DENSITY DEFINITIONS

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Introduction

This paper provides an overview of the key terms used when generating or evaluating density data.

Density

is the mass of a material per unit volume of the material, most commonly reported in grams/cubic centimetre (g/cm^3) or tonnes per cubic metre (t/m^3) in the mining industry (outside the United States). For our purposes, density is normally determined on small samples, core or hand-sample-sized blocks, and represents the rock density and does not account for fracture porosity.

Bulk Density

Bulk density refers to the density of an in-situ rock mass. Bulk density accounts for porosity of the rock as well as fracture porosity. With rare exception, the bulk density will be somewhat less than the density determined using the methods in this document because fracture porosity is rarely accounted for in density determinations, but within the industry most people equate the measured density with bulk density. The error is generally, but not always, quite small.

Unless specifically indicated, density is usually a rock density that does not necessarily account for fracture or other porosity. Adjustment factors, where required, are used to convert determined density to bulk density.

Bulk density implies dry bulk density; however, it always best to confirm this and precede the term with ‘dry’ or ‘wet’. Only dry bulk density should be used in resource estimation because all assays are done on a dry basis. The same dry basis for the density and assays must be used or the estimate of resource inventory will be incorrect.

Note that iron ore is an exception. Although assays are always on a dry basis, wet density is used to estimate iron ore tonnage so there will be a slight disconnect between grade, tonnage, and contained metal. MTS has not investigated the impact on total metal, but it is likely small and this is a standard in the iron ore industry that is unlikely to change.

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Specific Gravity

Specific gravity (SG) is a *unitless ratio* of the mass of a sample in air versus the mass of a sample suspended in water. More specifically, the specific gravity is a number that expresses the ratio between the weight of a substance in air and the weight of an equal volume of water at 4ºC (Hurlbut, 1971). Specific gravity can be determined with a Jolly Balance using any scale of measurement that is handy: inches, meters, etc., because the units cancel during the calculation; thus, the unitless ratio. At 4ºC, using pure water, SG is numerically equivalent to density in g/cm^3. If the water used to determine SG is at other than 4ºC, SG and density are not numerically equivalent, although the discrepancy is not large enough to be a serious consideration (producing a measurement error of <0.004) until the water is at temperatures above 30º C.

Equating SG and density or attaching units to SGs are poor practices and in the extreme, damage the credibility of the report and reporter.

Table A summarizes the change in water density with temperature.

Table A: Change in Water Density with Temperature

Temp (°C)	Density Pure Water (g/cm^3)	Absolute Difference	% Difference
0	0.9999	0.0001	0.01
4	1.0000	0.0000	0.00
10	0.9997	0.0003	0.03
15	0.9991	0.0009	0.09
16	0.9990	0.0010	0.10
17	0.9988	0.0012	0.12
18	0.9986	0.0014	0.14
19	0.9984	0.0016	0.16
20	0.9982	0.0018	0.18
21	0.9980	0.0020	0.20
22	0.9978	0.0022	0.22
23	0.9976	0.0024	0.24
24	0.9973	0.0027	0.27
25	0.9971	0.0029	0.29
26	0.9968	0.0032	0.32
27	0.9965	0.0035	0.35
28	0.9963	0.0037	0.37
29	0.9960	0.0040	0.40
30	0.9957	0.0043	0.43
40	0.9922	0.0078	0.78

Note: Data from CRC Handbook of Chemistry and Physics 55th edition.

Water density can be estimated at any temperature from 4º to 99.9ºC using:

$$\boldsymbol{d\ (g/cm^3) = 0.00000003 * T^3 - 0.00000714 * T^2 + 0.00004618 * T + 0.99994185}$$

This equation provides a very good estimate of water density within the limits prescribed (r2 > 0.9999). These values can then be used to convert SG to density by accounting for water density. Densities determined in dirty hot water may have significantly larger discrepancies than indicated because of the increased density of dirty water.

Tonnage Factor

Tonnage Factor is a term used in the United States and locally elsewhere, that expresses density in terms of cubic feet per short ton (cu ft/st) or short tons per cubic foot (st/cu ft). The conversion is:

1 g/cm^3 = 32.0373 ft^3/st = 0.0312 st/ft^3

Ore

Ore is material that is reasonably believed to be able to produce metal or other valuable components at a profit.

Waste

Waste is material that cannot be reasonably believed to be able to produce metal or other valuable components at a profit.

Porosity

Porosity is the naturally occurring void space in rocks. This includes such voids as open fractures, cavities remaining after leaching of components (sulfides for example), space between mineral grains in sedimentary rocks, or any other void that is an integral part of the rock.

Fracture Porosity

Fracture porosity is porosity due to fracturing and faulting of the entire rock mass.

Immersion

Immersion refers the process of immersing a sample in water or other liquid of known density to determine the mass of the sample suspended in the liquid and thus the volume of the sample. At 4º C, the mass of water displaced, in grams, is equivalent to the volume of the sample in cm^3 because water, by definition, has a density of 1 g/cm^3 at 4ºC.

Dry Density

Dry density is the density of the material in question after it has been thoroughly dried. For most ore deposits, this is the important density value because grades (assays) are determined on dry samples. These are not true bulk densities because fracture porosity is not typically accounted for.

Wet Density

Wet density is the density of the material in question as it is removed from the ground. Although not important for most base and precious metal deposits, wet density is used almost exclusively in iron ore deposits because iron ore is generally not dried prior to shipping from the plant.

Abbreviations

Common abbreviations are provided in Table B.

Table B: Abbreviations

Abbreviation	Term
DD	Dry density
WD	Wet density
DBD	Dry bulk density
WBD	Wet bulk density
Ma	Mass of sample as obtained
Md	Mass of dry sample
Mdw	Mass of wax coated dry sample
Mdws	Mass of submerged wax coated dry sample
D_{H2O}	Water density
D_{wax}	Wax density (or other coating)
Mw	Mass of wax