

III A-PROPATH: Moist Air

Use is made of two different formulations. One is that of ideal gas mixture of dry air and steam. Another is that of real fluid.

1. General Features

1.1 FUNCTION SUBPROGRAM REFERENCE

Every A-PROPATH user has to make an initialization process by one of the following two procedures.

1.1.1 Initialization by COMMON VARIABLES

Every user's PROGRAM UNIT which is going to CALL the A-PROPATH FUNCTION SUBPROGRAM should include the following one LINE before the first EXECUTABLE STATEMENT.

```
COMMON/UNIT/KPA, MESS
```

KPA and MESS are reserved as INTEGER VARIABLES. Furthermore, the following two LINES must be placed in the user's PROGRAM UNIT before the first FUNCTION CALL appears.

```
KPA= M
MESS= N
```

where both M and N are INTEGERS selected by a user.

KPA specifies the units of pressure and temperature for A-PROPATH FUNCTIONS and their ARGUMENTS. Descriptions on the system of units will be found both in 1.3 and the relation between the value of M and the units is shown there. When a user wishes to use other units in his/her PROGRAM UNIT later, he/she is supposed to do the same at that place.

MESS specifies whether the message to the erroneous FUNCTION REFERENCE is to be printed out to the standard listing device or not. PROPATH does not return any messages when $N = 0$, while it does when $N \neq 0$.

1.1.2 Initialization by SUBROUTINE SUBPROGRAM KPAMES

The alternative method to set the values for KPA and MESS is to make use of SUBROUTINE SUBPROGRAM KPAMES as the following.

```
CALL KPAMES(KPA,MESS)
```

1.2 Operations to Manage Erroneous FUNCTION REFERENCE

A predetermined sequence of operations will occur to process the erroneous FUNCTION REFERENCE when an improper FUNCTION REFERENCE has been done. Erroneous FUNCTION REFERENCES are grouped into 3 levels, with the ascending severity of the user's mistake. (A user has committed a more serious mistake when he/she gets a level 2 ERROR than when a level 1 ERROR occurs)

1.2.1 Level 1 ERROR (Convergence Failure)

The method of iteration, which is built into some of the A-PROPATH FUNCTION SUBPROGRAMs to solve an implicit equation, may not work in some cases where a user has specified an ARGUMENT of FUNCTION very close to the saturation line or the critical point. A level 1 ERROR means A-PROPATH has stopped performing the iteration after the preset maximum number of iteration. Then the A-PROPATH FUNCTION SUBPROGRAM returns him/her an unexpected FUNCTION value and an ERROR message, though the user is not responsible for this type of ERROR,. A level 1 ERROR is processed as shown below.

```
value of FUNCTION returned to the CALLing program: -1.0E+10
output to the standard listing device:
**** NO CONVERGENCE AT (NAME OF FUNCTION CALLED) ****
```

The PROPATH group is working hard to ensure that A-PROPATH FUNCTION SUBPROGRAM will not react with level 1 ERRORS because of poor programming technique. However when a user wants to get a value of a thermophysical property just on the saturation line or at the critical point and not at a point very close to it, he/she should try to CALL another FUNCTION for the states on the saturation line or at the critical point.

1.2.2 Level 2 ERROR (Invalid ARGUMENT(s))

A level 2 ERROR occurs when the ARGUMENT a user transferred to A-PROPATH FUNCTION has failed to drop in the proper range. A level 2 ERROR is processed as shown below.

```
value of FUNCTION returned to the CALLing program: -1.0E+20
output to the standard listing device:
**** OUT OF RANGE AT (NAME OF FUNCTION) FOR (NAME OF SUBSTANCE) WHEN
(FIRST ARGUMENT) AND (SECOND ARGUMENT, if any) ****
```

FUNCTION tables provides the proper range of ARGUMENT(s) for each substance.

1.2.3 Level 3 ERROR (FUNCTION Unavailable)

A user encounters a level 3 ERROR when a A-PROPATH FUNCTION SUBPROGRAM is not available for the substance selected. A level 3 ERROR is processed as shown below.

```
value of FUNCTION returned to the CALLing program: -1.0E+30
output to the standard listing device:
**** FUNCTION (NAME OF FUNCTION CALLED) UNAVAILABLE FOR (NAME OF
SUBSTANCE) ****
```

Function table provides a list of FUNCTION SUBPROGRAMs available for each substance.

1.3 System of Units

All quantities, REAL ARGUMENTs and values of FUNCTION, are in the fundamental SI or in the coherent derived SI with two exceptions. Pressure can be in the unit of Pascal Pa or bar, and temperature in the unit of Kelvin K or degree Celsius °C. Users are allowed to make their own selection on these units by specifying a value to COMMON INTEGER VARIABLE KPA. The procedure to set a value to KPA is described in chapter 1, and the relation between the value of KPA and the units of pressure and temperature is shown in the table below. The temperature is based on the International Practical Temperature Scale, 1968.

Table III-1.3-1 Units of Pressure and Temperature Specified by KPA

KPA	unit of pressure	unit of temperature
0	Pa	K
1	bar	°C
2	bar	K
3	Pa	°C
others	Pa	K

1.4 Reserved NAMES in A-PROPATH

As listed below, A-PROPATH for moist air uses a lot of NAMES for its own purpose. These are the NAMES of FUNCTION SUBPROGRAMS to which a user can access directly, KPA, the first COMMON INTEGER VARIABLE, to specify the units of pressure and temperature, and MESS, the second COMMON INTEGER VARIABLE, to allow or suppress the error messages. These are supposed to appear in the user's PROGRAM UNIT only when they mean their original meaning. D, E, F, . . . are the first LETTERS in the NAMES listed in the same line.

NAMES of FUNCTION SUBPROGRAMS:

D : DPA, DPC, DPD, DPE, DPF, DSA, DSB, DSC, DSD, DSE, DSF
E : ENHFAC
F : FC
H : HA, HB, HC, HD
I : IDENTF
P : PST
R : RHA, RHB, RHD, RHE, RHF, RWA, RWB, RWC, RWD, RWE, RWF
S : SA, SB, SC, SD, SE, SF
T : TF, T68, T90
V : VA, VB, VC, VD, VE, VF
W : WBB, WBC, WBD, WBE, WBF
X : XA, XB, XC, XE

NAMES of COMMON INTEGER VARIABLES:

K : KPA
M : MESS

1.5 Naming Convention of FUNCTION SUBPROGRAMs in A-PROPATH

The NAMES of FUNCTION SUBPROGRAM have been allocated to in a regular pattern. This will help a user to remember them. The first one to six LETTERs stand for the kinds of the thermophysical properties. These are, in alphabetical order,

DP*	=dew point temperature
DS*	=degree of saturation
ENHFAC	=enhancement factor
FC	=fundamental constants
H*	=specific enthalpy
IDENTF	=package identification
PST	=saturation vapor pressure of pure water (or ice)
RH*	=relative humidity
RW*	=mole fraction of water vapor
S*	=specific entropy
T*	=dry-bulb temperature
V*	=specific volume
WB*	=thermodynamic wet-bulb temperature
X*	=humidity ratio (mixing ratio)

* stands for a character of one of A, B, C, D, E and F, and they represent the type of FUNCTIONs shown below:

Table III-1.5-1 Type of FUNCTIONs and Arguments in A-PROPATH

type	FUNCTION	ARGUMENTs
A	#A(P,T,WB)	P: total pressure T: dry-bulb temperature WB: thermodynamic wet-bulb temperature
B	#B(P,T,DP)	P: total pressure T: dry-bulb temperature DP: dew point temperature
C	#C(P,T,RH)	P: total pressure T: dry-bulb temperature RH: relative humidity
D	#D(P,T,X)	P: total pressure T: dry-bulb temperature X: humidity ratio
E	#E(P,T,H)	P: total pressure T: dry-bulb temperature H: specific enthalpy
F	#F(P,X,H)	P: total pressure X: humidity ratio H: specific enthalpy

stands for one or two alphabetical letters and means the dependent variables. From the table of reserved NAMES, # must be one of DP, DS, H, RH, RW, S, T, V, WB and X.

1.6 Fundamental Definitions and Terms of Moist Air

1.6.1 Important Constants and Others

Molecular Formula:	Two-component mixture of dry air and water vapor
Percentage composition of dry air by volume:	
N ₂ :	78.09 vol%
O ₂ :	20.95 vol%
Ar:	0.93 vol%
CO ₂ and others:	0.03 vol%
Relative Molecular Mass :	
Dry air:	28.9645
Water vapor:	18.01528
Gas Constant:	
Dry air:	287.055 J/(kg·K)
Water vaopr:	461.520 J/(kg·K)

1.6.2 Moist Air Terminology and Others

(1) Humidity Ratio (Mixing Ratio), X

The ratio of the mass of water vapor to the mass of dry air contained in a given moist air sample.

$$X = 0.62198RW/(1 - RW)$$

where the value of 0.62198 is the ratio of relative molecular masses between water vapor and dry air.

(2) Mole fraction of water vapor, RW

The number of moles of water vapor divided by the total number of moles of all components in a given moist air sample.

(3) Relative Humidity, RH

The ratio of the mole fraction of water vapor RW in a given moist air sample to the mole fraction RW_s in a air sample, saturated at the same temperature and pressure.

$$RH = (RW/RW_s)_{T,P}$$

(4) Degree of Saturation, DS

The ratio of the air humidity ratio X to the humidity ratio of saturated air X_s, at the same temperature and pressure.

$$DS = (X/X_s)_{T,P}$$

(5) Dew Point Temperature, DP

The temperature of moist air, saturated at the same pressure P, with the same humidity ratio X as that of the given sample of moist air. It is defined as the unique solution of DP the following equation:

$$X_s(P, DP) = X$$

(6) Thermodynamic Wet-Bulb Temperature, WB

The temperature defined as the unique solution WB(P,T,X) of the following equation:

$$H + (X'_s - X) \cdot H'_w = H'_s$$

or

$$H(P, T, X) + [X'_s(P, WB) - X] \cdot H'_w(P, WB) = H'_s(P, WB)$$

where

H = H(P,T,X) = specific enthalpy of moist air at pressure P, temperature T, and humidity ratio X.

H'_s = H'_s(P, WB) = specific enthalpy of moist air saturated at pressure P and temperature WB.

X'_s = X'_s(P, WB) = specific humidity ratio at pressure P and temperature WB.

H'_w = H'_w(P, WB) = specific enthalpy of liquid water (or ice) at pressure P and temperature WB.

The thermodynamic wet-bulb temperature is the same as the temperature of adiabatic saturation and hence it can alternatively be defined as the temperature at which water (or ice), by evaporating into moist air, can bring the air to saturation adiabatically at the same temperature and pressure.

(7) Enhancement Factor, ENHFAC

The enhancement factor accounts for the non-ideal behavior of moist air in the saturated state, which is defined by the following equation:

$$\text{ENHFAC} = \text{RW}_s \cdot \text{P}/\text{PST}$$

or

$$\text{ENHFAC}(\text{P}, \text{T}) = \text{RW}_s(\text{P}, \text{T}) \cdot \text{P}/\text{PST}(\text{T})$$

where

$$\text{RW}_s = \text{RW}_s(\text{P}, \text{T}) = \text{mole fraction of water vapor in moist air saturated with water at pressure P and temperature T.}$$

$$\text{PST} = \text{PST}(\text{T}) = \text{saturation vapor pressure of pure water (or ice) at temperature T.}$$

(8) Others

The values of humidity ratio X, specific volume V, specific enthalpy H and specific entropy S are based on unit mass of dry air in a given moist air sample. The unit symbol kg_{DA} in Tables III-2.1-1 and III-2.2-1 indicates kilogram of dry air. The subscripts a and s in the Tables indicate dry air and saturated air, respectively. Moreover, the FUNCTION subprograms do not cover the region of supersaturated air (fogged air).

1.7 An Example of User's PROGRAM UNIT

[**Example**] The dry- and wet-bulb temperatures of atmospheric air at 1.01325 bar are measured with a psychrometer and determined to be 25°C and 15°C, respectively. Determine (a) humidity ratio, (b) relative humidity, (c) dew point and (d) specific enthalpy of air.

Sample Program

```

1 *****
2 *   SAMPLE PROGRAM FOR /A-PROPATH/ USERS   *
3 *                                           *
4 *   EAMPLE FROM      Y.A. CENGEL AND M.A. BOLES *
5 *                   THERMODYNAMICS,         *
6 *                   MCGRAW-HILL 1989        *
7 *****
8 *
9 ***** EX.13-3 ON PAGE 603 *****
10 *
11   COMMON/UNIT/KPA, MESS
12   KAP=1
13   MESS=1
14   P=1.01325
15   T=25.0
16   TWB=15.0
17   OMEGA=XA(P,T,TWB)
18   PHI=RHA(P,T,TWB)
19   DEWPNT=DPA(P,T,TWB)
20   H=HA(P,T,TWB)
21   WRITE(6,*)'***** SAMPLE PROGRAM FOR /A-PROPATH/ USERS *****'
22   WRITE(6,*)'   HUMIDITY RATIO      OMEGA =',OMEGA
23   WRITE(6,*)'   RELATIVE HUMIDITY   PHI =',PHI
24   WRITE(6,*)'   DEW POINT           DEWPNT=',DEWPNT
25   WRITE(6,*)'   SPECIFIC ENTHALPY   H =',H
26   STOP
27   END

```

Output

```

***** SAMPLE PROGRAM FOR /A-PROPATH/ USERS *****
HUMIDITY RATIO      OMEGA = 6.522585E-03
RELATIVE HUMIDITY   PHI = 3.318627E-01
DEW POINT           DEWPNT= 7.706512
SPECIFIC ENTHALPY   H = 41739.000000

```