THE HISTORY OF THE FIEDLER ENGINE #24

In the 1920's, Max Fiedler built an unusual compression ignition engine. It was basically a two-stroke, ported machine with a 12:1 compression ratio. Scavenging pressure, however, was provided by double size auxiliary cylinders whose pistons were driven off the main crankshaft via Y-shaped connecting rods. The engine featured a simply, non-atomizing carburetor, short manifolds which avoided fuel heating and vaporization, 2:1 supercharging, and, naturally, unusually large combustion chambers for its 22:1 effective compression ratio. These factors combined to slow fuel evaporation and promote mixing. This engine ran smoothly on ordinary gasoline of the era, employing aluminum pistons.

When Fiedler joined the Reo Motor Car Company in 1929, he brought this engine with him, but decided to produce an enlarged version of four cylinders and 250 cubic inches displacement. He suspected he might be losing performance and economy through use of so simple a fuel system, and so elected to use conventional diesel injection equipment on the new machine. When he started the completed engine, it produced severe knock even before it was loaded, and bits of the aluminum pistons melted and left the engine via the exhaust. Fiedler was astounded, but the experience brought back memories of an experience in the German Navy. An engine over loaded with fuel had exploded while starting, and the experience had sewn grave doubts in his mind about the conventional theory of autoignition. How, he reasoned, could too much fuel cause an explosion when a stoichiometric mixture ratio is the optimum chemistry for burning?

Fiedler capped the pistons with a heavier metal, and began experimenting, first at Reo, and then at the University of Pennsylvania, He found first that vastly reducing the pop pressure of the injector needle valves would slightly reduce the knock, produce less smoke, and improve performance. The next step was to enlarge the holes in the lower nozzle to reduce the pressure in the nozzle tip until it was lower than the pressure generated in the injector valve. This included designing the valve so that there was no pressure differential. This represented a departure from the conventional method of controlling droplet size -- that of pumping fuel through a small orifice at a controlled rate. Fiedler then increased the pressure in the nozzle valve until it was about 1,800 psi, still very low for diesel injectors of the day. He got excellent results forming the droplets in the valve, and using the nozzle tip merely as a distribution duct. This meant the fuel system would produce droplets of constant size throughout the injection phase and regardless of engine rpm.

He made another basic departure. It seemed to him that a critical factor in determining the quantity of fuel delivered was the pressure which existed in the injection pump when the ports closed -- after all, injector lines had to be the same length to ensure equal fuel distribution. Perhaps the impulse at the beginning of the pump's stroke was largely responsible for metering the fuel. He ultimately changed the pump so the effective stroke was of minimal length (in terms of calculated displacement), bypasses were open through most of the stroke, and the pump merely delivered an impulse. This design eliminated the fine tolerances needed in a pump designed to meter through displacement of an infinitesimal volume.

Fiedler worked for years, developing hundreds of different nozzle designs, finding, for example, that flashing could occur, and that the resulting vapor could cause knock. He finally arrived at a design which ran the fuel into a ring from two opposite points just before throttling it into droplets. This quenched the bubbles.

In 1939 he delivered a major lecture at Philadelphia's Franklin Institute. He had a working nozzle which employed very early injection timing and short duration, relatively low pressures, and astoundingly large holes, and which would allow for a perfectly smooth indicator card (without a condenser), at unprecedented rates of two-stroke rpm. He also had combustion photos made inside a regular diesel, and a rigorous theory.

Fiedler's theory of conventional diesel combustion went like this:

1. Fuel is sent into the combustion chamber under tremendous pressure, in relatively narrow streams (shown by the photos), at high velocity, and in finely atomized form. The air at time of injection is extremely hot, well over the point at which heat can crack the fuel into hydrogen, methane, and carbon.

2. The fine atomization and high temperatures accelerate evaporation, while the high injection pressure creates a cohesive stream which does not readily respond to turbulence. Thus, a part of the combustion chamber is flooded with vapor. Since the vapor must find the greater portion of the fuel/air charge to form a stoichiometric mixture ratio, no combustion can occur, and none will so long as injection continues, due to flooding of a part of the chamber with fuel. The fuel vapor is exposed to the high heat of the chamber and even to the heat of compression, and readily absorbs heat. The

result, since combustion cannot occur, is cracking of the hydrocarbon into its components, as it occurs in an oil refinery.

3. There are two results. First, the carbon separates from the lighter portions of the molecule, and much of it refuses to ignite due to its high ignition temperature. Some of it even forms solid particles which pass through the entire combustion process and out the exhaust. Second, the pure hydrogen which results, being volatile, tends to mix readily with the air. Since there is enough air to also burn the carbon, the tendency is for an extremely lean hydrogen mixture to form in the early stages of the process, and this can produce violent detonation.

After injection stops and turbulence begins to mix the components of the fuel and air, combustion of the hydrogen begins. The result of this, and the imperfect mixture (extremely lean), is conditions of heat and chemistry which can dissociate some of the hydrogen molecules into atomic hydrogen in an endothermic process. When these atoms form a more readily combustible mixture, they combine to form h_2o in a reaction which liberates both the oxidation energy and the energy of dissociation simultaneously. This flame is used in hydrogen gas welding, and is described by the Encyclopedia Brittanica as "the hottest flame know to man". The heat will sometimes produce more atomic hydrogen which, in turn, will detonate violently. Fiedler explained the wavy lines on indicator diagrams as a result of this chemistry, and not indicator instrument vibrations. He brought out diagrams made on different scales to show that precisely the same pressure fluctuation occurred even with different natural vibration frequencies in the instrument. His indicator diagrams exhibited smooth energy release, which did not occur at injection, but only after compression of the charge had virtually stopped.

He was injecting the fuel in large droplets, under relatively low pressures and at resultant low velocities. Also, ignition timing was about 38 degrees BTC, so the fuel was injected into relatively cool air.

The coarse, wide angled, slow spray was more evenly distributed and more quickly responded to natural turbulence due to its lower velocity. Even distribution was also aided by short injection duration which allowed random distribution of the droplets more quickly. At the same time, the larger size of the droplets reduced the surface-to-volume ratio. With less surface exposed, initially to cooler air, the rate of evaporation was much slower.

The final result of all these factors was that the rate of evaporation and the rate of mixing of fuel with air were in balance, instead of being tipped in favor of evaporation. Fuel was protected by the mass of a large droplet and loss of heat through evaporation until just before forming a stoichiometric ratio. The droplets were large enough to protect the fuel through the most difficult part of the process -- the time right after injection when injection velocity was still high, minimizing mixing, and evaporation was at a maximum, because the largest total surface was exposed to hot air.

Thus, fuel was burned while still intact (or, combustion reactions were given the opportunity to begin while fuel was still intact). This discouraged knock, and encouraged formation of more volatile and chemically potent hydrocarbons high in hydrogen to aid combustion of the carbon. Fiedler claimed smoke-free running, better performance, and, owing to the pre-mixing, greater use of ingested air.

At that meeting, he also proposed designing an engine which would compress fuel/air mixture to its equilibrium temperature, thus employing the highest possible compression ratio, and forcing energy release to begin after TDC.

That engine is the Fiedler #24, and its big brother, the Fiedler 130. Fiedler finally produced an injection nozzle which employed only 200 psi to manufacture a very coarse spray. Injection occurs just after the crankcase ports close. The fuel droplets are so large and so much time is provided for mixing that a 34:1 compression ratio can be employed without flooding any part of the chamber and causing cracking. As the piston approaches TDC, rapid pressure rise begins. Fiedler finds that no energy release can occur in this phase unless fuel is broken down in pre-combustion reactions. He thinks fuel refusing to react when compressed faster than pressure would rise from burning might parallel the need for a greater voltage to ionize an air gap at higher pressures. It is not related to a static ignition point, for variations in rpm do not affect it, and extremely rapid pressure drop can also stop the combustion.

The equilibrium temperature of fuel burned without pre-combustion reactions is lower than the temperatures which seem to obtain in ordinary furnaces and engines. It is about 1,700 degrees F., or just slightly below the peak temperature due to compression alone with a 34:1 ratio. As a result, in the Fiedler #24, compression occurs without any release of energy, and combustion begins just as expansion begins, and occurs at a relatively constant temperature. At a lower rpm, combustion tends to be slower as slower conversion of heat to mechanical energy forces energy release to occur at a slower rate due to the effect of equilibrium temperature.

That such low combustion temperatures offer an opportunity to virtually eliminate nitrogen oxide emissions is obvious. The chemistry of combustion in the #24 and #130 engines seems also to be ideal for hydrocarbon and CO reduction, for an extraordinarily low exhaust temperature of 390 degrees F. pertains. The only explanation for this is controlled, steady, but relatively rapid energy release that is complete early enough in the stroke to provide the energy when it can most efficiently be converted to mechanical form.

The engine's low friction design (only anti-friction bearings are used), insulated cylinders (aluminum hard oxide coated), and the ability to run at full load at low rpm mean an unprecendented potential for economy. The lack of sensitivity to the volatility of the fuel means the Fiedler engines are also multifuel machines, able to run on either #2 furnace oil or gasoline (with oil added to the latter), with performance variations which reflect only BTU content.