S. W. CHI

Heat Pipe Theory and Practice

SERIES IN THERMAL AND FLUIDS ENGINEERING

HEAT PIPE THEORY AND PRACTICE
A Sourcebook

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The George Washington University

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HEAT PIPE THEORY AND PRACTICE: A Sourcebook

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Preface

The heat pipe, a device for transmitting heat from one location to another over a small temperature gradient, has found varied applications in many fields since the first publication of its operating principles in 1964 by scientists at Los Alamos Scientific Laboratory. The rapid expansion of heat pipe technology has prompted this author to organize, since 1971, an annual seminar at the George Washington University entitled "Heat Pipe Theory and Practice." This seminar provides an opportunity for engineers and educators to keep informed of progress in the various aspects of this new means of heat transmission. Heat pipe theory, application, and manufacturing technique have developed rapidly in recent years. In this book the author hopes to provide a comprehensive treatment of the various aspects (i.e., theory, design, manufacturing, and applications) of heat pipe technology. This volume should prove extremely useful to both the practicing engineer and the classroom instructor. Engineers who have been engaged in the design and development of other types of heat transmission devices but who now find themselves called upon to explore heat pipes will have a comprehensive collection of material available in a single volume. Mechanical engineering and technology instructors who have endeavored to design terminal courses for undergraduate students and beginning courses for graduate students will also find this book helpful. Heat pipe technology exposes students to the practical applications of the fundamental laws of thermodynamics, heat transfer, materials science, and manufacturing processes.

This volume begins with an introduction to heat pipe operating principles, types, and applications. This is followed by a comprehensive treatment of heat pipe theory, design, and manufacture. The organization of heat pipe theory provides parallel treatment of the fundamental laws of thermodynamics, heat transfer, fluid mechanics, and materials science during heat pipe analysis. For the problem-solving convenience of practicing engineers, design procedures are developed summarizing theoretical information. In addition, methods of summarizing voluminous research information are presented in some detail. Finally, current practices in the manufacture of heat pipes are described. The last chapter covers current and potential applications of the heat pipe to energy systems; this should be useful to engineers and architects interested in exploring energy conservation for buildings, other structures, and industries.

While it is perhaps too early in the development of heat pipe technology to say that there is only one approach to heat pipe theory, design, and manufacture, efforts have been made by a number of workers to determine the best available method. It is not intended in this writing to supersede these contributions. In fact, areas of controversy have purposely been avoided. Also, for clarity some aspects of heat pipe theory have been treated less rigorously than is possible. However, care has been taken to assure that no fundamental principles have been misrepresented by this approach. This book contains many carefully selected examples, which are tied in with the text and are an integral part of it. In fact, many of the examples extend beyond the subject matter and provide practical applications of the text material. These examples are worked out in detail using both British and SI units.

Since over a thousand articles and papers on heat pipes have been published in the last decade, a comprehensive bibliography has not been included. However, a few of the most pertinent references have been selected and are appended to the appropriate chapters. These references not only represent suggestions for further reading, but also should be considered sources of information. Additional materials have been drawn from participants of seminars at the George Washington University, in particular, Messrs. and Drs. W. B. Bienert, T. A. Cygnarowicz, L. S. Galowin, W. E. Harbaugh, J. E. Kemme, R. Kosson, R. McIntosh, and R. A. Rhodes, Jr. The author's knowledge in this subject area arises from contact with the work of a large number of people in government, industry, research laboratories, and universities. It is therefore impossible for the author to adequately acknowledge his debt to all concerned. However, he would like to express his gratitude in a general way to the personnel of NASA/GSFC who supported his research and have influenced this work.

It should be mentioned that this book would not have been written without the enthusiasm and encouragement of Professor F. Kreith who first suggested writing a book on this subject. For this, the author is deeply grateful. Also appreciated is the encouragement of Professors J. P. Hartnett and T. F. Irvine who included this author's work in their series of books on Thermal Engineering. Mr. William Begell and his staff at Hemisphere have also helped make this book possible. Finally, a thank you is due to my student, Mr. T. Jameson, who assisted in the preparation of the artwork and to Miss M. C. Ha, who typed the manuscript, for their patience in this endeavor.

In conclusion, the author welcomes criticisms either of detail or of the general scheme of the book. Only from such criticism can he hope to discover whether the right approach has been adopted in treating this new subject.

S. W. Chi

Nomenclature

A	area, Eq. (2-74)
A_b	bellow cross-sectional area, Eq. (5-40)
A_c	external surface area of condenser, Eq. (2-74)
A_c	cross-sectional area of duct for cold inlet air, Eq. (9-4)
A_e	external surface area of evaporator, Eq. (2-74)
A_f	interface area between pipe and external source and sink, Eq. (4-1)
A_f	area of fins, Eq. (4-6)
A_h	cross-sectional area of duct for hot exhaust gas, Eq. (9-4)
A_l	cross-sectional area for liquid flow, Sec. (2-3)
A_n	area of the unfinned portion of finned tube, Eq. (4-6)
A_p	cross-sectional area based upon pipe outside diameter, Eq. (2-74)
A_p	pipe external surface area in the absence of fins, Eq. (4-5)
A_s	area of wick pore at wick-vapor interface, Eq. (3-12)
A_v	vapor core cross-sectional area, Eq. (2-31)
A_w	wick cross-sectional area, Eq. (2-19)
A, B, C, D	integrating constants, Ex. (5-5)
c_f	specific heat of boiling liquid outside heat pipe, Eq. (4-12)
$c_{p,a}$	specific heat of air, Ex. (4-2)
$c_{p,f}$	specific heat of fluid flowing outside the heat pipe, Sec. (4-2)
C	constant, Eq. (4-2)
C_l	wetted perimeter for liquid flow, Sec. (2-3)
$C_{\min}$	heat capacity rate of hot or cold fluid, whichever is smaller, Eq. (9-1)
C_s	wetted perimeter of wick pore at wick-vapor interface, Eq. (3-13)
C_{sf}	constant, Eq. (4-12)
C_p	pipe perimeter defined as $2\pi r_o$, Eq. (5-1)
c_1, c_2	constants, Eq. (4-3)
d	screen wire diameter, Eq. (2-14)
d_i	pipe inside diameter, Ex. (2-2)
d_o	pipe outside diameter, Ex. (2-1)
d_v	vapor core diameter, Eq. (2-58a)
D	diffusion coefficient, Eq. (5-30)
D_v	dynamic pressure coefficient, Eq. (2-33)
f_l	drag coefficient for liquid flow, Eq. (2-18)

f_{max}	maximum tensile stress, Eq. (7-2)
f_u	ultimate tensile stress, Sec. (6-3)
f_v	drag coefficient for vapor flow, Eq. (2-31)
$f_{v,c}$	vapor drag coefficient for compressible flow, Eq. (2-38)
$f_{v,i}$	vapor drag coefficient for incompressible flow, Eq. (2-38)
F_A	shape factor for radiation, Eq. (4-7)
F_E	emissivity factor for radiation, Eq. (4-7)
F_l	frictional coefficient for liquid flow, Eq. (2-21)
F_s	shear force at liquid-vapor interface, Eq. (3-12)
F_t	surface tension force at liquid-wick interface, Eq. (3-13)
F_v	frictional coefficient for vapor flow, Eq. (2-33)
g	gravitational acceleration, Eq. (2-17)
h_c	overall heat transfer coefficient at condenser, Eq. (5-1)
h_e	overall heat transfer coefficient at evaporator, Eq. (5-49)
h_f	interface heat transfer coefficient between heat pipe and external heat sink or source, Eq. (4-1)
$h_{f,c}$	interface heat transfer coefficient between heat pipe and heat sink at condenser, Sec. (4-2)
$h_{f,e}$	effective interface heat transfer coefficient of finned tube, Eq. (4-5)
$h_{p,w}$	combined heat transfer coefficient of pipe wall and liquid-saturated wick, Ex. (5-4)
J	mechanical equivalent of heat, Eq. (2-77)
k	thermal conductivity, Eq. (2-46)
$k_{b,s}$	bellow spring constant, Eq. (5-40)
k_e	effective thermal conductivity of liquid-saturated wick, Eq. (2-46)
$k_{e,c}$	effective thermal conductivity of liquid-saturated wick at condenser, Eq. (2-78)
$k_{e,e}$	effective thermal conductivity of liquid-saturated wick at evaporator, Eq. (2-78)
k_f	thermal conductivity of fluid flow outside heat pipe, Sec. (4-2)
$k_{f,c}$	k_f at condenser section, Ex. (4-1)
k_l	thermal conductivity of liquid, Eq. (2-46)
k_w	thermal conductivity of wick material, Eq. (2-46)
k_p	thermal conducitivty of pipe material, Eq. (2-78)
k_1	thermal conductivity, Eq. (2-54)
k_2	thermal conductivity, Eq. (2-55)
K	wick permeability, Eq. (2-22)
K	nozzle discharge coefficient, Eq. (5-51)
K_1, K_2	constants, Eqs. (3-12) and (3-13)
l	height of tube external fin, Eq. (4-4)
L	effective heat pipe length, Eq. (2-63)
L	pipe length, Eq. (2-76)

L_a	length of heat pipe adiabatic section, Eq. (2-65)
L_c	length of heat pipe condenser, Eq. (2-65)
L_e	length of heat pipe evaporator, Eq. (2-65)
L_t	total length of heat pipe, Eq. (2-63)
$L_{c,a}$	length of active portion of condenser, Eq. (5-1)
$L_{c,i}$	length of inactive portion of condenser, Sec. (5-2)
m	parameter defined by Eq. (5-24)
m	fluid inventory, Eq. (8-1)
m_g	mass of gas, Eq. (5-2)
$\dot{m}_g$	gas mass flow rate, Eq. (5-30)
$\dot{m}_v$	vapor mass flow rate, Eq. (2-31) and Eq. (5-30)
$\dot{m}_v''$	vapor mass flow rate per unit area, Eq. (3-4)
M	molecular weight, Ex. (3-1)
M_g	gas molecular weight, Eq. (5-33)
M_v	vapor flow Mach number, Eq. (2-37)
M_v	vapor molecular weight, Eq. (5-33)
n	number of grooves, Ex. (2-1)
n	number of rows of tubes, Table (4-1)
N	screen mesh number, Eq. (2-28)
N_l	liquid transport factor, Eq. (6-3)
Nu_f	Nusselt number of fluid flowing outside tubes, Eq. (4-2)
$\mathrm{Nu}_{f,c}$	Nu_f at condenser section of heat pipe tubes, Ex. (4-1)
P	pressure, Eq. (3-20)
P_a, P_b, P_c, P_d	pressures referred to in Sec. (3-2)
P_c	capillary pressure, Eq. (2-1)
$P_{c,r}$	required capillary pressure for fluid circulation,(Sec. 2-6)
P_{cm}	maximum capillary pressure, Eq. (2-4)
$P_{\mathrm{cm},e}$	effective capillary pressure available for fluid circulation, Eq. (2-58)
P_g	hydrostatic pressure due to gravitational force, Eq. (7-13)
$P_{g,r}$	gas pressure in gas reservoir, Eq. (5-2)
$P_{g,i}$	gas pressure at inactive portion of condenser, Eq. (5-2)
P_l	liquid pressure, Eq. (2-1)
$P_{\max}$	maximum pressure differential, Sec. (2-6)
$P_{\min}$	minimum pressure differential, Sec. (2-6)
P_o	stagnation pressure, Eq. (3-1)
P_{pm}	maximum available pump pressure, Ex. (2-1)
P_{pw}	pressure at pipe-wick interface, Eq. (3-18)
P_t	total pressure defined by Eqs. (2-71) and (2-72)
P_v	vapor pressure, Eq. (2-1)
$P_{v,a}$	vapor pressure at active portion of condenser, Eq. (5-3)
$P_{v,a,\max}$	vapor pressure at active portion of condenser when the heat transfer is at the maximum of the controlled range, Eq. (5-47)
$P_{v,a,\min}$	vapor pressure at the active portion of condenser when heat transfer rate is at minimum of the controlled range, Eq. (5-48)

$P_{v,b}$	vapor pressure of control fluid inside bellow, Eq. (5-40)
$P_{v,b,\max}$	vapor pressure of control fluid inside bellow when heat transfer rate is at maximum of the controlled range, Eq. (5-47)
$P_{v,b,\min}$	vapor pressure of control fluid inside bellow when heat transfer rate is at minimum of the controlled range, Eq. (5-48)
$P_{v,c}$	vapor pressure at condenser, Eq. (5-53)
$P_{v,e}$	vapor pressure at evaporator, Eq. (5-53)
$P_{v,i}$	vapor pressure at inactive portion of condenser, Eq. (5-4)
$P_{v,r}$	vapor pressure in gas reservoir, Eq. (5-3)
$P_{v,s}$	vapor pressure at sink temperature, Ex. (5-2)
P_{wp}	saturation vapor pressure at wick-pipe interface, Eq. (3-18)
P_1, P_2	pressure, Eq. (2-77)
ΔP_l	liquid pressure drop, Eq. (2-1)
ΔP_v	vapor pressure drop, Eq. (2-1)
$\Delta P_\perp$	hydrostatic pressure in direction perpendicular to pipe axis, Eq. (2-58)
Pr_f	Prandtl number of fluid flowing outside pipe, Eq. (4-2)
$\mathrm{Pr}_{f,c}$	Prandtl number of fluid flowing outside condenser of section of pipe, Ex. (4-1)
Q	heat flow rate, Eq. (2-19)
Q'	heat flow rate per unit pipe length, Eq. (5-22)
$Q_{b,\max}$	boiling limit on heat transfer rate, Eq. (3-24)
$Q_{c,\max}$	capillary limit on heat transfer rate, Eq. (2-65)
$Q_{e,\max}$	entrainment limit on heat transfer rate, Eq. (3-17)
Q_L	assumed heat load, Ex. (2-4)
$Q_{\max}$	maximum heat transfer rate over control range, Eq. (5-14)
$Q_{\min}$	minimum heat transfer rate over control range, Eq. (5-48)
$Q_{s,\max}$	sonic limit on heat transfer rate, Eq. (3-10)
$(QL)_{c,\max}$	capillary heat transport factor, Eq. (2-63)
r	radius of cylinder, Eq. (2-5)
r_b	radius of vapor bubble, Eq. (3-18)
r_c	effective capillary radius, Eq. (2-4)
r_c	radius of contact of sintered spheres, Eq. (2-51)
r_f	outside fin radius of finned tube, Sec. (4-2)
$r_{h,l}$	hydraulic radius for liquid flow, Eq. (2-17)
$r_{h,s}$	hydraulic radius of wick at vapor-wick interface, Eq. (3-15)
$r_{h,v}$	hydraulic radius for vapor flow, Eq. (2-31)
r_i	inside radius of pipe, Eq. (2-78)
r_n	boiling nucleation radius, Eq. (3-24)
r_o	outside radius of pipe, Eq. (2-78)
r_s	sphere radius, Eq. (2-15)
r_v	vapor core radius, Eq. (2-78)
r_1	outside radius of annular, Sec. (2-3)

r_2	inside radius of annular, Sec. (2-3)
R	radius of curvature, Eq. (2-5)
R	thermal resistance, Eq. (2-75)
$\bar{R}$	universal gas constant, Ex. (3-1)
R_g	gas constant, Eq. (5-2)
$R_{p,c}$	thermal resistance of pipe wall at condenser section, Eq. (2-81)
$R_{p,e}$	thermal resistance of pipe wall at evaporator section, Eq. (2-81)
R_v	gas constant for vapor, Eq. (2-37)
R_v	thermal resistance for vapor flow from evaporator to condenser, Eq. (2-81)
$R_{w,c}$	thermal resistance of heat pipe wick at condenser section, Eq. (2-81)
$R_{w,e}$	thermal resistance of heat pipe wick at evaporator section, Eq. (2-81)
Re_f	Reynolds number for fluid flowing outside pipe, Eq. (4-2)
$\mathrm{Re}_{f,c}$	Reynolds number for fluid flowing outside condenser section of pipe, Ex. (4-1)
Re_l	liquid flow Reynolds number, Eq. (2-18)
Re_v	vapor flow Reynolds number, Eq. (2-31)
RD	heat pipe row depth, Eq. (9-5)
RD_s	heat pipe row depth under standard conditions, Eq. (9-5)
s	pitch of external fins, Eq. (4-4)
S	wire screen crimping factor, Eq. (2-28)
t	thickness, Eq. (7-2)
t_p	pipe wall thickness, Eq. (2-79)
t_w	wick thickness, Eq. (2-79)
T	temperature
T_c	average temperature of cold air, Eq. (9-3)
$T_{c,\mathrm{in}}$	inlet temperature of cold fluid, Eq. (9-1)
T_f	heat sink or source temperature, which may be fluid temperature, for convective interface or solid temperature for radiation interface, Eqs. (4-1) and (4-7)
$T_{f,c}$	temperature of fluid flowing outside condenser section of pipe, Ex. (4-1)
T_g	gas temperature, Eq. (5-2)
T_h	average temperature of hot gas, Eq. (9-4)
$T_{h,\mathrm{in}}$	inlet temperature of hot fluid, Eq. (9-1)
$T_{g,i}$	gas temperature at inactive portion of condenser, Eq. (5-2)
$T_{g,r}$	gas temperature in gas reservoir, Eq. (5-2)
T_p	temperature of pipe wall, Eq. (4-1)
$T_{p,c}$	condenser pipe wall temperature, Sec. (2-7)
$T_{p,e}$	evaporator pipe wall temperature, Sec. (2-7)
T_{pw}	temperature at pipe-wick interface, Sec. (2-7)
$T_{pw,c}$	condenser temperature at pipe-wick interface, Sec. (2-7)
$T_{pw,e}$	evaporator temperature at pipe-wick interface, Sec. (2-7)
T_o	stagnation temperature, Eq. (3-1)

T_s	sink temperature, Eq. (5-22)
$T_{s,c}$	sink temperature at condenser, Eq. (5-1)
$T_{s,e}$	source temperature at evaporator, Eq. (5-49)
T_v	vapor temperature, Eq. (2-37)
$T_{v,a}$	vapor temperature in active portion of condenser, Eq. (5-1)
$T_{v,a,\max}$	vapor temperature at active portion of condenser when heat transfer rate is at the maximum of the controlled range, Eq. (5-46)
$T_{v,a,\min}$	vapor temperature at active portion of condenser when heat transfer rate is at the minimum of the controlled range, Eq. (5-48)
$T_{v,c}$	vapor temperature in condenser, Sec. (2-7)
$T_{v,e}$	vapor temperature in evaporator, Sec. (2-7)
T_{wv}	temperature at wick-vapor interface, Sec. (2-7)
$T_{wv,c}$	T_{wv} at condenser section, Sec. (2-7)
$T_{wv,e}$	T_{wv} at evaporator section, Sec. (2-7)
T_1, T_2	temperature, Eq. (2-75)
ΔT	temperature drop, Ex. (4-1)
ΔT	temperature drop across wick structure, Eq. (6-2)
ΔT_p	temperature drop across pipe wall, Ex. (4-1)
$\Delta T_{p,c}$	temperature drop across pipe wall at condenser, Ex. (4-1)
$\Delta T_{p,e}$	temperature drop across pipe wall at evaporator, Ex. (4-1)
ΔT_v	temperature drop at vapor flow passage, Ex. (4-1)
$\Delta T_{w,c}$	temperature drop across wick structure at condenser, Ex. (4-1)
$\Delta T_{w,e}$	temperature drop across wick structure at evaporator, Ex. (4-1)
U_{HP}	heat transfer coefficient of heat pipe, Eq. (2-74)
$U_{HP,c}$	heat pipe heat transfer coefficient based upon condenser surface area, Eq. (2-74)
$U_{HP,e}$	heat pipe heat transfer coefficient based upon evaporator surface area, Eq. (2-74)
$U_{HP,p}$	heat pipe heat transfer coefficient based upon pipe cross-sectional area, Eq. (2-74)
v_c	velocity of cold inlet air, Eq. (9-3)
V_b	bellow volume under compression or expansion, Eq. (5-41)
$V_{b,o}$	bellow natural volume, Eq. (5-41)
V_c	condenser vapor core volume, Eq. (5-16)
V_c	volume flow rate of cold inlet air, Sec. (9-4)
V_{ex}	excess heat pipe working fluid in liquid phase, Eq. (5-42)
$V_{f,\max}$	maximum velocity of fluid flowing across tube banks, Sec. (4-2)
V_h	volume flow rate of hot exhaust gas, Eq. (9-2)
V_l	liquid velocity, Eq. (2-18)
V_r	volume of reservoir, Eq. (5-2)
V_v	vapor velocity, Eq. (2-32)
w	groove width, Eq. (2-9)
w	screen wire spacing, Eq. (2-13)

w_f	width of groove fin, Eq. (2-53)
We	Weber's number, Eq. (3-14)
x	axial position, Eq. (2-1)
x_b	bellow length under expansion or compression, Eq. (5-40)
$x_{b,o}$	bellow natural length, Eq. (5-40)
x_{ref}	reference axial position from which x is measured, Eq. (2-1)
x_{min}	axial position where capillary pressure is minimum, Eq. (2-2)
x_{max}	axial position where capillary pressure is maximum, Eq. (2-59)
α	aspect ratio defined in Sec. (2-3)
β	half angle of triangular groove, Eq. (2-10)
β	profile coefficient for momentum flux, Eq. (2-32)
γ_v	vapor specific heat ratio, Eq. (2-37)
δ	groove depth, Eq. (2-25)
δ	plate thickness, Eq. (2-76)
δ	thickness of tube external fin, Eq. (4-4)
ϵ	wick porosity, Eq. (2-19)
ϵ	effectiveness of heat exchanger, Eq. (9-1)
ϵ'	parameter for sintered metal, Eq. (2-51)
ϵ_p	emissivity of pipe wall surface, Eq. (4-8)
η_f	fin effectiveness, Eq. (4-6)
θ	liquid-solid wetting angle, Eq. (2-5)
λ	latent heat of vaporization, Eq. (2-19)
λ_f	latent heat of vaporization of fluid flowing outside pipe, Eq. (4-11)
μ_f	dynamic viscosity of fluid flowing outside pipe, Sec. (4-2)
$\mu_{f,c}$	μ_f at condenser section, Ex. (4-1)
μ_l	liquid dynamic viscosity, Eq. (2-18)
μ_v	vapor dynamic viscosity, Eq. (2-31)
ρ	gas-vapor mixture density, Eq. (5-30)
ρ	material density, Sec. (6-3)
ρ_f	density of fluid flowing outside pipe, Sec. (4-2)
ρ_l	liquid density, Eq. (2-17)
ρ_o	vapor density at stagnation condition, Eq. (3-1)
ρ_v	vapor density, Eq. (2-31)
σ	surface tension coefficient, Eq. (2-3)
σ_f	surface tension of boiling liquid outside pipe, Eq. (4-12)
$\bar{\sigma}$	Stefan-Boltzmann constant, Eq. (4-7)
τ_l	liquid frictional stress, Eq. (2-17)
τ_v	vapor frictional stress, Sec. (2-4)
χ_g	mass fraction of gas, Eq. (5-30)
ψ	heat pipe inclination measured from horizontal position, Eq. (2-17)

Contents

Heat Pipe Types and Applications

1-1 HEAT PIPE INVENTION AND OPERATING PRINCIPLES

Of the various means of transmitting heat, the heat pipe is, in many respects, the most satisfactory. The principle of the heat pipe was conceived in 1944 by Gaugler and in 1962 by Trefethen. However, it was not widely publicized until 1964 when Grover and his colleagues at the Los Alamos Scientific Laboratory independently reinvented the concept. Grover also demonstrated its effectiveness as a high-performance heat transmission device, named it the "heat pipe," and developed its applications. Since then over a thousand papers and patents have been published. Among the many outstanding advantages of using the heat pipe as a heat transmission device are: constructional simplicity, exceptional flexibility, accessibility to control, and ability to transport heat at high rate over considerable distance with extremely small temperature drop. Moreover, heat pipes require no external pumping power.

In its conventional form (see Fig. 1-1), the heat pipe is a closed tube or chamber of different shapes whose inner surfaces are lined with a porous capillary wick. The wick is saturated with the liquid phase of a working fluid and the remaining volume of the tube contains the vapor phase. Heat applied at the evaporator by an external source vaporizes the working fluid in that section. The resulting difference in pressure drives vapor from the evaporator to the condenser where it condenses releasing the latent heat of vaporization to a heat sink in that section of the pipe. Depletion of liquid by evaporation causes the liquid-vapor interface in the evaporator to enter into the wick surface (see Fig. 1-2) and a capillary pressure is developed there. This capillary pressure pumps the condensed liquid back to the evaporator for re-evaporation. That is, the heat pipe can continuously transport the latent heat of vaporization from the evaporator section to the condenser without drying out the wick. This process will continue as long as the flow passage for the working fluid is not blocked and a sufficient capillary pressure is maintained.

The amount of heat that can be transported as latent heat of vaporization is usually several orders of magnitude larger than that which can

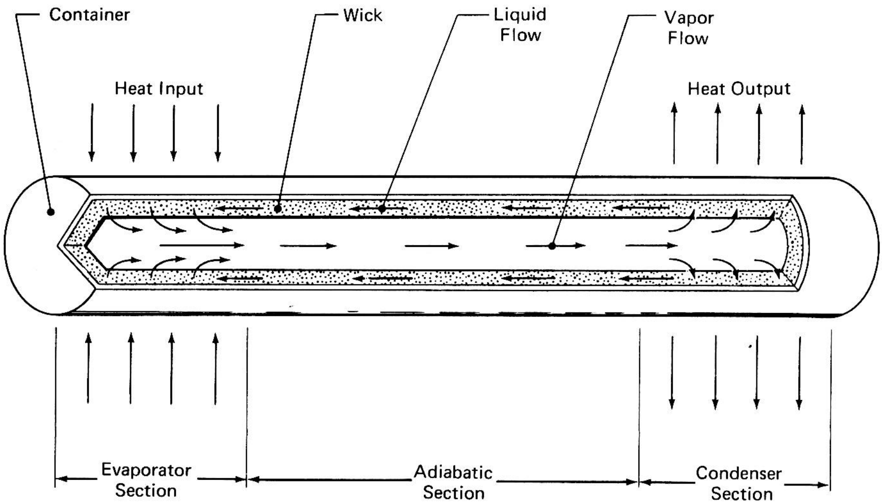

FIG. 1-1 Components and principle of operation of a conventional heat pipe.

be transported as sensible heat in a conventional convective system. The heat pipe can therefore transport a large amount of heat with a small unit size. The temperature drop in a heat pipe is equal to the sum of the temperature drops at the evaporator, vapor flow passage, and condenser. Because of their thin wick structure and the small temperature drop for their vapor flow, heat pipes having thermal characteristics orders of magnitude better than any known solid have been developed.

Unlike solid conductors, heat pipe characteristics are dependent not only upon size, shape, and material but also upon construction, working fluid, and heat transfer rate. Moreover, the heat pipe possesses heat transfer

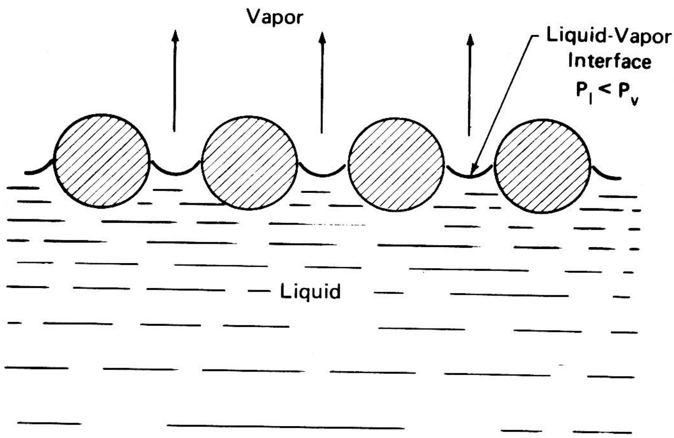

FIG. 1-2 Development of capillary pressure at liquid-vapor interface.