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THE HEAVY-DUTY DIESEL ENGINE: PROSPECTS FOR REDUCED EMISSIONS AND IMPROVED FUEL EFFICIENCY

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Summary
The interest in emissions from heavy diesel engines has awaken recently. This has led to intensified engine research and development.

The short-term solution has been to adjust parameters on existing engines, equipping them with charge-coolers and, in some cases, with particulate traps. Some of these measures have resulted in a slightly reduced fuel efficiency.

The long-term solution will be new engine generations, primarily developed to produce low emissions, both gaseous and particulate. New injection systems with facilities for timing control and rate shaping will enable very low levels of particulate and nitrogen oxide emissions to be obtained.

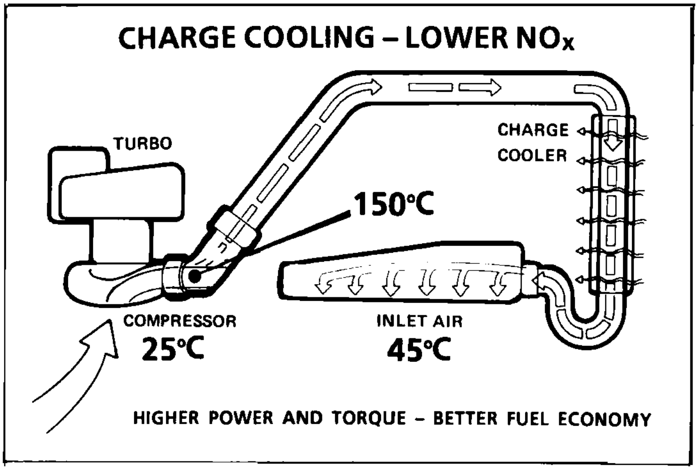
In combination with much improved hydrocarbon fuel, these engines will require no particulate traps. However, to eliminate all nuisance, catalytic converters will probably be used to eliminate hydrocarbon residue in the exhaust gases.

The diesel engine is currently the most fuel-efficient power unit, and it is constantly improving. The introduction of turbo-compounding will help further reduce fuel consumption, and thus the emissions of carbon dioxide from the diesel engine.

Background
As a truck producer must produce what his clients demand, most of the development work has earlier been focused on performance and economy. During the last ten years there has also been a slowly growing demand for low emissions. This demand has risen very quickly during the last five years and today the development work for low emissions has the same priority as for performance and economy.

To reduce emission of any of the four compounds, carbon monoxid, hydrocarbons, nitrogen oxides or particulates is rather simple. The problem is to reduce them simultaneously.

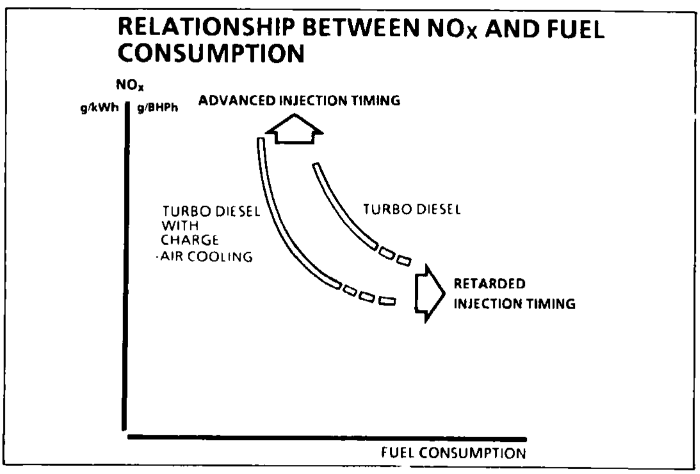
Nitrogen oxides
The means to reduce nitrogen oxides often tend to increase particulates and fuel consumption. Ten years ago it was the common opinion that reducing the emissions of nitrogen oxides from heavy duty diesel engines would mean increasing the fuel consumption dramatically. Now we know that that is not the case. If course, just changing the settings of the 1980 engine to reduce harmful emissions resul-



ted in high fuel consumption. But the introduction of charge air cooling made it possible to decrease both emission of nitrogen oxides and fuel consumption.

However just changing settings and introducing charge air cooling makes it possible to reach about 8.5 g/kWh nitrogen oxides with 5-10 % fuel consumtion penalty. By redesigning basic engine parameters such as inlet swirl, compression ratio, injection pressure and injection duration it is possible to achieve the limit proposed by the EEC commission for 1992 of 8 g/kWh nitrogen oxides with a fuel consumption penalty of only 2-3 percent. The limit of 7 g/kWh NOx proposed for 1996/1997 requires additional development work. At Scania we have proven the possibility to achieve nitrogen oxides emissions below 7 g/kWh on a city bus engine.

To further reduce emissions of nitrogen oxides fuel injection systems with full timing flexibility will be needed. Pilot injection may also extend the limits for nitrogen oxides further down. Rate shaping, that is low rate during ingnition lag and then high rate and pressure once combustion has started, is a further development which can reduce nitrogen oxides. Additional functions like water injection and ex-



haust gas recireulation also offers prospects for lower emissions of nitrogen oxides but also give problems with control and wear.

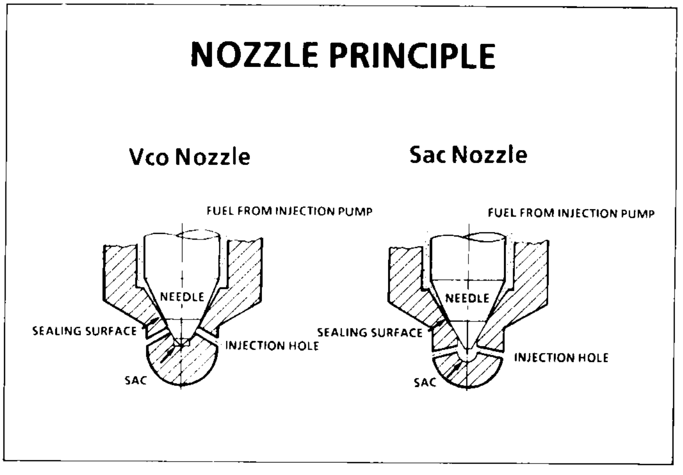
Achieving low NO_x – emissions without considering other emissions is rather easy. However hydrocarbons, carbon monoxide and particles must not be forgotten.

Carbon monoxide

The direct injection diesel engine has the advantage of inherent low carbon monoxide emissions. Even without regulations on carbon monoxide emission some current diesel engines have been developed to emission levels below those proposed for 1992 and 1996/1997. The adoption of turbocharging, charge air cooling and high pressure injection systems has gradually decreased carbon monoxide emission to a level where it has to be considered insignificant.

Hydrocarbons

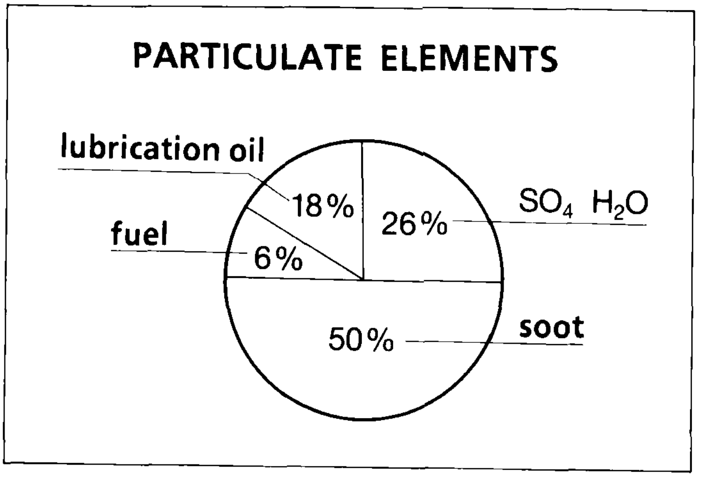
Gaseous hydrocarbons are emitted from diesel engines in very small quantities. However they have an unpleasant odour wich indentifies diesel exhaust. There is also concern that hydrocarbons may be carcinogenic. The main hydrocarbon source is the injector sac. The fuel volume trapped in the sac ofter injection evaporates and enters the combustion chamber after combustion. Thus it a not is combusted, but scavanged through the exhaust pipe. The sac volume has been reduced in steps over the years and further reduction can be forseen. In the future many engines will probably have valve covered orifices with no sac at all. This will mean a major reduction of hydrocarbon emission.



There are also additional causes for hydrocarbon emission. They have in common that combustion of the fuel is either not initiated correctly or interrupted to soon. To ensure good ignition of the fuel, high compression ratios will be used in future engines.

Particulate

Particulate emissions, solid and liquid, can be reduced in different ways. The solid part, the soot, must be reduced through better fuel-air mixing. This is achieved with very high injection pressure, optimized injector hole contiguration and an optimized air swirl in the combustion chamber. Better turbo chargers will give a more favourable air-fuel ratio so that rich air-fuel mixture is avoided in all driving conditions.



The introduction of electronic injection control makes it possible to correct injection for different ambient conditions and further decrease soot formation.

The fuel hydrocarbon part of the particles will be reduced by using valve covered orifice injectors.

The lube oil contribution can be reduced very much by using valve stem seals and improved piston rings. Also better lube oils will help reducing the lube oil share of the particulate.

The sulphate particulate can be eliminated by using sulphur-free fuel. This may sound expensive, but I am convinced that within a few years we will see a reduction of today's sulphur content of approximately 0.2 percent down to 0.05 percent. In Sweden there is already available limited quantities of diesel fuel with sulphur content below 0.005 percent.

All these measures on engine hardware and fuel will make it possible to reduce particulate emissions below the 0.4 g/kWh limit proposed for 1992.

After-treatment

What are the prospects of after-treatment of the exhaust? As oxygen content of diesel exhaust is rather high an oxidation catalyst easily oxidizes carbon monoxide and hydrocarbons. We are testing catalysts and have reached emission levels well below 0.1 g/kWh both for carbon monoxid and hydrocarbons.

As hydrocarbons are also a part of the particulate, such emissions are also reduced by the catalyst. The flow-through catalyst, however does not reduce soot emission to any significant extent. Therefore catalysts should be used with modern "smoke-less" engines.

Can the catalyst reduce emissions of nitrogen oxides? Not yet! But I am an optimist. I believe that catalyst companies will develop some kind of catalyst for nitrogen oxides. Such a catalyst would enable control of nitrogen oxides to a very low level and still optimize the engine for low fuel consumption and low particulate emission.

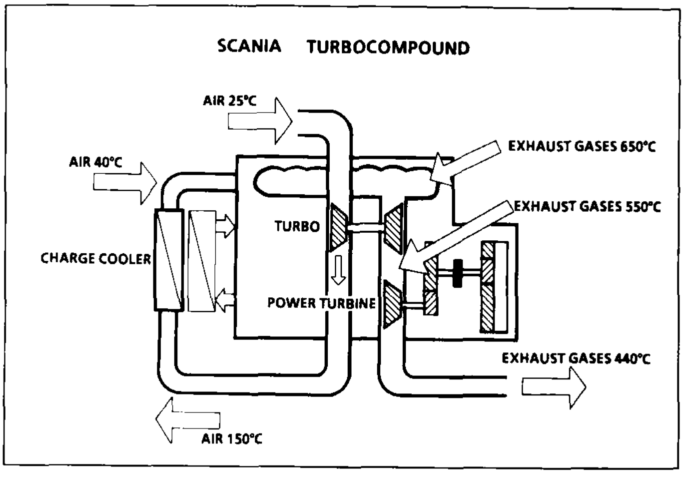
What about particulate traps? Particulate traps or filters may be a good help to reduce emissions of soot from today's diesel engines. But tomorrow's diesel engine will have so low soot emission that further reducing soot will not be worth the effort. To use the money for a trap to make a better engine will be more cost effective than equipping the present engine whit a trap.

Fuel efficiency

Will it be possible to maintain or even improve diesel engine efficiency with low emission engines? Well there are prospects of at least maintaining the efficiency of todays diesel engine.

Reducing losses, wherever they appear, helps in improving efficiency. Mechanical losses – friction – can be reduced by reducing the number of piston rings and reducing their tension. Introducing roller tappets also reduces friction. Better lube oils and better matching of materials makes it possible to use lower viscosity lube oils and this is important for friction reduction.

Optimizing inlet systems and exhaust systems to keep flow losses down will also contribute to improved fuel efficiency.



However, the major single contribution for improved efficiency will probably come from new turbo-machinery. The turbocompound engine, which has an additional turbine, after the turbocharger, transmitting its power to the crankshaft, can improve fuel efficiency substantially.

Turbocompounding may improve fuel efficiency by 4-5 percent.

New insulating materials may be used in pistons and exhaust ducts to increase the exhaust energy which will further contribute to the efficiency of the turbocompound engines.

The Future

Seeing all the possibilities of diesel development makes me confident that the future belongs to the diesel, a diesel engine with very low emissions and superior economy. If we would get help from the catalyst companies to reduce nitrogen oxides in a catalytic converter, I believe that we have a clean engine within reach with 50 percent thermal efficiency.