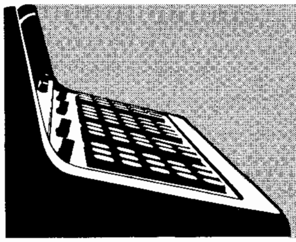


September 1, 1969

9100B THERMODYNAMICS PROGRAM LISTING

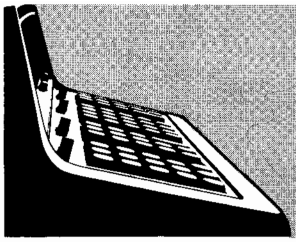
73851 - HEAT TRANSFER THROUGH A MULTILAYERED CYLINDER

This program calculates the rate of heat flow through a multilayered cylinder. Both convective and conductive layers are considered.

9100B ONLY

73852 - TRANSIENT CONDUCTION IN A SLAB

Given the initial temperature of a slab and a fluid, this program determines the temperature (as a function of time and distance) of the slab as it is immersed into the fluid.



PART NO.
09100-73851

HEAT TRANSFER THROUGH A MULTILAYERED CYLINDER

This program determines the rate of heat flow per unit length through a multilayered cylinder. It has practical application wherever fluids of different temperatures are separated by a cylindrical surface since both convective and conductive layers are considered.

The basic equation is:

$$q = U_n A(\Delta T)$$

where

$$A = 2\pi \cdot r_o L ,$$

and

$$U_n = \frac{1}{\left(\frac{r_o}{r_{c1}h_1} + \frac{r_o}{r_{c2}h_2} + \cdots\cdots\right) + \left(\frac{r_o \ln\left(\frac{r_{o1}}{r_{i1}}\right)}{k_1} + \frac{r_o \ln\left(\frac{r_{o2}}{r_{i2}}\right)}{k_2} + \cdots\cdots\right)}$$

Nomenclature

U_n - Outside over-all heat transfer coefficient
r_o - Outside radius of the cylinder
k_n - Thermal conductivity of a conductive layer
r_{on} - Outside radius of a conductive layer
r_{in} - Inside radius of a conductive layer
h_n - Film coefficient of a convective layer
r_{cn} - Radius to a convective surface
ΔT - Temperature difference (inside - outside)
q - Heat transfer rate

Reference: Heat Transfer, Alan J. Chapman, Macmillan Company, New York, 1967.

USER INSTRUCTIONS

PRESS: END

ENTER PROGRAM: (Starting Address is 0-0)

PRESS: END

PRESS: CONTINUE

DISPLAY

0 ———— Z
0 ———— Y
0 ———— X

ENTER DATA: $r_o \rightarrow Z$, $T_o \rightarrow Y$, $T_i \rightarrow X$

PRESS: CONTINUE

DISPLAY

0 ———— Z
0 ———— Y
n ———— X

n is the layer to be entered

ENTER DATA: For conductive layer
$k \rightarrow Z$, $r_{on} \rightarrow Y$, $r_{in} \rightarrow X$

For convective layer
$0 \rightarrow Z$, $h \rightarrow Y$, $r_{cn} \rightarrow X$

NOTE: A convective layer is considered very thin and only the radius to the convection surface is entered.

PRESS: CONTINUE

Have all layers been entered?

NO

YES

PRESS: SET FLAG

PRESS: CONTINUE

DISPLAY

0 ———— Z
q/L ———— Y
0 ———— X

To run another problem

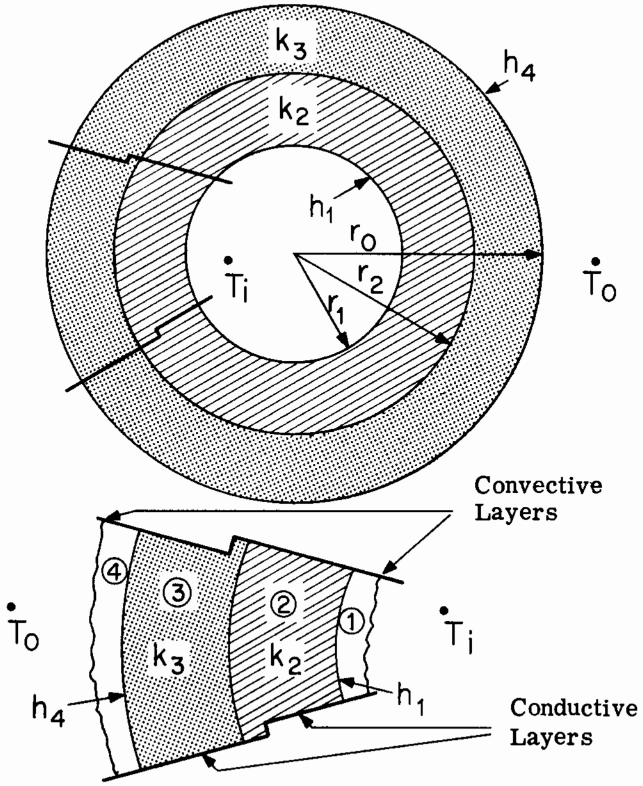
EXAMPLES

A.

r_o = .833 ft.
r_2 = .667 ft.
r_1 = .500 ft.
h_1 = 300 Btu/hr. ft.^{2} °F
k_2 = 40 Btu/hr. ft. °F
k_3 = .10 Btu/hr. ft. °F
h_4 = 6 Btu/ hr. ft.^{2} °F

T_o = 100° F
T_i = 500° F

4 LAYER PROBLEM



DATA ENTRY: .833 → Z, 100 → Y, 500 → X

Layer	X	Y	Z
1	.500	300	0
2	.500	.667	40
3	.667	.833	.10
4	.833	6	0

Results: q/L = 1031.558 Btu/hr. ft.

B. Same as above except k_3 = .01 Btu/hr. ft. °F (Better insulation).

Results: q/L = 112.008 Btu/ hr. ft.

Step	Key	Code	Display x	Display y	Display z
0 0	CLEAR	20		ENTER	
(+) 1	STOP	41	T_i	T_o	r_o
2	x⇄y	30			
3	−	34			
4	y→( )	40			
5	b	14			
6	↓	25			
7	y→( )	40			
8	a	13			
9	CLEAR	20			
a	1	01			
b	ACC +	60		ENTER	
c	f	15	r_{cn}	h	0
d	STOP	41	r_{in}	r_{on}	k
1 0	IF FLAG	43			
(+) 1	3	03			
2	b	14			
3	x→( )	23			
4	d	17			
5	0	00			
6	ROLL ↑	22			
7	IF x = y	50			
8	2	02			
9	d	17			
a	ROLL ↓	31			
b	d	17			
c	÷	35			
d	a	13			
2 0	x⇄y	30			
(+) 1	ln x	65			
2	×	36			
3	↓	25			
4	x⇄y	30			
5	÷	35			
6	0	00			
7	ACC +	60			
8	↑	27			
9	↑	27			
a	GO TO ( )	44			
b	0	00			
c	a	13			
d	a	13			

Step	Key	Code	Display x	Display y	Display z
3 0	ROLL ↑	22			
(+) 1	÷	35			
2	d	17			
3	÷	35			
4	0	00			
5	ACC +	60			
6	↑	27			
7	↑	27			
8	GO TO ( )	44			
9	0	00			
a	a	13			
b	1	01			
c	↑	27			
d	e	12			
4 0	÷	35			
(+) 1	2	02			
2	×	36			
3	π	56			
4	×	36			
5	a	13			
6	×	36			
7	b	14			
8	×	36			
9	CLEAR x	37			
a	CONT	47		DISPLAY	
b	END	46	0	q/L	0
c					
d					
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					

Step	Key	Code	Display x	Display y	Display z
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					
0					
1					
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a					
b					
c					
d					

Storage

f	
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d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
0						0						0					
1						1						1					
2						2						2					
3						3						3					
4						4						4					
5						5						5					
6						6						6					
7						7						7					
8						8						8					
9						9						9					
a						a						a					
b						b						b					
c						c						c					
d						d						d					
0						0						0					
1						1						1					
2						2						2					
3						3						3					
4						4						4					
5						5						5					
6						6						6					
7						7						7					
8						8						8					
9						9						9					
a						a						a					
b						b						b					
c						c						c					
d						d						d					

0						0					
1						1					
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3						3					
4						4					
5						5					
6						6					
7						7					
8						8					
9						9					
a						a					
b						b					
c						c					
d						d					

Storage	
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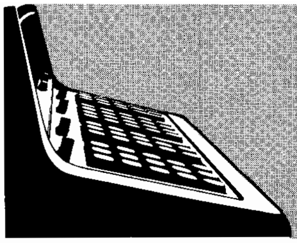
0	

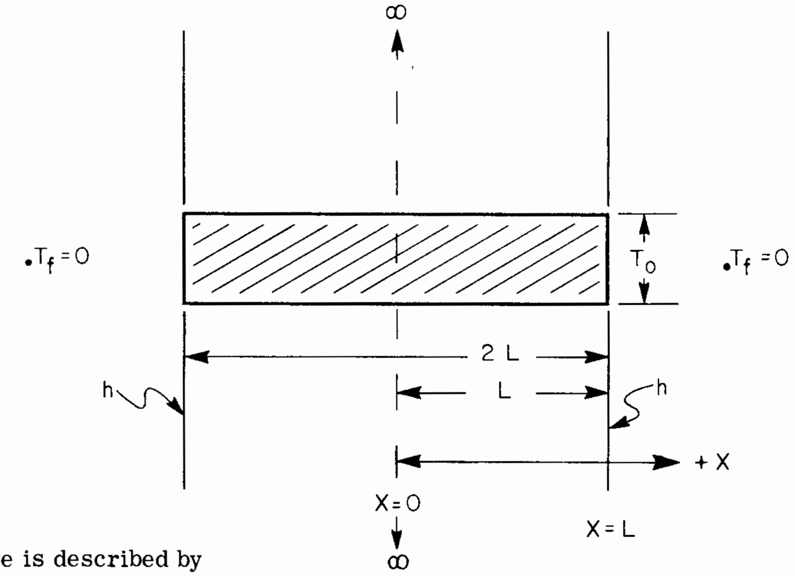


9100B ONLY
PART NO.
09100-73852

TRANSIENT CONDUCTION IN A SLAB

This program calculates, as a function of time and position, the temperature of a plane in a slab which has been heated to an initial temperature and then placed in a fluid of a different temperature. This is equivalent to plunging a heated bar into a quenching medium. The program assumes the slab is infinite, therefore, the problem involves one dimensional transient conduction.

The temperature of the fluid is taken to be zero and used as a reference. For example, if the temperature of the fluid is actually 40°F and the slab is initially at 100°F, the user would input 60°F (100 - 40) as the initial temperature of the slab. The actual temperature of a plane in the slab at a later time is then the calculated value plus 40°F (see example B).



The temperature is described by

$$T = 2T_o \sum_{n=1}^{\infty} e^{-\lambda_n^2 \alpha \tau} \frac{\sin(\lambda_n L)}{\lambda_n L + \sin(\lambda_n L)\cos(\lambda_n L)} \cdot \cos(\lambda_n X)$$

where λ_n is the nth root of

$$(\lambda_n L)\tan(\lambda_n L) - N_{Bi} = 0$$

and N_{Bi} is the Biot modulus $(N_{Bi} = hL/k)$.

Reference: Heat Transfer, Alan J. Chapman
Macmillan Company, New York, 1967.

Nomenclature:

T_o - Initial temperature of the slab

α - Thermal diffusivity of the slab

k - Thermal conductivity of the slab

h - Film coefficient

L - One-half the width of the slab

τ - Independent time variable

X - Independent space variable

T - Dependent temperature variable

T_f - Temperature of the fluid

NOTES:

1. The program performs the summation until adding the next term changes it less than 10^{-5}. To change this tolerance go to location (-5)(d) and enter the desired exponent.
2. The calculation of the roots ($\lambda_n L$) may be seen by placing a PAUSE at location (1) (c). The root ($\lambda_n L$) is displayed in the X register as the solution converges. Place a STOP at location (4)(1) for a display of the calculated root in the X register.
3. The execution time is about two minutes.

USER INSTRUCTIONS

SET: ☐ RADIANS

PRESS: END

ENTER PROGRAM: Side A followed by Side B

PRESS: CONTINUE

DISPLAY

0 ——— Z
0 ——— Y
1 ——— X

ENTER DATA: $N_{Bi} \rightarrow Z$, $T_o \rightarrow Y$, $L \rightarrow X$

PRESS: CONTINUE

DISPLAY

0 ——— Z
0 ——— Y
2 ——— X

ENTER DATA: $\alpha \rightarrow Z$, $\tau \rightarrow Y$, $X \rightarrow X$

PRESS: CONTINUE

DISPLAY

T ——— Z
n ——— Y
X ——— X

n is the number of terms used in the summation

To re-run problem with different X, τ, or α :

PRESS: CONTINUE

To run new problem:

PRESS: END

NOTE: Any consistent set of units may be used.

EXAMPLES

A.

N_{Bi} = 20
T_o = 120°F (T_f = 0°F)
L = .4 ft.
α = .02 ft.^{2}/hr.
τ = 1 hr.
X = .1 ft.

Results
T = 105.49°F
n = 4
X = .1 ft.

B.

N_{Bi} = 20
Temperature of the slab initially is 180°F
Temperature of the fluid is 30°F
T_o = 180° - 30° = 150°F
L = .4 ft.
α = .02 ft.^{2}/hr.
τ = 1 hr.
X = .1 ft.

Results
T = 131.87°F
n = 4
X = .1 ft.
Actual temperature is T + 30°F = 161.87°F

Step	Key	Code	Display		
			x	y	z
0 0	GO TO ( )	44			
(+) 1	8	10			
2	0	00			
3	•	21			
4	1	01			
5	x→( )	23			
6	7	07			
7	c	16			
8	GO TO ( )	44			
9	0	00			
a	c	16			
b	SET FLAG	54			
c	x→( )	23			
d	d	17			
1 0	↑	27			
(+) 1	tan x	71			
2	×	36			
3	b	14			
4	−	34			
5	↓	25			
6	↑	27			
7	y⇄( )	24			
8	6	06			
9	×	36			
a	↑	27			
b	d	17			
c	CONT	47			
d	IF FLAG	43			
2 0	4	04			
(+) 1	1	01			
2	ROLL ↓	31			
3	CLEAR x	37			
4	IF x<y	52			
5	3	03			
6	0	00			
7	IF x=y	50			
8	ROLL ↑	22			
9	GO TO ( )	44			
a	0	00			
b	b	14			
c	CHG SIGN	32			
d	•	21			

Step	Key	Code	Display		
			x	y	z
3 0	1	01			
(+) 1	y⇄( )	24			
2	7	07			
3	×	36			
4	y→( )	40			
5	7	07			
6	d	17			
7	+	33			
8	IF x=y	50			
9	0	00			
a	b	14			
b	↓	25			
c	GO TO ( )	44			
d	0	00			
4 0	c	16			
(+) 1	CONT	47			
2	↑	27			
3	x←( )	67			
4	c	16			
5	↑	27			
6	π	56			
7	+	33			
8	y→( )	40			
9	c	16			
a	↓	25			
b	CHG SIGN	32			
c	x→( )	23			
d	6	06			
5 0	↓	25			
(+) 1	RETURN	77			
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					

Step	Key	Code	Display		
			x	y	z
8 0	CLEAR	20			
(+) 1	1	01	ENTER		
2	STOP	41	L	T_0	N_{Bi}
3	x→( )	23			
4	−	34			
5	f	15			
6	y→( )	40			
7	−	34			
8	c	16			
9	ROLL ↑	22			
a	x→( )	23			
b	b	14			
c	CLEAR	20			
d	x→( )	23			
9 0	−	34			
(+) 1	a	13			
2	x→( )	23			
3	−	34			
4	b	14			
5	x→( )	23			
6	c	16			
7	GO TO ( )	44			
8	−	34			
9	0	00			
a	0	00			
b	CONT	47			
c	CONT	47			
d	CONT	47			

Storage

	+	−
f		L
e		$\alpha\ \tau$
d		X
c	$n\ \pi$	T_0
b	N_{Bi}	n
a		Σ
9		
8		
7		
6		
5		
4		
3		
2		
1		
0		

Step	Key	Code	Display x	y	z
0 0	2	02			
(−) 1	CHG SIGN	32			
2	x→( )	23			
3	6	06			
4	CHG SIGN	32	ENTER		
5	STOP	41	X	τ	a
6	x→( )	23			
7	−	34			
8	d	17			
9	ROLL ↓	31			
a	×	36			
b	y→( )	40			
c	−	34			
d	e	12			
1 0	x←( )	67			
(−) 1	−	34			
2	b	14			
3	↑	27			
4	1	01			
5	+	33			
6	y→( )	40			
7	−	34			
8	b	14			
9	GO TO ( )	44			
a	▲SUB▼	77			
b	+	33			
c	0	00			
d	3	03			
2 0	x→( )	23			
(−) 1	−	34			
2	9	11			
3	CLEAR x	37			
4	↓	25			
5	cos x	73			
6	x⇄y	30			
7	sin x	70			
8	×	36			
9	ROLL ↓	31			
a	+	33			
b	↓	25			
c	÷	35			
d	y⇄( )	24			

Step	Key	Code	Display x	y	z
3 0	−	34			
(−) 1	9	11			
2	x←( )	67			
3	−	34			
4	f	15			
5	÷	35			
6	↓	25			
7	↑	27			
8	×	36			
9	x⇄y	30			
a	↑	27			
b	x←( )	67			
c	−	34			
d	e	12			
4 0	×	36			
(−) 1	↓	25			
2	CHG SIGN	32			
3	e^x	74			
4	y⇄( )	24			
5	−	34			
6	9	11			
7	×	36			
8	x←( )	67			
9	−	34			
a	d	17			
b	ROLL ↑	22			
c	×	36			
d	CLEAR x	37			
5 0	↓	25			
(−) 1	cos x	73			
2	×	36			
3	x←( )	67			
4	−	34			
5	a	13			
6	+	33			
7	y→( )	40			
8	−	34			
9	a	13			
a	−	34			
b	|y|	55			
c	ENTER EXP	26			
d	5	05			

Step	Key	Code	Display x	y	z
6 0	CHG SIGN	32			
(−) 1	IF x>y	53			
2	6	06			
3	7	07			
4	GO TO ( )	44			
5	1	01			
6	0	00			
7	x←( )	67			
8	−	34			
9	a	13			
a	↑	27			
b	2	02			
c	×	36			
d	x←( )	67			
7 0	−	34			
(−) 1	c	16			
2	×	36			
3	x←( )	67			
4	−	34			
5	b	14			
6	↑	27			
7	x←( )	67			
8	−	34			
9	d	17			
a	CONT	47	DISPLAY		
b	STOP	41	X	n	T
c	GO TO ( )	44			
d	+	33			

Storage	
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2	
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0	

	Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
				x	y	z				x	y	z				x	y	z
8	0	8	10				0						0					
(-)	1	C	16				1						1					
	2	END	46				2						2					
	3						3						3					
	4						4						4					
	5						5						5					
	6						6						6					
	7						7						7					
	8						8						8					
	9						9						9					
	a						a						a					
	b						b						b					
	c						c						c					
	d						d						d					

0						0						0					
1						1						1					
2						2						2					
3						3						3					
4						4						4					
5						5						5					
6						6						6					
7						7						7					
8						8						8					
9						9						9					
a						a						a					
b						b						b					
c						c						c					
d						d						d					

0						0					
1						1					
2						2					
3						3					
4						4					
5						5					
6						6					
7						7					
8						8					
9						9					
a						a					
b						b					
c						c					
d						d					

Storage	
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HEWLETT · PACKARD

HEWLETT · PACKARD

HEWLETT · PACKARD

HEWLETT · PACKARD

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
0						0						0					
1						1						1					
2						2						2					
3						3						3					
4						4						4					
5						5						5					
6						6						6					
7						7						7					
8						8						8					
9						9						9					
a						a						a					
b						b						b					
c						c						c					
d						d						d					

Step	Key	Code	x	y	z	Step	Key	Code	x	y	z	Step	Key	Code	x	y	z
0						0						0					
1						1						1					
2						2						2					
3						3						3					
4						4						4					
5						5						5					
6						6						6					
7						7						7					
8						8						8					
9						9						9					
a						a						a					
b						b						b					
c						c						c					
d						d						d					

Step	Key	Code	x	y	z	Step	Key	Code	x	y	z
0						0					
1						1					
2						2					
3						3					
4						4					
5						5					
6						6					
7						7					
8						8					
9						9					
a						a					
b						b					
c						c					
d						d					

Storage	
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