

BETACAP: A FAMILY OF CLEVER DILUTERS

There are several ways to make a diluter, and apparently the most trivial technology does not necessarily reserve surprises. Here we will talk about the technique of equal capillaries, and in particular how simple basic equations can be used in an advanced way, if managed with pressure control.

The starting point is elementary: with the same viscosity, equal pressures applied to equal capillaries induce equal flows (when we say "equal", in nature we mean very, very similar).

Wanting to take advantage of the availability of a pressure control function with a calculated set-point, it is possible to think of performing any possible compensations, the function to be realized being known.

We thought and realized it, acting on three functions:

- compensation of the effect due to different viscosities in the incoming gases (gas to be diluted and diluent)
- correction of systematic dilution errors, indicated in the metrological certificate
- possibility of defining the desired dilution in a continuous manner specifying the required concentration.

Start of the calculation procedure

The capillary technique is well known, both in physics and medicine and the universally accepted representation is due to Poiseuille, which quantifies the value of the flow rate at the entrance of a capillary:

$$Q_{IN} = \frac{\pi \cdot R^4 \cdot \Delta P}{8 \cdot \eta \cdot L} \quad \text{while outgoing, according to Boyle's law} \quad Q_{OUT} = \frac{\pi \cdot R^4 \cdot \Delta P}{8 \cdot \eta \cdot L} * \frac{P_{IN}}{P_{OUT}}$$

where R and L are the dimensional parameters of the capillary, ΔP the differential pressure applied to the ends of the capillary and P_{IN} , P_{OUT} the absolute pressures at the ends of the capillary

$$P_{IN} = \Delta P + P_{OUT}$$

Note: applying Boyle's law we make the approximation that all gases are "perfect". A second approximation is linked to the fact that Poiseuille's law holds for a strictly laminar motion, which does not exist in nature, but is quite equivalent to a real laminar motion.

By applying Poiseuille to the dilution ratio formula we obtain the analytical representation of the diluter: the starting point of our work

$$1) \quad K_{Dil.} = \frac{Q_{TG1}}{Q_{TG1} + Q_{TG0}} \quad \text{which for BetaCAP30 becomes:} \quad K_{Dil.} = \frac{N * \frac{dP1}{\eta_1} * (dP1 + P_{OUT})}{N * \frac{dP1}{\eta_1} * (dP1 + P_{OUT}) + (30 - N) * \frac{dP0}{\eta_0} * (dP0 + P_{OUT})}$$

For other BetaCAP series diluters the formulas may change, but the method does not change. To allow the User maximum flexibility (he can request the realization of a given dilution ratio, or alternatively the production of a specific concentration in the gas leaving the diluter.

The two alternatives are related by

$$C_{dil.} = C_{Bs} * K_{dil.} + C_{Bz} * (1 - K_{dil.}) \quad \text{that becomes:} \quad K_{dil.} = \frac{C_{dil.} - C_{Bz}}{C_{Bs} - C_{Bz}}$$

in which $C_{dil.}$ is the concentration required at the outlet of the diluter for a given component present in the mixture to be diluted and / or in the diluent, while C_{Bs} and C_{Bz} are the concentrations of that

Be.T.A. Strumentazione S.r.l.

Sede operativa : 28071 Borgolavezzaro (No) - via 4 Novembre, 8 - Tel : 0321 887 712 - Fax : 0321 885 529
 Sede legale : 27036 Mortara (Pv) - via L.Goia,16 - Capitale sociale: 12.000 Euro i.v. - C.F./P.IVA n° 01926350180
 Iscr. c/o CCIAA di Pavia R.E.A. n° 231667 e R.I. di Pavia. (tutta la corrispondenza va inviata alla sede operativa)

component in the span (gas to be diluted) and zero (diluent gas) cylinders. The following calculations therefore always start from a K_{dil} request. We note immediately that in the conversion of the user request from C_{dil} to K_{dil} , the value of K_{dil} is not necessarily one of the 31 values (0 / 30,1 / 30,2 / 30 ... 30/30) but it can have a decimal numerator N_d for a dilution $N_d / 30$.

If in formula 1) we replace K_{dil} with a value $N / 30$ (with integer N), we use the same N to the right of the equality and set equal values for η_1 and η_0 , the result will be of the type $dP_1 = dP_0$ and represents the simplest case of a capillary diluter, where it is possible to replace the flow ratios with the ratios between the number of capillaries affected by the gas to be diluted and the total number of installed capillaries (in this case 30). The dilution ratio does not change with dP_1 , if it varies, remaining equal to dP_0

Note that equation 1) is not sufficient to determine the unknown terms, which are two (dP_1 and dP_0): we therefore consider a system in which equation 1 is added with an equation (also a function of dP_1 and dP_0) which imposes a specific (configurable) flow of diluted gas at the outlet, constant as the dilutions change.

Compensation of viscosity effects

Viscosity is a characteristic parameter of the chemical components in the fluid state and of the respective mixtures. It varies with temperature and (very little in the context of low pressures) with pressure and can be found from various sources in the literature, such as dynamic viscosity at a given temperature and pressure

To favor our customers, we have published on the Beta-strumentazione.it website a calculation sheet which, based on the composition of a mixture, provides the viscosity value of the mixture itself. Most of the mixtures used in the environmental field (hundreds or thousands of ppm of active gas in a neutral gas, where the same neutral gas is the diluent gas) do not require compensation of viscosities, but in some cases (active gases with concentrations of some or more volumes% or diluent gases other than the diluting gas filling component).

The viscosity differences can also be very significant, up to η_1 / η_0 ratios in the order of 70/300 or vice versa: to compensate for the effect of these differences it would be necessary to apply to the capillaries of the two branches (capillaries affected by TG1 and capillaries involved from TG0) so different pressures to limit the range of use of the diluter. A "trick" is then used: by imposing equal pressures P (TG1) and P (TG0) in the usual formula 1) we obtain N as a function of K_{dil} . (the goal of dilution) and the two known viscosities.

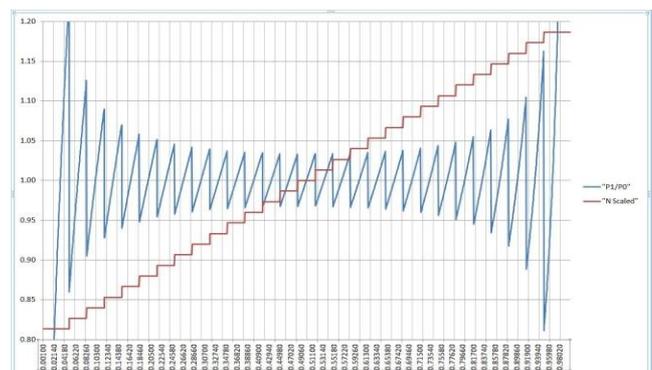
The result of the calculation is a decimal value, higher than the required value (Dilution = $N / 30$) if $\eta_1 > \eta_0$ and lower in the reverse case. The higher TG1 flow resistance is compensated by shifting the distribution between capillaries to vice versa in the case of $\eta_1 < \eta_0$.

As the capillaries cannot be broken, the subdivision (N capillaries affected by TG1 and $30-N$ capillaries affected by TG0) will be obtained by rounding the decimal value N_d . If $N > N_d$, the decimals added in the rounding are compensated by a value of $dP_1 < dP_0$, while if $N < N_d$, the decimals subtracted are compensated by a value of $dP_1 > dP_0$. All this results from the natural development of the calculations.

The following graph shows the trend of the pressure ratio dP_1 / dP_0 and of the integer N (not shown in scale) variable from 0 to 30, while in abscissa is the dilution factor (between 0 and 1).

It is interesting to observe a single step of the track that represents the number N of capillaries affected by TG1 and to consider three parts:

- in the central zone $N_d (= K_{dil} \times 30)$ is very close to N : dP_1 and dP_0 are equal or almost equal because no correction is needed (the decimal part of N_d is almost nil)

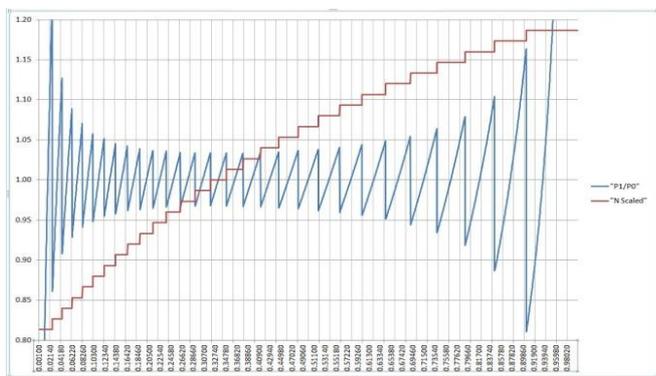


- in the left zone, N_d is less than N and a dilution less than $N / 30$ is needed: dP_1 must therefore be lower than dP_0 ($dP_1 / dP_0 < 1$)

- in the area on the right N_d is greater than N and a dilution greater than $N / 30$ is required: dP_1 must therefore be greater than dP_0 ($dP_1 / dP_0 > 1$).

At each change of pitch from $N-1$ to N and from N to $N + 1$ there is a sudden inversion (if in the figure the trace is not vertical it is only due to the small number of samplings): here we realize the same dilution (almost identical) at the rightmost point of the $N-1$ step and at the leftmost point of the N step with very different configurations of the diluter (the distribution of the capillaries on TG1 and TG0 changes and the ratio between the applied pressures is reversed).

In fact, with a stable analyzer, but not necessarily calibrated, it is possible to verify that the two dilutions have slightly different results, but this empirical test makes it possible to determine a corrective parameter that makes the two points coincide, or almost over the whole range of dilutions.



The case of using two TG1 and TG0 mixtures with significantly different viscosities is slightly different: as shown in the graph on the left, ($\eta_1 / \eta_0 = 2$) the values of N do not move to the two extremes (0 and 30) but are modified in the central zone, and precisely they grow to compensate for the greater resistance to the flow of TG1.

In this way the ratio between P (TG1) and P (TG0) is always contained between 0.8 and 1.2 allowing the optimal use of the diluter.

A "forcing" is used to manage the two extreme dilutions 0/30 and 30/30: the rounded value of $N = 0$ or $N = 30$ is accepted only if $N_d = 0$ or $N_d = 30$. Otherwise, the difference decimals between N and N_d could not be compensated for by an unbalance of the pressures (the 30 capillaries are fed either only by TG0 (0/30) or only by TG1 (30/30)). If N is not acceptable, the value 0 is forced to 1 and the value 30 is forced to 29.

Compensation for certified errors

The metrological test procedure applied to a diluter of the BetaCAP family has the purpose of verifying if the proportion between the dilution ratios calculated by affecting the gas by diluting only one of the capillary groups at a time corresponds to the ratio between the number of capillaries contained in the group corresponding and all the capillaries installed. In BetaCAP30 the capillary groups are 5 and contain 1, 2, 4, 8, 15 capillaries.

The test result is expressed as tabular information and indicates for 7 different dilutions (0:30, 1:30, 2:30, 4:30, 8:30, 15:30, 30:30) the measured value of Q (TG1) and Q (OUT), from which the effective dilution is calculated. Finally the actual dilution is compared with the corresponding theoretical dilution ($N: 30$) and the relative deviation is indicated. Even if the possible dilutions are 31, the result allows to extend, by overlapping the effects, the result to all the combinations.

Operating with the same viscosity (as during the metrological test) each dilution factor is represented by the state of the 5 solenoid valves, each of which, if powered, admits to the corresponding group the gas to be diluted and, if not supplied, admits the diluent gas. The status of the diluter is therefore represented by a 5-digit binary number, EDCBA which from left to right indicates the status of the corresponding group: eg, $E = 1$ indicates that the group with 1 capillary is crossed by TG1, $D = 0$ indicates that the group with 2 capillaries is crossed by TG0, the combination EDCBA = 10100 indicates that the groups with 1 and 4 capillaries are crossed by TG1, while the groups from 2, 8 and 15 capillaries are crossed by TG0.

This setting allows us to simply calculate the total "certified" dilution factor for each of the settable theoretical factors:

$$\text{Set factor} = \frac{N}{30}$$

$$\text{Certified factor} = \frac{Q(01)_{TG1}}{Q(01)_{OUT}} * E + \frac{Q(02)_{TG1}}{Q(02)_{OUT}} * D + \frac{Q(04)_{TG1}}{Q(04)_{OUT}} * C + \frac{Q(08)_{TG1}}{Q(08)_{OUT}} * B + \frac{Q(15)_{TG1}}{Q(15)_{OUT}} * A$$

The number in round brackets indicates the dilution (i / 30) set during the reportable measurement of Q (i) TG1 and Q (i) OUT. The certified dilution factor is calculated as the sum of the certified dilutions on the active groups only: the EDCBA digits that multiply the certified factor of the different groups confirm the contribution (if = 1) or delete it (if = 0).

Knowing for each set dilution (understood as a combination of the "active" capillary groups) the corresponding certified dilution, I can induce a deviation opposite to that induced by the imperfect proportion of the capillaries and measured by the certifying body, multiplying the target as follows:

$$\text{Corrected Kdil.} = \text{Requested Kdil.} * \frac{\text{Kdil. Theoretical}}{\text{Kdil. Certified}}$$

The application of the dP1 and dP0 pressures calculated in this way will exert a deviation of the same amount but opposite direction with respect to the systematic error detected on the diluter by the metrological body, which will be canceled with the natural response of the diluter.