The RECCAT® system for incineration of UHC in the exhaust from engines

Niels Bjarne K. Rasmussen
Danish Gas Technology Centre (DGC) and RECCAT ApS
Dr. Neergaards Vej 5 B
DK-2970 Hørsholm, Denmark
Phone: +45 4516 9617 E-mail: info@reccat.dk & nbr@dgc.dk

Abstract

Most lean burn engines for natural gas (NG) or biogas firing have the problem of emitting 3-7% of the fuel in the exhaust. That is a loss of energy and it adds seriously to the emission of green house gases. The RECCAT system is primarily for NG (or biogas) engines but later particles from diesel engines may be incinerated by this concept.

The invention comprises a catalyst with internal heat exchange, a RECuperative CATalyst. The system is to be used e.g. in vehicles with combustion engines or in stationary engines with a certain amount of unburned gas components (UHC) in the exhaust that need to be incinerated. These components are converted by the catalyst. Without the heat exchanger methane (CH_4) would not be incinerated.

The device has been tested on a test engine for a period of more than 1000 hours with a UHC cleaning efficiency of above 98% without any degeneration of the catalyst. The cleaning efficiency for CO and aldehydes is even better: above 99.5%.

With this invention the maximum temperature is raised to a high level without the use of external energy. The only energy used is the energy from UHC and CO in the exhaust.

Figure 1 shows an example of the measured cleaning efficiency of the prototype of the RECCAT system. The first full scale unit came into operation in March 2006.

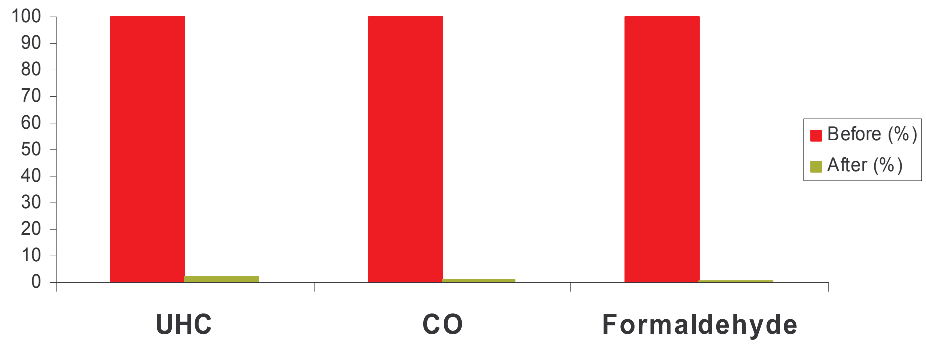


Figure 1. Example of cleaning efficiency of the RECCAT® system. UHC: >98%, CO: >99%, formaldehyde: >99.5%.

Keywords: recuperative catalyst, natural gas engine, incineration, UHC, CO, formaldehyde

Ideas

The predecessor for the RECCAT® system was the REKUP system. Figure 2 shows the REKUP system. From the exhaust of the turbocharger of the engine the flue gas is led through a heat exchanger to heat the gas from about 400°C to about 500°C. From here the gas is led through the catalyst in which the combustibles are incinerated and the temperature is raised about 50 deg due to the latent heat of the unburned. From the outlet of the catalyst the cleaned flue gas is led back through the heat exchanger in counter flow with the gas coming to the catalyst. The 50 deg temperature difference in the heat exchanger is high enough to raise the gas to 500°C if the efficiency of the heat exchanger is about 70%. The heat exchanger efficiency is defined by:

$$\eta_{hx} = \left(\frac{\Delta T_{fluegas}}{T_{\max} - T_{\min}} \right) = \left(\frac{T_{\max} - T_{\min} - \Delta T_{cat}}{T_{\max} - T_{\min}} \right) = \left(1 - \frac{\Delta T_{cat}}{T_{\max} - T_{\min}} \right) \quad [-] \qquad (1)$$

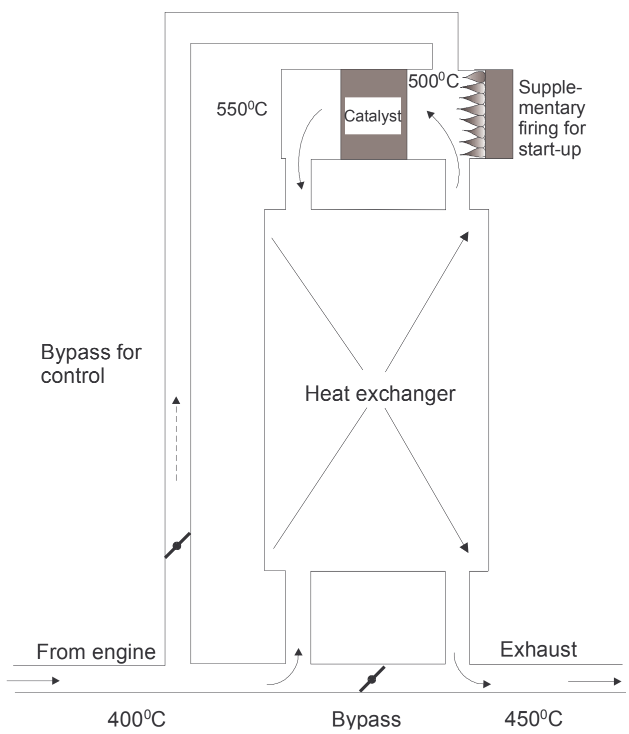


Figure 2. The predecessor for RECCAT®: The REKUP system.

In the test of the REKUP system a plate heat exchanger was used. The catalyst included precious metals. The test result was very good and the system worked.

The REKUP system has, however, several disadvantages. A bypass system and a valve to work at 400°C combined with a regulation system is a major disadvantage. To protect the catalyst from overheating, the bypass around the heat exchanger has to be regulated on the basis of the temperature in the catalyst. In the case of engine ignition failure or other reasons the UHC amount could rise to high levels. As the maximum temperature in the catalyst is dependent on the temperature rise in the catalyst as well as the efficiency of the heat exchanger it is necessary to reduce the heat exchanger efficiency for high levels of UHC or high inlet temperatures. This is done by the bypass system.

Another disadvantage is that sudden changes in combustibles or temperature in the exhaust may harm and destroy the catalyst. The reason is that the heat exchanger and catalyst are separated and the low weight and relatively low heat capacity of the catalyst makes it sensible to changes in temperature and amount of combustibles in the flue gas.

To avoid these disadvantages the RECCAT system was invented. Figure 3 shows the RECCAT system in which the heat exchanger and the catalyst are integrated in the same container, thus making a more compact system.

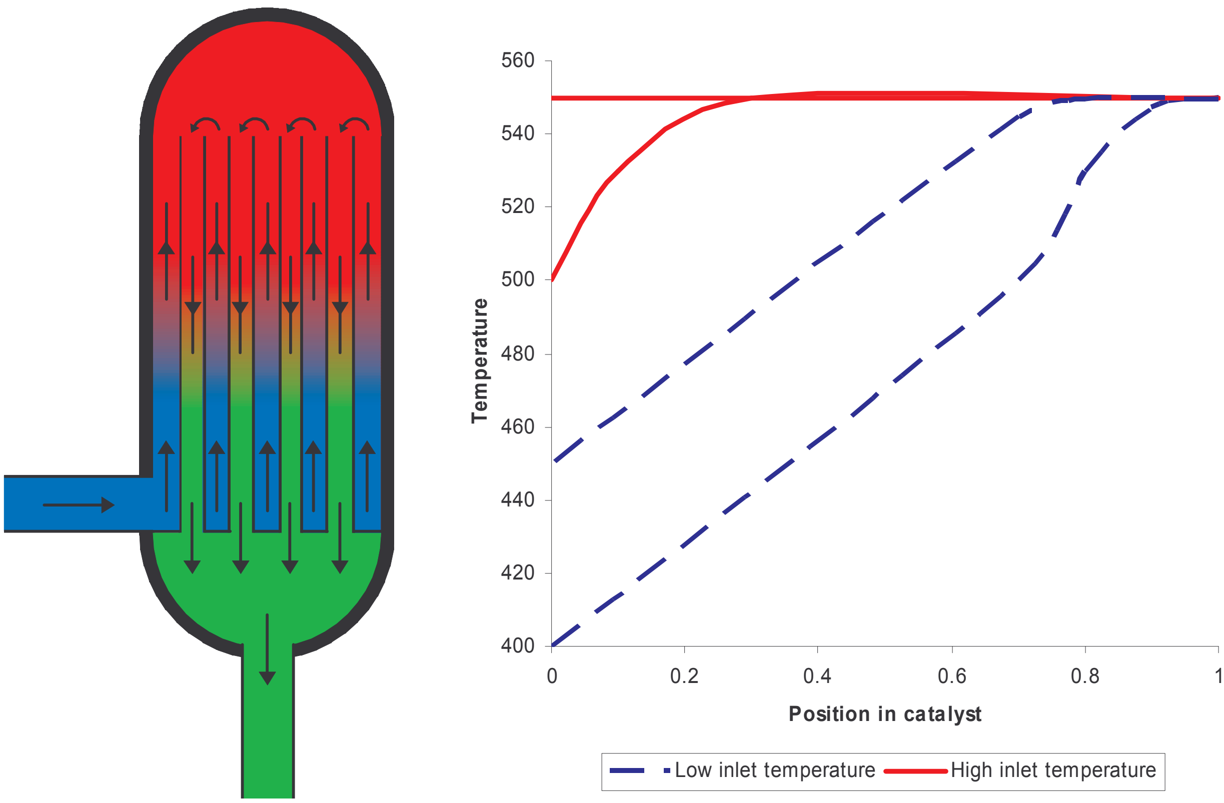


Figure 3. The basic RECCAT® system.

The invention results in an almost permanently constant maximum temperature in the catalyst, irrespective of the inlet temperature and irrespective of the variation of UHC. Thus, the catalyst can be designed to operate at this specific temperature, ensuring a better and safer incineration of the unburned components as well as saving expenditure for costly catalyst material.

The flue gas is led through the device via two or more passages with internal heat exchange. The catalyst is in the first passage. This special design makes the heat exchanger more efficient the slower the chemical reactions in the catalyst, and vice versa. Therefore, the catalyst will automatically adjust to the correct temperature for incinerating all combustibles.

The reason for the almost constant maximum temperature is the following: If the inlet temperature is high and the combustibles react already at the bottom (inlet) of the device, then the rest of the catalyst will be inactive as well as the top of the heat exchanger. This effect will keep the heat exchanger efficiency low and this keeps the temperature relatively low and thus prevents the catalyst to be overheated.

On the other hand, if the inlet temperature is low and the reactions take place at the top of the device, then the total heat exchanger will be active ensuring the temperature rise of the flue gas to the level of the reaction temperature. This is the basic idea of the RECCAT® system.

The relatively high heat capacity of the integrated system introduces several operational as well as functionality advantages of the system. Sudden changes in temperature or concentrations (within certain limits) are not able to damage the catalyst because of the heat exchange and long time constants of the system.

Furthermore it has been calculated that engine stop of 12 hours or less will cause temperature drop of less than 100 deg C of the reactor and the full activity will be regained quickly (about ½ hour) when the engine starts again.

The catalyst in the system is a metal oxide based catalyst without precious metals. It is not as sensitive to sulphur as other catalysts and it is easily regenerated if poisoned with sulphur.

Operational and functionality advantages:

- The high heat capacity makes the RECCAT incineration process robust to changes in operating conditions, e.g. changes in concentrations of combustibles or temperature
- The high heat capacity makes the RECCAT system able to work after several hours of engine stop without serious decrease in efficiency
- The reactor principle allows for a simple control system without valves and regulation.
- The reactor works sound-absorbing as a silencer
- The catalytic reactor contains a stable catalyst without precious metals

The RECCAT system incinerates all combustibles in the flue gas. NO_x is not a combustible and is not reduced. However, NO_x may be reduced by adjusting the engine. This usually gives a little more UHC (and CO) but that is no problem with the RECCAT system installed. The more "dirty" the engine burns the better for RECCAT. RECCAT is "fed" by the unburned.

Emission reduction by RECCAT:

- Meets legislation limits for CO-emission
- Meets legislation limits for UHC-emission
- Meets legislation limits for aldehydes emissions

- Incinerates emissions at start/stop of engine if the system is warm.
- Reduces problems of odour from engine
- Incinerates vapours of lubricating oil in the exhaust
- NO_x emission can be reduced indirectly

Prototype and test rig

Figure 4 shows the experimental setup for testing the prototype of the RECCAT system. The applied test engine is very convenient for this purpose. It has a high exhaust temperature and a high content of UHC. By installing a cooling system and a system for dilution of the flue gas with air it was possible to simulate exhaust temperatures between 325 and 550°C, and UHC concentrations between 2500 and 6000 ppmv (CH_4 equivalent).

For experimental reasons a bypass around the RECCAT system was made. Also a direct exit from the catalyst without heat exchanging was established by a valve. In the final version of the system no bypass is included.

The test engine is a 30 kW_e (100 kW firing rate) spark engine rebuilt for natural gas. The RECCAT reactor had a height of 1.5 m and a diameter of 0.3 m.

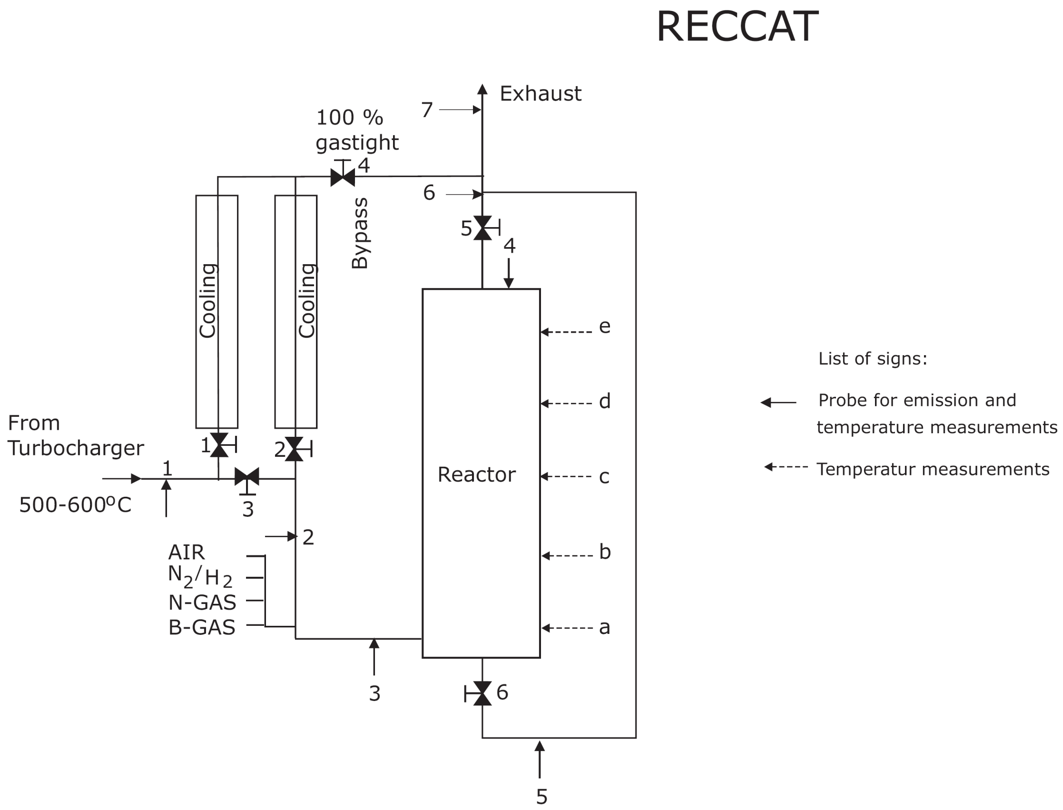


Figure 4. Test rig of the RECCAT® system.

Results

The device has been tested on the test engine for a period of more than 1000 hours with a UHC cleaning efficiency of above 98% without any degeneration of the catalyst. The cleaning efficiency for CO and aldehydes is even better: above 99.5%.

Figure 5 shows the UHC cleaning efficiency during the 1000 hours of operation. The efficiency at the end is exactly as good as at the beginning. When the average temperature in the reactor is above 590°C the efficiency is above 98%.

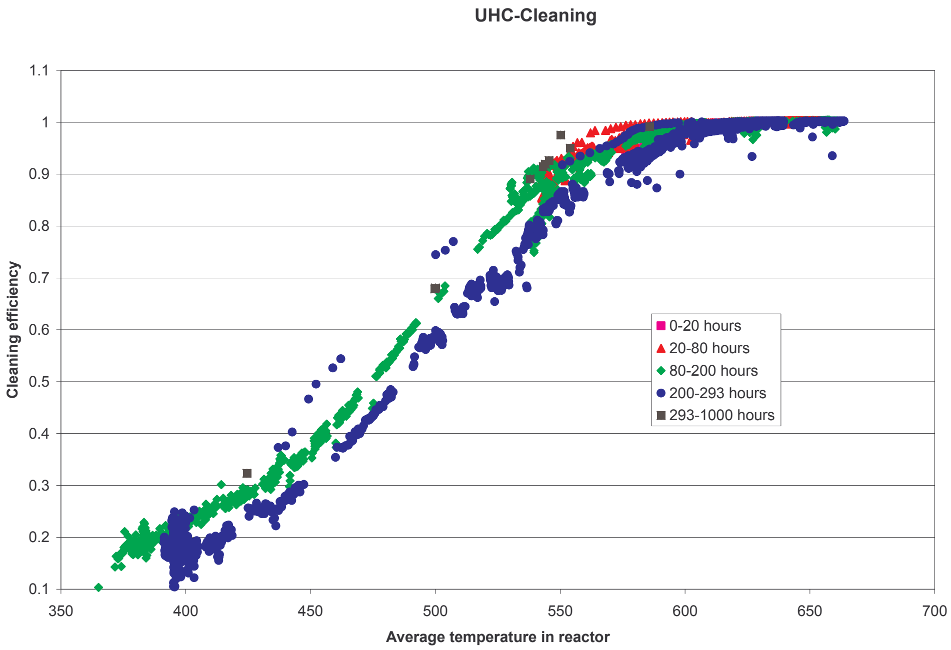


Figure 5. The measured UHC cleaning efficiency of the RECCAT® system.

Figure 6 illustrates the effect of the RECCAT system in the experimental set-up of the prototype. The x-axis shows the temperature from the engine to the RECCAT reactor. This has been varied by the cooling system and by adding air to the flue gas upstream of the reactor.

The y-axis shows the resulting max-temperature in the reactor. Furthermore, the temperature ranges for combustion of CO, C_xH_y (higher hydrocarbons) and CH_4 (methane) are shown on the y-axis. These ranges were not measured directly but deduced from the temperature profile. The square dots show measured max-temperature in the catalyst without heat exchange, whereas the round dots show max-temperature with RECCAT in operation, with an ensuing increase in max-temperature. The difference in temperature level between the two cases is due to the RECCAT system in operation. At ordinary engine exhaust temperatures (about 400°C), methane (CH_4) can only be removed with RECCAT in operation.

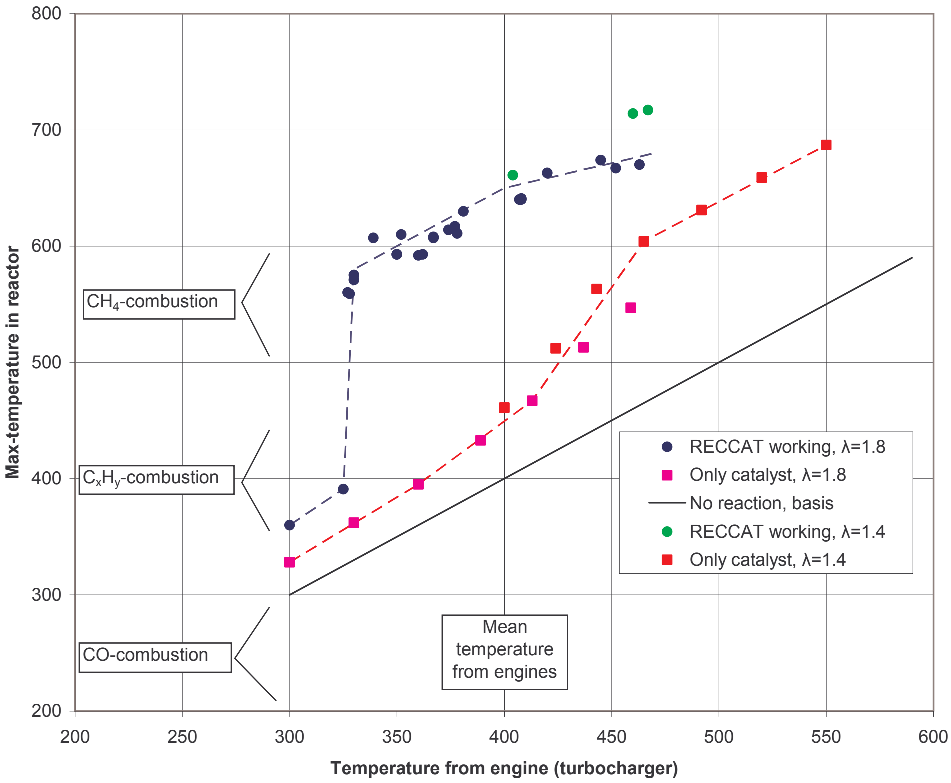
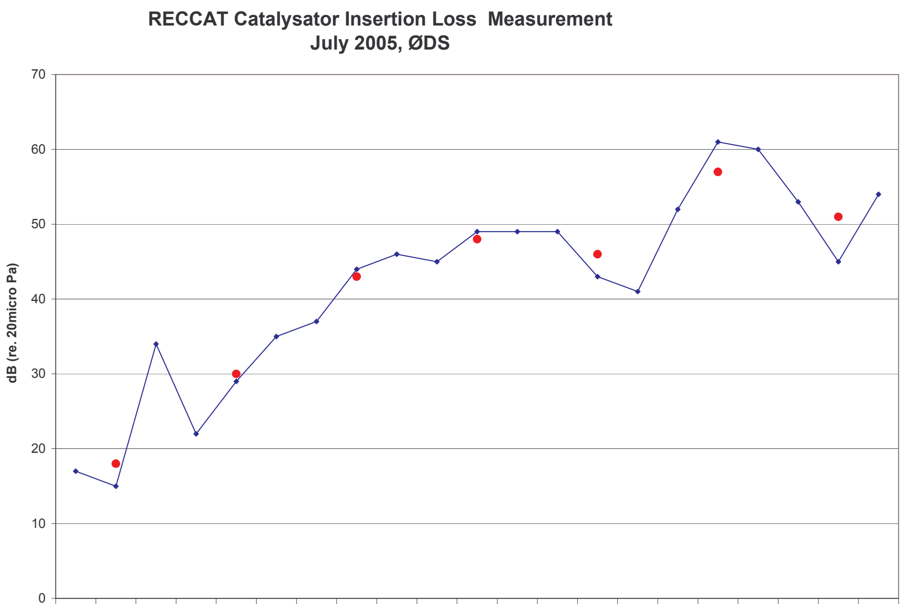


Figure 6. The effect of the RECCAT® system.



	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000
Insertion Loss (1/3 Octave Band)	17	15	34	22	29	35	37	44	46	45	49	49	49	43	41	52	61	60	53	45	54
Insertion Loss (1/1 Octave Band)		18			30			43			48			46			57			51	

Frequency (Hz)

Figure 7. Sound absorbing effect of the RECCAT® prototype.

When the RECCAT system is in ideal operation the following reactions take place: In the reactor close to the inlet the CO and the aldehydes are incinerated. Just above that the higher hydro carbons (C_xH_y) starts to react, and in the mid zone the C_xH_y and the main part of the methane (CH_4) react. At the top the final burn-out of CH_4 takes place. The flue gas then returns into the heat exchanger, heating up the reacting flue gas in counter flow and exiting the system with a temperature exceeding the inlet temperature corresponding to the latent heat of the unburned combustibles in the exhaust.

Sound absorbing effect

The RECCAT system works as a sound absorber. Especially the high frequencies are absorbed in the special construction inside of the reactor. The “insertion loss” of sound through the reactor of the prototype has been measured for cold conditions. Figure 7 shows the damping effect. For low frequencies the system works as effective as one commonly used silencer and for high frequencies the system works as two silencers. This means that the RECCAT system has a very high sound absorbing effect.

Practical applications

A RECCAT-system for a 1.5 MW engine has been installed at a demo plant in Denmark. Five units, each for 300 kW_e , or 0.5 kg/sec of flue gas, were produced and installed in March 2006. The devices have been made as simple as possible to reduce the cost and the risk of failure for the system.

For practical application and with exhaust temperature of about 400°C from the turbocharger the minimum required UHC in the exhaust is 3000 ppmv UHC measured as CH_4 equivalent (not propane equivalent). The reason is that a certain amount of energy is required to keep the heat exchanger working. About half of the natural gas fired engines in Denmark have UHC concentrations in that order of magnitude or higher. Mostly the lean burn engines have problems with high UHC levels in flue gas.

The pressure drop through the RECCAT-system of the demo plant has been calculated to be about 2000 Pa (20 mbar). The pressure drop of the prototype was higher but changes in the construction have been made for the demo plant to reduce the pressure drop.

Two patent applications are pending on the RECCAT system.

Conclusions

The RECCAT system removes practically 100% of all combustible gases from the exhaust and is state-of-the-art for cleaning of flue gases from CHP plants. NO_x can be reduced indirectly. Furthermore the RECCAT system works as a silencer. The RECCAT system sets up new standards for flue gas cleaning and is at the moment the technology that is closest to “zero emission” technology for natural gas fired, engine based, CHP plants.

Other kinds of catalysts for CO, UHC or aldehydes and partly sound absorbing silencers are redundant if the RECCAT system is installed on a natural gas fired engine.