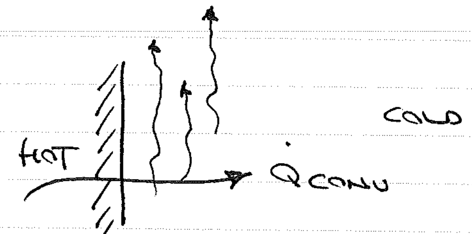
## HEAT TRANSFER FROM FINNED SURFACES

CONVECTIVE HEAT TRANSFER WORKS BECAUSE HEAT IS TRANSFERRED FROM A SURFACE (WITH A GIVEN AREA) TO A MOVING FLUID.

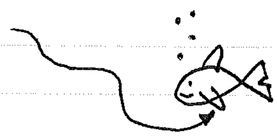
$$\dot{Q} = \dot{Q}_{conv} = hA\,(T_{surface} - T_{\infty})$$



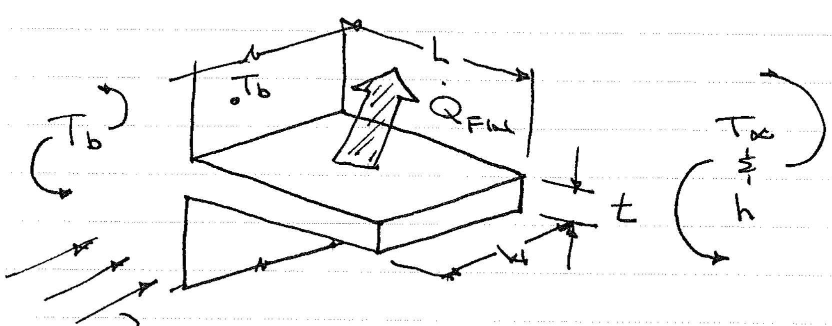

TO IMPROVE HEAT TRANSFER (MAKE $\dot{Q}$ BIGGER) YOU CAN:

1. INCREASE $T_{surface}$ (AND FRY WHAT YOU ARE COOLING!).
2. DECREASE $T_{\infty}$ (USE LIQUID $H_2$)
3. INCREASE $h$ (BY A FAN).
4. INCREASE $A$ (REDESIGN THE COOLING PACKAGE).

WE CAN INCREASE THE COOLING AREA BY GIVING AN OBJECT FINS.



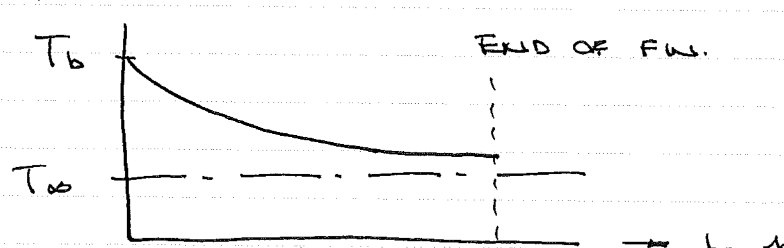
TYPICAL FIN.

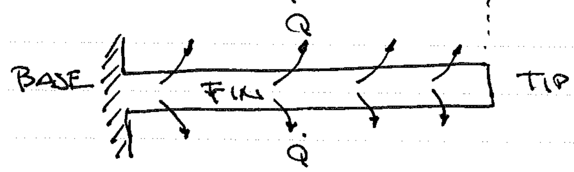



- THE RATE OF HEAT TRANSFER TO THE AIR IS DEPENDENT ON THE FIN TEMPERATURE.
- THE FIN TEMPERATURE DECREASES TOWARD THE TIP

∴ HEAT TRANSFER IS NOT CONSTANT OVER THE ENTIRE FIN.

$T_b$ = BASE TEMP. OF FIN AND WALL.



## FIN EFFICIENCY

$$\eta_{FIN} = \frac{\text{ACTUAL HEAT TRANSFER RATE FROM THE FIN}}{\text{IDEAL HEAT TRANSFER RATE FROM THE FIN IF THE ENTIRE FIN WERE AT } T_b \text{ (BASE TEMP.)}}$$

$$\eta_{FIN} = \frac{\dot{Q}_{FIN}}{\dot{Q}_{FIN,max}}$$

$$\dot{Q}_{FIN,max} = h\,A_{FIN}\,(T_b - T_\infty)$$

$$A_{FIN} = A_{\substack{FIN\\SIDES}} + A_{\substack{FIN\\TIP}}$$

SO IF YOU COULD SOMEHOW KNOW $\eta_{FIN}$ ...

$$\dot{Q}_{FIN} = \eta_{FIN}\,\dot{Q}_{FIN,max}$$

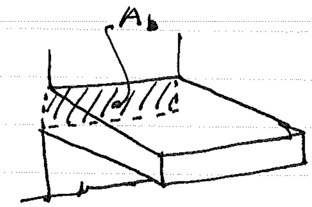
$$\boxed{\dot{Q}_{FIN} = \eta_{FIN}\,h\,A_{FIN}\,(T_b - T_\infty).}$$

TO GET $\eta_{FIN}$ USE THE GRAPHS IN THE HANDOUT.
FIG. 8-59 & FIG 8-60.

NOTE THAT TO GET $\eta_{FIN}$ YOU MUST
FIRST CALCULATE $A_{FIN}$ & $\xi$ (A CORRELATION PARAMETER)
FOR THE SPECIFIC FIN GEOMETRY.

## FIN EFFECTIVENESS

HOW GOOD IS THE FIN COMPARED ~~#~~ TO HAVING ~~...~~ ~~...~~ NO FIN ~~...~~ ATTACHED?




$$\dot{Q}_{NOFIN} = h A_b (T_b - T_\infty) \quad \text{NO FIN}$$

$A_b$ = AREA OF THE FINS BASE OR ROOT.

$\varepsilon_{FIN}$ = FIN EFFECTIVENESS

$$\varepsilon_{FIN} = \frac{\dot{Q}_{FIN}}{\dot{Q}_{NO,FIN}} = \frac{\dot{Q}_{FIN}}{h A_b (T_b - T_\infty)}$$

$$\varepsilon_{FIN} = \frac{\eta_{FIN} \cancel{h} A_{FIN} \cancel{(T_b - T_\infty)}}{\cancel{h} A_b \cancel{(T_b - T_\infty)}} = \frac{\eta_{FIN} A_{FIN}}{A_b}$$

ASSUMING THE $h$ IS THE SAME FOR BOTH SITUATIONS.

FOR A VERY LONG FIN (TIP TEMP = $T_\infty$).

$$\varepsilon_{FIN} = \sqrt{\frac{kp}{hA_c}}$$

$k$ = THERMAL CONDUCTIVITY OF THE FIN MATERIAL.

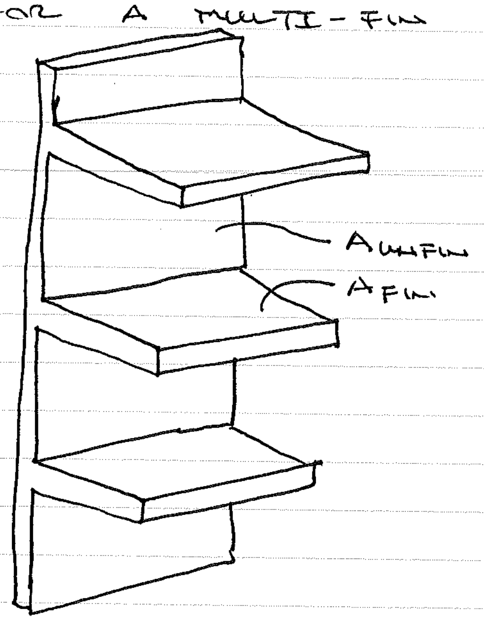
$p$ = LENGTH OF THE FINS PERIMETER

$A_c$ = THE FINS X-SECTIONAL AREA.

FROM THIS SOME IMPORTANT CONCLUSIONS CAN BE DRAWN.

1. $k$ SHOULD BE BIG
2. $P/A_c$ RATIO SHOULD BE BIG (CIRCULAR FINS ARE NOT GREAT).
3. $h$ SHOULD BE SMALL (NATURAL CONVECTION, FOR EXAMPLE)

FOR A MULTI-FIN ASSEMBLY ...

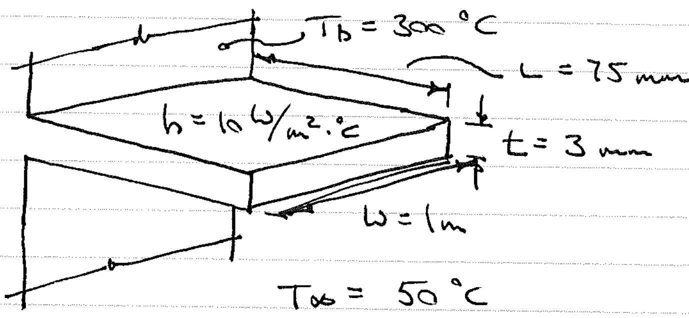



$$\dot{Q}_{TOTAL\ FIN} = \dot{Q}_{UNFIN} + \dot{Q}_{FIN}$$

$$\boxed{\dot{Q}_{TOTAL\ FIN} = h\left(A_{UNFIN} + \eta_{FIN} A_{FIN}\right)(T_b - T_\infty)}$$

FOR ALL FINS AND SURFACES.

EXAMPLE




$\dot{Q}_{FIN} = ?$

THE FIN IS ALUMINUM
$k = 200\ W/m \cdot °C$

FROM FIG. 8-59 ...

$$A_{FIN} = 2w\left(L + \tfrac{1}{2}t\right)$$
$$= 2(1)\left(0.075 + \tfrac{1}{2}(0.003)\right)$$
$$= 0.153\ m^2$$

$$\xi = \left(L + \tfrac{1}{2}t\right)\sqrt{h/kt}$$
$$= \left(0.075 + \left(\tfrac{1}{2}\right)(0.003)\right)\sqrt{\frac{10}{(200 \times 0.003)}}$$
$$= 0.312$$

$$\eta_{FIN} \cong 0.88$$

SO $\dot{Q}_{FIN} = \eta_{FIN}\, h\, A_{FIN}\, (T_b - T_\infty)$.
$$= (0.88)(10)(0.153)(300 - 50)$$
$$= 336.6 \text{ WATTS.}$$

$$\varepsilon_{FIN} = \frac{\eta_{FIN} A_{FIN}}{A_b}$$

$$A_b = w \times t = 1 \times 0.003 = 0.003\ m^2$$

$$= \frac{(0.88)(0.153)}{0.003} = 44.9$$

TIMES BETTER TO HAVE A FIN THAN NOT TO HAVE A FIN.

## HEAT SINK SELECTION

EXAMPLE

AN ~~[illegible]~~ POWER TRANSISTOR IS RATED TO ~~[illegible]~~ PRODUCE 60 WATTS AT FULL POWER.
THE CASE MUST NOT EXCEED 90 °C WITH AN AIR TEMP OF 30 °C

$$\dot{Q} = \frac{\Delta T}{R} \quad \text{SO} \quad R = \frac{\Delta T}{\dot{Q}} = \frac{90 - 30}{60} = 1 \ °C/W$$

NOW LOOK AT THE HANDOUT
CHOOSE A HEAT SINK WITH AN $R < 1 \ °C/W$
SUCH AS HS503A WHO'S $R = 0.9 \ °C/W$.

## HEAT TRANSFER IN COMMON CONFIGURATIONS

IN MORE COMPLEX SITUATIONS THAT INVOLVE PURELY CONDUCTIVE HEAT TRANSFER, ETC. ETC.

$$\dot{Q} = Sk\,(T_1 - T_2)$$

or $\dot{Q} = \dfrac{T_1 - T_2}{R_0}$ WHERE $R_S = \dfrac{1}{kS}$

$R_0$ = OVERALL R THAT INCLUDES $R_S$

SEE HANDOUT FOR SOME COMMON CONFIGURATIONS.

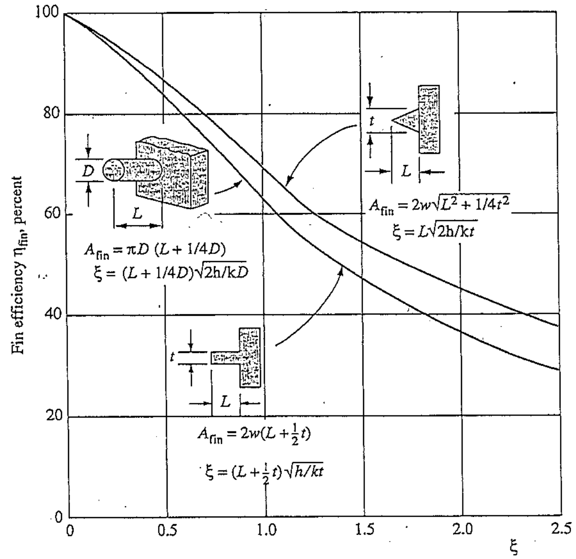



**FIGURE 8-59**

Efficiency of circular, rectangular and triangular fins on a plain surface of width $w$ (from Gardner).

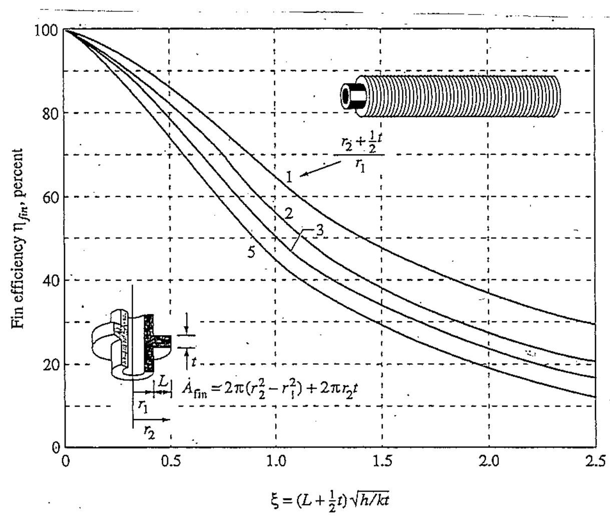



**FIGURE 8-60**

Efficiency of circular fins of length $L$ and constant thickness $t$ (from Gardner).

**TABLE 8-6**

**Combined natural convection and radiation thermal resistance of various heat sinks used in the cooling of electronic devices between the heat sink and the surroundings. All fins are made of aluminum 6063T-5, are black anodized, and are 76 mm (3 in.) long. (Courtesy of Vemaline Products, Inc.)**

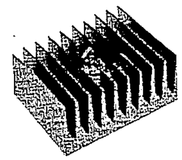
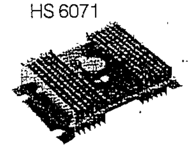
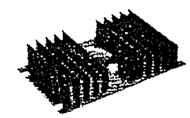
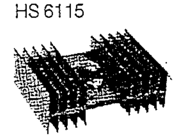
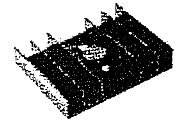
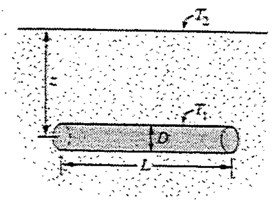
| | |
|---|---|
| HS 5030  | $R$ = 0.9°C/W (vertical)<br>$R$ = 1.2°C/W (horizontal)<br>Dimensions: 76 mm × 105 mm × 44 mm<br>Surface area: 677 cm$^2$ |
| HS 6065  | $R$ = 5°C/W<br>Dimensions: 76 mm × 38 mm × 24 mm<br>Surface area: 387 cm$^2$ |
| HS 6071  | $R$ = 1.4°C/W (vertical)<br>$R$ = 1.8°C/W (horizontal)<br>Dimensions: 76 mm × 92 mm × 26 mm<br>Surface area: 968 cm$^2$ |
| HS 6105  | $R$ = 1.8°C/W (vertical)<br>$R$ = 2.1°C/W (horizontal)<br>Dimensions: 76 mm × 127 mm × 19 mm<br>Surface area: 677 cm$^2$ |
| HS 6115  | $R$ = 1.1°C/W (vertical)<br>$R$ = 1.3°C/W (horizontal)<br>Dimensions: 76 mm × 102 mm × 25 mm<br>Surface area: 929 cm$^2$ |
| HS 7030  | $R$ = 2.9°C/W (vertical)<br>$R$ = 3.1°C/W (horizontal)<br>Dimensions: 76 mm × 97 mm × 19 mm<br>Surface area: 290 cm$^2$ |

**TABLE 8-7**

**Conduction shape factors $S$ for several configurations for use in $\dot{Q} = kS(T_1 - T_2)$ to determine the steady rate of heat transfer through a medium of thermal conductivity $k$ between the surfaces at temperatures $T_1$ and $T_2$**

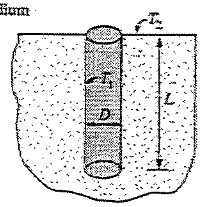
(1) Isothermal cylinder of length $L$ buried in a semi-infinite medium ($L >> D$ and $z > 1.5D$)

$$S = \frac{2\pi L}{\ln(4z/D)}$$



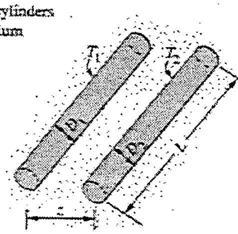

(2) Vertical isothermal cylinder of length $L$ buried in a semi-infinite medium ($L >> D$)

$$S = \frac{2\pi L}{\ln(4L/D)}$$




(3) Two parallel isothermal cylinders placed in an infinite medium ($L >> D_1, D_2, z$)

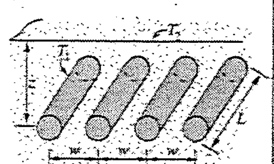
$$S = \frac{2\pi L}{\cosh^{-1}\left(\frac{4z^2 - D_1^2 - D_2^2}{2D_1D_2}\right)}$$




(4) A row of equally spaced parallel isothermal cylinders buried in a semi-infinite medium ($L >> D$, $z$ and $w > 1.5D$)

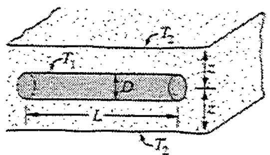
$$S = \frac{2\pi L}{\ln\left(\frac{2w}{\pi D}\sinh\frac{2\pi z}{w}\right)}$$

(per cylinder)



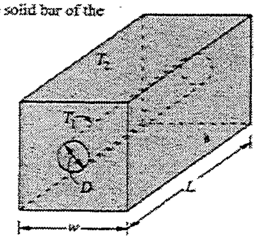

(5) Circular isothermal cylinder of length $L$ in the midplane of an infinite wall ($z > 0.5D$)

$$S = \frac{2\pi L}{\ln(8z/\pi D)}$$



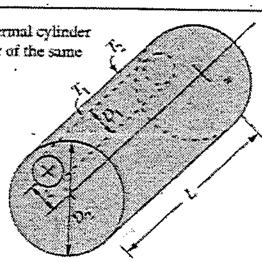

(6) Circular isothermal cylinder of length $L$ at the center of a square solid bar of the same length

$$S = \frac{2\pi L}{\ln(1.08\,w/D)}$$




(7) Eccentric circular isothermal cylinder of length $L$ in a cylinder of the same length ($L > D_2$)

$$S = \frac{2\pi L}{\cosh^{-1}\left(\frac{D_1^2 + D_2^2 - 4z^2}{2D_1D_2}\right)}$$




(8) Large plain wall

$$S = \frac{A}{L}$$

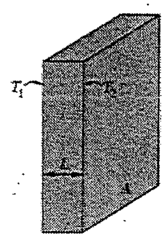
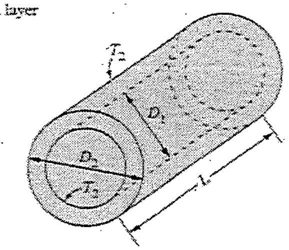



**TABLE 8-7 (Continued)**

(9) A long cylindrical layer

$$S = \frac{2\pi L}{\ln(D_2/D_1)}$$



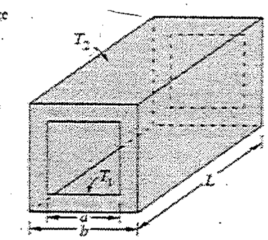

(10) A square flow passage

(a) For $a/b > 1.4$,

$$S = \frac{2\pi L}{0.93\ln(0.948\,a/b)}$$

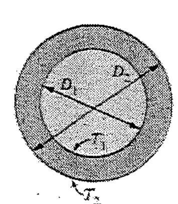
(b) For $a/b < 1.41$,

$$S = \frac{2\pi L}{0.785\ln(a/b)}$$




(11) A spherical layer

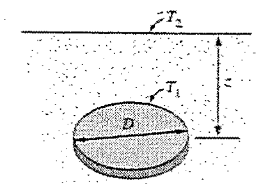
$$S = \frac{2\pi D_1 D_2}{D_2 - D_1}$$




(12) Disk buried parallel to the surface in a semi-infinite medium ($z >> D$)

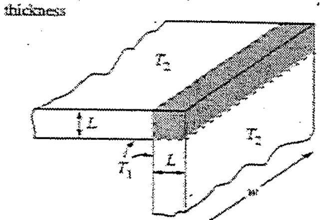
$$S = 4D$$

($S = 2D$ when $z = 0$)



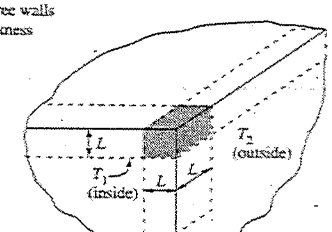

(13) The edge of two adjoining walls of equal thickness

$$S = 0.54\,w$$



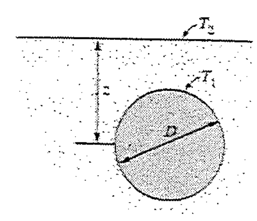

(14) Corner of three walls of equal thickness

$$S = 0.15L$$




(15) Isothermal sphere buried in a semi-infinite medium

$$S = \frac{2\pi D}{1 - 0.25D/z}$$




(16) Isothermal sphere buried in a semi-infinite medium at $T_2$ whose surface is insulated

$$S = \frac{2\pi D}{1 + 0.25D/z}$$