CNG Regulator / Fuel System Interactions

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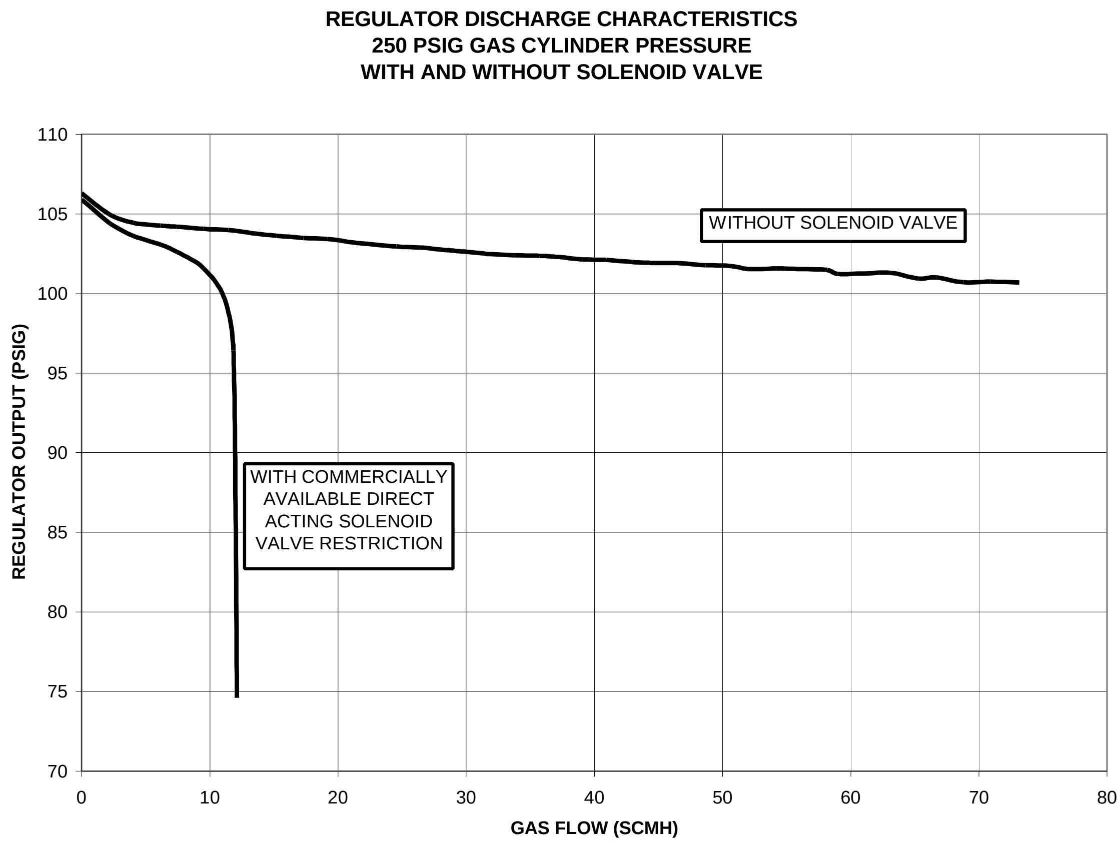
Abstract:

Successful implementation of a natural gas fuel management system requires complete understanding of the component requirements and capabilities. The fuel pressure reducing regulator in these systems is a very sensitive control element. The system, when configured correctly, can provide safe, reliable and predictable service for the life of the vehicle. If the fuel dynamics and system component interactions are not completely understood by the system designer, the interaction of the system and the pressure regulator may cause the regulator to respond in an undesirable manner, leading to unsatisfactory performance and life.

The pressure reducing regulator is a pressure controlled valve. This device is a mechanical valve, which rapidly responds to downstream conditions, and reacts appropriately to flow gaseous fuel until a pre determined pressure is achieved. Since the pressure regulator, by design, responds to system pressure conditions, it interacts with the entire fuel system. These interactions can be subtle or abrupt and can allow the system to function in a safe, reliable and predictable manner, or function erratically in an unsafe, unreliable and unpredictable manner.

The energy to drive suitable gas flow through the regulator comes from the stored energy of supply pressure. The pressure regulator requires a minimum amount of supply pressure to flow the required amount of gas, while maintaining the downstream pressure. Inadequate supply pressure in the storage cylinders, inadequate cylinder valve or in line solenoid valve size, excessively small high pressure line size, restrictions in an upstream coalescing filter and even excessive gas moisture or oil content can restrict the supply pressure to the regulator under dynamic flow conditions. The graph, presented below, was derived from flow bench regulator testing using a commercially available high pressure CNG solenoid valve.



As the graph suggests, the supply to the regulator can choke at low to moderate flow if the upstream components are not carefully selected or maintained. Supply valves and high pressure fuel lines need to be selected carefully during initial or retrofit design. Coalescing filters need to be adequately sized, with the collection bowl drained and the element replaced regularly. Fill station gas moisture and oil content need to be monitored as part of a preventative maintenance and/or fuel quality assurance program. Fill receptacle dust caps or covers need to be used and maintained to prevent the ingestion of road dust and dirt into the vehicle fuel system.

System cleanliness is critically important to the pressure regulator. Although most regulators are equipped with internal filters, these filters are typically small and can clog easily. An upstream, high pressure filter needs to be integrated into the vehicle fuel system not just to prevent clogging of the regulator, but to prevent the risk of damage to the valve of the regulator. Some particulates, such as metal filings, may be generated during upstream component fabrication or system assembly. Other particulates may be introduced into the system through the fuel fill connection, or be generated by wear of upstream components such as storage cylinder solenoid valves. A filter is required to protect the regulator and downstream components from these potentially harmful particulate contaminants. The photo below illustrates the damaging effect which particulates can have on the regulator valve seat.

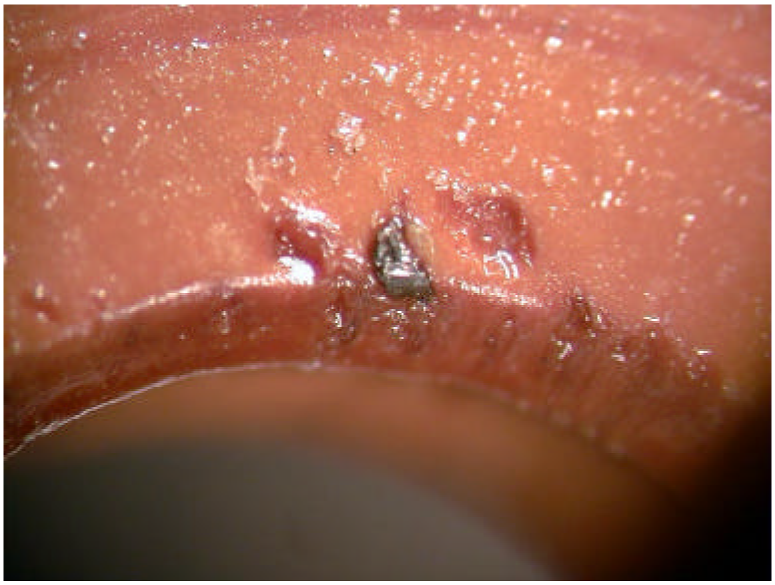


Photo 1 – Microphoto of metallic particulates lodged in valve seat.

Moisture levels can and do have an effect on both regulator and overall fuel system performance. The valve within a pressure regulator controls the flow from the high pressure source to the low pressure output. As gas flows by this valve it rapidly expands and cools. This phenomenon, the Joule Thomson expansion effect, can cause dramatic gas temperature drops. For example, if the gas enters the regulator at room temperature / 3000 psig and exits the regulator at 100 psig, the gas will cool to about –70° F. Although the regulator may be heated, the cold gas exiting the regulator at pressure can deposit ice or hydrates in the outlet port or fitting boundaries, which effectively reduces the flow passage size. This blockage will reduce the available gas flow and/or cause temporary pressure control problems. Typical symptoms of this phenomenon include poor vehicle driveablity, poor acceleration, and increased engine exhaust emissions.

If outlet line icing or hydrate formation occurs, the problem seems to go away if the vehicle is shut off for a short period. When restarted, the problem is gone, but will resume and get worst the more the vehicle is driven. Although the problem is temporary, the effects may not be. As the regulator outlet passages get restricted, the dynamic stability of the regulator may degrade. This degradation can cause the regulator to overcompensate for flow and pressure demands and could cause excessive wear and/or internal damage to the regulator.

As noted earlier, the pressure regulator uses heated engine coolant. The coolant is circulated through the regulator to prevent ice accumulation inside the regulator control valve. This coolant also keeps gas seals from becoming excessively cold and leaking. To permit engine heat to prevent excessive chilling of the regulator components, the coolant system must work properly. Degraded or incorrectly mixed engine coolant may not permit enough antifreeze protection for the cold surfaces inside an operating regulator. Ice formation can occur and prevent sufficient heat transfer to the regulator surfaces. If this would to occur, regulator problems such as poor transient response, poor gas flow characteristics and possible gas seal leakage could occur.

Excessive compressor oil vapors in the fuel can also lead to significant system problems. As the gas expands through the regulator, the gas cools to the point where oil vapors in the fuel can condense and precipitate out of the fuel. The oil does not cause the line blockage problems, like ice and hydrates, however the oil can migrate downstream and cause problems for the final fuel metering elements like fuel injectors. Different organic and synthetic oil precipitates can mix and gel over time, causing fuel injector blockage.

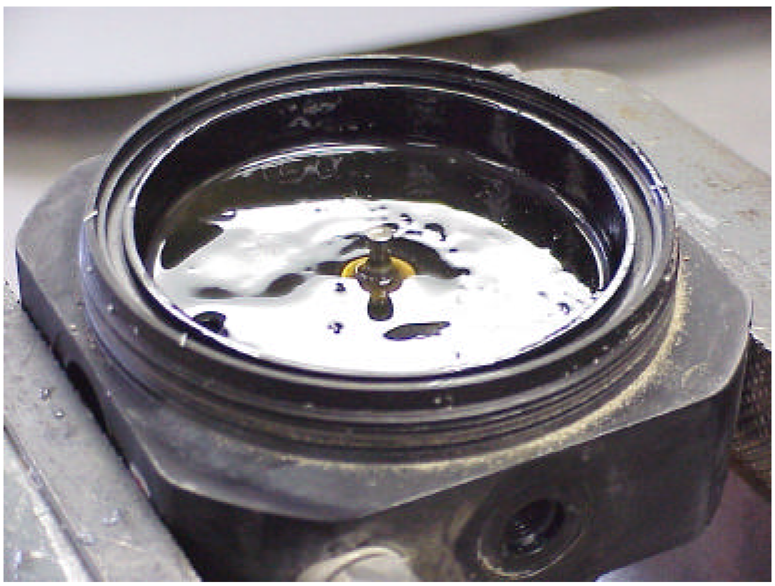


Photo 2 – Oil condensate inside regulator after approximately 35,000 miles.

Oil precipitation generally does not cause any problems for the regulator, unless excessive oil collects. If the regulator is mounted with the outlet port facing upward, oil can collect inside the regulator. In sufficient quantity, oil in the regulator can cause dynamic response issues or hydraulic lockup of the regulator's pressure sensing element.

Because the pressure regulator is a mechanical device, there are always dynamic response issues with changes in flow and pressure. The regulator valve is linked to the pressure sensing element and control springs. These components have mass, and as such the inertia to move them requires a small amount of time (a few milliseconds).

When the vehicle operator presses the accelerator pedal, the fuel metering system changes states to permit more gas flow to the engine. This change of state happens very quickly, but there is a slight time lag before the regulator sees this change. This is because the initial pressure drop in the fuel line (between the regulator and the fuel system) travels towards the regulator at the speed of sound. For example, the time for a pressure wave to travel fifteen (15) feet in an outlet line pressurized at one hundred (100) psig is approximately seven milliseconds (7 mS).

Because the regulator valve and control elements are basically a damped spring-mass system, a resonant frequency exists which must be avoided. Typically the resonant frequency is fairly high and the gas outlet fuel line fairly long, so the frequencies do not match. If the outlet fuel line is very short, the frequencies can approach each other and the internal damping of the regulator may not be sufficient to prevent pulse driven resonance. For this reason alone, it is recommended that the outlet line be made as long as practical. Well designed fuel systems will typically locate the regulator very close to the storage cylinders, safety shut off valve and high pressure filter. This design reduces the exposure of high pressure lines, while taking advantage of the benefits of a longer low pressure fuel line, including resonance damping and available ambient temperature surfaces to warm the flow of gas.

Some vehicle systems use both upstream and downstream filters. The downstream filter helps prevent hydrates, ice and oils from reaching the fuel metering elements, both by coalescing action as well as providing additional surface for heat transfer. The downstream filter also helps to damp out pulses from the fuel metering system in the low pressure line, reducing the potential for driven damped harmonic oscillation and accelerated regulator valve guide wear. Like the high pressure coalescing filter, a downstream filter must be also be regularly maintained to prevent excessive line pressure drop at high flow demands.

There are many regulator to system interactions, both design and maintenance based, which can cause the pressure regulator to respond poorly to fuel system operational demands. The following chart summarizes some of the system issues and the regulator response to these issues:

SYSTEM ISSUE	REGULATOR OR SYSTEM RESPONSE
Excessive fuel moisture content.	Icing within regulator. Intermittent driveability, acceleration and or emission problems. Potential permanent degradation of regulator performance.
Excessive compressor oils in fuel.	Oil Precipitation and migration. Potential fuel injector clogging. Component damage if solvents are used to clean or repair system clogging.
Particulate contamination - Assembly debris - Contaminants introduced during filling. - Upstream component wear.	Regulator valve damage. Potential fuel metering component damage. Potential gas release from low pressure relief valve.
Inadequate flow capacity to regulator. - Inadequate solenoid valve flow capacity. - Inadequate HP fuel line flow capacity. - Excessive pressure drop in HP filter. - Excessive moisture or oil clogs HP filter.	Poor flow performance at low storage tank pressures. Reduced vehicle range.
Low pressure fuel line too short.	Poor transient response characteristics. Potential harmonic oscillation and noise. Cold gas feed to fuel metering system

When the system is correctly configured and maintained, the regulator and other fuel system components will provide predictable, safe and reliable service for the life of the vehicle.