WASC 2338.

Nitrous Oxide & its use in Rocketry & High performance Piston Engines

NITROUS OXIDE AND ITS USE IN ROCKETRY AND HIGH-PERFORMANCE PISTON ENGINES

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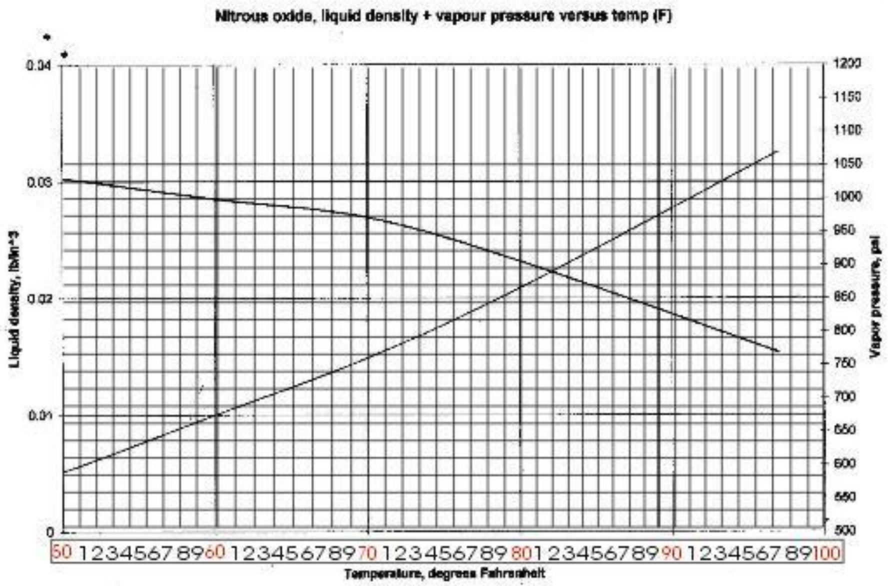
Nitrous oxide has long been employed both as an oxidizer in various forms of rocket propulsion, and as a performance enhancer for internal combustion engines. Many internet sites and published documents represent N2O as a harmless substance that can be handled safely with a minimum of expertise. As such it is very popular with amateur rocket enthusiasts, drag racers and others interested in getting more horsepower out of engines.

Nitrous oxide is, in fact, quite a unique substance with its own special physical and chemical properties, Properties that should be fully understood by anyone handling and using it in rockets or engines. Under certain circumstances, nitrous Oxide can explode in a very violent manner without any apparent source of ignition or oxidant to fuel such an explosion. These circumstances can easily occur during transfer and actual use and can occur in apparently normal conditions.

The attraction of N2O is that it is a good source of free oxygen, and that it is relatively easy and safe to handle and store. At lower temperatures it is a stable compound that is not very reactive, if a little corrosive. As it gets warmer it becomes less stable and predictable. High temperatures are needed to 'split' N2O into its two component elements, Nitrogen and Oxygen. Once split, a gas mixture of two parts Nitrogen to one part Oxygen is formed. One can see that this mixture is much richer in oxygen than is air. In air just under 80% of the mixture is Nitrogen and just over 20% Oxygen, four parts Nitrogen to one part Oxygen. It's that extra oxygen in N2O that makes rockets burn so well and gives the horsepower boost to piston engines.

The other attraction of N2O arises from its quirky physical properties. Normally stored under pressure as a liquid, it has a very high vapour-pressure that is commonly used to push the N2O out of its containing vessel either into a rocket or into an engine. This 'self propelling' characteristic removes the need for pumps or other devices to move large volumes of liquid very quickly. At 20 deg C, the vapour-pressure is 58.5 bar or 850 psi (pounds per square inch). Nitrous oxide is very temperature sensitive. The higher the temperature, the higher the vapour-pressure, and the opposite applies to lower temperatures. A chart is included that shows the relationship of temperature and pressure. At 36.4 deg C, N2O reaches its CRITICAL POINT, when it starts behaving strangely. At and above this temperature all the N2O in a vessel becomes gas. It also becomes much more reactive as it approaches this temperature and can be made to explode by the application of a compression force. By 'explode' one means an exothermic chemical reaction that is a true chemical explosion- not just simply a sudden release of high pressure gas. This stuff can go off like Semtex when it is too warm.



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The boiling point of a liquid is determined by the gas pressure it is subjected to. If you go up Everest and want to make a cup of tea, the tea won't be very hot, because, at that altitude, the air pressure is so low the water boils before it gets hot enough to make a decent cup of tea. Nitrous oxide behaves the same way. The lower the pressure, the lower its boiling point will be and vice-versa. At 20 deg C, the gas pressure needed to prevent boiling is 58.5 bar (850 psi). The instant that pressure is dropped, the nitrous oxide boils. The gas pressure that has this effect is, in this case, not air, but gaseous N2O, this gas is the nitrous version of the steam given off by water.

When a valve is opened to allow a rapid discharge of liquid N2O the gas pressure in the container will drop suddenly. As soon as this occurs the liquid N2O boils. Just as with water, the boiling will produce N2O gas and that gas will help to slow the pressure reduction. The gas can only be produced at a rate that is governed by the surface area of the liquid and the scale of the pressure drop. Once a valve is opened to release liquid, the pressure in the container will lower. This pressure is unlikely to be steady as all the N2O in the system is now boiling. Pockets of gas are forming randomly throughout the entire volume of the liquid, making the liquid itself compressible and, therefore, 'springy'.
This applies even to the liquid in the line leading to the engine it's supplying. This makes the rate of delivery to the engine much less predictable. It also means that gas bubbles are shot into the engine.

In the ideal set-up, for either a rocket or a conventional petrol motor, we want to deliver liquid N2O at a controllable rate. This makes the engine much easier to tune and to get a smooth performance. One often sees nitrous-aided cars venting the nitrous system to remove gas that may have formed in the lines. Initially this will deliver gasless liquid, but only for an instant as the liquid begins to boil.

Rocket motors that employ the 'boil-off' method to propel the N2O into the rocket always seem to 'pulse'. The exit flame is never steady. One suspects that the same effect will occur in a petrol engine. In a rocket this effect is exacerbated by the resulting rapid changes of pressure in the combustion chamber. The back –pressure on the incoming line will cause the boiling point to fluctuate rapidly, making the pulsing effect worse.
In petrol engines employing a valve 'overlap' the same will apply. It's quite common for my friend, Steve Woods, (who refills nitrous bottles at the track for his customers) to find that the bottle is so pumped full of air (with a little petrol thrown in, no doubt) that he has to let the air out before he can pump in the N2O. Racers beware – a pressurized container with air, petrol and N2O inside is a pretty unstable and dangerous bit of kit. The warmer it is, the more bomb-like it becomes.

For an engine tuner, or a rocket engineer, predictability is the key to ultimate performance. The ideal N2O supply system would never boil. It would deliver a predictable stream of non-compressible liquid, just like a petrol injector. This makes calculation of mixes and power output much easier and far more reliable. From both a safety and performance point of view, it would also be ideal to keep the N2O cold. Fluid densities go up and instability goes down. In a boil-off system, racers often employ bottle heaters to raise temperature in order to increase the delivery of N2O. The same effect could more safely be obtained by making the plumbing allow more N2O through.

In a boil-off system, as the bottle empties, gas will actually start to push the liquid aside and go directly down the line. If you watch water leaving your kitchen sink, as it empties a hole appears in the centre of the draining water as the liquid spins (coriolis effect). The same will happen inside a pressurized N2O container, with a resulting huge drop-off in performance. The emptier the container gets – the bigger the hole for gas to go down. Many racers counteract this by having more liquid than they need for the run, ensuring that the levels never get too low.

There is another complication with boil off-systems that is known as 'Slosh'. In horizontal motion, the liquid will slosh towards the rear of the vehicle, climbing up the side of the container, again allowing gas to bypass the liquid.

In larger rocket motors, some of the downsides of the boil-off method are overcome by filling the gas-space with Nitrogen gas at a much higher pressure than the vapour pressure of the N2O. This prevents boiling. Often an external reservoir of Nitrogen is attached to lower the rate of pressure-drop as the container empties its liquid. This does combat many of the downsides of the boil-off system, but by no means all. Slosh can still happen as can gas blow-by. Back pressure can still make the system pulse quite heavily and the higher pressures mean that even more N2O must be left behind to minimise the blow-by as the levels get low.

So pushing with Nitrogen solves some of the problem but not all. The system is still somewhat unpredictable and the performance curve will be all over the place.

The ideal would be to keep the gas away from the liquid but still exerting enough pressure to prevent boiling. This is known as positive displacement. Gas/liquid shock-absorbers employ this technique. Either a bladder or a piston is used to keep the two separated. The gas acts as a spring damper, smoothing out pulses but the liquid remains free of bubbles and acts in a predictable manner. These shock- absorbers are more properly called ‘Accumulators’. We’ve tried bladders in our rocket-motor tanks, but they just weren’t up to the rigours of the high pressures. It is possible to buy ready-made bladder accumulators, but they cost a fortune, have materials compatibility problems and they are much too heavy for racing and rocketry.

So we tried putting free-floating pistons inside cylindrical vessels, Nitrous on one side, Nitrogen on the other. Now there can be no slosh, and no blow-by. The piston/gas arrangement also acts as a damper, minimizing the effect of back-pressure coming up the line. If the Nitrogen pressure is kept high enough there will be no boiling. The result was a very smooth and predictable rocket performance. We can stay well away from the Critical Point, vastly improving the safety aspects of the operation. In fact, the colder it is, the better it works.

Piston accumulators work very well for Rockets and we see no reason why the same shouldn’t turn out to be true for piston engines. All a tuner needs is predictability – then the rest is much easier.