2.12 Air

Equations for the thermodynamic properties have been cited from Baehr et al.[1], and those for transport properties from Kadoya et al.[2].

2.12.1 Temperature Scale

International practical temperature scale 1968 (IPTS-1968)

2.12.2 The Names of Substance, Library File and Single Shot Program

Name of Substance:	Air
Library File for UNIX:	libjair.a
Library File for DOS,Windows95/NT:	JAIR.LIB
Single Shot Program for UNIX:	air-ss
Single Shot Program for DOS,Windows95/NT:	AIR–SS.EXE

2.12.3 Important Constants and Others

Molecular Formula:	Air mixture
	N_2= 0.7841 (kmol $_{N_2}$/kmol $_{Air}$)
	O_2= 0.2066 (kmol $_{O_2}$/kmol $_{Air}$)
	Ar= 0.0093 (kmol $_{Ar}$/kmol $_{Air}$)
Molecular Weight:	28.96
Gas Constant:	287.22 J/(kg·K)

Critical Constants (Maximum Temperature):	Critical Pressure:	3.76625×10^6Pa (37.6625 bar)
	Critical Temperature:	132.52K(−140.63°C)
	Critical Specific Volume:	3.19489×10^{-3}m^3/kg

Critical Constants (Minimum Pressure):	Critical Pressure:	3.77431×10^6Pa (37.7431 bar)
	Critical Temperature:	132.42K(−140.73°C)
	Critical Specific Volume:	2.96020×10^{-3}m^3/kg

Reference State:

At 1.01325 bar (1 atm) and −233.15°C(40 K)(ideal gas), 4845.72J/(kg·K) is assigned to the specific entropy. At −233.15°C(40 K)(ideal gas), 28325.0 J/kg is assigned to the specific internal energy.

2.12.4 Formula

Equation of State:

Equations (28) and (43b) in a function form of $P = P(\rho, T)$ in reference [1]. Here P=pressure, ρ=density and T=temperature.

Pressure and Temperature on Dew-Point Curve (Saturated Vapor):

Equation (36) in reference [1].

Pressure and Temperature on Bubble-Point Curve (Saturated Liquid):

Equation (37) in reference [1].

Properties at Vapor-Liquid Equilibrium:

saturated liquid; Equations (38a), (54) and (56) for specific volume, specific entropy, and specific enthalpy, respectively.

saturated vapor; Equations (36) and (43b) for specific volume, (36) and (46) for specific entropy, (36) and (45) for specific enthalpy, (36) and (48) for isochoric specific heat, and (36) and (49) for isobaric specific heat.

All of these equations have been cited from reference [1].

Transport Properties:
Viscosity and thermal conductivity from reference[2].

References

[1] H.D.Baehr and K.Schwier, Die thermodynamischen Eigenschaften der Luft, Springer-Verlag, (1961).
[2] K.Kadoya, N.Matsunaga and A.Nagashima, Viscosity and Thermal Conductivity of Dry Air in the Gaseous Phase, Journal of Physical and Chemical Reference Data, vol.14, No.4, (1985), p.947.

Table II–2.12–1 Air Function

No.	Name of Function	Function and Argument(s)	Range of Argument(s)
1	AIPPT(P,T)		
94	AJTPT(P,T)		
8A	AKPD(P)		
8B	AKPDD(P)		
82	AKPT(P,T)	AKPT: Isentropic Exponent [–] P∗: Pressure [Pa], [bar] T∗: Temperature [K], [°C]	$0 \leq P \leq 450 \times 10^6$ [Pa] $60 \leq T \leq 1523.15$ [K] $0 \leq P \leq 4500$ [bar] $-213.15 \leq T \leq 1250$ [°C] see Fig.II-2-3
8C	AKTD(T)		
8D	AKTDD(T)		
2	ALAPP(P)		
3	ALAPT(T)		
4	ALHP(P)	ALHP: Latent Heat of Vaporization [J/kg] P∗: Pressure [Pa], [bar]	$40 \times 10^3 \leq P \leq 3.6 \times 10^6$ [Pa] $0.4 \leq P \leq 36$ [bar]
5	ALHT(T)		
6	ALMPD(P)		
7	ALMPDD(P)		
8	ALMPT(P,T)	ALMPT: Thermal Conductivity [W/(m·K)] P∗: Pressure [Pa], [bar] T∗: Temperature [K], [°C]	$0 \leq P \leq 100 \times 10^6$ [Pa] $85 \leq T \leq 2000$ [K] $0 \leq P \leq 1000$ [bar] $-188.15 \leq T \leq 1726.85$ [°C] see Fig.II-2-1
9	ALMTD(T)		
10	ALMTDD(T)		
11	AMUPD(P)		
12	AMUPDD(P)		
13	AMUPT(P,T)	AMUPT: Coefficient of Viscosity [Pa·s] P∗: Pressure [Pa], [bar] T∗: Temperature [K], [°C]	$0 \leq P \leq 100 \times 10^6$ [Pa] $85 \leq T \leq 2000$ [K] $0 \leq P \leq 1000$ [bar] $-188.15 \leq T \leq 1726.85$ [°C] see Fig.II-2-2
14	AMUTD(T)		
15	AMUTDD(T)		
92	BPPT(P,T)		
90	BSPT(P,T)		
91	BTPT(P,T)		
93	BVPT(P,T)		
16	CPPD(P)		
17	CPPDD(P)	CPPDD: Isobaric Specific Heat of Saturated Vapor [J/(kg·K)] P∗: Pressure [Pa], [bar]	$1000 \leq P \leq 3.76625 \times 10^6$ [Pa] $0.01 \leq P \leq 37.6625$ [bar]
18	CPPT(P,T)	CPPT: Isobaric Specific Heat [J/(kg·K)] P∗: Pressure [Pa], [bar] T∗: Temperature [K], [°C]	$0 \leq P \leq 450 \times 10^6$ [Pa] $60 \leq T \leq 1523.15$ [K] $0 \leq P \leq 4500$ [bar] $-213.15 \leq T \leq 1250$ [°C] see Fig.II-2-3
19	CPTD(T)		
20	CPTDD(T)	CPTDD: Isobaric Specific Heat of Saturated Vapor [J/(kg·K)] T∗: Temperature [K], [°C]	$60 \leq T \leq 132.52$ [K] $-213.15 \leq T \leq -140.63$ [°C]

Table II–2.12–1 Air Function (cont'd)

No.	Name of Function	Function and Argument(s)	Range of Argument(s)
21	CRP('A')	CRP: Critical Constants H: 'A'='H': 34.248×10^3 [J/kg] Specific Enthalpy P∗: 'A'='P': 3.76625×10^6[Pa],37.6625 [bar] Pressure S: 'A'='S': 4.3843×10^3 [J/(kg·K)] Specific Entropy T∗: 'A'='T': 132.52 [K],−140.63 [°C] Temperature V: 'A'='V': 3.19489×10^{-3}[m^3/kg] Specific Volume	one of 'H', 'P', 'S', 'T' and 'V'
7A	CVPD(P)		
76	CVPDD(P)	CVPDD: Isochoric Specific Heat of Saturated Vapor [J/(kg·K)] P∗: Pressure [Pa], [bar]	$1000\leq P\leq3.76625\times10^6$ [Pa] $0.01\leq P\leq37.6625$ [bar]
77	CVPT(P,T)	CVPT: Isochoric Specific Heat [J/(kg·K)] P∗: Pressure [Pa], [bar] T∗: Temperature [K], [°C]	$0\leq P\leq450\times10^6$ [Pa] $60\leq T\leq1523.15$ [K] $0\leq P\leq4500$ [bar] $-213.15\leq T\leq1250$ [°C] see Fig.II-2-3
7B	CVTD(T)		
78	CVTDD(T)	CVTDD: Isochoric Specific Heat of Saturated Vapor [J/(kg·K)] T∗: Temperature [K], [°C]	$60\leq T\leq132.52$ [K] $-213.15\leq T\leq-140.63$ [°C]
2A	EPSPD(P)		
2B	EPSPDD(P)		
22	EPSPT(P,T)		
2C	EPSTD(T)		
2D	EPSTDD(T)		
89	FC('A')	FC: Fundamental Constants M: 'A'='M': 28.96 Relative Molecular Mass R: 'A'='R': 287.22 [J/(kg·K)] Gas Constant	one of 'M' and 'R'
9A	GAMPD(P)		
96	GAMPDD(P)		
95	GAMPT(P,T)		
9B	GAMTD(T)		
97	GAMTDD(T)		
23	HPD(P)	HPD: Specific Enthalpy of Saturated Liquid [J/kg] P∗: Pressure [Pa], [bar]	$40\times10^3\leq P\leq3.6\times10^6$ [Pa] $0.4\leq P\leq36$ [bar]
24	HPDD(P)	HPDD: Specific Enthalpy of Saturated Vapor [J/kg] P∗: Pressure [Pa], [bar]	$1000\leq P\leq3.76625\times10^6$ [Pa] $0.01\leq P\leq37.6625$ [bar]
71	HPS(P,S)	HPS: Specific Enthalpy [J/kg] P∗: Pressure [Pa], [bar] S: Specific Entropy [J/(kg·K)]	$1000\leq P\leq450\times10^6$ [Pa] $0.01\leq P\leq4500$ [bar] see Fig.II-2-5 for S
25	HPT(P,T)	HPT: Specific Enthalpy [J/kg] P∗: Pressure [Pa], [bar] T∗: Temperature [K], [°C]	$1000\leq P\leq450\times10^6$ [Pa] $60\leq T\leq1523.15$ [K] $0.01\leq P\leq4500$ [bar] $-213.15\leq T\leq1250$ [°C] see Fig.II-2-3
26	HPX(P,X)	HPX: Specific Enthalpy of Mixture [J/kg] P∗: Pressure [Pa], [bar] X: Dryness Fraction [–]	$40\times10^3\leq P\leq3.6\times10^6$ [Pa] $0.4\leq P\leq36$ [bar] $0\leq X\leq1.0$ [–]
27	HTD(T)	HTD: Specific Enthalpy of Saturated Liquid [J/kg] T∗: Temperature [K], [°C]	$68\leq T\leq132$ [K] $-205.15\leq T\leq-141.15$ [°C]
28	HTDD(T)	HTDD: Specific Enthalpy of Saturated Vapor [J/kg] T∗: Temperature [K], [°C]	$60\leq T\leq132.52$ [K] $-213.15\leq T\leq-140.63$ [°C]
29	HTX(T,X)		

Table II–2.12–1 Air Function (cont'd)

No.	Name of Function	Function and Argument(s)	Range of Argument(s)
84	IDENTF('A')	IDENTF : CHARACTER TYPE FUNCTION for Package Identification (Length 20) C: 'A'='C': 'AIR' Molecular Formula S: 'A'='S': 'AIR' Name of Substance V: 'A'='V': '10.1' Version Number	one of 'C', 'S' and 'V'
66	PLDT(T)		
68	PMLT(T)		
85	PRPD(P)		
86	PRPDD(P)		
81	PRPT(P,T)	PRPT: Prandtl Number [–] P∗: Pressure [Pa], [bar] T∗: Temperature [K], [°C]	$0 \le P \le 0.1473 \times 10^6$ [Pa] $85 \le T \le 1523.15$ [K] $0.1473 \times 10^6 < P \le 3.3 \times 10^6$ [Pa] TSPDD(P)≤T≤1523.15 [K] $3.3 \times 10^6 < P \le 42.791 \times 10^6$ [Pa] $159 \le T \le 1523.15$ [K] $42.791 \times 10^6 < P \le 92.72 \times 10^6$ [Pa] TPV(P,1.42×10^{-3} m^3/kg) ≤T≤1523.15 [K] $92.72 \times 10^6 < P \le 100 \times 10^6$ [Pa] $223.15 \le T \le 1523.15$ [K] $0 \le P \le 1.473$ [bar] $-188.15 \le T \le 1250$ [°C] $1.473 < P < 33$ [bar] TSPDD(P)≤T≤1250 [°C] $33 < P \le 427.91$ [bar] $-78.15 \le T \le 1250$ [°C] $427.91 < P \le 927.2$ [bar] TPV(P,1.42×10^{-3} m^3/kg) ≤T≤1250 [°C] $927.2 < P \le 1000$ [bar] $-40 \le T \le 1250$ [°C]
87	PRTD(T)		
88	PRTDD(T)		
99	PSBT(T)		
30	PST(T)		
72	PSTD(T)	PSTD∗: Pressure [Pa], [bar] on Bubble-Point Curve (Saturated Liquid) T∗: Temperature [K], [°C]	$68 \le T \le 132.42$ [K] $-205.15 \le T \le -140.73$ [°C]
73	PSTDD(T)	PSTDD∗: Pressure [Pa], [bar] on Dew-Point Curve (Saturated Vapor) T∗: Temperature [K], [°C]	$60 \le T \le 132.52$ [K] $-213.15 \le T \le -140.63$ [°C]
31	SIGP(P)		
32	SIGT(T)		
33	SPD(P)	SPD: Specific Entropy of Saturated Liquid [J/(kg·K)] P∗: Pressure [Pa], [bar]	$40 \times 10^3 \le P \le 3.6 \times 10^6$ [Pa] $0.4 \le P \le 36$ [bar]
34	SPDD(P)	SPDD: Specific Entropy of Saturated Vapor [J/(kg·K)] P∗: Pressure [Pa], [bar]	$1000 \le P \le 3.76625 \times 10^6$ [Pa] $0.01 \le P \le 37.6625$ [bar]
35	SPT(P,T)	SPT: Specific Entropy [J/(kg·K)] P∗: Pressure [Pa], [bar] T∗: Temperature [K], [°C]	$1000 \le P \le 450 \times 10^6$ [Pa] $60 \le T \le 1523.15$ [K] $0.01 \le P \le 4500$ [bar] $-213.15 \le T \le 1250$ [°C] see Fig.II-2-3

Table II–2.12–1 Air Function (cont'd)

No.	Name of Function	Function and Argument(s)	Range of Argument(s)
36	SPX(P,X)	SPX: Specific Entropy of Mixture [J/(kg·K)] P∗: Pressure [Pa], [bar] X: Dryness Fraction [–]	$40\times10^3\leq P\leq3.6\times10^6$ [Pa] $0.4\leq P\leq36$ [bar] $0\leq X\leq1.0$ [–]
37	STD(T)	STD: Specific Entropy of Saturated Liquid [J/(kg·K)] T∗: Temperature [K], [°C]	$68\leq T\leq132$ [K] $-205.15\leq T\leq-141.15$ [°C]
38	STDD(T)	STDD: Specific Entropy of Saturated Vapor [J/(kg·K)] T∗: Temperature [K], [°C]	$60\leq T\leq132.52$ [K] $-213.15\leq T\leq-140.63$ [°C]
39	STX(T,X)		
67	TLDP(P)		
69	TMLP(P)		
64	TPH(P,H)	TPH∗: Temperature [K], [°C] P∗: Pressure [Pa], [bar] H: Specific Enthalpy [J/kg]	$1000\leq P\leq450\times10^6$ [Pa] $0.01\leq P\leq4500$ [bar] see Fig.II-2-4 for H
6H	TPH2(P,H)		
65	TPS(P,S)	TPS∗: Temperature [K], [°C] P∗: Pressure [Pa], [bar] S: Specific Entropy [J/(kg·K)]	$1000\leq P\leq450\times10^6$ [Pa] $0.01\leq P\leq4500$ [bar] see Fig.II-2-5 for S
6S	TPS2(P,S)		
98	TPSEUP(P)		
70	TPV(P,V)	TPV∗: Temperature [K], [°C] P∗: Pressure [Pa], [bar] V: Specific Volume [m^3/kg]	$1000\leq P\leq450\times10^6$ [Pa] $0.01\leq P\leq4500$ [bar] see Fig.II-2-6 for V
41	TRPL('A')		
100	TSBP(P)		
40	TSP(P)		
74	TSPD(P)	TSPD∗: Temperature [K], [°C] on Bubble-Point Curve (Saturated Liquid) P∗: Pressure [Pa], [bar]	$40\times10^3\leq P\leq3.77434\times10^6$ [Pa] $0.4\leq P\leq37.7434$ [bar]
75	TSPDD(P)	TSPDD∗: Temperature [K], [°C] on Dew-Point Curve (Saturated Vapor) P∗: Pressure [Pa], [bar]	$1000\leq P\leq3.76625\times10^6$ [Pa] $0.01\leq P\leq37.6625$ [bar]
42	UPD(P)	UPD: Specific Internal Energy of Saturated Liquid [J/kg] P∗: Pressure [Pa], [bar]	$40\times10^3\leq P\leq3.6\times10^6$ [Pa] $0.4\leq P\leq36$ [bar]
43	UPDD(P)	UPDD: Specific Internal Energy of Saturated Vapor [J/kg] P∗: Pressure [Pa], [bar]	$1000\leq P\leq3.76625\times10^6$ [Pa] $0.01\leq P\leq37.6625$ [bar]
79	UPS(P,S)	UPS: Specific Internal Energy [J/kg] P∗: Pressure [Pa], [bar] S: Specific Entropy [J/(kg·K)]	$1000\leq P\leq450\times10^6$ [Pa] $0.01\leq P\leq4500$ [bar] see Fig.II-2-5 for S
44	UPT(P,T)	UPT: Specific Internal Energy [J/kg] P∗: Pressure [Pa], [bar] T∗: Temperature [K], [°C]	$1000\leq P\leq450\times10^6$ [Pa] $60\leq T\leq1523.15$ [K] $0.01\leq P\leq4500$ [bar] $-213.15\leq T\leq1250$ [°C] see Fig.II-2-3
45	UPX(P,X)	UPX: Specific Internal Energy of Mixture [J/kg] P∗: Pressure [Pa], [bar] X: Dryness Fraction [–]	$40\times10^3\leq P\leq3.6\times10^6$ [Pa] $0.4\leq P\leq36$ [bar] $0\leq X\leq1.0$ [–]
46	UTD(T)	UTD: Specific Internal Energy of Saturated Liquid [J/kg] T∗: Temperature [K], [°C]	$68\leq T\leq132$ [K] $-205.15\leq T\leq-141.15$ [°C]
47	UTDD(T)	UTDD: Specific Internal Energy of Saturated Vapor [J/kg] T∗: Temperature [K], [°C]	$60\leq T\leq132.52$ [K] $-213.15\leq T\leq-140.63$ [°C]

Table II–2.12–1 Air Function (cont'd)

No.	Name of Function	Function and Argument(s)	Range of Argument(s)
48	UTX(T,X)		
49	VPD(P)	VPD: Specific Volume of Saturated Liquid [m^3/kg] P∗: Pressure [Pa], [bar]	$40\times10^3\leq P\leq3.6\times10^6$ [Pa] $0.4\leq P\leq36$ [bar]
50	VPDD(P)	VPDD: Specific Volume of Saturated Vapor [m^3/kg] P∗: Pressure [Pa], [bar]	$1000\leq P\leq3.76625\times10^6$ [Pa] $0.01\leq P\leq37.6625$ [bar]
80	VPS(P,S)	VPS: Specific Volume [m^3/kg] P∗: Pressure [Pa], [bar] S: Specific Entropy [J/(kg·K)]	$1000\leq P\leq450\times10^6$ [Pa] $0.01\leq P\leq4500$ [bar] see Fig.II-2-5 for S
51	VPT(P,T)	VPT: Specific Volume [m^3/kg] P∗: Pressure [Pa], [bar] T∗: Temperature [K], [°C]	$1000\leq P\leq450\times10^6$ [Pa] $60\leq T\leq1523.15$ [K] $0.01\leq P\leq4500$ [bar] $-213.15\leq T\leq1250$ [°C] see Fig.II-2-3
52	VPX(P,X)	VPX: Specific Volume of Mixture [m^3/kg] P∗: Pressure [Pa], [bar] X: Dryness Fraction [–]	$40\times10^3\leq P\leq3.6\times10^6$ [Pa] $0.4\leq P\leq36$ [bar] $0\leq X\leq1.0$ [–]
53	VTD(T)	VTD: Specific Volume of Saturated Liquid [m^3/kg] T∗: Temperature [K], [°C]	$68\leq T\leq132.52$ [K] $-205.15\leq T\leq-140.63$ [°C]
54	VTDD(T)	VTDD: Specific Volume of Saturated Vapor [m^3/kg] T∗: Temperature [K], [°C]	$60\leq T\leq132.52$ [K] $-213.15\leq T\leq-140.63$ [°C]
55	VTX(T,X)		
8E	WPD(P)		
8F	WPDD(P)		
83	WPT(P,T)	WPT: Velocity of Sound [m/s] P∗: Pressure [Pa], [bar] T∗: Temperature [K], [°C]	$0\leq P\leq450\times10^6$ [Pa] $60\leq T\leq1523.15$ [K] $0\leq P\leq4500$ [bar] $-213.15\leq T\leq1250$ [°C] see Fig.II-2-3
8G	WTD(T)		
8H	WTDD(T)		
56	XPH(P,H)	XPH: Dryness Fraction [–] P∗: Pressure [Pa], [bar] H: Specific Enthalpy of Mixture [J/(kg·K)]	$40\times10^3\leq P\leq3.6\times10^6$ [Pa] $0.4\leq P\leq36$ [bar] HPD(P)≤H≤HPDD(P) [J/kg]
57	XPS(P,S)	XPS: Dryness Fraction [–] P∗: Pressure [Pa], [bar] S: Specific Entropy of Mixture [J/(kg·K)]	$40\times10^3\leq P\leq3.6\times10^6$ [Pa] $0.4\leq P\leq36$ [bar] SPD(P)≤S≤SPDD(P) [J/(kg·K)]
58	XPU(P,U)	XPU: Dryness Fraction [–] P∗: Pressure [Pa], [bar] U: Specific Internal Energy of Mixture [J/kg]	$40\times10^3\leq P\leq3.6\times10^6$ [Pa] $0.4\leq P\leq36$ [bar] UPD(P)≤U≤UPDD(P) [J/kg]
59	XPV(P,V)	XPV: Dryness Fraction [–] P∗: Pressure [Pa], [bar] V: Specific Volume of Mixture [m^3/kg]	$40\times10^3\leq P\leq3.6\times10^6$ [Pa] $0.4\leq P\leq36$ [bar] VPD(P)≤V≤VPDD(P) [m^3/kg]
60	XTH(T,H)		
61	XTS(T,S)		
62	XTU(T,U)		
63	XTV(T,V)		

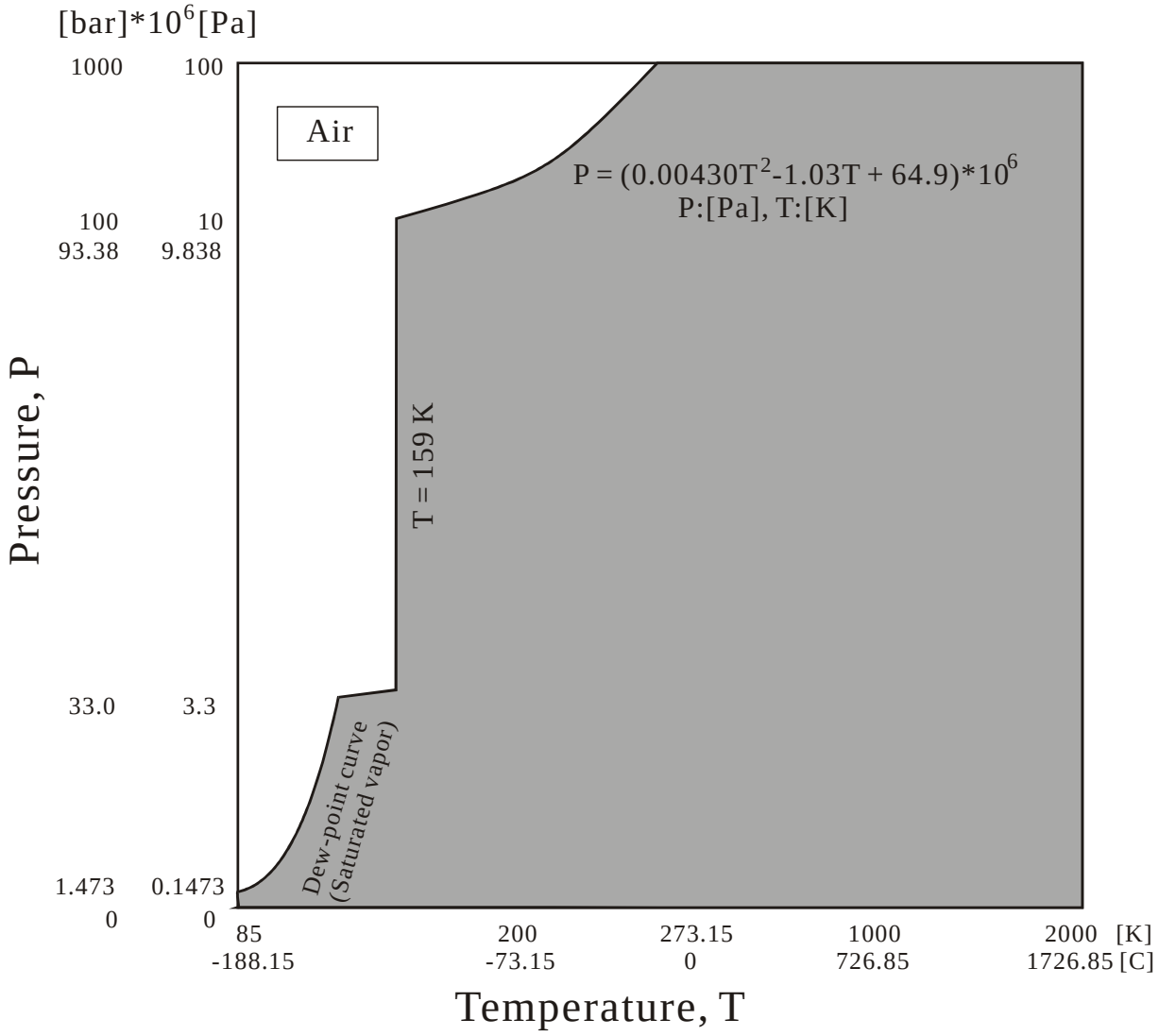

Fig.II–2.12–1 Range of Arguments(P,T) for ALMPT(P,T).

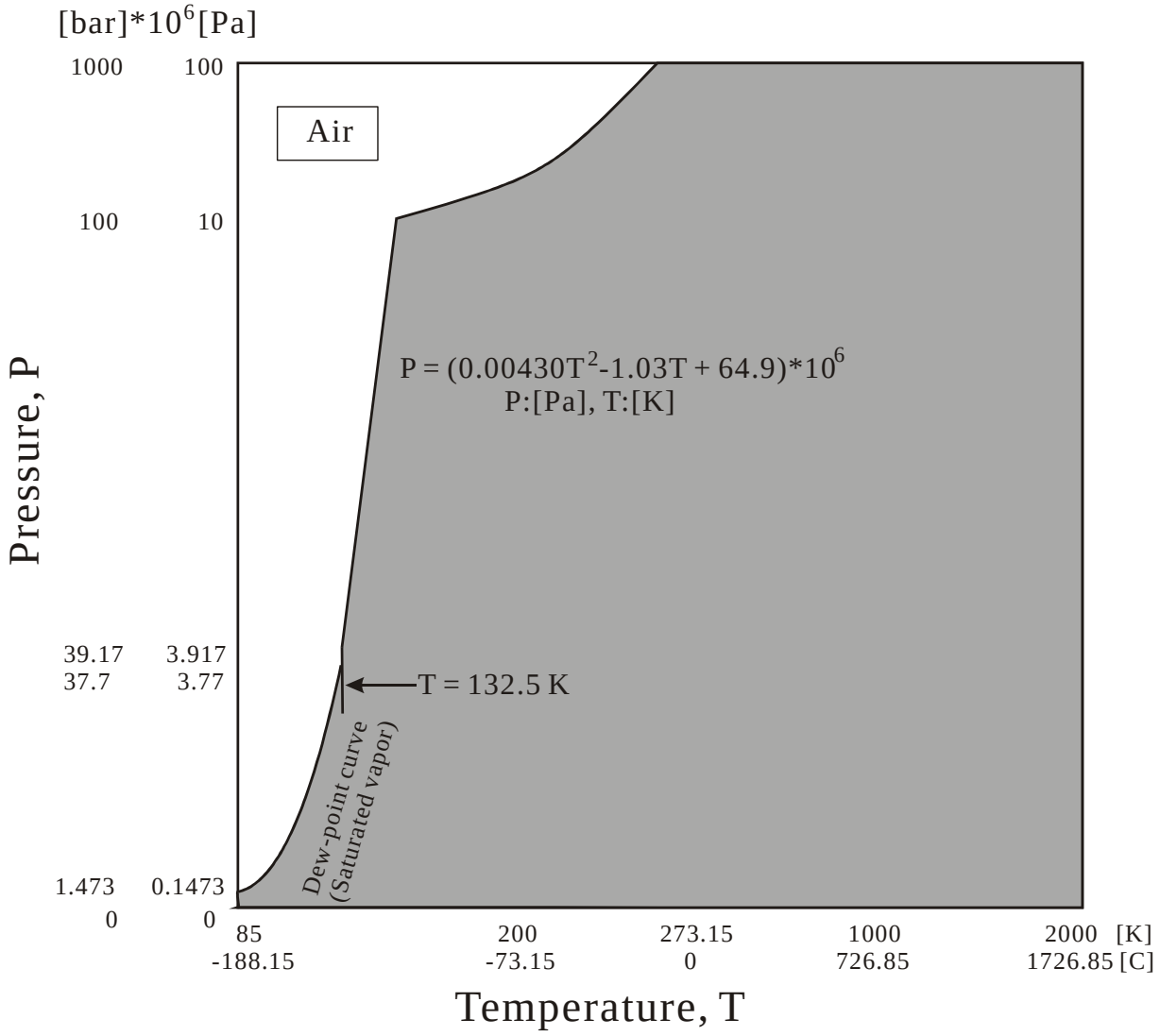

Fig.II–2.12–2 Range of Arguments(P,T) for AMUPT(P,T).

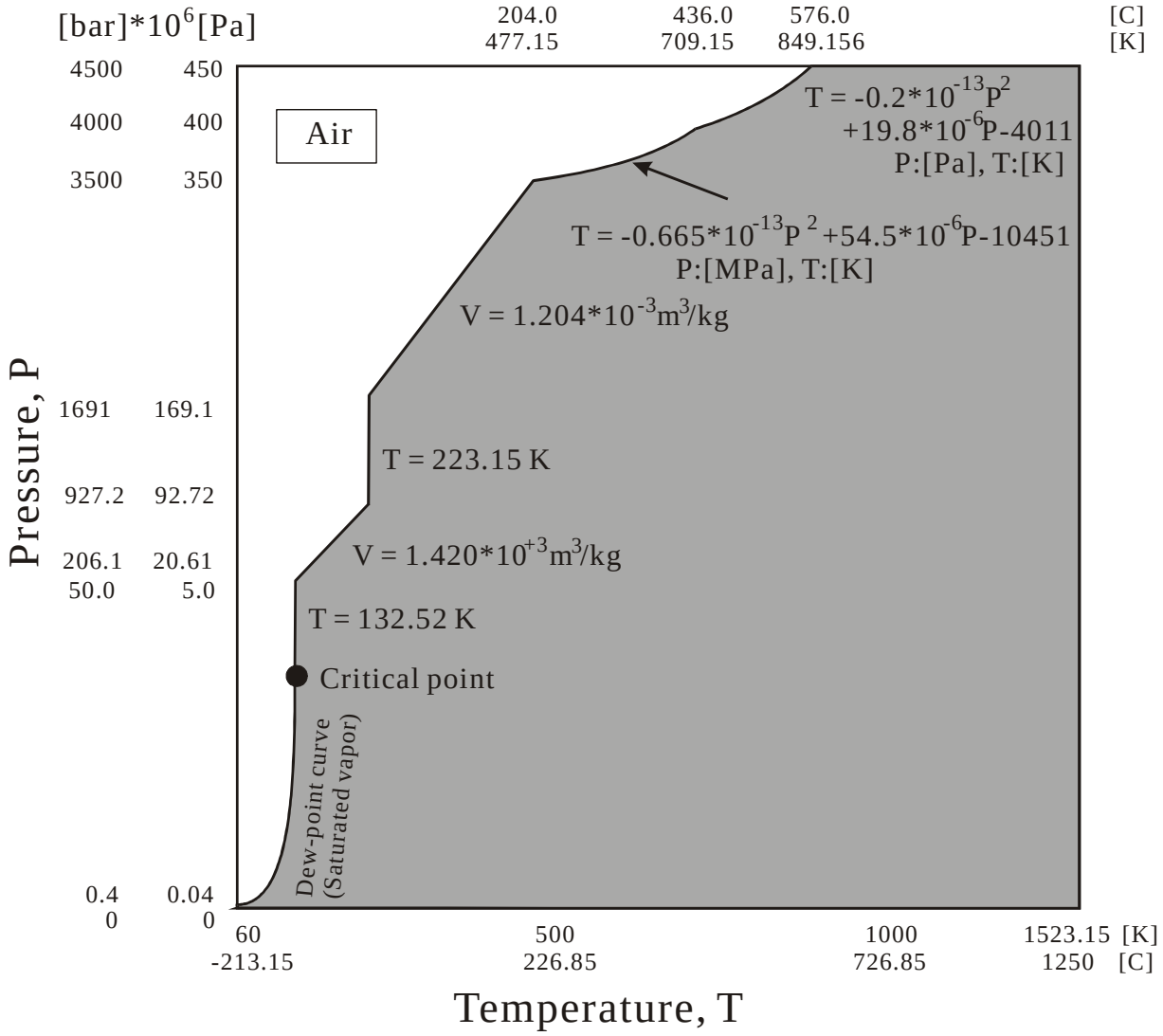

Fig.II–2.12–3 Range of Arguments(P,T) for AKPT(P,T),CPPT(P,T),CVPT(P,T),HPT(P,T), SPT(P,T),UPT(P,T),VPT(P,T) and WPT(P,T).

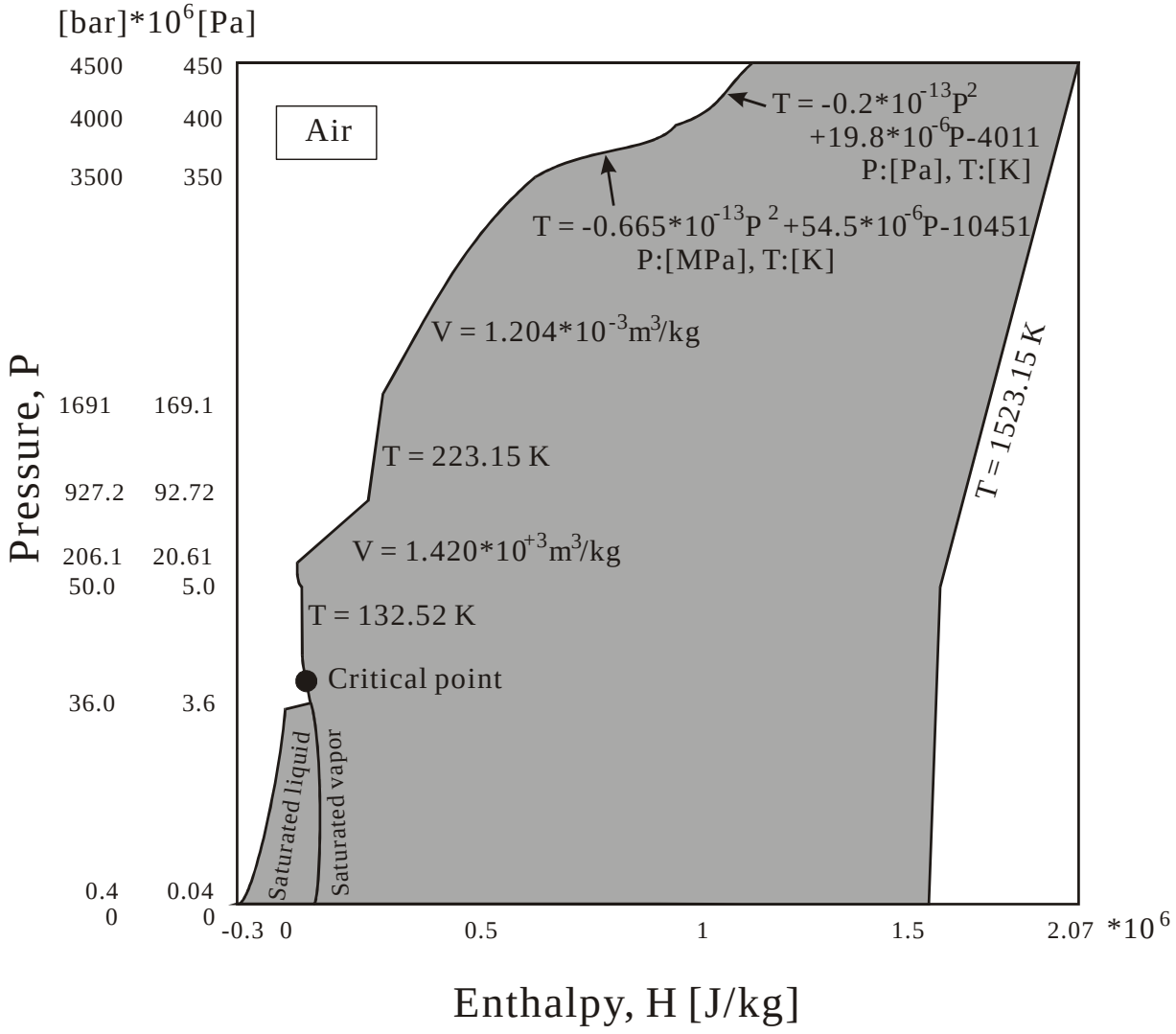

Fig.II–2.12–4 Range of Arguments(P,H) for TPH(P,H).

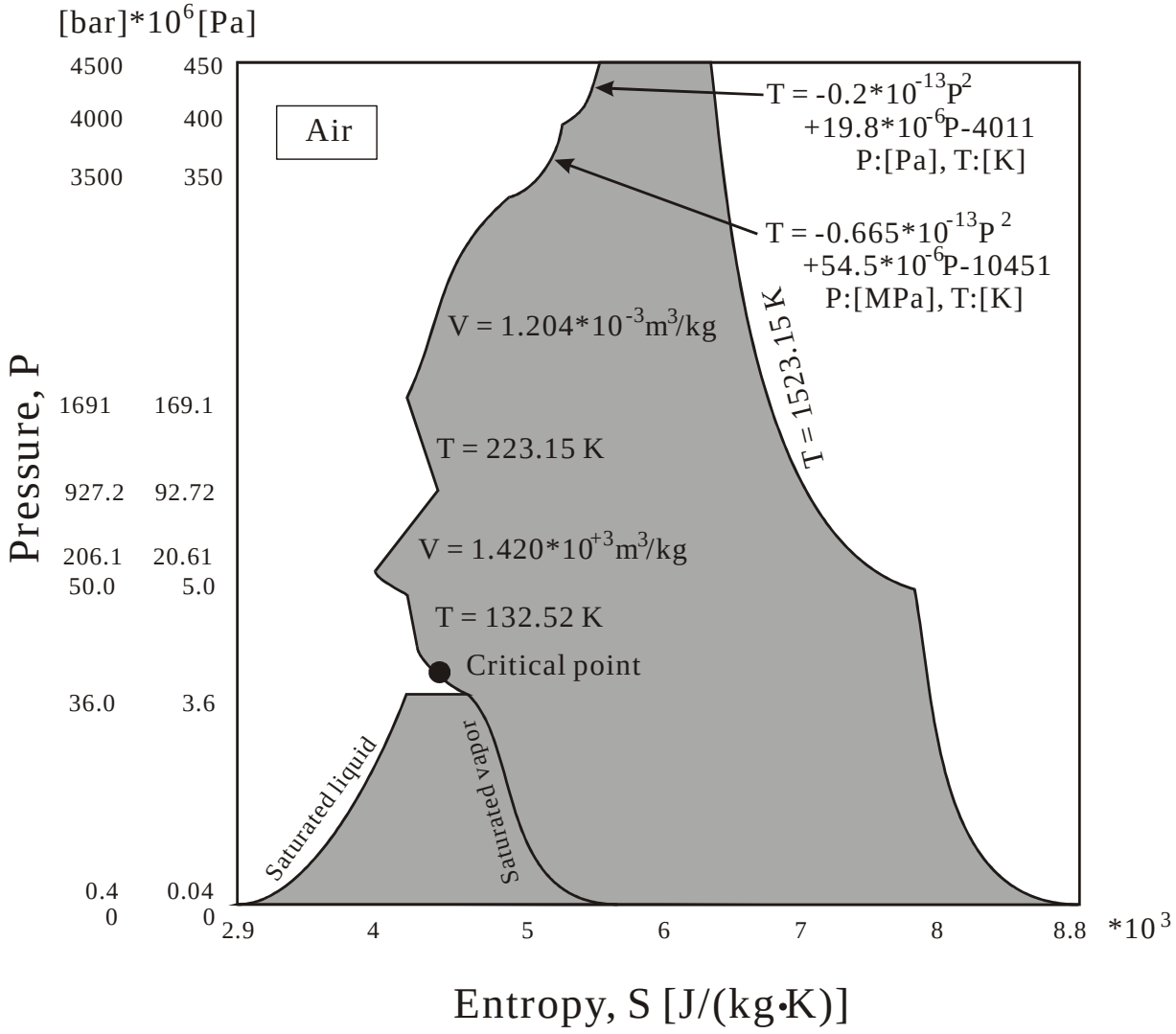

Fig.II–2.12–5 Range of Arguments(P,S) for HPS(P,S),TPS(P,S),UPS(P,S) and VPS(P,S).

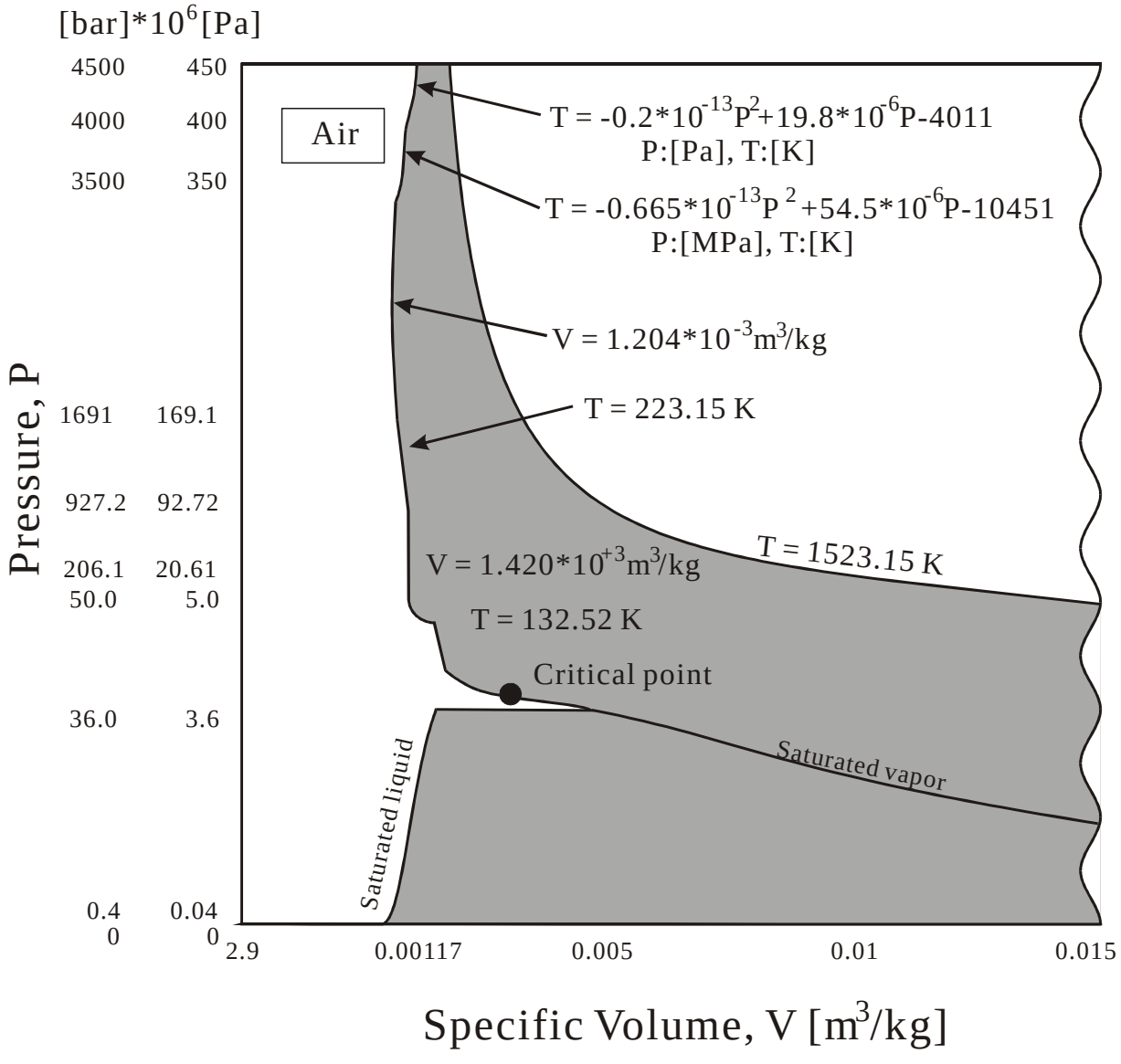

Fig.II–2–6 Range of Arguments(P,V) for TPV(P,V).