Dosages for Adjusting Alkalinity

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Inaccuracies in currently published swimming pool alkalinity dosage charts are described, and corrected charts are presented, along with calculations for verifying the correct values.

As a result of a project previously undertaken by the authors (Skinner 1994), the need has been manifested for accurate dosage charts for use when adjusting alkalinity by the addition of common acids or bases. A large number of the existing charts in publication contain unacceptable margins of error. More accurate charts have been developed and appear hereafter, along with explanations of the method for calculating the correct amounts, possible reasons for the inaccuracy in previous charts, and recommendations for the appropriate use of some of the base chemicals.

Please note that, in the interests of accuracy, amounts in all charts have been rounded to the nearest one–hundredth. Obviously these small fractions are not expected to be metered in the field.

Also, note that when chemicals are added, the amount of alkalinity increase or decrease is constant – it is not dependent on the method of application used (i.e.: concentrated vs. diluted addition). The reason that more acid is required on these charts than on existing charts is related, not to application concerns, but to inappropriate calculations used in the past, as described below.

Muriatic Acid

The majority of charts currently published for use in ascertaining the dosage required for decreasing alkalinity with muriatic acid understate the amount of acid required by approximately 20% (Dickman *pH* 57; Mitchell 34; *Pool* 23). The accurate amounts appear in the following chart. The calculation used to develop this chart is based on the fact that muriatic acid, as commonly used in the swimming pool industry, is a 31.45% aqueous solution of hydrochloric acid (HCl). Interestingly, concentrated HCl, as used in the laboratory, is a 37% aqueous HCl solution... about 20% stronger than pool acid! It is logical to postulate, then, that at some point or points in the past a chemist was asked to develop a chart for alkalinity reduction, and that the chemist used the laboratory formulation, rather than the pool formulation as a guide. As evidenced by the proliferation of charts manifesting the 20% error, the 37% standard was either used by more than one chemist, or the finished chart was repeatedly adopted by others.

There are several methods which can be used for calculating the correct dosage amount. For instance, one part per million alkalinity, divided by the atomic weight of calcium carbonate multiplied by 1000, multiplied by the twice the atomic weight of hydrochloric equals the amount per liter, in milliliters, to add per 1 ppm decrease desired:

$$\frac{1}{(100.09)(1000)} \times 2(36.453) = 0.000728404$$

This amount divided by the strength of the HCl solution

$$0.000728404 \div .3145 = 0.002316069$$

and then divided by the specific gravity of the solution

$$0.002316069 \div 1.16 = 0.001996611$$

then multiplied by the number of liters in a 20,000 gallon pool

$$0.001996611 \times 75{,}706 = 151.1554323$$

and then multiplied by the conversion factor for milliliters to liters

$$151.1554323 \div 1000 = 0.151155432$$

and the conversion factor for liters to quarts

$$0.151155432 \times 1.0567 = 0.159725944$$

shows that (a rounded amount of) 0.16 quarts muriatic acid is required for a 1 ppm alkalinity reduction in

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a 20,000 gallon pool.

Once this 0.16 number is arrived at, two options are available for more practical in–the–field use: either to develop a simplified formula which can be used each time acid is to be added, or to develop a correct version of the familiar dosage chart by extrapolating the 0.16/20,000 ratio for other chemical doses/volumes.

To develop the accompanying chart, a simplified, generic version of the equation was developed, which can also be used directly for dosing in the field. In this version, the pool volume is divided by a special divisor unique to the specific product being used (125,000 for muriatic acid) and then multiplied by the change desired (in ppm), which equals the amount of chemical (in quarts, for muriatic acid) to add. The special divisor can be found via the following formula:

$$\frac{(1\text{ qt.})(.946\ {}^{L}/_{qt})(.3145\ \%HCl)(1.16\text{ spec. grav.})(1000\ {}^{g}/_{kg})}{36.46g\ {}^{HCl}/_{mole}}$$

= 9.466 moles

$$\frac{(9.466\text{ moles})(100.09{}^{g}/_{eq}\ CaCO_3)(1000{}^{mg}/_{g})}{(2\text{ eq HCl/eq }CaCO_3)(1\text{ ppm change})(3.785\ {}^{L}/_{gal})}$$

= 125158.7768 (the divisor for muriatic acid)

This divisor can also be arrived at by reversing part of the first set of equations: by dividing the sample volume (20,000 gallons) by the 1 ppm dosage (0.16). The resultant generic formula for adjusting alkalinity with muriatic acid (and the other chemicals discussed below) appears in Table 1.

It may be important to note here that there are recommended limits to the amount of muriatic acid that should be added in a single application. By showing the correct dosages to accomplish an overall alkalinity change using muriatic acid it is not the authors' intent to encourage exceeding recommended maximum single–application dosages. Also, for these and other calculations, the authors have relied on the MSDS sheets in their possession for the basic chemical data, which for muriatic acid are: formulation (HCl), weight (36.453), specific gravity (1.16), and solution strength (31.45%).

Sodium Bisulfate

Sodium bisulfate, commonly referred to by service technicians as "dry acid", is often used in the swimming pool industry, since it may be easier to apply in a safe manner. Sodium bisulfate for use in pools is a powder which is usually 94.5% sodium bisulfate ($NaHSO_4$). Since the charts typically published for sodium bisulfate also include a 20% understatement, plus what appear to be minor conversion errors, it may be assumed that the author(s) of the chart made a conversion from the muriatic chart, rather than calculating directly from $NaHSO_4$ (Dickman *pH* 58; Mitchell 34; *Pool* 22). The combination of these errors combines to create as much as a 30% total error in the entire chart. The following are the correct equations, where one part per million alkalinity, divided by the atomic weight of calcium carbonate multiplied by 1000, multiplied by the twice the atomic weight of sodium bisulfate equals the amount per liter, in grams, of 100% sodium bisulfate to add per ppm increase desired:

$$\frac{1}{(100.09)(1000)} \times 240.1112 = 0.002398952$$

This amount multiplied by the conversion factor to convert from grams to pounds

$$0.002398952 \times 0.00220462 = 0.000005288$$

and then multiplied by the number of liters in a 20,000 gallon pool

$$0.000005288 \times 75{,}706 = 0.400333328$$

and then divided to compensate for the 94.5% strength

$$0.400333328 \div .945 = .423633151 \text{ pounds}$$

shows that .42 pounds sodium bisulfate is required for a 1 ppm alkalinity drop in a 20,000 gallon pool.

Even producing a sodium bisulfate chart is problematical – concentration strengths of various brands of sodium bisulfate vary, ranging typically from 88% to 95%, so in–the–field results will be inconsistent unless the same exact concentration strength is used every time. One packager whose product was used in the verification of this study even labels different sized containers of sodium bisulfate at different strengths – 9½ pound containers at 88%, and 1½ pound containers at 94.5% – meaning either that they package different strengths of product for different sized containers, or that one or the other container is mislabeled. Their MSDS provided to the distributor only cites the 88% strength. The MSDS in the authors' possession that was used for these equations uses the more common 94.5% figure.

Again, a simplified version of the equation has been presented for use in developing the chart and for use in the field: the pool volume divided by 47,058 and then multiplied by the change desired (in ppm) equals the amount of chemical (in pounds) to add. Note that the actual division of 20,000 by 0.42 yields 47,619. However, this divisor results in inconvenient fractions, so the divisor has been slightly adjusted for convenience.

Lowering Alkalinity Using Muriatic Acid

Gallons

ppm	1,000	5,000	10,000	15,000	20,000	25,000	50,000
10	2.56 oz.	0.80 pts.	0.80 qts.	1.20 qts.	1.60 qts.	2.00 qts.	1.00 gal.
20	5.12 oz.	1.60 pts.	1.60 qts.	2.40 qts.	3.20 qts.	1.00 gal.	2.00 gal.
30	7.68 oz.	1.20 qts.	2.40 qts.	3.60 qts.	1.20 gal.	1.50 gal.	3.00 gal.
40	10.24 oz.	1.60 qts.	3.20 qts.	1.20 gal.	1.60 gal.	2.00 gal.	4.00 gal.
50	12.80 oz.	2.00 qts.	1.00 gal.	1.50 gal.	2.00 gal.	2.50 gal.	5.00 gal.
60	15.36 oz.	2.40 qts.	1.20 gal.	1.80 gal.	2.40 gal.	3.00 gal.	6.00 gal.
70	1.12 pts.	2.80 qts.	1.40 gal.	2.10 gal.	2.80 gal.	3.50 gal.	7.00 gal.
80	1.28 pts.	3.20 qts.	1.60 gal.	2.40 gal.	3.20 gal.	4.00 gal.	8.00 gal.
90	1.44 pts.	3.60 qts.	1.80 gal.	2.70 gal.	3.60 gal.	4.50 gal.	9.00 gal.
100	1.60 pts.	1.00 gal.	2.00 gal.	3.00 gal.	4.00 gal.	5.00 gal.	10.00 gal.

Lowering Alkalinity Using Sodium Bisulfate

Gallons

ppm	1,000	5,000	10,000	15,000	20,000	25,000	50,000
10	0.21 lbs.	1.06 lbs.	2.13 lbs.	3.19 lbs.	4.25 lbs.	5.31 lbs.	10.63 lbs.
20	0.43 lbs.	2.13 lbs.	4.25 lbs.	6.38 lbs.	8.50 lbs.	10.63 lbs.	21.25 lbs.
30	0.64 lbs.	3.19 lbs.	6.38 lbs.	9.56 lbs.	12.75 lbs.	15.94 lbs.	31.88 lbs.
40	0.85 lbs.	4.25 lbs.	8.50 lbs.	12.75 lbs.	17.00 lbs.	21.25 lbs.	42.50 lbs.
50	1.06 lbs.	5.31 lbs.	10.63 lbs.	15.94 lbs.	21.25 lbs.	26.56 lbs.	53.13 lbs.
60	1.28 lbs.	6.38 lbs.	12.75 lbs.	19.13 lbs.	25.50 lbs.	31.88 lbs.	63.75 lbs.
70	1.49 lbs.	7.44 lbs.	14.88 lbs.	22.31 lbs.	29.75 lbs.	37.19 lbs.	74.38 lbs.
80	1.70 lbs.	8.50 lbs.	17.00 lbs.	25.50 lbs.	34.00 lbs.	42.50 lbs.	85.00 lbs.
90	1.91 lbs.	9.56 lbs.	19.13 lbs.	28.69 lbs.	38.25 lbs.	47.81 lbs.	95.63 lbs.
100	2.13 lbs.	10.63 lbs.	21.25 lbs.	31.88 lbs.	42.50 lbs.	53.13 lbs.	106.3 lbs.

Raising Alkalinity Using Sodium Bicarbonate

Gallons

ppm	1,000	5,000	10,000	15,000	20,000	25,000	50,000
10	0.14 lbs.	0.70 lbs.	1.40 lbs.	2.10 lbs.	2.80 lbs.	3.50 lbs.	7.00 lbs.
20	0.28 lbs.	1.40 lbs.	2.80 lbs.	4.20 lbs.	5.60 lbs.	7.00 lbs.	14.00 lbs.
30	0.42 lbs.	2.10 lbs.	4.20 lbs.	6.30 lbs.	8.40 lbs.	10.50 lbs.	21.00 lbs.
40	0.56 lbs.	2.80 lbs.	5.60 lbs.	8.40 lbs.	11.20 lbs.	14.00 lbs.	28.00 lbs.
50	0.70 lbs.	3.50 lbs.	7.00 lbs.	10.50 lbs.	14.00 lbs.	17.50 lbs.	35.00 lbs.
60	0.84 lbs.	4.20 lbs.	8.40 lbs.	12.60 lbs.	16.80 lbs.	21.00 lbs.	42.00 lbs.
70	0.98 lbs.	4.90 lbs.	9.80 lbs.	14.70 lbs.	19.60 lbs.	24.50 lbs.	49.00 lbs.
80	1.12 lbs.	5.60 lbs.	11.20 lbs.	16.80 lbs.	22.40 lbs.	28.00 lbs.	56.00 lbs.
90	1.26 lbs.	6.30 lbs.	12.60 lbs.	18.90 lbs.	25.20 lbs.	31.50 lbs.	63.00 lbs.
100	1.40 lbs.	7.00 lbs.	14.00 lbs.	21.00 lbs.	28.00 lbs.	35.00 lbs.	70.00 lbs.

Raising Alkalinity Using Sodium Carbonate

Gallons

ppm	1,000	5,000	10,000	15,000	20,000	25,000	50,000
10	0.09 lbs.	0.44 lbs.	0.88 lbs.	1.32 lbs.	1.77 lbs.	2.21 lbs.	4.42 lbs.
20	0.18 lbs.	0.88 lbs.	1.77 lbs.	2.65 lbs.	3.53 lbs.	4.42 lbs.	8.83 lbs.
30	0.26 lbs.	1.32 lbs.	2.65 lbs.	3.97 lbs.	5.30 lbs.	6.62 lbs.	13.25 lbs.
40	0.35 lbs.	1.77 lbs.	3.53 lbs.	5.30 lbs.	7.07 lbs.	8.83 lbs.	17.66 lbs.
50	0.44 lbs.	2.21 lbs.	4.42 lbs.	6.62 lbs.	8.83 lbs.	11.04 lbs.	22.08 lbs.
60	0.53 lbs.	2.65 lbs.	5.30 lbs.	7.95 lbs.	10.60 lbs.	13.25 lbs.	26.49 lbs.
70	0.62 lbs.	3.09 lbs.	6.18 lbs.	9.27 lbs.	12.36 lbs.	15.46 lbs.	30.91 lbs.
80	0.71 lbs.	3.53 lbs.	7.07 lbs.	10.60 lbs.	14.13 lbs.	17.66 lbs.	35.33 lbs.
90	0.79 lbs.	3.97 lbs.	7.95 lbs.	11.92 lbs.	15.90 lbs.	19.87 lbs.	39.74 lbs.
100	0.88 lbs.	4.42 lbs.	8.83 lbs.	13.25 lbs.	17.66 lbs.	22.08 lbs.	44.16 lbs.

Raising Alkalinity Using Sodium Sesquicarbonate

Gallons

ppm	1,000	5,000	10,000	15,000	20,000	25,000	50,000
10	0.13 lbs.	0.63 lbs.	1.25 lbs.	1.88 lbs.	2.50 lbs.	3.13 lbs.	6.25 lbs.
20	0.25 lbs.	1.25 lbs.	2.50 lbs.	3.75 lbs.	5.00 lbs.	6.25 lbs.	12.50 lbs.
30	0.38 lbs.	1.88 lbs.	3.75 lbs.	5.63 lbs.	7.50 lbs.	9.38 lbs.	18.75 lbs.
40	0.50 lbs.	2.50 lbs.	5.00 lbs.	7.50 lbs.	10.00 lbs.	12.50 lbs.	25.00 lbs.
50	0.63 lbs.	3.13 lbs.	6.25 lbs.	9.38 lbs.	12.50 lbs.	15.63 lbs.	31.25 lbs.
60	0.75 lbs.	3.75 lbs.	7.50 lbs.	11.25 lbs.	15.00 lbs.	18.75 lbs.	37.50 lbs.
70	0.88 lbs.	4.38 lbs.	8.75 lbs.	13.13 lbs.	17.50 lbs.	21.88 lbs.	43.75 lbs.
80	1.00 lbs.	5.00 lbs.	10.00 lbs.	15.00 lbs.	20.00 lbs.	25.00 lbs.	50.00 lbs.
90	1.13 lbs.	5.63 lbs.	11.25 lbs.	16.88 lbs.	22.50 lbs.	28.13 lbs.	56.25 lbs.
100	1.25 lbs.	6.25 lbs.	12.50 lbs.	18.75 lbs.	25.00 lbs.	31.25 lbs.	62.50 lbs.

Lowering Total Alkalinity with Muriatic Acid:

(Volume ÷ 125,000) x ___ ppm desired change = ___ quarts

Lowering Total Alkalinity with Sodium Bisulfate:

(Volume ÷ 47,058) x ___ ppm desired change = ___ pounds

Raising Total Alkalinity with Sodium Bicarbonate:

(Volume ÷ 71,425) x ___ ppm desired change = ___ pounds

Raising Total Alkalinity with Sodium Carbonate:

(Volume ÷ 113,231) x ___ ppm desired change = ___ pounds

Raising Total Alkalinity with Sodium Sesquicarbonate:

(Volume ÷ 80,000) x ___ ppm desired change = ___ pounds

Table 1 – Simplified formulas for alkalinity adjustment

Sodium Bicarbonate

Sodium Bicarbonate ($NaHCO_3$) is perhaps the most common base chemical used in the pool industry to elevate alkalinity and pH levels. However, as with the muriatic chart, many of the charts published in service training manuals for sodium bicarbonate are incorrect; now overstating, rather than understating, the required amount of chemical required for alkalinity adjustment – this time by about 7% (Dickman *pH* 59; Mitchell 33; *Pool* 21). This overstatement is likely due to rounding the numbers for convenience, but the accompanying chart is more accurate for this chemical.

The full equations used for correction of the error follow, where one part per million alkalinity, divided by the atomic weight of calcium carbonate multiplied by 1000, multiplied by twice the atomic weight of sodium bicarbonate equals the amount per liter, in grams, of sodium bicarbonate to add per ppm increase desired:

$$\frac{1}{(100.09)(1000)} \text{ x } 2(84.0077) = 0.001678643$$

This amount multiplied by the conversion factor to convert from grams to pounds

0.001678643 x 0.00220462 = 0.0000037

and then multiplied by the number of liters in a 20,000 gallon pool

0.0000037 x 75,706 = .280170525 pounds

shows that .28 pounds sodium bicarbonate is required for a 1 ppm alkalinity lift in a 20,000 gallon pool.

For this powder, and for all of the following powders, no mention is made in the MSDS's in the authors' possession that the compound is not at 100% strength.

A simplified version of the equation, used to develop the chart and usable in the field is: the pool volume divided by 71,425 and then multiplied by the change desired (in ppm) equals the amount of chemical (in pounds) to add. Again, a slight amount of rounding has been used on the divisor for more convenient dosage amounts. The resultant adjustment is in the hundredths of a pound – much less than the 7% error on other charts.

Sodium Carbonate

Depending on various factors, there are situations when the use of sodium carbonate (soda ash – Na_2CO_3) is preferable to sodium bicarbonate. Sodium carbonate is more economical than sodium bicarbonate, pound for pound. On top of the price differential (sodium carbonate is cheaper), it also provides, pound for pound, 60% more alkalinity lift than sodium bicarbonate. This fact is misunderstood by many in the industry, and may be one reason why alkalinity charts for sodium carbonate are rarely published. Sodium carbonate, however, also provides greater pH lift than the bicarbonate, and therefore cannot always be used. In situations where there is only room for alkalinity increase – where the pH is already high enough – sodium bicarbonate is usually the preferable product. Also, in situations where the dissolved solids or hardness levels of the water are high, the risk of a calcium carbonate precipitate (cloud) formation is greatly increased when using sodium carbonate, and it may therefore be an inappropriate product to use until the water is softened. The amount of pH lift provided by sodium bicarbonate can be insignificant, depending on certain factors, and therefore a general rule for use in the field could be that if both pH and alkalinity must be raised, and if an amount less than 2 pounds of sodium carbonate per 10,000 gallons (per application) is required for the needed alkalinity lift, using sodium carbonate is usually more effective, economical, and desirable.

The equations for sodium carbonate are as follows, where one part per million alkalinity, divided by the atomic weight of calcium carbonate multiplied by 1000, multiplied by the atomic weight of sodium carbonate equals the amount per liter, in grams, of sodium carbonate to add per ppm increase desired:

$$\frac{1}{(100.09)(1000)} \text{ x } 105.9794 = 0.001058841$$

This amount multiplied by the conversion factor to convert from grams to pounds

0.001058841 x 0.00220462 = 0.000002334

and then multiplied by the number of liters in a 20,000 gallon pool

0.000002334 x 75,706 = .176697804 pounds

shows that .18 pounds sodium carbonate is required for a 1 ppm alkalinity lift in a 20,000 gallon pool.

A simplified version of the equation, used to develop the chart and usable in the field is: the pool volume divided by 113,231 and then multiplied by the change desired (in ppm) equals the amount of chemical (in pounds) to add. Again, a slight amount of rounding has been used on the divisor for more convenient dosage amounts.

Sodium Sesquicarbonate

Sodium sesquicarbonate ($Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$), used by many service firms, combines the qualities of sodium carbonate and sodium bicarbonate: it provides less alkalinity increase than sodium carbonate, but more than sodium bicarbonate. It provides less pH increase than sodium carbonate, but more than sodium bicarbonate. It is less soluble than sodium bicarbonate but more soluble than sodium carbonate. It can be useful when more alkalinity and pH lift is desired but where solubility may be a problem. It is typically more expensive than sodium carbonate but cheaper than sodium bicarbonate. Few charts for sodium sesquicarbonate are published, but the one the authors found was correct (Dickman "Help") The equation for sodium sesquicarbonate follows, where one part per million alkalinity, divided by the atomic weight of calcium carbonate multiplied by 1000, multiplied by two thirds (because of the hydrated form) the atomic weight of sodium sesquicarbonate equals the amount per liter, in grams, of sodium sesquicarbonate to add per ppm increase desired per liter:

$$\frac{1}{(100.09)(1000)} \times {}^{2}/_{3}(226.0179) = 0.001505431$$

This amount multiplied by the conversion factor to convert from grams to pounds

$$0.001505431 \times 0.00220462 = 0.000003318$$

and then multiplied by the number of liters in a 20,000 gallon pool

$$0.000003318 \times 75{,}706 = 0.251192508 \text{ pounds}$$

shows that .25 pounds sodium sesquicarbonate is required for a 1 ppm alkalinity lift in a 20,000 gallon pool.)

A simplified version of the equation, used to develop the chart and usable in the field is: the pool volume divided by 80,000 and then multiplied by the change desired (in ppm) equals the amount of chemical (in pounds) to add.

Other Considerations

There are other charts available that bear mentioning.

Some charts have been published, similar to those above, but for pH adjustment rather than for alkalinity adjustment. Although these charts may be useful at times as a rough guide, they are only adequate when the alkalinity level is approximately 100 or higher. If the alkalinity is in ranges of about 50 or lower, much more dramatic and drastic results will occur than what could be expected by the chart... which could be detrimental to swimmers or to the pool. When adjusting pH, acid/base demand tests are much more reliable, since the method of titration takes into consideration not only the amount of pH change desired, but also the buffer strength of the water.

Calcium chloride charts, for use in increasing hardness, which are included in many of the sources, appear to be within acceptable standards of accuracy.

Note on Calculating Pool Volume

Research has shown that alkalinity change is constant with a given amount of acid or base, regardless of the application method. This principle can also be used as a simple method for the calculation of the volume of water in any shape of pool. Formulas exist for the calculation of standard rectangular, round, true kidney, and oval pools. Less than adequate methods of approximation are used for the determination of volume in irregularly shaped, or free–form pools. With the advent of artistic and creative pools shapes, as well as non–standard depths and wall slopes, accurate determination of volume, short of metering the water as the pool is being filled, has been difficult.

If an accurate method of alkalinity determination is available, and if the water balance is stable, test the alkalinity of the water. Then add the acid or base product. The next day, test the alkalinity again. The volume of the pool will be (the number in the simple formula for that product) multiplied by (the amount of product used – in quarts for muriatic, in pounds for the others) divided by (the amount the alkalinity changed, in ppm), or:

$$\frac{\text{(divisor)(amount used)}}{\text{(ppm change in TA)}} = \text{(the pool volume)}$$

As an example, if two and a half pounds of sodium carbonate changed the alkalinity 14 ppm, the volume is just over 20,000 gallons: 113,231 times 2.5 = 283,077.5 ÷ 14 ≈ 20,220:

$$\frac{\left(\frac{1 \text{ lb } Na_2CO_3}{105.9794 \text{ g}}\right)(453.8\ {}^{g}/_{lb})(100.09 \text{ g } CaCO_3/_{mole})(1000\ {}^{mg}/_{g})}{(3.785\ {}^{L}/_{gal})(1\ {}^{mg}/_{L} \text{ change})}$$

$$= \quad 113{,}231 \text{ (the divisor for sodium carbonate)}$$

$$\frac{(113{,}231)(2.5)}{14} \approx 20{,}220$$

Obviously, the accuracy level of the alkalinity test method employed is a big factor in the accuracy of the resultant volume. Field drop titration methods using drops indicating 10 ppm each are not useful. Lab or technical field test units with accuracies of ± 2 ppm work fairly well.

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