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NOMENCLATURE

D = percentage deviation defined by Equation 3
I = algebraic sum of areas in Figure 4, defined by Equation 2
J = parameter defined by Herington, Equation 4
p = vapor pressure of pure component, mm Hg
T_{min} = lowest boiling point of system, ° K
x = mole fraction or weight fraction in liquid phase as indicated
y = mole fraction or weight fraction in vapor phase as indicated
γ = activity coefficient
θ = difference in boiling points of system at given pressure, ° C or ° K
π = total pressure, mm of Hg
Σ = sum of areas A and B in Figure 4 without regard to sign

Subscripts

1, 2 = components water and glycerol, respectively
i = component 1 or 2

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Enthalpies of Tetralin and Mixtures of Tetralin and *n*-Pentane

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Enthalpy measurements for Tetralin and five mixtures of Tetralin with *n*-pentane are presented for the temperature range 120° to 660° F., with pressures up to 1400 p.s.i.a.

A FLOW CALORIMETER has been used to measure the enthalpy of Tetralin (1,2,3,4-tetrahydronaphthalene) and mixtures containing 19.7, 39.9, 58.8, 79.5, and 89.3 mole % *n*-pentane. The temperature ranged from 120° to 688° F., with pressures up to 1400 p.s.i.a. The flow calorimeter has been described (*4*). Comparison with the literature values for pentane (*2*) and water (*7*) shows that the apparatus measures enthalpy differences with an average deviation of 1.5 B.t.u. per pound.

The *n*-pentane used was of very high purity, and by chromatographic analysis had only a trace of isopentane. The Tetralin was purified by fractional distillation, using a laboratory-packed column with about 20 theoretical stages and a reflux ratio of 40 to 1. The selected pure Tetralin portion had a refractive index of 1.5410 n_D^{20}, and a density of 0.9691 at 60° F.

The calorimeter measures the enthalpy of the hydro-

Table I. Properties of Liquid Phase Tetralin Systems with *n*-Pentane at 75° F and 1 Atm

Material	Wt. % *n*-Pentane	Liquid Density, G./Cm.^{3}	Heat of Mixing, B.t.u./Lb.	Enthalpy to Add, B.t.u./Lb.
100% Tetralin	0	0.9619	0	91.7
19.7 mole % pentane	11.8	0.9133	1.53	97.4
39.9 mole % pentane	26.6	0.8527	1.92	103.5
58.8 mole % pentane	43.7	0.7867	1.81	109.8
79.5 mole % pentane	67.9	0.7113	1.11	118.2
89.3 mole % pentane	82.0	0.6681	0.64	122.4
100 mole % pentane	100.0	0.6219	0	129.4

Table II. Smoothed Values of Enthalpy for Tetralin

Units. B.t.u. per lb.
Base level. Pure saturated liquid Tetralin at −200° F.

Temp., ° F.	P.S.I.A.								
	0	25	40	70	100	150	200	1000	1400
75		91.7	91.7	91.8	91.9	92.0	92.2	94.0	95.0
120		110.0					110.3		112.1
160		127.2					127.5		129.2
200		145.2					145.5		147.2
240		163.8					164.1		165.6
280		183.2					183.4		184.7
320		202.8					203.0		204.0
360		223.6					223.8		224.7
400		245.2					245.3		246.0
440		267.0					267.1		268.0
451.5		268.2[a]							
451.5		398.8[a]							
460		403.4	278.0				278.1		279.0
480	416.4	414.3	289.8				290.0		290.7
495			298.6[a]						
495			420.4[a]						
500	427.3	425.3	423.1	301.6			301.8		302.5
520	438.2	436.1	434.0	313.6			313.8		314.4
540	449.2	447.0	445.2	326.2			326.3		326.4
550.5				332.7[a]					
550.5				448.0[a]					
560	460.1	457.8	456.4	453.6	338.8		338.8		338.7
580	471.0	468.8	467.3	464.4	351.4		351.3		350.8
591.4					358.9[a]				
591.4					467.3[a]				
600	482.1	479.9	478.3	475.4	472.2	364.3	364.2		363.7
620	492.8	490.7	489.3	486.5	483.3	377.7	377.6		376.7
640	503.7	501.7	500.2	497.5	494.6	391.5	391.3		389.8
643						393.7[a]			
643						490.8[a]			
650	509.2	507.2	505.8	503.1	500.2	495.2		397.1	396.4
660	514.7	512.8	511.3	508.7	505.8	501.4		404.1	403.0

[a] Enthalpy value on two-phase boundary.

carbon fluid relative to the liquid phase at 75° F. and the pressure of measurement. A total of 1108 measurements was obtained (deposited with ASIS).

To make the measured values more useful, the enthalpies have been corrected to the API data book (*1*) basis of −200° F. and the pure saturated liquids. Two corrections are needed. The measured enthalpy values need to be adjusted to allow for changes in pressure at 75° F. in the liquid phase. The thermodynamic equation of state was used to shift all the data to the basis of 75° F. and the saturated liquid state, as described in more detail previously (*4*). To relate the data to the −200° F. basis, the difference in enthalpy between 75° and −200° F. is required at the saturated liquid condition for the pure components. This difference was ascertained in the earlier study (*4*) to be 129.4 B.t.u. per pound for *n*-pentane. McCullough, Finke, Messerly, Topp, Kincheloe, and Waddington (*6*) show enthalpy values for Tetralin that cover the range from 75° to −200° F. At −34° F. Tetralin solidifies. The enthalpy difference between the supercooled liquid at −200° F. and the liquid at 75° F. was estimated to be 91.7 B.t.u. per pound, determined by plotting saturated liquid enthalpy values of Tetralin against temperature and extrapolating to −200° F. It is believed that this value is within 1 B.t.u. per pound of the true value. Although a small uncertainty exists, the use of the supercooled liquid as the reference state is consistent with the API data book base level. The exact difference in enthalpy between the solid state at −200° F. and the liquid at 75° F. is 115.0 B.t.u. per pound, indicating a heat of fusion of 23.3 B.t.u. per pound at −200° F. For the mixtures the additive term needed to convert to the −200° F. basis is a weight average of 91.7 and 129.4 for Tetralin and pentane, respectively, plus the heat of mixing at 75° F. Lundberg (*5*) shows heats of mixing for the binary systems *n*-heptane and *n*-hexadecane with Tetralin. The values of the heats of mixing for the pentane-Tetralin mixture were obtained by a straight-line plot of the heat of mixing at constant Tetralin composition dependent upon the normal boiling point of the paraffin component. This resulted in a small adjustment from the heats of mixing for the heptane-Tetralin system measured by Lundberg. Within the accuracy of enthalpy measurement, the direct use of the measured heptane-Tetralin values appears to have been satisfactory. The validity of this procedure was checked by plotting the resulting enthalpy values at zero pressure and at fixed isotherms against weight per cent pentane. The results showed a linear plot, confirming expectations.

The physical properties of Tetralin and the mixtures are listed in Table I, showing composition, density, heat of mixing at 75° F. and the liquid phase, and the B.t.u. per pound added to the saturated liquid enthalpy at 75° F. to convert to the −200° F. basis. Table II shows smoothed values of enthalpy for Tetralin. The upper temperature is limited to 660° F. Attempts to measure at higher temperatures resulted in apparently low values, confirmed by the deposition of carbonaceous solid material in the high temperature zones of the calorimeter and the development of impurities in the Tetralin. Tables III, IV, V, VI, and VII are smoothed enthalpy values for the Tetralin mixtures. Figure 1 illustrates the enthalpy behavior established by these measurements in the vicinity of the critical point

Table III. Smoothed Values of Enthalpy for Mixture of 19.7 Mole % Pentane and 80.3 Mole % Tetralin

Units. B.t.u. per lb.
Base Level. Pure saturated liquid components at −200° F.

Temp., °F.	P.S.I.A.											
	0	25	40	70	100	150	200	300	400	600	1000	1400
75		97.4	97.4	97.5	97.6	97.7	97.8	98.0	98.3	98.7	99.7	100.6
120		116.0								117.1		118.7
160		133.9								134.9		136.4
200		152.7								153.6		154.8
226.5		165.6[a]										
240		174.2	172.0							172.7		173.6
260		186.9	182.1							182.6		183.3
280		199.5	192.3							192.8		193.5
291.3			198.3[a]									
300		212.7	204.7	202.9						203.2		203.7
320		225.9	218.5	213.7						213.9		214.2
340		239.7	232.0	224.4						224.6		224.9
360		254.4	236.1	235.5						235.7		235.9
369.5				240.9[a]								
380		272.6	261.2	250.5	246.7					246.9		247.1
400		296.5	277.8	265.8	258.2					258.3		258.5
414.8					267.1[a]							
420			297.2	279.8	271.9	270.0				270.1		270.2
440				295.2	287.7	281.9				281.9		282.0
460			369.5	312.2	302.9	294.1				294.1		294.1
477.9			421.8[a]									
480	426.1		423.1		319.5	306.4				306.3		306.2
488.2						311.6[a]						
500	437.2		433.8	362.0	337.8	323.4	319.0			318.7		318.0
520	448.2		444.7	416.5	360.2	342.4	331.9			331.2		329.8
531.6				447.5[a]								
540	459.5		455.8	453.5	390.9	359.8	345.2			344.1		341.9
543.5							347.6[a]					
560	470.6		466.7	464.3	428.5		365.5	359.0		357.7		354.3
576					469.3[a]							
580	481.7		477.9	475.4	471.7		384.6	373.2		371.5		366.8
600	492.9		489.3	486.5	483.5	449.0	406.3	388.1		385.8		379.5
603								390.3[a]				
610	498.5		494.7	492.1	489.2	465.3	418.7	396.3				385.9
620	504.0		500.4	497.7	495.2	481.1	433.3	404.6	396.7	395.7	394.2	382.3
627.4						492.2[a]						
640	515.5		511.7	509.5	507.1	499.8	467.0	422.8	411.2	409.6	407.5	405.4
650	521.2		517.5	515.3	513.1	505.7	485.1	434.0	419.2	417.3	414.5	412.0
660	526.6		523.5	521.3	519.2	511.6		445.7	427.5	425.3	421.7	418.7
680								474.5	447.3	442.2	436.7	433.0

[a] Enthalpy value on two phase boundary

Table IV. Smoothed Values of Enthalpy for Mixture of 39.9 Mole % Pentane and 60.1 Mole % Tetralin

Units. B.t.u. per lb.
Base Level. Pure saturated liquid components at −200° F.

Temp., °F.	P.S.I.A.											
	0	25	40	70	100	150	200	300	400	600	1000	1400
75		103.5	103.5	103.6	103.7	103.8	103.9	104.2	104.4	104.9	105.8	106.8
120		123.8								125.0		126.8
160		142.4								143.5		145.0
176.3		150.4[a]										
180		156.3	152.3							153.2		154.5
200		176.6	162.3							163.1		164.2
214.2			169.4[a]									
220		192.4	177.9	172.5						173.2		174.2
240		206.8	197.5	182.9						183.5		184.4
260		220.6	213.2	193.4						194.0		194.9
268.4				197.9[a]								
280		234.4	227.6	211.4	204.2					204.7		205.4
300		248.3	242.2	228.6	215.3					215.6		216.2
311.6					221.8[a]							
320			256.8	243.8	233.1	226.5				226.7		227.0
340			271.7	259.4	249.9	238.0				238.1		238.3
360				275.0	265.4	249.8				249.7		249.5
368.2						254.6[a]						
380				290.5	280.8	266.4	261.8			261.5		261.0
400		371.1		306.7	296.6	283.3	274.0			273.6		272.9

(continued)

Table IV. (*Continued*)

Temp.,	P.S.I.A.											
° F.	0	25	40	70	100	150	200	300	400	600	1000	1400
410.2							280.4[a]					
418.9		407.4[a]										
420		407.8		324.3	313.2	299.7	291.9	286.5		286.1		284.9
440		418.1	396.9	346.4	330.5	316.7	309.6	299.3		298.8		297.3
451.2								306.5[a]				
451.8			422.4[a]									
460			426.6	374.3	349.9	333.8	325.7	314.4	312.2	311.7		309.8
480			436.9	406.3	372.3	351.9	342.1	329.8	325.4	324.8		322.8
500	449.5		447.7	444.0	397.7	371.6	359.6	344.9	339.2	336.4		335.3
501				445.6[a]								
520	461.2		458.7	456.9	427.8	395.5	378.1	360.6	353.7	349.3		347.9
540	472.3		469.9	468.3	461.2	420.8	399.6	377.4		352.6		360.4
542.5					465.4[a]							
560	483.6		471.1	479.2	475.5	446.8	422.8	395.6	386.1	376.1	374.5	373.0
580	495.3		492.5	490.6	487.1	473.9	447.3	415.2	403.8	390.9	387.9	385.4
589						486.8[a]						
600	506.6		503.8	502.1	498.5	493.4	473.1	437.3	422.4	406.3	402.4	398.4
619.6							500.3[a]					
620	518.5		515.2	513.3	510.0	505.2	500.6	462.3	443.0	422.4	416.8	412.8
640	530.0		526.7	524.9	521.6	516.1	511.4	488.8	464.9	439.5	432.0	428.0
660	541.8							513.6[a]	488.6	459.4	447.8	
680										483.2	463.9	

[a] Enthalpy value on two phase boundary

Table V. Smoothed Values of Enthalpy for Mixture of 58.8 Mole % Pentane and 41.2 Mole % Tetralin

Units. B.t.u. per lb.
Base Level. Pure saturated liquid components at −200° F.

Temp.,	P.S.I.A.											
° F.	0	25	40	70	100	200	300	400	535	580	1000	1400
75		109.8	109.9	110.0	110.1	110.3	110.6	110.9	111.2	111.3	112.5	113.6
120		131.1						132.0			133.5	134.5
158.6		150.1[a]										
160		155.8	150.8					151.6			152.9	153.8
180		197.0	161.0					161.8			163.0	163.9
188			165.1[a]									
200			192.5	171.3				172.1			173.5	174.5
220			217.7	181.9				182.6			183.9	184.7
232.7				188.7[a]								
240			234.8	203.1	192.9			193.4			194.4	195.1
260				232.5	204.1			204.6			205.6	206.3
265.2					207.1[a]							
280					232.5	215.6		215.9			216.9	217.6
300					256.8	227.3		227.6			228.4	229.0
320						239.2		239.5			240.2	240.7
340						251.6		251.8			252.3	252.7
342.4						253.1[a]						
360						276.3		264.1			264.8	265.0
380		384.0				300.0		277.1			277.2	277.4
393		403.6[a]										
400		407.3	387.1					290.3			293.2	290.0
420		417.6	415.2						303.8		302.7	302.3
421.2			416.6[a]									
440		427.9	426.5	402.0					317.3		315.6	314.8
460	441.1	438.5	437.3	430.7	405.0				331.0		328.7	327.7
463.7				436.0[a]								
480	452.3	449.9	448.5	445.2	429.1			358.4	345.5		342.6	341.3
498.8					452.0[a]							
500	463.9	461.3	460.3	456.3	452.6			377.0	361.2	360.5	356.9	355.0
520	474.7		472.1	468.4	464.9			396.3	379.3	376.9	370.6	368.6
540	487.2		484.0	480.9	477.5		431.0	416.3	398.2	394.6	384.6	382.5
560	497.7		496.0	493.3	490.4	472.9	451.1	436.4	417.5	414.6	398.5	396.2
571						487.1[a]						
580	511.0		508.3	506.1	503.1	493.9	471.3	456.1	437.4	434.6	412.7	409.9
600	521.3		520.5	518.6	516.0	508.0	491.5	475.0	458.2	454.4	428.3	424.5
612.8							504.2[a]					
620	535.0		532.8	531.1	528.8	521.5	510.5	493.2		474.1	445.0	440.1
640	547.4		545.4	543.5	541.5	534.6	527.9	510.1			463.0	456.8

[a] Enthalpy value on two phase boundary.

Table VI. Smoothed Values of Enthalpy for Mixture of 79.5 Mole % Pentane and 24.1 Mole % Tetralin

Units. B.t.u. per lb.
Base Level. Pure saturated liquid components at −200° F.

Temp.,	P.S.I.A.											
° F.	0	40	70	100	150	200	300	500	600	800	1000	1400
75		118.5	118.7	118.8	118.9	119.1	119.3	119.9	120.2	120.7	121.3	122.3
120		140.8								143.4		145.4
160		162.7								164.7		166.3
172		169.4										
180		220.2	173.9							175.6		176.9
200		256.8	185.4							186.8		187.9
213.7			193.3[a]									
220			223.5	197.0						198.4		199.4
240			269.9	208.7						210.1		211.1
243				210.5[a]								
260			291.2	263.7	220.9					222.0		222.9
280			308.7	294.8	233.4					234.3		235.0
285					236.6[a]							
300		337.9	325.0	314.1	279.5	246.0				246.9		247.5
314.5						255.5[a]						
320		355.2	341.7	331.8	309.8	273.4	259.0			259.7		260.3
340		375.2	357.5	348.2	331.9	313.3	272.5			273.0		273.3
360		397.0	374.4	364.3	351.9	337.9	286.2			286.5		286.7
362.8							288.2[a]					
380		412.8	394.4	382.0	369.7	357.4	324.8	300.4	300.4	300.4	300.4	300.4
400		423.6	420.7	401.7	386.8	375.7	352.5	314.8		314.9		315.0
401			422.5[a]									
420		434.9	433.2	423.8	405.6	394.4	374.7	329.3	328.6	328.5	328.2	328.0
428.9				435.7[a]								
436.1								341.2[a]				
440		446.0	444.3	442.4	426.8	413.5	395.5	347.7	344.2	343.1	342.5	342.0
456.8									357.6[a]			
459.3					449.8[a]							
460		457.4	455.7	454.1	450.2	438.4	415.0	378.0	361.8	358.0	357.4	356.2
480	470.8	469.0	467.2	465.9	462.0	453.9	434.3	402.8	387.0	375.3	373.2	371.0
486						460.9[a]						
490	477.5	475.1	473.3	471.7	467.8	463.3	444.2	414.2	399.8	384.1	381.2	378.5
500	483.1	481.2	479.4	477.5	473.9	469.6	454.3	423.2	412.5	393.2	389.4	385.9
518.3							472.8[a]					
520	495.1	493.2	491.2	489.5		482.4	474.2	446.9	436.1	412.7	405.4	401.3
540	507.7	505.8	503.7	502.0		495.4	487.9	467.4	457.5	433.9	422.0	416.8
580	532.0	530.2	528,9	527.5		521.3	515.2	512.0	494.5	474.0	458.4	449.2
620	557.2	555.9	554.5	553.2		547.4	532.0	521.6	526.0	511.9	495.4	482.8
640	569.3					560.4	555.2	545.8	540.9	530.0	513.4	498.4

[a] Enthalpy value on two phase boundary.

Table VII. Smoothed Values of Enthalpy for Mixture of 89.3 Mole % Pentane and 10.7 Mole % Tetralin

Units. B.t.u. per lb.
Base Level. Pure saturated liquid components at −200° F.

Temp.,	P.S.I.A.											
° F.	0	40	70	100	200	300	400	500	600	800	1000	1400
75		121.8	121.9	122.0	122.3	122.5	122.8	123.0	123.4	123.9	124.5	125.5
120		146.1					147.0			147.9		149.3
160		168.8					169.4			170.0		170.9
163.7		170.9[a]										
180		267.6	180.3				180.7			181.2		182.0
200		293.9	192.2				192.6			193.1		193.8
204.2			194.8[a]									
220			282.0	204.3			204.7			205.2		206.9
234.3				213.2[a]								
240			309.8	260.3	216.8		217.0			217.4		218.0
260				312.3	229.5		229.7			230.0		230.4
280					243.0		243.0			243.0		243.0
299.8					256.4[a]							
300		369.8			257.1	256.6	256.5			256.4		256.1
320		383.8			330.9	270.8	270.4	270.3	270.2	270.0	269.8	269.4
335.5		396.8[a]										
340	403.9	399.4	389.8	379.9	356.6	285.3	285.0	284.8	284.6	284.3	284.0	283.6
346						289.6[a]						
360	414.3	410.9	407.2	397.3	376.6	335.6	299.8	299.6	299.3	298.9	298.4	297.8
362.8			409.8[a]									
374.7							310.7[a]					

(continued)

Table VII. (*Continued*)

Temp., °F.	P.S.I.A. 0	40	70	100	200	300	400	500	600	800	1000	1400
380	425.1	421.9	419.4	415.6	395.3	370.8	325.8	314.9	314.3	313.4	312.8	312.2
384.8				420.3[a]								
400	436.1	433.1	430.8	429.0	413.1	393.4	369.9	330.3		328.3	327.6	326.7
404.3								333.8				
420	447.6	444.5	442.3	440.6	429.9	414.7	398.4	364.3	347.0	344.2	342.9	340.9
434.6					441.9[a]							
440	459.1	456.1	454.0	452.3	445.2	432.6	419.4	397.1	369.0	360.6	358.4	355.0
450	465.0	462.2		458.2	451.3	441.1	429.3	410.6	386.6	369.3	366.8	
460	471.2	468.4		464.6	457.5	449.4[a]	438.5	422.4	401.7	378.3	375.2	369.6
470	477.3	474.7		470.9	463.8	456.3	447.3	433.2	416.2	387.6	383.9	377.3
480	483.4	480.8		477.3	470.1	463.4	455.2	443.6	429.8	397.6	392.9	384.8
500	495.9	493.6		490.2	483.4	477.4	470.3	462.5	451.3	420.6	411.9	401.4
540	520.9	518.8		515.6	509.8	504.7	498.7	491.9	483.0	462.9	449.7	436.0
580	546.2	544.2		541.0	536.1	531.2	525.6	520.4	513.0	499.4	487.6	470.5
620	571.7	569.8		567.0	562.3	557.4	552.7	548.6	543.2	533.0	522.8	505.0
640	584.7	582.8		580.4	575.4	570.8	566.4	562.8	558.2	548.9	539.4	522.4

[a] Enthalpy value on two phase boundary.

for the system containing 79.5 mole % pentane in Tetralin. The nature of the measurements permits evaluation of the dew point locus up to 530° F. from the discontinuity between the gas phase and the two-phase isobars. Above 530° F. the slopes are too similar to detect a break, and the two-phase locus is presented as an estimated dashed line. Figure 1 is typical of the plots that may be obtained from Tables II through VII.

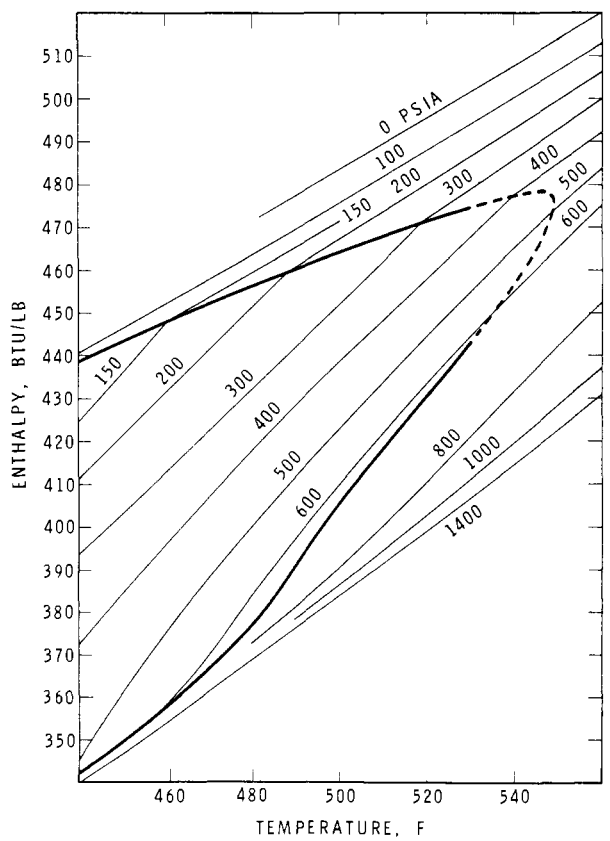

Figure 1. Enthalpy of mixture of 79.5 mole % pentane in Tetralin

Previous to these measurements McCullough *et al.* (*6*) presented saturated liquid enthalpy values for pure Tetralin up to 114° F. that agree well with the enthalpies of this study. Vvendenskii and Maioron (*8*) reported heat capacity values for gaseous Tetralin at low pressures that show a significantly greater change in enthalpy with temperature than measured in this work. In addition, Herz and Schuftan (*3*) list a value of 142.6 B.t.u. per pound for the latent heat of vaporization of Tetralin at 77° F. Extrapolation of these newly measured data, and use of the Clausius-Clapeyron equation, indicate a value of 176 B.t.u. per pound at 77° F. With the exception of these fragmentary literature results, the present set of measurements appear to be an initial study of the enthalpy of Tetralin and Tetralin-pentane mixtures.

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