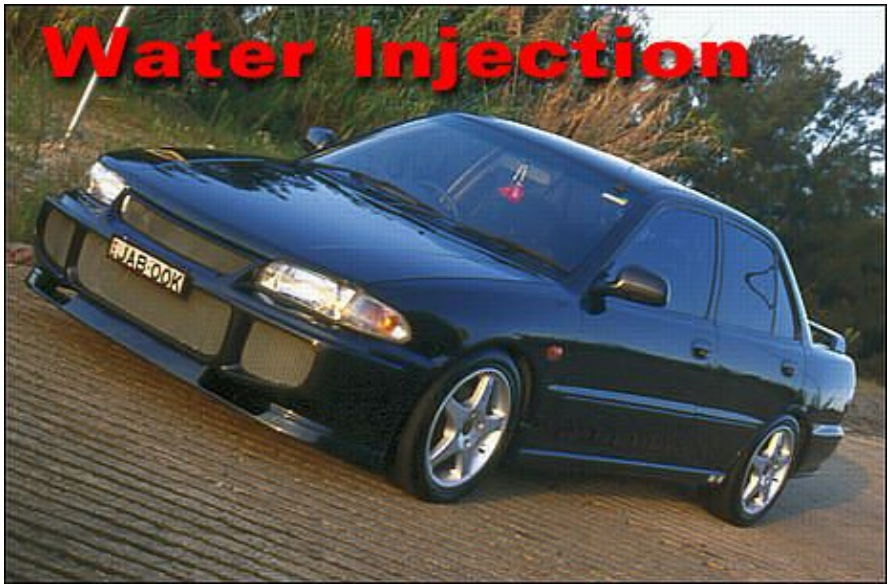


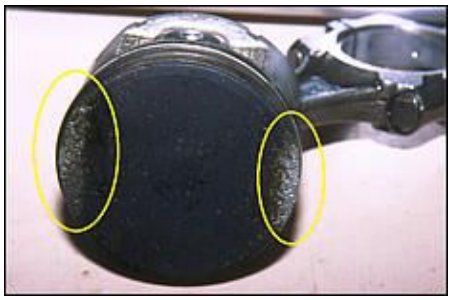
Water Injection

It lets you safely develop more power with nearly no running costs!

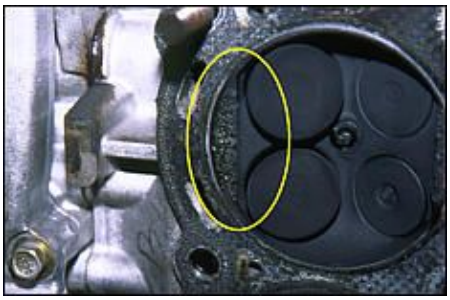
by Julian Edgar

Water injection is a technology that is nearly as old as the car itself. However, like many automotive technologies, it has waxed and waned as fashion has dictated. Water injection has the ability to suppress detonation, allowing the use of higher cylinder pressures. It is easy to control and relatively simple to install. In times of tight emission controls, decreasing fuel octane and rising petrol costs, water injection is one of the best ways of controlling detonation. And it has another major advantage over taking other approaches - the 'fuel' is available at almost zero cost!

How it Works



Water injection is used to suppress detonation. Detonation occurs when the flame front does not burn progressively across the combustion chamber but instead explodes into action. This causes a massive and sharp increase in combustion pressures which can damage pistons, rings and even heads. Detonation can sometimes be heard as a 'tink, tink' sound coming from the engine. The piston and head shown here has suffered severely from detonation.



Water injection works in three ways. Firstly, when the water is injected into the intake system prior to the cylinder head, the small droplets absorb heat from the intake air. Water has a very high specific heat rating (it can absorb lots of energy while only slowly increasing in temperature) and so the intake air is initially cooled. Next, the small drops of water start to evaporate. Water has a very high latent heat of evaporation (its change of state absorbs a lot of heat) and so the intake air charge is cooled still further. Finally, when the remaining water droplets and water vapour reach the combustion chamber, steam is produced. This acts as an anti-detonant and also keeps the interior of the engine very clean, so preventing the build-up of carbon "hot spots".

Water injection was first experimented with in the 1930s. At the time it was discovered that detonation could initially be prevented by enriching the air/fuel ratio. As cylinder pressures rose still further and that approach ceased being effective, the injection of water into the intake air stream was found to prevent detonation. Interestingly, the detonation remained suppressed, even if the air/fuel ratio was then leaned-out. This occurred because the excess fuel was being used to cool the combustion process. When water replaced fuel in performing this function, less fuel was then required.

This has major implications for both emissions and fuel economy at high engine loads. In fact Saab on some of their recent turbocharged cars has used water injection at high loads in conjunction with leaner air/fuel ratios to reduce emissions output and improve fuel consumption. To put this another way, at high engine loads it is possible to reduce the amount of fuel being used, replacing it with water without sustaining any loss of power!

Always Water?

While I have referred to 'water' injection, many systems add a 50/50 mix of water and methanol, or water and methylated spirits. Research carried out during World War II indicated that pure water is best at suppressing detonation, while a 50/50 mixture of water and methanol permits the greatest power output before detonation occurs. One reason for this may be that the alcohol burns more slowly than petrol, so causing peak cylinder pressures to occur at a later crankshaft rotation, increasing torque.

The question of whether a water injection system can increase engine power is a contentious one. While the intake air will be lower in temperature (and so denser) when a water injection system is operating, the presence of an increased amount of water vapour in the air means that there is less room for oxygen. It is for this reason that dry air (that is, air with a low relative humidity) can allow an engine to develop more power. So when the air is cooler but its water vapour content is higher, will more power be developed? If no changes are made to air/fuel mixtures, theoretically the two factors almost exactly cancel each other out.

This means that if water injection is used without any changes made to the tuning of the engine, improvements in power are possible but not probable. However, if the engine air/fuel ratio is leaned out, or boost is increased, or the ignition timing is advanced, more power is very likely. Supercharged aircraft engines using water injection had mechanisms that leaned out the air/fuel ratio simultaneously with the operation of the water injection. However it is very important to note that making random changes to the air/fuel ratio and ignition timing at high engine loads can be very dangerous for the health of the engine. Such changes should be made with care - **it is very easy to blow up a forced induction engine with random leaning of the mixtures and/or ignition timing changes!**

Both methanol and methylated spirits mix well with water when it is required that a mix be injected. However it is important to note that both of these mixtures are inflammable and so the anti-detonant injection system's storage container, pump and lines should all be designed and installed with the carriage of an inflammable liquid in mind.

Note that it has been suggested in some circles that the water can be directly added to the petrol by using a solvent such as acetone. However, I have not heard of anyone actually doing this!

Water Injection Systems

A water injection system should:

- Distribute the water equally to each cylinder;
- automatically start the water flow prior to it being required;
- have positive shut-off (eg via a solenoid valve) when water injection is not required;
- either warn the driver or decrease engine power (eg by dropping boost) should the water supply be exhausted;
- be very reliable.

Many aftermarket water injection systems do not satisfy any (let alone all!) of these criteria.

To be most effective, a water injection system should add water in proportion to the changing airflow. In other words, the flow of water should match the flow of air, with small amounts of water being added at low loads and high amounts at high loads. If very accurate control of the water injection quantity is available, maximum water flow per cfm of induction air should occur at peak torque when cylinder pressures are at their highest.

The water should be injected in as fine a spray as possible. Doing this results in each drop being smaller, increasing the surface area to volume ratio and so promoting evaporation. The smaller drops are also less inclined to fall out of the air, wetting the intake manifold walls and perhaps then being distributed unevenly from cylinder to cylinder. A small droplet size means that a high-pressure pump and a well-designed spray nozzle are required.

UK company URL at www.aquamist.co.uk produces some very sophisticated water injection systems - probably the world's best. The company has developed their own pumps which work at high pressures and low flows. The pumps use an approach a little like a bicycle pump. Water is drawn in during the induction stroke of the solenoid-like pump, then pushed out past a valve by internal spring pressure. The stainless steel armature pulses in this way 50 times a second, delivering up to 160cc a minute at over 70 psi. The pump has built-in electronics to control this pulsing, with a 0-12 volt input control signal able to vary the flow. While URL use a sophisticated ECU to control some versions of the system, the availability of the control signal input means that the output of the airflow meter or MAP sensor could probably be adapted for the same purpose.

An alternative to a pump is to use boost pressure to force the water through a nozzle. If this system is adopted, the spray can be used only in a forced induction car with the water introduced prior to the compressor. A very special nozzle is also needed if the spray is to be sufficiently fine to pass through the compressor without long-term damage occurring. People using coarse droplet water injection in front of turbos have reported that over a period of time the edge of the compressor blades develop a serrated edge - presumably from the impact of the water droplets.

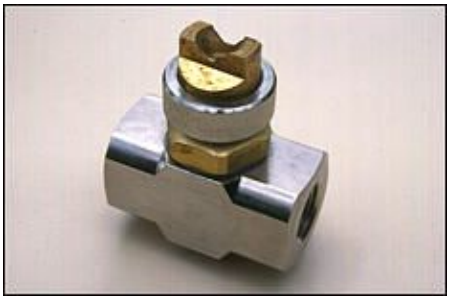
The injection of water can occur at a number of different points within the intake system. In a naturally aspirated car, the nozzle is usually situated prior to the throttle body. In a forced induction car, the nozzle can be situated:

- before the compressor,
- after the compressor
- after the compressor but before an intercooler
- after an intercooler.

URL suggest a nozzle position just prior to the throttle body for road cars, while the supercharged aircraft of many years ago used up to 18 nozzles positioned around the supercharger exit diffuser. Testing of the two systems discussed below indicated that the best nozzle location should be found through experimentation. The amount of water that needs to be added to an engine is also best assessed through trial and error. If the flow of water is initially high and then is slowly reduced, this approach can be done quite safely. However, testing on aircraft engines indicates that the mass of water required to suppress detonation is 20-30 per cent of the weight of the total liquid charge (that is, the water plus the petrol) being consumed. The system should be configured so that water is only ever injected when there are high intake airflows.

Boost Pressure Water Injection

A good quality boost-pressure controlled water injection system can be built using off-the-shelf components. The system gives an extremely fine spray and can be used with water/methanol as well as pure water. While the injection of water is not proportional to load (it is proportional to boost pressure), there is a variation in the supply of water which is still better than many systems provide. The best part of the system is that it is maintenance-free, other than requiring the refilling of the water tank as required and the occasional cleaning of the filter.



The nozzle used is an air atomising design produced by US company Spraying Systems. It has two connections - one for compressed air and the other for water. The compressed air is directed out of two orifices so that it collides with the water stream, scattering it into the tiny droplets. The pressure to supply both the water and the compressed air comes from the turbo or supercharger. The part number for the nozzle is SUE18A and it is available from agricultural irrigation and spray suppliers.

Unlike many air atomising nozzles, the SUE18A works effectively at pressures below 50kPa (7psi). Around 200 ml/min flows through the nozzle when it is supplied with water and air at around 20 psi (1.4 Bar) boost. If this flow is too great, a ball valve can be placed in the water supply hose to allow easy adjustment of the flow. If the ball valve is closed down to restrict the water supplied, the remaining water will then be even better atomised! If more than 200 ml/minute of water is required I suggest that you use two or more nozzles.

The water supply for the nozzle should be through a small water filter to avoid filter blockages occurring. An appropriate filter is available from the suppliers of the nozzle or a small garden irrigation filter can be used. The nozzle must be mounted so that it flows into the intake system before the compressor and the water should be injected after the airflow meter (if present) to prevent the water droplets upsetting the air metering.

The fluid storage container must be pressurised if the water is to be forced through the nozzle. A custom tank can be made or a large pressurised radiator header tank pressed into service. Preferably the tank should be at least 5 litres in volume for each nozzle used. Note that the tank must be capable of handling the constant cycling of internal pressures up to the peak boost level. A low fluid warning buzzer should be fitted.

Plumb the system using a ball valve to adjust the supply of water and a boost-pressure triggered solenoid (pictured) to give a positive starting and stopping behaviour. An alternative to the use of the solenoid is to install a vacuum-operated valve (such as the EGR valve) to vent the tank back to the inlet system, causing the tank pressure to more closely follow boost when the throttle is lifted. However, the solenoid valve is the safer of the two approaches: **if the water ever flows into the intake when the engine is stopped, very major engine damage can be caused when it is attempted to be re-started!**

Pumped Water Injection

If you require that the water be injected after the turbo or supercharger, or a large pressurised tank is unwieldy, a pumped system is a better option. This type of system is also suitable for a naturally aspirated car.

The pumped water injection system again uses Spraying Systems nozzles. The SF2 and SF3 Fogging Nozzles are designed for humidifying the air in chook sheds, amongst other agricultural applications! The nozzles require only pressurised water to produce a fine spray, although note that the droplets are not as fine as those produced by the air atomising nozzle described above. The nozzles can be equipped with in-built filters and check valves that prevent them dripping.

The electric pumps used in for agricultural crop spraying or in good quality windscreen washer systems can be used. If the spray nozzle is located after the throttle butterfly, a solenoid valve should be inserted in the water supply line so that there is no possibility of water being sucked through the pump during periods of high manifold vacuum. The easiest activation technique for the pump is to use a manifold pressure switch that simply turns on the water injection when the engine is on boost, though of course this then does not give proportional control. Another approach that will give slightly earlier switch-on is to use a throttle microswitch (pictured).

Another entirely different way of varying the water injection rate is to drive the pump with a trailer electric brake controller. These devices are available from caravan and similar suppliers and are designed to energise the electro-magnets that are located in the brake assemblies of some caravans and trailers. One class of controllers does this by measuring the braking force that the car is undergoing and increasing its output voltage proportionally. I envisage the controller reversed in orientation so that it measures acceleration. If it was then connected to the water injection pump, the harder the car accelerated, the higher would be the pump speed and so the greater would be the addition of water into the intake air!

Water Injection versus Intercooling

So which is better if you are running a forced aspirated car - water injection or intercooling? Each has its own advantages and disadvantages. Intercooling is a reliable means of reducing intake air temperatures and depending on the approach chosen, it can be a very simple system. However, it should be noted that while air/air intercoolers have few component parts, water/air intercooling is more complex than water injection. Intercooling systems require little or no maintenance, and a good intercooling system will provide an engine power increase in addition to preventing detonation. However, intercoolers are much larger than water injection systems and are generally harder to package. Finally, all intercoolers cause a restriction to intake flow.

Water injection is very effective at preventing detonation. It is not subject to efficiency drop-offs through heat soak and causes no restriction to intake flow. It is easy to fit as an add-on to an existing system, and because its components can be spread around the car, it is generally very easy to package. Unlike intercooling, water injection will not necessarily give a power increase. However, the biggest disadvantage is the requirement to carry a relatively large water tank - and to keep on filling it!

	Advantages	Disadvantages	
Intercooling	• Reliable • System can be very simple • Always improves power • System break-down usually immediately recognisable • No ongoing maintenance • Weight • Bulk • Major underbonnet changes • Usually poses a flow restriction	**Water Injection**	• Very effective at preventing detonation • System components can be spread around car • Can be used to inject octane booster • Generally low cost • No intake flow restriction • Reduces emissions • Requires regular filling of water tank • System breakdown can be difficult to recognise • Large filled water tank is heavy • Variable flow systems are complex • Effectiveness will vary depending on weather

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