## GAS DILUTION WITH THE EQUAL CAPILLARIES TECHNIQUE

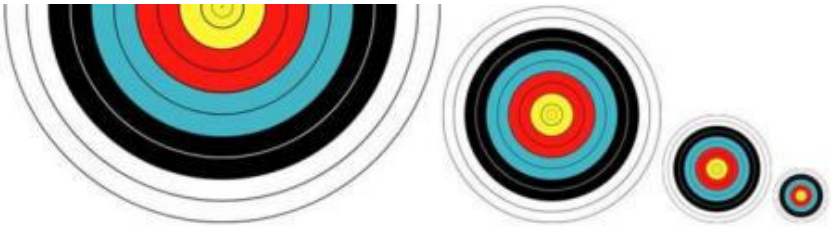
The advantages of the equal capillaries technique are surprising and leads to reach accuracy values of one order of magnitude better than all the other dynamic dilution techniques. This comparison will be supported by analyzing the accuracy available with two different techniques.

Nozzles (sonic or non-sonic) technique

With this technique, a series of different size nozzles is used to provide, applying a constant pressure, a flows series complying with the $2^n$ progression. That means if the smaller nozzle is involved by a flow q, the flow through the next is 2•q, through the next again is 4•q, and so on. Combining in parallel different nozzles combinations, all of the integer multiples of q may be obtained. Supplying one part of the nozzles with the gas to be diluted and the remaining with the diluting gas, all the possible dilutions are obtained at intervals whose distance depends upon the number of used nozzles.

For example, with 3 nozzles 8 dilutions are possible (0, 1/7, 2/7, 3/7….6/7, 7/7) , with 4 are possible 16 and so on, complying with the progression $2^n$ . The advantage of this technique is in the fact that using few nozzles many dilution ratios are possible.

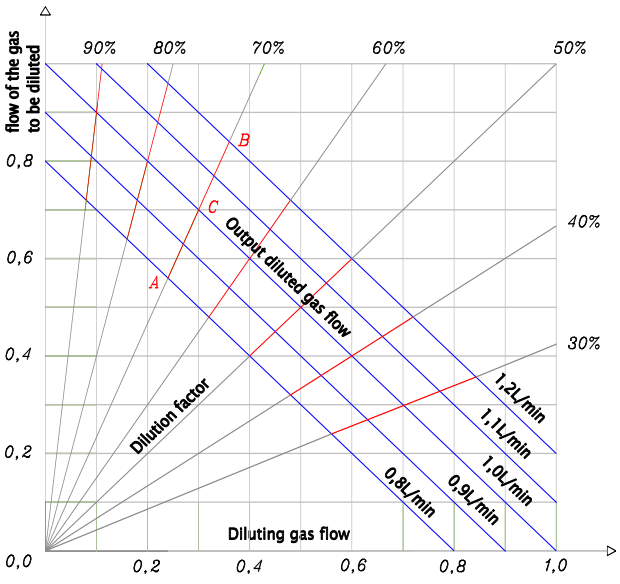
It's important to verify how much the selection of the nozzles may be accurate before they are installed in the diluter in a way that the wanted flows progression be complied. The series of four targets shown here gives an idea of the proportions between the required flows measurements :



Having 4 nozzles, 4 flows must be measured and the targets diameters are proportional to the relevant flows.

The flow meter is necessarily selected in a way that the higher flow to be measured is within the measuring range, and his repeatability may be in the order of 0,2% of the range. Which is the relative repeatability measuring the lower flow, 8 times lower ? Obviously it will be about 1,6% of the reading, because the reading is 8 times lower.

And then, why not to use more than one flow meter, each having a range more suitable for the measurement to be done ? In fact one reason may suggest to avoid this choice : the sole important requirement for a gas diluter is the correctness of the flows ratio, because the dilution factor is that.

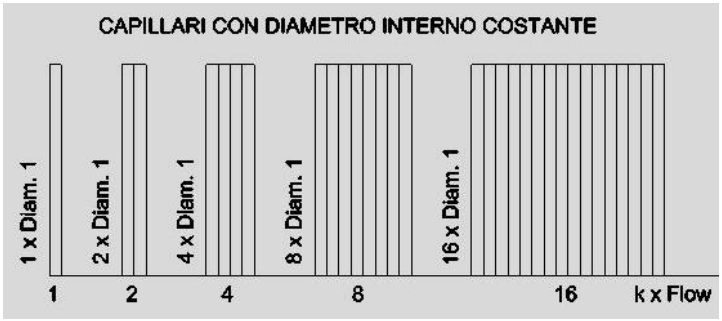



If the flows would be both double of the wanted value, the dilution ratio and the diluted concentration would be as wanted, just the output flow would be double, but this may be not critical.

In the left image, the dilution diagram, we may see that, moving from point A to point B, the flows do change (maintaining the same proportions) but the dilution ratio don't change. Performing all the measurements with the same instrument gives the advantage that the sensitivity error don't affect the test : just a zero offset null, linearity and repeatability is required.

Using multiple flow meters, the traceable sensitivity calibration is required and, despite that, the sensitivity errors mismatching is generally much higher than repeatability, giving the higher contribution to the uncertainty of dilution ratio

Equal capillaries technique



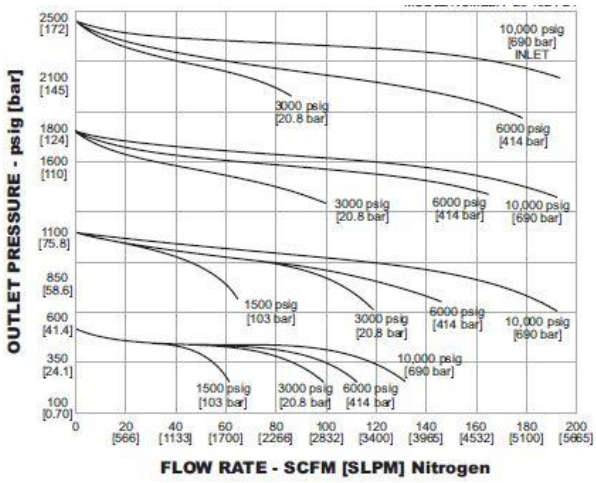

Also the technique of the equal capillaries may use the binary progression described above: instead of being obtained with elements of different cross-section it is realized by bringing together the capillaries in groups, complying with the same progression 2^n : single capillary, group of two capillaries, group of 4, group of 8 etc.
The advantage of grouping consists in the fact of reducing the number of flow controlling elements (solenoid valves). All the equal capillaries that make up a group are arranged in parallel so that the flow corresponding to a group is equal to the sum of the flows carried out by the capillaries of the group itself.
The disadvantage of this solution consists in the greater number of the required elements : to obtain 8 dilution ratios 7 capillaries are necessary against the 4 orifices of the case described above, and to obtain 16 dilutions 15 capillaries are necessary against 5 orifices and the ratio capillaries / orifices worsens dramatically for larger numbers. But let's evaluate the advantages : in the choice of the equal capillaries, the situation is quite different from the previous case. Choosing a flow meter having a measuring range suitable for measurement of one capillary, all remaining are measured in a narrow scope of values, and if the deviation is excessive capillary is discarded. Returning to the analogy of the targets, the situation is illustrated by the example shown here, but the size

of the targets should not lead us into error: the value of the flow to be measured can be increased (almost) at will, increasing the pressure applied, and the sensitivity of the meter can be freely selected so that all measures are in the top quarter of the measuring range of the instrument. So apart from the needs of space in printing, the 15 targets should be represented by all size equal to the greater of the five targets of the previous case. If then the measuring repeatability of a flow is, as above, in the order of 0,2% of the measure itself, all the flows will be measured with the same repeatability. When combining the groups, the uncertainty about the flow of a group, relatively to the sum of the flows in the capillaries of the group is even better, both for statistical reasons, and because the breeder do compensate for the elements "poor" with those "abundant".
But the fact of repeating almost equal measures has further advantages: short or medium term drifts in the measuring system are well controlled interspersing the extent of the capillaries to be selected with the measure of a comprehensive reference, selected, but not necessarily traceable, for the reasons already stated above
a) The linearity of the measuring system does not affect the test, precisely because the measures are in a close neighborhood of a point (capillaries exceeding that tolerance are anyhow discarded)
b) Even in this case it is not required traceability of the measurement, because the objective is the search of the capillaries equal to each other, not of those characterised by a specific value

Pressures control

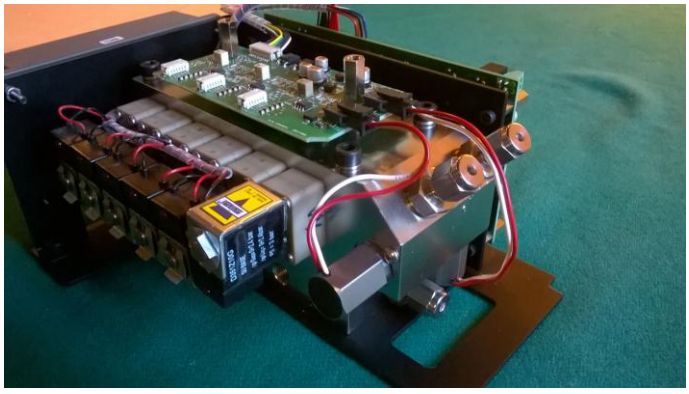
In addition to the effectiveness of the capillaries equality, a second element plays an important role for the accuracy of the diluter : the pressures applied to the capillaries. Two different gas (the gas to be diluted and the diluting gas) are crossing separately the capillaries: a share of these is crossed by the gas to be diluted and the remainder by the diluting gas. The allocation of the two quotas is managed by solenoid valves according to the requested dilution ratio.
All capillaries have in common the drain (output of the diluted gas), but it is necessary that the two incoming gases or mixtures have the same pressure so that the equality of flows is maintained even during the use of the diluter. Sometimes, it is the case of incoming gases with different viscosity, it is necessary (or desirable) unbalancing the pressures applied by virtue of the relationship between the different viscosity (applied pressure and viscosity have linear but reverted effect on the flow in the capillaries).

As indicated by all the suppliers of mechanical pressure regulators, the controlled pressure is always dropping down (more or less) when the flow increase (as shown in the image). Unfortunately, in a diluter when the dilution ratio is changed, while an input flow falls, the other grows and the differences between the applied pressures are additive.




In a diluter with capillaries, but same is with the orifices, the calibration of the pressures does not need traceability, in fact, each applied pressure is important just relatively to the other one : the pressures ratio between the applied pressures is important : you could double both pressures without changing the dilution ratio

To ensure the wanted pressures ratio, very linear sensors had been selected and the calibration function is realized by applying the same references (zero and span) in one time to all three sensors and the control is electronic (PID) . Also, to avoid that the outlet back-pressure changes may have influence on the pressures applied to the capillaries, the pressures control is of differential type (input-output) on both sides (gas to be diluted and diluting gas).



Finally, to ensure uniformity of capillaries temperature, these are "embedded" between the two shells of solid material (fluorinated resin or stainless steel). The best performances are got immediately after the switching on and are maintained for years.

This construction gives further advantages :

a) The ways of connection between the ends of the capillaries and all other components (sensors and valves) are obtained by internal communicating holes and so the risk of leakages is minimized.

b) The result is a compact and extremely rugged module, with very low dead volumes.

The comparison between the two techniques (equal capillaries and scaled nozzles) would have led to the same conclusions by replacing the orifices with flow regulators: also in this case, for the determination of the polynomial correction of linearity, it's required the measurement of flows very different from each other so as to verify the flow regulators on the entire operating range, which generally covers almost a decade. Il fact, the MFC are always qualified in terms of accuracy relative to full scale and not to the value of actually regulated flow.

Until now it is highlighted, where possible, that traceable references are not required for selecting equal capillaries, but for "legal" applications traceability is mandatory. Among other things, when the diluter is assembled, the individual capillaries are no longer accessible or measurable individually: we know that they are nearly equal (if they were identical the dilution uncertainty would be limited to the uncertainty of the applied pressures ratio ±2hPa), but to release a verification it is necessary to involve accredited laboratories that perform traceable measures on either inflows and the outflow using traceable instruments and repeating the test activating in sequence each capillaries group.