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DENSITY AND OXYGEN CONTENT OF MOIST AIR

OUTEUR : / AUTHOR : G.A.W. VAN DOORNUM

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DENSITY AND OXYGEN CONTENT OF MOIST AIR

1. The normal ambient air always contains some water vapour. Its presence has two effects:

   i) It acts as a diluent and reduces the concentration of the constituents of dry air, that of the oxygen content being usually the most important aspect;

   ii) As water vapour is less dense than air, the density of moist air is less than that of dry air.

   A knowledge of the density is required for the evaluation of air-flow measurements involving orifice plates, pitot tubes and similar equipment. The oxygen content must be known when the air requirements of a combustion process have to be computed.

   At the temperature and humidity normally prevailing in Pretoria, the density correction will normally not exceed 1%, which in most cases is hardly significant. At higher temperatures and humidities, the effect on the density and oxygen concentration can be appreciable and has to be taken into consideration.

2. If the atmosphere contains water vapour, the total absolute pressure B is the sum of the partial pressures of the air, p_a, and of the water vapour, p. The maximum value of p is the saturation pressure p_s, which depends on the temperature according to a relation represented by the attached tables and diagrams.

   The actual value of p can then be expressed as

$$p = \Phi p_s \qquad (1)$$

where Φ is the relative humidity, a figure between 0 and 1, usually expressed as a percentage.

The mass of water which can exist in the vapour state within a given volume is likewise a maximum at saturation and is, per cubic metre, equal to ρ_s (kg/m^3). The actual quantity x (kg/m^3) can then be expressed as

$$x = \beta \rho_s \tag{2}$$

where β is the saturation factor.

β is related to Φ by the equation

$$\beta = \Phi \frac{B - p_s}{B - p} \tag{3}$$

In most cases, p_s and p are considerably smaller than B, in which case (and also when $p \approx p_s$)

$\beta = \Phi$

ρ_s is, like p_s, a function of the temperature. Data are indicated in the tables and figures.

In the range 0°C to 40°C, the expression $\rho_s = 9{,}6 \times 10^{-4}\ p_s$, or even $\rho_s = 10^{-3}\ p_s$ is sufficiently accurate for most purposes.

The mass of 1m^3 of moist air, or in other words its density ρ , obviously equals

$$\rho = \rho d + x \quad (\text{kg/m}^3)$$

where ρd is the mass of 1m^3 of dry air of partial pressure $p_a = B - p$ at the prevailing temperature t(°C).

The density of air at a pressure of 760 mm ~~mercury~~ (101325 N/m^2 or 10332,3 kgf/m^2) equals

$$\rho_o = 1{,}2928 \text{ kg/m}^3$$

/The .....

The density of dry air at the temperature $T = t + 273{,}16$(K) and pressure D_a (mm Hg) consequently equals

$$\rho_d = 1{,}2928 \frac{D_a}{760} \frac{273{,}16}{T} = 0{,}46466 \frac{p_a}{T}$$

The exact expression for the density ρ of moist air is thus

$$\rho = 0{,}46466 \frac{B - p}{T} + x =$$

$$0{,}46466 \frac{B - \Phi ps}{T} + \Phi \rho_s \frac{B - ps}{B - \Phi ps} \qquad (4)$$

In many cases, and certainly when $t \leq 40^{\circ}C$, this may be simplified to

$$\rho = 0{,}4647 \frac{B}{T} - 0{,}4647 \frac{\Phi\, ps}{T} + 10^{-3}\, \Phi\, p_s \text{ , or}$$

$$\rho = 0{,}4647 \frac{B}{T} - \left(\frac{0{,}465}{T} - 0{,}001\right) \Phi\, p_s$$

$$\rho = \rho\,(B,T) - \Phi\, f \qquad (5)$$

The first term $\rho\,(B,T)$ is the density of dry air at the ambient temperature and total pressure, as indicated by a barometer, which may be derived from Tables Nos. 2 or 3. The second term Φf is a correction factor depending only on the temperature and humidity; the value of f is indicated in Table No.1 and figure No.3.

The mass of dry air actually present in $1 m^3$, or ρd, is less than $\rho(B,T)$ and follows from

$$\rho_d = \rho\,(B,T) \frac{B - \Phi\, ps}{B}$$

The concentrations of the constituents of dry air, as those of nitrogen, oxygen, etc., are likewise reduced by the factor

$$K = \frac{B - \Phi\, ps}{B}$$

/Some .....

Some examples, illustrating the foregoing and indicating the magnitude of the corrections, follow hereunder.

Examples.

1. $B = 650$ mm Hg, $t = 25^{o}C$ $\Phi = 50\%$.

Table No. 2 supplies $p_s = 24{,}2$ mm Hg, $f = 14 \times 10^{-3}$, while Table No.3 indicates $\rho\,(B,T) = 1{,}013$ kg/m^3. The actual density thus equals $\rho = 1{,}013 - 0{,}007 = 1{,}006$. The factor $K = \frac{650 - 12{,}1}{650} = 0{,}98$

The correction to the density is thus, for most purposes, hardly significant. The oxygen concentration is reduced to $0{,}98 \times 21 = 20{,}6\%$. For technical applications, this is not of much interest. However, if one calibrates a magnetic oxygen meter with ambient air, the deviation is of sufficient magnitude to be taken into consideration.

2. A wet blast gas producer is operated with air, saturated at $55^{o}C$, 650 mm Hg.

From Table No.1 : $p_s = 118$ mm Hg, $\rho_w = 0{,}104$ kg/m^3. From eq. (4)

$$\rho = 0{,}46466 \frac{532}{328{,}16} + 0{,}104 = 0{,}754 + 0{,}104 = 0{,}858 \text{ kg/m}^3$$

$$K = \frac{532}{650} = 0{,}82.$$

The density of dry air at 650 mm Hg, $55^{o}C$, would have been $\rho\,(B,T) = 0{,}920$ kg/m^3.

The oxygen content of the wet blast equals $0{,}82 \times 21 = 17{,}2\%$. The moisture content of the wet blast is $\frac{104}{858}.100 = 12{,}1\%$ by weight.

/In .....

In this case, the effect of the water vapour on density and oxygen content is appreciable.

G.A.W. VAN DOORNUM
CHIEF RESEARCH OFFICER

Pretoria.
19th June, 1973.
GAWvD/EMc

TABLE NO. 1

PROPERTIES OF WATER VAPOUR

Temp. °C	Saturation Pressure mm Hg	Saturation Pressure N/m^2	Saturation Pressure kgf/m^2	Density g/m^3	Correction -f
0	4,58	611	62,28	4,85	0,003
5	6,54	872	88,90	6,80	0,005
10	9,20	1227	125,13	9,40	0,006
15	12,78	1704	173,76	12,82	0,008
20	17,53	2337	238,3	17,29	0,011
25	23,75	3167	322,9	23,64	0,014
30	31,81	4241	432,5	30,36	0,018
35	42,17	5623	573,5	39,60	0,023
40	55,31	7375	752,0	51,14	0,029
45	71,87	9582	977,1	65,44	
50	92,52	12335	1258	82,98	
55	118,1	15740	1605	104,3	
60	149,4	19920	2031	130,2	
65	187,5	25010	2550	161,1	
70	233,7	31150	3177	198,1	
75	289,2	38550	3931	241,8	
80	355,2	47360	4829	293,3	
85	433,5	57800	5894	353,4	
90	525,9	70110	7149	423,5	

An approximate equation for ps (in mmHg) is

$$\log ps = 8{,}8730 - \frac{2241{,}14}{T}$$

TABLE NO. 2

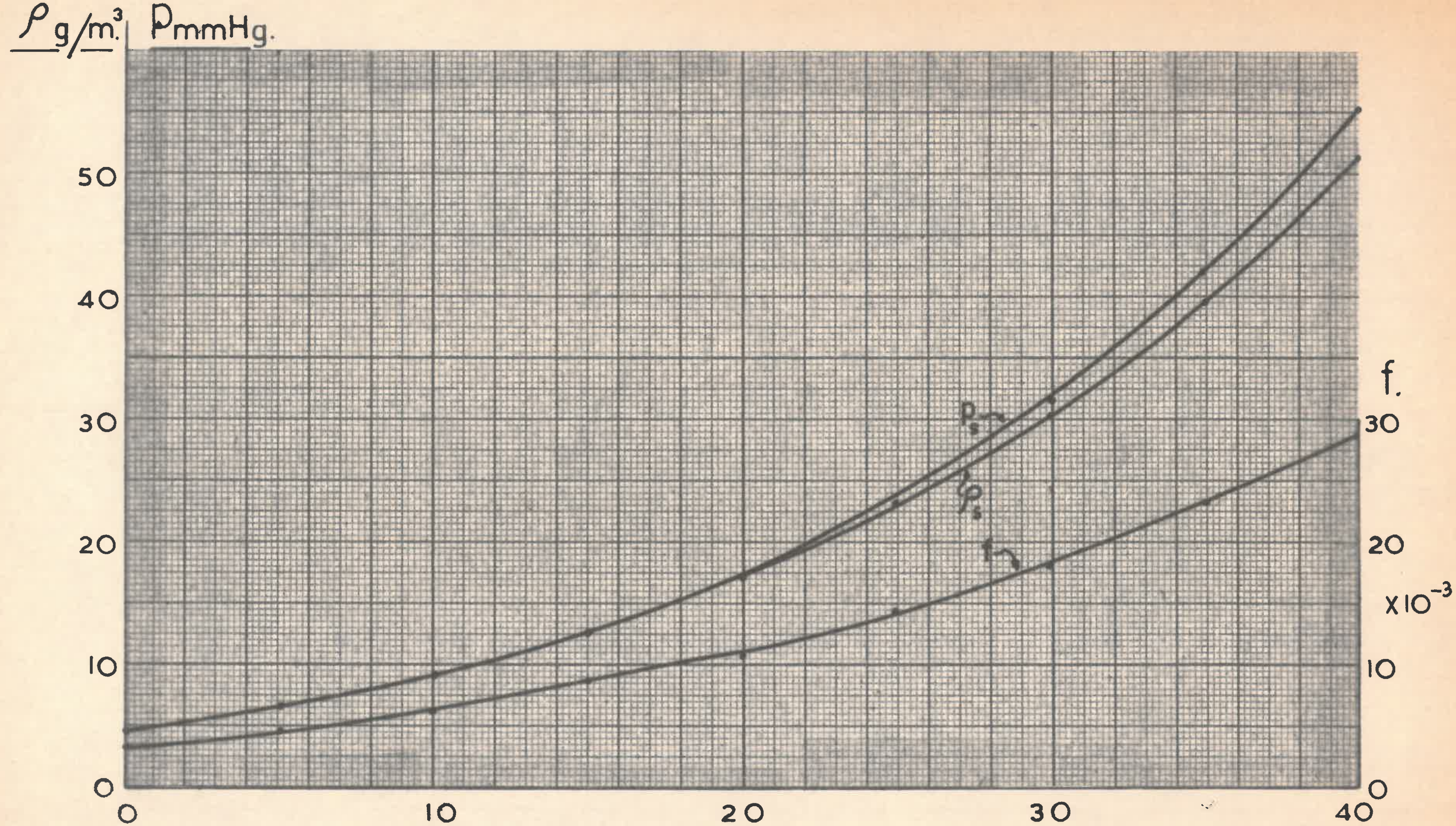
DENSITY OF DRY AIR

B mm Hg	Temperature, °C								
	0	5	10	15	20	25	30	35	40
640	1,089	1,069	1,050	1,032	1,014	0,997	0,981	0,965	0,950
645	1,097	1,078	1,059	1,040	1,022	1,005	0,989	0,973	0,957
650	1,106	1,086	1,067	1,048	1,030	1,013	0,996	0,980	0,965
655	1,114	1,094	1,075	1,056	1,038	1,021	1,004	0,988	0,972
660	1,123	1,103	1,083	1,064	1,046	1,029	1,012	0,995	0,979
665	1,131	1,111	1,091	1,072	1,054	1,036	1,019	1,003	0,987
670	1,140	1,119	1,100	1,080	1,062	1,044	1,027	1,010	0,994
675	1,148	1,128	1,108	1,089	1,070	1,052	1,035	1,018	1,002
680	1,157	1,136	1,116	1,097	1,078	1,060	1,042	1,025	1,009
685	1,165	1,144	1,124	1,105	1,086	1,068	1,050	1,033	1,016
690	1,174	1,153	1,132	1,113	1,094	1,075	1,058	1,041	1,024
695	1,182	1,161	1,141	1,121	1,102	1,083	1,065	1,048	1,031
700	1,191	1,169	1,149	1,129	1,110	1,091	1,073	1,056	1,039
705	1,199	1,178	1,157	1,137	1,118	1,099	1,081	1,063	1,046
710	1,208	1,186	1,165	1,145	1,125	1,107	1,088	1,071	1,054
715	1,216	1,194	1,173	1,153	1,133	1,114	1,096	1,078	1,061
720	1,225	1,203	1,182	1,161	1,141	1,122	1,104	1,086	1,068
725	1,233	1,211	1,190	1,169	1,149	1,130	1,111	1,093	1,076
730	1,242	1,220	1,198	1,177	1,157	1,138	1,119	1,101	1,083
735	1,250	1,228	1,206	1,185	1,165	1,146	1,127	1,108	1,091
740	1,259	1,236	1,214	1,193	1,173	1,153	1,134	1,116	1,098
745	1,267	1,245	1,223	1,201	1,181	1,161	1,142	1,123	1,106
750	1,276	1,253	1,231	1,209	1,189	1,169	1,150	1,131	1,113
755	1,284	1,261	1,239	1,218	1,197	1,177	1,157	1,139	1,120
760	1,293	1,270	1,247	1,226	1,205	1,185	1,165	1,146	1,128
765	1,301	1,278	1,255	1,234	1,213	1,192	1,173	1,154	1,135
770	1,310	1,286	1,264	1,242	1,221	1,200	1,180	1,161	1,143

TABLE NO. 3

DENSITY OF DRY AIR

B	Temperature, ^{o}C										
mm Hg	20	21	22	23	24	25	26	27	28	29	30
640	1,014	1,011	1,008	1,004	1,001	0,997	0,994	0,991	0,988	0,984	0,981
641	1,016	1,013	1,009	1,006	1,002	0,999	0,996	0,992	0,989	0,986	0,983
642	1,018	1,014	1,011	1,007	1,004	1,001	0,997	0,994	0,991	0,987	0,984
643	1,019	1,016	1,012	1,009	1,006	1,002	0,999	0,995	0,992	0,989	0,986
644	1,021	1,017	1,014	1,010	1,007	1,004	1,000	0,997	0,994	0,990	0,987
645	1,022	1,019	1,015	1,012	1,009	1,005	1,002	0,999	0,995	0,992	0,989
646	1,024	1,021	1,017	1,014	1,010	1,007	1,003	1,000	0,997	0,994	0,990
647	1,026	1,022	1,019	1,015	1,012	1,008	1,005	1,002	0,998	0,995	0,992
648	1,027	1,024	1,020	1,017	1,013	1,010	1,007	1,003	1,000	0,997	0,993
649	1,029	1,025	1,022	1,018	1,015	1,012	1,008	1,005	1,001	0,998	0,995
650	1,030	1,027	1,023	1,020	1,016	1,013	1,010	1,006	1,003	1,000	0,996
651	1,032	1,028	1,025	1,021	1,018	1,015	1,011	1,008	1,005	1,001	0,998
652	1,034	1,030	1,027	1,023	1,020	1,016	1,013	1,009	1,006	1,003	0,999
653	1,035	1,032	1,028	1,025	1,021	1,018	1,014	1,011	1,008	1,004	1,001
654	1,037	1,033	1,030	1,026	1,023	1,019	1,016	1,013	1,009	1,006	1,002
655	1,038	1,035	1,031	1,028	1,024	1,021	1,017	1,014	1,011	1,007	1,004
656	1,040	1,036	1,033	1,029	1,026	1,022	1,019	1,016	1,012	1,009	1,006
657	1,041	1,038	1,034	1,031	1,027	1,024	1,021	1,017	1,014	1,010	1,007
658	1,043	1,039	1,036	1,032	1,029	1,026	1,022	1,019	1,015	1,012	1,009
659	1,045	1,041	1,038	1,034	1,031	1,027	1,024	1,020	1,017	1,013	1,010
660	1,046	1,043	1,039	1,036	1,032	1,029	1,025	1,022	1,018	1,015	1,012



TEMPERATURE. — °C

SATURATION PRESSURE AND DENSITY OF WATER VAPOUR.

CORRECTION FACTOR. – f