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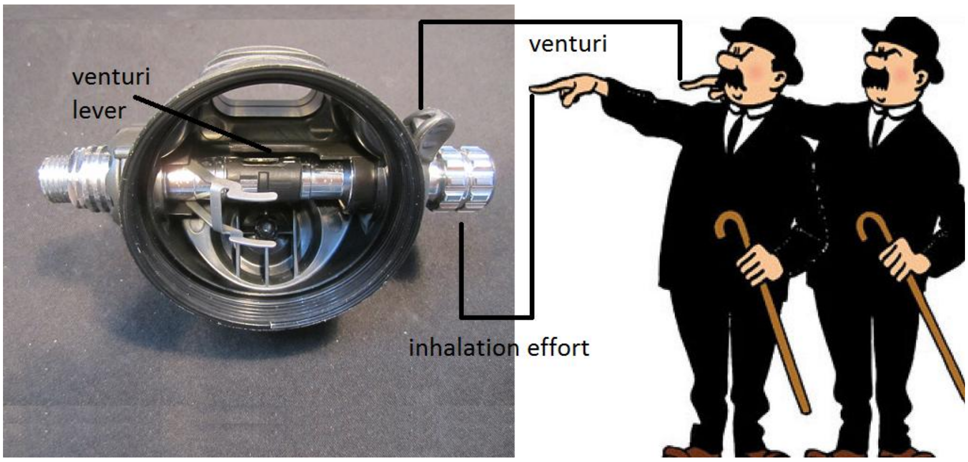
Tech talk #5: "The Dupond-Dupont -Dilemma" of second stage features part II

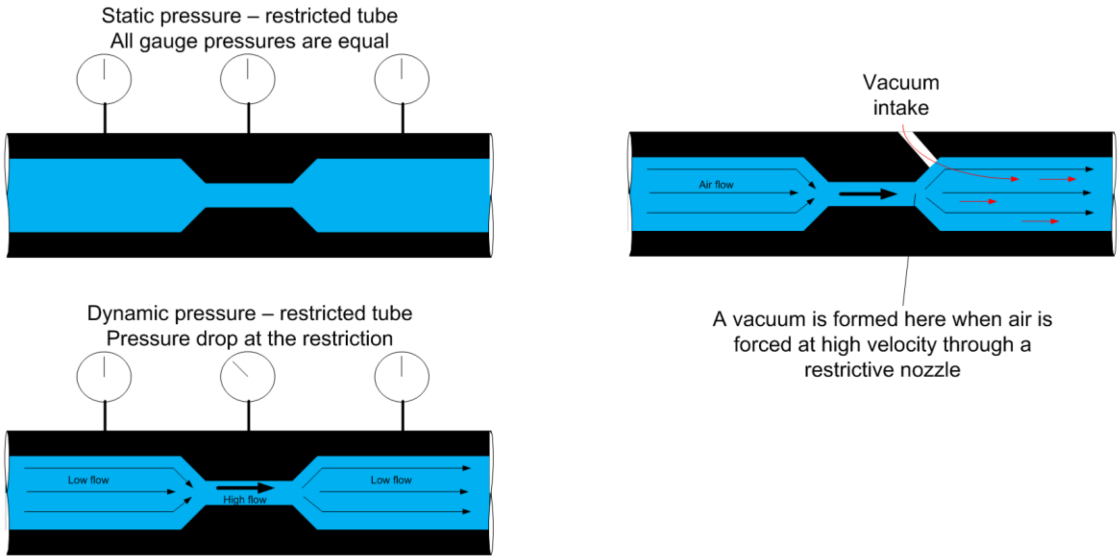
In our previous tech talk we've had a look at the 'diver adjustable inhalation effort' and the effects of this special second stage feature. Let's continue our quest and unravel the basics of the 'venturi effect' and how it will facilitate the breathing effort of the diver.



Assuming you have a second stage with a venturi lever or a pre-dive switch, a little experiment you could consider yourself: put the switch in the off-position and tap the purge button firmly, your regulator is likely not going to free-flow. Now put the switch to the on-position and repeat, most likely your regulator is free-flowing. What causes this to happen?

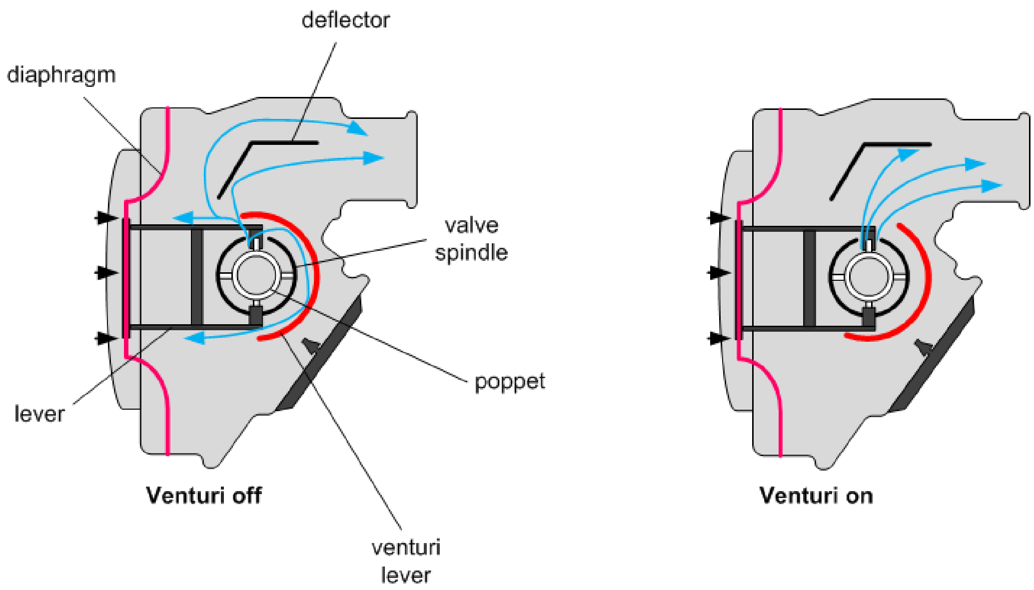
First order of the day: a little understanding of the principles behind this phenomenon. Back to physics 101. Somewhere in the seventeen hundreds, a Swiss mathematician and physicist named Daniel Bernoulli published in his book 'Hydrodynamica' (1738) the 'Bernoulli's principle': in simple words it states that the higher the speed of a flowing fluid or gas, the lower the pressure.

Almost simultaneously, Giovanni Battista Venturi – an Italian physicist – postulated that reduction in fluid pressure will occur when a fluid flows through a constricted section of a pipe. Taking the latter one step further, we easily can create a vacuum to 'assist' sucking a fluid: when air exits a constriction it is moving very rapidly in comparison to the surrounding air particles. This fast moving air draws some of the surrounding slow-moving air particles along with it. As slow-moving air particles are continuously dragged away, this results in the lowering of air pressure (a vacuum) in the region surrounding the fast-moving airflow.



Hopefully you still remember from your open water course that as a diver breathes in, his/her inhalation draws a flexible diaphragm inside the second stage towards the diver. As the diaphragm moves it presses against a lever, the lever in turn opens a valve to allow air to enter the second stage. When a diver stops inhaling, the diaphragm relaxes into its original position, releasing the lever and stopping the airflow. This means that the diver must continuously inhale in order to keep the valve open.

Manufacturers will come up with some clever solutions in order to establish the 'venturi effect' and funnel the airflow. By doing so, the vacuum created by the venturi effect will actually assist drawing in the diaphragm - during inhalation -, making the sustained breathing effort easier. So our ultimate goal for scuba regulators is to use the vacuum created by the venturi effect to reduce the breathing effort, in other words, make the regulator breathe easier. However, one word of caution, it important to understand that for a venturi effect to take place, we need 'flow' so the venturi effect will not affect the static cracking effort.

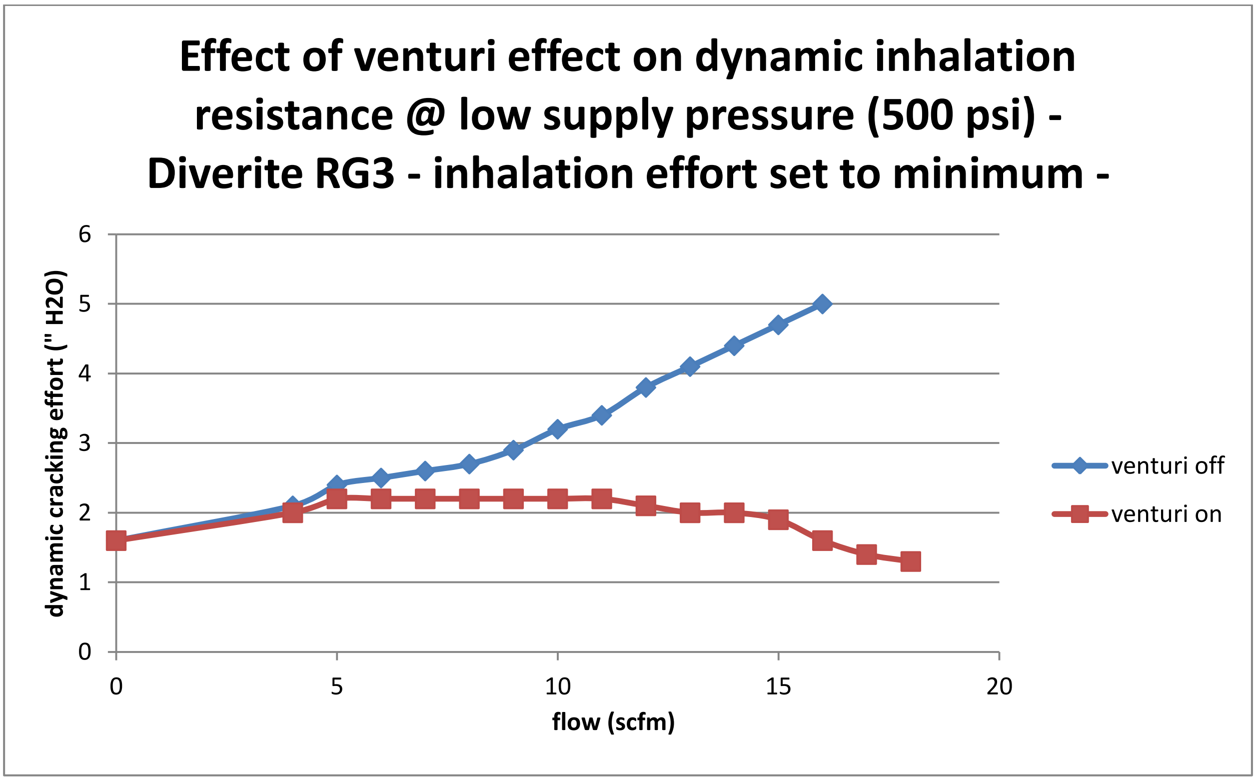


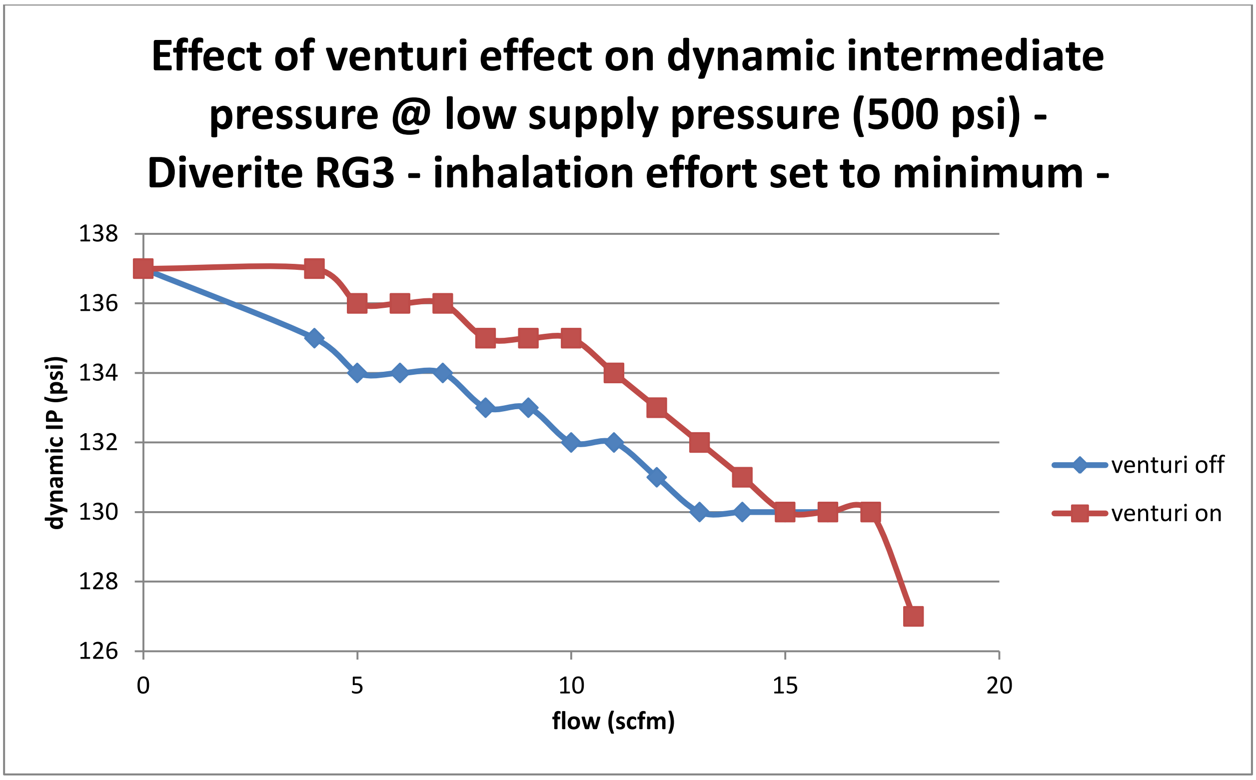
These days, nearly all regulators will have some form of venturi build in, some of them diver adjustable, some of them fixed, some of them automatic. All kinds of fancy terminology is used to describe this feature: VIVA (venturi initiated vacuum assist), VAD (vortex assisted design), AFC (automatic flow control), MBS (master breathing system – note: MBS is a combination of venturi and inhalation effort control in one function -)... To confuse the terminology even a little more, diver controllable venturi assist is sometimes labelled as: dive/pre-dive switch, on/off switch, +/- switch... or simply venturi lever.

Manufactures also opt for unique design features in order to create and control the venturi effect, some examples hereof are: curved plates, pre-dive switch, air flow tubes, tube injectors, directed jet, deflector plates... Which methodology and up to what level the venturi will affect the breathing effort are all factors manufacturers will carefully consider and experiment with during the design stage of the regulator.

As our detectives Dupond-Dupont were struggling with the identification, function and effects of the different knobs and levers on a second stage, we've put some regulators on the bench and attempted to visualise what happens when the venturi lever is activated. We halted the experiment when either an inhalation effort of 5" of water was reached or when we were no longer able to increase the flow rate.

- Experiment 1: we put the Diverite RG3 first and second stage on the flow bench. As this regulator has a diver adjustable inhalation effort, this was set to minimum (as to eliminate the effect hereof). We supplied the regulator with a low supply pressure of 500 psi and ran a flow test with the venturi lever in the off/minimum and the fully on/maximum position. Measured was the dynamic cracking effort at different flow rates. As can be seen in the graph, with the venturi lever in the off/minimum position (blue curve) the dynamic cracking effort rises. With the venturi lever in the on/maximum position (red curve) the dynamic cracking effort initially rises a little. As the air flow through the second stage increases, the dynamic cracking effort starts to drop: due to the increased air flow, the venturi effect kicks in and becomes more and more pronounced, decreasing the breathing resistance.

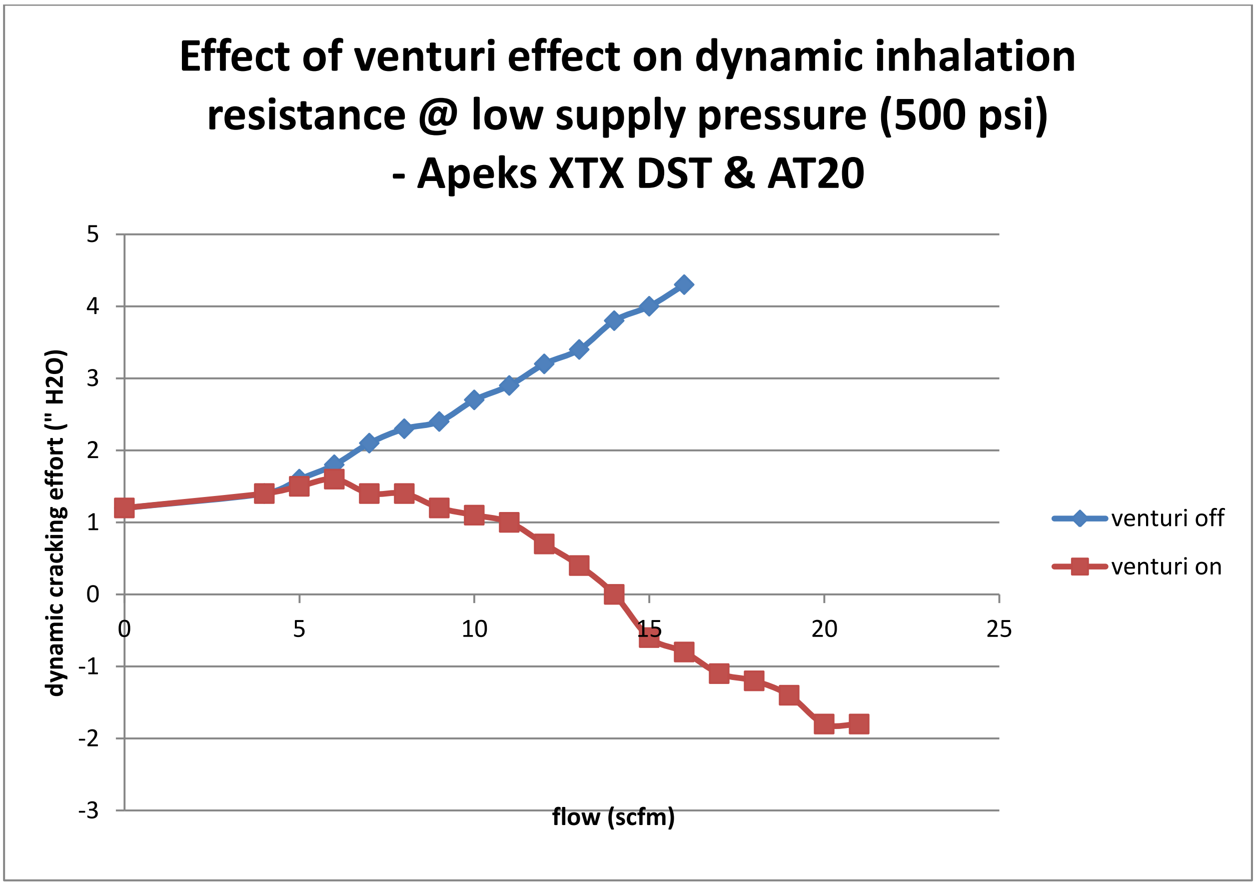


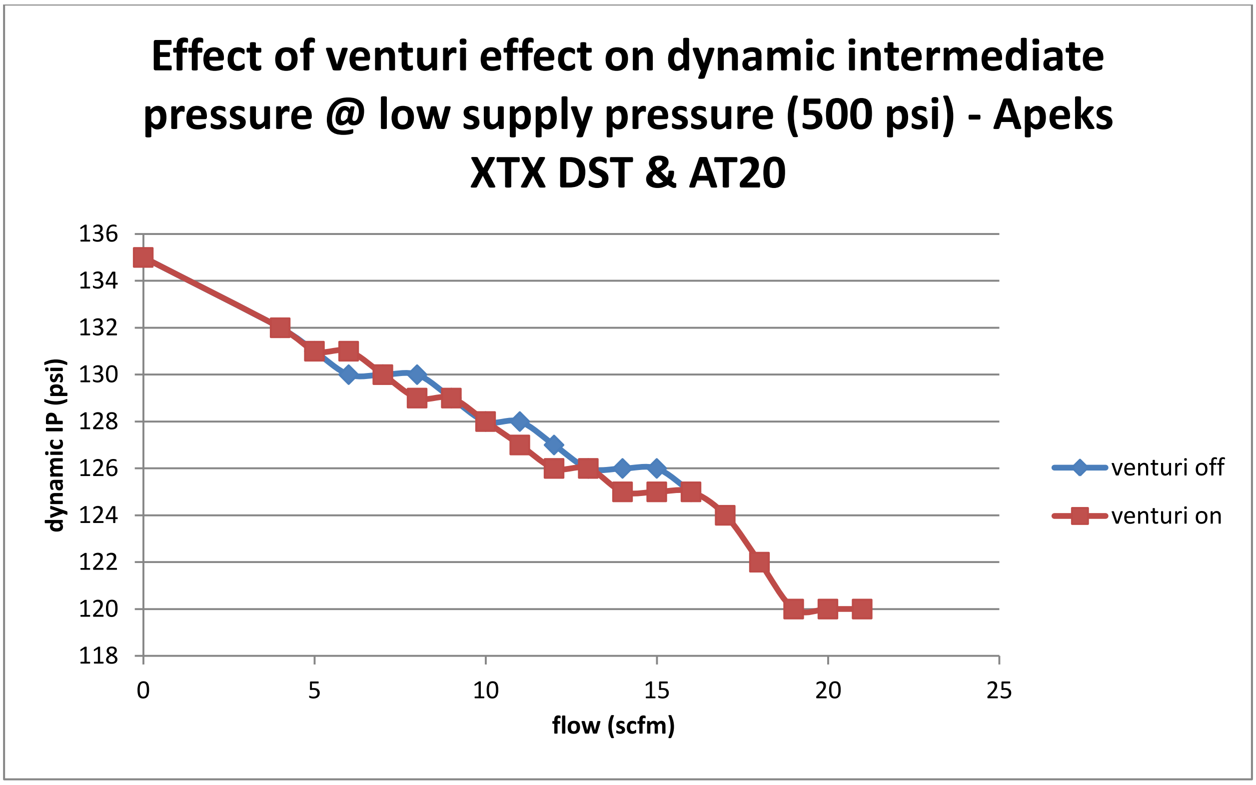


Diverite RG3 1st and 2nd stage, inhalation resistance minimum					
Low supply pressure (500 psi)					
		venturi off		venturi on	
flow		cracking effort	dynamic IP	cracking effort	dynamic IP
scfm	lpm	" H2O	psi	" H2O	psi
0	0	1.6	137	1.6	137
4	113	2.1	135	2	137
5	142	2.4	134	2.2	136
6	170	2.5	134	2.2	136
7	198	2.6	134	2.2	136
8	226	2.7	133	2.2	135
9	255	2.9	133	2.2	135
10	283	3.2	132	2.2	135
11	311	3.4	132	2.2	134
12	340	3.8	131	2.1	133
13	368	4.1	130	2	132
14	396	4.4	130	2	131
15	425	4.7	130	1.9	130
16	453	5	130	1.6	130
17	481			1.4	130
18	509			1.3	127
19	538				
20	566				

- Experiment 2: we put the Apeks XTX DST first and AT20 second stage on the flow bench. This second stage has no diver adjustable inhalation effort. We supplied the regulator with a low supply pressure of 500 psi and ran a flow test with the venturi lever in the off/minimum and the fully on/maximum position. Measured was the dynamic cracking effort at different flow rates. As can be seen in the graph, with the venturi lever in the off/minimum position (blue curve) the dynamic cracking effort rises. With the venturi lever in the on/maximum position (red curve) the dynamic cracking effort initially rises a little. As the air flow through the second stage increases, the dynamic cracking effort starts to drop as due to the increased air flow, the venturi effect kicks in and becomes more and pronounced, decreasing the breathing resistance. In this configuration, the amount of venturi assist becomes rather significant and the breathing resistance becomes 'negative'. The flow at which point this happens is called the crossover-flow. The venturi assist is strong enough to override the mechanical resistance of the valve (*). In other words, the venturi assist is now overriding the diver's inhalation effort and air is being 'force fed' to the diver (a bit of a free-flow). As a diver, it's a personal feeling to consider this comfortable or not. If you feel this is just too much for personal comfort, as a diver you can dial the venturi lever back to reduce the venturi effect.

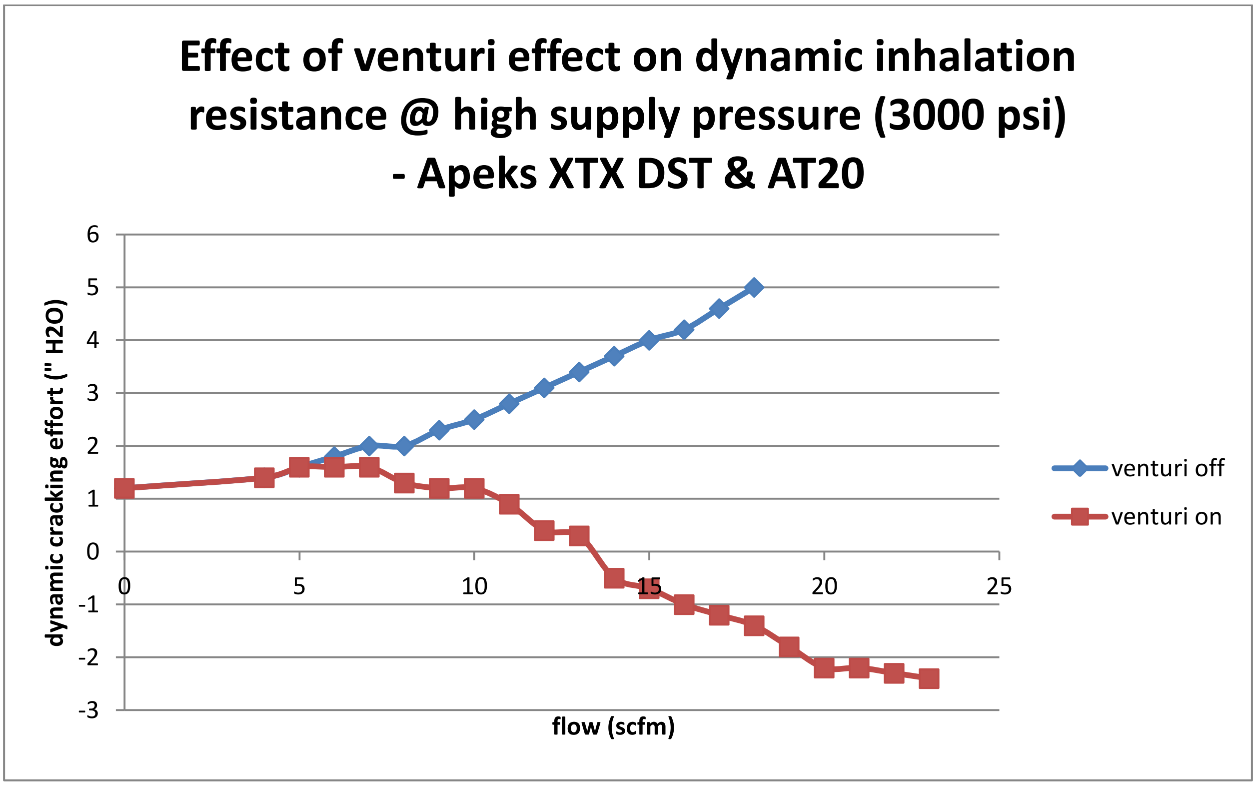
  (*) As the lever is depressed throughout the stroke range, the speed of the airflow progressively increases; when the pressure drop incurred by the increased velocity of the airflow is greater than the mechanical resistance of the valve, the lever will be pulled wide open, this in turn further increases the speed of the airflow and venturi vacuum…

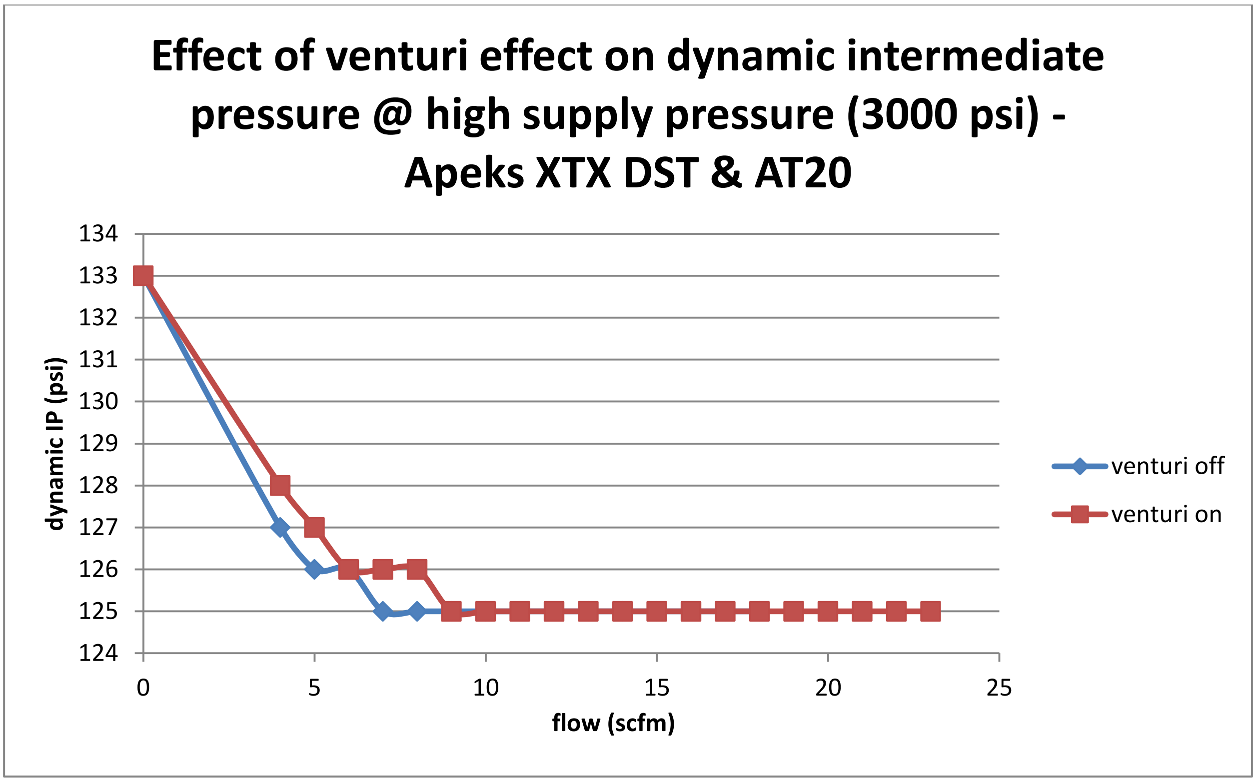




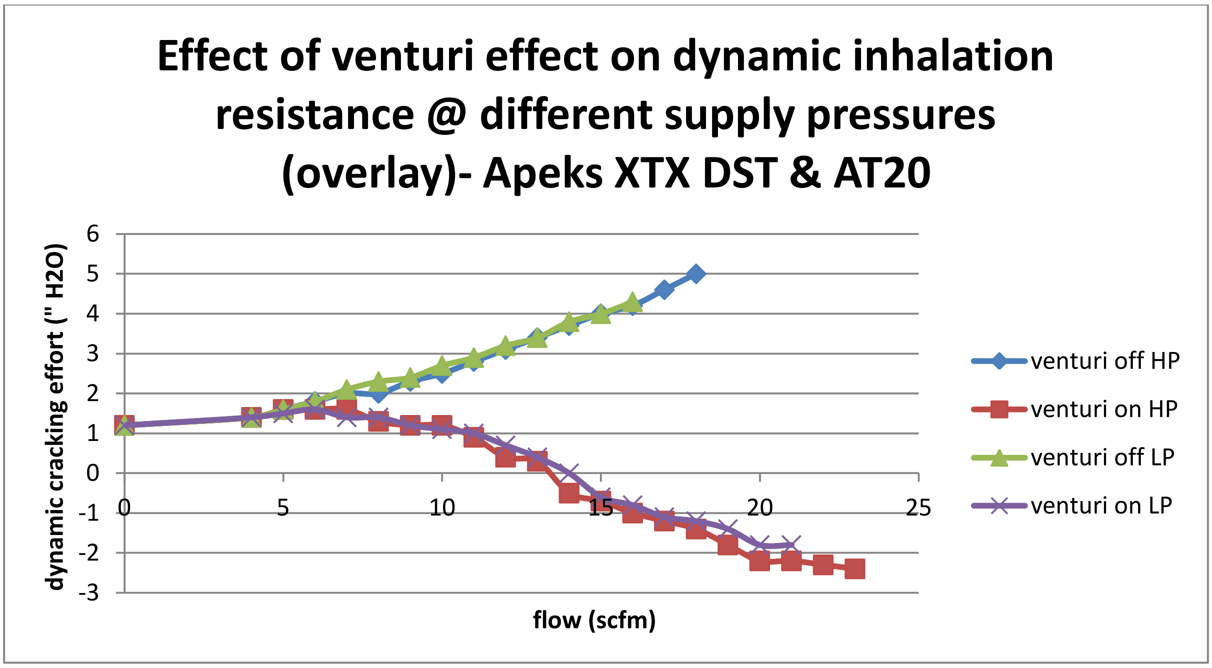
Apeks XTX DST & Apeks AT20					
Low supply pressure (500 psi)					
		venturi off		venturi on	
flow		cracking effort	dynamic IP	cracking effort	dynamic IP
scfm	lpm	" H2O	psi	" H2O	psi
0	0	1.2	135	1.2	135
4	113	1.4	132	1.4	132
5	142	1.6	131	1.5	131
6	170	1.8	130	1.6	131
7	198	2.1	130	1.4	130
8	226	2.3	130	1.4	129
9	255	2.4	129	1.2	129
10	283	2.7	128	1.1	128
11	311	2.9	128	1	127
12	340	3.2	127	0.7	126
13	368	3.4	126	0.4	126
14	396	3.8	126	0	125
15	425	4	126	-0.6	125
16	453	4.3	125	-0.8	125
17	481	[redacted]		-1.1	124
18	509			-1.2	122
19	538			-1.4	120
20	566			-1.8	120
21	594			-1.8	120

- Experiment 3: we put the Apeks XTX DST first and AT20 second stage on the flow bench. This second stage has no diver adjustable inhalation effort. We supplied the regulator with a high supply pressure of 3000 psi and run a flow test with the venturi lever in the off/minimum and the fully on/maximum position. Measured was the dynamic cracking effort at different flow rates. Results and discussion are similar to those in experiment 2. The fact that there is little difference in the results comparing high versus low supply pressure should not come as a total surprise: the Apeks XTX DST is a balanced diaphragm first stage. This design will eliminate nearly all variance in the intermediate pressure due to a changing supply pressure.

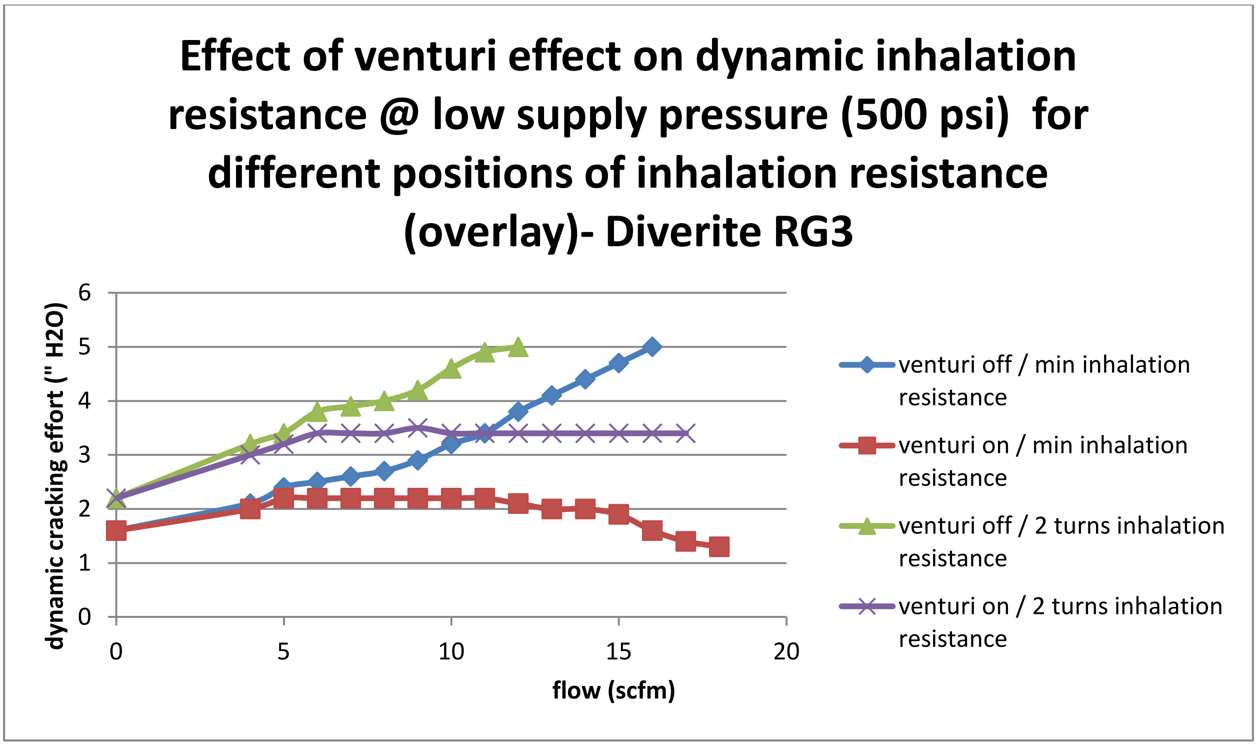


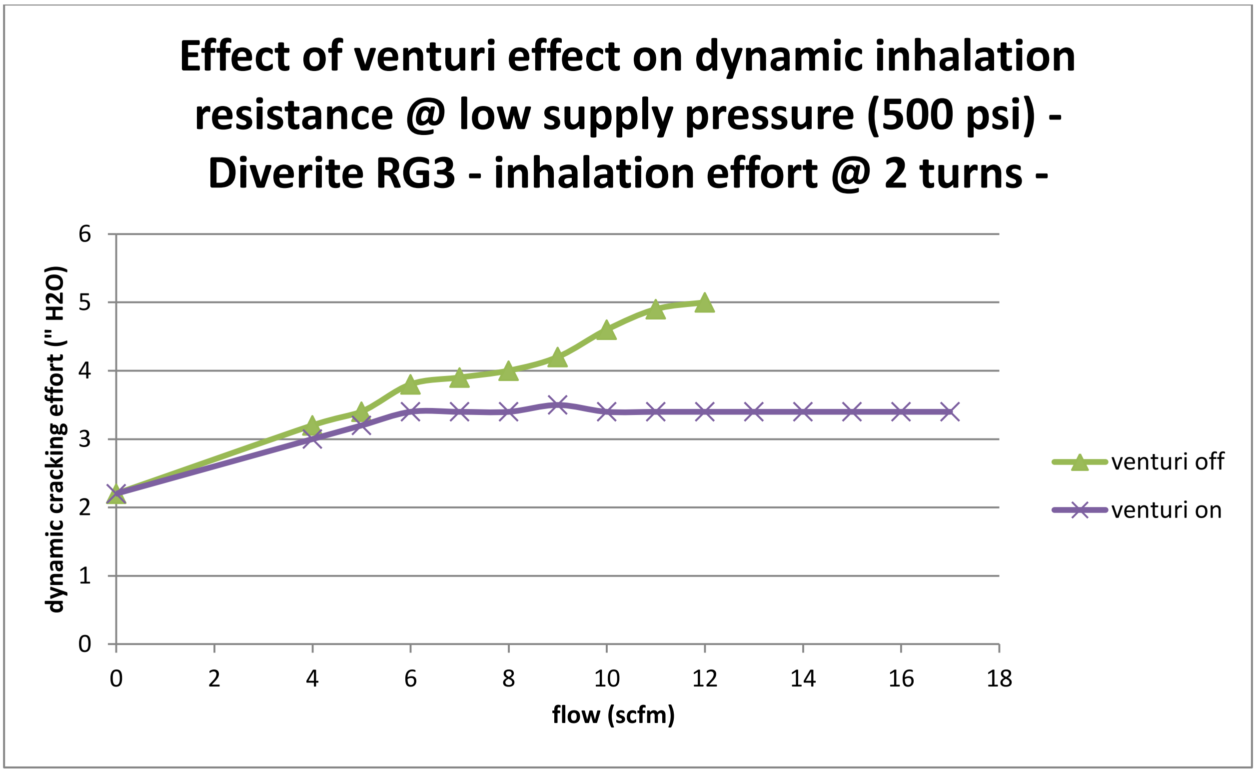


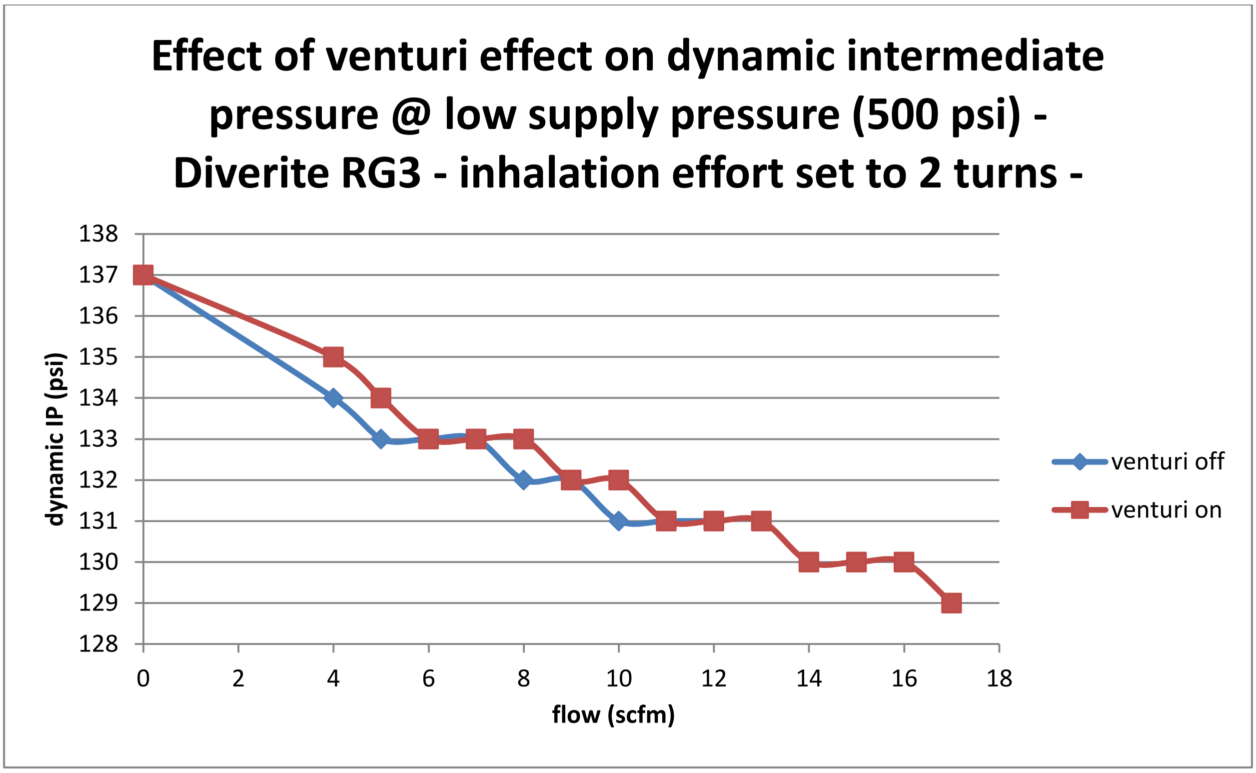
Apeks XTX DST & Apeks AT20					
High supply pressure (3000 psi)					
		venturi off		venturi on	
flow		cracking effort	dynamic IP	cracking effort	dynamic IP
scfm	lpm	" H2O	psi	" H2O	psi
0	0	1.2	133	1.2	133
4	113	1.4	127	1.4	128
5	142	1.6	126	1.6	127
6	170	1.8	126	1.6	126
7	198	2	125	1.6	126
8	226	2	125	1.3	126
9	255	2.3	125	1.2	125
10	283	2.5	125	1.2	125
11	311	2.8	125	0.9	125
12	340	3.1	125	0.4	125
13	368	3.4	125	0.3	125
14	396	3.7	125	-0.5	125
15	425	4	125	-0.7	125
16	453	4.2	125	-1	125
17	481	4.6	125	-1.2	125
18	509	5	125	-1.4	125
19	538			-1.8	125
20	566			-2.2	125
21	594			-2.2	125
22	623			-2.3	125
23	651			-2.4	125



- Experiment 4: we put the Diverite RG3 first and second stage on the flow bench. In experiment 1, the diver adjustable inhalation effort, this was set to minimum. In this experiment we dialled the adjustable inhalation effort 2 turn clockwise (increasing the 'base' inhalation effort). We supplied the regulator with a low supply pressure of 500 psi and run a flow test with the venturi lever in the off/minimum and the fully on/maximum position. Measured was the dynamic cracking effort at different flow rates. To make the test results more interesting, we over-layed them directly over the test results of experiment 1: test results from experiment 1 are illustrated by the blue & red curves; the results from experiment 4 are illustrated by the green & purple curves. It can be observed that the form of the graphs of experiment 4 is similar to those of experiment 1. However from experiment 4 you can clearly observe a shift upwards of the graph (more inhalation effort is present due to the increased initial spring tension). With the venturi set to maximum in experiment 4, it is clear that the venturi effect still will reduce the inhalation effort, but the overall effect is much less than in experiment 1. The increased inhalation resistance due to the increased spring tension will partially counteract the effects of the venturi. Food for thought: it makes me wonder why divers would turn the inhalation resistance to the maximum position and at the same time try to overcompensate the hard breathing by turning the venturi lever to the maximum position.


Effect of venturi effect on dynamic inhalation resistance @ low supply pressure (500 psi) for different positions of inhalation resistance (overlay)- Diverite RG3
dynamic cracking effort (" H2O)
flow (scfm)
venturi off / min inhalation resistance
venturi on / min inhalation resistance
venturi off / 2 turns inhalation resistance
venturi on / 2 turns inhalation resistance


Effect of venturi effect on dynamic inhalation resistance @ low supply pressure (500 psi) - Diverite RG3 - inhalation effort @ 2 turns -
dynamic cracking effort (" H2O)
flow (scfm)
venturi off
venturi on



Effect of venturi effect on dynamic intermediate pressure @ low supply pressure (500 psi) - Diverite RG3 - inhalation effort set to 2 turns -
dynamic IP (psi)
138
137
136
135
134
133
132
131
130
129
128
0
2
4
6
8
10
12
14
16
18
flow (scfm)
venturi off
venturi on

Diverite RG3 1st and 2nd stage - inhalation resistance @ 2 turns					
Low supply pressure (500 psi)					
		venturi off		venturi on	
flow		cracking effort	dynamic IP	cracking effort	dynamic IP
scfm	lpm	" H2O	psi	" H2O	psi
0	0	2.2	137	2.2	137
4	113	3.2	134	3	135
5	142	3.4	133	3.2	134
6	170	3.8	133	3.4	133
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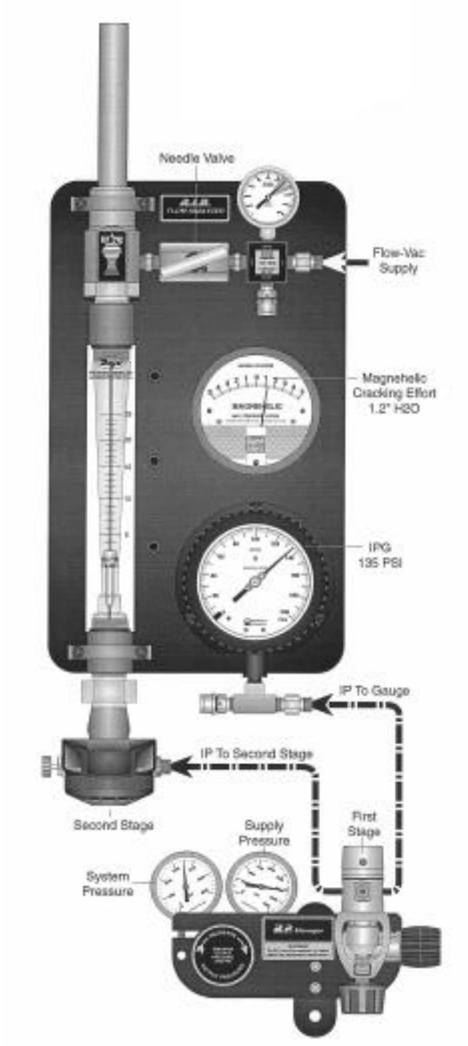
11	311	4.9	131	3.4	131
12	340	5	131	3.4	131
13	368			3.4	131
14	396			3.4	130
15	425			3.4	130
16	453			3.4	130
17	481			3.4	129
18	509				
19	538				
20	566				

Finally let's not forget that these test scenarios were performed under atmospheric pressure (i.e. at the surface). Most likely there will be a correlation between atmospheric flow and flow at depth; however, no data in the matter exists to define this relationship. The increased density of the air and a rise of the intermediate pressure at depth will produce different results both in flow as in inhalation effort. As well bear in mind that the exact figures and how the venturi affects the inhalation resistance is regulator specific (i.e. brand and type).

If you're interested figuring out the specifics of your regulator and how strong the venturi assist is, ask you service centre to produce a set of graphs for your reference.

This article does not favour any brands nor claims performance comparisons between brands or condemns brands, it's just an experiment.

Test set-up:



Needle Valve
Flow-Vac
Supply
Magnehelic
Cracking Effort
1.2" H2O
IPG
135 PSI
IP To Gauge
IP To Second Stage
Second Stage
First
Stage
Supply
Pressure
System
Pressure