Math for Operators

A Guide to using the ABC/EOCP Canadian Standardized Formula Handouts for Wastewater Treatment, Wastewater Collection, Water Treatment, Water Distribution and Laboratory Exams

With solved examples of every formula in both US and Metric units

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Introduction

This manual was written to provide operators with a guide to the use of the formulas found in the handouts provided to certification examination candidates. The formulas used will be those found in the Canadian version of the Association of Boards of Certification's (ABC) handout and in the handout provided by the Environmental Operators Certification Program (EOCP) in British Columbia.

Commencing in 2018 the ABC/EOCP standardized exam began using both United States and metric units in the both the stem and the answer choices. The format uses US units first followed by metric units in brackets. Where US units are converted to metric units the value obtained will be rounded to one decimal place. For example:

A clarifier is 100 feet (30.5 m) in diameter and 15 feet (4.8 m) deep. Calculate its volume.

a) 117,750 cubic feet (3,505.2 cubic metres)

A reservoir is 32 feet (9.8 m) deep. What is the pressure at the bottom of the reservoir?

a) 13.85 psi (95.5 kPa)

This workbook will use that format.

Each formula is accompanied by one or more solved examples of a question which would require the use of the formula to obtain a solution. Each of the sample questions begins with **the question stated in bold text**. Each of the sample questions contains the basic equation used, a step-by-step guide to developing the information needed to solve the question and the solved question using a "dimensional analysis" approach which first sets out the question in words and then solves it by substituting the appropriate numerical value. Many of the questions will have application to other disciplines. For example, operators in any of the four disciplines may need to calculate hydraulic detention time – it may be called a reservoir for a water distribution operator, a wet well for a collection system operator, and a clarifier for either a wastewater or water treatment plant operator but the basic mathematical concept is the same.

Additional information can be found in the publications of the following organizations and agencies:

American Water Works Association
California State University, Sacramento
Metcalf and Eddy / AECOM
Water Environment Federation
Association of Boards of Certification
Environment Canada
Provincial and State Operator Certification Programs
United States Environmental Protection Agency

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Glossary of Abbreviations

The following abbreviations may be used in this document:

atm	Atmospheres
BOD_5	Biochemical oxygen demand
C	Celsius
$CBOD_5$	Carbonaceous BOD_5
cfs	Cubic feet per second
cm	Centimeter(s)
COD	Chemical oxygen demand
DO	Dissolved oxygen
EMF	Electromotive force
F	Fahrenheit
F:M ratio	Food to microorganism ratio
ft	Feet
ft lb	Foot pound
g	Gram(s)
gal	US gallons
gfd	US gallons flux per day
gpcd	US gallons per capita per day
gpd	US gallons per day
gpg	Grains per US gallon
gpm	US gallons per minute
hp	Horsepower
hr	Hour(s)
in	Inch(es)
kg	Kilograms
km	Kilometre
kPa	kiloPascal(s)
kW	kiloWatt
kWh	KiloWatt hours
L	Litre(s)
lb	Pound(s)
Lpcd	Litres per capita per day
Lpd	Litres per day
Lpm	Litres per minute
LSI	Langelier Saturation Index
m	Meter(s)
MCRT	Mean cell residence time
mEq	Milliequivalent
MG	Million US gallons
MGD	Million US gallons per day
mg/L	Milligram(s) per litre
min	Minute(s)
mL	Millilitres(s)
ML	Million litres (aka Megalitre)
MLD	Million litres per day
MLSS	Mixed liquor suspended solids
MLVSS	Mixed liquor volatile suspended solids
OCR	Oxygen consumption rate
ORP	Oxidation reduction potential
OUR	Oxygen uptake rate
PE	Population equivalent
ppb	Parts per billion
ppm	Parts per million
psi	Pounds per square inch
Q	Flow
RAS	Return activated sludge
RBC	Rotating biological contactor
RPM	Revolutions per minute
$SBOD_5$	Soluble BOD
SDI	Sludge density index
sec	Second(s)
SOUR	Specific oxygen uptake rate
SRT	Solids retention time
SS	Settleable solids
SSV_{30}	Settled sludge volume, 30 minutes
SVI	Sludge volume index
TOC	Total organic carbon
TS	Total solids
TTHM	Total Trihalomethanes
TSS	Total suspended solids
VS	Volatile solids
VSS	Volatile suspended solids
W	Watt(s)
WAS	Waste activated sludge
yd	Yard(s)
yr	Year

Units of Measure

As noted in the introduction, math questions on an EOCP/ABC certification will contain both United States common units of measure and System Internationale units of measure (i.e., metric units).

CAUTION

Due to rounding of the conversion factors used and the ABC/EOCP practice of rounding all conversions of US units to metric units to a single decimal point, operators will find that the metric answer and the US unit answer given in a math problem will not convert to precisely the same value. i.e., a US unit answer when converted to metric units will not give the same answer as would be found if the problem was solved using the metric values given and vice versa. Generally, the values will be within 5% of each other.

United States Units

The United States of America remains the only industrialized country in the world to continue to use non-metric units. This despite the fact that the US Congress adopted the metric system as the official system of measurement in the United States in 1893 (Mendenhall Order) and, most recently, again in 1975 with the *Metric Conversion Act*.

The use of two different unit systems caused the loss of the Mars Climate Orbiter in 1999. NASA specified metric units in the contract. NASA and other organizations applied metric units in their work, but one subcontractor, Lockheed Martin, provided software that calculated and reported thruster performance data to the team in pound-force-seconds, rather than the expected newton-seconds. The spacecraft was intended to orbit Mars at about 150 kilometers (93 miles) altitude, but incorrect data caused it to descend instead to about 57 kilometers (35 miles), burning up in the Martian atmosphere.

Nevertheless, the United States continues to use non-metric units.

In our industry, the most commonly used US units are: parts per million for concentrations; pounds per square inch for pressure; inches, feet and miles for linear dimensions; square feet, square yards and acres for area; cubic feet, gallons and million gallons for flow or volume; and pounds or tons for weight.

Conversion factors can be found in the EOCP/ABC math formula handout.

System Internationale Units (The Metric System)

The metric system is used in all of the industrialized countries of the world except the United States.

Canada began the conversion to a metric system of measurement in 1970 and by 1975 it was in universal use throughout the country.

Introduced in France in 1779 the metric system originally was limited to two units – the metre and the kilogram.

Metre

The metre (meter in the US), symbol m, is the base unit of length in the International System of Units (SI). Originally intended to be one ten-millionth of the distance from the Earth's equator to the North Pole (at sea level), since 1983, it has been defined as "the length of the path travelled by light in vacuum during a time interval of 1 ⁄ 299,792,458 of a second ($\approx 3 \times 10^{-9}$ seconds).

Kilogram

The kilogram, also known as the kilo, symbol kg, is the base unit of mass in the International System of Units and, until 2019, was defined as being equal to the mass of the International Prototype Kilogram (IPK).

The IPK is made of a platinum-iridium alloy, which is 90% platinum and 10% iridium (by mass) and is machined into a cylinder with a height and diameter of approximately 39 millimeters to minimize its surface area. The cylinder has a mass which is almost exactly equal to the mass of one liter of water.

In 2019, the kilogram was redefined in terms of three fundamental physical constants: The speed of light, *c*, a specific atomic transition frequency Δv_{cs} and the Planck constant, *h*.

It is defined by taking the fixed numerical value of the Planck constant *h* to be $6.62607015 \times 10^{-34}$ when expressed in the unit J·s, which is equal to $kg \cdot m^2 \cdot s^{-1}$, where the metre and the second are defined in terms of *c* and Δv_{cs} . The second, symbol s, is defined by taking the fixed numerical value of the caesium frequency Δv_{cs}, the unperturbed ground-state hyperfine transition frequency of the caesium-133 atom, to be equal to 9,192,631,770 when expressed in the unit Hz, which is equal to s^{-1} (are you confused yet?).

The metric system is decimal, except where the non-SI units for time (hours, minutes, seconds) and plane angle measurement (degrees, minutes, seconds) are concerned. All multiples and divisions of the decimal units are factors of the power of ten.

Decimal prefixes are a characteristic of the metric system; the use of base 10 arithmetic aids in unit conversion. Differences in expressing units are simply a matter of shifting the decimal point or changing an exponent; for example, the speed of light may be expressed as 299,792,458 m/s or 2.99792458×10^8 m/s.

A common set of decimal-based prefixes is applied to some units which are too large or too small for practical use without adjustment. The effect of the prefixes is to multiply or divide the unit by a factor of ten, one hundred or one thousand. The prefix *kilo*, for example, is used to multiply the unit by 1000, and the prefix *milli* is to indicate a one-thousandth part of the unit. Thus, the *kilogram* and *kilometre* are a thousand grams and metres respectively, and a *milligram* and *millimetre* are one thousandth of a gram and metre respectively. These relations can be written symbolically as:

1 mg = 0.001 g   1 km = 1000 m

When applying prefixes to derived units of area and volume that are expressed in terms of units of length squared or cubed, the square and cube operators are applied to the unit of length including the prefix, as illustrated here:

1 mm^2 (square millimetre) = $(1\ mm)^2$ = $(0.001\ m)^2$ = 0.000 001 m^2

1 km^2 (square kilometre) = $(1\ km)^2$ = $(1000\ m)^2$ = 1,000,000 m^2

1 mm^3 (cubic millimetre) = $(1\ mm)^3$ = $(0.001\ m)^3$ = 0.000 000 001 m^3

1 km^3 (cubic kilometre) = $(1\ km)^3$ = $(1000\ m)^3$ = 1,000,000,000 m^3

On the other hand, prefixes are used for multiples of the non-SI unit of volume, the litre (L), or the stere (cubic metre). Examples: 1 mL = 0.001 L,   1 kL = 1,000 L = 1m^3

The tonne (1,000 kg), the litre (now defined as exactly 0.001 m^3), and the hectare (10,000 m^2), continue to be used alongside the SI units.

ppm and mg/L

The acronym ppm stands for parts per million and was commonly used in the pre-metric era. In the metric system we use the acronym mg/L which stands for milligrams per litre. The metric system assigns a weight of one kilogram to one litre of water. One kilogram of water contains one million milligrams and thus a value of one milligram per litre is exactly equivalent to one part per million parts. The two terms can be used interchangeably.

Proof:

Consider that by definition, 1 Litre of water weighs 1 kilogram

1 kilogram contains 1,000 grams

1 gram contains 1,000 milligrams

Therefore, 1 kilogram contains 1,000 grams × 1,000 milligrams/gram = 1,000,000 milligrams (mg)

Thus,

$$\frac{1\text{ mg}}{\text{L}} = \frac{1\text{ mg}}{\text{kg}} = \frac{1\text{ mg}}{1{,}000\text{ g}} = \frac{1\text{ mg}}{1{,}000{,}000\text{mg}} = 1\ \text{part/million parts} = 1\text{ppm}$$

Units and Equivalents in the Metric System

Tera	(T)	10^{12}	1,000,000,000,000
Giga	(G)	10^{9}	1,000,000,000
Mega	(M)	10^{6}	1,000,000
Kilo	(K)	10^{3}	1,000
Hecto	(H)	10^{2}	100
Deca	(D)	10^{1}	10
Deci	(d)	10^{-1}	1/10
Centi	(c)	10^{-2}	1/100
Milli	(m)	10^{-3}	1/1,000
Micro	(µ)	10^{-6}	1/1,000,000
Nano	(n)	10^{-9}	1/1,000,000,000
Pico	(p)	10^{-12}	1/1,000,000,000,000

Quantity Measured	Unit	Symbol	Relationships
Distance, length, width, thickness, girth, etc.	millimetre centimetre metre kilometre	mm cm m km	10 mm = 1 cm 100 cm = 1 m 1,000 m = 1 km
Mass (Weight)	milligram gram kilogram tonne	mg g kg t	1,000 mg = 1 g 1,000 g = 1 kg 1,000 kg = 1 t
Area	square metre hectare square kilometre	m^2 ha km^2	10,000 m^2 = 1 ha 100 ha = 1 km^2
Volume	millilitre cubic centimetre litre cubic metre Megalitre	mL cm^3 (or cc) L m^3 ML	1 cm^3 = 1 mL 1,000 mL = 1 L 1,000L = 1 m^3 1,000 m^3 = 1 ML
Velocity (Speed)	metres/second kilometre/hour	m/s km/h	
Temperature	degree Celsius	°C	
Pressure	kilopascal	kPa	9.8 kPa = 1 m of head
Energy	joules kilowatt-hour	J kWh	
Power	watt	W	

Significant Figures and Rounding

When we use a handheld calculator or the calculator function on our smart phone, laptop or tablet it is not uncommon to get an answer to the fifth or sixth decimal point. But is that answer accurate? Is that level of precision necessary? The accuracy of any answer is based on the accuracy of the values used in determining the answer and that depends on the precision of the measuring instrument or even the skill of the person using the instrument.

The rules for determining the number of significant figures or digits that an answer should contain are relatively straightforward.

There are three rules that apply to “rounding off” numbers until the appropriate numbers of significant figures remain:

1. When a figure less than five is dropped, the next figure to the left remains unchanged. For example, the number 11.24 becomes 11.2 when it is required that the four be dropped
2. When the figure is greater than five that number is dropped and the number to the left is increased by one. For example, 11.26 becomes 11.3

The third rule, which is less commonly used, helps to prevent rounding bias in long series of numbers.

3. When the figure that needs to be dropped is a five, round to the nearest even number. For example, 11.35 becomes 11.4 and 46.25 becomes 46.2

Zero – Is it significant or not?

A zero may be a significant figure, if it is a measured value, or be insignificant and serve only as a place holder or spacer for locating the decimal point. If a zero or zeroes are used to give position value to the significant figures in the number, then the zero or zeroes are not significant. Consider this:

1.23 mm = 0.123 cm = 0.000123 m = 0.00000123 km

In the example above, the zeroes are insignificant and only give the significant figures, 123, a position that indicates their value.

The Megalitre Shortcut

Many questions ask the operator to calculate the weight of a substance added to a process or wasted from a process per unit of time given the concentration of the substance in mg/L and the flow in either liters or cubic metres per unit of time.

Regardless of the substance, whether it be COD, BOD_5, suspended solids, volatile solids, mixed liquor suspended solids or waste or return activated sludge the standard equation is:

$$\text{Loading, kg/day} = \frac{\text{Flow, m}^3}{\text{unit of time}} \times \frac{\text{Concentration, mg}}{\text{L}}$$

or

Loading, kg/day = (Flow, m^3/unit of time)(Concentration, mg/L)

To solve the equation the operator inserts conversion factors and sets up the equation as follows:

$$\text{Loading} = \frac{\text{X mg}}{\text{L}} \times \frac{\text{Y m}^3}{\text{Time}} \times \frac{1\,\text{kg}}{10^6\,\text{mg}} \times \frac{10^3\ \text{L}}{\text{m}^3} = \text{Z kg/time}$$

Where X = the concentration, Y = the flow and Z = the product after all of the math has been done

The benefit of the long form equation is that it allows the operator to "cancel out" words above and below the vinculum (the line which separates the numerator and denominator in a fraction) to see if the equation has even been set up properly before doing the math.

As an alternative to setting up the equation long form, the operator can simply convert the flow to Megalitres (ML) [1 Megalitre = 1,000 cubic metres = 1,000,000 liters] and multiply by the concentration given in mg/L.

Why does this work? Consider that:

$$\frac{1\text{mg}}{\text{L}} = \frac{1{,}000\ \text{mg}}{1{,}000\ \text{L}} = \frac{1{,}000{,}000\ \text{mg}}{1{,}000{,}000\ \text{L}} = \frac{1\ \text{kg}}{\text{ML}}$$

Because 1,000,000 mg = 1 kg and 1,000,000 L = 1,000 m^3 = 1 ML

The following example illustrates the use of this shortcut.

What is the loading on a basin if 2,500 cubic metres of a substance having a concentration of 180 mg/L is added per day?

Example 1 - Insert known values and solve, long form

$$\text{Loading} = \frac{180\ \text{mg}}{\text{L}} \times \frac{2{,}500\ \text{m}^3}{\text{day}} \times \frac{1\ \text{kg}}{10^6\text{mg}} \times \frac{10^3\text{L}}{\text{m}^2} = 450\ \ \text{kg/day}$$

Example 2 – Megalitre shortcut

Step 1 – Convert 2,500 m^3 to Megalitres = 2.500 / 1,000 = 2.5 ML

Insert known values and solve

Loading = (180 mg/L)(2.5 ML/day) = 450 kg/day

How many kilograms of solids are in an aeration basin 30 m long, 10 m wide and 3.5 m deep if the concentration of the MLSS is 2,450 mg/L?

Step 1 – Calculate volume of aeration basin = LWD = (30)(10)(3.5) = 1,050 cubic metres = 1.05 ML

Insert known values and solve

$$\text{Loading} = \frac{2{,}450\ \text{mg}}{\text{L}} \times \frac{1{,}050\ \text{m}^3}{\text{day}} \times \frac{1\ \text{kg}}{10^6\text{mg}} \times \frac{10^3\text{L}}{\text{m}^2} = 2{,}572.5\ \text{kg}$$

Or

Solids = (2,450 mg/L)(1.05 ML) = 2,572.5 kg

Things That Are Equal to One

When setting up a problem it is often useful to insert conversion factors that will allow us to move from the units given in the problem to the units that are needed to answer the problem. Luckily in mathematics, multiplying and dividing by the number one (1) has no effect on the answer so the insertion of a conversion factor (so long as it is equal or equivalent to one) has no impact on the numerical answer but it will help us move from one unit to another.

Some conversion factors that are equal to one include:

$$\frac{1m^3}{1{,}000\text{ L}} \qquad \frac{10{,}000\text{ m}^2}{\text{ha}} \qquad \frac{1\text{ kg}}{10^6\text{ mg}} \qquad \frac{1{,}000\text{g}}{\text{kg}}$$

$$\frac{1\text{ML}}{1{,}000\text{ m}^3} \qquad \frac{1{,}000\text{ mg}}{\text{g}} \qquad \frac{10^6\text{ mg}}{1\text{ Kg}} \qquad \frac{1\text{kPa}}{1{,}000\text{ Pa}}$$

Exponents and Powers of 10

In mathematics an exponent is the number to which the base number is to be multiplied by itself. In the example which follows the number 2 is the base and the exponent 3 indicates the number of times the base is to be multiplied by itself. Exponents are written as a superscript to the right of the number.

$$2^3 = (2)(2)(2) = 8$$

The expression $b^2 = b{\cdot}b$ is called the square of b. The area of a square with side-length b is b^2.

The expression $b^3 = b{\cdot}b{\cdot}b$ is called the cube of b. The volume of a cube with side-length b is b^3.

So 3^2 is pronounced "three squared", and 2^3 is "two cubed".

The exponent tells us how many copies of the base are multiplied together.

For example: $3^5 = 3{\cdot}3{\cdot}3{\cdot}3{\cdot}3 = 243$.

The base 3 appears 5 times in the repeated multiplication, because the exponent is 5. Here, 3 is the base, 5 is the exponent, and 243 is the power or, more specifically, the fifth power of 3, or 3 raised to the fifth power, or 3 to the power of 5.

The word "raised" is usually omitted, and very often "power" as well, so 3^5 is typically pronounced "three to the fifth" or "three to the five".

Powers of ten

In the base ten (decimal) number system, integer powers of 10 are written as the digit 1 followed or preceded by a number of zeroes determined by the sign and magnitude of the exponent. For example, $10^3 = 1{,}000$ and $10^{-4} = 0.0001$.

Exponentiation with base 10 is used in scientific notation to denote large or small numbers. For instance, 299,792,458 m/s (the speed of light in vacuum, in metres per second) can be written as 2.99792458×10^8 m/s and then approximated as 2.998×10^8 m/s.

SI prefixes based on powers of 10 are also used to describe small or large quantities. For example, the prefix kilo means $10^3 = 1{,}000$, so a kilometre is 1,000 metres.

Powers of 10 when the exponent is a positive number

$$8.64 \times 10^{\mathbf{4}}$$

The small number 4 in the top right hand corner is the exponent.

10^4 is a shorter way of writing $10 \times 10 \times 10 \times 10$, or 10,000

$8.64 \times 10^4 = 8.64 \times 10{,}000 = 86{,}400$

10 to the power of any positive integer (i.e. 1, 2, 3, etc.) is a one followed by that many zeroes.

$10^2 = 10 \times 10 = 100$

$10^3 = 10 \times 10 \times 10 = 1,000$

$10^6 = 10 \times 10 \times 10 \times 10 \times 10 \times 10 = 1,000,000$

Powers of 10 when the exponent is a negative number:

$$8.64 \times 10^{-4}$$

The small number -4 in the top right hand corner is the exponent.

$$10^{-4} \text{ is a shorter way of writing } \frac{1}{10^4} = \frac{1}{10 \times 10 \times 10 \times 10} = \frac{1}{10{,}000} = 0.0001$$

Therefore:

$$8.64 \times 10^{-4} = \frac{8.64}{10 \times 10 \times 10 \times 10} = \frac{8.64}{10{,}000} = 0.000864$$

The decimal moves 4 places to the left

10 to the power of any negative integer (i.e. 1, 2, 3, etc.) is a one divided by the product of the power.

$$10^{-2} = \frac{1}{10 \times 10} = \frac{1}{100} = 0.01$$

$$10^{-3} = \frac{1}{10 \times 10 \times 10} = \frac{1}{1{,}000} = 0.001$$

$$10^{-4} = \frac{1}{10 \times 10 \times 10 \times 10} = \frac{1}{10{,}000} = 0.0001$$

To recap -

If our exponent is a negative number, e.g.

10^{-x} then the decimal place moves "x" places to the LEFT

For example

$3.21 \times 10^{-3} \rightarrow .0\ 0\ 3.21 \rightarrow 0.00321$

3 jumps to the left

$4 \times 10^{-6} \rightarrow .0\ 0\ 0\ 0\ 0\ 4. \rightarrow 0.000004$

6 jumps to the left

If our exponent is a positive number, e.g.

10^{y} then the decimal place moves "y" places to the RIGHT

For example

$3.21 \times 10^{3} \rightarrow 3.2\ 1\ 0 \rightarrow 3210$

3 jumps to the right

$$4 \times 10^6 \rightarrow 4\,0\,0\,0\,0\,0\,0. \rightarrow 4{,}000{,}000$$

6 jumps to the right

Multiplying and dividing by powers of ten

When we multiply two values expressed as powers of ten we add the exponents together

$$10^2 \times 10^3 = 10^{2+3} = 10^5$$

Example 1

$$125 \times 3{,}600 = 450{,}000$$

$$(1.25 \times 10^2) \times (3.6 \times 10^3) = 1.25 \times 3.6 \times 10^{2+3} = 4.5 \times 10^5 = 450{,}000$$

When we divide to values expressed as powers of ten we subtract the exponents

$$\frac{10^2}{10^3} = 10^{2-3} = 10^{-1}$$

Example 2

$$\frac{125}{3{,}600} = 0.034$$

$$\frac{1.25 \times 10^2}{3.6 \times 10^3} = \frac{1.25}{3.6} \times 10^{2-3} = 0.34 \times 10^{-1} = 0.034$$

Note: normally, one would not use powers of ten notation for relatively small numbers such as those shown in the examples. The skill becomes useful in reducing some of the conversion factors used when converting from, say, milligrams per litre to kilograms per day

Basic Math Skills

Order of Operation – BEDMAS

BEDMAS is an acronym which can be used to help remember the correct order in which mathematical operations are carried out when solving an equation. That order is:

1	Brackets	( )
2	Exponents	3^2
3	Division	÷
4	Multiplication	×
5	Addition	+
6	Subtraction	−

Example 1 – Consider the equation:

$$(5-2)^2 + \frac{4(2+1)}{6} - 1$$

Solve using BEDMAS

$$\text{Brackets } (5-2)^2 + \frac{4(2+1)}{6} - 1 = (3)^2 + \frac{4(3)}{6} - 1$$

$$\text{Exponents } \ (3)^2 + \frac{4(3)}{6} - 1 = 9 + \frac{4(3)}{6} - 1$$

$$\text{Division/Multiplication} \quad 9 + \frac{4(3)}{6} - 1 = 9 + \frac{12}{6} - 1 = 9 + 2 - 1$$

$$\text{Addition } \ 9 + 2 - 1 = 11 - 1$$

$$\text{Subtraction } \ 11 - 1 = 10$$

When solving a fractional expression, you treat each part (the numerator and the denominator) as separate equations and apply the rules of BEDMAS accordingly. Finally, divide the numerator by the denominator.

Useless fact: the line separating the numerator and the denominator is called the vinculum.

Example 2 – Consider the equation: 8 + 3^2(3 × 5) – 6(3 + 5)

$$\text{Brackets } \ 8 + 3^2(3 \times 5) - 6(3+5) = 8 + 3^2(15) - 6(8)$$

$$\text{Exponents } \ 8 + 3^2(15) - 6(8) = 8 + 9(15) - 6(8)$$

$$\text{Division/Multiplication } \ 8 + 9(15) - 6(8) = 8 + 135 - 48$$

$$\text{Subtraction } \ 8 + 135 - 48 = 143 - 48 = 95$$

Addition and Subtraction

In addition and subtraction, only similar units expressed to the same number of decimal places may be added or subtracted. The number with the least number of decimal places a limit on the number of decimals that the answer can justifiably contain. For example, suppose you have been asked to add together the following values: 446 mm + 185.22 cm + 18.9 m. First convert the quantities to similar units (in this case metres) and then chose the least accurate number, which is 18.9. As it only has one digit to the right of the decimal point, the other two values will have to be rounded off.

446 mm	=	0.446 m	=	0.4 m
185.22 cm	=	1.8522 m	=	1.8 m
18.9 m	=	18.9 m	=	18.9 m
				21.1 m

When adding numbers (including negative numbers), the rule is that the least accurate number will determine the number reported as the sum. The number of significant figures reported in the sum cannot be greater than the least significant figure in the group being added.

In the next example, the least precise number, 170, dictates that the other three numbers will have to be changed (rounded off) before addition is done.

1.023 g	=	1 g
23.22 g	=	23 g
170 g	=	170 g
1.008 g	=	1 g
		195 g

Multiplication and Division

The rules for rounding off in multiplication and division are different for those used in addition and subtraction. In multiplication and division the number with the fewest significant figures will dictate how the answer is finally written. Suppose we have to multiply 26.56 by 6.2.

$$(26.56)(6.2) = 164.672$$

In the equation above, the first number has four significant figures while the second number only has two. Therefore the answer should only be written with two significant figures as 160 because the least precise value (6.2) only has two significant figures.

Pi (**π**)

π (sometimes written **pi**) is a mathematical constant which equals the ratio of a circle's circumference to its diameter.

$$\pi = \frac{\text{circumference}}{\text{diameter}} \approx 3.14$$

Pi is an irrational number, which means that its value cannot be expressed exactly as a fraction having integers in both the numerator and denominator (for example, 22÷7). Consequently its decimal representation never ends and never repeats. Reports on the latest, most-precise calculation of π are common. The record as of November 2021, stands at 62 trillion decimal digits by a team from Switzerland's University of Applied Science at Graubünden. Why? Because they can.

The value used for π in all calculations in this book and on the EOCP exams is 3.14.

NASA uses a value of 3.141592653589793 when calculating interplanetary orbits which proves, once again, that water and wastewater treatment isn't rocket science.

The constant 0.785

The number 0.785 often appears in formulas requiring the calculation of the area of a circle.

The equations: Area = $0.785(D)^2$ and Area = πr^2 will give the same answer. Why?

Proof:

If $\pi = 3.14$ and the radius of a circle is equal to one half the diameter i.e. $r = D \div 2$

$$\text{Then,} \qquad \text{Area} = \pi 2^2 = \pi\left(\frac{D}{2}\right) \times \left(\frac{D}{2}\right) = \pi\left(\frac{D^2}{4}\right) = \frac{3.14D^2}{4} = 0.785D^2$$

Because $3.14 \div 4 = 0.785$

Both formulas are correct but to avoid confusion operators should chose to use one or the other in all of their calculations. In this manual, the formula $A = \pi r^2$ will be used when the radius is given and $A = 0.785\ D^2$ when the diameter is given.

Before we get started

8 Simple Steps to Solving a Math Problem (and 1 more)

1. Make sure all the units are the same, you cannot multiply meters by millimetres, feet by inches or litres by kilograms. Look to the answer choices or the wording of the question to determine which units you should use.
2. If you think visually, make a sketch
3. Ensure you understand the question – read it then read it again. Read it slowly.
4. Write down the things you know – what data did the question provide?
   Separate the wheat from the chaff, sometimes the question will provide you with more information than is really needed to solve it.
5. Find the applicable formula and write it down. The variables provided, information given and the units required in the answer will help you select the correct formula
6. Break the question into manageable sections, don't try and devise a super-formula.
7. Double check your calculations – calculator keys are small and fingers are big.
8. Does the answer look reasonable and are the units correct?

And 1 more

9. Time management – don't be afraid to flag the question and move onto the next one. Once you have finished all the other questions, then you can go back and work on the ones you flagged.

How do you eat a meal like this? One bite at a time!

Remember this, each question on a certification examination is worth exactly 1 mark. Don't burn up time that could have been spent answering questions to which you knew the answer. Pick the low-hanging fruit first and then go back for the hard ones.

At the end of it all, if you haven't been able to achieve an answer that matches any of the ones given then guess. You have a 1 in 4 chance of being right and there is no penalty for being wrong.

The odds of winning the Lotto Max are 1 in 33,294,800 but you still buy tickets!

Geometry – Perimeter, Circumference, Area and Volume

Geometry is a branch of mathematics concerned with questions of shape, size, relative position of figures, and the properties of space.

Geometry arose independently in a number of early cultures as a practical way for dealing with lengths, areas and volumes

Some of the formulas that we still use today were first devised and recorded in the 3rd century BCE, by the Greek mathematician Euclid of Alexandria in his 13 volume treatise *Elements* which served as the main textbook for teaching mathematics (especially geometry) from the time of its publication until the late 19th or early 20th century.

Operators of water and wastewater treatment plants need to be familiar with the formulas for calculating areas, perimeters and volumes of a variety of geometric shapes. The shapes described below can be found in treatment process tanks and basins, in clarifiers, lagoons, trenches, storage hoppers and a variety of other locations and applications.

As the picture above shows, operators may be called upon to calculate the area of rectangles (aeration basins, primary clarifiers, clear wells) and circles (clarifiers); the volume of polyhedrons (aeration basins, clarifiers, etc.), cylinders (clarifiers, digestors, reservoirs) and occasionally, a sphere (gas holder) or a storage hopper with a conical bottom and cylindrical barrel. Linear measurements such as the amount of perimeter fencing required or the circumference of circular process tank must also be calculated from time to time.

The tools to carry out these calculations are presented in the remainder of this section.

Linear Measurement

Perimeter

A **perimeter** is a path that surrounds a two-dimensional shape. The word comes from the Greek words *peri* (around) and *meter* (measure). The term may be used either for the path or its length—it can be thought of as the length of the outline of a shape

In our industry this term is usually applied to shapes which are square or rectangular. A rectangle is any four-sided shape having at least 1 right angle and a length which is longer than its width. A square is any four-sided shape having at least 1 right angle and all four sides equal in length.

A practical application may be the calculation of the linear metres of fencing required to enclose a space.

The formula for calculating the perimeter of a rectangle is:

$$\text{Perimeter} = 2 \times (\text{length} + \text{width})$$

It is written as:

$$\mathrm{P} = 2\ \times (\mathrm{L} + \mathrm{W})\ \text{ or }\ \mathrm{P} = 2(\mathrm{L} + \mathrm{W})\ \text{ or }\ \mathrm{P} = 2\mathrm{L} + 2\mathrm{W}$$

How many feet (metres) of fencing will be required to enclose a building lot that is 59 feet (18 metres) wide by 148 feet (45 metres) long?

Known: Length = 148 ft (45 m), Width = 59 ft (18 m)

Insert known values and solve:

$$\mathrm{P} = 2 \times (\mathrm{L} + \mathrm{W}) = 2 \times (148\ \mathrm{ft} + 59\ \mathrm{ft}) = 2 \times (207\ \mathrm{ft}) = 414\ \text{feet}$$

$$\mathrm{P} = 2 \times (\mathrm{L} + \mathrm{W}) = 2 \times (45\ \mathrm{m} + 18\ \mathrm{m}) = 2 \times (63\ \mathrm{m}) = 126\ \text{metres}$$

Circumference of a circle

The term circumference is used to refer to the distance around the outside of a circular or elliptical shape (its perimeter).

Calculation of the circumference of a circle requires the operator to know either its diameter (the distance across a circle at its widest point) or its radius (the distance from the center of a circle to its circumference or one half the diameter) and the value of the constant pi (3.14).

The formula for calculating the circumference of a circle is:

$$\text{circumference} = \text{pi}\ \times \text{diameter}\ \text{ or }\ \text{pi} \times 2 \times \text{radius}$$

It is written as:

$$\mathrm{C} = \pi\mathrm{d}\ \text{ or } \mathrm{C} = 2\pi\mathrm{r}$$

What is the circumference of a secondary clarifier with a diameter of 147 feet (45 metres)?

Known: Diameter = 147 feet (45 metres), pi (π) = 3.14

Insert known values and solve:

$$\mathrm{C} = \pi\mathrm{d} = 3.14 \times 147\ \mathrm{ft} = 461.6\ \text{feet}$$

$$\mathrm{C} = \pi\mathrm{d} = 3.14 \times 45\ \mathrm{m} = 141.3\ \text{metres}$$

What is the circumference of a gravity thickener with a radius of 29.5 feet (9 metres)?

Known: radius = 29.5 feet (9 metres), pi (π) = 3.14

Insert known values and solve:

$$\mathrm{C} = 2\pi \mathrm{r} = 2 \times 3.14 \times 29.5 \text{ ft} = 185.3 \text{ feet}$$
$$\mathrm{C} = 2\pi \mathrm{r} = 2 \times 3.14 \times 9 \text{ m} = 56.52 \text{ metres}$$

Circumference of an ellipse

There is no simple formula with high accuracy for calculating the circumference of an ellipse. There are simple formulas but they are not exact, and there are exact formulas but they are not simple. Thankfully, there are not many elliptical storage tanks or clarifiers being constructed. The most accurate of the simple formulae for the circumference of an ellipse is:

$$\text{circumference} = \pi \times [3(\mathrm{a} + \mathrm{b}) - \sqrt{(3\mathrm{a} + \mathrm{b})(\mathrm{a} + 3\mathrm{b})}\ ]$$

Where “a” and “b” are the major and minor axes of the ellipse and “a” is not more than three times the length of “b”. Even then, the formula is only accurate to ±5%

Area

The area of a geometrical shape such as a circle, square, rectangle or triangle is the space contained within the boundary of the shape (i.e. its perimeter). Two dimensions are required to calculate the area of a shape and that area is reported as “units” squared. In the metric system the units that are most commonly used are the square metre (m^2) and the square centimetre (cm^2). Large shapes such as land surveys and wastewater lagoons are often reported in units of hectares (10,000 m^2).

Area of a Circle

The area of a circle can be calculated using two different formulas depending on whether the radius or the diameter of the circle is known. (the diameter of a circle is equal to 2 times its radius and the radius of a circle is equal to one half of the diameter).

The formulas are:

$$\text{Area} = \pi \times (\text{radius})^2 \text{ or } \text{Area} = \pi \times \text{radius} \times \text{radius} = \pi r^2$$
$$\text{Area} = 0.785 \times (\text{diameter})^2 = 0.785\mathrm{D}^2$$

Calculate the surface area of a secondary clarifier which has a diameter of 82 feet (25 metres).

Insert known values and solve:

$$\text{Area} = 0.785 \times (82 \text{ ft})^2 = 5{,}278.3 \text{ ft}^2$$
$$\text{Area} = 0.785 \times (25 \text{ m})^2 = 490.6 \text{ m}^2$$

Calculate the surface area of a thickener with a radius of 15 feet (4.6 metres).

$$\text{Area} = \pi(\mathrm{r})^2 = 3.14 \times (15 \text{ ft})^2 = 3.14 \times 15 \text{ ft} \times 15 \text{ ft} = 706.5 \text{ ft}^2$$
$$\text{Area} = \pi(\mathrm{r})^2 = 3.14 \times (4.6 \text{ m})^2 = 3.14 \times 4.6 \text{ m} \times 4.6 \text{ m} = 66.4 \text{ m}^2$$

Circular shapes found in the industry include clarifiers, thickeners, wet wells, meter vaults and pipes.

Area of a Cone (lateral surface area)

The practical application of this formula would be to calculate the surface area of a conical section of a hopper or the floor of a clarifier, trickling filter or anaerobic digestor in order to determine the amount of a coating needed.

The formula is:

$$\text{Area} = \pi \times \text{radius} \times \sqrt{(\text{radius})^2 + (\text{height})^2}$$

It is written:

$$\text{Area} = \pi \times \text{r} \times \sqrt{\text{r}^2 + \text{h}^2}$$

A gravity thickener 32.8 feet (10 metres) in diameter has a cone shaped floor. The cone is 4.9 feet (1.5 metres deep. A skim coat of concrete is to be applied to the floor. Calculate the number of square feet (metres) to be covered.

Known: Radius = ½ of diameter = 5 metres, height = 1.5 metres

Insert known values and solve

US units

$$\text{Area} = \pi \times \text{r} \times \sqrt{\text{r}^2 + \text{h}^2}$$

$$\text{Area} = 3.14 \times 16.4 \text{ ft} \times \sqrt{(16.4 \text{ ft})^2 + (4.9 \text{ feet})^2}$$

$$\text{Area} = 3.14 \times 16.4 \text{ ft} \times \sqrt{292.9 \text{ ft}} = 881.4 \text{ ft}^2$$

Metric units

$$\text{Area} = \pi \times \text{r} \times \sqrt{\text{r}^2 + \text{h}^2}$$

$$\text{Area} = 3.14 \times 5\text{m} \times \sqrt{(5\text{m})^2 + (1.5\text{m})^2}$$

$$\text{Area} = 3.14 \times 5\text{m} \times \sqrt{27.25 \text{ m}^2} = 82 \text{ m}^2$$

Area of a Cone (total surface area)

The formula is:

$$\text{Area} = \pi \times (\text{radius})^2 + \sqrt{(\text{radius})^2 + (\text{height})^2}$$

You need to paint a cone shaped hopper with a lid. The hopper is 8 feet (2.4 metres) deep and 12 feet (3.6 meters) in diameter. How many square feet (square meters) will you have to paint?

Known: radius = ½ of the diameter

US units

$$\text{Area} = \pi \times (6 \text{ ft})^2 \times \sqrt{(6\text{ft})^2 + (8\text{ft})^2}$$
$$= 3.14 \times 36\text{ft}^2 + \sqrt{36\text{ft}^2 + 64\text{ft}^2}$$

$$\text{Area} = \pi \times (6 \text{ ft})^2 \times \sqrt{(6\text{ft})^2 + (8\text{ft})^2} = 3.14 \times 36\text{ft}^2 + \sqrt{36\text{ft}^2 + 64\text{ft}^2}$$

$$\text{Area} = \pi \times (\text{radius})^2 + \sqrt{(\text{radius})^2 + (\text{height})^2}$$

$$\text{Area} = 3.14 \times 36\text{ft}^2 + 10 \text{ ft}^2 = 123 \text{ ft}^2$$

Metric units

$$\text{Area} = \pi \times (1.8\text{m})^2 + \sqrt{(1.8\text{m})^2 + (2.4\text{m})^2} = 3.14 \times 3.24m^2 + \sqrt{3.24m^2 + 5.76m^2}$$

$$\text{Area} = \pi \times (1.8\text{m})^2 + \sqrt{(1.8\text{m})^2 + (2.4\text{m})^2} = 3.14 \times 3.24m^2 + \sqrt{3.24m^2 + 5.76m^2}$$

$$\text{Area} = (3.14 \times 3.24m^2) + 3m^2 = 13.2m^2$$

NOTE: *it is generally accepted that the math questions on a certification exam can be solved with a basic four function calculator, therefore, it is unlikely that any questions requiring the calculation of a square root will appear on the exam*.

Area of a Cylinder (total and lateral surface area)

Calculating the area of a cylinder is a two-step operation. First the operator must calculate the circumference of the cylinder (i.e. the distance around the outside) and multiply that value by the height, depth or length of the cylinder as the case may be.

The practical application of this calculation is to determine the surface of area of a pipe, storage tank or reservoir in order to determine the quantity of paint or some other type of coating to be applied.

The equation for the lateral surface area is:

Area = Circumference × Height

It is written as:

$$\text{Area} = \text{C} \times \text{H} \ \text{ or } \ \text{Area} = \pi \times \text{D} \times \text{H}$$

If the total area of a cylinder is to be calculated, as in calculating the surface area of a fuel tank then the two ends of the cylinder must also be accounted for and the formula becomes:

$$[\text{End \#1 SA}] + [\text{End \#2 SA}] + [\pi \times \text{Diameter} \times \text{Height}]$$

Where SA = surface area. This equation can be simplified to:

$$\text{Total surface area} = \pi \times \text{D} \times \text{H} + (2 \times 0.785\text{D}^2)$$

A newly purchased fuel storage tank which is 10 feet (3 metres) long and 5 feet (1.5 metres) in diameter needs to be painted. Calculate the total surface area to be painted.

US units

$$\text{Total surface area} = 3.14 \times 5\text{feet} \times 10\text{ feet} + (2 \times 0.785 \times [10\text{ feet}]^2) = 314\text{ ft}^2$$

Metric units

$$\text{Total surface area} = 3.14 \times 1.5\text{ m} \times 3\text{m} + (2 \times 0.785 \times [3\text{m}]^2) = 28.3\ m^2$$

Area of a Square or Rectangle

The area of a square or rectangle is equal to the product of one long side multiplied by one short side or in the case of a square by one side multiplied by another.

The formula for the area of a square or rectangle is:

$$\text{Area} = \text{Length} \times \text{Width}$$

It is written as:

$$\text{A} = \text{L} \times \text{W} \ \text{ or } \ \text{A} = \text{LW} \ \text{ or } \ \text{A} = (\text{L})(\text{W})$$

What is the surface area of a primary clarifier that is 26 feet (8 metres) wide and 164 feet (50 metres) long?

Insert known values and solve;

US Units

$$\text{Area} = 26 \text{ ft} \times 164 \text{ ft} = 4{,}264 \text{ ft}^2$$

Metric units

$$\text{Area} = 8 \text{ m} \times 50 \text{ m} = 400 \text{ m}^2$$

Area of a Right Triangle

The area of a right triangle is equal to its base (any side of the triangle) multiplied by its height (perpendicular to, or at 90° to the base), divided by two (often written as multiplication by ½).

The formula is

$$\text{Area} = \frac{\text{Base} \times \text{Height}}{2}$$

It is written as:

$$\text{A} = \frac{(\text{B}) \times (\text{H})}{2} \quad \text{or} \quad \frac{1}{2}\text{B} \times \text{H}$$

A compost pile is 7 metres wide and 3 metres high. What is its cross-sectional area?

Known: Width (base) = 7 metres, Height = 3 metres

Insert known values and solve:

$$\text{Area} = \frac{7 \text{ m} \times 3\text{m}}{2} = 10.5 \text{ m}^2$$

Area of a Trapezoid

Calculating the area of a trapezoid falls somewhere between calculating the area of a square and calculating the area of a triangle. Trapezoidal shapes found in the industry include trenches dug for the installation of pipelines and stock piles of materials such as wood chips, compost or soil.

The area of trapezoid is equal to the sum of its two sides divided by 2 times its height. The formula is:

$$\text{Area} = \frac{\text{side 1} + \text{side 2}}{2} \times \text{height}$$

A pile of compost has a base 5 meters wide, a top 2.5 metres wide and a height of 2 meters. Calculate the cross-sectional area of the pile.

Known: side 1 = 5 m, side 2 =2.5 m, height = 2 m

Insert known values and solve

$$\text{Area} = \frac{\text{side 1} + \text{side 2}}{2} \times \text{height} = \frac{5\text{ m} + 2.5\text{ m}}{2} \times 2\text{ m} = 7.5\text{m}^2$$

Area of a Sphere

This formula is provided in the EOCP handout with the notation that it might be used to calculate the surface area of an air bubble. It could also be used to calculate the surface area of a gas holder associated with an anaerobic digestor.

The equation is: $\text{Area} = 4 \times \pi \times (\text{radius})^2$

It is written: $\text{Area} = 4\pi\text{r}^2 \text{ or } \pi\text{d}^2 \text{ (where d = diameter)}$

Area of an Irregular Shape

Occasionally it is necessary to calculate the area of an irregular shape such as a sewage lagoon. One way to do this is to break the shape into a number of shapes for which we have formulas (such as squares, rectangles or triangles). The area of each shape can be calculated, then added together to equal the area of the entire shape.

Volume

A measure of the three dimensional space enclosed by a shape. As volume is a three-dimensional measurement, the units used to describe it need to have three dimensions as well. These units are reported as "units" cubed or cubic "units". In the US system volumes are often expressed as cubic inches, cubic feet and cubic yards. In the metric system volume is often expressed as cubic metres (m^3), cubic centimetres (cm^3) and liters (1,000 cm^3). Large volumes are also reported as Megalitres (1 ML = 1,000,000 L =1,000 m^3).

In the water and wastewater industry operators often need to calculate the volume of a basin (rectangular), clarifier, digestor or reservoir (cylinder), compost pile or stockpile (triangular) or a storage hopper (conical) or of a structure that is a combination of shapes (e.g. a digestor with a cylindrical body and a conical floor)

Volume of a Cone

Calculation of the volume of a cone is used less frequently but it may be required when calculating the volume of a storage hopper or the conical floor section of a digestor, clarifier or trickling filter.

The volume of a cone is equal to the one third (⅓) the area of its circular base (the radius of the cylinder squared, multiplied by the constant π), multiplied by the height

The formula is:

$$\text{Volume} = \frac{\pi \times (\text{radius})^2 \times \text{height}}{3} \quad \text{or} \quad \text{V} = \frac{\pi\text{r}^2\text{h}}{3} \text{ or } \text{V} = \frac{0.785\text{D}^2 h}{3}$$

Calculate the volume of conical hopper 6.6 feet (2 metres) deep and 4.9 feet (1.5 metres) in diameter.

Known: diameter = 1.5 metres, therefore radius = 1.5÷2=0.75 m, depth = 2 metres

Insert known values and solve:

US units

$$V = \frac{0.785D^2h}{3} = \frac{0.785(4.9\text{ feet})^2 \times 6.6\text{ ft}}{3} = 41.5\text{ ft}^3$$

Metric units

$$V = \frac{0.785D^2h}{3} = \frac{0.785(1.5\text{m})^2 \times 2\text{m}}{3} = 1.18\text{ m}^3$$

Volume of a Cylinder

Calculation of the volume of a cylinder will probably be the most frequently used volume calculation after the calculation for the volume of a rectangular basin. Cylinders are found as circular clarifiers, reservoirs and water and sewer pipelines.

The volume of a cylinder is equal to the area of its circular base (the diameter of the cylinder, multiplied by the constant 0,785), multiplied by the height.

The formula is

$\text{Volume} = 0.785(\text{diameter})^2 \text{ or } \pi \times (\text{radius})^2 \times \text{height}$

It is written:

$$V = \pi r^2 h \quad \text{or} \quad V = 0.785D^2 h$$

What is the volume of a reservoir that is 90 feet (27.4 metres) in diameter and 15 feet (4.5 metres) deep?

Known: Diameter = 90 feet (27.4 metres), depth = 15 feet (4.5 metres)

Insert known values and solve

US units

$$V = 0.785D^2h = 0.785(90\text{ ft})^2 \times 15\text{ ft} = 95{,}377.5\text{ ft}^3$$

Metric units

$$V = 0.785D^2h = 0.785(27.4\text{ m})^2 \times 4.5\text{ m} = 2{,}652\text{ m}^3$$

Volume of a Rectangular Tank

The volume of a box or cube is equal to its length, multiplied by its width, multiplied by its height, (depth or thickness). In the case of a cube, all three lengths are the same.

The formula is

$$\text{Volume} = \text{length} \times \text{width} \times \text{height}$$

It is written:

$$\mathrm{V} = \mathrm{LWH} \;\text{ or } \mathrm{V} = (\mathrm{L})(\mathrm{W})(\mathrm{H}) \;\text{ or }\; \mathrm{V} = \mathrm{L} \times \mathrm{W} \times \mathrm{H}$$

Sometimes the word “depth” and the letter “D” is substituted for height

Calculate the volume of an aeration basin 50 metres long by 6 metres wide by 4.5 metres deep.

Known: Length = 50 m, Width = 6 m, Depth = 4.5 m

Insert known values and solve:

$$\mathrm{V} = \mathrm{LWD} = 50\ \mathrm{m} \times 6\ \mathrm{m} \times 4.5\ \mathrm{m} = 1{,}350\ \mathrm{m}^3$$

Volume of a Prism

The mathematical name for a three-dimensional shape that is triangular in cross-section is a prism. Examples of prismatic structures in the wastewater industry include spoil piles, compost piles and tanks which have a triangular cross section in their floors for the purposes of collecting sludge or grit.

The equation for the volume of a prism is one half its base times its height times its length

The formula is

$$\text{Volume of a prism} = \frac{\text{base} \times \text{height}}{2} \times \text{length}$$

It is written:

$$\mathrm{V} = \frac{\mathrm{B} \times \mathrm{H}}{2} \times \mathrm{L}$$

Calculate the volume of a compost pile 3 metres high by 6 metres wide by 30 metres long.

Known: Base = 6 metres, Height = 3metres, Length = 30 metres

Insert known values and solve:

$$\mathrm{V} = \frac{\mathrm{B} \times \mathrm{H}}{2} \times \mathrm{L} = \frac{6\ \mathrm{m} \times 3\ \mathrm{m}}{2} \times 30\ \mathrm{m} = 270\ \mathrm{m}^3$$

Volume of a lagoon (a frustrum)

The correct name for a truncated pyramid is a frustrum. The EOCP handout provides a formula for calculating the volume of a lagoon which is a type of inverted truncated pyramid.

The volume of a frustrum is equal to one half (1/2) the average length times the average width times the depth.

The formula is:

$$\text{Volume} = \text{average length } \times \text{average width } \times \text{depth}$$

It is written:

$$V = \frac{L_{top} + L_{bottom}}{2} \times \frac{W_{top} + W_{bottom}}{2} \times \text{depth}$$

Where L = length and W = Width

A lagoon measures 328 feet (100 metres) wide by 984 feet (300 metres) long on the surface, its bottom dimensions are 262 feet (80 metres) wide by 919 feet (280 metres) long. It is 8 feet (2.5 metres) deep. What is its volume?

US units

Inset known values and solve

$$V = \frac{984 \text{ ft} + 919 \text{ ft}}{2} \times \frac{328 \text{ ft} + 262 \text{ ft}}{2} \times 8\text{ft} = 2{,}245{,}540\text{ft}^3$$

Metric units

Insert known values and solve:

$$V = \frac{300 \text{ m} + 280 \text{ m}}{2} \times \frac{100 \text{ m} + 80 \text{ m}}{2} \times 2.5 \text{ m} = 65{,}250 \text{ m}^3$$

Note: many other formulas exist for calculating the volume of a frustrum which give a more accurate result than the one used by the EOCP. For example:

$$V = \frac{(A_{top} + A_{bottom} + \sqrt{A_{top} \times A_{bottom}}\,)}{3} \times \text{depth}$$

Yields a slightly different and more accurate answer.

$$V = \frac{\left(30{,}000 \text{ m}^2 + 22{,}400 \text{ m}^2 + \sqrt{30{,}000 \text{ m}^2 \times 22{,}400 \text{ m}^2}\,\right)}{3} \times 2.5 \text{ m} = 65{,}269 \text{ m}^3$$

Amperes

See Basic Electrical Concepts

Average (arithmetic mean)

The term “arithmetic mean” is just another way of saying “average”.

The arithmetic average of a series of numbers is simply the sum of the numbers divided by the number of values in the series.

The equation is:

$$\text{Average} = \frac{\text{Sum of all terms}}{\text{Number of terms}}$$

What is the average concentration of volatile acids in a digestor supernatant given the following data? All values given are in mg/L

Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.	Sun
234	261	280	272	259	257	244

Insert known values and solve

$$\text{Average VSS} = \frac{234 + 261 + 280 + 272 + 259 + 257 + 244}{7 \text{ days}} = 258 \text{ mg/L}$$

Calculate the 7 day running average for BOD_5 removal during days 8, 9 and 10 given the following data:

Day	BOD_5, mg/L	Day	BOD_5, mg/L
1	212	9	226
2	231	10	211
3	244	11	245
4	235	12	206
5	217	13	193
6	202	14	188
7	194	15	189
8	209	16	204

Step 1 – Calculate the average for day 8 and the previous 6 days (7 days total)

$$\text{Average, days 2 to 8} = \frac{231 + 244 + 235 + 217 + 202 + 194 + 209}{7} = 219 \text{ mg/L}$$

Step 2 – Calculate Day 9, 7 day running average by dropping day 2 and adding day 9

$$\text{Average, days 3 to 9} = \frac{244 + 235 + 217 + 202 + 194 + 209 + 226}{7} = 218 \text{ mg/L}$$

Step 3 - Calculate Day 10, 7 day running average by dropping day 3 and adding day 10

$$\text{Average, days 4 to 10} = \frac{235 + 217 + 202 + 194 + 209 + 226 + 211}{7} = 213 \text{ mg/L}$$

Given the following data, calculate the unknown values

Day	Effluent BOD5, mg/L	Unknown values
Monday	28	**Arithmetic mean, mg/L**
Tuesday	32	**Median, mg/L**
Wednesday	34	**Range, mg/L**
Thursday	32	**Mode, mg/L**
Friday	29	**Geometric mean, mg/L**
Saturday	23	
Sunday	35	

Note: a scientific calculator is required to determine the geometric mean

Calculate the arithmetic mean (average)

$$\text{Arithmetic mean} = \frac{28+32+34+32+29+23+35}{7} = 30.4, \text{round to } 30 \text{ mg/L BOD}_5$$

Median, Range, and Mode

Determine the median of BOD_5 mg/L

To determine the median value, put the data in ascending order and choose the middle value

1	2	3	4	5	6	7
23	28	29	32	32	34	35

In this case, the middle or median value is 32 mg/L BOD_5

Determine the mode of BOD_5 mg/L

Mode is the measurement that occurs most frequently. In this case it is 32 mg/L as it appears twice in the data set.

Determine the range of BOD_5 mg/L

The equation is: Range = Largest value – smallest value = 35 mg/L – 23 mg/L = 12 mg/L BOD_5

Average (geometric mean)

The equation is: Geometric mean = $[(x_1)(x_2)(x_3)(x_4)(x_5)(x_6)(x_7)]^{1/n}$

Where x = the value of the measurement and n = the number of measurements.

$$\text{Geometric mean} = [23 \times 28 \times 29 \times 32 \times 32 \times 34 \times 35]^{\frac{1}{7}} = 30.2 \text{ mg/L BOD}_5$$

Note: for any series of numbers, the geometric mean will always be less than the arithmetic mean. Determination of the geometric mean requires a scientific calculator with an nth root function. Current EOCP practice is to only include mathematical questions that can be solved with a basic four function calculator so it is unlikely that a question involving solving for the geometric mean will appear on a certification exam.

Basic Chemistry

Molarity

A more accurate way of expressing the concentration of a solution than percent strength is molarity (*M*). Molarity is defined as the number of moles of a substance per litre of solution. A mole is a quantity of a substance equal in weight (in grams) to the substances molecular weight. For example, the molecular weight of calcium carbonate ($CaCO_3$) is 100.09 and therefore, if you had 100.09 grams of calcium carbonate you would have 1 mole of calcium carbonate.

Not that kind of mole!

The equation is:

$$\text{Molarity} = \frac{\text{moles of solute}}{\text{litres of solution}}$$

If 0.6 moles of sodium hydroxide (NaOH) are dissolved in 2.5 litres of water, what is the molarity of the resulting solution?

$$\text{Molarity} = \frac{\text{moles of solute}}{\text{litres of solution}} = \frac{0.6 \text{ moles}}{2.5 \text{ litres of solution}} = 0.24M$$

Normality

Normality is defined as the number of equivalent weights of a solute per litre of solution. In order to determine the normality of a solution one must first calculate how many equivalent weights of the solute are contained in the total weight of the solution.

When carrying out an acid-base titration, the number of hydrogen atoms in an acid molecule can provide a quick indication of the normality of an acid which contains one mole per litre. For example

- Hydrochloric acid (HCl) contains one hydrogen atom and if the concentration of the acid were 1 mole / litre its normality would be 1
- Sulfuric acid (H_2SO_4) contains two hydrogen atoms and if the concentration of the acid were 1 mole / litre its normality would be 2
- Phosphoric acid (H_3PO_4) contains three hydrogen atoms and if the concentration of the acid were 1 mole / litre its normality would be 3

The equation is:

$$\text{Normality} = \frac{\text{number of equivalent weights of solute}}{\text{litres of solution}}$$

If 2.1 equivalents of sodium hydroxide (NaOH) were used to make 1.75 litres of solution what is the normality of the solution?

Step 1 – Insert known values and solve:

$$\text{Normality} = \frac{\text{number of equivalent weights of solute}}{\text{litres of solution}} = \frac{2.1 \text{ Eq}}{1.75 \text{ L}} = 1.2 \text{ N}$$

Operators who wish to delve a little deeper into the field of Chemistry may wish to obtain copies of the American Water Works Association (AWWA) publications Basic Chemistry for Water and Wastewater Operators (ISBN 1-58321-148-9) by D.S. Sarai, PhD. or Basic Science Concepts and Applications for Wastewater (ISBN 1-58321-290-6) by P.L. Antonelli et al

Milliequivalents and Waste Milliequivalents

The use of equivalent weights in general chemistry has largely been superseded by the use of molar masses. Equivalent weights may be calculated from molar masses if the chemistry of the substance is well known. For example:

- sulfuric acid has a molar mass of 98.078 g/ mol, and supplies two moles of hydrogen ions per mole of sulfuric acid, so its equivalent weight is

$$\frac{98.078\ \text{grams/mole}}{2\ \text{equivalents/mole}} = 49.04\ \text{grams/equivalent}$$

- potassium permanganate has a molar mass of 158.034 g /mol, and reacts with five moles of electrons per mole of potassium permanganate, so its equivalent weight is

$$\frac{158.034\ \text{grams/mole}}{5\ \text{equivalents/mole}} = 31.6068\ \text{grams/equivalent}$$

Some contemporary general chemistry textbooks make no mention of equivalent weights. Others explain the topic, but point out that it is merely an alternate method of doing calculations using moles.

A milliequivalent is simply 1/1,000 of an equivalent.

The equations for the calculation of both milliequivalents and waste milliequivalents are the same:

$$\text{Milliequivalent, mEq} = \text{mL of substance} \times \text{Normality of substance}$$

How many milliequivalents will be found in 5 mL of a 0.2 Normal solution of hydrochloric acid?

Step 1 – Insert known values and solve

$$\text{Milliequivalent, mEq} = 5\ \text{mL} \times 0.2\ \text{N} = 1\ \text{mEq}$$

Number of Equivalent Weights

Equivalent weight (also known as gram equivalent) is a term which has been used in several contexts in chemistry. In its most general usage, it is the mass of a given substance (mass of one equivalent) which will:

- combine or displace directly or indirectly with 1.008 parts by mass of hydrogen or 8 parts by mass of oxygen.– values which correspond to the atomic weight divided by the usual valence,
- or supply or react with one mole of hydrogen cations (H^+) in an acid-base reaction
- or supply or react with one mole of electrons (e^-) in a redox reaction.

The equivalent weight of a compound can be calculated by dividing the molecular weight by the number of positive or negative electrical charges that result from the dissolution of the compound.

The use of equivalent weights in general chemistry has largely been superseded by the use of molar masses. Equivalent weights may be calculated from molar masses if the chemistry of the substance is well known. For example:

- Sulfuric acid has a molar mass of 98.078 g/ mol, and supplies two moles of hydrogen ions per mole of sulfuric acid, so its equivalent weight is 98.078 g/ mol ÷2 Eq/ mol = 49.039 g /Eq.
- Potassium permanganate has a molar mass of 158.034 g /mol, and reacts with five moles of electrons per mole of potassium permanganate, so its equivalent weight is 158.034 g/ mol ÷ 5 Eq/ mol = 31.6068 g /Eq

The equation is:

$$\text{Number of equivalent weights} = \frac{\text{total weight, g}}{\text{equivalent weight, g}}$$

If 75 g of sulfuric acid (H_2SO_4) were used in making up a solution, how many equivalents weights of H_2SO_4 were used?

Step 1 – Calculate the equivalent weight of H_2SO_4

$$\text{Equivalent weight} = \frac{\text{weight of 1 mole } H_2SO_4}{\text{equivalents per mole}} = \frac{98.078\text{g}}{2} = 49.04\text{ g}$$

Step 2 – Insert known values and solve

$$\text{Number of equivalent weights} = \frac{\text{total weight, g}}{\text{equivalent weight, g}} = \frac{75\text{ g}}{49.04\text{ g}} = 1.53$$

Unless the EOCP also provides a copy of the Periodic Table of Elements with the exam it is highly unlikely that a question regarding Equivalent Weights will appear on an exam. Officially, the abbreviation of the term equivalent is equiv *but common usage is to use the term* Eq *as the abbreviation.*

Number of Moles

A general discussion of the periodic table of the elements, Avogadro's number and the derivation of an element's atomic weight is beyond the scope of this manual. In simplest terms, a mole of a substance is a quantity of that substance whose mass (weight) in grams is equal to its atomic weight or the sum of atomic weights of the elements which make up a molecule.

For example, carbon has an atomic weight of 12 and therefore, one mole of carbon weighs 12 grams. Water (H_2O) contains two atoms of hydrogen each of which have an atomic weight of 1 and one atom of oxygen which has an atomic weight of 16 for a total atomic weight of 18 and therefore, 1 mole of water weighs 18 grams.

In the chemistry laboratory we often need to know how many moles of a substance are present.

The equation is:

$$\text{Number of moles} = \frac{\text{Total weight, g}}{\text{Molecular weight, g}}$$

Calculate the number of moles of calcium hydroxide that are present in a 25 gram sample of the material. The atomic weights are: calcium = 40, oxygen = 16 and hydrogen = 1

Step 1 – Calculate the gram molecular weight of calcium hydroxide $Ca(OH)_2$

Ca = 1 ×40 = 40   O = 2×16 =32   H = 2×1 =2 = 40+32+2=74 grams

Insert known values and solve

$$\text{Number of moles} = \frac{\text{Total weight, g}}{\text{Molecular weight, g}} = \frac{25\text{ g}}{74\text{ g}} = 0.34\text{ moles}$$

Alkalinity

The alkalinity of a wastewater is a measure of its ability to resist changes in pH. It is reported as mg/L of calcium carbonate ($CaCO_3$).

The formula is:

$$\text{Alkalinity as mg CaCO}_3/\text{L} = \frac{\text{titrant volume, mL} \times \text{acid normality} \times 50{,}000}{\text{sample volume, mL}}$$

A 100 mL sample of effluent was titrated with 22 mL of 0.2N sulfuric acid. What was its alkalinity?

$$\text{Alkalinity } = \frac{22\text{ mL} \times 0.2 \times 50{,}000}{100\text{ mL}} = 2{,}200\text{ mg/L as CaCO}_3$$

Hardness

The hardness of a water is normally of more interest to water treatment operators than to wastewater operators. However, hard water can lead to scaling in boilers and heat exchanger piping.

When the titration factor is 1.00 of EDTA, the formula is:

$$\text{Hardness, as mg/L CaCO}_3 = \frac{\text{Titrant volume, mL} \times 1{,}000}{\text{Sample volume, mL}}$$

When the titration factor is some number other than 1.00 of EDTA the formula is:

$$\text{Hardness (EDTA), as mg/L CaCO}_3 = \frac{\text{Titrant volume, mL} \times \text{mg CaCO}_3\text{ equivalent to 1 mL EDTA titrant} \times 1{,}000}{\text{Sample volume, mL}}$$

What is the $CaCO_3$ hardness of a water sample if 42 mL of titrant is required to reach the endpoint (where the colour changes from wine red to blue) on a 100 mL sample?

Known: titrant volume = 42 mL, sample volume = 100 mL

Insert known values and solve

$$\text{Hardness, as mg/L CaCO}_3 = \frac{\text{Titrant volume, mL} \times 1{,}000}{\text{Sample volume, mL}}$$

$$\text{Hardness} = \frac{42\text{ mL} \times 1{,}000}{100\text{ mL}} = 420\text{ mg/L as CACO}_3$$

Basic Electrical Concepts – Amperes, Resistance, Voltage, Power

The Law which relates voltage, amperage and resistance in an electrical circuit known as Ohm's Law. Ohm's Law states that the electromotive force (voltage) in a circuit is the product of current flow (amperes) and resistance (ohms).

Four formulas can be derived from Ohm's Law:

$$\mathrm{E} = \mathrm{I} \times \mathrm{R} \quad \text{or } \mathrm{I} = \frac{\mathrm{E}}{\mathrm{R}} \quad \text{or} \quad \mathrm{R} = \frac{\mathrm{E}}{\mathrm{I}} \text{ and } \mathrm{P} = \mathrm{E} \times \mathrm{I}$$

Where: E = Volts, I = Amperes, R = resistance measured in Ohms (Ω), P = power measured in Watts

Three different formula are used to calculate power depending on whether the voltage supply is direct current, alternating current or three phase alternating current.

The formulas are:

$$\text{Power, kW in a Direct current circuit} = \frac{\text{Volts} \times \text{Amperes}}{1{,}000}$$

$$\text{Power, kW in an Alternating current circuit} = \frac{\text{Volts} \times \text{Amperes} \times \text{Power Factor}}{1{,}000}$$

$$\text{Power, kW in an Altenating } 3\emptyset \text{ current circuit} = \frac{\text{Volts} \times \text{Amperes} \times \text{Power Factor} \times 1.732}{1{,}000}$$

Operators should have a basic knowledge of the application of Ohm's Law so as to undertake simple electrical calculations.

What is the amperage (I) draw required to illuminate a 120 Watt incandescent lamp in a 110 Volt AC circuit?

The equation is: P = E × I

Step 1 – Rearrange the equation to solve for I

$$\text{if } \mathrm{P} = \mathrm{E} \times \mathrm{I} \quad \text{then} \quad \mathrm{I} = \frac{\mathrm{P}}{\mathrm{E}} = \frac{120}{110} = 1.09 \text{ amperes}$$

What is the voltage (E) on a circuit if the current (I) is 7 amperes and the resistance (R) is 17 ohms. .

The equations is: E = (I)(R)

Insert known values and solve

Voltage = (7 amps)(17 ohms) = 119 Volts

What is the resistance in a circuit if the voltage is 120 and the amperes are 19?

The equation is: R= E / I

Insert known values and solve

Resistance = (120 volts) / (19 amperes) = 6.3 ohms

Biochemical Oxygen Demand (seeded, mg/L)

Biochemical oxygen demand measures the amount of oxygen consumed by microorganisms as they metabolize organic material – either in a wastewater treatment process or in the natural environment. Biochemical oxygen demand is the source of the food in the Food to Microorganism equation.

The test is carried out in a darkened incubator over five days ±6 hours at a temperature of 20˚C ±1˚C in a 300 mL BOD bottle. The acronym used is often written as BOD_5. BOD_5 values are typically expressed in mg/L.

Occasionally an operator will need to calculate the BOD of a sample which has been disinfected and contains no viable microorganisms. In this case the sample needs to be "seeded" with a small aliquot of wastewater with a known BOD concentration.

The formula for calculating a "seeded" BOD is:

$$\frac{[(\text{initial DO, mg/L} - \text{final DO, mg/L}) - \text{seed correction factor, mg/L}] \times 300\text{ mL}}{\text{mL of sample}}$$

Two calculations are needed in this case to solve this formula.

The formula for calculating the seed correction in mg/L is:

$$\text{Seed correction, mg/L} = \frac{\text{BOD of seed stock, mg/L} \times \text{Volume of seed stock, mL}}{\text{Total Volume of BOD bottle, 300 mL}}$$

Calculate the seeded BOD_5 in mg/L given the following data:

$DO_{initial}$: 8.6 mg/L	DO_{final}: 3.2 mg/L	Sample size: 125 mL
Seed stock sample: 5 mL	Seed stock BOD: 95 mg/L	Total diluted volume: 300 mL

Insert known values and solve:

Step 1 – Calculate the seed correction in mg/L

$$\text{Seed correction, mg/L} = \frac{\text{BOD of seed stock, mg/L} \times \text{Volume of seed stock, mL}}{\text{Total Volume of BOD bottle, 300 mL}}$$

$$\text{Seed correction} = \frac{95\ \text{mg/L} \times 5\text{ mL}}{300\text{ mL}} = 1.58\ mg/L$$

Step 2 – Calculate the seeded BOD

$$\frac{[(\text{initial DO, mg/L} - \text{final DO, mg/L}) - \text{seed correction factor, mg/L}] \times 300\text{ mL}}{\text{mL of sample}}$$

$$\frac{[(8.6,\text{mg/L} - 3.2,\text{mg/L}) - 1.58,\text{mg/L}] \times 300\text{ mL}}{125\text{ mL}} = 9.2\,\text{mg/L}$$

Biochemical Oxygen Demand (unseeded, mg/L)

The formula for calculating an unseeded BOD sample is:

$$\text{BOD, mg/L} = \frac{(\text{DO}_{\text{initial}} - \text{DO}_{\text{final}}) \times 300\text{ mL}}{\text{Sample volume, mL}}$$

A 25 mL sample of final effluent had an initial DO of 6.2 mg/L and a final DO of 3.9 mg/L. Calculate the BOD of the sample.

Known: $DO_{initial}$ = 6.2 mg/L, DO_{final} = 3.9 mg/L, Sample volume = 25 mL

Insert known values and solve:

$$\text{BOD} = \frac{(\text{DO}_{\text{initial}} - \text{DO}_{\text{final}}) \times 300\text{ mL}}{\text{Sample volume, mL}} = \frac{(6.2\ \text{mg/L} - 3.9\,\text{mg/L}) \times 300\text{ mL}}{25\text{ mL}} = 27.6\,\text{mg/L}$$

Blending

See section on Two and Three Normal Equations.

Colony Forming Units (CFU) / 100 mL

The membrane filtration method of testing for coliform group bacteria is a relatively simple and inexpensive way to quickly analyze a water or wastewater sample. To be useful, a filter must have between 20 and 60 colonies when counted. Filters with colony counts outside this range should not be used.

The formula is:

$$\#\text{CFU/100mL} = \frac{\#\text{ of colonies on plate} \times 100}{\text{mL of sample}}$$

A 9 mL sample produce a plate count of 36 colonies. What CFU/100 mL value is this equal to?

$$\text{CFU/100 mL} = \frac{\#\text{ of colonies on plate} \times 100}{\text{mL of sample}} = \frac{36 \times 100}{9} = 400\text{ CFU/100mL}$$

Chemical Feed Pump Setting, % stroke

Many chemical feed pumps have the ability to vary their output by changing the length of the stroke, the frequency of the stroke or both. Adjustments are made to ensure that the optimum chemical dosage is applied.

The formula is:

$$\text{Feed pump setting, \% stroke} = \frac{\text{Desired output}}{\text{Maximum output}} \times 100\%$$

A diaphragm pump used to meter sodium hypochlorite has a maximum output of 158 gpm (10 L/s). What % stroke should be selected to deliver 36.5 gpm (2.3 L/s)?

US units

$$\text{Feed pump setting, \% stroke} = \frac{36.5\text{ gpm}}{\text{Maximum output 158 gpm}} \times 100\% = 23\%$$

Metric units

$$\text{Feed pump setting, \% stroke} = \frac{2.3\ \text{L/s}}{10\ \text{L/s}} \times 100\% = 23\%$$

Ratio Calculations

This problem can also be solved using a ratio, as follows:

Known: Initial speed setting = 100%, Initial dosage 10 L/s, required dosage = 2.3 L/s

Unknown: New speed setting

Set up the problem using the names of the variables.

$$\frac{\text{Initial speed setting , Percent}}{\text{Initial Chemical dosage, mL}} = \frac{\text{New speed setting, Percent}}{\text{Required dosage, mL}}$$

Rearrange equation, insert known values and solve

$$\frac{100\%}{10\ \text{L/s}} = \frac{\text{New speed setting,}\ \ \text{Percent}}{2.3\ \text{L/s}}$$

$$\text{New speed setting} = \frac{(100\%)(2.3\ \text{L/s})}{10\ \text{L/s}} = 23\%$$

Chemical Feed Pump Setting, mL/min (see Caution Note)

Accurate knowledge of the amounts of a chemical required for process control will prevent process upsets and ensure that the desired effect is obtained.

Caution

While on a nature tour in Barbados our group came upon a parrot sitting in a tree. Our guide said to us "*there are two kinds of parrots in Barbados, this kind and the other kind*". These formulas fall into that category.

The US formula ignores the concentration of the chemical being used and produces a feed rate derived from the specific gravity of the solution being fed.

The metric formula produces a feed rate based on the specific gravity and the % weight of active chemical per unit volume of the solution being fed.

The two formulas measure quite different things and the answers obtained, though accurate for the formula being used, will be quite different.

These formulae are under review by ABC/EOCP. The term "feed chemical density" is ambiguous and not normally used to describe the concentration of a chemical in a solution.

Until such time as the review is complete, use the formulas given on the ABC/EOCP handout to answer a certification question.

Two different formulas are provided for the calculation of chemical feed rates. Due to the length of the formulas, the words Chemical Feed Pump Setting will be abbreviated to **CFPS**.

They are:

$$\text{CFPS, mL/minute} = \frac{\text{flow, MGD} \times \text{dose, mg/L} \times 3.785\ \text{L/gal} \times 1{,}000{,}000\ \text{gal/MG}}{\text{Feed chemical density, mg/mL} \times 1{,}440\ \text{min/day}}$$

$$\text{CFPS, mL/minute} = \frac{\text{flow, m}^3\text{/day} \times \text{dose, mg/L}}{\text{Feed chemical density, g/cm}^3 \times \text{Active chemical \% expressed as a decimal} \times 1{,}440}$$

What chemical pump feed rate is required if a 12.5% sodium hypochlorite (NaOCl) solution is used to disinfect a daily flow of 0.66 million gallons (2,500 cubic metres) if the dosage required is 8.5 mg/L?

Known: A 12.5% solution of NaOCl has a specific gravity (density) of 1.21 kg/L (1,210 mg/mL)

Known 1% = 10,000 mg/L. Therefore, 12.5% = 125,000 mg/L = 125 mg/mL

Known: 12.5% expressed as a decimal = 0.125

US units

$$\text{CFPS, mL/minute} = \frac{\text{flow, MGD} \times \text{dose, mg/L} \times 3.785\ \text{L/gal} \times 1{,}000{,}000\ \text{gal/MG}}{\text{Feed chemical density, mg/mL} \times 1{,}440\ \text{min/day}}$$

Insert known values and solve

$$\text{CFPS, mL/minute} = \frac{0.66\text{MGD} \times 8.5\ \text{mg/L} \times 3.785\ \text{L/gal} \times 1{,}000{,}000\ \text{gal/MG}}{1210\ \text{mg/mL} \times 1{,}440\ \text{min/day}} = 12.18\ \text{mL/min}$$

Metric units

$$\text{CFPS, mL/minute} = \frac{\text{flow, m}^3\text{/day} \times \text{dose, mg/L}}{\text{Feed chemical density, g/cm}^3 \times \text{Active chemical \% expressed as a decimal} \times 1{,}440}$$

Insert known values and solve

$$\text{CFPS, mL/minute} = \frac{2{,}500\ \text{m}^3\text{/day} \times 8.5\ \text{mg/L}}{1.21\ \text{g/cm}^3 \times 0.125 \times 1{,}440} = 97.56\ \text{mL/min}$$

Now let's look at the problem in a different way. We will use the Thanksgiving dinner analogy and solve the problem one bite at a time!

What chemical pump feed rate is required if 12.5% sodium hypochlorite (NaOCl) solution is used to disinfect a daily flow of 0.66 million gallons (2,500 cubic metres) if the dosage required is 8.5 mg/L?

Step 1 – Calculate the kilograms of sodium hypochlorite required per day

$$\text{NaOCL required} = \frac{8.5\ \text{mg}}{\text{L}} \times \frac{2{,}500\ \text{m}^3}{\text{day}} \times \frac{1\ \text{kg}}{10^6 \text{mg}} \times \frac{10^3 \text{L}}{\text{m}^3} = 21.25\ \text{kg/day}$$

But the solution only contains 12.5% NaOCl

Step 2 – Calculate how many litres of solution are required

$$\text{NaOCL required} = \frac{21.25\ \text{kg}}{\text{day}} \times \frac{100\ \text{kg solution}}{12.5\ \text{kg NaOCL}} \times \frac{1\ \text{L}}{1.21\ \text{kg}} = 140.49\ \ \text{L/day}$$

But the question asked for the feed rate in **millilitres per minute**.

We could use the litres per day formula and simply divide the answer by 1,440 as shown below

$$\text{CFPS} = \frac{140.49\ \ \text{L/day}}{1{,}440\ \text{min/day}} = \frac{0.09756\ \text{L}}{\text{min}} \times \frac{1{,}000\ \text{mL}}{\text{L}} = 97.56\ \text{mL/min}$$

Composite Sample Single Portion

When sampling, it is important that the size of sample taken is representative of the whole. Grab samples are taken to get an instantaneous snapshot of the process while composite samples are taken to get a picture of the process over a longer time period.

The equation for selecting a single sample size is:

$$\text{Composite sample single portion} = \frac{\text{instantaneous flow} \times \text{total sample volume}}{\text{number of samples} \times \text{average flow}}$$

A treatment plant uses a composite sample to sample for TSS in the influent. The sampler is set to take 24 samples over the course of 24 hours for a total sample volume of 10 litres. The daily flow through the plant is 12,500 cubic metres. Calculate the sample volume that would be taken at a time when the instantaneous flow was 870 m^3/hour.

Insert known values and solve:

$$\text{Composite sample single portion} = \frac{870\ \ \text{m}^3/\text{hr} \times 10\ \text{L}}{24 \times 520.8\ \ \text{m}^3/\text{hr}} = 0.69\ \text{L}$$

CT Calculation

The CT value is simply the product of the chlorine residual concentration in milligrams per litre (mg/L) multiplied by the time in minutes that it takes the chlorinated water to reach the first customer in the water distribution system. The value must be calculated using the peak hour flow in a system as that is when the time will be shortest.

The equation is:

$$\text{CT Value} = \text{disinfectant residual concentration, mg/L} \times \text{Time in minutes}$$

In its simplest form a CT value calculation would look like this:

Calculate the CT value if the chlorine residual is 0.2 mg/L and the contact time is 27 minutes.

CT = 0.2 mg/L ×27 minutes = 5.4 mg/L/min

Where a system contains no storage travel time in the pipeline is calculated by dividing the pipe volume (between the point of application and the first customer) by the flow in litres per second. Where a system contains a storage reservoir between the point of application and the first customer, calculation of time (T) must take into account the time spent in the reservoir.

Water with a chlorine residual of 1.7 mg/L is flowing at a velocity of 2.4 m/sec in a 200 mm diameter supply main. What is the CT value at the first customer's house if it is located 2 km downstream of the point at which the chlorine residual was measured?

Step 1 – Calculate the travel time in minutes

$$\text{Time} = 2{,}000\text{m} \times \frac{1 \text{ second}}{2.4 \text{ m}} \times \frac{1 \text{ minute}}{60 \text{ seconds}} = 13.88 \text{ minutes}$$

Step 2 – Insert known values and solve

$$\text{CT Value} = \text{chlorine residual}\,, \text{mg/L} \times \text{Time, min} = 1.7 \text{ mg/L} \times 13.88 \text{ min} = 23.6 \text{ mg} \cdot \text{min/L}$$

Cycle Time, minutes

Establishment of appropriate pumping cycle times is important to protect the life of electrical motors and to prevent the development of septic conditions in wet wells, clarifiers and sumps.

The equations are:

$$\text{Cycle time, minutes} = \frac{\text{Wet well storage volume, } \mathit{gallons}}{\text{Pump capacity, gpm} - \text{wet inflow, gpm}}$$

$$\text{Cycle time, minutes} = \frac{\text{Wet well storage volume, m}^3}{\text{Pump capacity, m}^3\text{/minute} - \text{Wet well inflow, m}^3\text{/minute}}$$

Calculate the cycle time for a wet well that is 9.8 feet (3 metres) in diameter and 15 feet deep (4.6 metres) deep if the inflow to the wet well is 145 gallons per minute (0.55 m^3/minute) and the lift pump has a capacity of 475 gallons per minute (30 L/s).

US units

Step 1 –Calculate the volume of the wet well

$$\text{Volume} = 0.785\text{D}^2 \times \text{h} = 0.785 \times (9.8 \text{ feet})^2 \times 15 \text{ feet} \times \frac{7.48 \text{ gal}}{\text{ft}^3} = 8{,}459 \text{ gallons}$$

Step 2 – Insert known values and solve

$$\text{Cycle time} = \frac{8{,}459 \text{ gallons}}{475 \text{ gpm} - 145 \text{ gpm}} = \frac{8{,}459 \text{ gallons}}{330 \text{ gpm}} = 25.6 \text{ minutes}$$

Metric units

Step 1 –Calculate the volume of the wet well

$$\text{Volume} = 0.785\text{D}^2 \times \text{h} = 0.785 \times (3\text{m})^2 \times 4.6\text{m} = 32.5\text{m}^3$$

Step 2 – Convert pump capacity to m^3/minute

$$\text{Pump output} = \frac{30 \text{ L}}{\text{s}} \times \frac{60 \text{ s}}{\text{min}} \times \frac{1 \text{ m}^3}{1{,}000 \text{ L}} = 1.8 \text{ m}^3/\text{minute}$$

Step 3 – Insert known values and solve

$$\text{Cycle time} = \frac{32.5 \text{ m}^3}{1.8 \text{ m}^3/\text{minute} - 0.55 \text{ m}^3/\text{minute}} = \frac{32.5 \text{ m}^3}{1.25 \text{ m}^3/\text{minute}} = 26 \text{ minutes}$$

Degrees Celsius

In the metric system, temperature is measured in degrees Celsius. On this scale, water freezes at 0° and boils at 100°

The equation to convert from Centigrade to Fahrenheit is:

$$\text{Degrees Celsius} = \frac{°\text{F} - 32}{1.8}$$

Convert 70°F to Celsius

$$\text{Degrees Celsius} = \frac{°\text{F} - 32}{1.8} = \frac{70 - 32}{1.8} = 21.1°\text{C}$$

Degrees Fahrenheit

In the United States temperature is measure in degrees Fahrenheit. On this scale, water freezes at 32° and boils at 212°

The equation to convert from Fahrenheit to Centigrade is:

$$\text{Degrees Fahrenehit} = (°\text{C} \times 1.8) + 32$$

Convert 22° Celsius to Fahrenheit

$$\text{Degrees Fahrenehit} = (°\text{C} \times 1.8) + 32 = (22 \times 1.8) + 32 = 71.6°\text{F}$$

Detention time (or Hydraulic Retention Time)

Detention time measures the length of time a particle of water remains in a tank, basin, pond or pipe. i.e. the time elapsed from the moment a particle enters the tank to the moment when it leaves the tank. It is often measured for lagoons, aeration basins, clarifiers, wet wells, UV or chlorine contact chambers, force mains and outfalls.

The equation for detention time is:

$$\text{Detention time} = \frac{\text{Volume}}{\text{Flow}}$$

When using this equation the units for volume and flow must be the same. This may require the operator to convert flow from litres per second to cubic metres per day or hour.

What is the detention time in days for an aerated lagoon that is 394 feet (120 metres) long, 164 feet (50 metres) wide and 4.8 feet (1.45 metres) deep if it receives a flow of 58,916 gallons (223 cubic metres) per day?

US units

Step 1 – Convert flow to cubic feet per day

$$58{,}916 \text{ gpd} \times \frac{1 \text{ ft}^3}{7.48 \text{ gal}} = 7{,}876.4\text{ft}^3$$

Step 2 – Insert known values and solve

$$\text{Detention time} = \frac{\text{Volume}}{\text{Flow}} = \frac{394 \text{ ft} \times 164 \text{ ft} \times 4.8 \text{ ft}}{7{,}876.4 \text{ ft}^3/\text{day}} = \frac{310{,}156.8 \text{ ft}^3}{7{,}875.5 \ \text{ft}^3/\text{day}} = 39 \text{ days}$$

Metric units

Step 1 – Calculate the volume of the lagoon

$$\text{Volume} = \text{L} \times \text{W} \times \text{D} = 120 \text{ m} \times 50 \text{ m} \times 1.45 \text{ m} = 8{,}700 \text{ m}^3$$

Insert known values and solve

$$\text{Detention time} = \frac{\text{Volume}}{\text{Flow}} = \frac{8{,}700 \text{ m}^3}{223 \ \text{m}^3/\text{day}} = 39 \text{ days}$$

Feed Rate

The ability to calculate the feed rate is an important tool to avoid over or under dosing a unit process.

The equations are:

$$\text{Feed rate, lb/day} = \frac{\text{Dose, mg/L} \times \text{Flow, MGD} \times 8.34 \text{ lb/gal}}{\text{Purity, \% expressed as a decimal}}$$

$$\text{Feed rate, kg/day} = \frac{\text{Dose, mg/L} \times \text{Flow, m}^3/\text{day}}{\text{Purity, \% expressed as a decimal} \times 1{,}000}$$

What is the feed rate if a 12% solution of alum is fed at a dose of 4 mg/L into a flow of 1.32 MGD (5,000 m^3) per day?

US units

$$\text{Feed rate, lb/day} = \frac{\text{Dose, mg/L} \times \text{Flow, MGD} \times 8.34 \text{ lb/gal}}{\text{Purity, \% expressed as a decimal}}$$

$$\text{Feed rate, lb/day} = \frac{4 \ \text{mg/L} \times 1.32 \text{ MGD} \times 8.34 \text{ lb/gal}}{0.12} = 366.96 \ \text{lb/day}$$

Metric units

$$\text{Feed rate, kg/day} = \frac{\text{Dose, mg/L} \times \text{Flow, m}^3/\text{day}}{\text{Purity, \% expressed as a decimal} \times 1{,}000}$$

$$\text{Feed rate, kg/day} = \frac{4 \ \text{mg/L} \times 5{,}000 \ \text{m}^3/\text{day}}{0.12 \times 1{,}000} = 166.6 \text{ kg/day}$$

Feed Rate (Fluoride)

Fluoridation of a drinking water supply, while more common in the 1970s and 80s is still practiced in many communities. Three fluoride containing chemicals are used: sodium fluoride (NaF), sodium fluorosilicate (Na_2SiF_6) and fluorosilicic acid (H_2SiF_6). Sodium fluoride is the chemical of choice when a fluoride saturator is used.

Chemical	Formula	Available Fluoride Ion	Chemical Purity
sodium fluoride	NaF	0.452 or 45.2%	98%
sodium fluorosilicate	Na_2SiF_6	0.607 or 60.7%	98%
fluorosilicic acid	H_2SiF_6	0.792 or 79.2%	23%

The equations are:

$$\text{Feed rate, lb/d} = \frac{\text{Dosage, mg/L} \times \text{Capacity, MGD} \times 8.34\ \text{lb/gal}}{\text{Available Fluoride ion, \% as a decimal} \times \text{Purity, \% as a decimal}}$$

$$\text{Feed rate, kg/d} = \frac{\text{Dose, mg/L} \times \text{Capacity, m}^3\text{/d}}{\text{Available Fluoride ion, \% as a decimal} \times \text{Purity, \% as a decimal} \times 1{,}000}$$

Or

$$\text{Feed rate, kg/d} = \frac{\text{Dose, mg/L} \times \text{Capacity, ML/d}}{\text{Available Fluoride ion, \% as a decimal} \times \text{Purity, \% as a decimal}}$$

A water treatment plant produces 2.8 MGD (10,600 m^3/day) and the desired dosage is 1.1 mg/L what would the fluoride feed rate be if the chemical used is sodium fluorosilicate?

US units

Insert known values and solve:

$$\text{Feed rate, lb/d} = \frac{1.1\ \text{mg/L} \times 2.8\ \text{MGD} \times 8.34\ \text{lb/gal}}{0.607 \times 0.98} = 43.2\ \text{lb/day}$$

Metric units

Insert known values and solve:

$$\text{Feed rate, kg/d} = \frac{1.1\ \text{mg/L} \times 10{,}600\ \text{m}^3\text{/d}}{0.607 \times 0.98 \times 1{,}000} = 19.6\ \text{kg/day}$$

Feed Rate (Fluoride Saturator)

The use of a fluoride saturator and sodium fluoride provides the operator with a solution that always contains 18,000 mg/L of fluoride ion. This is because sodium fluoride has a solubility of 4.0 grams per 100 mL of water at the range of temperatures normally encountered in water treatment plant operations. The equation shown below illustrates how this occurs.

$$\frac{4\ \text{g}}{100\ \text{mL}} \times \frac{1{,}000\ \text{mg}}{\text{g}} \times \frac{1{,}000\ \text{mL}}{\text{L}} \times 0.45 = 18{,}000\ \text{mg/L}$$

The equations are:

$$\text{Feed rate (fluoride saturator), gpm} = \frac{\text{Plant capacity, gpm} \times \text{Dosage, mg/L}}{18{,}000\ \text{mg/L}}$$

$$\text{Feed rate (fluoride saturator), L/min} = \frac{\text{Plant capacty, L/min} \times \text{Dosage, mg/L}}{18{,}000\ \text{mg/L}}$$

A water treatment plant is using a fluoride saturator to provide feed stock for fluoridation. The plant produces 1.5 MGD (5,678 m^3/day) and wants to fluoridate at 1 mg/L. What is the fluoride feed rate?

US units

Step 1 – Calculate the plant capacity in gallons per minute

$$\text{Plant capacity} = \frac{1{,}000{,}000\ \text{gal}}{\text{day}} \times \frac{1\ \text{day}}{24\ \text{hours}} \times \frac{1\ \text{hour}}{60\ \text{minutes}} = 694\ \text{gal/min}$$

Step 2 – Insert known values and solve

$$\text{Feed rate (fluoride saturator), gpm} = \frac{694\ \ \text{gal/min} \times 1\ \ \text{mg/L}}{18{,}000\ \text{mg/L}} = 0.04\ \text{gal/min}$$

Metric units

Step 1 – Calculate the plant capacity in litres per minute

$$\text{Plant capacity} = \frac{5{,}678\ m^3}{\text{day}} \times \frac{1{,}000\ \text{L}}{\text{m}^3} \times \frac{1\ \text{day}}{1{,}440\ \text{minutes}} = 3{,}943\ \text{L/min}$$

Step 2 – Insert known values and solve

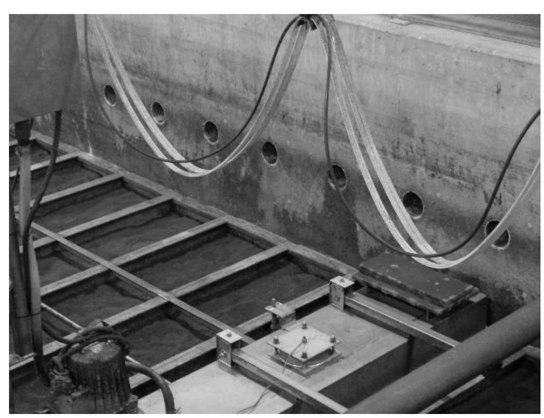
$$\text{Feed rate (fluoride saturator), gpm} = \frac{3{,}943\ \ \text{L/min} \times 1\ \ \text{mg/L}}{18{,}000\ \text{mg/L}} = 0.22\ \text{L/min}$$

Filtration

Both water and wastewater treatment plants use filtration to produce high quality water. Regardless of whether the filter uses sand or a synthetic media, backwashing is required. Filters are backwashed to release the impurities trapped in the filter media. Backwashing may be initiated on a timed cycle or on differential head.

Filter Backwash Rate

The equations for filter loading and filter backwash are the same. The only difference is the direction water is travelling through the filter



The equations typically used are:

$$\text{Filter backwash rate} = \frac{\text{Flow, gpm}}{\text{Filter area,}\ \ \text{ft}^2}$$

$$\text{Filter backwash rate}\quad \frac{\text{Flow, L/sec}}{\text{Filter area,}\ \ \text{m}^2}$$

A filter having a surface area of 10 feet (3 metres) by 16 feet (5 metres) is backwashed at a rate of 317 gallons per minute (20 L/s) for 1 minute. What is the filter backwash rate?

US units

Insert known values and solve

$$\text{Filter backwash rate, gpm/ft}^2 = \frac{\text{Flow, gpm}}{\text{Filter area, ft}^2} = \frac{317\text{ gpm}}{10\text{ ft} \times 16\text{ ft}} = 1.98\,\text{gpm/ft}^2$$

Metric units

Insert known values and solve

$$\text{Filter backwash rate, L/m}^2\text{/s} = \frac{\text{Flow, L/s}}{\text{Filter area, m}^2} = \frac{20\ L/s}{3m \times 5m} = 1.3\,\text{L/m}^2\text{/s}$$

Filter Backwash Rise Rate

Periodically the flow is reversed in a filter in order to flush trapped particles out of the filter. To do this a sufficient volume of water (typically 3 times the loading rate) needs to be rapidly introduced into the filter in order to lift and separate the media. The rise rate is a measure of how rapidly the water level rises in the filter during the backwash process.

The equations are:

$$\text{Filter backwash rise rate, in/min} = \frac{\text{backwash rate, gpm/ft}^2 \times 12\,\text{in/ft}}{7.48\ \text{gal/ft}^3}$$

$$\text{Filter backwash rise rate, cm/min} = \frac{\text{water rise, cm}}{\text{time, min}}$$

A filter that is 12 feet (3.7 metres) long by 20 feet (6.1 metres) wide is backwashed at a rate of 3,250 gallons per minute (205 L/s) for 1 minute. What is the filter backwash rise rate?

The solution to this problem includes a number of intermediate steps

US units

Step 1 – Calculate the surface area of the filter.

$$\text{Surface area} = 12\text{ ft} \times 20\text{ ft} = 240\text{ ft}^2$$

Step 2 – Calculate the backwash rate in gpm/ft^2

$$\text{Filter backwash rate, gpm/ft}^2 = \frac{\text{Flow, gpm}}{\text{Filter area, ft}^2} = \frac{3250\text{ gpm}}{240\text{ ft}^2} = 13.5\,\text{gpm/ft}^2$$

Insert calculated values and solve:

$$\text{Filter backwash rise rate, in/min} = \frac{13.5\ \text{gpm/ft}^2 \times 12\,\text{in/ft}}{7.48\ \text{gal/ft}^3} = 21.65\ in/min$$

Metric units

Step 1 – Calculate the surface area of the filter.

$$\text{Surface area} = 6.1\text{m} \times 3.7\text{m} = 22.6\ \text{m}^2$$

Step 2 – Calculate the backwash rate in cubic metres

$$\text{Backwash rate} = \frac{205\ \text{L}}{\text{s}} \times \frac{1\ \text{m}^3}{1{,}000\ \text{L}} \times \frac{60\ \text{s}}{\text{minute}} = 12.3\ \ \text{m}^3/\text{minute}$$

Step 3 – Calculate the depth (rise) of the backwash water

$$\text{Depth} = \frac{\text{Volume}}{\text{Area}} = \frac{12.3\text{m}^3}{22.6\ \text{m}^2} = 0.54\text{m} = 54\ \text{cm}$$

Step 4 - Insert calculated values and solve:

$$\text{Filter backwash rise rate, cm/minute} = \frac{\text{Water rise, cm}}{\text{Time, minutes}} = \frac{54\ \text{cm}}{1\ \text{minute}} = 54\ \text{cm/minute}$$

Filter Drop Test Velocity

The equations are:

$$\text{Filter drop test velocity, ft/min} = \frac{\text{water drop, feet}}{\text{time, minutes}}$$

$$\text{Filter drop test velocity, m/min} = \frac{\text{water drop, meters}}{\text{time, minutes}}$$

The influent to a filter that is 12 feet (3.7 metres) wide by 20 feet (6.1 metres) long is turned off. Over the space of 5 minutes the water level in the filter drops 2.5 feet (0.76 metres). Calculate the filter drop velocity.

US units

$$\text{Filter drop test velocity, ft/min} = \frac{\text{water drop, feet}}{\text{time, minutes}} = \frac{2.5\ \text{ft}}{5\ \text{min}} = 0.5\ \text{ft/min}$$

Metric units

$$\text{Filter drop test velocity, m/min} = \frac{\text{water drop, meters}}{\text{time, minutes}} = \frac{0.76\ \text{m}}{5\ \text{min}} = 0.15\ \text{m/min}$$

Filter Loading Rate

As noted in the section on filter backwashing, the equations are the same for loading and backwashing, only the direction of flow is different.

The equations are:

$$\text{Filter loading rate, gal/min/ft}^2 = \frac{\text{Flow, gallons/minute}}{\text{Filter area, ft}^2}$$

$$\text{Filter loading rate, L/sec/m}^2 = \frac{\text{Flow, litres/second}}{\text{Filter area, m}^2}$$

A filter having a surface area of 10 feet (3 metres) by 16 feet (5 metres) loaded at a rate of 317 gallons per minute (20 L/s) for 1 minute. What is the filter loading rate?

US units

Insert known values and solve

$$\text{Filter loading rate, gpm/ft}^2 = \frac{\text{Flow, gpm}}{\text{Filter area, ft}^2} = \frac{317\text{ gpm}}{10\text{ ft} \times 16\text{ ft}} = 1.98\,\text{gpm/ft}^2$$

Metric units

Insert known values and solve

$$\text{Filter loading rate, L/m}^2\text{/s} = \frac{\text{Flow, L/s}}{\text{Filter area, m}^2} = \frac{20\ L/s}{3m \times 5m} = 1.3\,\text{L/m}^2\text{/s}$$

Filter Yield (see Caution Note)

The filter yield equations are used in the operation of vacuum filter units. In wastewater treatment, vacuum filters have been replaced by either belt filter presses, rotary presses or centrifuges.

Caution

The metric equation given in the ABC handout is incorrect. The correct metric equation is shown below:

$$\text{Filter yield, kg/m}^2\text{/hour} = \frac{\text{Solids concentration, \% × sludge feed rate, L/hr}}{\text{Surface area of filter, m}^2}$$

Until such time as ABC rectifies this error, if a filter yield equation is encountered on a certification exam use the filter yield equations given in the handout as the answers provide for the question choices will be based on the incorrect formula.

The equations are:

$$\text{Filter yield, lb/ft}^2\text{/hr} = \frac{\text{Solids loading , lb/hr × \% recovery (as a decimal)}}{\text{Filter operation, hr/day × Filter area, ft}^2}$$

$$\text{Filter yield, kg/m}^2\text{/hour} = \frac{\text{Solids concentration, \% × sludge feed rate, L/hr × 10}}{\text{Surface area of filter, m}^2}$$

A rotary drum vacuum filter fed at a rate of 71 gallons per minute (4.5 L/s) produces a cake with 25% solids content. The drum has a surface area of 301 square feet (28 square metres). What is the filter yield?

US units

Step 1 – convert gallons per hour to pounds per hour

$$\text{Solids loading rate} = \frac{71\text{ gallons}}{\text{min}} \times \frac{60\text{ min}}{\text{hr}} \times \frac{8.34\text{ pounds}}{\text{gallon}} = 35{,}528\ \text{lb/hr}$$

Step 2 – Insert known values and solve

$$\text{Filter yield, lb/ft}^2\text{/hr} = \frac{35{,}528\text{, lb/hr} \times 0.25}{1 \times 301\text{ ft}^2} = 29.5$$

Metric units

Step 1 – Convert L/s to L/hour

$$\text{Sludge feed rate} = \frac{4.5\text{ L}}{\text{s}} \times \frac{3{,}600\text{ s}}{\text{hour}} = 16{,}200\ \text{L/hour}$$

Step 2 – Convert 25% to a decimal value, insert known values and solve:

$$\text{Filter yield, kg/m}^2\text{/hour} = \frac{\text{Solids concentration, \%} \times \text{sludge feed rate, L/hr} \times 10}{\text{Surface area of filter, m}^2}$$

$$\text{Filter yield, kg/m}^2\text{/hour} = \frac{.25 \times 16{,}200\ \text{L/hr} \times 10}{28\text{ m}^2} = 1{,}446\ \text{kg/m}^2\text{/hour}$$

Flow Rate

Operators need to know how to calculate flow in order to enhance settling in grit chambers or prevent settling in gravity sewers and force mains and to calculate appropriate chemical dosage. Excessive velocities in pipe lines can accelerate wear.

Flow is measured as a volume (e.g. US gallon, cubic foot, litre, cubic metre, and megalitre) per unit of time (e.g. second, minute, hour, day).

The basic equations are:

$$\text{Flow rate} = \frac{\text{Area, ft}^2}{\text{Velocity, ft/sec}} \quad \text{or} \quad \frac{\text{Area, m}^2}{\text{Velocity m/sec}}$$

A number of formulas are used:

$$\text{Flow (Q) in an open channel} = \text{Area, (width} \times \text{depth)} \times \text{Velocity}$$

$$\text{Flow (Q) in a pipe} = \text{Area, }(0.785\text{D}^2) \times \text{Velocity}$$

Both formulas can be rearranged to solve for velocity or area if the other two values are known

$$\text{If Flow} = \text{Area} \times \text{Velocity then Velocity} = \frac{\text{Flow}}{\text{Area}} \text{ and Area} = \frac{\text{Flow}}{\text{Velocity}}$$

Note: this formula applies only to incompressible fluids like water and wastewater. A different formula would be used to calculate the velocity of say, an air stream.

What is the flow in cubic feet per minute (liters per second) in a pipe with a diameter of 8 inches (20 centimetres) if the water is flowing at a velocity of 1.6 feet per second (0.5 metres per second)? Assume that the pipe is flowing full.

US units

Step 1 – Calculate the area of the pipe in square feet.

$$\text{Area} = 0.785(\text{D})^2 = 0.785 \times (0.66\text{ ft})^2 = 0.342\text{ ft}^2$$

Step 2 – Insert known values and solve

$$\text{Flow} = \text{Area} \times \text{Velocity} = 0.342\text{ ft}^2 \times 1.6\text{ ft/s} = 0.55\ \text{ft}^3\text{/s}$$

Metric units

Step 1 – Calculate the area of the pipe in square metres.

$$\text{Area} = 0.785(\text{D})^2 = 0.785 \times (0.2\text{ m})^2 = 0.0314\text{ m}^2$$

Step 2 – Insert known values and solve

$$\text{Flow } = \text{Area} \times \text{Velocity} = 0.0314\text{ m}^2 \times 0.5\text{ m/s} = 0.016\ \text{ m}^3/\text{s}$$

Step 3 – Convert flow to L/s

$$\frac{0.016\text{ m}^3}{\text{s}} \times \frac{1{,}000\text{ L}}{\text{m}^3} = 16\ \text{ L/s}$$

Food / Microorganism Ratio

The food to microorganism (F:M) ratio is one of the most important calculations for the control of the activated sludge process. The operator, for all practical purposes, has no control over the volume of flow entering the plant or the concentration of BOD_5 contained in the flow. If the operator is to balance the food (BOD_5) available to the microorganisms present to consume it the balance will be achieved by wasting or not wasting microorganisms from the process. In the F:M equation microorganisms are measured as mixed liquor volatile suspended solids (MLVSS). The F:M ratio is usually reported as a dimensionless number.

The equations are:

$$\text{Food to Microorganism ratio (F: M)} = \frac{\text{BOD}_5\text{ added, lb/day}}{\text{MLVSS under aeration, lb}}$$

$$\text{Food to Microorganism ratio (F: M)} = \frac{\text{BOD}_5\text{ added, kg}}{\text{MLVSS under aeration, kg}}$$

Or

$$\text{F: M} = \frac{\text{BOD}_5\text{ added, kg}}{\text{MLVSS concentration} \times (\text{Volume of aeration basin} + \text{clarifier})}$$

Where:

$$\text{BOD}_5\text{ added} = \text{BOD}_5\text{, mgL} \times \text{Flow}$$

$$\text{MLVSS} = \text{Mixed liquor volatile solids, mg/L} \times \text{Volume of (aeration tank} + \text{clarifier)}$$

Note: In most problems, the only volume or dimensions given will be for those of the aeration basin(s).

Given the following data, calculate the F:M ratio:

Flow: 2.7 MGD (10,220 m^3/day)

Aeration tank volume: 65,000 ft^3 (1,840 m^3)

Primary effluent BOD_5 = 220 mg/L

MLVSS = 2,450 mg/L

In US units

Step 1 – Calculate the pounds of BOD_5 added each day

$$\text{BOD}_5\text{ added} = \frac{220\text{ mg}}{\text{L}} \times \frac{2.7\text{ MG}}{\text{day}} \times \frac{8.34\text{ lb}}{\text{gal}} = 4953.9\ \text{ lb/day}$$

Step 2 – Calculate kg of MLVSS under aeration

$$\text{MLVSS under aeration} = \frac{2{,}450\text{mg}}{\text{L}} \times \frac{0.486\text{ MG}}{\text{day}} \times \frac{8.34\text{ lb}}{\text{gal}} = 9{,}930\text{ lb}$$

Step 3 – Insert calculated values and solve:

$$\text{F:M} = \frac{\text{BOD}_5\text{ added, lb}}{\text{MLVSS under aeration, lb}} = \frac{4{,}953.9\ lb}{9930\ lb} = 0.49$$

In metric units

Step 1 – Calculate the kg of BOD_5 added each day

$$\text{BOD}_5\text{ added} = \frac{220\text{ mg}}{\text{L}} \times \frac{10{,}220\text{ m}^3}{\text{day}} \times \frac{1\text{ kg}}{10^6\text{mg}} \times \frac{10^3\text{L}}{\text{m}^3} = 2{,}248.4\ \text{kg/day}$$

Or

$$\text{BOD}_5\text{ added} = 220\ \text{mg/L} \times 10.22\text{ ML} = 2{,}248.4\ \text{kg/day}$$

Step 2 – Calculate kg of MLVSS under aeration

$$\text{MLVSS under aeration} = \frac{2{,}450\text{mg}}{\text{L}} \times \frac{1{,}840\text{ m}^3}{\text{day}} \times \frac{1\text{ kg}}{10^6\text{mg}} \times \frac{10^3\text{L}}{\text{m}^3} = 4{,}508\text{ kg}$$

Or

$$\text{MLVSS under aeration} = 2{,}450\ \text{mg/L} \times 1.84\text{ ML} = 4{,}508\text{ kg}$$

Step 3 – Insert calculated values and solve:

$$\text{F:M} = \frac{\text{BOD}_5\text{ added, kg}}{\text{MLVSS under aeration, kg}} = \frac{2{,}248.4\ kg}{4508\ kg} = 0.49$$

Sludge Wasting Rate

The activated sludge process will produce between 0.4 to 0.8 kg of solids for each kg of BOD removed. In order to maintain the proper F:M ratio in the process some sludge needs to be removed or wasted from the process. Sludge wasting is normally calculated on the basis of maintaining a desired MLSS concentration in the aeration basin or on maintaining a desired MCRT. The formulas are presented below:

Wasting to maintain a **desired MLSS concentration**

$$\text{Waste sludge, m}^3 = \frac{(\text{Actual MLSS} - \text{Desired MLSS, mg/L}) \times \text{Aeration tank volume, m}^3}{\text{Return activated sludge concentration, mg/L}}$$

Wasting to maintain **a desired MCRT**

$$\text{Waste sludge, kg/day} = \frac{\text{kg MLSS in aeration basin + clarifer}}{\text{MCRT, days}} - \text{Effluent TSS, kg}$$

A wastewater treatment plant has been found to operate best with a MLSS concentration of 2,400 mg/L. Over time the MLSS concentration has increased to 2,580 mg/L. If the plant has an aeration basin volume of 2,000 cubic metres and a RAS concentration of 3,220 mg/L how much RAS should be wasted to bring the plant back into peak performance?

Known: Actual MLSS = 2,580 mg/L, Desired MLSS = 2,400 mg/L, RAS = 3,220 mg/L
Aeration basin volume = 2,000 m^3

Insert known values and solve

$$\text{Waste sludge, m}^3 = \frac{(\text{Actual MLSS} - \text{Desired MLSS, mg/L}) \times \text{Aeration tank volume, m}^3}{\text{Return activated sludge concentration, mg/L}}$$

$$\text{Waste sludge, m}^3 = \frac{(2{,}580\ \text{mg/L} - 2{,}400\ \text{mg/L}) \times 2{,}000\ \text{m}^3}{3{,}220\ \text{mg/L}} = 111.8\ \text{m}^3$$

A treatment plant has been operating with a 7 day MCRT but now the operator wants to reduce the MCRT to 5 days. The MLSS concentration is 2,650 mg/L and effluent suspended solids are 8 mg/L. The combined volume of the aeration basin and clarifier is 3,582 m^3 and the flow through the plant is 12,500 m^3/day. How many kilograms of solids need to be wasted from the process to achieve a 5 day MCRT?

Known:

Desired MCRT = 5 days	MLSS = 2,650 mg/L	Effluent TSS = 8 mg/L
Flow = 12,500 m^3/day	Aeration tank volume + Clarifier volume = 3,582 m^3	

Step 1 – Calculate the kg of MLSS in inventory

$$\text{MLSS} = 2{,}650\ \text{mg/L} \times 3.582\ \text{ML} = 9{,}492\ \text{kg}$$

Step 2 – Calculate the kg of effluent TSS

$$\text{Effluent TSS} = 8\ \text{mg/L} \times 12.5\ \text{ML} = 100\ \text{kg}$$

Step 3 – Insert known and calculated values and solve

$$\text{Waste sludge, kg/day} = \frac{\text{kg MLSS in aeration basin + clarifer}}{\text{MCRT, days}} - \text{Effluent TSS, kg}$$

$$\text{Waste sludge} = \frac{9{,}492\ \text{kg}}{5\ \text{days}} - 100\ \text{kg} = 1{,}798\ \text{kg}/day$$

Force and Pressure

Pressure is a measure of a force applied against a surface and is usually expressed as force per unit area. In the metric system pressure is measured and expressed in Pascals (Pa) or kilopascals (kPa).

Force is measured in Newtons (N) or kiloNewtons (kN). In the US system, force is measured in pounds and pressure is measured in pounds per square inch.

One Pascal is equal to a force of one Newton per square metre. A Newton is equal to the force required to accelerate one kilogram at a rate of one metre per second per second (1kg·m/s^2). A Canadian $5 bill resting on the palm of your hand exerts a pressure of approximately 1 Pascal.

A column of water 1 metre high exerts a pressure of 9.804139432 kPa. This manual will use a rounded value of 9.8 kPa. In the US system, a column of water 2.31 feet high exerts a pressure of 1 pound per square inch.

Atmospheric pressure at sea level is 101.325 kPa or 14.7 pounds per square inch

The equations for the calculation of force are:

$$\text{Force, lb} = \text{pressure, psi} \times \text{area, in}^2$$

$$\text{Force, newtons, N} = \text{Pressure, Pa} \times \text{Area, m}^2$$

A 10 inch (250 mm) diameter pipeline is pressurized to 108 psi (750 kPa). What is the force exerted on the end cap on the pipe?

US units

Step 1 – calculate the area of the end cap

$$\text{Area} = 0.785 \times (10\ \text{in})^2 = 78.5\text{in}^2$$

Step 2 – Insert known values and solve

$$\text{Force, lb} = \text{Pressure, psi} \times \text{area, in}^2 = 108\ \text{psi} \times 78.5\ \text{in}^2 = 8{,}478\ \text{lb}$$

In metric units

Step 1 – Calculate the surface area of the end cap

$$\text{Area} = \pi\text{r}^2 = 0.785 \times (0.25\text{m})^2 = 0.049\text{m}^2$$

Insert known values and solve

$$\text{Force, N} = \text{Pressure, Pa} \times \text{Area, m}^2$$

$$\text{Force} = \text{Pressure} \times \text{Area} = 750\text{kPa} \times \frac{1{,}000\ \text{Pa}}{\text{kPa}} \times 0.049\text{m}^2 = 36{,}796\ \text{Newtons}$$

> For those not uses to the concept of Newtons as a force, it might be helpful to know that
> 9.8 Newtons = 1 kilogram force and that 1 kPa = 1 kN/m^2
>
> In the problem above we can convert force in Newtons to a force in kilograms by:
>
> $$36{,}796\ \text{N} \times \frac{1\text{kg}}{9.8\text{N}} = 3{,}754.7\ \text{kg}$$

Head is often expressed in units of height such as meters or feet. On Earth, additional height of fresh water adds a static pressure of about 9.8 kPa per meter (0.098 bar/m) or 0.433 psi per foot of water column height.

$$\text{Head, ft} = \text{Pressure, psi} \times \frac{2.31\ \text{ft}}{\text{psi}}$$

$$\text{Head, m} = \text{Pressure, kPa} \times \frac{1\text{m}}{9.8\ \text{kPa}}$$

What is the depth of water in a storage tank if the pressure at the bottom of the tank is 7.8 psi (54 kPa)?

Insert known values and solve:

US units

$$\text{Head, ft} = \text{Pressure, psi} \times \frac{2.31\text{ ft}}{\text{psi}} = 7.8\text{psi} \times \frac{2.31\text{ ft}}{\text{psi}} = 18\text{ feet}$$

Metric units

$$\text{Head} = \text{Pressure, kPa} \times \frac{1\text{m}}{9.8\text{ kPa}} = 54\text{ kPa} \times \frac{1\text{m}}{9.8\text{ kPa}} = 5.5\text{ m}$$

What pressure will a pump generate if it can lift water to a height of 138 feet (42 meters)? (Assume no friction losses in the piping system)

Rearrange the equation, insert known values and solve:

US units

$$\text{Pressure} = \text{Head, ft} \times \frac{\text{psi}}{2.31\text{ ft}} = 138\text{ ft} \times \frac{1\text{ psi}}{2.31\text{ ft}} = 59.7\text{ psi}$$

Metric units

$$\text{Pressure} = \text{Head, m} \times \frac{9.8\text{ kPa}}{\text{m}} = 42\text{ m} \times \frac{9.8\text{ kPa}}{\text{m}} = 411.6\text{ kPa}$$

Horsepower (Pumping Calculations)

Calculations of pump curves, required power and system heads is usually left to the design engineer. However, it is useful for the operator to be able to calculate efficiencies and capacities of pumps within their system in the event that a change to the system is contemplated.

In the U.S. system the terms water horsepower, motor horsepower and brake horsepower are used. In the metric system the term horsepower is replaced with the term power. (1 Horsepower = 746 watts = 0.746 kW)

Horsepower, Brake

This term is used when calculating the power required to lift a specified volume of fluid (flow) a specified distance (head). If the fluid being pumped is anything other than water, the numerator of the equation should contain a factor to account for the specific gravity of the fluid. In the ABC and EOCP formulas it is assumed that the specific gravity of the fluid is 1 and therefore, the factor is omitted from the equation.

The equations are:

$$\text{Horsepower, brake, hp} = \frac{\text{flow, gpm} \times \text{head, ft}}{3960 \times \text{pump efficiency expressed as a decimal}}$$

$$\text{Horsepower, brake, kW} = \frac{9.8 \times \text{flow, m}^3/\text{sec} \times \text{head, m}}{\text{pump efficiency expressed as a decimal}}$$

$$\text{Power required, kW} = \frac{9.81 \times \text{Flow, m}^3/\text{s} \times \text{Head, m} \times \text{Specific gravity}}{\text{Pump efficency, \%} \times \text{Motor efficiency, \%}}$$

For those who prefer working in the metric system, two more equations are available for use when flow is given in either litres per second or litres per minute.

For flows in litres per minute

$$\text{Power, kW} = \frac{\text{Flow, L/min} \times \text{Head, m}}{6{,}125}$$

For flows in litres per second

$$\text{Power required, kW} = \frac{9.81 \times \text{Flow, L/s} \times \text{Head, m} \times \text{Specific gravity}}{1{,}000 \times \text{Pump efficency, \%} \times \text{Motor efficiency, \%}}$$

Note: For all formulas express % as a decimal. E.g. 95% = .95

When the question stem does not provide values for specific gravity, pump efficiency or motor efficiency the equation simplifies to:

$$\text{Power required, kW} = \frac{9.81 \times \text{Flow, L/s} \times \text{Head, m}}{1{,}000}$$

What is the brake horsepower required for a pump required to meet the following parameters:

Motor efficiency = 90%	**Pump efficiency = 85%**
Discharge head = 148 feet (45 metres)	**Flow = 1,009 gallons / minute (5,500 m^3/day)**

US units

Step 1 – insert known values and solve

$$\text{Horsepower, brake, hp} = \frac{\text{flow, gpm} \times \text{head, ft}}{3960 \times \text{pump efficiency expressed as a decimal}} = \frac{1{,}009 \times 148}{3{,}960 \times 0.85} = 44.4$$

Metric units

Step 1 – Calculate the flow in cubic metres per second

$$\text{Flow} = \frac{5{,}500\text{m}^3}{\text{day}} \times \frac{1 \text{ day}}{86{,}400 \text{ seconds}} = 0.06 \ \text{m}^3/\text{s}$$

Step 2 – Insert known values and solve

$$\text{Power required, kW} = \frac{9.81 \times \text{Flow, m}^3/\text{s} \times \text{Head, m} \times \text{Specific gravity}}{\text{Pump efficency, \%} \times \text{Motor efficiency, \%}}$$

$$\text{Power required, kW} = \frac{9.81 \times 0.06 \ \text{m}^3/\text{s} \times 45 \text{ m} \times 1}{0.9 \times 0.85} = \frac{26.487}{0.765} = 34.6 \text{ kW}$$

Efficiency Calculations

Before discussing the formulas and calculations surrounding the efficiency of a pump, motor and pump-motor combination it will be useful to first define some terms.

- Motor Horsepower (mhp) is a measure of the electrical power supplied to the terminals of the electric motor. It is the input power to the motor. One horsepower is defined as being equal to 746 Watts or 0.746 kilowatt.
- Brake Horsepower (bhp) is the output power of the motor. It is also known as the shaft horsepower (shp). The brake horsepower of a motor is always less than the input or motor horsepower supplied to the motor due to friction, resistance within the stator, rotor and core and the load applied to the motor.
- Water Horsepower (whp) is the output power of a pump. That is, the energy imparted to the fluid being pumped in order to raise a given volume of it to a given height.
  The water horsepower is always less than the shaft or brake horsepower applied to the pump shaft due to friction, friction losses and inefficiencies in impellor and volute design.
- Wire to water horsepower (also called wire-to-water efficiency or overall efficiency) is the energy that is imparted to the water divided by the energy supplied to the motor. It is work done divided by work applied.

The term metric horsepower is strictly defined as the power required to raise a mass of 75 kilograms against the earth's gravitational force over a distance of one metre in one second; this is equivalent to 735.49875 Watts or 98.6% of an imperial electrical horsepower which is equal to 746 Watts.

In this manual and in the EOCP and ABC handouts 1 horsepower = 746 Watts.

Horsepower, Motor, hp

The formulas for calculating motor horsepower are:

$$\text{Motor horsepower, hp} = \frac{\text{flow, gpm} \times \text{head, ft}}{3{,}960 \times \text{\%pump efficiency(decimal)} \times \text{\%motor efficiency(decimal)}}$$

$$\text{Motor horsepower, kW} = \frac{9.8 \times \text{flow, } \text{m}^3/\text{sec} \times \text{head, m}}{\text{\%pump efficiency(decimal)} \times \text{\%motor efficiency(decimal)}}$$

What is the brake horsepower required for a pump required to meet the following parameters:

Motor efficiency = 90% **Pump efficiency = 85%**

Discharge head = 148 feet (45 metres) **Flow = 1,009 gallons / minute (5,500 m^3/day)**

US units

Step 1 – insert known values and solve

$$\text{Motor horsepower, hp} = \frac{\text{flow, gpm} \times \text{head, ft}}{3{,}960 \times \text{\%pump efficiency(decimal)} \times \text{\%motor efficiency(decimal)}}$$

$$\text{Motor horsepower, hp} = \frac{1{,}009, \text{gpm} \times 148, \text{ft}}{3{,}960 \times 0.85 \times 0.90} = \frac{149{,}332}{3029.4} = 49.29 \text{ hp}$$

Metric units

Step 1 – Calculate the flow in cubic metres per second

$$\text{Flow} = \frac{5{,}500\text{m}^3}{\text{day}} \times \frac{1\ \text{day}}{86{,}400\ \text{seconds}} = 0.06\ \ \text{m}^3/\text{s}$$

Step 2 – Insert known values and solve

$$\text{Power required, kW} = \frac{9.81 \times \text{Flow, m}^3/\text{s} \times \text{Head, m}}{\text{Pump efficency, \%} \times \text{Motor efficiency, \%}}$$

$$\text{Power required, kW} = \frac{9.81 \times 0.06\ \ \text{m}^3/\text{s} \times 45\ \text{m}}{0.9 \times 0.85} = \frac{26.487}{0.765} = 34.6\ \text{kW}$$

Horsepower, Water, hp

The formulas used to measure water horsepower are:

$$\text{Horsepower, Water, hp} = \frac{\text{flow, gpm} \times \text{head, ft}}{3{,}960}$$

$$\text{Horsepower, Water, kW} = 9.8 \times\ \text{flow,}\ \ \text{m}^3/\text{sec} \times \text{head, m}$$

What is the water horsepower required for a pump required to meet the following parameters:

Discharge head = 148 feet (45 metres) **Flow = 1,009 gallons / minute (5,500 m^3/day)**

US units

Step 1 – insert known values and solve

$$\text{Horsepower, Water, hp} = \frac{\text{flow, gpm} \times \text{head, ft}}{3{,}960} = \frac{1{,}009 \times 148}{3{,}960} = 37.7\ \text{hp}$$

Metric units

Step 1 – Calculate the flow in cubic metres per second

$$\text{Flow} = \frac{5{,}500\text{m}^3}{\text{day}} \times \frac{1\ \text{day}}{86{,}400\ \text{seconds}} = 0.06\ \ \text{m}^3/\text{s}$$

Step 2 – Insert known values and solve

$$\text{Horsepower, Water, kW} = 9.8 \times\ \text{flow,}\ \ \text{m}^3/\text{sec} \times \text{head, m} = 9.8 \times 0.06 \times 45 = 26.5\ \text{kW}$$

Wire to Water Efficiency, %

The equations for wire to water efficiency are:

$$\text{Wire to water efficiency, \%} = \frac{\text{Water hp}}{\text{Motor hp}} \times 100\%$$

$$\text{Wire to water efficiency, \%} = \frac{\text{flow, gpm} \times \text{total dynamic head, ft} \times 0.746\,\text{kW/hp} \times 100\%}{3{,}960 \times \text{electrical demand, kW}}$$

What is the wire to water efficiency in percent of a pump system has a water horsepower requirement of 37.7 horsepower and a motor horsepower of 49.29?

Step 1 – Insert known values and solve

$$\text{Wire to water efficiency, \%} = \frac{\text{Water hp}}{\text{Motor hp}} \times 100\% = \frac{37.7\text{ hp}}{49.29\text{ hp}} \times 100\% = 76.5\%$$

Supplemental Equations

The formulas used to measure efficiency in pumping applications are:

$$\text{Motor efficiency} = \frac{\text{Brake horsepower} \times 100}{\text{Motor horsepower}} \text{ or } \frac{\text{bhp} \times 100}{\text{mhp}}$$

$$\text{Pump efficiency} = \frac{\text{Water horsepower} \times 100}{\text{Brake horsepower}} \text{ or } \frac{\text{whp} \times 100}{\text{bhp}}$$

$$\text{Overall efficiency (wire to water efficency)} = \frac{\text{Water horsepower} \times 100}{\text{Motor horsepower}} \text{ or } \frac{\text{whp} \times 100}{\text{mhp}}$$

$$\text{Wire to water efficiency} = \text{Decimal motor efficiency} \times \text{decimal pump efficiency} \times 100\%$$

What is the motor power if the brake power is 35 kW and the motor efficiency is 88%?

Insert known values and solve

$$\text{Motor horsepower} = \frac{\text{Brake horsepower} \times 100}{\text{Motor efficiency, \%}} = \frac{40\text{ kW} \times 100}{88\%} = 45.5\text{ kW}$$

Find the water horsepower if the brake horsepower is 34 kW and the pump efficiency is 81%

The equation is: Water horsepower = (brake horsepower)(pump efficiency)

Water horsepower = (brake horsepower)(pump efficiency) = (34 kW)(0.81) = 27.5 kW

What is the brake horsepower if the water horsepower is 40 kW and the pump efficiency is 78%?

Step 1 – Rearrange the water horsepower equation, insert known values and solve

$$\text{Brake horsepower} = \frac{\text{water horsepower}}{\text{efficiency}} = \frac{40\text{ kW}}{.78} = 51\text{ kW}$$

What is the motor horsepower if 60 kW of water horsepower is required to run a pump with a motor efficiency of 93% and a pump efficiency of 85%?

The equation is:

$$\text{Motor horsepower} = \frac{\text{water horsepower}}{\text{motor efficiency} \times \text{pump efficiency}}$$

Insert known values and solve

$$\text{Motor horsepower} = \frac{60\text{ kW}}{.93 \times .85} = \frac{60\text{ kW}}{.79} = 76\text{ kW}$$

Trivia question: Ever wonder where the factor 3,960 comes from in the US formulas?

Well, behind the scenes some folks realized that I horsepower equals the amount of work required to lift 550 pounds a distance of 1 foot in one second and that equates to 33,000 foot pounds per minute. They also realized that a US gallon of water weighs 8.333 pounds. There is a lot more mental gymnastics behind those two numbers but when you divide 33,000 by 8.333 you get 3,960. And now you know.

Loading rate - Hydraulic

Hydraulic loading rates are important control parameters for clarifiers, rotating biological contactors, trickling filters and activated sludge processes. They can be used to determine sludge withdrawal rates and contact times between food and microorganisms.

The equations are:

$$\text{Hydraulic loading rate, gpd/ft}^2 = \frac{\text{Total flow applied, gpd}}{\text{Surface area, ft}^2}$$

$$\text{Hydraulic loading rate, m}^3\text{/day/m}^2 = \frac{\text{Total flow applied, m}^3\text{/day}}{\text{Surface area, m}^2}$$

Calculate the hydraulic loading rate on a circular clarifier 90 feet (27.5 metres) in diameter if it receives a flow of 2.88 MGD (10,900 m^3/day) at a MLSS concentration of 2,825 mg/L.

US units

Step 1 – Calculate the surface area of the clarifier

$$\text{Area} = 0.785D^2 = 0.785 \times (90\ ft)^2 = 6{,}358.5 ft^2$$

Insert known values and solve

$$\text{Hydraulic loading rate} = \frac{\text{Flow}}{\text{Surface area}} = \frac{2{,}880{,}000\ \text{gal/day}}{6{,}358.5\ \text{ft}^2} = 452.9\ \text{gpd/ft}^2$$

Metric units

Step 1 – Calculate the surface area of the clarifier

$$\text{Area} = 0.785D^2 = 0.785 \times (27.5m)^2 = 593.7\text{m}^2$$

Insert known values and solve

$$\text{Hydraulic loading rate} = \frac{\text{Flow}}{\text{Surface area}} = \frac{10{,}900\ \text{m}^3\text{/day}}{593.7\ \text{m}^2} = 18.4\ \text{m}^3\text{/m}^2\text{/day}$$

Loading Rate – Mass

Calculating the mass of solids added to or removed from a process is the most commonly performed calculation in wastewater mathematics. The task is embedded in almost every single math problem found on a certification examination.

The basic equations are:

$$\text{Loading rate (Mass), lb/day} = \text{Flow, MGD} \times \text{Concentration, mg/L} \times 8.34\ \text{lb/gal}$$

$$\text{Loading rate (Mass), kg/day} = \frac{\text{Volume, m}^3\text{/day} \times \text{Concentration, mg/L}}{1{,}000}$$

In most applications of the formula some conversion factors will need to be applied to convert the values given to the values desired. E.g. from mg/L to kg or kg/m^3

When the value desired is in kilograms the following formula may be used:

$$\text{Mass, kg} = \text{concentration, mg/L} \times \text{Volume, ML}$$

Where flow or volume are expressed in Megalitres, symbol ML (Megalitre = 10^6 L or 10^3 m^3)

Calculate the pounds (kilograms) of MLSS under aeration in an aeration basin 160 feet (48.8 m) long by 16 feet (4.9 m) wide by 10 feet (3 m) deep if the MLSS concentration is 2,658 mg/L.

US units

Step 1 – Calculate the volume of the aeration basin

$$\text{Volume} = \text{L} \times \text{W} \times \text{D} = 160 \text{ ft} \times 16 \text{ ft} \times 10 \text{ ft} = 25{,}600 \text{ ft}^3$$

Step 2 – Convert cubic feet to gallons

$$25{,}600 ft^3 \times \frac{7.48\ gallons}{ft^3} \times \frac{1\ MGD}{10^6 gallons} = 0.191\ MGD$$

Step 3– Insert known values and solve:

$$\text{Loading rate (Mass), lb/day} = 0.191 \text{ MGD} \times 2{,}658 \text{ mg/L} \times 8.34 \text{ lb/gal} = 4{,}234 \text{ lb}$$

Metric units

Step 1 – Calculate the volume of the aeration basin

$$\text{Volume} = \text{L} \times \text{W} \times \text{D} = 50\text{m} \times 5\text{m} \times 3\text{m} = 750 \text{ m}^3$$

Insert known values and solve:

$$\text{Mass} = \text{Concentration} \times \text{Flow}$$

$$\text{Mass} = \frac{2{,}658 \text{ mg}}{\text{L}} \times 750\text{m}^3 \times \frac{1{,}000\text{L}}{\text{m}^3} \times \frac{1 \text{ kg}}{10^6\text{mg}} = 1{,}993.5 \text{ kg}$$

In the equation above two conversion factors, $\frac{1{,}000\text{L}}{\text{m}^3}$ and $\frac{1 \text{ kg}}{10^6\text{mg}}$ were required

Alternate formula:

$$\text{Mass, kg} = \text{concentration, mg/L} \times \text{Volume, ML}$$

Step 1 – Convert 750 m^3 to ML. 750 m^3 = 0.75 ML

Insert known values and solve

$$\text{Mass} = 2{,}658 \text{ mg/L} \times 0.75\text{ML} = 1{,}993.5 \text{ kg}$$

Calculate the kilograms of BOD added to a sequencing batch reactor each day if the influent BOD concentration is 168 mg/L and the flow is 1.71 MGD (75 L/s).

US units

Step 1 – Insert known values and solve.

$$\text{Mass, lb/day} = 1.71 \text{ MGD} \times 168 \text{ mg/L} \times 8.34 \text{ lb/gal} = 2{,}395.9 \text{ lb/day}$$

Metric units

Step 1 – Apply conversions factors, insert known values and solve

$$\text{Mass} = \frac{168\ \text{mg}}{\text{L}} \times \frac{75\ \text{L}}{\text{second}} \times \frac{86{,}400\ \text{seconds}}{\text{day}} \times \frac{1\ \text{kg}}{10^6\text{mg}} = 1{,}088.6\ \text{kg/day}$$

In the equation above two conversion factors, $\frac{86{,}400\ \text{seconds}}{\text{day}}$ and $\frac{1\ \text{kg}}{10^6\text{mg}}$ were required.

Hypochlorite Strength, %

The manufacturers of sodium hypochlorite have devised a number of ways to express the concentration of sodium hypochlorite in a solution.

Commercial sodium hypochlorite is usually delivered to treatment facilities at concentrations of between 10 and 15 trade percent. Trade percent is often used to express the concentration of sodium hypochlorite solutions but it does not accurately reflect the concentration of either sodium hypochlorite or chlorine in the solution.

Grams per Liter (g/L) Available Chlorine

The weight of available chlorine, in grams contained in one liter of sodium hypochlorite solution.

Trade percent available chlorine

Commonly used to denote the strength of commercial sodium hypochlorite solutions, it is similar to grams per liter, except that the unit of volume is 100 milliliters (mL) instead of one liter. Its value is therefore one tenth of the value of grams per liter. This is also sometimes referred to as “available chlorine volume percent”.

This is the most common way of specifying the strength of a sodium hypochlorite solution used by vendors.

$$\text{trade \% available chlorine} = \frac{\text{grams per litre available chlorine}}{10}$$

Weight percent available chlorine

Dividing trade percent by the specific gravity of the sodium hypochlorite solution gives weight percent, or percent available chlorine, by weight

$$\text{weight \% available chlorine} = \frac{\text{grams per litre available chlorine}}{10 \times (\text{specific gravity of solution})}$$

Weight percent sodium hypochlorite

Like trade percent available chlorine, this term is commonly used to denote the strength of commercial sodium hypochlorite solutions. It is a measure of the weight of sodium hypochlorite per 100 parts by weight of sodium hypochlorite solution.

Weight percent of sodium hypochlorite is defined as the weight of sodium hypochlorite per 100 parts by weight of sodium hypochlorite solution.

It is calculated by converting weight percent of available chlorine into its equivalent as sodium hypochlorite; that is, multiplying by the ratio of their respective molecular weights as shown below

$$\frac{\text{molecular weight of NaOCl}}{\text{molecular weight of Cl}_2} = \frac{74.44}{70.91} = 1.05$$

$$\text{weight \% NaOCl} = \text{weight \% available chlorine} \times 1.05$$

Or

$$\text{weight \% NaOCl} = \frac{\text{trade \% available chlorine} \times 1.05}{\text{specific gravity of solution}}$$

Comparison of metrics for determining the strength of NaOCl solutions

Trade %	Specific gravity	Available Cl_2 g/L	Available Cl_2 weight %	NaOCl weight %
0.8	1.01	8	0.80	0.84
2	1.034	20	1.93	2.03
4	1.062	40	3.77	3.95
6	1.089	60	5.51	5.78
8	1.116	80	7.17	7.53
10	1.142	100	8.76	9.20
12	1.168	120	10.27	10.79
15	1.206	150	12.44	13.06

The information presented above outlines the various ways in which the strength of sodium hypochlorite is measured and sold. The formulas which follow are the ones provided in the ABC/EOCP handout. They are used to calculate the % hypochlorite strength by weight.

Hypochlorite Strength, % (by weight)

The equations are:

$$\text{Hypochlorite Strength, \%} = \frac{\text{Chlorine required, pounds}}{\text{Hypochlorite solution needed, gallons} \times 8.34\,\text{lb/gal}} \times 100\%$$

$$\text{Hypochlorite Strength, \%} = \frac{\text{Chlorine required, kg} \times 100}{\text{Hypochlorite solution needed, kg}}$$

4 pounds (1.8 kg) of 65% calcium hypochlorite are added to a 45 gallon (170.3 litre) drum of water. What is the per cent strength (by weight) of the resulting hypochlorite solution?

US units

Step 1 – Calculate the number of pounds of available chlorine

$$4\text{ lb} \times \frac{.65\text{ lb Ca(OCl)}_2}{\text{lb}} = 2.6\text{ lb}$$

Step 2 – Convert pounds of $Ca(OCl)_2$ to gallons

$$\text{gal Ca(OCl)}_2 = 2.6\text{ lb} \times \frac{1\text{ gal}}{8.34\text{ lb}} = 0.31\text{ gallons}$$

Step 3 – Insert known values and solve

$$\text{Hypochlorite Strength, \%} = \frac{\text{Chlorine required, pounds}}{\text{Hypochlorite solution needed, gallons} \times 8.34\,\text{lb/gal}} \times 100\%$$

$$\text{Hypochlorite Strength, \%} = \frac{2.6\text{ pounds}}{(45\text{ gal} + 0.31\text{ gal}) \times 8.34\,\text{lb/gal}} \times 100\% = 0.68\%$$

Metric units

Step 1 – Calculate the number of kilograms of available chlorine

$$1.8\text{ kg} \times \frac{.65\text{ kg Ca(OCl)}_2}{\text{kg}} = 1.17\text{ kg}$$

Step 2 – Convert kg of $Ca(OCl)_2$ to liters

$$\text{litres Ca(OCl)}_2 = 1.17\text{ kg} \times \frac{1\text{ L}}{1\text{ kg}} = 1.17\text{ L}$$

Step 3 – Insert known values and solve

$$\text{Hypochlorite Strength, \%} = \frac{\text{Chlorine required, kg} \times 100}{\text{Hypochlorite solution needed, kg}}$$

$$\text{Hypochlorite Strength, \%} = \frac{1.17\text{ kg} \times 100}{(170.1\text{ L} + 1.17\text{ L}) \times 1\text{ kg/L}} = 0.68\%$$

Langelier Saturation Index (LSI)

The Langelier Saturation Index was developed in the mid 1930s by Dr. Wilfred Langelier, a professor at the University of California, Berkely. The Index became a tool to determine if water is corrosive or scale-forming, based on the chemistry of the water.

The equation is:

$$\text{Langelier Saturation Index (LSI)} = \text{pH} - \text{pH}_s$$

Where pH is the pH of the water and pH_s is the pH of the water when saturated with calcite or calcium carbonate.

If the Langelier Index is negative, then the water is under saturated with calcium carbonate and will tend to be corrosive in the distribution system. If the Langelier Index is positive, then the water is over saturated with calcium carbonate and will tend to deposit calcium carbonate forming scales in the distribution system and If Langelier Index is close to zero, then the water is just saturated with calcium carbonate and will neither be strongly corrosive or scale forming.

Calculate the LSI if the pH is 7.5 and the pH_s is 8.43

$$\text{Langelier Saturation Index (LSI)} = \text{pH} - \text{pH}_s = 7.5 - 8.43 = -3.43$$

If such a question were posed on a certification exam it becomes a simple matter of having the ability to perform a simple subtraction to solve.

In reality, calculation of the LSI is not such a simple matter and for completeness, the mathematics behind deriving a value for pH_s are shown below.

Calculation of pH_s requires knowledge of the water's alkalinity, hardness, temperature and total dissolved solids content.

pH_s is the pH at saturation in calcite or calcium carbonate and is defined as:

$$pH_s = (9.3 + A + B) - (C + D)$$

Where:

A = (Log_{10} [TDS] - 1) / 10

B = -13.12 x Log_{10} (°C + 273) + 34.55

C = Log_{10} [Ca^{2+} as $CaCO_3$] - 0.4

D = Log_{10} [alkalinity as $CaCO_3$]

In the sample question given above, let us look at how the pH_s of 8.43 was derived.

Water Analysis:
Our water sample had a temperature of 15 ˚C, a pH of 7.5, total dissolved solids (TDS) of 320 mg/L, hardness of 150 mg/L as $CaCO_3$ and alkalinity of 34 mg/L as $CaCO_3$

Calculation of pH_s

pH_s = (9.3 + A + B) - (C + D) where:

$$\mathrm{A} = \frac{\mathrm{Log_{10}(TDS)} - 1}{10} = \frac{2.50 - 1}{10} = 0.15$$
$$\mathrm{B} = -13.12 \times \mathrm{Log_{10}}(15 + 273) + 34.55 = (-13.12 \times 2.45) + 34.55 = 2.28$$
$$\mathrm{C} = \mathrm{Log_{10}}(\mathrm{Ca^{2+} as\ CaCO_3}) - 0.4 = \mathrm{Log_{10}}(150) - 0.4 = 2.17 - 0.4 = 1.77$$
$$\mathrm{D} = \mathrm{Log_{10}}(\mathrm{Alkalinity\ as\ CaCO_3}) = \mathrm{Log_{10}}(34) = 1.53$$

Insert calculated values and solve

$$\mathrm{pH_s} = (9.3 + \mathrm{A} + \mathrm{B}) - (\mathrm{C} + \mathrm{D})$$
$$\mathrm{pH_s} = (9.3 + 0.15 + 2.28) - (1.77 + 1.53) = 11.73 - 3.3 = 8.43$$

To summarize, calculation of pH_s is a lengthy process which requires the use of logarithmic tables or a scientific calculator with a log function. Neither are provided at a certification exam session, nor are the formula required to calculate the parameters A, B, C and D. Operators can rest assured that any LSI question will provide the two values necessary to solve the formula given in the ABC/EOCP handout.

Leakage

It is a fact of life that unlined concrete reservoirs will eventually develop some leaks. The AWWA recommends that in a 24 hour period, leakage in an unlined concrete reservoir with a water depth of 7.6 metres (25 feet) or less should not exceed 0.1 percent of the water volume. For a fully lined concrete reservoir, leakage should not exceed 0.025 percent of the water volume

The **equations** are:

$$\text{Leakage, gal/day} = \frac{\text{Volume, gallons}}{\text{Time, days}}$$

$$\text{Leakage, L/day} = \frac{\text{Volume, Litres}}{\text{Time, days}}$$

In its simplest form, a water leakage question might look like this:

A leak test was carried out on a reservoir and it was found that 3,000 gallons (11,356 L) had leaked over a period of 3 days. What was the leakage rate?

US units

Insert known values and solve:

$$\text{Leakage, gal/day} = \frac{\text{Volume, gallons}}{\text{Time, days}} = \frac{3{,}000\ \text{gal}}{3\ \text{days}} = 1{,}000\ \text{gal/day}$$

Metric units

Insert known values and solve:

$$\text{Leakage, L/day} = \frac{\text{Volume, Litres}}{\text{Time, days}} = \frac{11{,}356\ \text{L}}{3\ \text{days}} = 3{,}785\ \text{L/day}$$

On a Class III or IV exam you will have to work for your money and the question might look like this:

The Town of Whyus carried out a leak detection test on their 60 foot (18.3m) diameter unlined concrete reservoir which normally operates with a water depth of 22 feet (6.7m). After a period of 36 hours it was discovered that the water depth had decreased by 0.33 feet (0.1 metres). What was the leakage rate?

Step 1 – Calculate the volume of water lost

$$\text{Volume lost} = \text{Area} \times \text{depth} = \pi r^2 d = (30\ \text{ft})^2 \times 3.14 \times .33\text{ft} = 932.6\text{ft}^3$$

$$\text{Volume lost} = \text{Area} \times \text{depth} = \pi r^2 d = (9.15\text{m})^2 \times 3.14 \times .0.1\ \text{m} = 26.3\text{m}^3$$

But the equations ask for volumes in either US gallons or litres

$$932.6\text{ft}^3 \times \frac{7.48\ \text{gallons}}{\text{ft}^3} = 6{,}975.8\ \text{gallons}$$

$$26.3\text{m}^3 \times \frac{1{,}000\ \text{L}}{\text{m}^3} = 26{,}300\ \text{L}$$

Step 2 – Insert known values and solve

US units

$$\text{Leakage, gal/day} = \frac{\text{Volume, gallons}}{\text{Time, days}} = \frac{6{,}975.8 \text{ gallons}}{1.5 \text{ days}} = 4{,}650.5 \text{ gal/day}$$

Metric units

$$\text{Leakage, L/day} = \frac{\text{Volume, Litres}}{\text{Time, days}} = \frac{26{,}300 \text{ L}}{1.5 \text{ days}} = 17{,}533 \text{ L/day}$$

It wasn't part of the question but does the Town's reservoir meet the AWWA standard?

Mean Cell Residence Time / Solids Retention Time/Sludge Age

Mean cell residence time, sludge age and solids retention time are all methods used by an operator to control the inventory of solids in the process and to maintain the desired food to microorganism ratio or the environment necessary for certain species to thrive (e.g. nitrifiers/denitrifiers or phosphorous accumulating microorganisms).

Mean Cell Residence Time (MCRT)

The mean cell residence time calculation is a refinement of the solids retention (or detention) time and the sludge age calculation. MCRT takes into account solids which are stored in the secondary clarifier as well as solids that are removed from the process as waste activated sludge and effluent suspended solids. It is a subtractive process as it monitors solids lost from the process. It is an important design and operating parameter with values normally expressed in days.

The equations are:

$$\text{MCRT, days} = \frac{(\text{Aeration tank TSS, lb}) + (\text{Clarifier TSS, lb})}{(\text{TSS wasted, lb/day}) + (\text{Effluent TSS, lb/day})}$$

$$\text{MCRT, days} = \frac{\text{MLSS, mg/L} \times (\text{volume of aeration basin} + \text{clarifier, m}^3)}{(\text{WAS, mg/L} \times \text{WAS Flow}) + (\text{Effluent TSS, mg/L} \times \text{Effluent Flow})}$$

Where: MLSS = mixed liquor suspended solids, TSS = total suspended solids, WAS = waste activated sludge, Effluent TSS = effluent total suspended solid, Effluent flow = flow leaving the plant.

It is assumed that the solids concentration in the clarifier is the same as that in the aeration basin (i.e. the MLSS concentration)

Given the following data, calculate the mean cell residence time for this treatment plant:

Volume of aeration basin + clarifier = 0.46 MG (1,800 m^3)	**MLSS = 2,625 mg/L**
WAS = 1,653 lb/day (750 kg/day)	**Effluent TSS = 33 lb/day (15 kg/day)**

The simplified equation is:

$$\text{MCRT} = \frac{\text{weight of solids under aeration}}{\text{weight of solids lost per day}}$$

US units

Step 1 – Calculate the pounds of solids under aeration

$$\text{MLSS under aeration} = \frac{2{,}625\text{mg}}{\text{L}} \times \frac{0.46\text{ MG}}{\text{day}} \times \frac{8.34\text{ lb}}{\text{gal}} = 10{,}070.5\text{ lb}$$

Step 2 – Insert known values and solve

$$\text{MCRT} = \frac{\text{kg solids under aeration}}{\text{kg solids lost per day}} = \frac{10070.5\text{ lb}}{1653\ \text{lb/day} + 33\ \text{lb/day}} = 5.97 \cong 6\text{ days}$$

Metric units

Step 1 – Calculate the kilograms of solids under aeration

$$\text{kg solids under aeration} = 2{,}625\,\text{mg/L} \times 1.8\text{ ML} = 4{,}725\text{ kg}$$

Step 2 – Insert known values and solve

$$\text{MCRT} = \frac{\text{kg solids under aeration}}{\text{kg solids lost per day}} = \frac{4{,}725\text{ kg}}{750\text{ kg} + 15\text{ kg}} = 6\text{ days}$$

Solids Retention Time

The solids retention time takes into account only the solids in the aeration basin and the solids removed from the process as waste activated sludge. The basic maths are the same as those for the MCRT calculations.

The equations are:

$$\text{SRT, days} = \frac{(\text{Aeration tank TSS, lb})}{(\text{TSS wasted, lb/day})}$$

$$\text{SRT} = \frac{\text{MLSS, mg/L} \times (\text{volume of aeration basin, m}^3)}{(\text{WAS, mg/L} \times \text{WAS Flow})}$$

Sludge Age

Sludge age (also known as solids retention time and Gould sludge age) is an important parameter in the operation of the activated sludge process. Similar in concept to detention time, sludge age refers to the amount of time, in days, that solids remain under aeration. It is an additive process as it measures solids added to the process each day. Sludge age is controlled by varying the waste activated sludge rate.

The equations for sludge age are:

$$\text{Sludge age, days} = \frac{\text{lb solids under aeration}}{\text{lb solids added per day}}$$

$$\text{Sludge age, days} = \frac{\text{kg solids under aeration}}{\text{kg solids added per day}}$$

The influent to an extended aeration package plant adds 450 pounds (204 kilograms) per day of solids to the aeration basin. If the solids under aeration weigh 6,713 pounds (3045 kilograms), what is the sludge age in days?

Insert known values and solve

US units

$$\text{Sludge age, days} = \frac{\text{lb solids under aeration}}{\text{lb solids added per day}} = \frac{6{,}713\ \text{lb}}{450\ \text{lb/day}} = 15\ \text{days}$$

Metric units

$$\text{Sludge age, days} = \frac{\text{kg solids under aeration}}{\text{kg solids added per day}} = \frac{3{,}045\ \text{kg}}{204\ \text{kg/day}} = 15\ \text{days}$$

Organic Loading Rate, Attached Growth Systems

Organic loading rates provide the operator with an indication of the amount of food entering a biological process. The concept is more generally applied to wastewater lagoons (kg/ha/day), trickling filters (kg/m^3/day) and rotating biological contactors (g/m^2/day) than it is to the activated sludge process where the concept of food to microorganism ratio is used.

The general equation for organic loading is:

$$\text{Organic loading rate} = \frac{\text{Flow} \times \text{concentration}}{\text{area}} \text{ or } \frac{\text{Flow} \times \text{concentration}}{\text{volume}}$$

For most applications the mass being added is either total suspended solids (TSS) or biochemical oxygen demand (BOD)

Mass loadings for clarifiers, lagoons, and rotating biological contactors are area based while mass loadings for aeration basins, trickling filters and digestors are volume based.

Rotating Biological Contactor

Organic loadings to rotating biological contactors (RBC) are calculated based on the surface area of the media being rotated through the influent to the process.

The surface area is calculated in square feet in the US system and square metres in the metric system. Biochemical oxygen demand (BOD_5) is typically measured as soluble BOD ($SBOD_5$).

The equations are:

$$\text{OLR, lb SBOD}_5\ /\ \text{day}/1{,}000\text{ft}^2 = \frac{\text{Organic load, lb SBOD}_5\ /\text{day}}{\text{surface area of media, 1,000 ft}^2}$$

$$\text{OLR, kg SBOD}_5\ /\ \text{day}/\text{m}^2 = \frac{\text{Organic load, kg SBOD}_5\ /\text{day}}{\text{surface area of media, m}^2}$$

Calculate the $SBOD_5$ loading rate on a rotating biological contactor. The influent flow is 0.26 MGD (1000 m^3/day) with a BOD of 185 mg/L. The RBC has 400 disks each 11.5 feet (3.5 metres) in diameter mounted on its shaft.

This problem cannot be solved in a single step. We first have to use the mass equation to calculate the number of pounds or kilograms of $SBOD_5$ added per day and we have to remember that each disk has two sides.

The equation is:

$$\text{Organic loading rate} = \frac{\text{Flow} \times \text{concentration}}{\text{surface area} \times \text{number of disks} \times 2}$$

US units

Step 1 – Calculate the mass of SBOD applied

$$\text{Mass of SBOD} = \text{Flow} \times \text{concentration} = 185 \ \text{mg/L} \times 0.26 \ \text{MGD} \times 8.34 \ \text{lb/gal} = 401 \ \text{lb/day}$$

Step 2 – Calculate surface area of disks

$$\text{Area} = 0.785D^2 \times 2 \times \text{number of disks} = 0.785 \times 2 \times (11.5 \text{ ft})^2 \times 400 = 83{,}053 \text{ ft}^2$$

Step 3 – Insert known values and solve

$$\text{Organic loading rate} = \frac{\text{Mass of SBOD applied}}{\text{Surface area}} = \frac{401 \ \text{lb/day}}{83{,}053 \text{ ft}^2} = 0.005 \ \text{lb SBOD/ft}^2\text{/day}$$

Metric units

Step 1 – Calculate the mass of BOD applied

$$\text{Mass of BOD} = \text{Flow} \times \text{concentration} = 185 \ \text{mg/L} \times 1.0 \ \text{ML/day} = 185 \ \text{kg/day}$$

Step 2 – Calculate surface area of disks

$$\text{Area} = 0.785D^2 \times 2 \times \text{number of disks} = 0.785 \times 2 \times (3.5 \text{ m})^2 \times 400 = 7{,}693 \text{ m}^2$$

Step 3 – Insert known values and solve

$$\text{Organic loading rate} = \frac{\text{Mass of BOD applied}}{\text{Surface area}} = \frac{185 \ \text{kg/day}}{7{,}693 \text{ m}^2} = 0.02 \ \text{kg BOD/m}^2\text{/day}$$

Note: organic loading to a RBC is usually reported as g BOD/m^2/day.

Trickling Filter

The calculation for the loading rate for a trickling filter is similar to that for a RBC with the following differences: in the numerator, BOD is used instead of SBOD and in the denominator the volume of the filter is used instead of surface area.

The equations are:

$$\text{OLR, lb BOD}_5\text{ / day/1,000ft}^3 = \frac{\text{Organic load, lb BOD}_5\text{ /day}}{\text{volume of media, 1,000 ft}^3}$$

$$\text{OLR, kg BOD}_5\text{ / day/m}^2 = \frac{\text{Organic load, kg BOD}_5\text{ /day}}{\text{volume of media, m}^3}$$

A trickling filter with a diameter of 135 feet (41 metres) and a media depth of 5 feet (1.5 metres) receives a flow of 1.95 MGD (7,382 cubic metres) with a BOD of 110 mg/L. Calculate the organic loading for this filter.

US units

Step 1 – Calculate the volume of the filter

$$\mathrm{Volume} = 0.785\mathrm{D}^2 \times \mathrm{h} = 0.785 \times (135\ \mathrm{feet})^2 \times 5\ \mathrm{feet} = \ 71{,}533\mathrm{ft}^3$$

Step 2 – Calculate the organic loading to the filter

$$\text{Mass of SBOD} = \text{Flow} \times \text{concentration} = 110\ \ \mathrm{mg/L} \times 1.95\ \mathrm{MGD} \times 8.34\ \ \mathrm{lb/gal} = 1{,}788.9\ \ \mathrm{lb/day}$$

Step 3 – Insert known values and solve

$$\text{Organic loading rate} = \frac{1{,}788.9\ \ \mathrm{lb/day}}{71.533\ 10^3\mathrm{ft}^3} = 25\ \ \mathrm{lb\ BOD/day/1{,}000ft^3}$$

Metric units

Step 1 – Calculate the volume of the filter

$$Volume = 0.785D^2 \times h = 0.785 \times (41\ m)^2 \times 1.5m = \ 1{,}979.4m^3$$

Step 2 – Calculate the organic loading to the filter

$$\text{Mass of SBOD} = \text{Flow} \times \text{concentration} = 110\ \ \mathrm{mg/L} \times 7.382\ \mathrm{ML} = 812\ \ \mathrm{kg/day}$$

Step 3 – Insert known values and solve

$$\text{Organic loading rate} = \frac{812\ \ \mathrm{kg/day}}{1{,}979.4\ \mathrm{m}^3} = 0.41\ \ \mathrm{kg\ BOD/day/}m^3$$

Oxygen Uptake Rate

The Oxygen Uptake Rate (OUR) test measures the amount of oxygen consumed by a sample over a period of time. It is measured in mg/L O_2/minute or mg/L O_2/hour.

The equations are:

$$\text{Oxygen uptake rate} = \frac{\text{oxygen usage, mg/L}}{\text{time, minutes}}$$

Or

$$\text{Oxygen uptake rate} = \frac{\text{initial DO, mg/L} - \text{final DO, mg/L}}{\text{elapsed time, minutes}}$$

These quick tests have many advantages; rapid measure of influent organic load and biodegradability, indication of the presence of toxic or inhibitory wastes, degree of stability and condition of a sample, and calculation of oxygen demand rates at various points in the aeration basin. As always, trends are more useful than instantaneous values.

Calculate the OUR of a sample if the initial dissolved oxygen concentration is 5.9 mg/L and after 10 minutes the final dissolved oxygen concentration is 1.4 mg/L.

Insert known values and solve

$$\mathrm{OUR} = \frac{5.9\ \mathrm{mg/L} - 1.4\ \mathrm{mg/L}}{10\ \mathrm{minutes}} \times \frac{60\ \mathrm{minutes}}{\mathrm{hour}} = 27\ \mathrm{mg/L}\ \ \mathrm{O_2/hour}$$

Population Equivalent, Organic

Knowledge of typical per capita water usage or BOD_5 contributions can be used to calculate the population load on a wastewater treatment plant or conversely, if the population is known to determine whether excessive infiltration and inflow is present.

The general equations are:

$$\text{Population equivalent (organic loading)} = \frac{\text{flow, MGD} \times \text{BOD, mg/L} \times 8.34\ \text{lb/gal}}{0.17\ \text{lb BOD/person/day}}$$

$$\text{Population equivalent (organic loading)} = \frac{\text{Flow, m}^3\text{/day} \times \text{BOD, mg/L}}{1{,}000 \times 0.077\ \text{kg BOD/person/day}}$$

$$\text{Population equivalent} = \frac{\text{Population served}}{\text{Size of treatment process (e.g. area or volume)}}$$

Calculate the population loading on a lagoon if the population is 12,500 people and the lagoon system totals 20 acres (8 hectares).

$$\text{Population equivalent} = \frac{\text{Population served}}{\text{Area, acres}} = \frac{12{,}500}{20\ \text{acres}} = 625\ \text{people/acre}$$

$$\text{Population equivalent} = \frac{\text{Population served}}{\text{Area, ha}} = \frac{12{,}500}{8\ \text{ha}} = 1{,}562\ \text{people/ha}$$

A treatment plant receives a daily flow of 2.5 MGD (9,500 m^3) with a BOD of 222 mg/L. Calculate the equivalent population served.

The equation is:

US Units

Step 1 – Insert known values and solve:

$$\text{Population equivalent} = \frac{2.5\ \text{MGD} \times 222\ \text{mg/L} \times 8.34\ \text{lb/gal}}{0.17\ \text{lb BOD/person/day}} = 27{,}228\ \text{people}$$

Metric units

$$\text{Population equivalent (organic loading)} = \frac{\text{Flow, m}^3\text{/day} \times \text{BOD, mg/L}}{1{,}000 \times 0.077\ \text{kg BOD/person/day}}$$

Step 1 – Insert known values and solve

$$\text{Population equivalent} = \frac{9{,}500\ \text{m}^3\text{/day} \times 222\ \text{mg/L}}{1{,}000 \times 0.077\ \text{kg BOD/person/day}} = \frac{2{,}109{,}000}{77} = 27{,}389\ \text{people}$$

Alternate method:

Step 1 – Calculate the kg of BOD_5 received at the plant each day

$$\text{kg BOD} = \text{flow} \times \text{concentration} = 9.5\ \text{ML} \times 222\ \text{mg/L} = 2{,}109\ \text{kg/day}$$

Step 2 – Insert known values and solve

$$\text{Population} = \frac{\text{kg BOD /day}}{0.077\ \text{kg BOD/ person/day}} = \frac{2{,}109\ \text{kg BOD}}{0.077\text{kg BOD/ person/day}} = 27{,}389\ \text{people}$$

Recirculation Ratio

Recirculation of flow from the secondary clarifier to the trickling filter is a technique used to dilute the strength of the influent to the trickling filter, maintain a relatively uniform flow to the filter, reduce odor and filter flies and to ensure the filter does not dry out during periods of low flow. Recirculation ratios generally range from 1:1 to 2:1

The equation is:

$$\text{Recirculation ratio} = \frac{\text{recirculated flow}}{\text{primary effluent flow}}$$

What is the recirculation ratio for a trickling filter if the influent to the plant is 3.3 MGD (12.5 ML/day) and a flow of 5.75 MGD (21.8 ML/day) is recirculated to the trickling filter?

Insert known values and solve:

US units

$$\text{Recirculation ratio} = \frac{\text{recirculated flow}}{\text{primary effluent flow}} = \frac{5.75}{3.3} = 1.74{:}\,1$$

Metric Units

$$\text{Recirculation ratio} = \frac{\text{recirculated flow}}{\text{primary effluent flow}} = \frac{21.8}{12.5} = 1.74{:}\,1$$

What is the trickling filter's recirculated flow if the influent flow to the plant was 5.9 ML/day and the recirculation ratio was 1.65:1 ?

Rearrange the equation to solve for recirculated flow then insert known values and solve

$$\text{If Recirculation ratio} = \frac{\text{recirculated flow}}{\text{primary effluent flow}}$$

$$\text{Then Recirculated flow} = \text{Recirculation ratio} \times \text{Primary effluent flow}$$

$$\text{Recirculated flow} = 1.65 \times 5.9\ \text{ML/day} = 9.74\ \text{ML/day}$$

Reduction of Volatile Solids, %

A modified version of the % removal formula is used when dealing with volatile solids reduction in an anaerobic digestor and the reduction in moisture content in digestor sludge or a composting process. There have been a number of formulas used in the past to calculate volatile solids reduction in anaerobic digestors. Current practice is to use what is called the "Van Kleeck" formula for modern digestors. In this formula all percent values are expressed as a decimal. E.g. 25% = 0.25

The formula is:

$$\%\ \text{Volatile solids reduction} = \frac{(\text{Volatile solids in} - \text{Volatile solids out})}{\text{Volatile solids in} - (\text{volatile solids in} \times \text{volatile solids out})} \times 100\%$$

It is often written as:

$$\%\text{VS reduction} = \frac{(\text{VS}_{\text{in}} - \text{VS}_{\text{out}})}{\text{VS}_{\text{in}} - (\text{VS}_{\text{in}} \times \text{VS}_{\text{out}})} \times 100\% \ \text{ or } \ \frac{(\text{in} - \text{out})}{\text{in} - (\text{in} \times \text{out})} \times 100\%$$

Calculate the % volatile solids reduction in an anaerobic digestor which is fed primary sludge with a volatile solids content of 87% and produces a digested sludge with a volatile solids content of 59%

Known: Volatile solids in = 87% = 0.87, Volatile solids out = 59% = 0.59

Step 1 – Insert known values and solve:

$$\%\text{VS reduction} = \frac{(\text{VS}_{\text{in}} - \text{VS}_{\text{out}})}{\text{VS}_{\text{in}} - (\text{VS}_{\text{in}} \times \text{VS}_{\text{out}})} \times 100\%$$

$$\text{VS reduction} = \frac{(0.87 - 0.59)}{0.87 - (0.87 \times 0.59)} \times 100\% = \left(\frac{.28}{.87 - .51}\right) = \left(\frac{.28}{.36}\right) \times 100\% = 77.8\%$$

Percent Reduction in Flow

See the following section for solved examples. This equation is the same as the percent removal equation with the exception of a change in wording.

$$\text{reduction in flow, \%} = \frac{\text{original flow} - \text{reduced flow}}{\text{original flow}} \times 100$$

Percent Removal

After the solids equation, the percent removal calculation is one the most commonly calculated values.

Percent removal calculations whether for BOD_5, TSS or VSS inform the operator of the efficiency of the unit process and provide information on the impact of the material removed on the next downstream process. (E.g. thickeners, digestors or dewatering equipment). The percent removal statement may sometimes be worded as percent reduction.

The equation is

$$\%\ \textbf{removal efficiency} = \frac{(\textbf{parameter in} - \textbf{parameter out})}{\textbf{parameter in}} \times \mathbf{100}\% \quad \textbf{or} \quad \frac{(\textbf{in} - \textbf{out})}{\textbf{in}} \times \mathbf{100}\%$$

What is the removal efficiency of a primary clarifier if the influent TSS are 195 mg/L and the effluent TSS are 82 mg/L

Known: Influent TSS =195 mg/L, effluent TSS = 82 mg/L

Insert known values and solve

$$\text{removal efficiency} = \frac{(\text{in} - \text{out})}{\text{in}} \times 100\% = \frac{(195 - 82)}{195} \times 100\% = \frac{113}{195} \times 100\% = 57.9\%$$

Percent Return Rate (Sludge Return Rate, %)

One of the parameters for the control of the activated sludge process is the rate at which settled MLSS is returned from the clarifier to the aeration basin. Different variations of the activated sludge process have different optimum return rates. In addition to the return of solids from the clarifier, some biological nutrient removal processes have internal sludge recycle streams as well.

The equation is:

$$\text{Return rate, \%} = \frac{\text{Return flow rate}}{\text{Influent flow rate}} \times 100$$

Calculate the percent sludge return rate if the influent flow is 2.5 MGD (9,500 m^3/day) and the RAS return rate is 1.9 MGD (85 L/second).

US units

$$\text{Return rate, \%} = \frac{\text{Return flow rate}}{\text{Influent flow rate}} \times 100 = \frac{1.9\ MGD}{2.5\ MGD} \times 100 = 76\%$$

Metric units

Step 1 – Calculate the RAS rate in cubic metres per day

$$\text{RAS rate} = \frac{85\ \text{L}}{\text{s}} \times \frac{86{,}400\ \text{s}}{\text{day}} \times \frac{1\text{m}^3}{1{,}000\ \text{L}} = 7{,}344\ \text{m}^3/\text{day}$$

Step 3– Insert known values and solve:

$$\text{Return rate} = \frac{\text{Return flow rate}}{\text{Influent flow rate}} \times 100 = \frac{7{,}344\ \text{m}^3/\text{day}}{9{,}500\ \text{m}^3/\text{day}} \times 100 = 77\%$$

Return Sludge Rate – Solids Balance

The equations are

$$\text{Recycle Flow (RAS)} = \frac{\text{Flow into aeration basin} \times \text{MLSS, mg/L}}{\text{return activated sludge, mg/L} - \text{mixed liquor suspended solids, mg/L}}$$

Or

$$\text{Recycle flow (RAS)} = \frac{\text{flow}}{\frac{100}{(\text{MLSS, \%} \times \text{SVI}) - 1}} \text{ or } \frac{\text{flow}}{.01 \times [(\text{MLSS, \%} \times \text{SVI}) - 1)]}$$

For US units flow is in Million Gallons per Day for metric unit flow is in cubic metres per day

Calculate the return activated sludge rate for a treatment plant given the following data:

Flow: 3.2 MGD (12,000 m^3/day)	**MLSS = 2,400 mg/L**
Return activated sludge: 3,600 mg/L	**SVI = 212**

Insert known values and solve

Equation 1

$$\text{Recycle Flow (RAS)} = \frac{\text{flow} \times \text{MLSS, mg/L}}{\text{RAS, mg/L} - \text{MLSS, mg/L}}$$

$$\text{Recycle Flow (RAS)} = \frac{3.2\ \text{MGD} \times 2{,}400\ \text{mg/L}}{3{,}600\ \text{mg/L} - 2{,}400\ \text{mg/L}} = 6.4\ \text{MGD}$$

$$\text{Recycle Flow (RAS)} = \frac{12{,}000\ \text{m}^3/\text{d} \times 2{,}400\ \text{mg/L}}{3{,}600\ \text{mg/L} - 2{,}400\ \text{mg/L}} = 24{,}000\,\text{m}^3/\text{day}$$

Equation 2

$$\text{Recycle flow (RAS)} = \frac{\text{flow}}{.01 \times [(\text{MLSS, \%} \times \text{SVI}) - 1)]}$$

$$\text{Recycle flow (RAS)} = \frac{3.2\ \text{MGD}}{.01 \times [(0.24\% \times 212) - 1)]} = \frac{3.2\ \text{MGD}}{0.5} = 6.4\ \text{MGD}$$

$$\text{Recycle flow (RAS)} = \frac{12{,}000\ \text{m}^3/\text{day}}{.01 \times [(0.24\% \times 212) - 1)]} = \frac{12{,}000\ \text{m}^3/\text{day}}{0.5} = 24{,}000\,\text{m}^3/\text{day}$$

Slope, %

Wastewater treatment systems occasionally utilize gravity as a driving force to convey wastewater through pipes. Pipes need to be installed at a constant grade (or slope) to ensure that wastewater will flow at the proper velocity required to ensure that solids remain entrained in the water.

Slope is expressed as a decimal value and grade is simply the slope expressed as a percentage. (i.e. a slope of 0.02 is equivalent to a grade of 2%). Solving slope and grade problems will be simplified if a sketch is drawn.

The basic equation for slope (and grade) is:

$$\text{Slope} = \frac{\text{Rise or drop}}{\text{Run}} \ \text{ and } \ \text{Grade, \%} = \frac{\text{Rise or drop}}{\text{Run}} \times 100$$

Calculate the slope / grade of a pipe if it drops 8.2 feet (2.5 meters) in 295 feet (90 meters).

Known: Rise (drop) = 8.2 feet (2.5 m), Run = 295 feet (90 m)

Insert known values and solve

US units

$$\text{Slope} = \frac{\text{Rise or drop}}{\text{Run}} = \frac{8.2\ \text{feet}}{295\ \text{feet}} = 0.028 = 2.8\%$$

Metric units

$$\text{Slope} = \frac{\text{Rise or drop}}{\text{Run}} = \frac{2.5\text{ m}}{90\text{ m}} = 0.028 = 2.8\%$$

An outfall leaves a treatment plant at an elevation 12 metres above sea level. It terminates 4.5 kilometres from the treatment plant at a depth of 80 metres below sea level. What is the grade of the outfall?

Known: Drop = 12m + 80 m = 92 m, Run = 4.5 km = 4,500 m

Insert known values and solve:

$$\text{Grade, \%} = \frac{\text{Rise or drop}}{\text{Run}} \times 100 = \frac{92\text{ m}}{4{,}500\text{ m}} \times 100 = 2\%$$

Solids, mg/L

The ability to calculate the solids content of a sample is a useful tool in measuring process efficiency.

The equation is:

$$\text{Solids} = \frac{\text{dry solids, grams} \times 1{,}000{,}000}{\text{sample volume, mL}}$$

A 100 mL sample of final effluent was filtered through a filter paper that weighed 0.2184 grams. After drying overnight, the filter paper was weighed and found to weigh 0.2188 grams. What was the weight of solids in mg/L?

Step 1 – Calculate the weight of solids captured on the filter paper

$$\text{Weight} = (\text{filter plus solids}) - (\text{filter}) = 0.2188\text{ g} - 0.2184\text{ g} = 0.0004\text{ g}$$

Step 2 – Insert known values and solve

$$\text{Solids} = \frac{\text{dry solids, grams} \times 1{,}000{,}000}{\text{sample volume, mL}} = \frac{0.0004 \times 1{,}000{,}000}{100} = 4\ \text{mg/L}$$

Sludge Density Index (SDI)

The sludge density index is a less commonly used parameter. It reports a value in units of g/mL versus mL/g. (remember, density is measured as weight per unit volume)

Two formulas are available to calculate the sludge density index (SDI)

$$\text{SDI} = \frac{100}{\text{Sludge volume index}} \quad or\ \text{SDI} = \frac{\text{MLSS, g} \times 100\%}{\text{Settled sludge volume, mL/L}}$$

A settleability test on an MLSS sample with a concentration of 2,810 mg/L carried out in a 1 liter graduated cylinder had a settled sludge volume (SSV) of 245 mL The operator calculated that the sludge volume index (SVI) was 87. What is the sludge density index for this sample?

Known: SSV = 245 mL, MLSS = 2,810 mg/L = 2.81 g/L

Insert known values and solve

$$\text{or}\ \ \text{SDI} = \frac{100}{\text{Sludge volume index}} = \frac{100}{87} = 1.15\ \text{g/mL}$$

Or

$$\text{SDI} = \frac{\text{MLSS, g} \times 100\%}{\text{Settled sludge volume, mL/L}} = \frac{2.81\ \text{g} \times 100\%}{245\ \ \text{mL/L}} = 1.15\ \ \text{g/mL}$$

As with SVI the results of the calculation are usually reported as a dimensionless number.

As the examples show, both formulas give the same answer. Operators can choose either method but once a formula is chosen it is recommended that the operator stick with that formula.

Sludge Volume Index (SVI)

The sludge volume index (SVI) and sludge density index (SDI) inform the operator about the way in which activated sludge flocculates and settles in the secondary clarifier. They play a role in determining return sludge rates and mixed liquor suspended solids.

- An SVI less than 80 indicates excellent settling and compacting characteristics
- An SVI between 80 and 150 indicates moderate settling and compacting characteristics
- An SVI greater than 150 indicates poor settling and compacting characteristics

Samples for the settleability and SVI tests should be taken from the end of an actively aerated basin before clarification.

Three equations are commonly used. They are:

$$\text{SVI} = \frac{\text{Settled sludge volume, mL/L} \times 1{,}000\ \text{mg/g}}{\text{Mixed liquor suspended solids, mg/L}}$$

$$\text{SVI} = \frac{\text{Settled sludge volume, mL/L}}{\text{Mixed liquor suspended solids, g/L}}$$

$$\text{SVI} = \frac{\text{settled sludge volume, \%}}{\text{mixed liquor suspended solids, \%}}$$

A settleability test on an MLSS sample in a 1 liter graduated cylinder had a settled sludge volume (SSV) of 245 mL, If the MLSS concentration was 2,810 mg/L what was the sludge volume index?

Known: SSV = 245 mL, MLSS = 2,810 mg/L = 2.81 g/L

Insert known values and solve

$$\text{SVI} = \frac{\text{Settled sludge volume, mL} \times 1{,}000}{\text{Mixed liquor suspended solids, mg/L}} = \frac{245\ \text{mL} \times 1{,}000}{2{,}810\ \text{mg/L}} = 87\ \ \text{mL/g}$$

$$\text{SVI} = \frac{\text{Settled sludge volume, mL/L}}{\text{Mixed liquor suspended solids, g/L}} = \frac{245\ \ \text{mL/L}}{2.81\ \text{g}} = 87\ \ \text{mL/g}$$

The third variation of the SVI equation requires us to convert the settled sludge volume and the MLSS concentration to a per cent value.

$$\text{SSV} = \frac{245 \text{ mL}}{1{,}000 \text{ mL}} \times 100\% = 24.5\%$$

$$\text{MLSS} = 2{,}810 \frac{\text{mg}}{\text{L}} \times \frac{1\%}{10{,}000 \text{ mg/L}} = 0.281\%$$

Insert calculated values and solve

$$\text{SVI} = \frac{\text{settled sludge volume, \%}}{\text{mixed liquor suspended solids, \%}} = \frac{24.5\%}{0.281\%} = 87 \text{ mL/g}$$

Although the units for SVI are in mL/g the results of the calculation are usually reported as a dimensionless number.

As the examples show, all three formulas give the same answer. Operators can chose any formula but once a formula is chosen it is recommended that the operator stick with that formula to avoid confusion.

Percent Solids Capture (Centrifuge)

Knowledge of the % solids capture in centrifuge operation will aid the operator in adjusting the polymer dosage and other operating parameters of the centrifuge.

The equation is:

$$\text{Solids capture\%} = \left[\frac{\text{Cake TS\%}}{\text{Feed Sludge TS\%}}\right] \times \left[\frac{\text{Feed sludge TS\%} - \text{Centrate TSS\%}}{\text{Cake TS\%} - \text{Centrate TSS\%}}\right] \times 100$$

Calculate the percent solids capture for a centrifuge which produces a 24% cake when fed a 3.2% sludge. The centrate has a TSS of 0.45%.

Insert known values and solve.

$$\text{Solids capture\%} = \left[\frac{24}{3.2}\right] \times \left[\frac{3.2 - 0.45}{24 - 0.45}\right] \times 100$$

$$\text{Solids capture\%} = [7.5] \times \left[\frac{2.75}{23.55}\right] \times 100$$

$$\text{Solids capture\%} = 7.5 \times 0.117 \times 100 = 87.58\%$$

Solids Concentration, mg/L

The ability to calculate the solids concentration of a sample is a skill which every treatment plant operator who works in the laboratory must develop. Knowledge of the amount of solids entering, leaving and within a plant is essential for process control and permit compliance.

The formula is:

$$\text{Solids, mg/L} = \frac{\text{Weight of dry solids, g} \times 1{,}000{,}000}{\text{Sample volume, mL}}$$

A 25 mL sample was filtered on a Whatman GF/C 5.5 cm diameter filter. The weight of the filter paper was 0.1785 grams and the weight of the dried filter paper plus retained solids was 0.1833 grams. What was the solids concentration for this sample?

Step 1 – Calculate the weight of dry solids

$$\text{Dry solids} = 0.1833\text{ g} - 0.1785\text{g} = 0.0048\text{ g}$$

Step 2 – Insert calculate value and solve:

$$\text{Solids} = \frac{0.0048\text{ g} \times 1{,}000{,}000}{25\text{ mL}} = 192\text{ mg/L}$$

Solids Loading Rate

Many unit processes are dependent on careful control of solids loading rates to ensure that the ability to maintain aerobic conditions is not overwhelmed by excessive loading (e.g. aerobic digestors, AS processes, lagoons) or that solids handling capabilities are not exceeded (e.g. thickeners).

The equations are:

$$\text{Solids loading rate, lb/day/ft}^2 = \frac{\text{solids applied, lb/day}}{\text{Surface area, ft}^2}$$

$$\text{Solids loading rate, kg/day/m}^2 = \frac{\text{solids applied, kg/day}}{\text{Surface area, m}^2}$$

A gravity thickener receives 106,000 gallons (400 cubic metres) of 2% primary sludge per day. Calculate the solids loading rate if the thickener is 30 feet (9 metres) in diameter.

US units

Step 1 – Calculate pounds of solids applied per day

$$\text{Solids applied} = 0.106\text{ MGD} \times 20{,}000\text{ mg/L} \times 8.34\text{ lb/gal} = 17{,}681\text{ pounds}$$

Step 2 – Calculate surface area of thickener

$$\text{Area} = 0.785(\text{D})^2 = 0.785\ (30\text{ ft})^2 = 70.65\text{ft}^2$$

Step 3 – Insert known values and solve:

$$\text{Solids loading rate} = \frac{\text{solids applied, lb/day}}{\text{Surface area, ft}^2} = \frac{17{,}681\text{ lb/day}}{70.65\text{ft}^2} = 250\text{ lb/day/ft}^2$$

Metric units

Step 1 – Calculate pounds of solids applied per day

$$\text{Solids applied} = 20{,}000\text{ mg/L} \times 0.4\text{ ML} = 8{,}000\text{ kg}$$

Step 2 – Calculate surface area of thickener

$$\text{Area} = 0.785(\text{D})^2 = 0.785\ (9\text{m})^2 = 63.6\text{m}^2$$

Step 3 – Insert known values and solve:

$$\text{Solids loading rate} = \frac{\text{solids applied, kg/day}}{\text{Surface area, m}^2} = \frac{8{,}000\text{ kg/day}}{63.6\text{m}^2} = 126\text{ kg/day/m}^2$$

Solids Retention Time

The ABC/EOCP formula/conversion table states: "*see Mean Cell Residence Time*". As explained below, the two calculations are not equal and will return different results. As long as all parties using the data derived are using the same formula the difference will not matter.

Like the MCRT equation, solids retention time is a subtractive process as it monitors solids lost from the process. It is slightly less accurate than the MCRT as it does not take into account solids lost in the final effluent or solids held in the secondary clarifier.

It is an important design and operating parameter with values normally expressed in days.

The equations are:

$$\text{Solids Retention Time (SRT), days} = \frac{\text{MLSS under aeration, lb}}{\text{WAS, lb/day}}$$

$$\text{Solids Retention Time (SRT)} = \frac{\text{MLSS, mg/L} \times \text{Aeration basin volume, m}^3}{\text{WAS, mg/L} \times \text{WAS Flow, m}^3\text{/day}}$$

The aeration basin at a treatment plant contains 0.52 MG (2,000 m^3) of MLSS with a concentration of 2,400 mg/L. The operator has set the waste rate at 0.085 MGD (325 m^3/day). The WAS has a concentration of 4,800 mg/L. What is the solids retention time?

US units

Step 1 – Calculate the pounds of MLSS under aeration

$$\text{lb MLSS} = 2{,}400\,\text{mg/L} \times 0.52\text{ MG} \times \frac{8.34\,lb}{gal} = 10{,}408.3\text{ lb}$$

Step 2 – Calculate the kg of WAS waste per day

$$\text{lb WAS wasted} = \frac{4{,}800\text{ mg}}{\text{L}} \times \frac{0.085\text{ MG}}{\text{day}} \times \frac{8.34\text{ lb}}{\text{gal}} = 3{,}402.7\text{ lb/day}$$

Step 3 – Insert known values and solve:

$$\text{SRT} = \frac{\text{lb MLSS under aeration}}{\text{lb WAS wasted/day}} = \frac{10408.3\text{ lb}}{3{,}402.7\ \text{ lb/day}} = 3\text{ days}$$

Metric units

Step 1 – Calculate the kg of MLSS under aeration

$$\text{kg MLSS} = 2{,}400\,\text{mg/L} \times 2.0\text{ ML} = 4{,}800\text{ kg}$$

Step 2 – Calculate the kg of WAS waste per day

$$\text{kg WAS wasted} = \frac{4{,}800\text{ mg}}{\text{L}} \times \frac{325\text{ m}^3}{\text{day}} \times \frac{1\text{ kg}}{10^6\text{ mg}} \times \frac{10^3\text{L}}{\text{m}^3} = 1{,}560\text{ kg/day}$$

Step 3 – Insert known values and solve:

$$\text{SRT} = \frac{\text{kg MLSS under aeration}}{\text{kg WAS wasted/day}} = \frac{4{,}800\text{ kg}}{1{,}560\text{ kg/day}} = 3\text{ days}$$

Specific Gravity

Specific Gravity and Density

Specific gravity is a measure that compares the density of a substance to another. The basis for comparison for liquids and solids is water which has a density of 1 gram per cubic centimetre.

The specific gravity of a substance will determine whether it will sink (sp gr >1) or float (sp gr <1) and can therefore be removed through sedimentation or floatation.

The density of a substance is a measure of its mass for a given volume. It is usually expressed in units of grams per cubic centimetre (g/cm^3) or kilograms per cubic metre (kg/m^3).

The formulas are:

$$\text{Specific gravity} = \frac{\text{Specific weight of substance, lb/gal}}{8.34\ \text{lb/gal}}$$

$$\text{Specific gravity} = \frac{\text{Specific weight of the substance, kg/L}}{1\ \text{kg/L}}$$

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

Specific Gravity of Liquids

How much will the contents of a 54 gallon (205 L) drum full of sodium hypochlorite weigh if the specific gravity of solution is 1.19?

US units

$$\text{Specific gravity} = \frac{\text{Specific weight of substance, lb/gal}}{8.34\ \text{lb/gal}}$$

Step 1 – Rearrange the formula to solve for weight

$$\text{Weight of substance} = \text{Specific gravity} \times \text{volume, gallons} \times \frac{8.34\ \text{lb}}{\text{gallon}}$$

$$\text{Weight of substance} = 1.19 \times 54\ \text{gallons} \times \frac{8.34\ \text{lb}}{\text{gallon}} = 535.9\ \text{pounds}$$

Metric units

$$\text{Specific gravity} = \frac{\text{Mass of the substance, kg/L}}{\text{Mass of 1 litre of water}}$$

Step 1 – rearrange the formula to solve for mass.

$$\text{Mass} = \text{Specific gravity} \times 1\ \text{kg/L} \times \text{Volume} = 1.19 \times \frac{1\ \text{kg}}{\text{L}} \times 205\ \text{L} = 244\ \text{kg}$$

Specific Gravity of Solids

A piece of metal that weighs 62.6 pounds (28.4 kilograms) in air is weighed in water and found to weigh 42.3 pounds (19.2 kilograms). What is the specific gravity of this metal?

Step 1 – Subtract the weight in water from the weight in air to determine the loss of weight in water

Weight loss = 62.6 pounds – 42.3 pounds = 20.3 pounds of weight loss in water

Weight loss = 28.4 kg – 19.2 kg = 9.2 kg of weight loss in water

Step 2 – Find the specific gravity by dividing the weight of the metal in air by the weight loss in water

$$\text{Specific gravity} = \frac{\text{Weight of the substance in air}}{\text{Loss of weight in water}} = \frac{62.6 \text{ pounds}}{20.3 \text{ pounds}} = 3.08$$

$$\text{Specific gravity} = \frac{\text{Weight of the substance in air}}{\text{Loss of weight in water}} = \frac{28.4 \text{ kg}}{9.2 \text{ kg}} = 3.08$$

Density

A substance weighs 11.3 ounces (321 grams) and occupies a volume of 9.76 cubic inches (160 mL). What is its density in pounds per cubic foot (g/cm^3)?

Insert known values and solve

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} = \frac{11.3 \text{ ounces} \times \frac{1 \text{ pound}}{16 \text{ ounces}}}{9.76 \text{ in}^3 \times \frac{1 \text{ ft}^3}{1{,}728 \text{in}^3}} = \frac{0.706 \text{ lb}}{0.0056 \text{ ft}^3} = 126 \text{ lb/ft}^3$$

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} = \frac{321 \text{ g}}{160 \text{ cm}^3} = 2.0 \text{ g/cm}^3$$

Specific Oxygen Uptake Rate or Respiration Rate, mg/g/hr

The Specific Oxygen Uptake Rate (SOUR), also known as the oxygen consumption or respiration rate, is defined as the milligrams of oxygen consumed per gram of volatile suspended solids (VSS) per hour.

The equation is:

$$\text{SOUR} = \frac{\text{SOUR, mg/L/min (60min)}}{\text{MLVSS, g/L (1 hr)}}$$

The expanded equation below provides a path to deriving the values required to solve for the SOUR

$$\text{SOUR} = \frac{\text{Initial DO, mg/L} - \text{Final DO, mg/L}}{\text{elapsed time, minutes}} \times \frac{60 \text{ minutes}}{\text{hour}} \times \frac{1{,}000 \text{ mg/g}}{\text{MLVSS, mg/L}}$$

Calculate the specific oxygen uptake rate (SOUR) of a sample with a volatile solids concentration of 2,400 mg/L if the initial dissolved oxygen concentration was 4.4 mg/L and the final dissolved oxygen concentration was 2.1 mg/L after 10 minutes

Insert known values and solve:

$$\text{SOUR} = \frac{\text{Initial DO, mg/L} - \text{Final DO, mg/L}}{\text{elapsed time, minutes}} \times \frac{60 \text{ minutes}}{\text{hour}} \times \frac{1{,}000 \text{ mg/g}}{\text{MLVSS, mg/L}}$$

$$\text{SOUR} = \frac{4.4 \text{ mg/L} - 2.1 \text{ mg/L}}{10 \text{ minutes}} \times \frac{60 \text{ minutes}}{\text{hour}} \times \frac{1{,}000 \text{ mg/g}}{2{,}400 \text{ mg/L}} = 5.75 \text{ mg/O}_2\text{/g MLVSS/hour}$$

Surface Loading Rate (aka Surface Overflow Rate)

The surface loading rate (sometimes called the surface overflow rate [SOR] or the rise rate) is another measure used to determine the loading on a clarifier. As the SOR increases the velocity with which the water moves up and out of the clarifier increases and particles which may settle slowly can be carried over the weir leading to a decrease in effluent quality and percent removal rates.

Surface overflow rates are typically expressed in units of volume/time/area (e.g. gallons/day/square foot, litres/second/square metre or cubic metres/day/square metre).

The equation is:

$$\text{Surface overflow rate (SOR)} = \frac{\text{Flow}}{\text{Surface area}} = \frac{\text{Flow, gpd}}{\text{Surface area, ft}^2} = \frac{\text{Flow, Lpd}}{\text{Surface area, m}^2}$$

It is written:

$$\text{SOR} = \frac{\text{Q}}{\text{A}}$$

What is the surface overflow rate in a basin that is 121 feet (37 metres) long and 36 feet (11 metres) wide if the flow is 1.3 MGD (4,921 cubic metres) per day?

Known: Length = 121 ft., width = 36 ft., Flow = 1.3 MGD= 1,300,000 gallons/day

Known: Length = 37 m, width = 11 m, Flow = 4,921 m^3/day

US units

Step 1 – Calculate area of basin:

$$\text{Area} = \text{L} \times \text{W} = 121\ \text{ft} \times 36\ \text{ft} = 4{,}356\ \text{ft}^2$$

Insert known values and solve

$$\text{Surface overflow rate (SOR)} = \frac{\text{Flow}}{\text{Surface area}} = \frac{1{,}300{,}000\ \text{gpd}}{4{,}356\ \text{ft}^2} = 298.4\ \text{gal/ ft}^2\text{/day}$$

Metric units

Step 1 – Calculate area of basin:

$$\text{Area} = \text{L} \times \text{W} = 37\ \text{m} \times 11\ \text{m} = 407\ \text{m}^2$$

Insert known values and solve

$$\text{Surface overflow rate (SOR)} = \frac{\text{Flow}}{\text{Surface area}} = \frac{4{,}921\ \text{m}^3\text{/day}}{407\ \text{m}^2} = 12.1\ \text{m}^3\text{/ m}^2\text{/day}$$

Two and Three Normal Equation

These equations are known as the dilution equations as they are used to make up solutions by either diluting a concentrated solution with water or by mixing two solutions of known concentration to form a third solution with a concentration somewhere between the concentrations of the stock solutions.

Concentration may be expressed as moles of a chemical, the normality of the chemical, the percent (%) concentration of the chemical or the concentration in milligrams per litre.

When using two and three normal equations, the values being compared must be of the same units. i.e. if C_1 is in mg/L then C_2 must also be in mg/L.

The formula for a two normal equation is:

$$(C_1 \times V_1) = (C_2 \times V_2)$$

Where C = Concentration and V = Volume

The formula for a three normal equation is:

$$(C_1 \times V_1) + (C_2 \times V_2) = (C_3 \times V_3)$$

Where C = Concentration and V = Volume

Two normal equation

What volume of a 5% solution will be required to make up 80 mL of a 0.4% solution?

Step 1 – Rearrange the standard equation to solve for the unknown.

$$(C_1 \times V_1) = (C_2 \times V_2)$$

$$0.4\% \times 80\text{ mL} = 5\% \times ?\text{ mL}$$

$$?\text{ mL} = \frac{0.4\% \times 80\text{ mL}}{5\%} = 6.4\text{ mL}$$

Three normal equation

An operator mixes 15 mL of a 1 Normal solution with 30 mL of a 2.5 Normal solution. What is the Normality of the resulting 45 mL of solution?

$$(C_1 \times V_1) + (C_2 \times V_2) = (C_3 \times V_3)$$

Step 1 – insert known values

$$(1\text{ N} \times 15\text{ mL}) + (2.5\text{N} \times 30\text{ mL}) = (?\text{ N} \times 45\text{ mL})$$

$$15 + 75 = 45?$$

$$\text{Normality of final solution} = \frac{90}{45} = 2.0\text{ N}$$

Dilution Calculations

Sometimes we want to dilute a chemical (typically sodium or calcium hypochlorite) by mixing it with water or, less frequently, by mixing two different concentrations of a chemical together to produce a new concentration somewhere between the two. There are a number of formulae that can be used

Dilution Box

The dilution box is a useful tool for solving dilution problems when two solutions of different strength are being used to make a third solution of a desired strength.

t is especially useful when an exact amount of the new product is desired. The dilution box is set up as follows:

A → C → D   D = B – C = parts of A required

B → C → E   E = A – C = parts of B required

D + E   = Total Parts required

In the dilution box method, the two numbers on the left (A, B) represent the known concentrations. The number in the center (C) represent the desired concentration. The numbers on the right (D,E) are determined by subtracting diagonally the existing concentrations from the desired concentration. Ignore any negative values as a result of the subtractions.

How many liters of a 15% solution must be mixed with a 2.1% solution to make exactly 2,500 liters of an 8% solution?

Step 1 – Set up the dilution box

15%		5.9	5.9 parts of the 15% solution are required for every 12.9 parts
	8%		
2.1%		7.0	7.0 parts of the 2.1% solution are required for every 12.9 parts
		12.9	total parts

Step 2 – Solve for volumes needed

$$\frac{(5.9\text{ parts})(2{,}500\text{L})}{12.9\text{ parts total}} = 1{,}143\text{ L of the 15\% solution}$$

$$\frac{(7.0\text{ parts})(2{,}500\text{L})}{12.9\text{ parts total}} = 1{,}357\text{ L of the 2.1\% solution}$$

To make 2,500 L of 8% solution, mix 1,143 L of 15% solution and 1,357 L of 2.1% solution

Dilution using water

The Chlorine Institute provides a formula for diluting sodium hypochlorite solutions

$$\text{V} = \text{X} \times \text{H} \times \frac{\text{A} - \text{B}}{\text{B}}$$

Where:
- A = Weight percent of initial (strong) sodium hypochlorite solution
- B = Weight percent of desired (diluted) sodium hypochlorite solution
- X = Litres of initial (strong) sodium hypochlorite solution
- H = Specific gravity of initial (strong) sodium hypochlorite solution
- V = Volume in litres of water required for dilution of initial (strong) sodium hypochlorite solution

How many litres of water will be required to dilute a 20 L pail of 12% sodium hypochlorite to 4% sodium hypochlorite? (12% NaOCl has a specific gravity of 1.16)

Known: A = 12%, B = 4%, X = 20 L, H = 1.16

Insert known values and solve

$$\text{V} = \text{X} \times \text{H} \times \frac{\text{A} - \text{B}}{\text{B}} = 20\text{ L} \times 1.16 \times \frac{12\% - 4\%}{12\%} = 15.46\text{ L}$$

Threshold Odour Number (TON)

This a method is for the determination of odor in drinking water. A sample is diluted with odor-free water until the least definitely perceptible odor is detected by the test panel. There is no absolute threshold odor concentration, because of inherent variations in individual olfactory capability. A given person varies in sensitivity over time.

The comparisons are made at a temperature of 60°C. The odor at the threshold point is expressed quantitatively by the threshold odor number (TON). This threshold method is applicable to samples ranging from nearly odorless natural waters to industrial wastes with threshold numbers in the thousands.

The formula is:

$$\text{Threshold Odour Number} = \frac{\text{A} + \text{B}}{\text{A}}$$

Where A = the volume of the odour causing sample and B = the volume of odour free water.

Because the sum of A+B always equals 200 the formula can be restated as

$$\text{Threshold Odour Number} = \frac{200}{\text{A}}$$

A 50 mL sample when added to 150 mL of odour free water produces no detectable odour. What is the odour threshold number for this sample?

$$\text{Threshold Odour Number} = \frac{\text{A} + \text{B}}{\text{A}} = \frac{50 + 150}{50} = 4$$

Total Solids, %

The total solids test returns a value for both suspended and dissolved solids in a sample. The test is performed by evaporating the contents of an evaporating dish, drying the dish at 103°C and then weighing the dish and the residue it contains.

The formula is:

$$\text{Total Solids, \%} = \frac{(\text{dried weight, g}) - (\text{tare weight, g})}{(\text{wet weight, g}) - (\text{tare weight, g})} \times 100$$

What was the percent total solids content of a sample given the following data: Tare weight = 43.7g, Wet weight = 70.8g, Dried weight = 44.1g

$$\text{Total Solids, \%} = \frac{(\text{dried weight, g}) - (\text{tare weight, g})}{(\text{wet weight, g}) - (\text{tare weight, g})} \times 100$$

Insert known values and solve

$$\text{Total Solids, \%} = \frac{(44.1\text{ g}) - (43.7\text{ g})}{(70.8\text{ g}) - (43.7\text{ g})} \times 100 = \frac{0.4\text{ g}}{27.1\text{ g}} \times 100 = 1.47\%$$

Velocity

Knowledge of the velocity of wastewater is useful in determining the detention time in sewers, the design of grit channels and the efficiency of primary clarifiers.

Four equations are given for calculation of velocity. They are:

$$\text{Velocity} = \frac{\text{Flow rate, ft}^3\text{/second}}{\text{Area, ft}^2} \quad \text{or} \quad \frac{\text{Flow rate, m}^3\text{/second}}{\text{Area, m}^2}$$

These equations are simply a rearrangement of the classic flow equation (Flow=Area × Velocity)

The second group of equations introduce the factors of distance and time.

$$\text{Velocity} = \frac{\text{Distance, ft}}{\text{Time, seconds}} \quad \text{or} \quad \frac{\text{Distance, m}}{\text{Time, seconds}}$$

What is the velocity of water in a pipe with a diameter of 8 inches (200 mm) if the water flow rate is 254 gallons per minute (16 L/s)? (assume that the pipe is flowing full)

US units

Step 1 – Calculate the cross-sectional area of the pipe in square feet

$$\text{Area} = 0.785(\text{D})^2 = 0.785(0.66\text{ ft})^2 = 0.35\text{ft}^2$$

Step 2 – Convert flow to cubic feet per second

$$\text{Flow rate} = \frac{254\text{ gallons}}{\text{minute}} \times \frac{1\text{ minute}}{60\text{ seconds}} \times \frac{1\text{ ft}^3}{7.48\text{ gallons}} = 0.57\text{ ft}^3\text{/sec}$$

Step 3 - Insert known values and solve

$$\text{Velocity} = \frac{\text{Flow rate, ft}^3\text{/second}}{\text{Area, ft}^2} = \frac{0.57\text{ ft}^3\text{/sec}}{0.35\text{ft}^2} = 1.6\ \text{ft/sec}$$

Metric units

Step 1 – Calculate the area of the pipe in square metres.

$$\text{Area} = \pi \times (\text{radius})^2 = 3.14 \times 0.1\text{ m} \times 0.1\text{ m} = 0.0314\text{ m}^2$$

Step 2 – Convert flow rate to cubic metres per second

$$\text{Flow rate} = \frac{16\text{ L}}{\text{sec}} \times \frac{1\text{ m}^3}{1{,}000\text{ L}} = 0.016\ \text{m}^3\text{/sec}$$

Step 3 - Insert known values and solve

$$\text{Velocity} = \frac{\text{Flow rate, m}^3\text{/second}}{\text{Area, m}^2} = \frac{0.016\ \text{m}^3\text{/s}}{0.0314\text{ m}^2} = 0.51\ \text{m/s}$$

Dye is introduced into a sewer. Two minutes later the dye is observed at a manhole 300 feet (91 metres) downstream. What is the velocity of the wastewater in the sewer?

$$\text{Velocity} = \frac{\text{Distance, ft}}{\text{Time, seconds}} \quad \text{or} \quad \frac{\text{Distance, m}}{\text{Time, seconds}}$$

US units

$$\text{Velocity} = \frac{\text{Distance, ft}}{\text{Time, seconds}} = \frac{300 \text{ feet}}{120 \text{ seconds}} = 2.5 \text{ ft/second}$$

Metric units

$$\text{Velocity} = \frac{\text{Distance, m}}{\text{Time, seconds}} = \frac{91 \text{ metres}}{120 \text{ seconds}} = 0.76 \text{ m/sec}$$

Sometimes this questions is framed such that the first of the dye was observed at 110 seconds and the last of the day at 130 seconds. In this case, time becomes the average of the two observations i.e. $(T_1 + T_2) \div 2$

Percent Volatile Solids (Percent (%) Removal Calculation)

After the solids equation, the percent removal calculation is one the most commonly calculated values.

Percent removal calculations whether for BOD_5, TSS or VSS inform the operator of the efficiency of the unit process and provide information on the impact of the material removed on the next downstream process. (E.g. thickeners, digestors or dewatering equipment). The percent removal statement may sometimes be worded as percent reduction.

The equation is

$$\% \text{ removal efficiency} = \frac{(\text{parameter in} - \text{parameter out})}{\text{parameter in}} \times 100 \text{ or } \frac{(\text{in} - \text{out})}{\text{in}} \times 100$$

What is the removal efficiency of a primary clarifier if the influent TSS are 195 mg/L and the effluent TSS are 82 mg/L?

Known: Influent TSS =195 mg/L, effluent TSS = 82 mg/L

Insert known values and solve

$$\text{removal efficiency} = \frac{(\text{in} - \text{out})}{\text{in}} \times 100 = \frac{(195 \text{ mg/L} - 82 \text{ mg/L})}{195 \text{ mg/L}} \times 100 = 57.9\%$$

The equation is also used in the laboratory to calculate the volatile solids fraction of a suspended solids sample using a muffle furnace. The concept is the same, the words are different

The equation is:

$$\text{Volatile solids, \%} = \frac{(\text{Dry solids, g} - \text{Residue, g})}{\text{Dry solids, g}} \times 100$$

Calculate the % volatiles solids if the weight of the filter paper and ash is 1.293 grams and the weight of the filter paper and dry solids was 3.518 grams

$$\text{Volatile solids, \%} = \frac{(3.518 \text{ g} - 1.293 \text{ g})}{3.518 \text{ g}} \times 100 = \frac{2.225 \text{ g}}{3.518\text{g}} \times 100 = 63.2\%$$

Water Use

Designers of wastewater treatment plants will select a gallons or litres per capita per day flow as a data point in the design of a plant. Operators can compare the population served to the flow to determine whether infiltration and inflow is increasing or decreasing over time.

The formulas are:

$$\text{Gallons per capita per day , gpcd} = \frac{\text{Volume of wastewater treated, gal/day}}{\text{Population served.}}$$

$$\text{Litres per capita per day , Lpcd} = \frac{\text{Volume of wastewater treated, L/day}}{\text{Population served.}}$$

A small package treatment plant receives a flow of 317,000 gallons per day (1,200 m^3/day) from a population of 3,750. What is the per capita per day flow?

US units

$$\text{Gallons per capita per day , gpcd} = \frac{317{,}000\text{, gal/day}}{3{,}750} = 84 \text{ gpcd}$$

Metric units

$$\text{Litres per capita per day , Lcd} = \frac{1{,}200 \text{ m}^3 \times 1{,}000 \text{ L/m}^3}{3{,}750} = 320$$

Weir Overflow Rate

The weir overflow rate is one of the measures used to determine the loading on a clarifier. As overflow rates increase the velocity with which the water moves over the weir increases and particles which may settle slowly can be carried over the weir leading to a decrease in effluent quality and percent removal rates. Weir overflow rates are typically expressed in units of volume/time/length (e.g. gallons/day/foot, litres/second/metre or litres/day/metre).

The formulas for the weir overflow rate (WOR) are:

$$\text{Weir overflow rate} = \frac{\text{Flow}}{\text{Weir length}} = \frac{\text{Flow, gpd}}{\text{Weir length, ft}} \; or \; \frac{\text{Flow, Lpd}}{\text{Weir length, m}}$$

A rectangular clarifier has a total weir length of 200 feet (60.9 metres). What is the WOR if the daily flow is 110,952 gallons (4,200 m^3) per day?

US units

Insert known values and solve

$$\text{Weir overflow rate} = \frac{\text{Flow}}{\text{Weir length}} = \frac{110{,}952 \text{ gal/day}}{200 \text{ ft}} = 554.8 \text{ gal/ft/day}$$

Metric units

Step 1 – convert flow from cubic metres per day to liters per day

$$\text{Flow} = \frac{4{,}200\ \text{m}^3}{\text{day}} \times \frac{1{,}000\ \text{L}}{\text{m}^3} = 420{,}000\ \text{L/day}$$

Insert known values and solve

$$\text{Weir overflow rate} = \frac{\text{Flow}}{\text{Weir length}} = \frac{420{,}000\ \text{L/day}}{60.9\ \text{m}} = 6{,}896\ \ \text{L/m/day}$$

A circular clarifier has a diameter at the weir of 32 metres. If the daily flow is 7,600 cubic metres per day what is the WOR in cubic metres/day/metre of weir length?

Known: Diameter = 32 m, Flow = 7,600 m^3/day

Step 1 – Calculate the weir length

$$\text{Circumference} = \ \pi\text{d} = 3.14 \times 32\ \text{m} = 100.5\ \text{m}$$

Insert known values and solve

$$\text{Weir overflow rate} = \frac{\text{Flow}}{\text{Weir length}} = \frac{7{,}600\ \ \text{m}^3/\text{day}}{100.5\ \text{m}} = 75.6\ \ \text{m}^3/\text{m}/\text{day}$$

End Note

So there you have it, a tour through the mathematical formulas commonly used in our industry. Every mathematical question you will find on a certification exam can be solved using one of or a combination of these formulas.

Some of you will find other ways to arrive at the correct answer and the formula you use will be valid and, if it works for you, use it. Other texts and resources may also provide different ways of arriving at a solution and they too are valid and useful ways to solve a problem.

For those of you who like switching back and forth between US and metric units, handheld metric conversion calculators can be purchased from Canon (Model FC-43S) and Sharp (Elsimate EL-344R) at most office supply stores or on-line.