The Development of Today's Diesel Engine for Alternative Fuels

Introduction

Detroit Diesel Corporation (DDC) is committed to providing the very finest engines used in a variety of heavy duty applications, such as construction, industrial, military, marine, generator sets, and of course, the on-highway emission-regulated markets of urban transit buses and heavy-duty highway trucks.

	1991	1994	1996
HC	1.3	1.3	1.3
CO	15.5	15.5	15.5
NOx	5.0	5.0	4.0
PM	0.25	0.10	0.10

Figure 1: Clean Air Act Amendments of 1990.
U.S Heavy Duty Truck Engine Emission Standards (GM/BHP-HR)

Emission Control Regulations

Heavy-duty engines, which are defined by the U.S. Environmental Protection Agency (EPA) as engines going into vehicles of over 8,500 lbs GVW, have been emission regulated since 1974. The future emission regulations for heavy-duty trucks, Figure 1, are defined by the 1990 Clean Air Act for 1991, 1994, 1996, and 1998, for oxides of nitrogen (NOx), hydrocarbons (HC), carbon monoxide (CO), and particulates (PM). The DDC Series 60 engine is a good example of a heavy-duty engine which was designed in the early 1980's as a modern, high-technology engine to meet the emission and fuel economy requirements of the '90's. The six cylinder four-stroke cycle Series 60 has two displacements - 11.1L and 12.7L, covering the power range from 285 to 470 horsepower. The engine is turbocharged, and aftercooled with air-to-air charge cooling, to give the lowest air intake temperature possible for good fuel economy and NOx emissions. The engine was also designed with technology features such as cast iron crosshead pistons with a high top compression ring, overhead camshaft for actuating the two intake valves, two exhaust valves, and high pressure injectors, short intake and exhaust ports for good flow efficiency, and electronic unit injectors. The electronic unit injectors are the heart of the engine, pumping fuel into the cylinders at over 28,000 psi, with variable timing provided by the fast-acting solenoid valve. Customising the variable timing with software in the engine mounted microprocessor allows the engine to achieve excellent fuel economy, as well as meet the exhaust emission standards. The Series 60 engine has been emission certified for 1994, with results shown in Figure 2 using a low sulphur fuel, .05% as allowed in the EPA standards. This illustrates the low particulates of the Series 60, and how changes in computer programming and the low sulphur diesel fuel allowed compliance with current standards: The Series 60 engine has been used in industry research studies to investigate the effect of clean diesel fuels on diesel emissions. Some of these emission results illustrate low aromatic and high cetane fuels can also help to reduce PM. Clean diesel fuels were also investigated by DDC, using two very low sulphur, low aromatic diesel fuels, which when combined with very high injection pressure, allowed the Series 60 engine to achieve even lower emission levels. Investigations have also been made by DDC with an oxygenated diesel fuel containing esters and alcohols, which reduce particulate emissions.

	GM/BHP-HR			
	HC	CO	NOx	PM
1995 Standard	1.3	15.5	5.0	0.10
11.1L - 325 hp	0.08	1.12	4.9	0.061
12.7L - 470 hp	0.08	1.12	4.7	0.078

Figure 2: 1994 Emission Certification Results
** With DDEC III & 0.05% Sulphur #2 Diesel Fuel*

The conclusion DDC has reached from these studies is that clean diesel fuels, or reformulated diesel fuels, such as those with low sulphur, low aromatics, high cetane, and some oxygen, when combined with high technology diesel engines such as the DDC Series 60, can meet the stringent 199U NOx standards for highway trucks.

EPA CLEAN AIR ACT AMENDMENTS OF 1990

U.S. HEAVY-DUTY URBAN BUS ENGINE EMISSION STANDARDS - GM/BHP-HR

	1993	1994	1996	1998
HC	1.3	1.3	1.3	1.3
CO	15.5	15.5	15.5	15.5
NOx	5.0	5.0	5.0*	4.0
PM	0.10	0.07**	0.05***	0.05***

* 4.0 in California
** 0.07 applies to certification, Selective Enforcement Audits (SEA) & in-use emission recall testing
*** 0.05 applies to certification & SEA; in-use testing standard is 0.07

Figure 3

The urban transit bus emission standards were also defined by the 1990 Clean Air Act as shown in Figure 3. The 1993 PM standard of 0.10 g/hp-hr is the same as the truck standard for 1994, and the 1994 urban bus standard is 0.07 g/hp-hr. These urban bus standards require either exhaust after - treatment (particulate traps or catalytic converters), or alternative fuels (methanol, ethanol, or natural gas). All of these technologies have been evaluated at various bus properties around the United States and Canada.

Development of Alternative Engines

The Detroit Diesel 6V-92TA two-stroke-cycle engine is used in the predominance of urban buses in the United States and Canada.

This V6 engine with 92 cubic inches of displacement per cylinder, is turbo-charged and after-cooled (TA), and comes in a variety of configurations for bus applications (left-hand rotation, right-hand rotation, 43° tilt, 15° tilt, upright, vee-drive transmission, tee-drive transmission, etc.). The 6V-92TA utilises the electronic unit injectors, similar to the Series 60.

The injectors and microprocessors are part of the Detroit Diesel Electronic Control (DDEC) system. Meeting the 1993 PM standard of 0.10 g/hp-hr or the 1994 PM standard of 0.07 g/hp-hr required either exhaust after-treatment or the use of alternative fuels.

Particulate Control

Particulate traps have been under development for a number of years: The system DDC used on the 6V-92TA bus engine was the ceramic wall flow monolith type, which traps the particulate and uses an electric heater to regenerate the trap (burn-off the trapped particulate). The system used is a dual-trap system, which allows one trap to regenerate while the other one is trapping, thus never needing to bypass to atmosphere. The dual traps are engine mounted at DDC, and use the space the muffler previously occupied in the bus (the trap also acts as the muffler). The trap system was also very effective in reducing emissions where particulates are about 0.02 g/hp-hr. This type of particulate trap was running in buses in New York City, Los Angeles, and Dayton. Other systems are also available using fuel burners to regenerate the trap or using ceramic yarn cartridges to trap the particulate. Reliability, durability, and emission deterioration are a problem with the various trap systems. DDC offered an emission certified trap system in 1991, but that system is no longer available.

Alternative Fuel Engines

Alternative fuels for diesel engines have been under development since 1980, as both an emission control strategy, and an energy independency strategy. DDC has been developing engines to burn methanol, ethanol, compressed natural gas, liquefied natural gas, and liquefied petroleum gas. The initial DDC strategy has been to develop alternative fuel engines that autoignite the fuel (compression ignition like a diesel) rather than convert the engines to spark ignition (spark plugs) like heavy duty gasoline engines. The two-cycle DDC engines allow autoignition due to the air-fuel ratio control, provided by the bypass blower system.

The modifications required for the GV-92TA alcohol (methanol and ethanol) engine are higher compression ratio pistons, glow-plug cylinder heads, glow-plug controller, and changes for material compatibility. Glow-plugs are required for cold starting, and in some cases for light load operation. DDC has built several hundred alcohol engines since the first bus started operation in 1983 in San Francisco. Urban transit buses are operating on 100% methanol (M100) in Los Angeles, Riverside, New York, Phoenix, Denver, Winnipeg, and Medicine Hat. Heavy duty school buses are operating in California on 85% methanol and 15% unleaded gasoline (M85). The results of this testing over the last twelve years, with many millions of miles of operation, has shown both the advantages and disadvantages of operating on M100 fuel. Changes had to be made in the engine: increased compression ratio from 19:1 to 23:1, changed location of the glow-plug in the cylinder head, and modified materials introduced as incompatibilities were found. The most important discovery was the incompatibility of methanol and lubricating oil, which required an additive, Avocet, to be used in the fuel to prevent injector tip plugging and injector plunger seizures. The thermal efficiency of the methanol engine has not been as good as that of a diesel, but considering its low NOx emissions, it may be equal to a diesel at equal NOx. Since the heating value of methanol is 2.3 times lower than diesel fuel, and the engine efficiency is lower, it takes about 2.5 times as much methanol as diesel fuel to produce the same horsepower. The emissions from the methanol engine, M100, are excellent with or without a catalytic converter. Ethanol, mixed with 5% unleaded gasoline (E95) is also an alternative alcohol fuel, and demonstrations are already underway in truck applications. Figure 4 shows certification data for these fuels compared with the 1994 urban bus standards.

6V-92TA CERTIFICATION EMISSION RESULTS

URBAN BUS ENGINE - ALCOHOL

	GM/BHP-HR			
	HC	CO	NOx	PM
1994 Urban Bus Standard	1.3	15.5	5.0	0.07**
M100*	0.08	2.05	1.70	0.026
M99* + 1% Avocet	0.22	0.61	3.96	0.039
M85*	0.23	1.60	4.05	0.026
E95*	0.73	1.71	4.15	0.039

* With catalytic converter & including deterioration factor
** Anticipated

Figure 4

The DDC 6V-92TA engine has also been developed to operate on natural gas, either compressed (CNG) or liquefied (LNG). The first development was the dual-fuel pilot ignition type natural gas engine. This engine operates like a diesel with a small quantity of diesel fuel providing the ignition source for the natural gas that is injected above the intake ports. DDC has also evaluated a compression ignition version of the 6V-92TA engine.

Current Development

Current development at DDC is to utilise the very successful 550/560 four stroke overhead cam engine, utilising a lean burn combustion process. The engines are derived from the Series 50/ Series 60 Diesel engine. The design features of these gas engines include spark ignition, lean burn natural gas combustion process, distributorless high energy ignition system, combined with electronic control of the following engine functions through the DDEC system

- air-fuel ratio
- spark timing
- throttle position
- fuel delivery
- speed governing
- knock sensing
- fuel shut-off valve.

The turbo-charger is fitted with wastegate control, and the system requires a low pressure natural gas fuel supply regulator.

The DDEC control system is shown in Figure 5. A summary of the hardware changes compared to the diesel are shown in Figure 6.

6V-92TA CERTIFICATION EMISSION RESULTS

URBAN BUS ENGINE - ALCOHOL

	GM/BHP-HR			
	HC	CO	NOx	PM
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M85*	0.23	1.60	4.05	0.026
E95*	0.73	1.71	4.15	0.039

* With catalytic converter & including deterioration factor
** Anticipated

Figure 5

SERIES 50 G
HARDWARE CHANGES vs. DIESEL

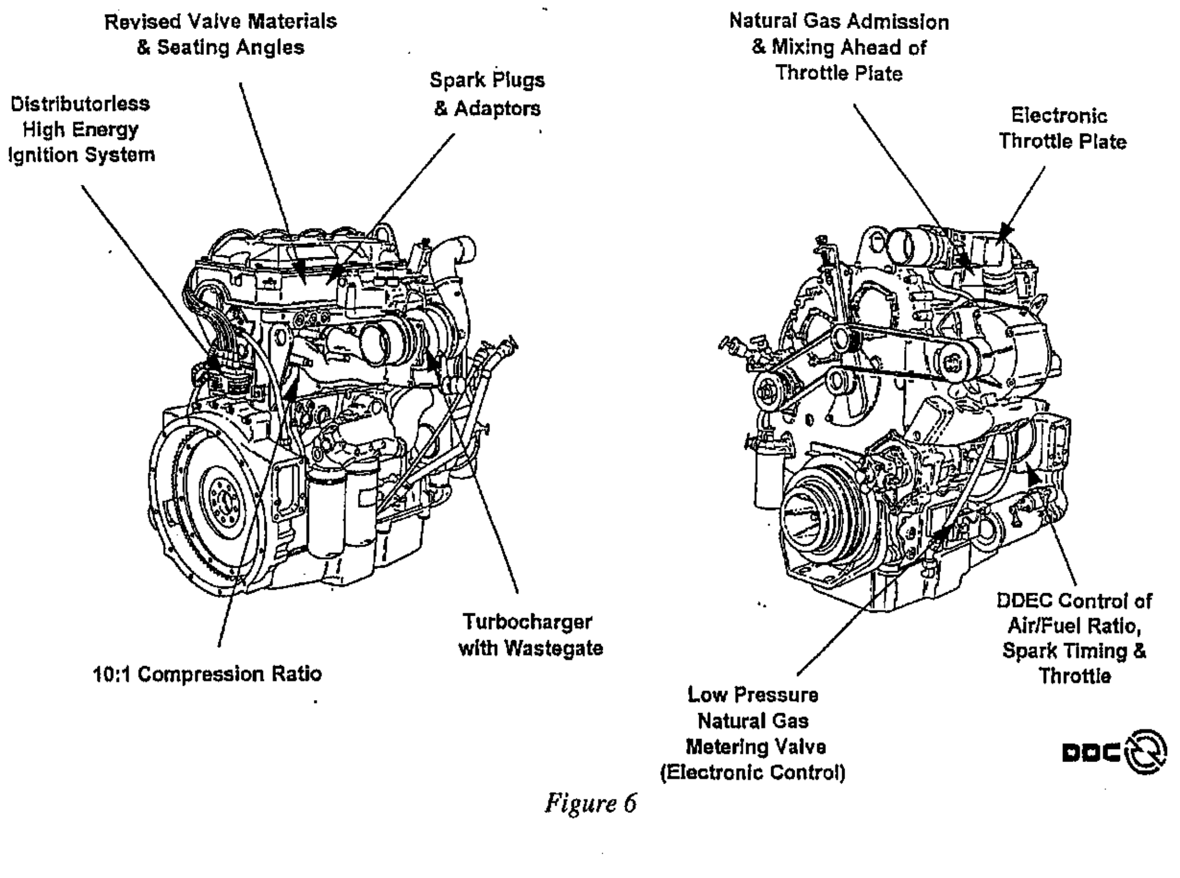

Figure 6

The Series 50G Gas Engine

The Series 50G gas engine has the same rated horsepower and peak torque characteristics as a Series 50 diesel urban bus engine. Lean burn combustion, turbocharging with air-to-air charge cooling, and electronic engine controls provide superior fuel economy (thermal efficiency) and knock-free engine operation compared with carbureted natural gas engines.

The natural gas metering valve is electronically actuated and DDEC controlled. The valve meters and controls the admission of low pressure gas to the intake air stream, after the air-to-air charge cooler and ahead of the throttle body. Since the pressure of the gas delivered to the metering valve is less than 70 psi, standard natural gas vehicle fuel systems are readily compatible with the Series 50G.

The Series 50G engine is designed so that it meets California transient emission standards for heavy-duty natural gas transit bus engines, as well as those standards anticipated to be revised by the Federal EPA. California and Federal engine exhaust emission certification testing was completed in June 1994. The results of the certification data is shown in Figure 7.

SERIES 50G

275 HORSEPOWER - 1994 EMISSION CERTIFICATION DATA *

	GM/BHP-HR			
	NMHC	CO	NOx	PM
CARB NG Standard	1.2	15.5	5.0	0.07
Without Converter (actual)	0.7	1.7	1.9	0.02
Deterioration Factor (DF)**	0.2	1.1	0.7	0.04
Certification Level	0.9	2.8	2.6	0.06

Example With Converter (actual)	0.1	0.0	2.0	0.01

* S-50G will be certified at 250, 275 & 300 hp

** DF assigned by CARB; actual DF being established by DDC

DDC

Figure 7

Conclusion

In conclusion, the 1990 Clean Air Act has set; standards through 1998 for truck and bus applications. Whilst manufacturers have research and development programs for future product running on alternative fuels, the DDC Series 50/60 engine has demonstrated its ability to meet these more restrictive truck standards using the engine's high technology, including engine electronics and higher fuel injection pressure with clean, or reformulated, diesel fuel. The DDC S50 engine used in urban transit bus applications, has shown its ability to met future bus standards using clean diesel fuel, with a catalytic converter. DDC offers engines that have been developed to burn alternative fuels such as methanol, ethanol and natural gas. These alternative fuel engines are being demonstrated at various bus sites (and some truck sites) and they have demonstrated very clean exhaust emission characteristics.