# Electronically Controlled Engine Starting Fluid Injection Systems For Use As Cold Start Assist in Direct Injection (DI) Diesel Engines

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# Electronically Controlled Engine Starting Fluid Injection Systems For Use As Cold Start Assist In Direct Injection (DI) Diesel Engines

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The effects of introducing ethyl ether into a DI diesel engine's combustion chamber to initiate the combustion process of the engine's primary fuel has long been realized[1].

Why Ether

Since the invention of the diesel engine in the late 1800's by Rudolph Diesel[2], the limitation of the engine's ability to "cold start" has been a situation with which diesel engine users have had to contend. The phenomenon of compression ignition relies on the temperature of the engine's combustion chamber reaching the auto ignition temperature of the fuel being injected[3]. Typically, fuel oils have an auto ignition temperature of approximately 371$^0$C (700$^0$F)[4]. Eventually, as the engine's combustion chamber ambient temperature decreases, the ability to reach the necessary compression combustion temperature in a reasonable and acceptable cranking and starting time, will not be possible. Ethyl ether has an auto ignition temperature of around 180$^0$C (356$^0$F), which if introduced into the engine's combustion chamber(s), will allow the combustion process to begin in a reasonable period of cranking time on a cold soaked diesel engine. Ethyl ether has been used in various forms as an aid to the cold start combustion process. Some of the first applications of ether involved the equipment operator or an assistant holding an ether soaked cloth in front of the engine's air intake system while the engine was being cranked, to allow the ether vapors to enter the fresh air intake of the engine and eventually, the combustion chambers. Ether capsules, aerosol spray cans, pump type systems, remotely operated high pressure systems, automatic, and electronically controlled engine starting fluid injection systems, accordingly, have been developed and used throughout the years to cold start assist DI diesel engines.

Ethyl ether has an auto ignition temperature of 180$^0$C (356$^0$F). The explosive or combustible limits by volume of ethyl ether in air, range from 1.85 - 48%. Ethyl ether has specific heat value of 0.5476 gram calories[5]. The proper mixture of ethyl ether, hydrocarbons including heptane, and a suitable propellant, create an effective engine starting fluid formula. To be efficient in the combustion process, this mixture should contain at least a 70% blend of ethyl ether. When this formula is injected into a diesel engine's air intake system at the correct time and in the proper amounts during cold starting, the results are smooth and even combustion characteristics comparable to the engine's efficient combustion process during normal operating temperatures.

Application of Engine Starting Fluid

The three most critical requirements to be followed in the efficient application of engine starting fluid are: 1) the formulation of the starting fluid, 2) the state or form of the starting fluid when injected, and perhaps the most important, 3) the starting fluid versus intake air ratio that is introduced into the engine's combustion chamber. The starting fluid versus intake air ratio should be fixed at the maximum amount of engine starting fluid required during cold starting and allowed to lean out thereafter. An acceptable ratio during engine starting is 91 parts of starting fluid per million parts of air.

As an example, on a four stroke cycle engine with a displacement of approximately 800 cubic inches and a cranking speed of 100 RPM, the amount of starting fluid injected should be 0.475 milliliters (.3363 gr.) per second. Depending upon the starting fluid formulation, this ratio will contribute approximately 2646 gram calories (10.5 BTU's) per second. Under most circumstances, the additional heat added to the combustion chamber by the above process will be sufficient to initiate the combustion of the injected fuel from the engine's primary fuel oil injection system. The engine will start and continue to run smoothly as long as the combustion chamber's temperatures remain above the auto ignition temperature of the engine's primary fuel.

<u>Automatic Starting Fluid System</u>

The subject system uses a United States Department of Transportation 39 NRC pressure vessel which contains a mixture of approximately 70% ethyl ether, with hexane, heptane, and carbon dioxide or ethylene as a propellant. The service pressure of the subject cylinder is approximately 1020 KPA (148 PSI), at 20$^0$C (68$^0$F). The starting fluid cylinder is affixed to an electrically operated solenoid valve (Figure 1). The solenoid valve used for the following test is of the "activated flow", normally closed design. This valve will allow the flow of starting fluid through the valve and to the starting fluid metering orifice immediately upon valve activation.

The system's metering orifice which is responsible for regulating the injected starting fluid to air ratio, is located directly at the bottom of the solenoid valve. The activated flow valve design and the attached metering orifice results in a precise and predictable means of controlling the amount of starting fluid injected into the engine.

As the valve is activated, the flow of starting fluid will be regulated and allowed to begin the vaporization process as it leaves the metering orifice. By exposing the pressurized fluid to atmospheric pressure at this point the propellants contained in the fluid will begin to boil off and force the starting fluid liquid and vapors

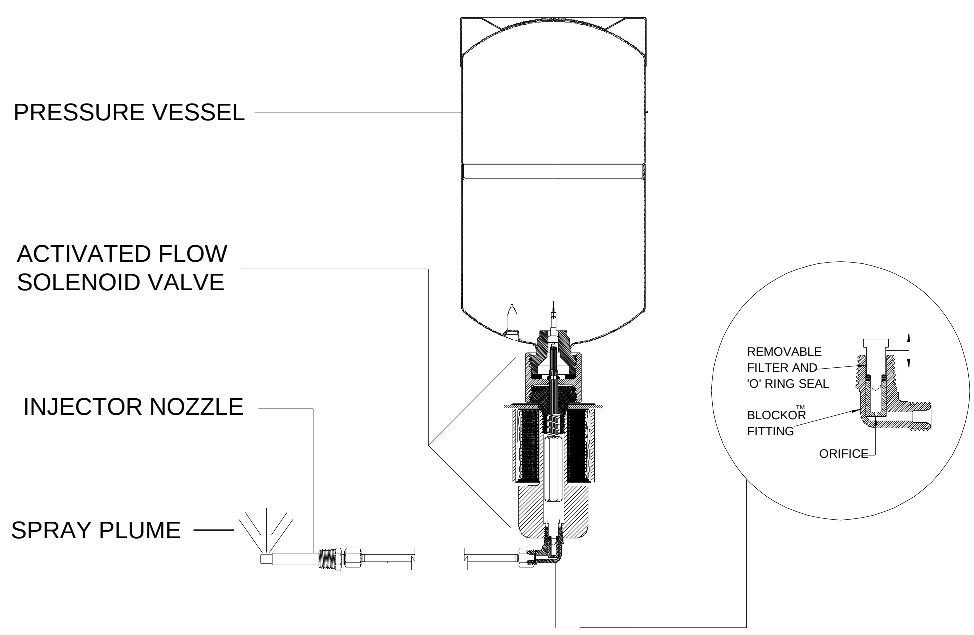


Figure 1 Cross Sectional View

through the conduit (typically 3.175 millimeter, .125 inch, outside diameter nylon tubing), which connects the valves metering orifice to an injector nozzle located in the engine's air intake system. This technique is very efficient in allowing the process of vaporization to occur before the ether actually reaches the system's injector nozzle or the engine's air intake system.

The injector nozzle should be located in a centralized location of the engine's air intake system (Figure 2). The nozzle should also be located on the pressure side of turbo-charged engines but not necessarily directly in the air intake manifold. Engine starting fluid injector nozzles that are located in the intake manifold do not always insure an even distribution of starting fluid vapors to all of the combustion chambers[6]. An even distribution of starting fluid vapors to all of the combustion chambers is essential if the engine is expected to be running smoothly and evenly during the starting and post starting period while starting fluid injection continues. Generally, the spray plume that is emitted from the nozzle should be directed against the oncoming air stream in the engine's air intake system.

Electronically Controlled (EC) System

The function of the Electronic Control (EC) System is to monitor engine characteristics and insure that, based on these characteristics, starting fluid is injected at the proper time during cranking and for the correct period of time thereafter to ensure a smooth and efficient start. By monitoring specific inputs from the sensors installed on the engine, the microprocessor in the electronically controlled system will determine the beginning of starting fluid injection and, if necessary, the post injection cycle. There are basically three inputs (and an optional fourth), that are needed to determine if and when the use of starting fluid is warranted (Figure 3).

Primary Input

The first and primary input used is a signal from the fuel solenoid or vehicle ignition switch that indicates the subject engine is indeed going into a start cycle. This criteria is of importance because there will be many instances in the engine’s life cycle that it will be cranked over without the operator or a service mechanic actually intending to start the engine. If the engine is going to be cranked over without the intention of starting it, the injection of starting fluid would not be warranted.

Second Input

The second input used by the microprocessor is the engine coolant or block temperature. This input will determine if the engine is at a temperature at which the injection of starting fluid should be enacted. The specific temperature that this action will take place would be determined by the engine’s cold start characteristics and/or the particular application of the engine in the equipment that is being operated. The sensor used in the EC application is of the common thermistor

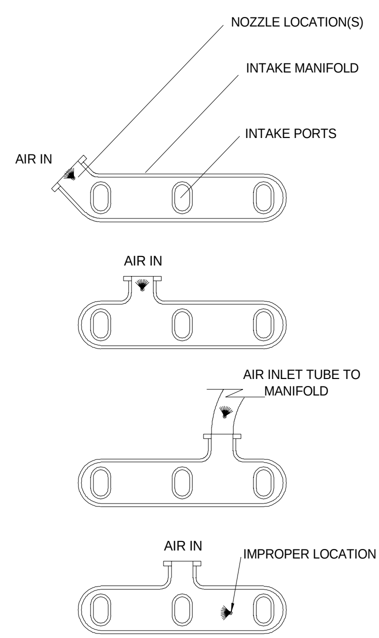


Figure 2 Examples Of Injector Nozzle Locations In Air Intake System

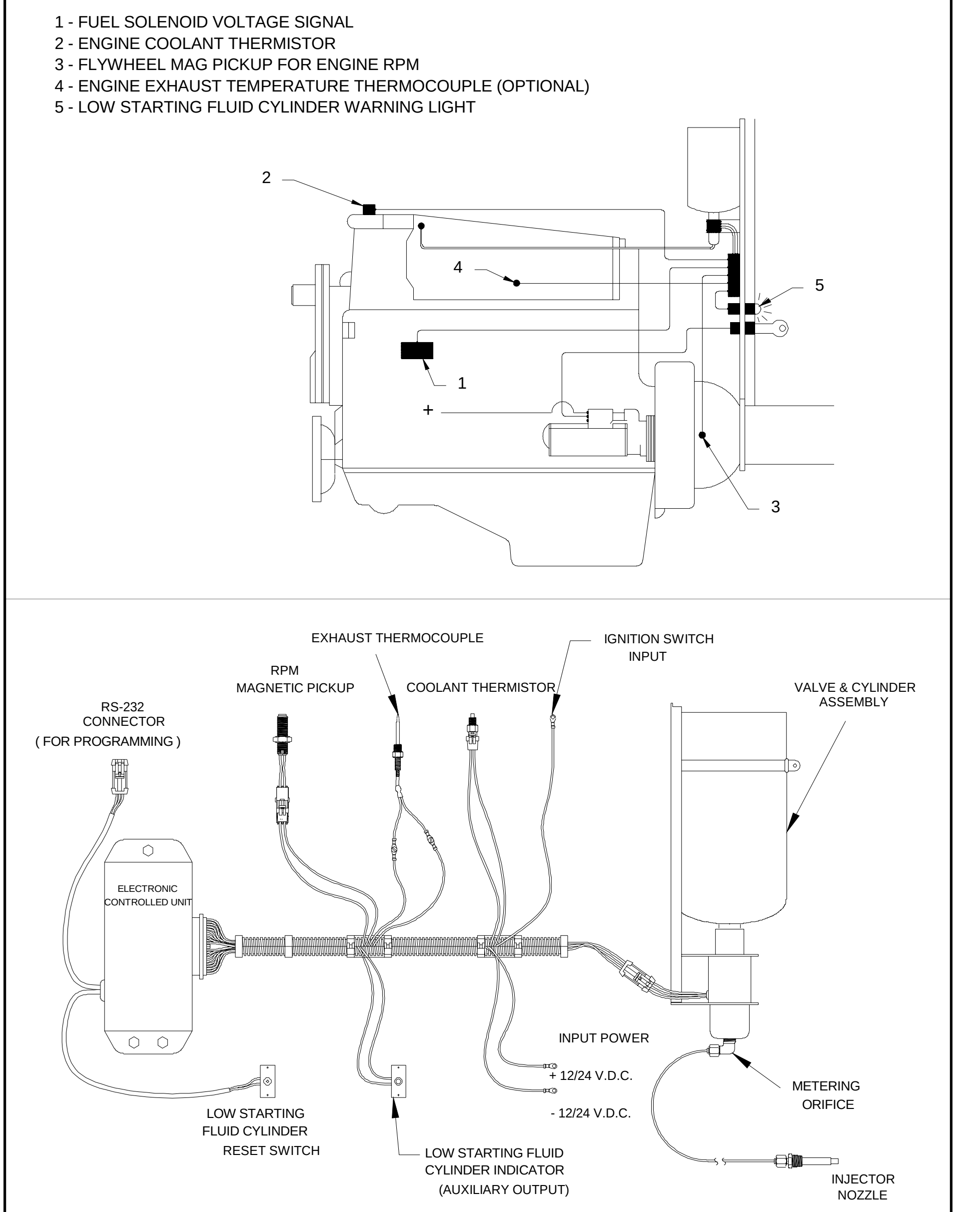


Figure 3 EC System

design. By using a thermistor, the microprocessor will determine actual engine temperature. This information is used not only to determine if the use of starting fluid is warranted during cranking, but if and how long a post cranking cycle of starting fluid injection should be provided. In certain applications, severely cold engines may actually require an injection cycle of starting fluid before a start attempt is made on the engine. This "pre-load" cycle can be programmed into and controlled by the EC if the application warrants it.

Third Input

The third input is provided by a magnetic pick-up installed on the engine in a manner that it will sense engine crankshaft speed. This input is perhaps the most beneficial in that the microprocessor can determine when starting fluid injection is required based on a minimum and a maximum engine crankshaft speed. By monitoring this input the injection of starting fluid will be initiated only when the added BTU's provided by the ether will assist the engine's combustion process.

Optional Fourth Input

A fourth and optional input would be the engine's exhaust gas temperature. This input would be used to disable the injection of starting fluid if the engine's exhausted combustion gasses indicated that the engine did not require the additional use of starting fluid. This criteria may be of importance in stationary engine type applications where "full-load" demands will be placed on the engine immediately after starting.

Programmability of Inputs

It should be noted that through the application development period of an EC to a particular operation or installation, all these criteria and parameters are completely programmable by "communicating" with the EC through a RS232 communication link with a personal computer.

Benefits of EC System

By processing these three (or four), criteria, and based on the parameters programmed into the microprocessor, the EC will enact the injection of starting fluid into the engine when required in an effective and beneficial manner under all engine starting circumstances.

Another benefit of using the microprocessor in this system is to monitor the total amount of time that the engine starting fluid solenoid valve has been activated. Based on this total valve "on time", the microprocessor can determine when the engine starting fluid cylinder has nearly depleted its contents. At this time the microprocessor can activate an electrical circuit that would indicate it is time to service or replace the starting fluid cylinder.

Supporting Data

A comparison of oscillograph charts acquired during laboratory development of the EC, shows the benefits of using an EC System (Figure 4). Charts A-1 through A-4 depict a cold engine start without an EC System. Charts B-1 through B-4 depict the same engine under the same cold start conditions using an EC System. The obvious benefits are:

1. Decrease initial cranking time to “First Fire”.
2. Eliminate additional cranking cycles on cold soaked engines.
3. Lessen the engine vibration due to uneven combustion chamber firing by monitoring the entire "warm up" period and providing starting fluid until the engine is running smoothly.
4. Help prevent dilution of engine lube oil, from unburnt fuel, by reducing the time combustion chambers are not firing.
5. Reduce exhaust "white smoke" by shortening the time combustion chambers are not firing.

In laboratory experimentation and analysis, by placing a thermocouple at each of the engines exhaust ports, comparison of engine exhaust port temperature is a prime example of the efficiency of the EC System (Figure 5). The depicted chart represents a cold soaked engine that was started without the use of an EC System. The subsequent chart shows the effectiveness of the EC System under the same cold start circumstances in achieving and maintaining combustion chamber temperatures that relate to the clean and efficient burning of the diesel fuel.

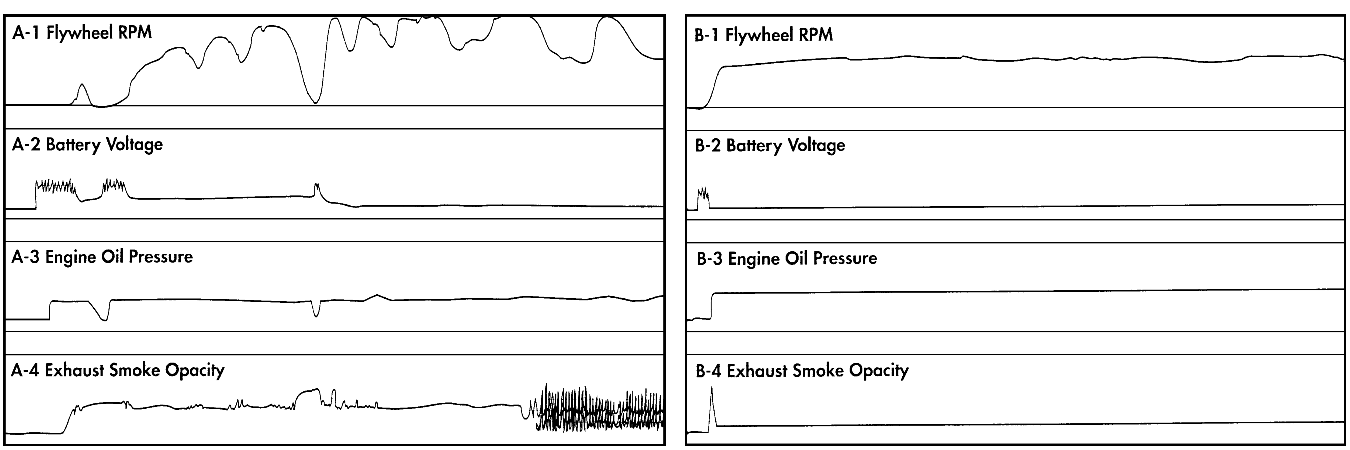


Figure 4 Oscillograph Charts

The charts show engine RPM is smooth, normal engine idle speed is maintained, and most importantly, engine speed is completely under the influence of the engine's governor or throttle control. Only one cranking cycle was required to start the engine which is beneficial for extending cranking motor and battery life and extremely important for air starter applications. Normal lubricating oil pressure was attained in only three seconds. In addition, opacity levels of exhaust gas were extremely low. White smoke was virtually non-existent.

## Conclusion

The aspects of the EC Starting Fluid System may be fully realized as modern electronically controlled diesel engines provide the data necessary to the EC for starting fluid control through the engine's electronic control module's (ECM), data link. Ultimately, control of the starting fluid system will probably be entirely controlled internally by the engine's ECM.

The overall benefits of a properly applied engine starting fluid system will be realized by the reduction in the maintenance that is usually associated with the cold starting characteristics of a diesel engine. Reduced cranking times, single crank cycle starts, and complete and efficient combustion cycles will result in less strain on the engine and its starting components, therefore benefiting the entire vehicle's life expectancy.

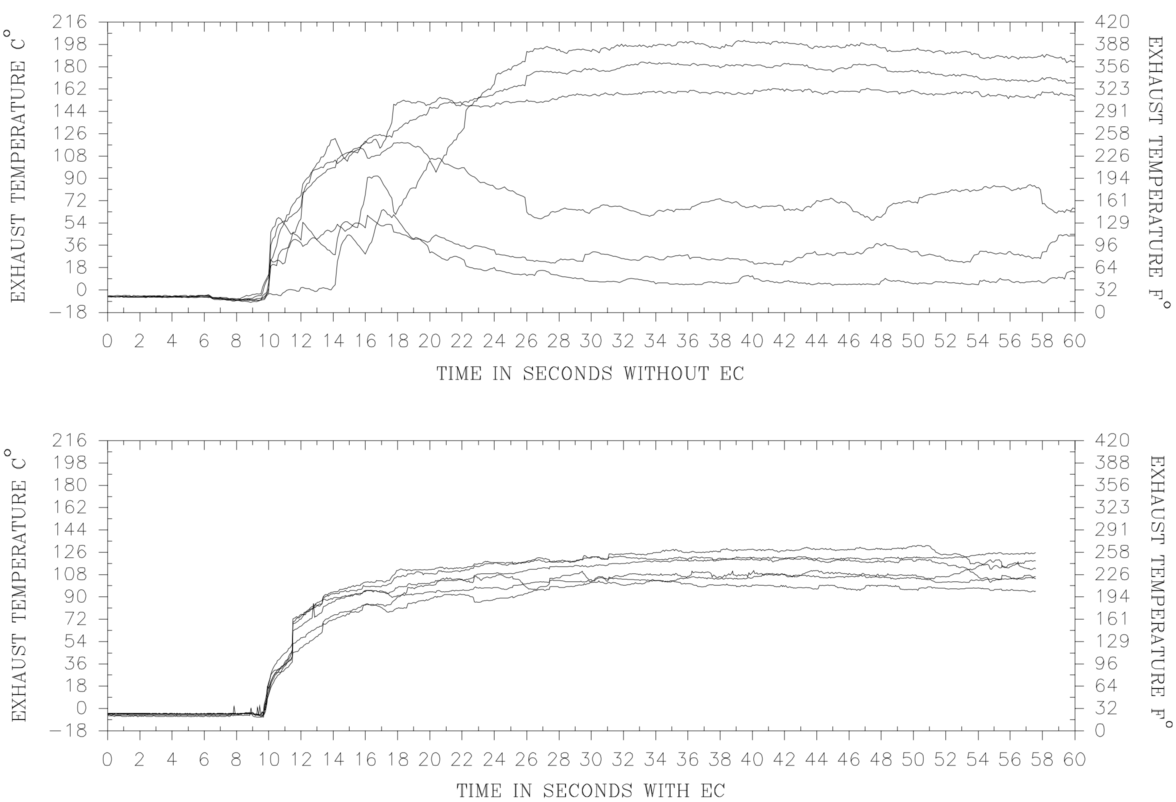


Figure 5 Engine Exhaust Port Temperatures

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