2.4 Argon

Equations for thermodynamic properties have been cited from the IUPAC Table [1], one for surface tension from Miller et al.[2], and one for thermal conductivity from reference [3].

2.4.1 Temperature Scale

International practical temperature scale 1968 (IPTS-1968)

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

Name of Substance:	Argon
Library File for UNIX:	libjarg.a
Library File for DOS,Windows95/NT:	JARG.LIB
Single Shot Program for UNIX:	arg-ss
Single Shot Program for DOS,Windows95/NT:	ARG–SS.EXE

2.4.3 Important Constants and Others

Molecular Formula:	Ar
Relative Molecular Mass:	39.948
Gas Constant:	208.13 J/(kg·K)

Critical Constants:

Critical Pressure:	4.998×10^{6}Pa (49.98 bar)
Critical Temperature:	150.86 K (−122.29°C)
Critical Specific Volume:	$1.8667\times10^{-3}\mathrm{m}^3/\mathrm{kg}$

Triple Point:

Pressure:	0.06875×10^{6}Pa (0.6875 bar)
Temperature:	83.78 K (−189.37°C)

Reference State:

At 1.01325 bar(1 atm) and 25°C(298.15 K)(gas), 154.735 J/(mol·K) and 6197 J/mol are assigned to the specific entropy and the specific enthalpy, respectively.

2.4.4 Formula

Equation of State:

Equation (7) in a function form of $P = P(\rho, T)$ in reference [1]. Here P=pressure, ρ=density and T=Temperature.

Vapor Pressure:

Equation (5) in reference [1].

Properties on Bubble-Point Curve:

Equation (9) in reference [1].

Properties at Vapor-Liquid equilibrium:

saturated liquid: Equations (5) and (9) for specific volume, equations at page 7 for specific enthalpy and specific entropy, respectively.

saturated vapor: Equations (5) and (7) for specific volume, equation (7) and equations at page 7 for specific enthalpy and specific entropy, and equations (7) and (9) for isochoric specific heat and isobaric specific heat, respectively. However, the constant CO_3=-360.553×10^4 in eq.(9) has been corrected to CO_3=-360.553×10^7.

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

Transport Properties:
Thermal conductivity for saturated liquid from reference [3].

The Other Properties:
Surface tension from reference [2].

References

[1] International Thermodynamic Tables of the Fluid State, Argon, 1971, IUPAC, (1972).
[2] J.W.Miller Jr and C.L.Yaws, Chemical Engineering, vol.83, No. 23, (1976), p.127.
[3] Thermal conductivity, TPRC Data Series, vol.3, Plenum, (1970).

Table II–2.4–1 Argon 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)		
8C	AKTD(T)		
8D	AKTDD(T)		
2	ALAPP(P)	ALAPP: Laplace Coefficient [m] P∗: Pressure [Pa], [bar]	$68.75\times10^3 \leq P \leq 4.998\times10^6$ [Pa] $0.6875 \leq P \leq 49.98$ [bar]
3	ALAPT(T)	ALAPT: Laplace Coefficient [m] T∗: Temperature [K], [°C]	$83.78 \leq T \leq 150.86$ [K] $-189.37 \leq T \leq -122.29$ [°C]
4	ALHP(P)	ALHP: Latent Heat of Vaporization [J/kg] P∗: Pressure [Pa], [bar]	$68.75\times10^3 \leq P \leq 4.998\times10^6$ [Pa] $0.6875 \leq P \leq 49.98$ [bar]
5	ALHT(T)	ALHT: Latent Heat of Vaporization [J/kg] T∗: Temperature [K], [°C]	$83.78 \leq T \leq 150.86$ [K] $-189.37 \leq T \leq -122.29$ [°C]
6	ALMPD(P)	ALMPD: Thermal Conductivity of Saturated Liquid [W/(m·K)] P∗: Pressure [Pa], [bar]	$68.75\times10^3 \leq P \leq 3.1675\times10^6$ [Pa] $0.6875 \leq P \leq 31.675$ [bar]
7	ALMPDD(P)		
8	ALMPT(P,T)		
9	ALMTD(T)	ALMTD: Thermal Conductivity of Saturated Liquid [W/(m·K)] T∗: Temperature [K], [°C]	$83.78 \leq T \leq 140$ [K] $-189.37 \leq T \leq -133.15$ [°C]
10	ALMTDD(T)		
11	AMUPD(P)		
12	AMUPDD(P)		
13	AMUPT(P,T)		
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]	$68.75\times10^3 \leq P \leq 4.998\times10^6$ [Pa] $0.6875 \leq P \leq 49.98$ [bar]
18	CPPT(P,T)	CPPT: Isobaric Specific Heat [J/(kg·K)] P∗: Pressure [Pa], [bar] T∗: Temperature [K], [°C]	$10.0\times10^3 \leq P \leq 100\times10^6$ [Pa] $83.78 \leq T \leq 1100$ [K] $0.1 \leq P \leq 1000$ [bar] $-189.37 \leq T \leq 826.85$ [°C] see Fig.II-2-1
19	CPTD(T)		
20	CPTDD(T)	CPTDD: Isobaric Specific Heat of Saturated Vapor [J/(kg·K)] T∗: Temperature [K], [°C]	$83.78 \leq T \leq 150.86$ [K] $-189.37 \leq T \leq -122.29$ [°C]
21	CRP('A')	CRP: Critical Constants H: 'A'='H': 189.17×10^3 [J/kg] Specific Enthalpy P∗: 'A'='P': 4.998×10^6 [Pa], 49.98 [bar] Pressure S: 'A'='S': 2.201×10^3 [J/(kg·K)] Specific Entropy T∗: 'A'='T': 150.86 [K], −122.29 [°C] Temperature V: 'A'='V': 1.8667×10^{-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]	$68.75\times10^3 \leq P \leq 4.998\times10^6$ [Pa] $0.6875 \leq P \leq 49.98$ [bar]

Table II–2–1 Argon Function (cont'd)

No.	Name of Function	Function and Argument(s)	Range of Argument(s)
77	CVPT(P,T)	CVPT: Isochoric Specific Heat [J/(kg·K)] P∗: Pressure [Pa], [bar] T∗: Temperature [K], [°C]	$10.0\times10^3\leq P\leq100\times10^6$ [Pa] $83.78\leq T\leq1100$ [K] $0.1\leq P\leq1000$ [bar] $-189.37\leq T\leq826.85$ [°C] see Fig.II-2-1
7B	CVTD(T)		
78	CVTDD(T)	CVTDD: Isochoric Specific Heat of Saturated Vapor [J/(kg·K)] T∗: Temperature [K], [°C]	$83.78\leq T\leq150.86$ [K] $-189.37\leq T\leq-122.29$ [°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': 39.948 Relative Molecular Mass R: 'A'='R': 208.13 [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]	$68.75\times10^3\leq P\leq4.998\times10^6$ [Pa] $0.6875\leq P\leq49.98$ [bar]
24	HPDD(P)	HPDD: Specific Enthalpy of Saturated Vapor [J/kg] P∗: Pressure [Pa], [bar]	$68.75\times10^3\leq P\leq4.998\times10^6$ [Pa] $0.6875\leq P\leq49.98$ [bar]
71	HPS(P,S)	HPS: Specific Enthalpy [J/kg] P∗: Pressure [Pa], [bar] S: Specific Entropy [J/(kg·K)]	$10.0\times10^3\leq P\leq100\times10^6$ [Pa] $0.1\leq P\leq1000$ [bar] see Fig.II-2-3 for S
25	HPT(P,T)	HPT: Specific Enthalpy [J/kg] P∗: Pressure [Pa], [bar] T∗: Temperature [K], [°C]	$10.0\times10^3\leq P\leq100\times10^6$ [Pa] $83.78\leq T\leq1100$ [K] $0.1\leq P\leq1000$ [bar] $-189.37\leq T\leq826.85$ [°C] see Fig.II-2-1
26	HPX(P,X)	HPX: Specific Enthalpy of Mixture [J/kg] P∗: Pressure [Pa], [bar] X: Dryness Fraction [–]	$68.75\times10^3\leq P\leq4.998\times10^6$ [Pa] $0.6875\leq P\leq49.98$ [bar] $0\leq X\leq1.0$ [–]
27	HTD(T)	HTD: Specific Enthalpy of Saturated Liquid [J/kg] T∗: Temperature [K], [°C]	$83.78\leq T\leq150.86$ [K] $-189.37\leq T\leq-122.29$ [°C]
28	HTDD(T)	HTDD: Specific Enthalpy of Saturated Vapor [J/kg] T∗: Temperature [K], [°C]	$83.78\leq T\leq150.86$ [K] $-189.37\leq T\leq-122.29$ [°C]
29	HTX(T,X)	HTX: Specific Enthalpy of Mixture [J/kg] T∗: Temperature [K], [°C] X: Dryness Fraction [–]	$83.78\leq T\leq150.86$ [K] $-189.37\leq T\leq-122.29$ [°C] $0\leq X\leq1.0$ [–]
84	IDENTF('A')	IDENTF: CHARACTER TYPE FUNCTION for Package Identification (Length 20) C: 'A'='C': 'AR' Molecular Formula S: 'A'='S': 'ARGON' 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)		

Table II–2.4–1 Argon Function (cont'd)

No.	Name of Function	Function and Argument(s)	Range of Argument(s)
81	PRPT(P,T)		
87	PRTD(T)		
88	PRTDD(T)		
99	PSBT(T)		
30	PST(T)	PST∗: Saturation Pressure [Pa], [bar] T∗: Temperature [K], [°C]	83.78≤T≤150.86 [K] −189.37≤T≤−122.29 [°C]
72	PSTD(T)		
73	PSTDD(T)		
31	SIGP(P)	SIGP: Surface Tension [N/m] P∗: Pressure [Pa], [bar]	68.75×10^3≤P≤4.998×10^6 [Pa] 0.6875≤P≤49.98 [bar]
32	SIGT(T)	SIGT: Surface Tension [N/m] T∗: Temperature [K], [°C]	83.78≤T≤150.86 [K] −189.37≤T≤−122.29 [°C]
33	SPD(P)	SPD: Specific Entropy of Saturated Liquid [J/(kg·K)] P∗: Pressure [Pa], [bar]	68.75×10^3≤P≤4.998×10^6 [Pa] 0.6875≤P≤49.98 [bar]
34	SPDD(P)	SPDD: Specific Entropy of Saturated Vapor [J/(kg·K)] P∗: Pressure [Pa], [bar]	68.75×10^3≤P≤4.998×10^6 [Pa] 0.6875≤P≤49.98 [bar]
35	SPT(P,T)	SPT: Specific Entropy [J/(kg·K)] P∗: Pressure [Pa], [bar] T∗: Temperature [K], [°C]	10.0×10^3≤P≤100×10^6 [Pa] 83.78≤T≤1100 [K] 0.1≤P≤1000 [bar] −189.37≤T≤826.85 [°C] see Fig.II-2-1
36	SPX(P,X)	SPX: Specific Entropy of Mixture [J/(kg·K)] P∗: Pressure [Pa], [bar] X: Dryness Fraction [–]	68.75×10^3≤P≤4.998×10^6 [Pa] 0.6875≤P≤49.98 [bar] 0≤X≤1.0 [–]
37	STD(T)	STD: Specific Entropy of Saturated Liquid [J/(kg·K)] T∗: Temperature [K], [°C]	83.78≤T≤150.86 [K] −189.37≤T≤−122.29 [°C]
38	STDD(T)	STDD: Specific Entropy of Saturated Vapor [J/(kg·K)] T∗: Temperature [K], [°C]	83.78≤T≤150.86 [K] −189.37≤T≤−122.29 [°C]
39	STX(T,X)	STX: Specific Entropy of Mixture [J/(kg·K)] T∗: Temperature [K], [°C] X: Dryness Fraction [–]	83.78≤T≤150.86 [K] −189.37≤T≤−122.29 [°C] 0≤X≤1.0 [–]
67	TLDP(P)		
69	TMLP(P)		
64	TPH(P,H)	TPH∗: Temperature [K], [°C] P∗: Pressure [Pa], [bar] H: Specific Enthalpy [J/kg]	10.0×10^3≤P≤100×10^6 [Pa] 0.1≤P≤1000 [bar] see Fig.II-2-2 for H
6H	TPH2(P,H)		
65	TPS(P,S)	TPS∗: Temperature [K], [°C] P∗: Pressure [Pa], [bar] S: Specific Entropy [J/(kg·K)]	10.0×10^3≤P≤100×10^6 [Pa] 0.1≤P≤1000 [bar] see Fig.II-2-3 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]	10.0×10^3≤P≤100×10^6 [Pa] 0.1≤P≤1000 [bar] see Fig.II-2-4 for V
41	TRPL('A')	TRPL∗: Properties at Triple Point P∗:'A'='P': 68.75×10^3 [Pa], 0.6875 [bar] Pressure T∗:'A'='T': 83.78 [K], −189.37 [°C] Temperature	one of 'P' and 'T'
100	TSBP(P)		
40	TSP(P)	TSP∗: Saturation Temperature [K], [°C] P∗: Pressure [Pa], [bar]	68.75×10^3≤P≤4.998×10^6 [Pa] 0.6875≤P≤49.98 [bar]

Table II–2.4–1 Argon Function (cont'd)

No.	Name of Function	Function and Argument(s)	Range of Argument(s)
74	TSPD(P)		
75	TSPDD(P)		
42	UPD(P)	UPD: Specific Internal Energy of Saturated Liquid [J/kg] P∗: Pressure [Pa], [bar]	$68.75\times10^3\leq P\leq4.998\times10^6$ [Pa] $0.6875\leq P\leq49.98$ [bar]
43	UPDD(P)	UPDD: Specific Internal Energy of Saturated Vapor [J/kg] P∗: Pressure [Pa], [bar]	$68.75\times10^3\leq P\leq4.998\times10^6$ [Pa] $0.6875\leq P\leq49.98$ [bar]
79	UPS(P,S)		
44	UPT(P,T)	UPT: Specific Internal Energy [J/kg] P∗: Pressure [Pa], [bar] T∗: Temperature [K], [°C]	$10.0\times10^3\leq P\leq100\times10^6$ [Pa] $83.78\leq T\leq1100$ [K] $0.1\leq P\leq1000$ [bar] $-189.37\leq T\leq826.85$ [°C] see Fig.II-2-1
45	UPX(P,X)	UPX: Specific Internal Energy of Mixture [J/kg] P∗: Pressure [Pa], [bar] X: Dryness Fraction [–]	$68.75\times10^3\leq P\leq4.998\times10^6$ [Pa] $0.6875\leq P\leq49.98$ [bar] $0\leq X\leq1.0$ [–]
46	UTD(T)	UTD: Specific Internal Energy of Saturated Liquid [J/kg] T∗: Temperature [K], [°C]	$83.78\leq T\leq150.86$ [K] $-189.37\leq T\leq-122.29$ [°C]
47	UTDD(T)	UTDD: Specific Internal Energy of Saturated Vapor [J/kg] T∗: Temperature [K], [°C]	$83.78\leq T\leq150.86$ [K] $-189.37\leq T\leq-122.29$ [°C]
48	UTX(T,X)	UTX: Specific Internal Energy of Mixture [J/kg] T∗: Temperature [K], [°C] X: Dryness Fraction [–]	$83.78\leq T\leq150.86$ [K] $-189.37\leq T\leq-122.29$ [°C] $0\leq X\leq1.0$ [–]
49	VPD(P)	VPD: Specific Volume of Saturated Liquid [m^3/kg] P∗: Pressure [Pa], [bar]	$68.75\times10^3\leq P\leq4.998\times10^6$ [Pa] $0.6875\leq P\leq49.98$ [bar]
50	VPDD(P)	VPDD: Specific Volume of Saturated Vapor [m^3/kg] P∗: Pressure [Pa], [bar]	$68.75\times10^3\leq P\leq4.998\times10^6$ [Pa] $0.6875\leq P\leq49.98$ [bar]
80	VPS(P,S)		
51	VPT(P,T)	VPT: Specific Volume [m^3/kg] P∗: Pressure [Pa], [bar] T∗: Temperature [K], [°C]	$10.0\times10^3\leq P\leq100\times10^6$ [Pa] $83.78\leq T\leq1100$ [K] $0.1\leq P\leq1000$ [bar] $-189.37\leq T\leq826.85$ [°C] see Fig.II-2-1
52	VPX(P,X)	VPX: Specific Volume of Mixture [m^3/kg] P∗: Pressure [Pa], [bar] X: Dryness Fraction [–]	$68.75\times10^3\leq P\leq4.998\times10^6$ [Pa] $0.6875\leq P\leq49.98$ [bar] $0\leq X\leq1.0$ [–]
53	VTD(T)	VTD: Specific Volume of Saturated Liquid [m^3/kg] T∗: Temperature [K], [°C]	$83.78\leq T\leq150.86$ [K] $-189.37\leq T\leq-122.29$ [°C]
54	VTDD(T)	VTDD: Specific Volume of Saturated Vapor [m^3/kg] T∗: Temperature [K], [°C]	$83.78\leq T\leq150.86$ [K] $-189.37\leq T\leq-122.29$ [°C]
55	VTX(T,X)	VTX: Specific Volume of Mixture [m^3/kg] T∗: Temperature [K], [°C] X: Dryness Fraction [–]	$83.78\leq T\leq150.86$ [K] $-189.37\leq T\leq-122.29$ [°C] $0\leq X\leq1.0$ [–]
8E	WPD(P)		
8F	WPDD(P)		
83	WPT(P,T)		
8G	WTD(T)		
8H	WTDD(T)		

Table II–2.4–1 Argon Function (cont'd)

No.	Name of Function	Function and Argument(s)	Range of Argument(s)
56	XPH(P,H)	XPH: Dryness Fraction [–] P∗: Pressure [Pa], [bar] H: Specific Enthalpy of Mixture [J/kg]	$68.75\times10^3 \leq P \leq 4.998\times10^6$ [Pa] $0.6875 \leq P \leq 49.98$ [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)]	$68.75\times10^3 \leq P \leq 4.998\times10^6$ [Pa] $0.6875 \leq P \leq 49.98$ [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]	$68.75\times10^3 \leq P \leq 4.998\times10^6$ [Pa] $0.6875 \leq P \leq 49.98$ [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]	$68.75\times10^3 \leq P \leq 4.998\times10^6$ [Pa] $0.6875 \leq P \leq 49.98$ [bar] VPD(P)≤V≤VPDD(P) [m^3/kg]
60	XTH(T,H)	XTH: Dryness Fraction [–] T∗: Temperature [K], [°C] H: Specific Enthalpy of Mixture [J/kg]	$83.78 \leq T \leq 150.86$ [K] $-189.37 \leq T \leq -122.29$ [°C] HTD(T)≤H≤HTDD(T) [J/kg]
61	XTS(T,S)	XTS: Dryness Fraction [–] T∗: Temperature [K], [°C] S: Specific Entropy of Mixture [J/(kg·K)]	$83.78 \leq T \leq 150.86$ [K] $-189.37 \leq T \leq -122.29$ [°C] STD(T)≤S≤STDD(T) [J/(kg·K)]
62	XTU(T,U)	XTU: Dryness Fraction [–] T∗: Temperature [K], [°C] U: Specific Internal Energy of Mixture [J/kg]	$83.78 \leq T \leq 150.86$ [K] $-189.37 \leq T \leq -122.29$ [°C] UTD(T)≤U≤UTDD(T) [J/kg]
63	XTV(T,V)	XTV: Dryness Fraction [–] T∗: Temperature [K], [°C] V: Specific Volume of Mixture [m^3/kg]	$83.78 \leq T \leq 150.86$ [K] $-189.37 \leq T \leq -122.29$ [°C] VTD(T)≤V≤VTDD(T) [m^3/kg]

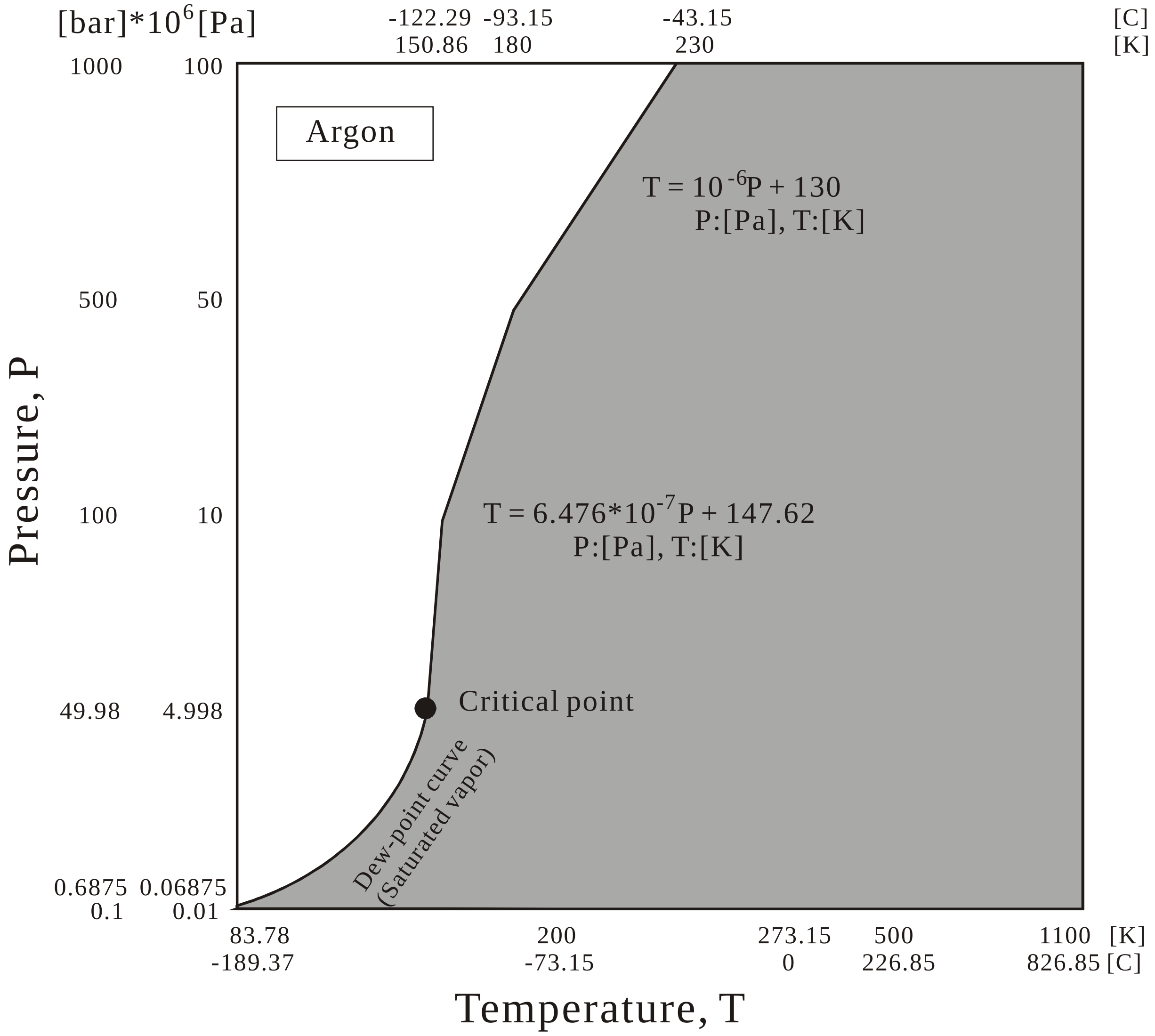

Fig.II–2.4–1 Range of Arguments(P,T) for CPPT(P,T),CVPT(P,T),HPT(P,T), SPT(P,T),UPT(P,T) and VPT(P,T).

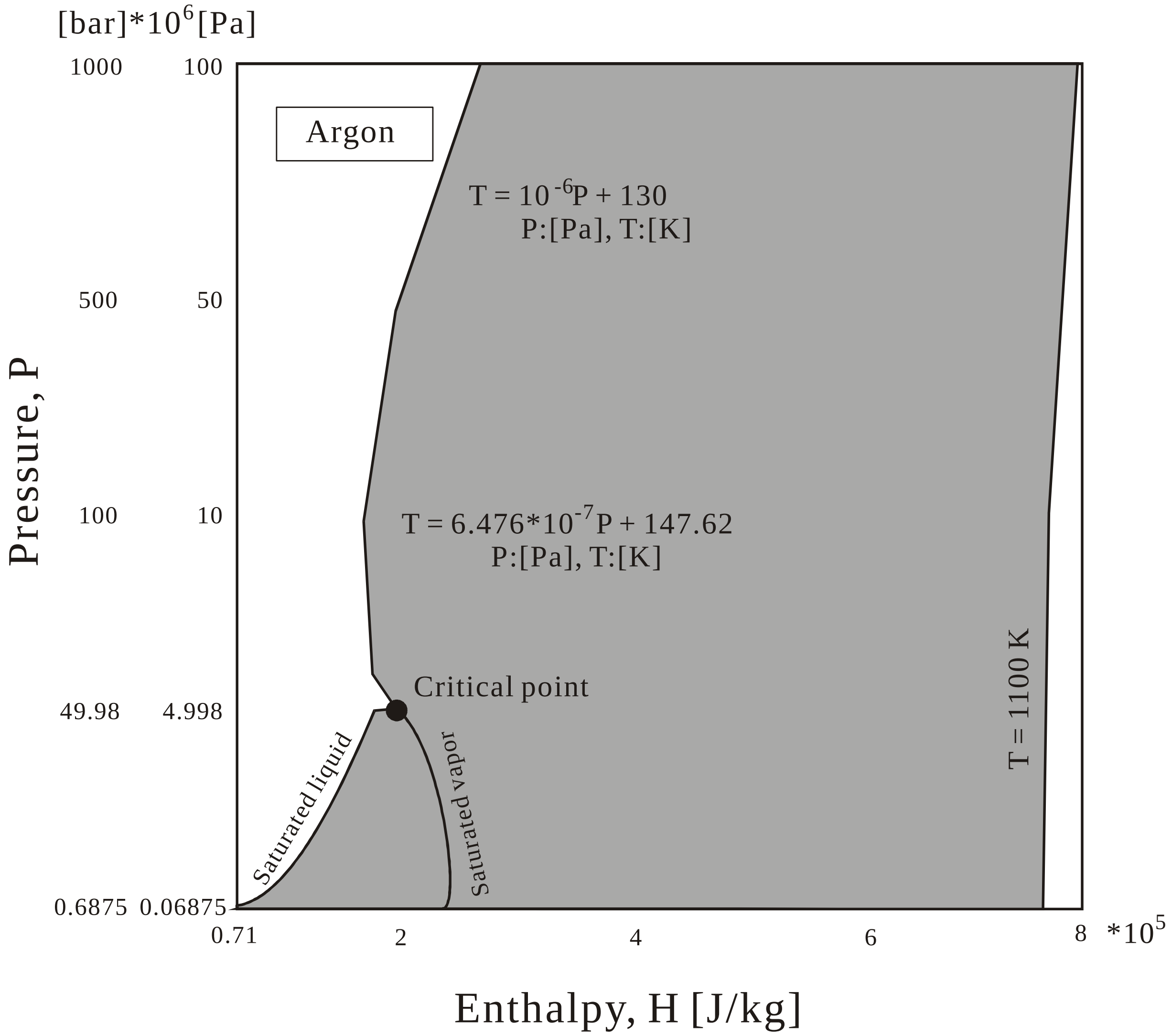

Fig.II–2.4–2 Range of Arguments(P,H) for TPH(P,H).

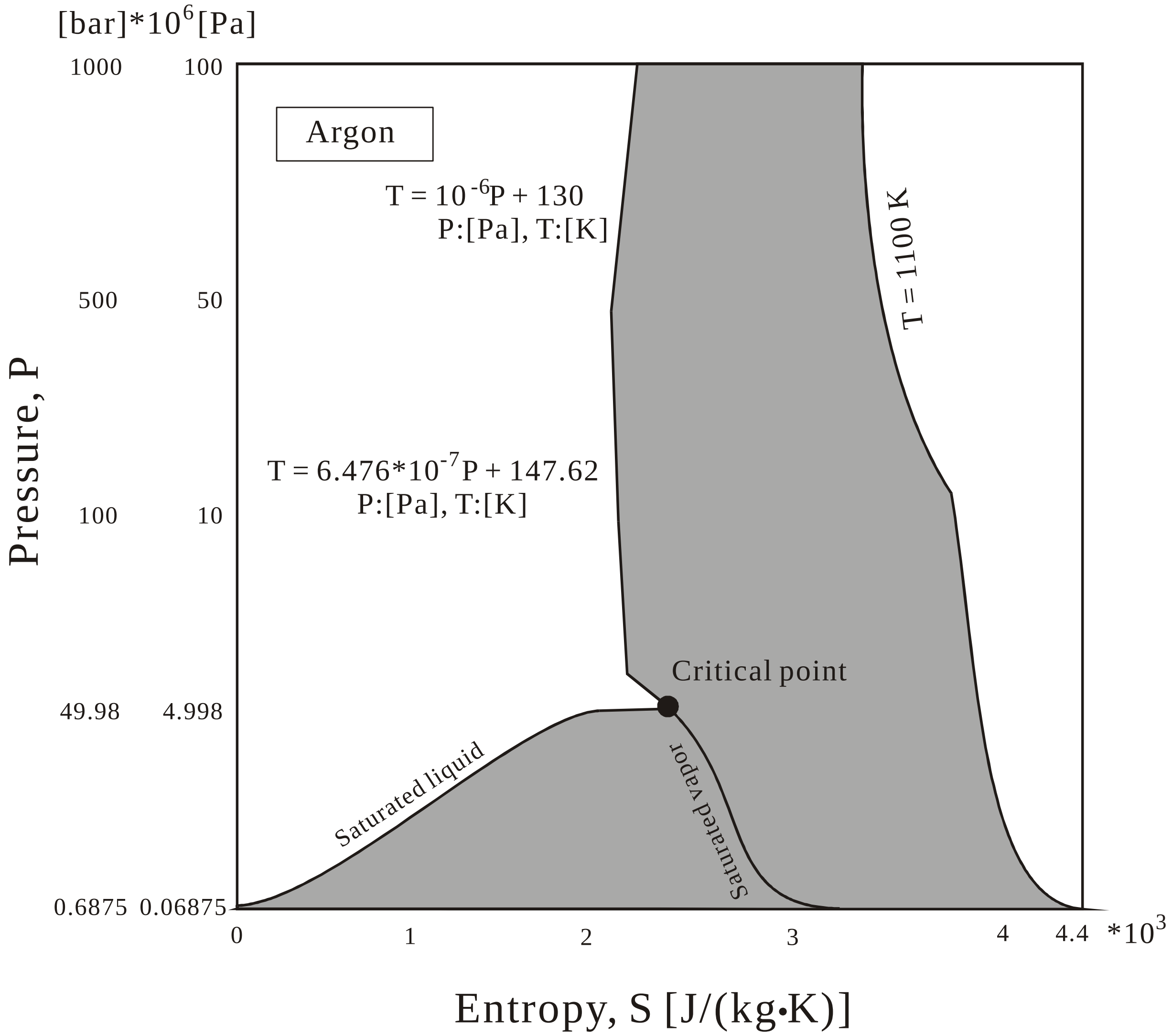

Fig.II–2.4–3 Range of Arguments(P,S) for HPS(P,S) and TPS(P,S).

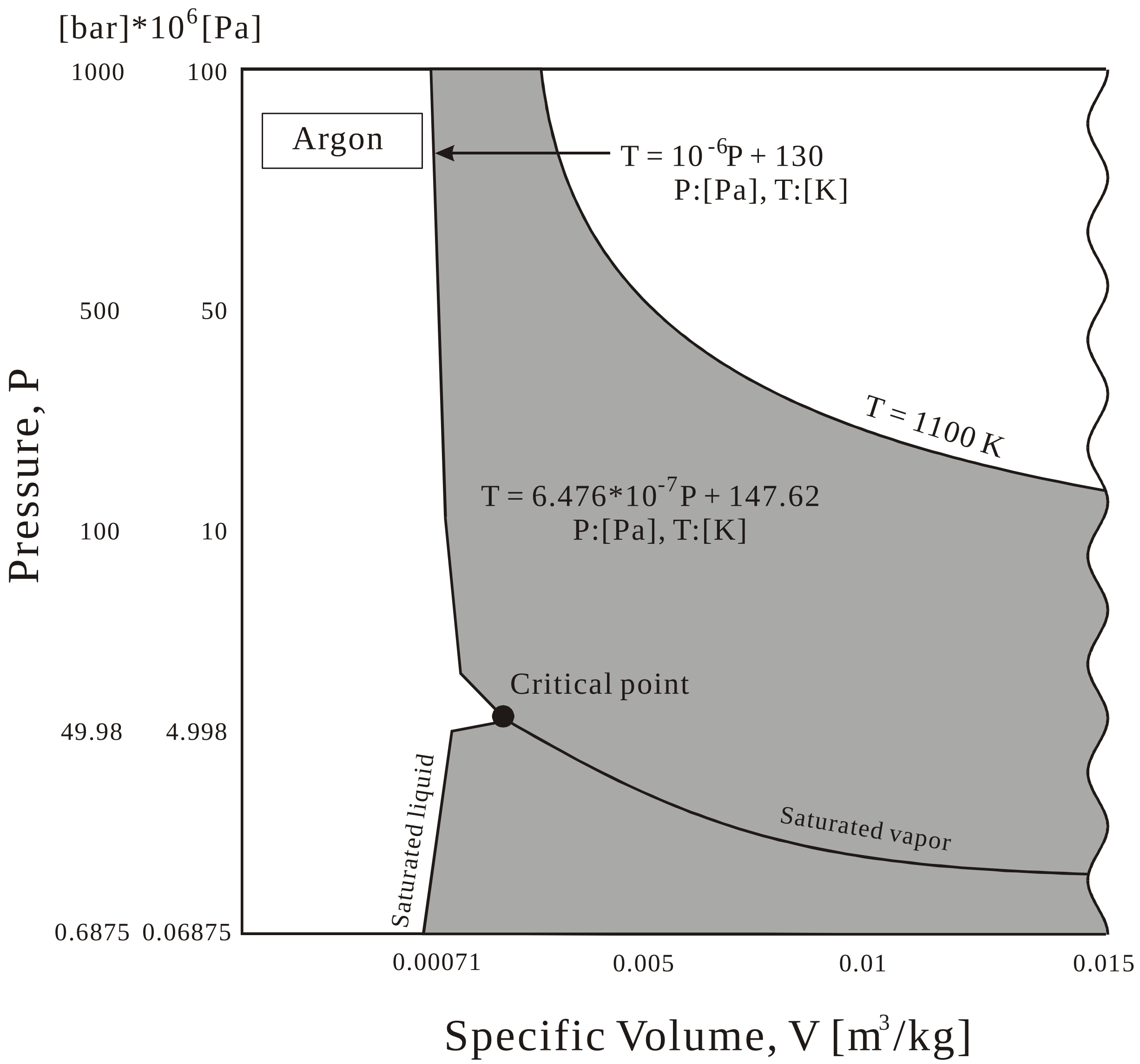

Fig.II–2.4–4 Range of Arguments(P,V) for TPV(P,V).