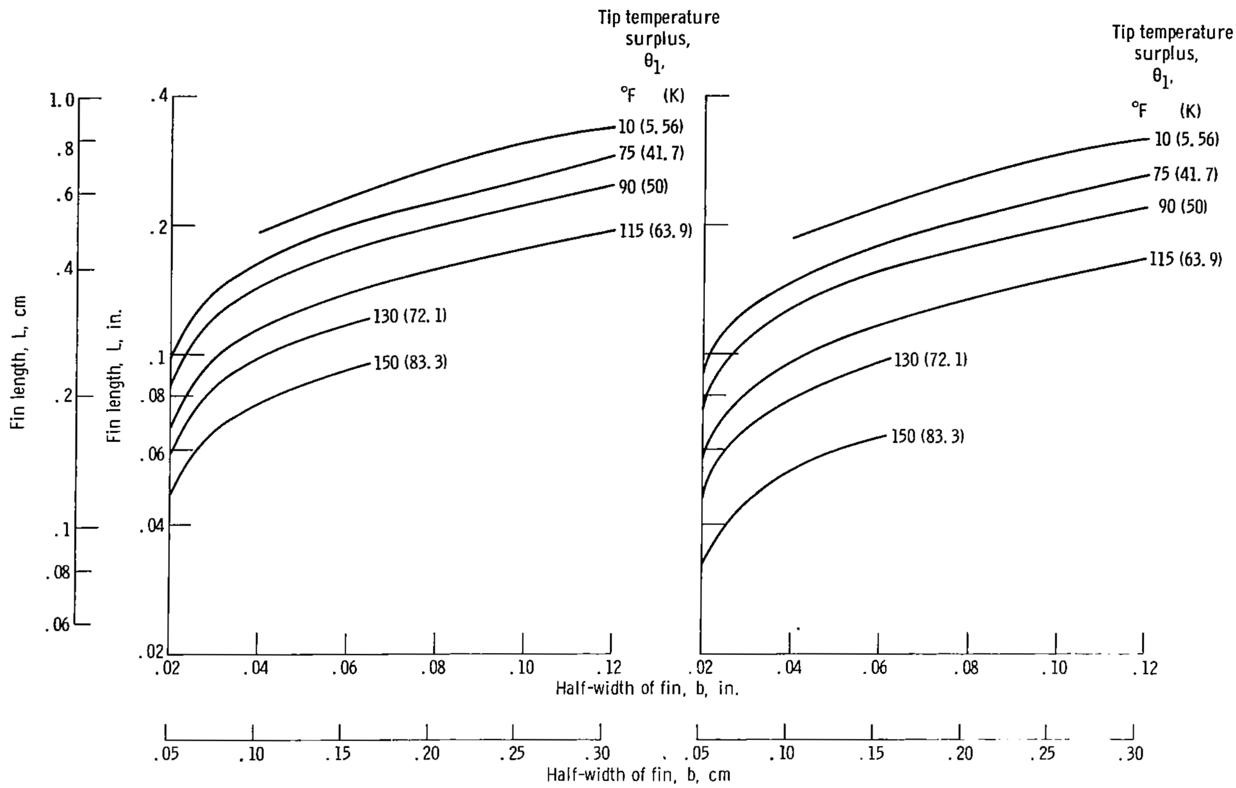
$$\theta_3 = 75^{\circ}\text{ F (41.6 K) Leidenfrost temperature}$$

$$h_3 = 1.33\times10^{3}\text{ Btu/(hr)(ft}^2)(^{\circ}\text{F) (7.55}\times10^{3}\text{ W/(m}^2\text{)(K))}$$

Assume that the thermal conductivity of the alloy is 31.5 Btu per hour per foot per $^{\circ}$F (54.5 W/(m)(K)). Use of equations (9a) and (10) results in the configuration requirements shown in figure 11, where the lengths of the fins are plotted against the half-widths of the fins for various tip temperatures, $\theta_b = 175^{\circ}$ F (97.2 K) and $\theta_b = 200^{\circ}$ F (111 K). For example, for a fin with a half-width thickness of 0.04 inch (0.102 cm) and a base temperature surplus of 175° F (97.2 K), the length cannot be more than 0.145 inch (0.368 cm) if the fin is to be nonwetting throughout (i.e., hotter than the Leidenfrost temperature); the fin cannot be longer than 0.185 inch (0.470 cm) if the accumulation of nonboiling liquid is to be avoided. However, if the length of the fin is fixed at 0.2 inch (0.508 cm), the fin thickness should be at least 0.15 inch (0.381 cm) for complete nonwetting, or at least 0.1 inch (0.254 cm) thick for complete boiling. In short, a tape insert could have liquid accumulation at the tip if the fin is too long or too thin.

Example 3: Heat Loss from Ends of Test Section

In many boiling heat-transfer experiments, the test section is a heating tube or



(a) Base temperature surplus, 200° F (111 K).

(b) Base temperature surplus, 175° F (97.2 K).

Figure 11. - Size of fin required to maintain given tip temperature.

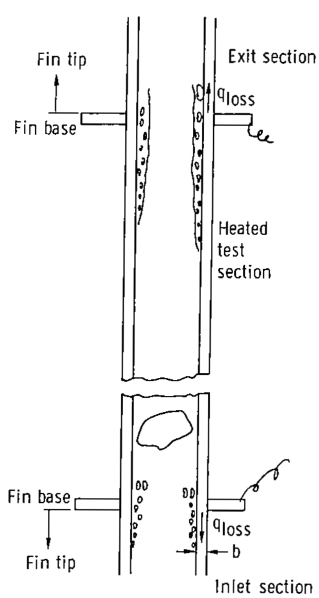


Figure 12. - Schematic representation of heat loss from heated test section to unheated inlet and exit sections.

channel connected with the unheated inlet and exit sections. If the tube wall is not extremely thin and if the wall temperature surplus is sufficiently high, enough heat leaks to both unheated sections to cause them to act like fins with boiling taking place at the interior surface (fig. 12). The proposed method provides a means of estimating the heat losses. For the cases where the outside wall of the tube is well insulated, the wall thickness should be used as the half-thickness b, and the temperature surplus at the tip is set as zero. The tip zone of the fin is cooled by convection.

CONCLUDING REMARKS

When a fin is cooled by various modes of boiling, the heat-transfer coefficient can vary over a wide range. The approach assuming a constant heat-transfer coefficient as conventionally used for fin problems is no longer valid. In this report, a model was proposed in which the fin was postulated to be a stack of fins joined together, with each section being cooled by a different heat-transfer mechanism. For each of these sections, the heat-transfer coefficient was assumed to be proportional to the n^{th} power of the temperature difference. The differential equations for the heat conduction in a fin with a variable heat-transfer coefficient were solved as equations (9a) and (10). These two equations provided a means of calculating both heat flux at the base and the fin length for a given set of tip and base temperatures. Equations were also proposed for the less common case of fitting the heat-transfer coefficient by Gaussian curves.

The method can provide either a quick, first-order estimate through simple calculations or a more exact solution through the use of a high-speed computer.

Three examples were cited to illustrate the practical application of the curve-fitting-parameter analysis of boiling on a fin. One example showed that the range of operating temperatures of nuclear fuel rods could be greatly broadened without the adverse impact of burnout, if a jacket of the fuel rod were made in the shape of a spline. Another example showed that accumulation of liquid at the tip of a tape insert in a boiling two-phase flow channel could be avoided if the fin (i.e., the tape insert) can be made short and stubby to ensure boiling over the entire surface. The third example was an estimation of heat losses at the ends of the heating section, wherein the connected inlet and exit sections were considered as fins.

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NASA-Langley, 1968 —— 33 E-4263