WATER INJECTION

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A superb octane-improver and ancillary coolant is that oldie but goodie **water injection**: humidifying the combustion air.

Contrary to what would be expected from the fact that water vapour is a product of combustion, its presence before the fuel is burnt stimulates more complete burning. Several benefits, easily added to a wide variety of engines, can flow from this odd fact. Few if any commercial kits are on sale in N.Z., but I have invented an extremely simple, cheap rig for DIY water-injection, which I disclose here with full instructions. Also I seize the opportunity to gush on, as enthusiasts tend to about obscure technologies with which they have fallen in love. As this is not a technical journal but an enthusiasts' club mag, I will become autobiographical to some extent.

History

The essential idea was developed in the first decade of the 20th century. The original purpose was cooling. By 1910 some engines which had been water-cooled were simply produced without water-jackets after addition of 'internal cooling' as water-injection was first called.

Those engines had compression ratios around 4:1 and the phenomenon of pre-ignition (knocking, pinking) was unknown. Later however this became the main reason for water injection, which turns out to give spectacular octane improvement, allowing CR on petrol as high as 13:1. By the end of World War II many aero engines used water-injection. German versions used water-methanol mixtures, partly because straight water would freeze in winter. The Wright Cyclone, a main U.S. aero engine, tested with water and methanol-water (the two liquids being miscible in all proportions, unlike methanol & petrol), showed 50:50 best (as had the Germans). The results were summarised as "high savings in fuel cost - 52% at 100% power, decreasing to 25% at low cruise powers . . . pure water is approximately equal to fuel when used as an engine internal coolant at high power". Water gained the Corsair (flown by some Kiwi pilots in the Pacific) 350bhp on its normal maximum of 2100bhp - a 17% increase. These were supercharged engines, so the results may not translate readily to normal aspiration.

Another alcohol, infamous ethanol, was similarly mixed with water before injection, but was not as good.

When Renault attacked Formula 1 with twin turbos cramming several atmospheres of boost into Gordini's 1500cc V6, they readily achieved 450bhp but burned holes in pistons. Then a Kiwi mechanic recalled water-injection; a reliable 550bhp won the championship. The Saab works turbo rally car at one period had a water tank as big as the petrol tank.

Some modern gas-turbine aero engines use water-injection for maximum power at takeoff. Various naval and railway external-combustion rigs are improved by steam injection.

Practical Experience

My main motive initially was to facilitate use of the low-octane petrol which was the only unleaded petrol available in N.Z. Troublesome, even dangerous, solvent effects have shown imported half-aromatics 96-octane petrol to be a far inferior way, compared with water, to resist knock.

Many standard motors can benefit from water injection. Over the past decade I have done many thousands of miles, and a small amount of dynamometer testing, mostly on the Renault 'Sierra' motor (which powered the models 8, 10, 12, and some versions of the 4 & 5). Power, economy, emissions and cooling are all improved by a water:fuel ratio as low as 5%. At CR 8.5:1 knocking is abolished even if ignition is advanced 30°. Certainly, water is a much better octane-booster than lead: more effective, vastly cheaper, and incomparably healthier.

Friends have tested my water kits on Solex, Stromberg, Zenith, SU, Toyota, Nissan, etc. carbs. Results have been generally good but unaccountably differing. One reason why I have not published a formal account of this testing is that the scientific mind's craving for regular patterns is frustrated by the puzzling extent of variation between different engines.

Although no general rule-of-thumb promises can be formulated, the indications are that water-injection is well worth a try. Here are a few reports on experience with my water kits.

(1) **Mercedes Benz 280** (Solex carb) On a windless day, cruising at the speed limit, the return from Tauranga to Auckland used 14% less petrol than the outward journey had without water.

(2) **Renault 10**, 1108cc During several trips between Auckland & Wellington, I had been in the habit of cruising around 1/3 throttle (just off the power jet), 50-55 mph, 45-40mpg. With water:fuel at 5 - 10%, on this same journey, I took to cruising at 3/4 throttle or more (65 - 80mph) - and still got 44 mpg. Back down off the power jet, the former cruising regime gave 53 mpg.

(3) **Toyota Starlet** 1l Torque at low revs was so increased that the mechanic at first thought the owner had slipped in a bigger motor. Making good play with the extra power, the mathematician owner achieved petrol savings of only 4%.

(4) **Leyland A70-powered house-truck** (Solex carb) The 1966 2l motor, CR 6:1, could cruise this heavy vehicle comfortably at no more than 45 mph. Having settled onto this cruising condition, with stable temperature etc., the former military aviator barked the order for his wife to unclamp the clothes-peg on the plastic in-cab water-pipe. Their heads were pinned back onto the quilted headboard, their facial features hideously distorted by massive *g* -forces; able to move only their eyeballs, they beheld in the rear-vision mirrors blue smoke billowing from the rear tyres as, at unchanged throttle, The Silver Snail spurted up to 55 mph. And the coolant temperature dropped slightly. "She climbs hills noticeably further before losing speed in any given gear". More torque was available at low revs. With water:fuel at 25%, fuel consumption was improved about 15%, despite the faster cruising.

Saving one litre of fuel in every seven, and getting a broader useable power band, on the cheaper low-octane petrol, for negligible capital & running costs, is a very good deal. Sure, turbocharging it isn't; but the price is right, and you'd be assisting public health. My guess is that slow-revving motors, like the A70, will achieve good gains with water; and certainly any motor with CR around 10:1 or higher will benefit; "in between", so to speak, are recent motors which are already fairly efficient, CR around 9:1, on which the benefits will probably be less marked. Anyway, it's very easy to try!

How Does It Work?

Most of the technical publications have been by oil- or engine-company scientists, through the SAE. Leaving aside the puzzling variations and a few unexplained anomalies, the results can be summarised as follows.

Humidified combustion air lowers by hundreds of degrees the peak temperature in internal combustion (petrol or diesel). The residual pockets of exhaust gases turn out to be so much cooler that they are not able to provoke preignition on the next compression stroke. Despite this lower combustion temperature, the fuel is burned more completely, especially if given more time by extra ignition advance. Decreased in the exhaust gases are carbon monoxide (40 - 60%), oxides of nitrogen (10 - 85%), and unburnt fuel. Exhaust gases, and therefore valves, run cooler. The more complete combustion gives more power &/or economy. It is feasible to feed a warmed-up motor as much water as fuel, but most of the benefit is gained at water:fuel ratios as low as 1:20, which is convenient in that a water bottle of 2 or 3l is filled when taking on about 40l of petrol.

Formation of 'coke' deposits is inhibited; indeed, pre-existing coke is eroded. This latter fact gives a vague clue to how the water works: it modifies combustion chemistry, probably by producing highly reactive transient free radicals *e.g.* OH. However it may work, it is not by expansion of water droplets to steam, because the water is already vapour before the mixture gets ignited. Water-injection is (like many medicines) a good example of a clear benefit whose chemical mechanism remains unknown.

Mechanical engineers in the universities of NSW and Auckland have conducted research on water-injection - the latter unfortunately allowing students to pursue arcane side-tracks such as turbocharged CNG. The estimable English carb manufacturer Mr Gardner tells me he agrees fully with the present article on the basis of his experience.

I do not know of any definitive testing whether the cooler exhaust temperatures slow the dreaded valve-seat recession (last refuge of the apologists for lead).

A few encouraging successes have been achieved with emulsifiers for putting the water in the fuel itself. Some huge slow power-station diesels inject up to 50% water, emulsified in the fuel. But this promising approach is beyond ordinary motorists.

How To Do It…

Commercial water-injection kits, which were relatively abundant in the late '50s and early '60s, generally used complicated equipment to evaporate the water into the mixture after the carb. Some had heaters. What I have discovered is that the best insertion point is just outside the throttle butterfly. Here the vacuum is nil at idle or on over-run, when no water is wanted; as the butterfly is opened, suction increases progressively up to about 1/3 of an atmosphere, and is still about 1/6 atm. at full-throttle running. As it happens, this is the point where a small hole takes vacuum for the distributor retard. This vacuum, emerging at a nozzle on the carb body (in no predictable spatial relationship to the actual hole in the venturi), is very suitable as the means of feeding water: it serves as the motive force, which varies automatically according to need. (I have recently learned that the same idea occurred to Motor Specialties engineers Chris Marks and the late Philip Charlton 35 years ago.) No transducers, pumps or heaters are needed. The mixture is humidified, after all the fuel has been loaded into the air; methods which pump the water in the top of the air cleaner, before the fuel (*e.g.* Holley, Edelbrock, J. C. Whitney), seem to me liable to change the fuel:air ratio and therefore may require rejetting of the carb.

The suction at this nozzle is so great - up to 10 ft. of water barometer - that the water feed-rate must be limited by a constriction. Stainless-steel needles of suitable bore are abundant in the world of modern medicine and can, with care to prevent misunderstanding, be procured free.

(A few motors, *e.g.* Vauxhall & Bedford, take the vacuum for the distributor from the other side of the butterfly, *i.e.* from the intake manifold. In this vacuum *advance*, the distributor baseplate is spring-loaded in the opposite direction compared with the common vacuum retard. I comment in passing, tentatively, that the 'distorted mirror-image' vacuum regime of the manifold seems to me an inferior basis for spark-timing control; but in any case, it gives maximum suction when no water is needed, and is less suitable for the simple system of water-injection which I describe.)

On most motors, the pipe taking the vacuum to the distributor is connected to the vacuum nozzle on the carb by an inch or so of rubber tube (see diagram). Some older motors use a copper pipe with threaded unions. I give the instructions for the modern rubber system, which readers may care to try on any modern vehicles with which they are involved; for all-metal systems, I can give only a couple of suggestions and then await reports from club members who improve on them.

Multiple carbs can present a problem. Normally only one of them actually has a vacuum line to the distributor. It would be out of the question to put water into only that one carb. Fortunately, the other carbs sometimes have the equivalent nozzle, though blanked off; it must be liberated, and connected by a Y- or T-junction to the same bottle.

Only one CNG vehicle (Holden 186) has operated with one of my kits; power was much improved at high revs. No fuel consumption figures have been measured. Water injection allows fixed timing nearer the CNG optimum (around 30° ahead of standard petrol timing) without provoking pinking when switched to petrol.

As for that exotic modernity fuel-injection, I have no experience of adding water to such new-fangled gear. Presumably a much bigger needle at the right place in the air intake would work. I would be interested to co-operate in experimentation on this.

Instructions

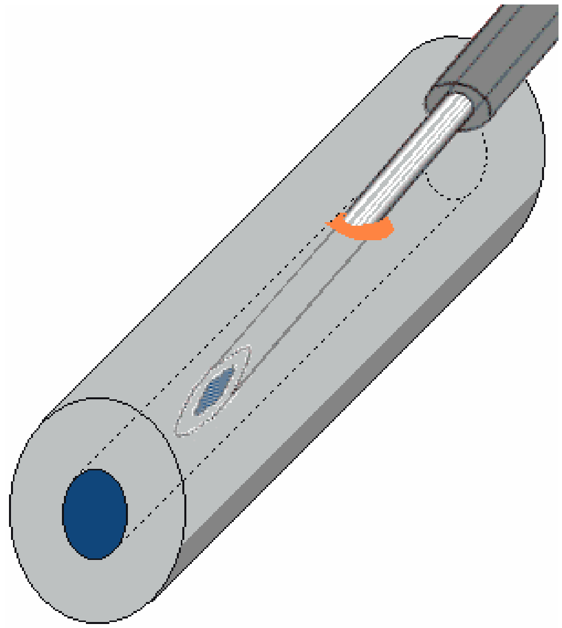
1. **Obtain** a water-bottle of 2 or preferably 3 (or more) litre. Plastic beverage bottles are sturdy. Dark material, or wrapping with opaque tape, will help to prevent microbial growth. The brown version of the classic "half-g" flagon could arguably suit certain sports-car images.
2. **Choose** the water-bottle mounting site. This must be lower than the carb (gravity feed is disastrous); how much lower is not very important. Judicious proximity to the exhaust is OK for the plastic juice bottles, and indeed serves as a crude thermostatting; the surface tension and therefore the feed rate at the needle is somewhat affected by temperature.

   To inhibit bottle-flail, a shallow open-top box may be screwed &/or glued to some roughly vertical surface; or there may be an existing horizontal surface on which the bottle can rest, with convenient components preventing movement. A piece of a bicycle inner-tube can be useful for tying the bottle neck to some suitable static structure.
3. **Cut** 4mm I.D. plastic pipe to run from the bottom of the bottle to the carb.
4. **Make** a hole in the bottle cap for the pipe. Dirt must be excluded, but on the other hand air must bleed in to replace the water as it is extracted (= 1l /h); in practice the tightest hole us amateurs can make with *e.g.* a bradawl will probably let in this slow air bleed.
5. **Obtain** a needle. The double-ended needles used for 'Vacutainers' abound today, and are better because they have a threaded plastic hilt which readily screws (with added glue *e.g.* Bostik) into 4mm I.D. plastic water-pipe. If you have to use single-ended needles, carefully remove with side-cutters most of the finned hilt so as to permit glueing of the remaining hilt into

the water-pipe. A secondary filter can be inserted just before this junction, but is probably of little use and may get clogged with microbial slime.

Feed rate depends steeply on needle bore. The size of needle to give a suitable feed rate for your engine has to be found by test. The medical personnel who will probably get needles for you are likely to talk in arbitrary size codes ("21 gauge" etc.), but the small print on the packets usually gives rational measures. Often best is 0.71mm (22G) or 0.63mm (23G), but 0.8mm (21G) or 0.51mm (25G) is best for some motors.

6. **Add** a filter on the bottom end of the water-pipe. Many sports-car types will be able to procure, without undue embarrassment, the double layer of nylon mesh constituting a panty-hose hem. A rubber band holds approx. one hundredth of this on the end of the pipe, and holds on a small weight *e.g.* a nut to keep the pickup near the bottom of the bottle.



7. **Remove** the rubber tube from the carb nozzle. This neglected component is often degraded, even leaking, on older vehicles; it should be replaced if doubtful. Take the opportunity to inspect the whole carb-dizzie vacuum system for leaks which are inimical to not only water-injection but also the original, continued function of spark retard.

8. With the light coming over your shoulder, **lance** the needle into the rubber at a low angle until you see the glint of stainless steel in the lumen of the rubber tube.

9. **Seal** the needle's penetration in the rubber by a drop of glue on the outside.

10. **Replace** the rubber on the carb nozzle.

11. **Affix** the pipe to static brackets, struts, or whatever's handy to keep it out of harm's way, with twists of wire or similar.

12. **Check** that water is sucked up the pipe when the motor is gunned, but not at idle.

Problems

The only known major hazard is condensation of water in the oil. This can occur if, on a short run, the oil does not get warmed up and the throttle is opened too wide so as to give a high water feed rate. Evidence of this problem is white foam on the dipstick or the filler cap, as when a leaking head-gasket has connected a water-jacket into a combustion chamber. Any competent driver does not maltreat a cold engine that way, water or not; but if it should happen, the immediate response is to keep driving if possible, to warm up the engine fully and boil the water out of the oil. Actually, during the boiloff period, if the breather is connected as it should be just after the air-cleaner, particularly good performance is available! But it's better not to get the water in the oil in the first place, because that white foam is an inferior lubricant.

If you choose to get the full benefit by advancing the (static) ignition timing 20° or so, wild ping will set in if you then run out of water. This is not a major threat because

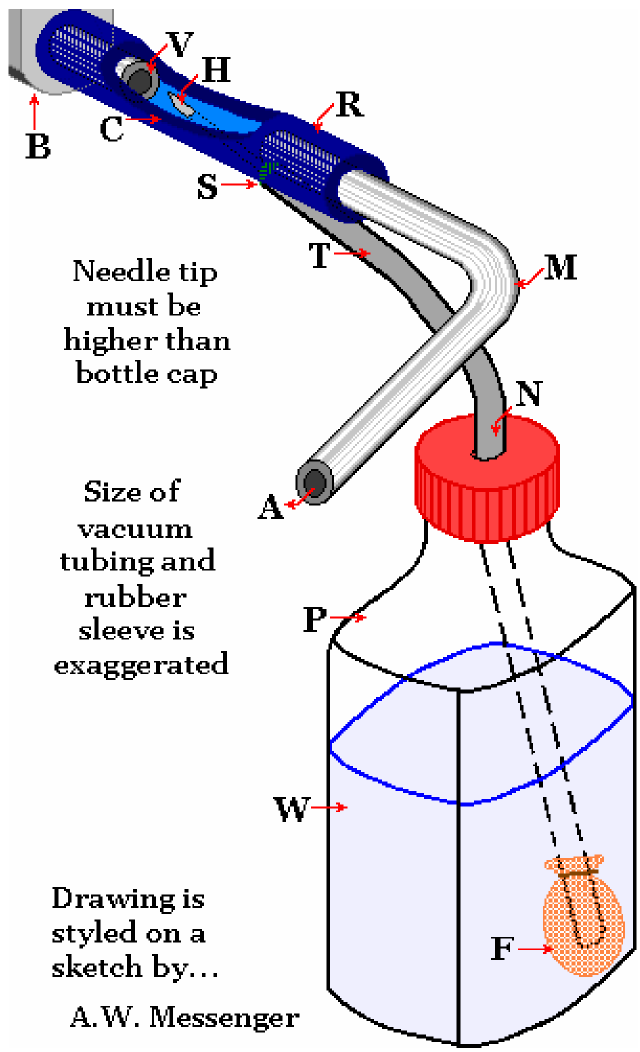
(a) the correct needle size will give you a convenient water:fuel consumption ratio corresponding to emptying the bottle no more often than the fuel tank,   and

(b) you carry spare water anyway.

Dirt can block the needle, especially on motors for which a relatively fine needle (*e.g.* 0.51mm) is needed to limit the water:fuel ratio around 5%. Filtering is therefore important. Nylon fabric is satisfactory. Cotton-wool can be stuffed up the first cm or so of the pipe, but is prone to blockage by microbial infestation (prevented by occasional slugs of methanol, if you can be bothered). It is best to replace the filter semi-annually.

The particular problem of inserting the needle in an all-metal vacuum line will, I hope, be tackled imaginatively. Obvious possibilities include making a tiny hole in the copper pipe into which the needle is then soldered or epoxy'd. Alternatively, some flexible tube may be found which will fit over the threaded fittings of the nozzle and the pipe, and into which the needle can be lanced as above.

- **KEY**
- **A... to advance and retard diaphragm on distributor.**
- **B... body of carburettor.**
- **C... cutaway section (for clarity).**
- **F... filter bag made from old nylon tights.**
- **H... hypodermic syringe needle.**
- **M... metal or plastic vacuum pipe.**
- **N... non sealed entry (for pressure balance).**
- **P... Plastic 3 litre bottle.**
- **R... rubber connecting hose.**
- **S... sealed junction between needle and tube**
- **T... tubing.**
- **V... vacuum nozzle.**
- **W... water with a dash of methanol.**



Concluding Remarks

The history of water-injection shows a peculiar waxing & waning. It deserves to wax anew on ordinary vehicles, after near-eclipse for three decades. Your typical modern motorist is in such a hurry to important commitments like playing squash that she will not be willing to put in a second fluid when stopping for fuel; but those eccentric drivers who actually care about machinery are more likely to invest time (as distinct from money, which is saved) in the simple, extremely cost-effective accessory of a water-injection rig which entails opening the bonnet when fuelling-up. For a 'cab-over' van or truck, the water bottle can sometimes be mounted in the cab (but 'ware gravity feed!)

Should economy contests become an integral part of club runs? They would stimulate not only careful testing of water-injection but also other influences on economy.

I look forward to participating in future developments of this interesting & worthwhile technology.