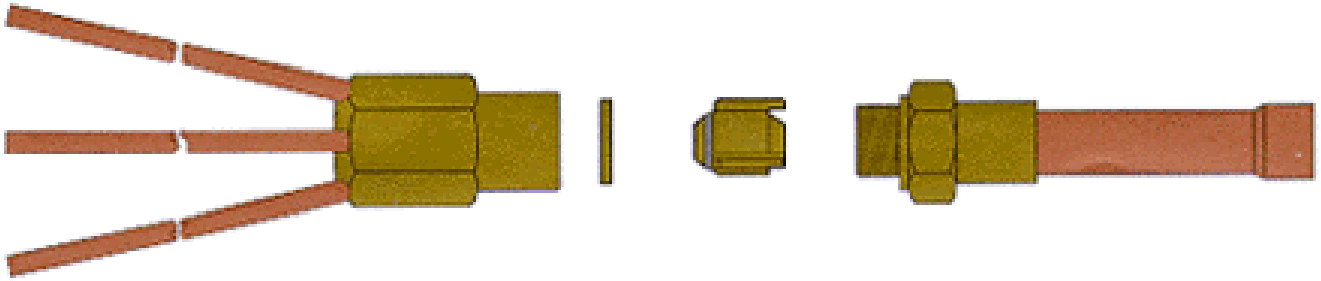
A Modern Approach to Selecting Capillary Tubes

Andy Schoen
Manager, Technical Services
Tecumseh Products Co.

Expansion Devices

Hand Expansion Valve

Short Tube Restrictor



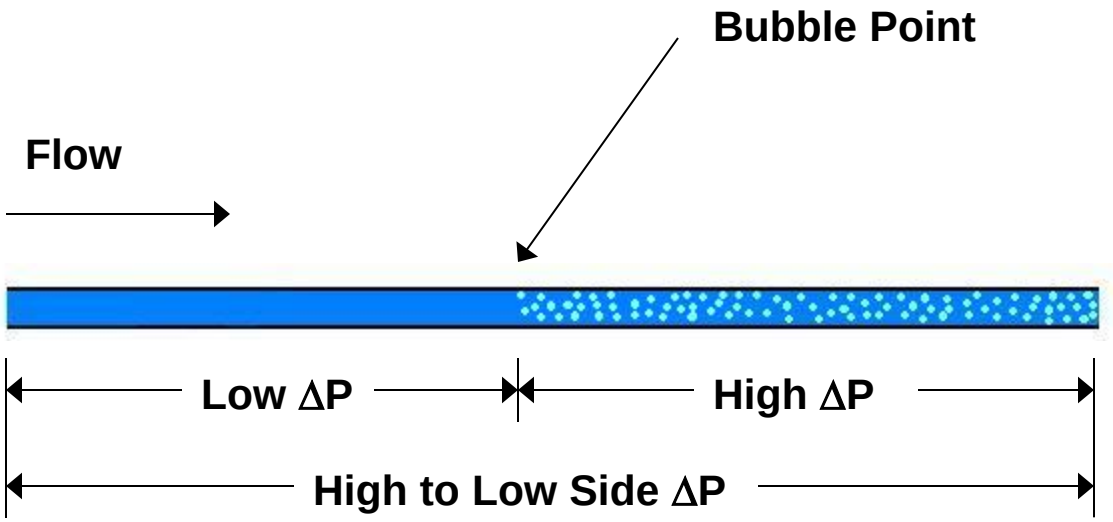
Automatic Expansion Valve

Thermostatic Expansion Valve

Electric Expansion Valve

Capillary Tube

Capillary Tube Flow



Henry Ehrens

THEORY AND FIELD PROBLEMS OF THE CAPILLARY TUBE

By HENRY EHRENS
Sealed Unit Parts CO., Inc.

INTRODUCTION

The capillary or restrictor tube needs no formal introduction to refrigeration service or design engineers. In fact everyone in the refrigeration industry has either heard of, or has had some experience with the cap tube, as we shall call it from no on.

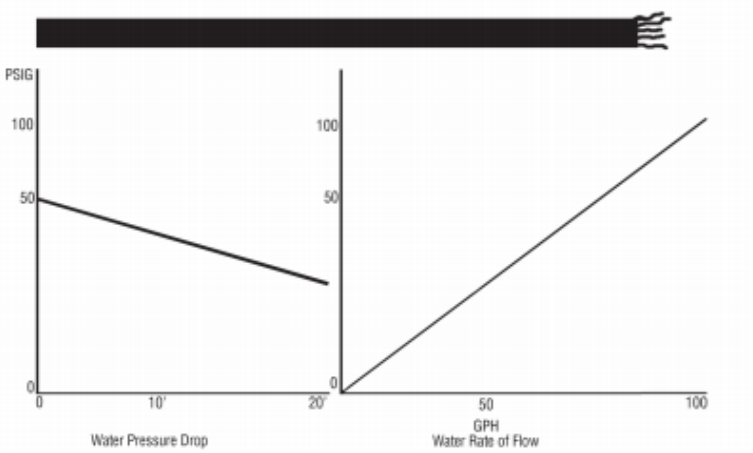
Of all the controls used in the refrigeration industry, if we pick out those that are used as pressure reducing devices, we find that they work the same way, in principle, in other industries. For instance, the automatic expansion valve is the same type of control used in reducing the pressure from oxy-acetylene tanks. The same type of valve is also used in water or air reduction. Some of the principles of the thermostatic expansion valve are also used in gas heating controls.

But when the cap tube is used in other industries it can only be used as a pressure reducing device, never as a controlling or regulating mechanism.

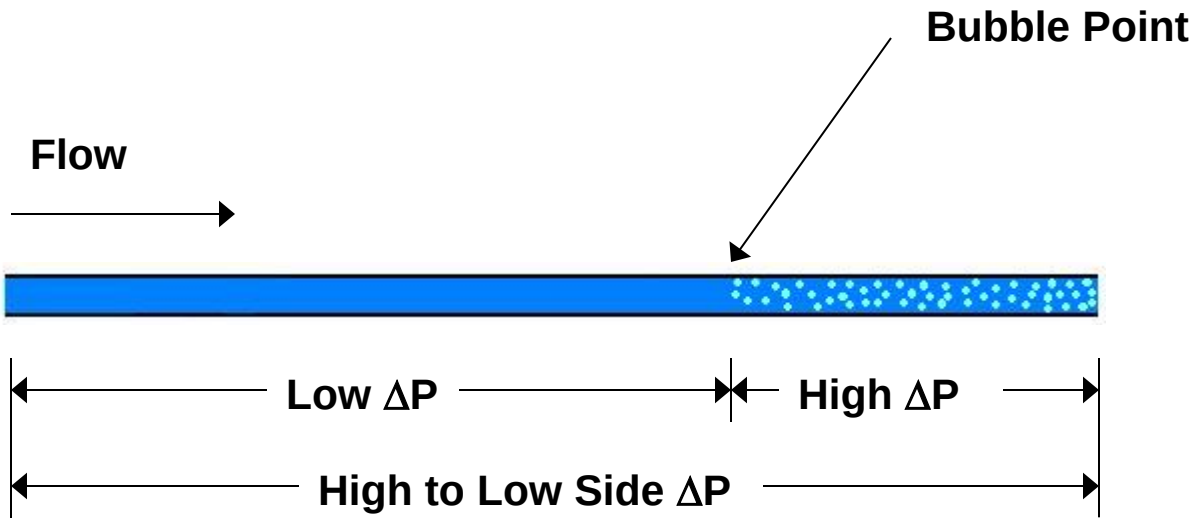
We shall see later on how a fixed length of tubing with a fixed bore can regulate the flow of refrigerant, and therefore can be classified as a refrigerant control.

What makes the cap tube unique to the refrigeration design engineer is that the cap tube is not an "off the shelf" item. In fact it that can go wrong with a cap tube, is that it can become restricted or clogged, and it's always protected by a strainer to prevent this from happening.

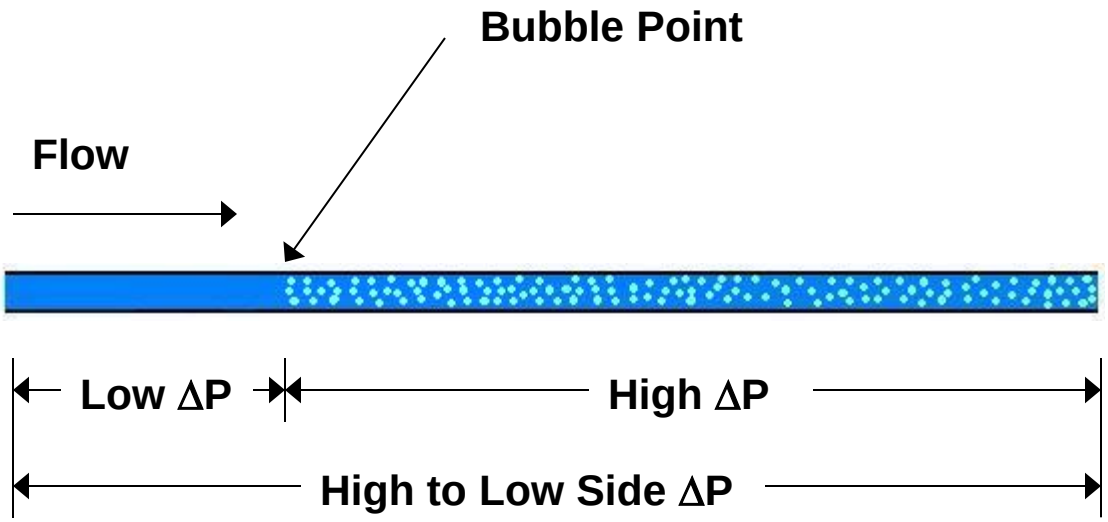
But the cap tube does become clogged and restricted despite the strainer, which we will discuss after we look at the theory and principles of cap tubes.



Lower Ambient Temperature



Higher Ambient Temperature



Supco Cap Tube Chart

SINGLE FEED

REF	HP	LOW	MED	HIGH
R12/R416A	1/8 HP	110" # 5	84" # 5	48" # 5
	1/6 HP	71" # 5	96" # 1	72" # 1
	1/5 HP	54" # 1	36" # 1	24" # 1
	1/4 HP	43" # 1	90" # 2	60" # 2
	1/3 HP	93" # 2	72" # 2	36" # 2
	1/2 HP	96" # 3	48" # 3	90" # 4
	3/4 HP	60" # 3	92" # 4	72" # 4
	1 HP	36" # 3	84" # 4	54" # 4
	1-1/2 HP	84" # 4	60" # 4	43" # 4
	2 HP	55" # 4	40" # 4	26" # 4
R134A / R401A R401B/R406A R409A/R500	1/8 HP	121" # 5	92" #5	53" # 5
	1/6 HP	78" # 5	106" #1	79" # 1
	1/5 HP	59" # 1	39" #1	26" # 1
	1/4 HP	47" # 1	99" #2	66" # 2
	1/3 HP	102" # 2	79" #2	39" # 2
	1/2 HP	105" # 3	52" # 3	99" # 4
	3/4 HP	66" # 3	101" #4	79" # 4
	1 HP	39" # 3	92" #4	59" # 4
	1-1/2 HP	92" # 4	66" #4	47" # 4
	2 HP	61" # 4	44" #4	29" # 4
R22	1/8 HP	132" # 5	101" # 5	58" # 5
	1/6 HP	86" # 5	116" # 1	86" # 1
	1/5 HP	64" # 1	42" # 1	28" # 1
	1/4 HP	51" # 1	109" # 2	72" # 2
	1/3 HP	112" # 2	87" # 2	43" # 2
	1/2 HP	115" # 3	57" # 3	109" # 4
	3/4 HP	72" # 3	111" # 4	87" # 4
	1 HP	42" # 3	101" # 4	65" # 4
	1-1/2 HP	101" # 4	72" # 4	51" # 4
	2 HP	67" # 4	48" # 4	32" # 4

J/B Cap Tube Chart

REFRIGERATION REFEREN(

Fan Cooled Units Only. Add

SINGLE FEED

H.P.	LOW		MED		HIGH	
R12 / R416A						
1/8	TC-26	110"	TC-26	84"	TC-26	48"
1/6	TC-26	71"	TC-31	96"	TC-31	72"
1/5	TC-31	54"	TC-31	36"	TC-31	24"
1/4	TC-31	43"	TC-42	90"	TC-42	60"
1/3	TC-42	93"	TC-42	72"	TC-42	36"
1/2	TC-49	96"	TC-49	48"	TC-64	90"
3/4	TC-49	60"	TC-64	92"	TC-64	72"
1	TC-49	36"	TC-64	84"	TC-64	54"
1-1/2	TC-64	84"	TC-64	60"	TC-64	43"
2	TC-64	55"	TC-64	40"	TC-64	26"
R134A / R401A / R401B / R406A, R409A / R500						
1/8	TC-26	121"	TC-26	92"	TC-26	53"
1/6	TC-26	78"	TC-31	106"	TC-31	79"
1/5	TC-31	59"	TC-31	39"	TC-31	26"
1/4	TC-31	47"	TC-42	99"	TC-42	66"
1/3	TC-42	102"	TC-42	79"	TC-42	39"
1/2	TC-49	105"	TC-49	52"	TC-64	99"
3/4	TC-49	66"	TC-64	101"	TC-64	79"
1	TC-49	39"	TC-64	92"	TC-64	59"
1-1/2	TC-64	92"	TC-64	66"	TC-64	47"
2	TC-64	61"	TC-64	44"	TC-64	29"

Cap Tube Sizing Problem

- Refrigerant R-134a
- Medium Temp Cooler
- 1/4 HP Compressor

Supco Cap Tube Chart

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	1/2 HP	96" # 3	48" # 3	90" # 4
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	2 HP	67" # 4	48" # 4	32" # 4

Compressor HP vs Rating

1/4 HP R-134a Commercial Temp Compressors

Model	Btu/h
TPA0421YXA	2050
TPA9421YXA	2075
TPA9423YXA	2320
AEA9423YXA	2390
TPB9423YAA	2675

Supco Cap Tube Chart

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Wolf and Pate Correlations

1995

$$\pi_8 = 1.8925\pi_1^{-0.484}\pi_2^{-0.824}\pi_4^{1.369}\pi_5^{0.0187}\pi_6^{0.773}\pi_7^{0.265}$$

where $\pi_5 = d_c^2 c_p \Delta t_{sc} / \nu_f^2 \mu_f^2$ and $2°\text{F} < \Delta t_{sc} < 30°\text{F}$.

2002

$$\pi_9 = 0.07602\pi_1^{-0.4583}\pi_3^{0.07751}\pi_5^{0.7342}\pi_6^{-0.1204}\pi_7^{0.03774}\pi_8^{-0.04085}\pi_{11}^{0.1768}$$

where $\pi_7 = \Delta T_{sc} C_{pfc} D_c^2 / \mu_{fc}^2 \nu_{fc}^2$ and $2°\text{F} < \Delta T_{sc} < 30°\text{F}$

Characteristics Considered

- Capillary Tube Length and ID
- Pressure (liquid and vapor)
- Density (liquid and vapor)
- Viscosity (liquid and vapor)
- Specific Heat (liquid and vapor)
- Surface Tension (liquid)
- Amount of Subcooling
- Latent Heat of Vaporization
- Heat Exchange Length

Edgar Buckingham

Buckingham π Correlation

$$f(q_1, q_2, \ldots, q_n) = 0$$

$$\pi_1 = f(\pi_2, \pi_3, \ldots, \pi_{n-m})$$

$$\pi_1 = \pi_2^{a1} \cdot \pi_3^{a2} \cdot \ldots \cdot \pi_{n-m}^{a(n-m-1)}$$

15 Different Parameters

π Parameter	Definition	Description
π_1	L_c/D_c	Geometry effect
π_2	L_i/D_c	Geometry effect
π_3	L_{hx}/D_c	Geometry effect
π_4	D_s/D_c	Geometry effect
π_5	$P_{capin} D_c^2 / \mu_{fc}^2 \nu_{fcT}$	Inlet pressure
π_6	$P_{suctin} D_c^2 / \mu_{fc}^2 \nu_{fc}$	Inlet pressure
π_7 (subcooled)	$\Delta T_{sc} C_{pfc} D_c^2 / \mu_{fc}^2 \nu_{fc}^2$	Inlet condition
π_7 (quality)	$1 - x$	Inlet condition
π_8	$\Delta T_{sh} C_{pfc} D_c^2 / \mu_{fc}^2 \nu_{fc}^2$	Inlet condition
π_9	$\dot{m}/D_c \mu_{fc}$	Flow rate
π_{10}	ν_{gc}/ν_{fc}	Density effect
π_{11}	$(\mu_{fc} - \mu_{gc})/\mu_{fc}$	Viscous effect
π_{12}	$h_{fgc} D_c^2 / \mu_{fc}^2 \nu_{fc}^2$	Vaporization effect
π_{13}	μ_{gs}/μ_{fc}	Viscous effect
π_{14}	ν_{gs}/ν_{fc}	Density effect
π_{15}	C_{pgs}/C_{pfc}	Specific heat effect

Wolf and Pate 2002 Correlation

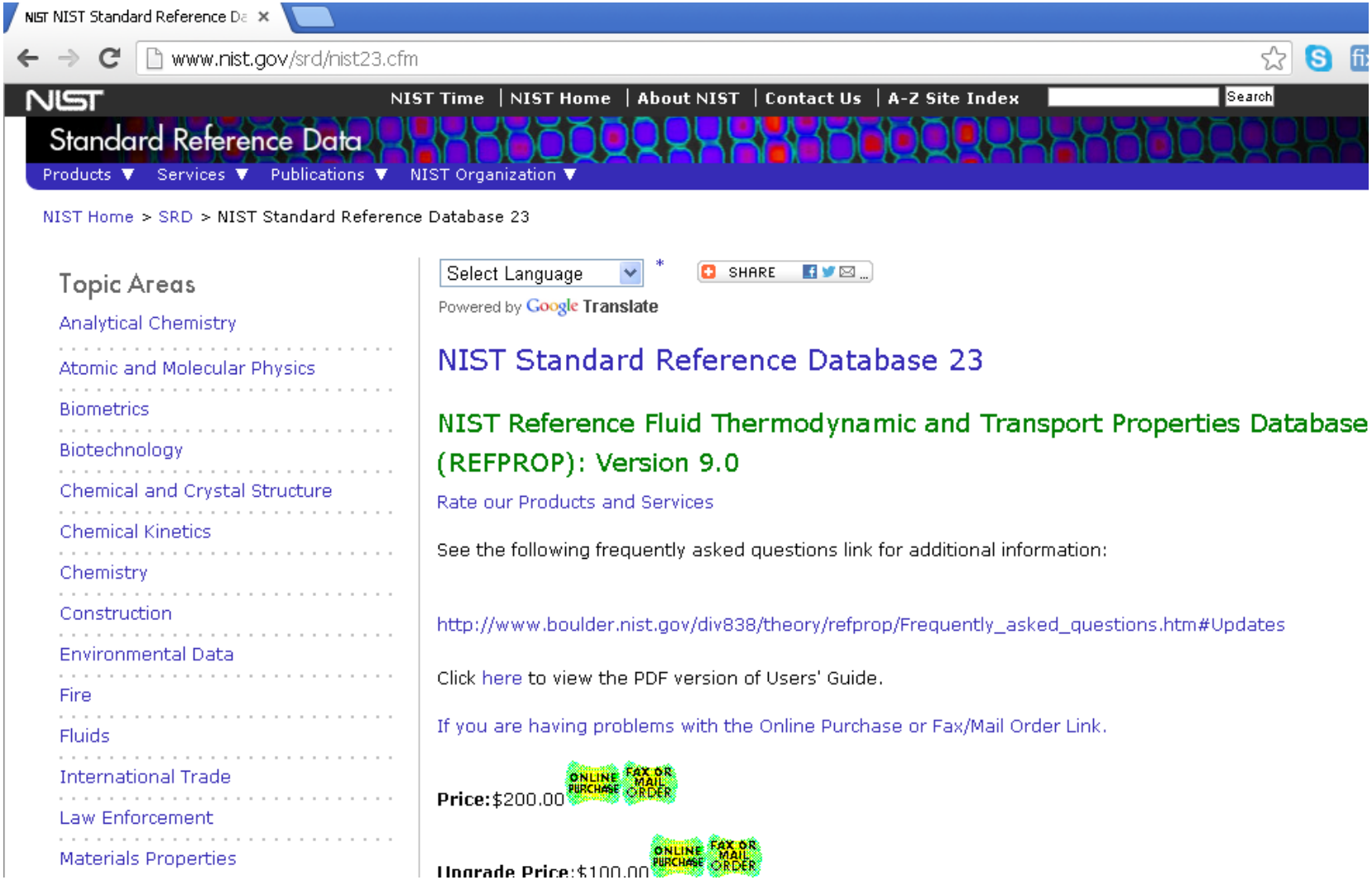
$$\pi_9 = 0.07602\pi_1^{-0.4583}\pi_3^{0.07751}\pi_5^{0.7342}\pi_6^{-0.1204}\pi_7^{0.03774}\pi_8^{-0.04085}\pi_{11}^{0.1768}$$

where $\pi_7 = \Delta T_{sc} C_{pfc} D_c^2 / \mu_{fc}^2 \nu_{fc}^2$ and $2°\text{F} < \Delta T_{sc} < 30°\text{F}$

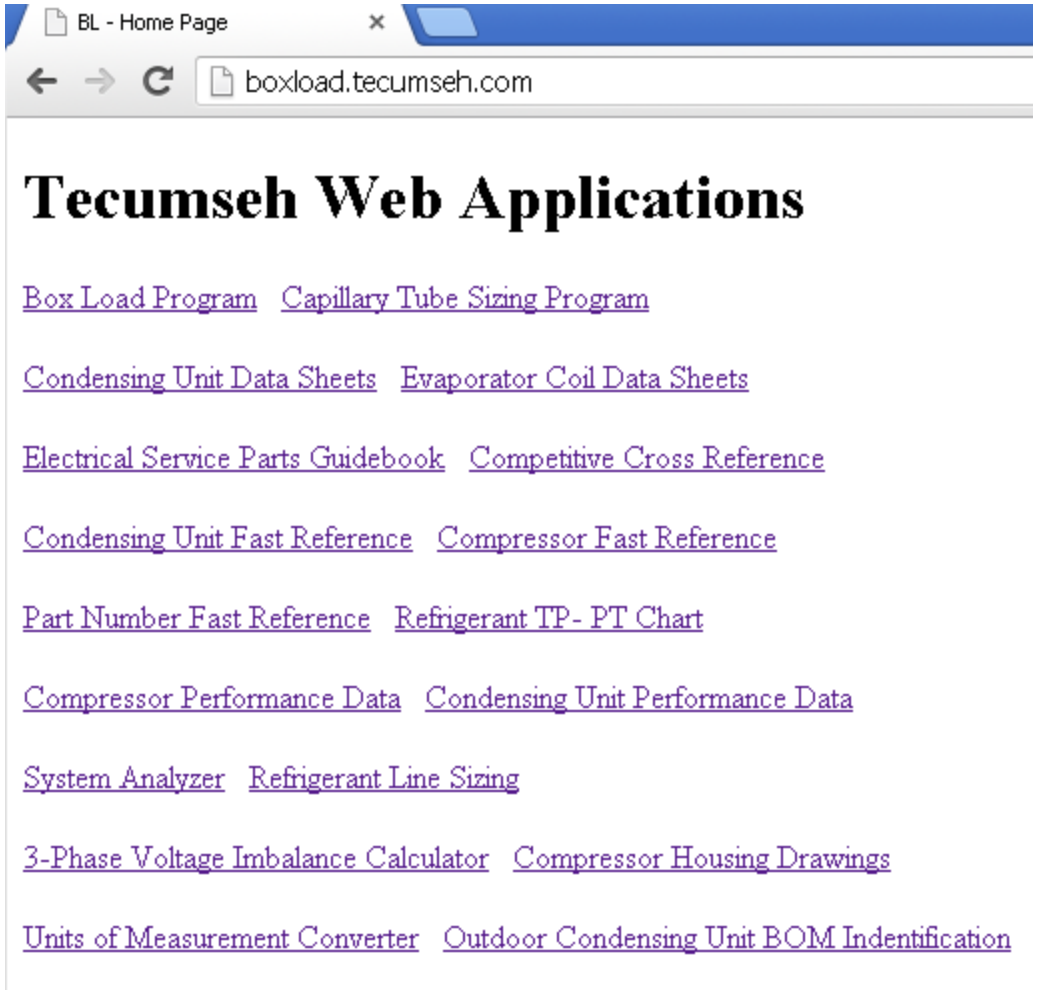
Characteristics To Determine

- Capillary Tube Length and ID
- Pressure (liquid and vapor)
- Density (liquid and vapor)
- Viscosity (liquid and vapor)
- Specific Heat (liquid and vapor)
- Amount of Subcooling
- Latent Heat of Vaporization
- Heat Exchange Length

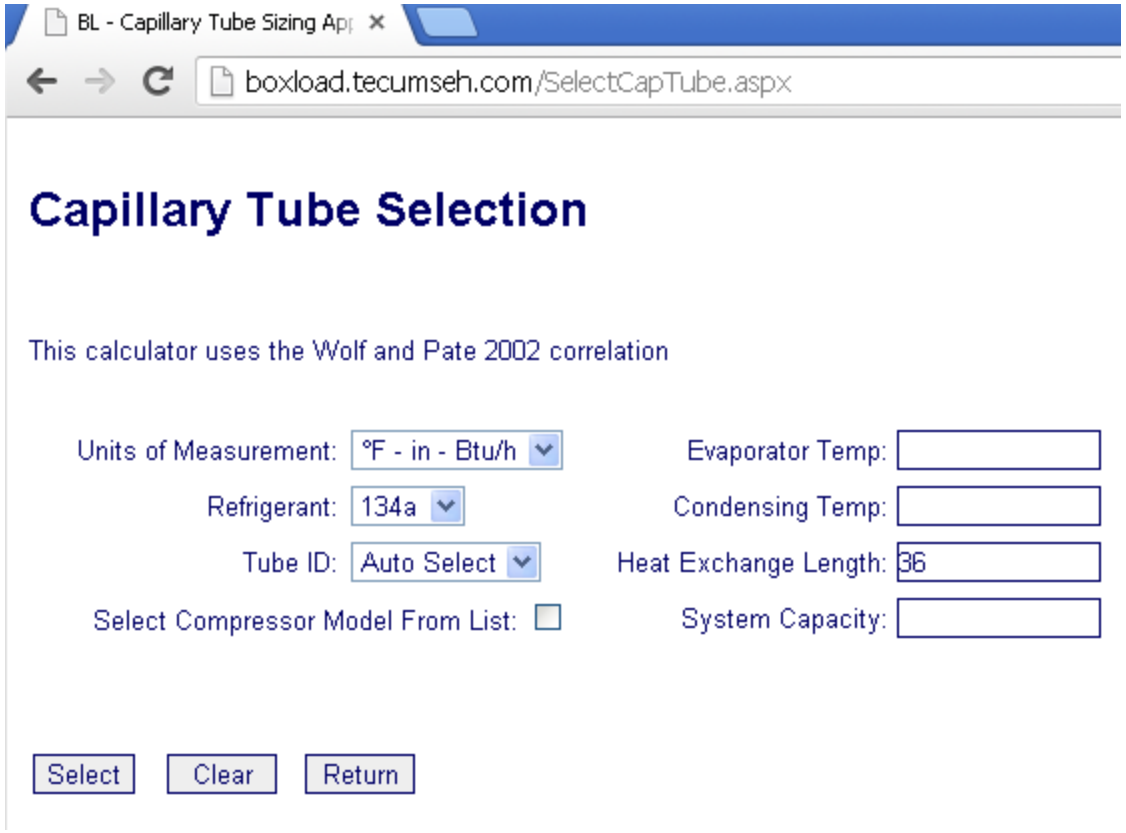
NIST Refprop



Tecumseh Web App Site



Capillary Tube Sizing Web App



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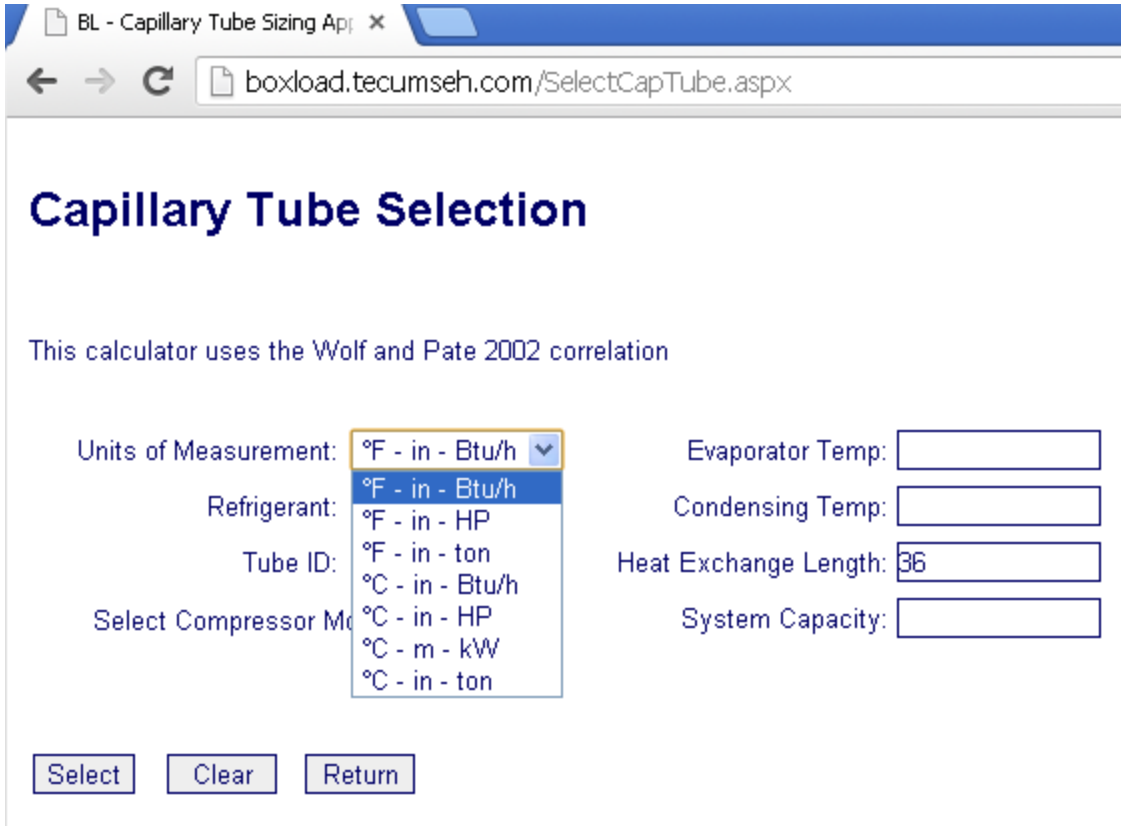
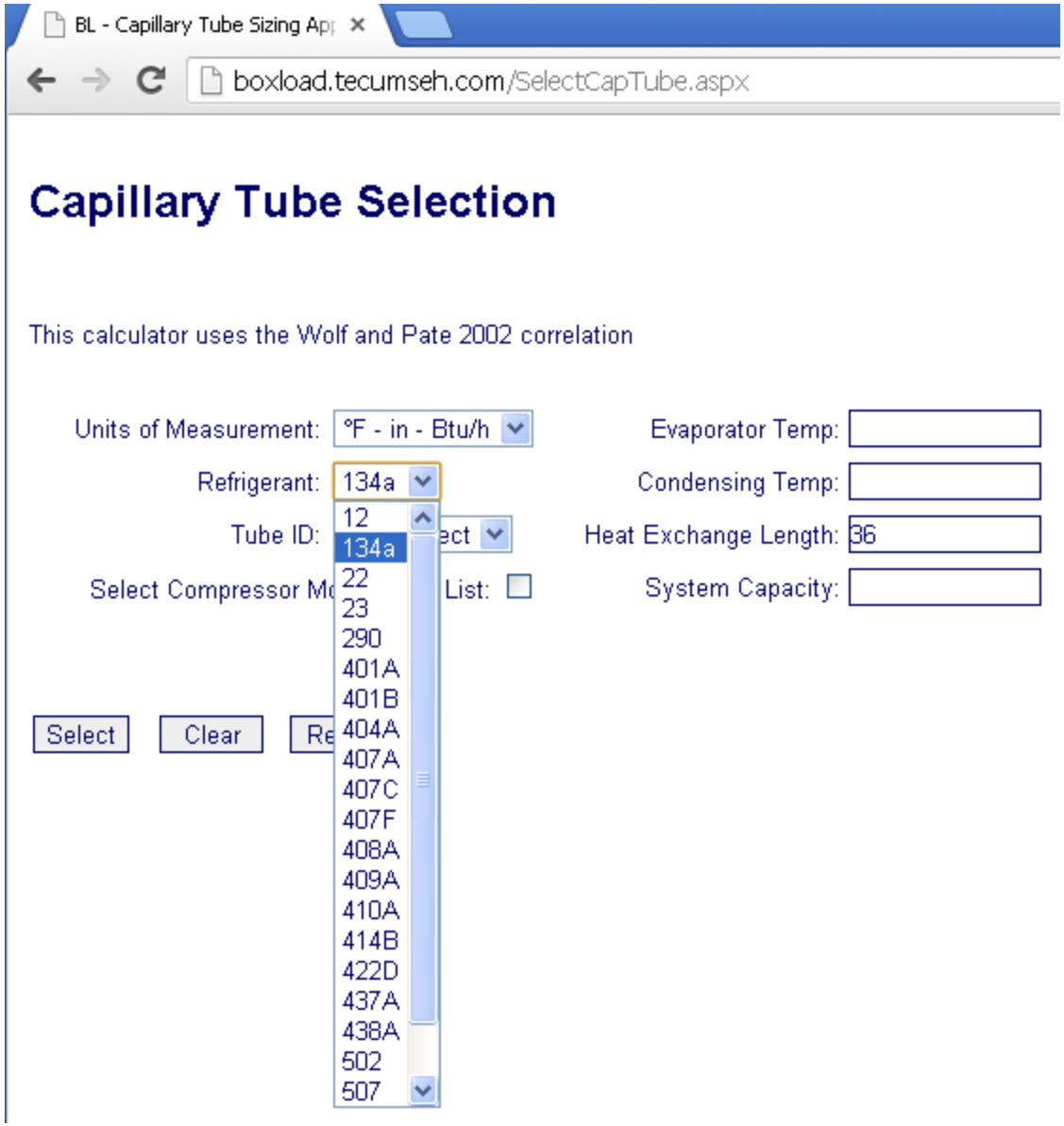


Capillary Tube Sizing Web App



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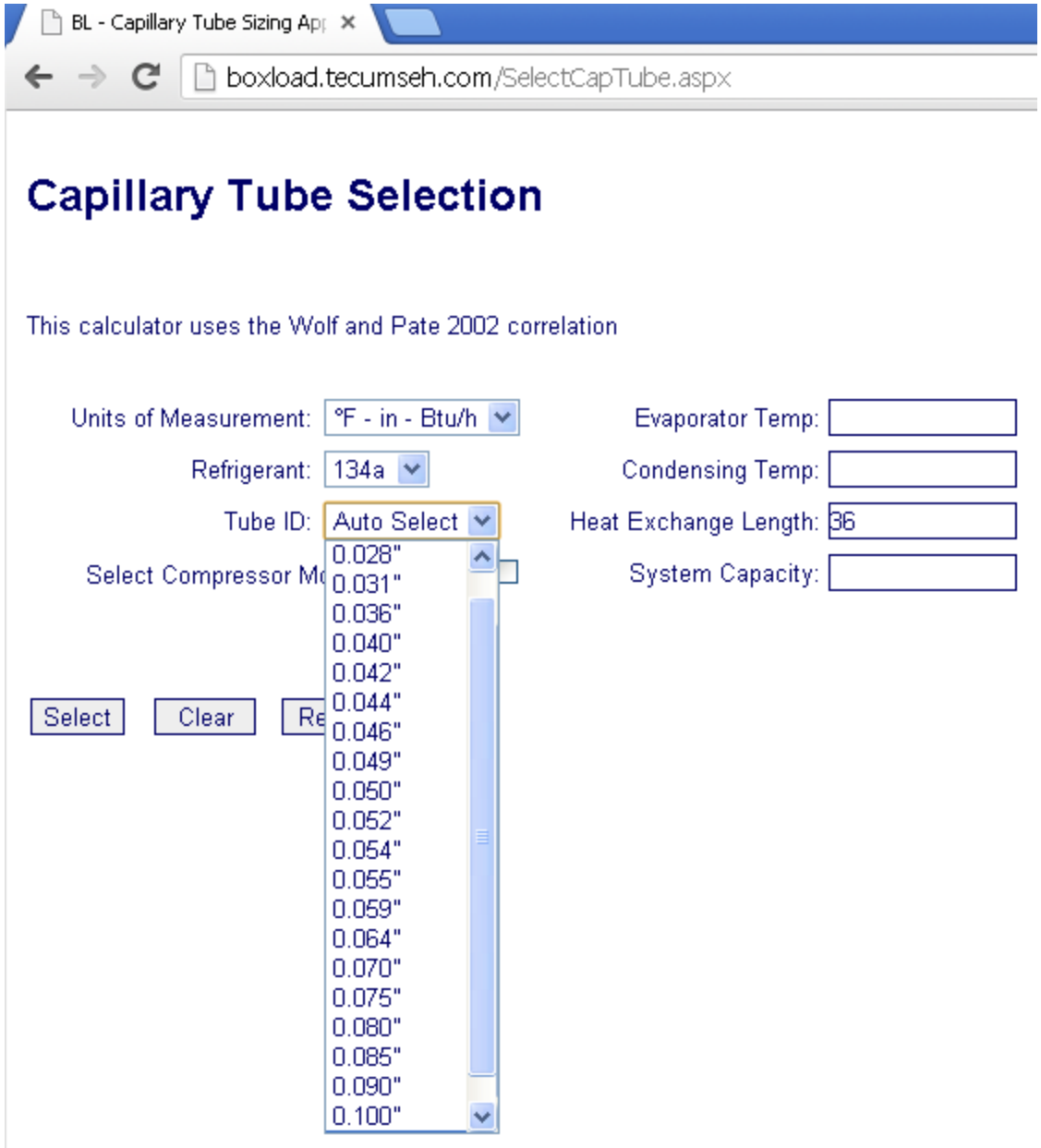
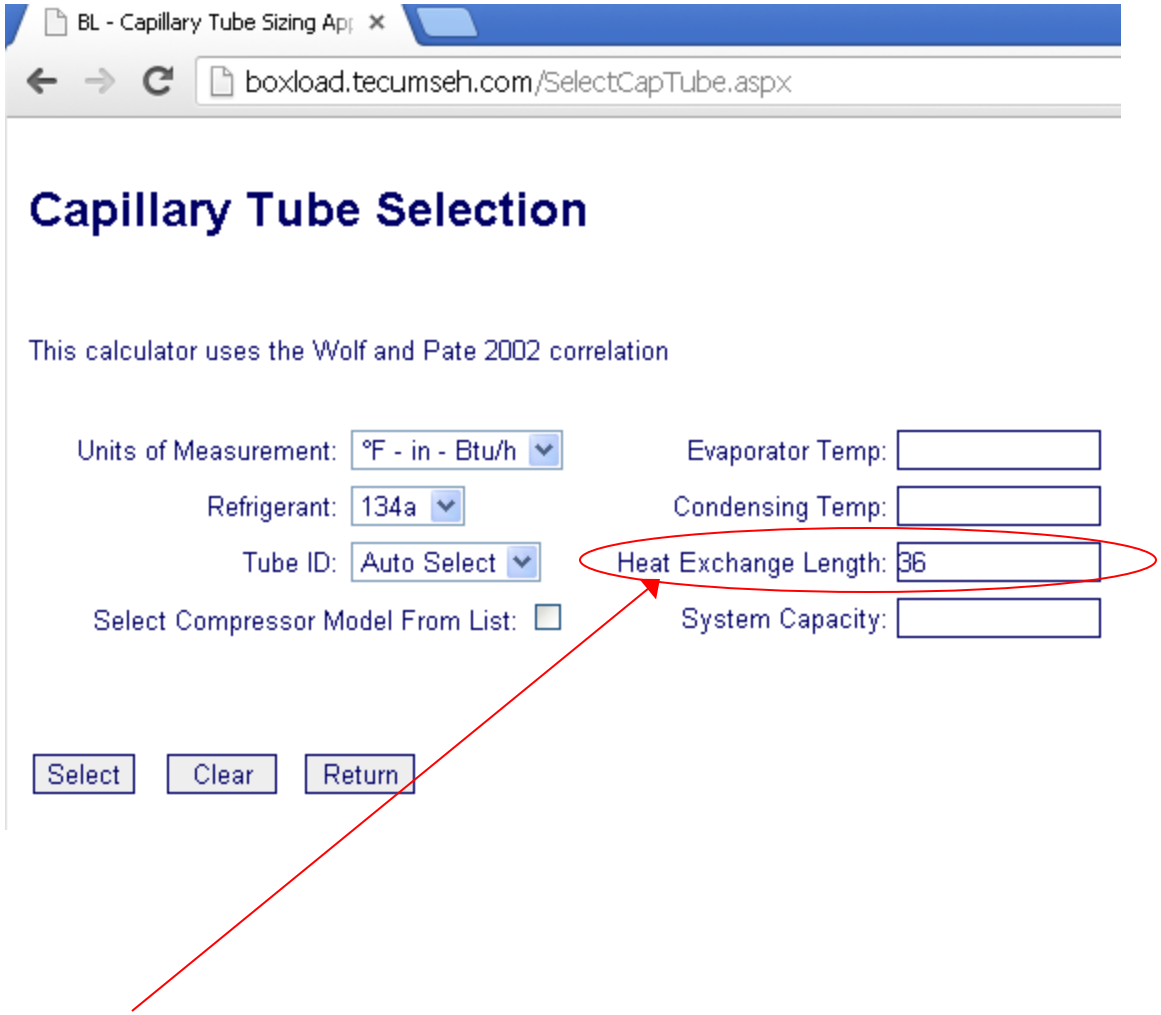
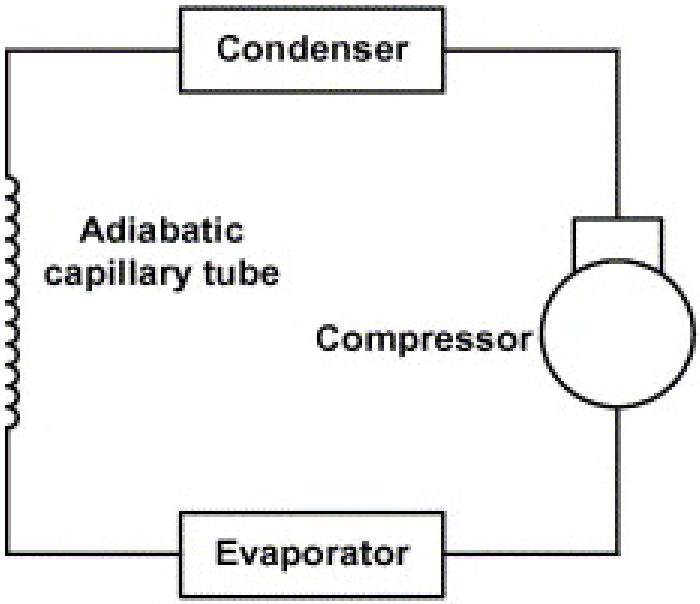
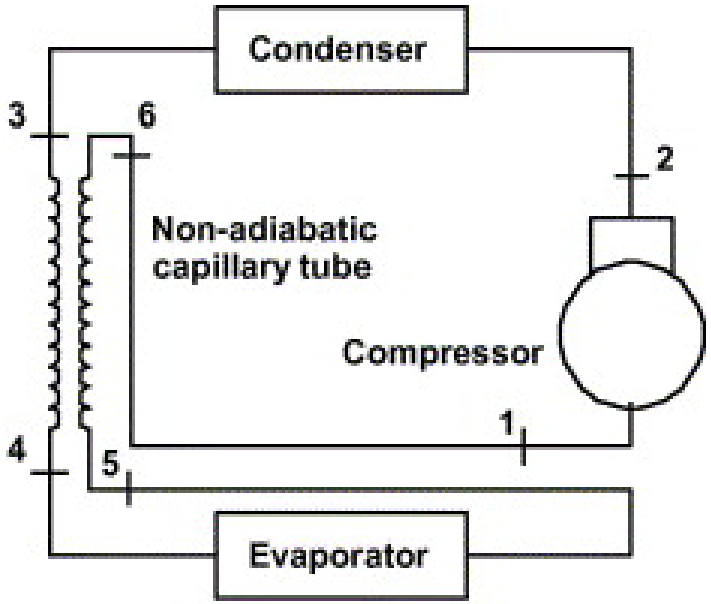


Capillary Tube Sizing Web App

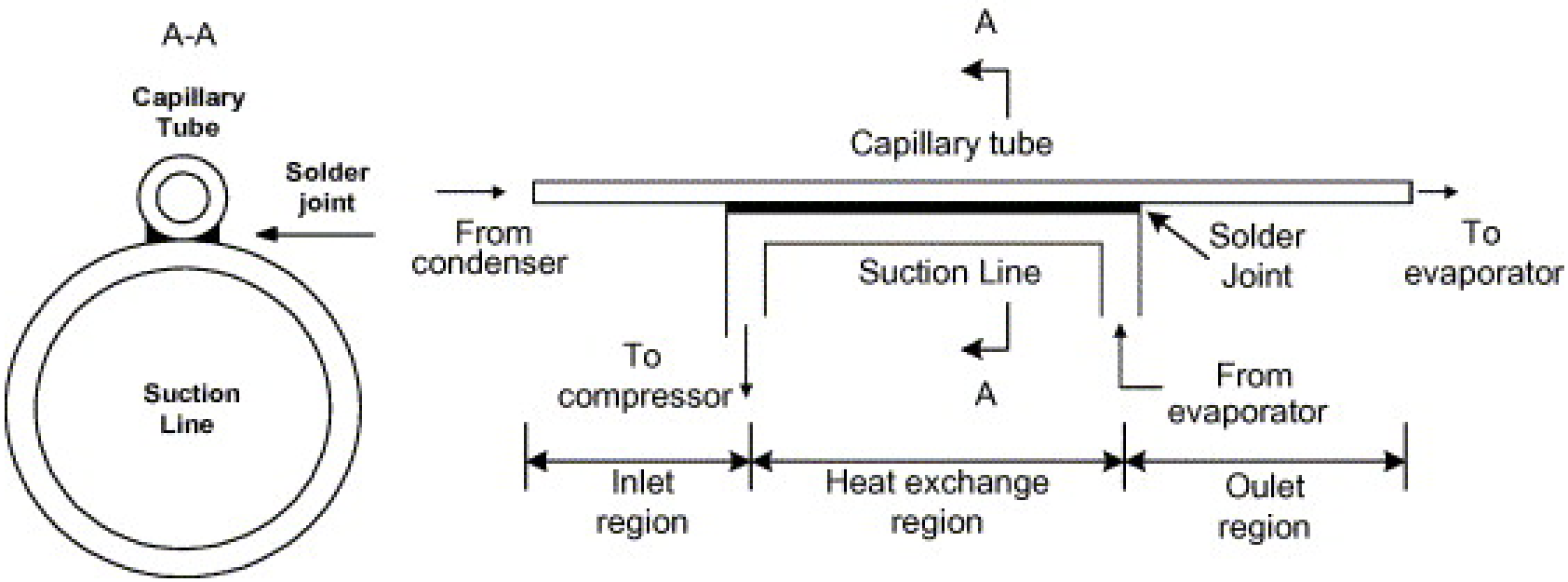


Adiabatic vs Non-adiabatic





Heat Exchange Length



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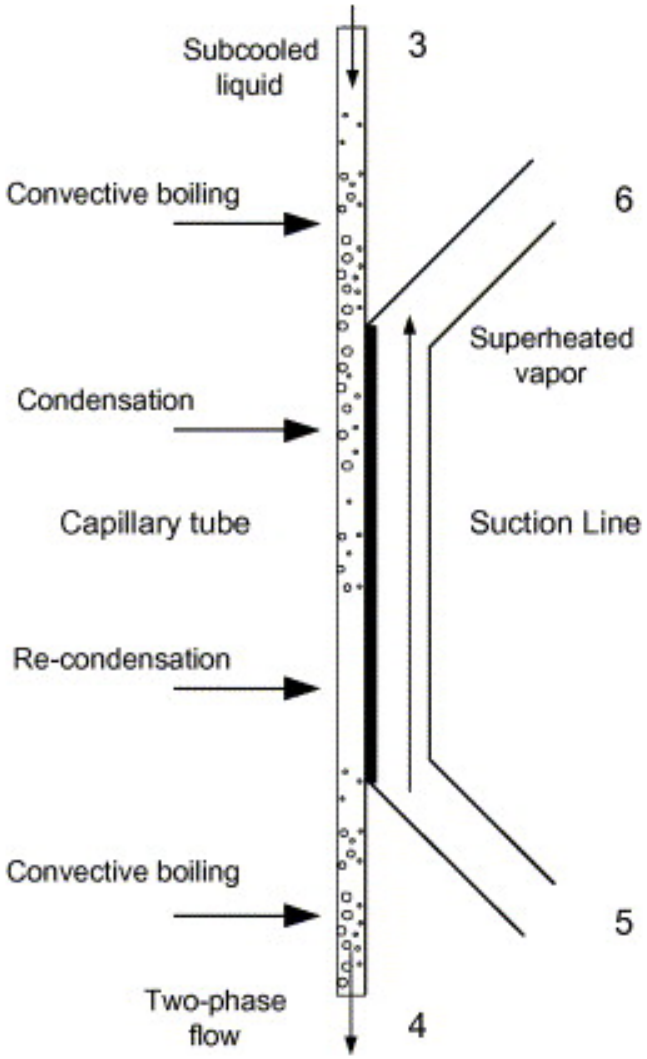
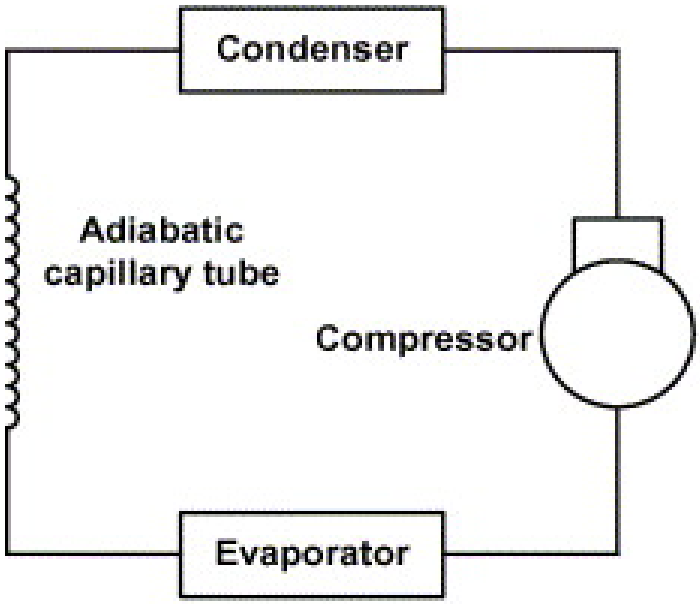
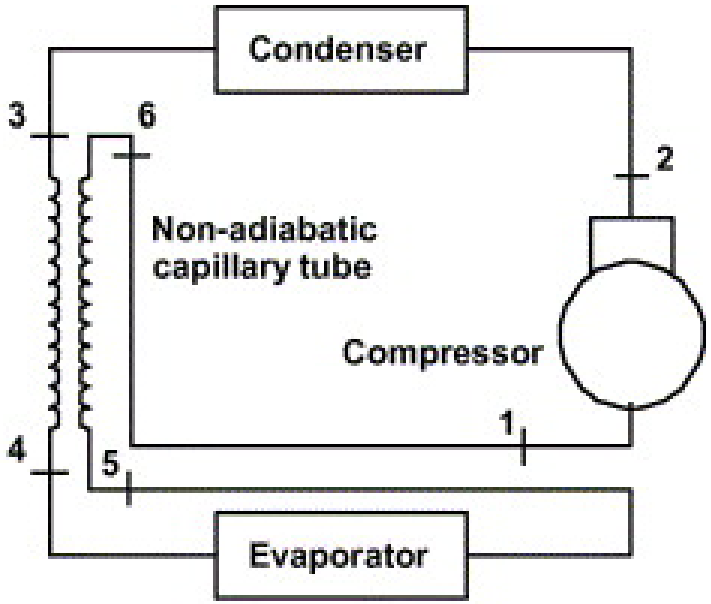
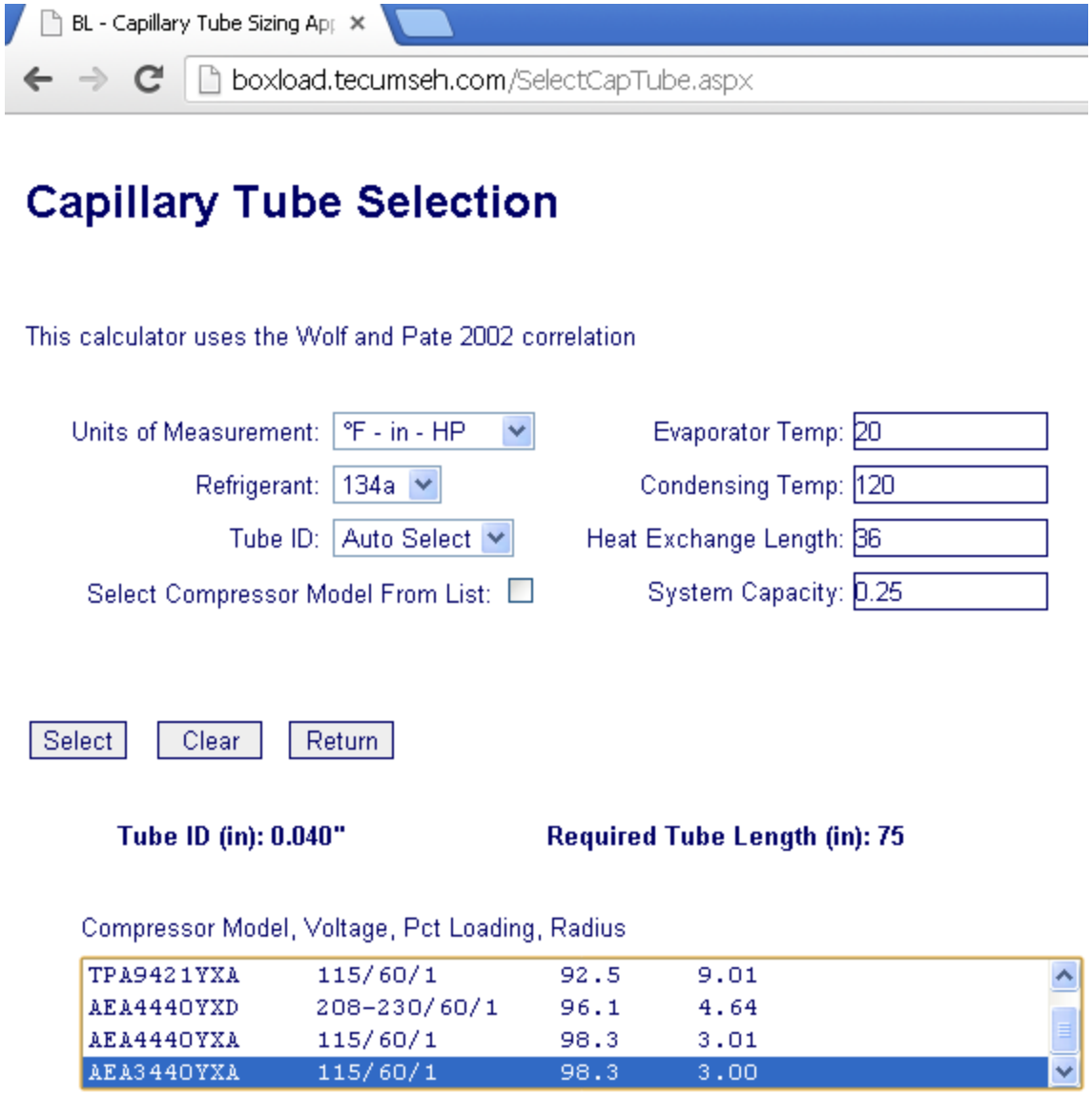


Why use heat exchange length?





Web App Selection using HP



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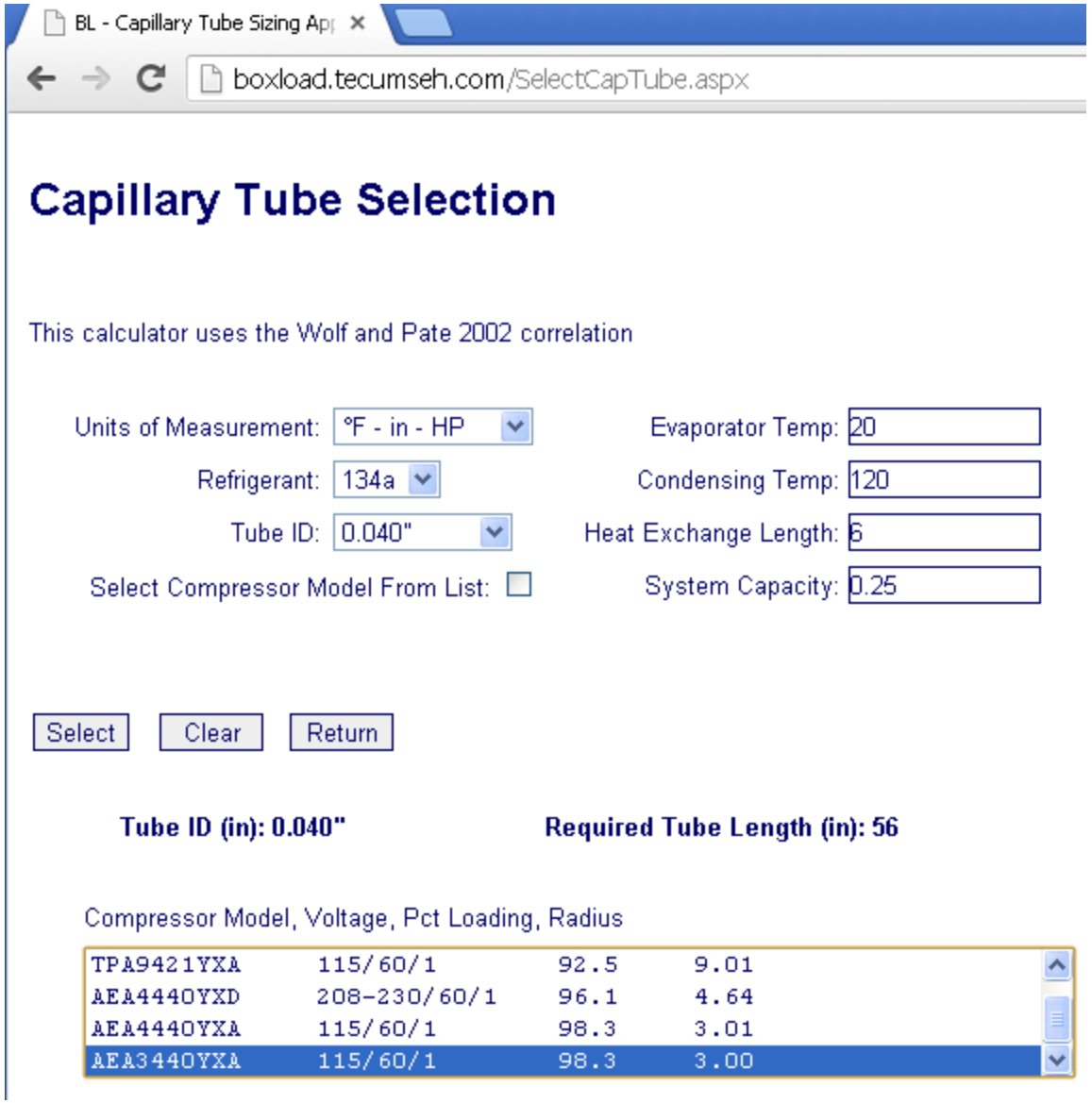
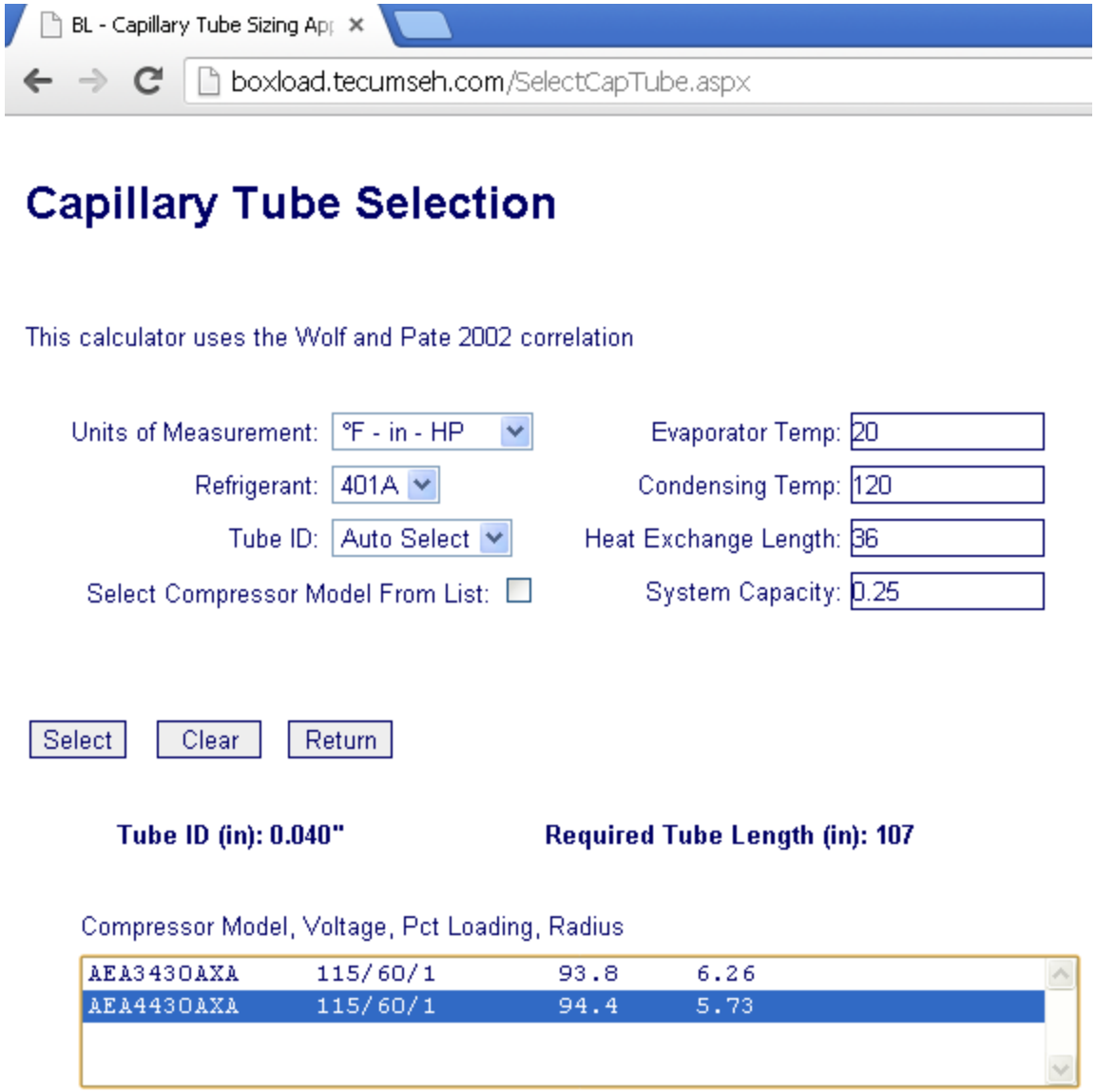
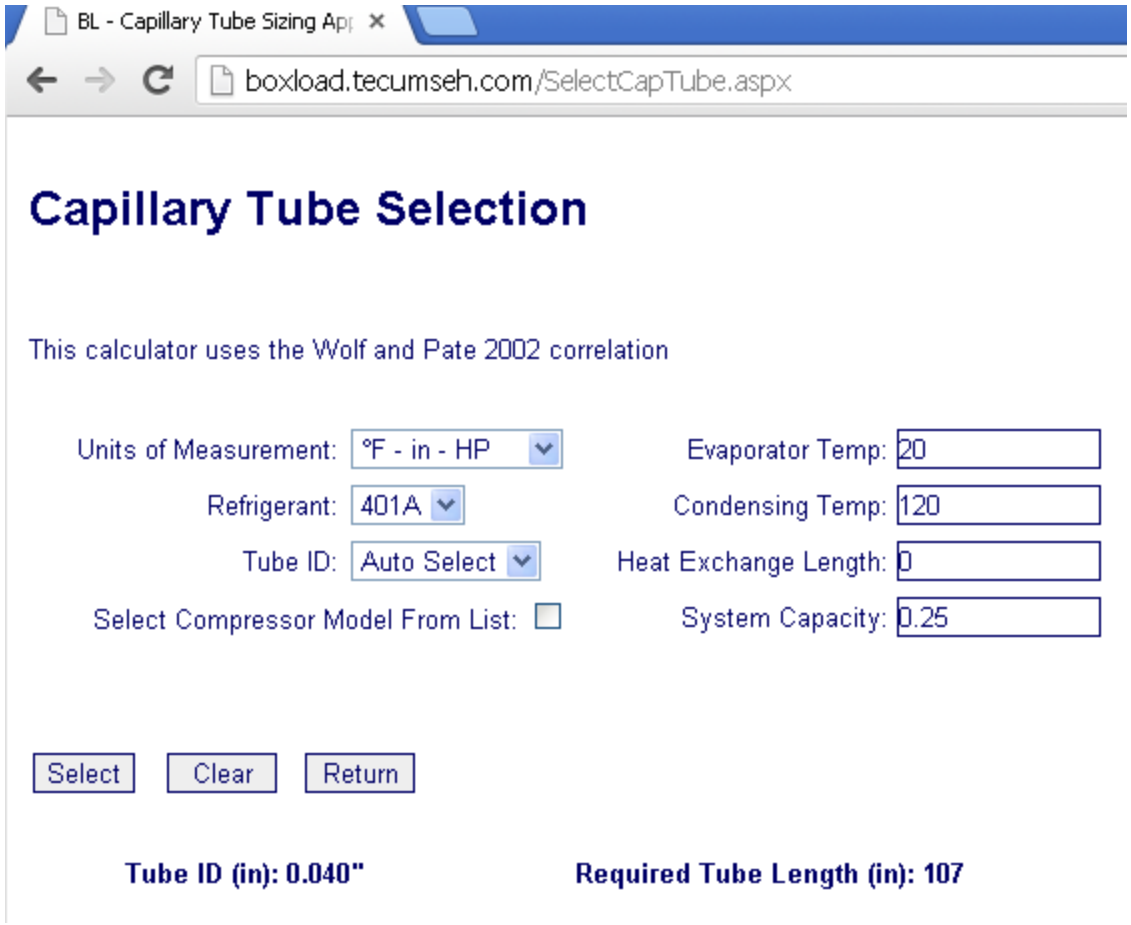


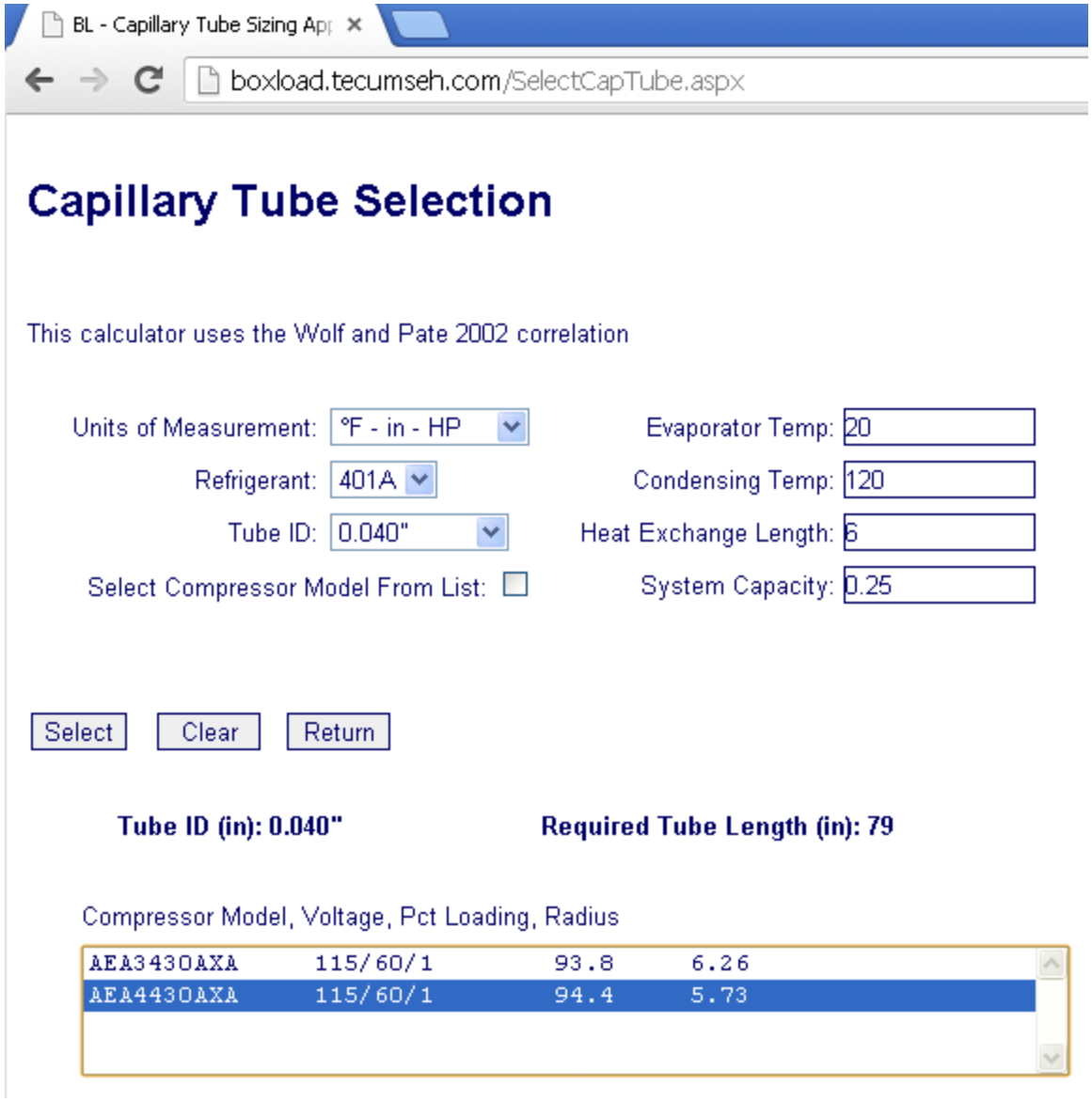
R401A Selection using HP



R401A Selection using HP



R401A Selection using HP



TPA9423YXA

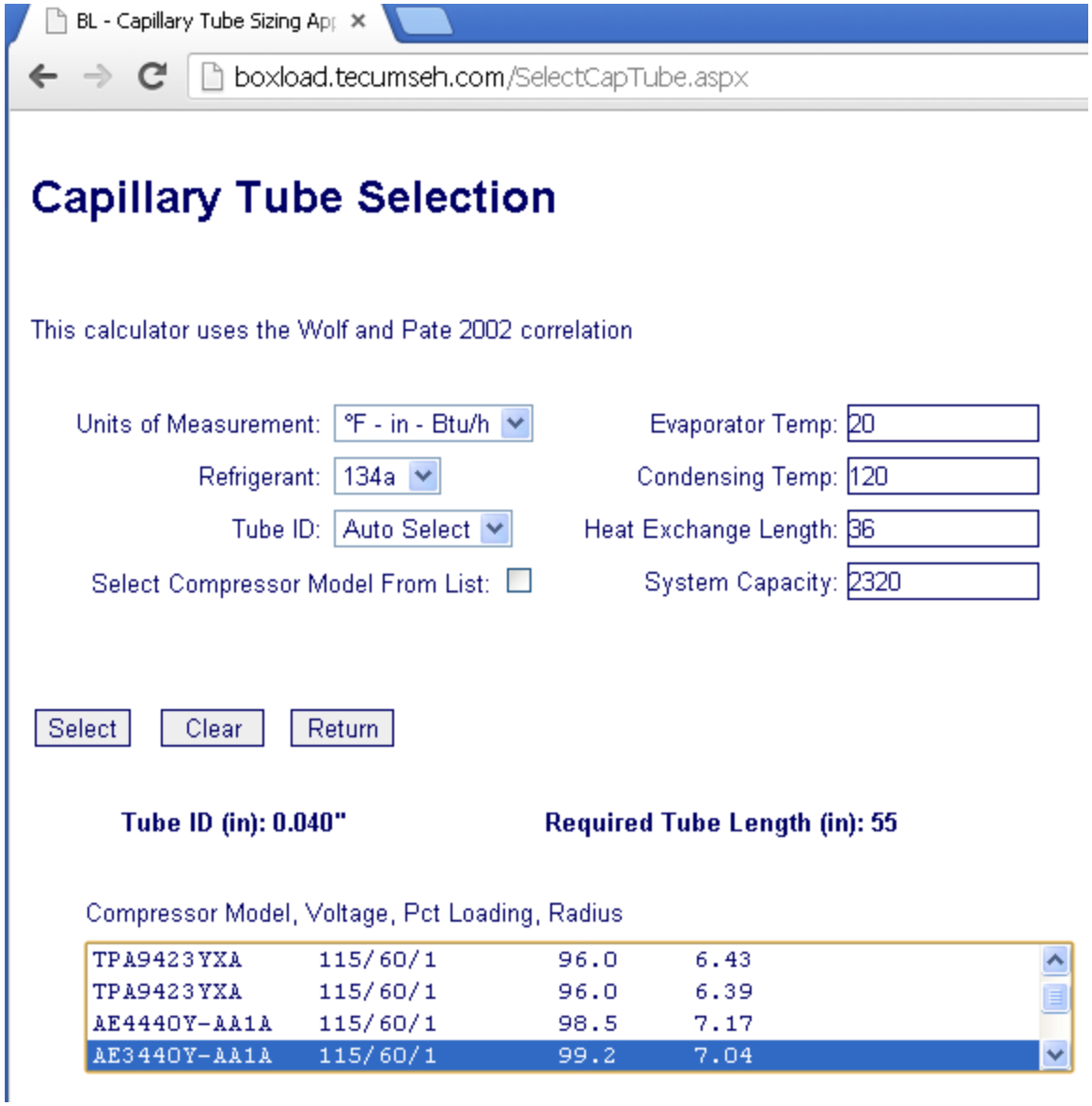
TECUMSEH PRODUCTS COMPANY
COMPRESSOR PERFORMANCE DATA

3/17/2003	RETURN GAS 40	TPA9423YXA
TEST VOLTAGE: 115	SUB COOLING 0	
MOTOR TYPE: CSIR	AMBIENT 95	115/60/1
RUN CAP: mfd	FORCED AIR: Yes	R - 134a

EVAP TEMP		CONDENSING TEMPERATURE (°F) 100	110	120	130	140
0	BTUH	1608	1475	1343	1211	1081
	WATTS	355	356	358	360	361
	AMPS	6.31	6.30	6.28	6.26	6.24
	LB/HR	24.1	23.2	22.2	21.3	20.3
5	BTUH	1855	1691	1527	1364	1201
	WATTS	377	381	384	388	391
	AMPS	6.36	6.36	6.35	6.34	6.33
	LB/HR	28.2	27.1	25.9	24.7	23.4
10	BTUH	2142	1948	1753	1559	1366
	WATTS	402	408	413	419	424
	AMPS	6.47	6.49	6.49	6.50	6.50
	LB/HR	33.0	31.6	30.1	28.7	27.2
15	BTUH	2467	2243	2019	1795	1571
	WATTS	428	436	444	452	460
	AMPS	6.62	6.65	6.68	6.71	6.73
	LB/HR	38.1	36.6	34.9	33.3	31.6
20	BTUH	2826	2573	2320	2067	1813
	WATTS	456	467	477	487	497
	AMPS	6.78	6.84	6.90	6.95	7.00
	LB/HR	43.7	41.9	40.1	38.3	36.4
25	BTUH	3218	2936	2655	2373	2091
	WATTS	484	497	510	523	536
	AMPS	6.93	7.03	7.12	7.20	7.28
	LB/HR	49.4	47.5	45.6	43.6	41.6
30	BTUH	3638	3329	3020	2711	2401
	WATTS	511	528	544	559	575
	AMPS	7.04	7.18	7.31	7.44	7.55
	LB/HR	55.3	53.3	51.2	49.2	47.0

Performance rated at 20ET/ 120CT/ 0SC/ 40 return

TPA9423YXA Selection at AHRI CBP



TPA9423YXA

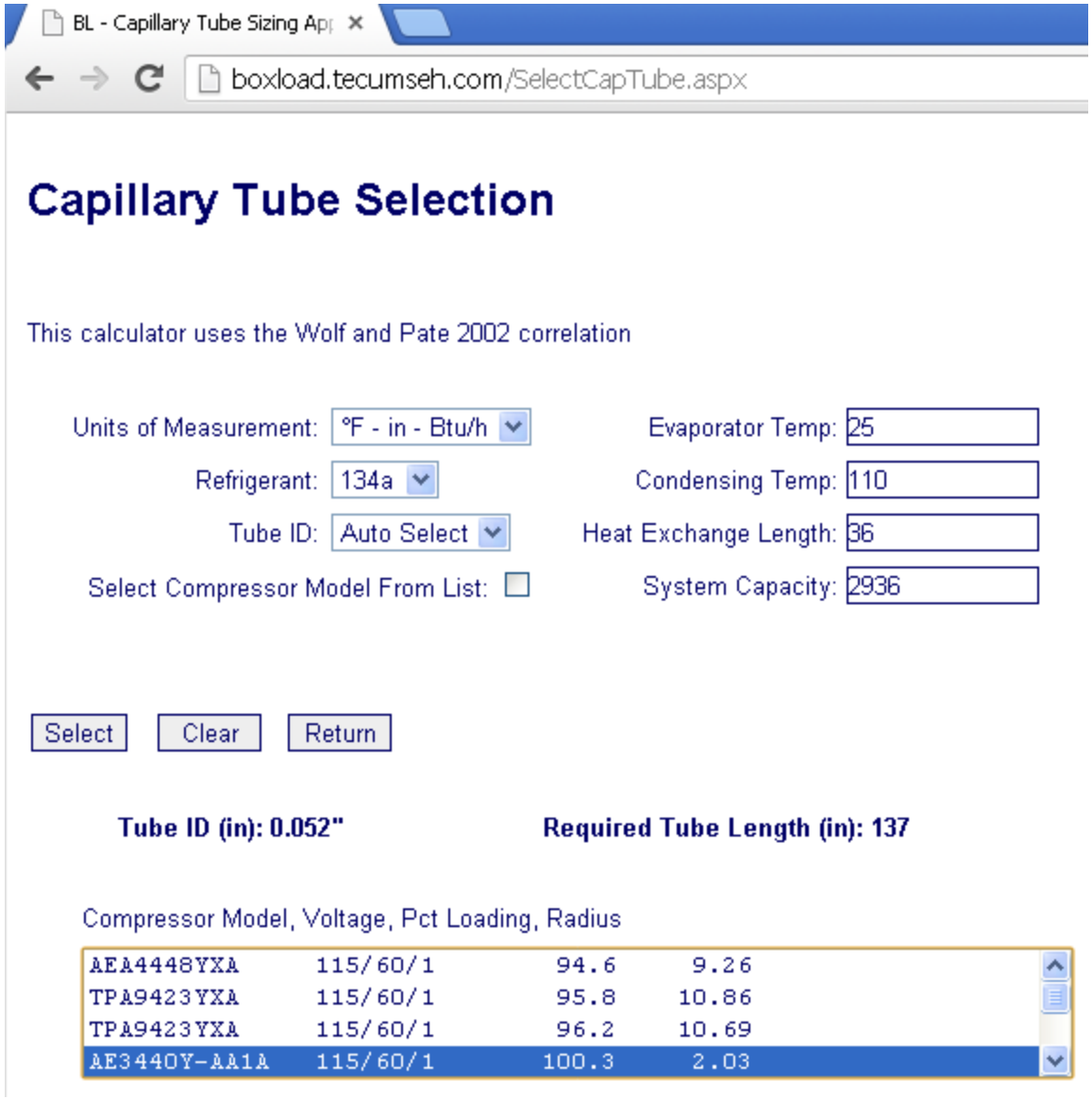
TECUMSEH PRODUCTS COMPANY
COMPRESSOR PERFORMANCE DATA

3/17/2003	RETURN GAS 40	TPA9423YXA
TEST VOLTAGE: 115	SUB COOLING 0	
MOTOR TYPE: CSIR	AMBIENT 95	115/60/1
RUN CAP: mfd	FORCED AIR: Yes	R - 134a

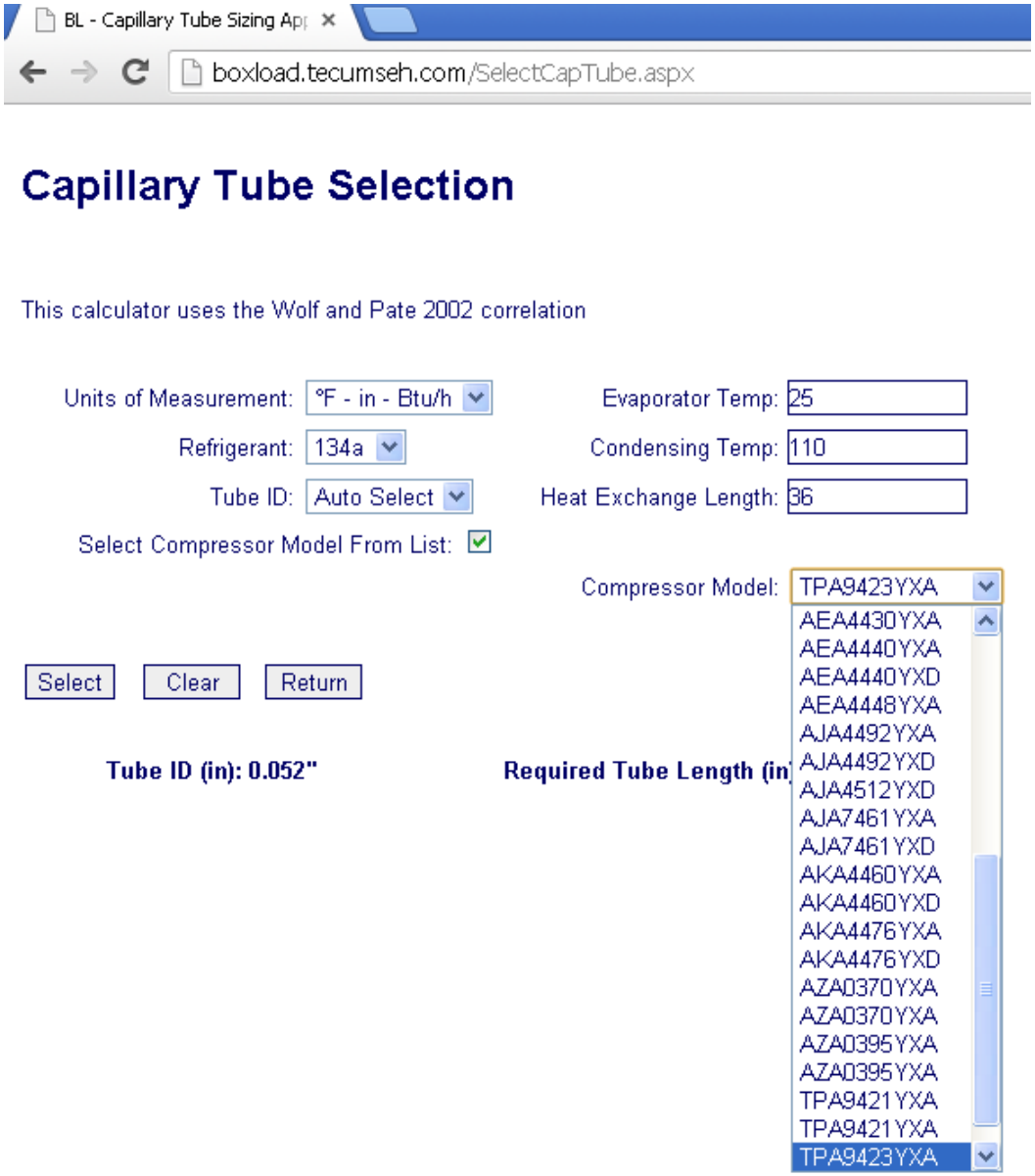
EVAP TEMP		CONDENSING TEMPERATURE (°F) 100	110	120	130	140
0	BTUH	1608	1475	1343	1211	1081
	WATTS	355	356	358	360	361
	AMPS	6.31	6.30	6.28	6.26	6.24
	LB/HR	24.1	23.2	22.2	21.3	20.3
5	BTUH	1855	1691	1527	1364	1201
	WATTS	377	381	384	388	391
	AMPS	6.36	6.36	6.35	6.34	6.33
	LB/HR	28.2	27.1	25.9	24.7	23.4
10	BTUH	2142	1948	1753	1559	1366
	WATTS	402	408	413	419	424
	AMPS	6.47	6.49	6.49	6.50	6.50
	LB/HR	33.0	31.6	30.1	28.7	27.2
15	BTUH	2467	2243	2019	1795	1571
	WATTS	428	436	444	452	460
	AMPS	6.62	6.65	6.68	6.71	6.73
	LB/HR	38.1	36.6	34.9	33.3	31.6
20	BTUH	2826	2573	2320	2067	1813
	WATTS	456	467	477	487	497
	AMPS	6.78	6.84	6.90	6.95	7.00
	LB/HR	43.7	41.9	40.1	38.3	36.4
25	BTUH	3218	2936	2655	2373	2091
	WATTS	484	497	510	523	536
	AMPS	6.93	7.03	7.12	7.20	7.28
	LB/HR	49.4	47.5	45.6	43.6	41.6
30	BTUH	3638	3329	3020	2711	2401
	WATTS	511	528	544	559	575
	AMPS	7.04	7.18	7.31	7.44	7.55
	LB/HR	55.3	53.3	51.2	49.2	47.0

Performance rated at 20ET/ 120CT/ 0SC/ 40 return

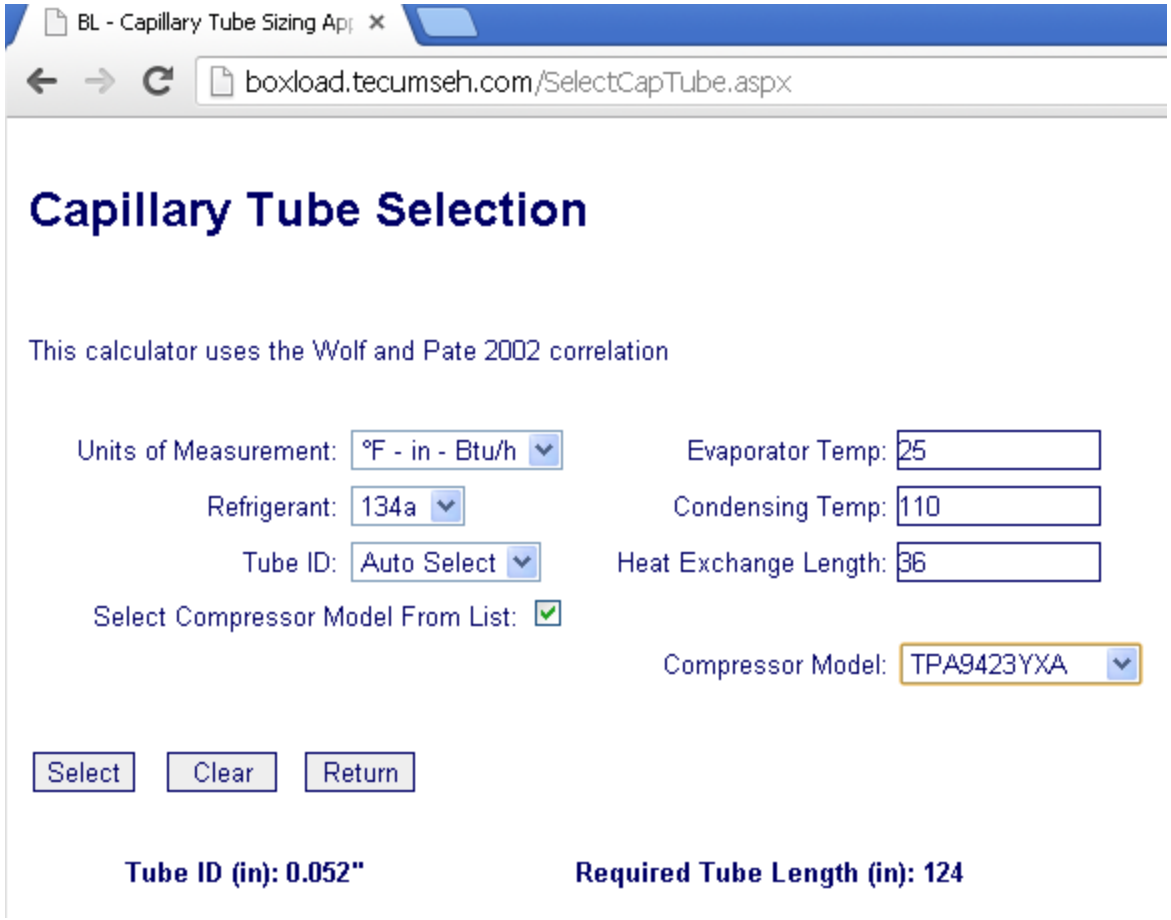
TPA9423YXA Selection @ 25°F/110°F



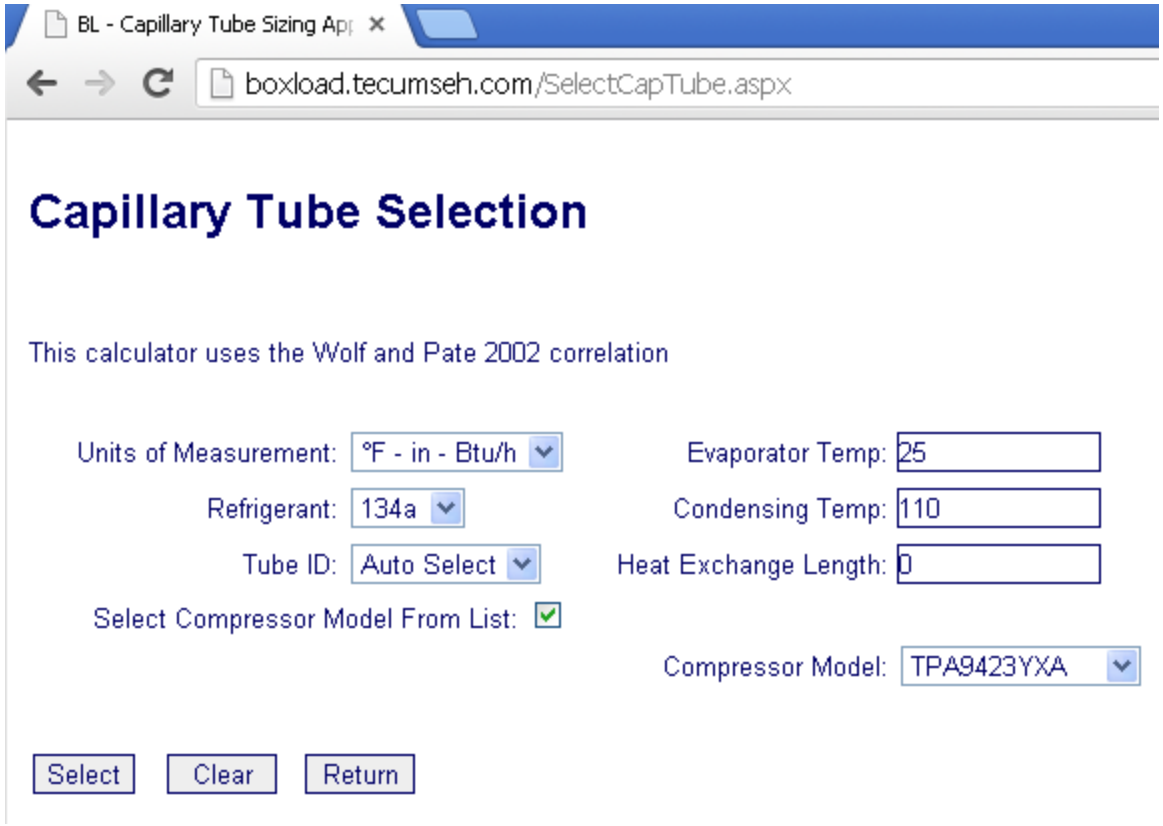
Cap Tube Selection using Comp Model



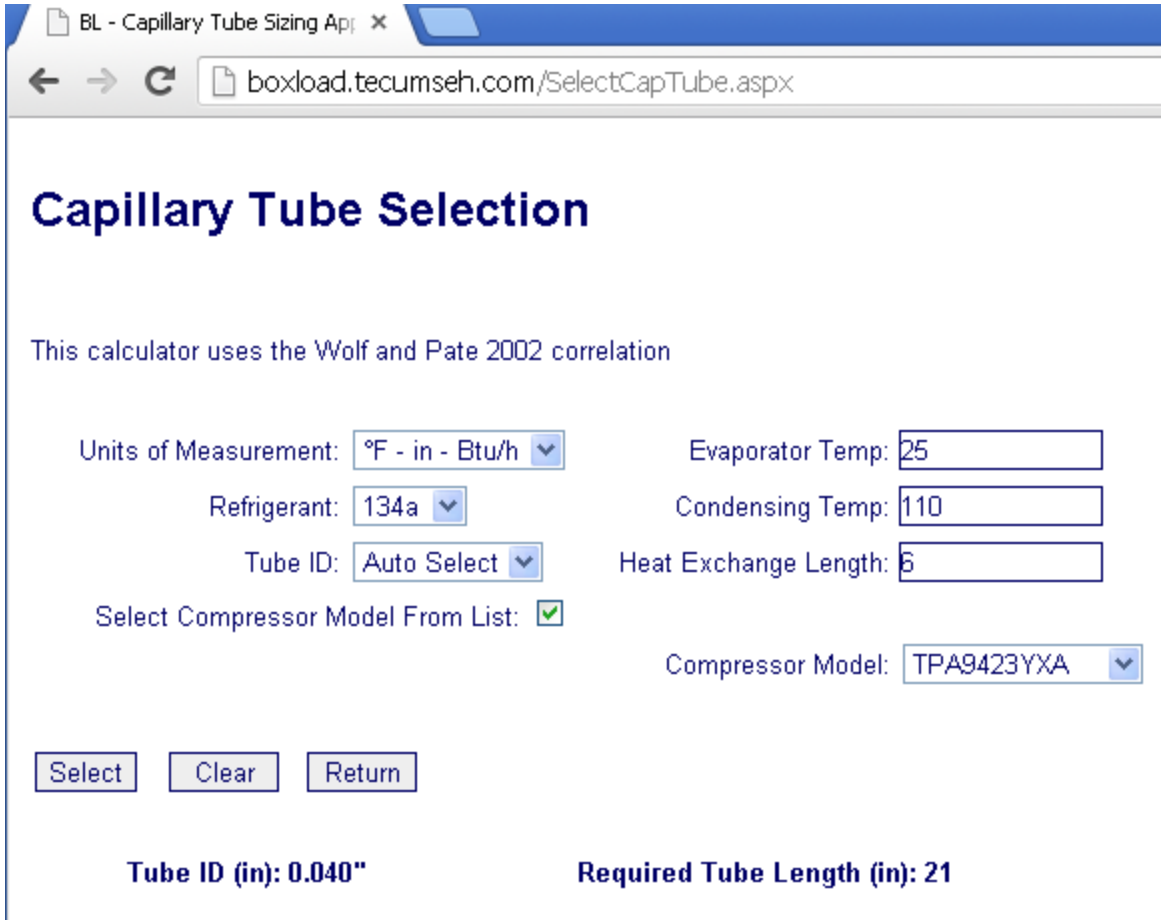
Cap Tube Selection using Comp Model



Cap Tube Selection using Comp Model



Cap Tube Selection using Comp Model

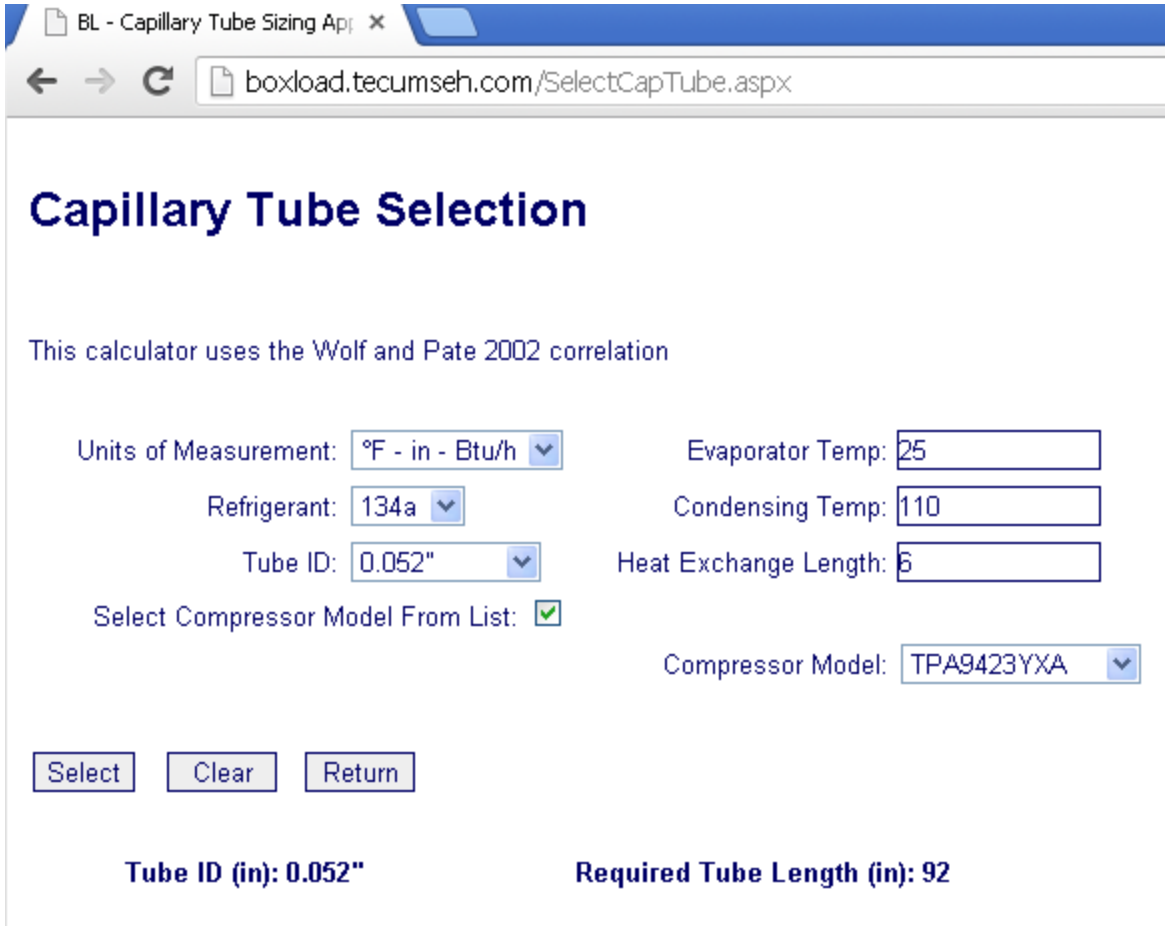


Supco Cap Tube Chart

SINGLE FEED

REF	HP	LOW	MED	HIGH
R12/R416A	1/8 HP	110" # 5	84" # 5	48" # 5
	1/6 HP	71" # 5	96" # 1	72" # 1
	1/5 HP	54" # 1	36" # 1	24" # 1
	1/4 HP	43" # 1	90" # 2	60" # 2
	1/3 HP	93" # 2	72" # 2	36" # 2
	1/2 HP	96" # 3	48" # 3	90" # 4
	3/4 HP	60" # 3	92" # 4	72" # 4
	1 HP	36" # 3	84" # 4	54" # 4
	1-1/2 HP	84" # 4	60" # 4	43" # 4
	2 HP	55" # 4	40" # 4	26" # 4
R134A / R401A	1/8 HP	121" # 5	92" #5	53" # 5
R401B/R406A	1/6 HP	78" # 5	106" #1	79" # 1
R409A/R500	1/5 HP	59" # 1	39" #1	26" # 1
	1/4 HP	47" # 1	99" #2	66" # 2
	1/3 HP	102" # 2	79" #2	39" # 2
	1/2 HP	105" # 3	52" # 3	99" # 4
	3/4 HP	66" # 3	101" #4	79" # 4
	1 HP	39" # 3	92" #4	59" # 4
	1-1/2 HP	92" # 4	66" #4	47" # 4
	2 HP	61" # 4	44" #4	29" # 4
R22	1/8 HP	132" # 5	101" # 5	58" # 5
	1/6 HP	86" # 5	116" # 1	86" # 1
	1/5 HP	64" # 1	42" # 1	28" # 1
	1/4 HP	51" # 1	109" # 2	72" # 2
	1/3 HP	112" # 2	87" # 2	43" # 2
	1/2 HP	115" # 3	57" # 3	109" # 4
	3/4 HP	72" # 3	111" # 4	87" # 4
	1 HP	42" # 3	101" # 4	65" # 4
	1-1/2 HP	101" # 4	72" # 4	51" # 4
	2 HP	67" # 4	48" # 4	32" # 4

Cap Tube Selection using Comp Model



Cap Tube Chart using Btu/h

Capillary Tube

Table A-1: Capillary tube selections assume a 115°F (46°C) liquid temperature and 3 ft of heat exchange length

Capillary Tube, Length - OD				
		Evaporator Temperature, °F (°C)		
Refrigerant	Btu/h per circuit	-10 (-23)	20 (-7)	45 (7)
R134a	500	0.028" - 17 ft	0.028" - 17 ft	0.028" - 17 ft
	750	0.028" - 7 ft	0.028" - 7 ft	0.028" - 7 ft
	1000	0.031" - 6½ ft	0.031" - 6½ ft	0.031" - 6½ ft
	1250	0.040" - 17½ ft	0.040" - 17½ ft	0.040" - 17½ ft
	1500	0.040" - 12 ft	0.040" - 12 ft	0.040" - 12 ft
	2000	0.040" - 6½ ft	0.040" - 6½ ft	0.040" - 6½ ft
	3000	0.052" - 11½ ft	0.052" - 11½ ft	0.052" - 11½ ft
	4000	0.052" - 6 ft	0.052" - 6 ft	0.052" - 6 ft
	6000	0.064" - 8 ft	0.064" - 8 ft	0.064" - 8 ft
	8000	0.064" - 4½ ft	0.064" - 4½ ft	0.064" - 4½ ft
	10000	0.064" - 12½ ft (2)	0.064" - 12½ ft (2)	0.064" - 12½ ft (2)
	12000	0.064" - 8 ft (2)	0.064" - 8 ft (2)	0.064" - 8 ft (2)

Questions?