The influence of engine start and stop on total emission from natural gas fired CHP engines

Main author
Torben Kvist Jensen
Danish Gas Technology Centre
Denmark

Co-author
Jan de Wit, Steen D. Andersen, Hanne Frederiksen
Danish Gas Technology Centre

Malene Nielsen
National Environmental Research Institute, DMU

IGRC2008@gasunie.nl

1. ABSTRACT

New and liberalized market conditions for electricity sales to the public grid lead to increased needs for fast up- and downloading of electricity production. This is pronounced in countries with a substantial electricity production from wind turbines.

Reduced periods of full load operation per each engine start will enhance the influence of the higher emissions during start up and shut down compared to steady full-load operation. Earlier emission measurements have shown elevated emissions at gas engines for CHP production during start and stop [1], [2].

In the study presented here measurements of the emissions of CO, NO_x and UHC (Unburned Hydro Carbons) were conducted on 12 different natural gas fired CHP engine based plants during engine start up, normal full-load operation and shut down. An analysis of the measurements showed that the influence of start and stop on overall emissions varies significantly from engine to engine. For a period of eight hours of operation per engine start the overall emissions were not significantly affected by the start and stop sequences. However, with only a few hours of operation per engine start the effect of start and stop matters. Two engines were successfully modified in order to reduce the emission during the engine start and stop. This finding cannot, however, be extrapolated to all other engine types.
The findings in this study have led to a minor revision of the national emission factors for natural gas fired engine based CHP plants [5].

C O N T E N T S

2. INTRODUCTION

The liberalised energy market results in new challenges for the power producing units. In countries like Denmark where a substantial amount of power is produced by wind turbines, there is a requirement for fast up- and downloading. Gas engine based CHP units have excellent performance characteristics in this respect [1].

Previous investigations have shown that an increased number of starts and stops of gas engine based CHP units will lead to higher emissions of UHC, NO_X and CO [2], [7].
From January 1st 2007, all units with an installed power larger than 5 MW_e will sell the electricity production at the open power market terms (Nord Pool). This might affect the operation pattern of these plants. Gas engine based CHP units represent an installed capacity of some 900 MW_e in Denmark. The majority of the gas engine based power capacity is installed in connection with district heating networks.

In order to assess the actual influence of starts and stops on the overall emissions of CO, NO_x and Unburned Hydro Carbons (UHC), measurements of these components were conducted during start up, shut down and steady full load operation on different engines installed at combined heat and power plants.

Twelve such engine CHP units were chosen for further analysis. The units were selected to be representative for the fuel consumption of natural gas engines in Denmark. From the conducted measurements the influence of start up and shut down on the emissions of CO, NO_x and UHC was determined. Both emissions at cold and warm starts were measured.

Partners of the project

- PonPower (the Danish Caterpillar gas engine agent)
- GE Jenbacher
- Wärtsila Danmark A/S
- Rolls Royce Marine
- National Environmental Research Institute, DMU
- Danish Gas Technology Centre, DGC

For further details please refer to [3], [4] and [5].

3. MEASUREMENTS AND EXAMINED ENGINES

The 12 CHP units that were chosen as being representative for the natural gas engine based power production in Denmark vary in different ways as for instance rated power, engine make and engine type. They represent the makes Wärtsilä, Rolls Royce, Jenbacher and Caterpillar and both open-chamber and pre-chamber engines are included in the investigation. The engine rated power varies from 735 kW_e to 6.000 kW_e.

For each of the 12 units the concentration of CO_2, O_2, CO, NO_x and UHC was measured in the exhaust gas. CO_2 and CO was measured by an infrared absorption analyser (IR), O_2 was measured using a paramagnetic analyser, NO_x was measured by chemiluminiscence (CLD) and

expressed as NO_2 equivalents. UHC was measured by a flame ionization detector (FID) and expressed as CH_4 equivalents.

3.1. Influence of start and stop on the emissions

The effect of a start and a stop sequence on the total emission from an engine depends on the concentration of the emission components as well as on the flow of exhaust gas during the start/stop sequence.

Knowing the flow of exhaust gas and the measured time resolved concentration of the specie *i* it is possible to determine the mass emitted of the specie *i* released during a start or a stop sequence lasting from t_1 to t_2 as

$$m_i = \int_{t_1}^{t_2} \dot{V}_{exhaust} \cdot C_i \, dt \qquad \text{Eq. 1}$$

C_i : concentration of the specie *i*

m_i : mass emitted of the specie *i*

$\dot{V}_{exhaust}$: volume flow of exhaust gas

During each of the conducted measurement programs both emissions and the natural gas consumption were measured. The exhaust gas flow was determined from the measured UHC, CO, O_2 and CO_2 concentration in the exhaust gas and the natural gas composition.

4. RESULTS

The influence of start and stop on the overall emissions varies significantly from engine to engine as shown on Figure 1. The values given in the figure are the overall emissions from an operation sequence consisting of one start up period, a period of steady full-load operation and a shut-down period compared to the emissions during steady full-load operation. This means that the value 0 corresponds to a case where there is no influence on start and stop on the overall emissions. The value +1 % corresponds to a case, where the start and the stop sequence increases the overall emission by 1 % compared to steady full load operation for a given period of operation. The value for CO for unit #10 exceeding the applied scale is 76 %.

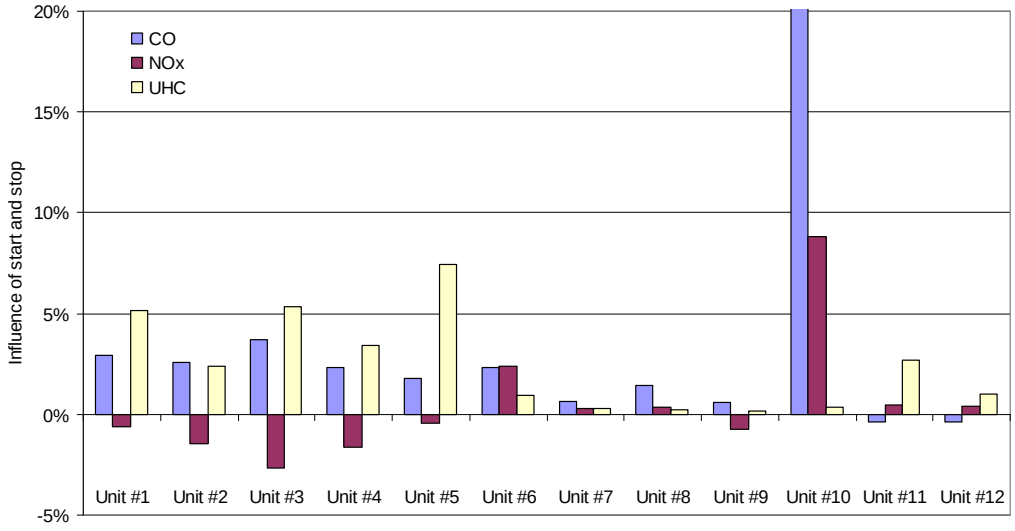

Figure 1. The relative influence of start and stop on the emissions from the examined units. One warm start per 8 hours of operation compared to steady state full load operation.

A small fraction of units that are poorly adjusted during start and stop as unit #10 might affect the cumulative emissions from gas engines. The average influence of start and stop on the overall emissions for the examined engine is given in Table 1 with and without unit #10.

Table 1. The effect of a poorly adjusted unit on the average value of the influence of start and stop on emissions. Eight hours of operation per engine start compared to steady state full load operation.

	CO	NO_x	UHC
Unit #10 included	6,9 %	0,4 %	2,6 %
Unit #10 excluded	1,4 %	-0,3 %	2,8 %

An increased number of engine starts will increase the influence of the emissions during start up and shut down. If the engines are only running for a few hours every time it will affect the overall emissions significantly. See Figure 2.

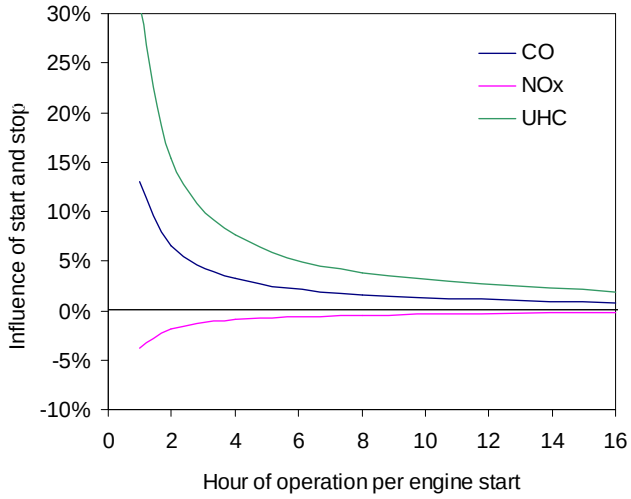

Figure 2. The relative influence of start and stop on the emissions depending on the operation period per engine start. Emissions are compared to steady state full load operation. Average value of examined pre-chamber engines.

4.1. Reduction of emissions during start up and shut down

Two engines of different makes have subsequently been modified in different ways in order to reduce the emissions during start up and shut down of the engine. Another aim of the modification was to reduce the required start-up period so the engine is on full load within 15 minutes as required in order to deliver system balance services. The examined engines are the ones denoted unit #2 and #4 in Figure 1.

The modifications were chosen, designed and implemented by the individual engine manufactures or their representative. For both engines the modifications were based on cutting off the fuel supply to a number of the cylinders during start up, thus letting the other cylinders be operated at a higher load. This means that engines, where the fuel and air are mixed and led to a receiver common for both engine banks cannot apply the suggested solution. Details are confidential and known by the manufactures only.
For both engines it was possible to reduce the start-up time to satisfy the demands required to deliver system balance or back-up services.

4.1.1. Modifications at Engine #2

The engine settings were modified in order to reduce emissions of unburned fuel (UHC) during start and stop. The results are shown in Figure 3. The values given in the figure are the overall emissions from an operation sequence consisting of one start-up period, a period of normal full load operation and a shut-down period compared to the emissions during steady full load operation.

It was found that it was possible to reduce the influence of start and stop on the total emissions of both CO and UHC emission by around one third without negative influence on the NO_x emissions. The second attempt denoted *Modified 2 (NO_x focus)* did reduce the NO_x emissions but that was obtained at the expense of higher UHC and CO emissions during warm start.
The bars value *Modified 3 (Short start up)* shows the results obtained with setting as *Modified 2* except that the start-up period was shortened. This shows that a shortened start-up period reduces the negative influence on CO and UHC emissions during start and stop. This is a result of a shorter period of time, where the engine is operated at non-optimal conditions. However, the overall NO_x emissions were practically not affected by the shorter start-up period.

The bars denoted "Original settings" and "Previous" are conducted with the exact same engine settings and shows a satisfying reproducibility.

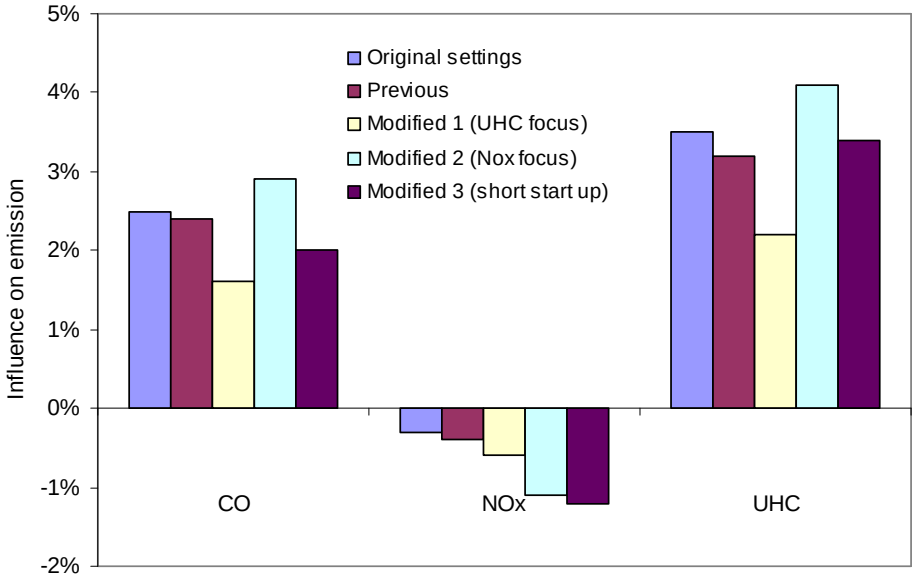

Figure 3. The influence of start and stop on the overall emissions for engine unit #2. One warm start per 8 hours of operation compared to steady state full-load operation. The bars denoted "Original settings" and "Previous" are conducted with exact same settings and show a satisfying reproducibility.

4.1.2. Modifications at Engine #4

The results of the measurements are compared with results of previously conducted measurements (Original settings (no cat.)), see Figure 4. The influence of start and stop on the CO emission was almost eliminated by the installation of the CO catalyst. This is true except for one case, namely during cold start with the original settings. Even in that case the influence of start and stop on the overall emission was reduced significantly. During the warm start-stop sequence the UHC emission was reduced to around one third compared to the original settings without affecting the NO_x emissions. In all warm start cases NO_x emissions are lower than during steady full load operation. During the cold start sequence the influence on the UHC emission was reduced to around the half applying the installed modifications. The NOx emissions were lower than steady state full load operation.

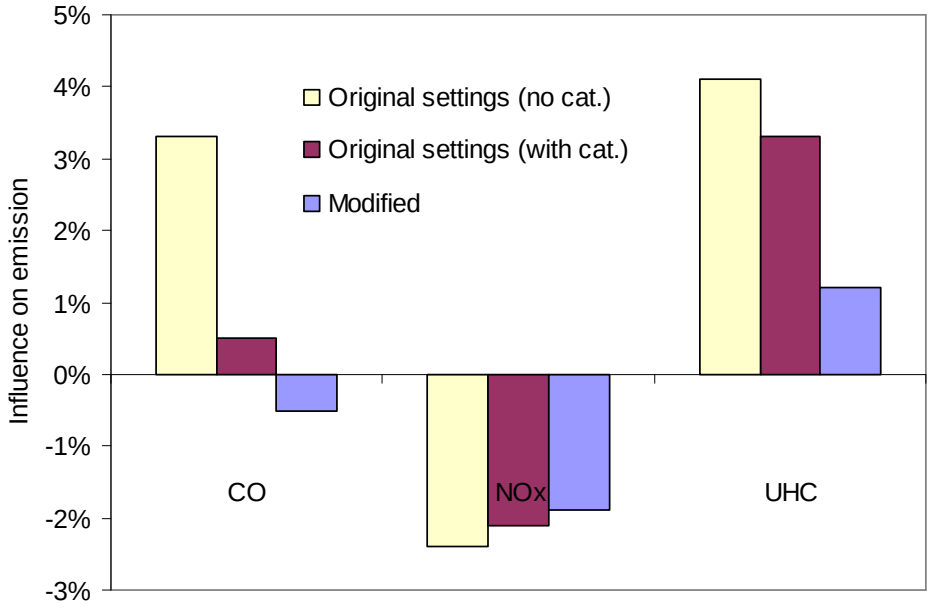

Figure 4. The influence of start and stop on the overall emissions for engine unit #4 . One warm start per 8 housr of operation compared to steady state full load operation.

5. REVISED FULL LOAD EMISSION FACTORS

October 2006 new emission regulations came into force for Danish gas engine and gas turbine based CHP plants [6]. In order to comply with these regulations many plant owners installed a CO catalyst. Other modifications and adjustments were carried out as well. Therefore, the national average emission factors have been updated. The update is based on

- Data from the Danish Environmental Protection Agency (EPA).
- A database containing data regarding of type and rated power of installed gas engines in Denmark.
- Emission factors applied until now.
- Emission limits given by the regulation.
- Emission data provided by engine manufacturer/suppliers Wärtsila and Rolls Royce.

Aggregated full load emission factors for gas engines for CHP production in Denmark are shown in Table 2 together with emission factors including the effect of start and stop. The updated emission factor for CO is reduced by 35 % and 11-12 % for NO_x and UHC when the effect of start and stop is included. This is valid for 8 hours of operation per engine start.

Table 2. Emission factors for natural gas fired CHP engines.

	Full load emission factor mg/m^3_n (ref. 5% O_2)	Previous full load emission factor g/GJ	Full load emission factor g/GJ	Emission factor. Effect of start-stop is included g/GJ
CO	351	175	109	115
NO_x	473	168	148	148
UHC (C)	1347	485	420	434
- CH_4	1444	520	450	465
- NMVOC[1]	325	117	101	105

[1] NMVOC - Non Methane Volatile Organic Compound.

Since last time the emission factors were updated the overall electrical efficiency has increased from 38,3 to 39,2 %.

6. CONCLUSIONS

The emissions of NO_x, CO and UHC were measured during start and stop from 12 various stationary lean burn natural gas fired engines installed at different combined heat and power (CHP) units in Denmark. The units have been chosen to be representative for the natural gas engine based power production in Denmark. The influence of start and stop on the overall emission was determined from the obtained data.

The measurements and analysis made shows that the CO emissions was 6,9 % higher due to start and stop compared to steady full load operation for an operation period of 8 hours consisting of one engine start, a period of steady full load operation and a shut down of the engine. However, one of the 12 engines was incorrectly adjusted during start and stop. If that one engine is omitted from the analysis the number would be 1,4 % instead. This investigation cannot tell whether one extreme unit out of 12 is representative. The overall NO_x emission was hardly affected by start and stop. The overall UHC emission was found to be 2,6 % higher than at steady full-load operation due to start and stop of the engine.

From the 12 engines, two were chosen for an investigation of the possibility of reducing the emissions during start and stop. It was possible to reduce the emissions during start and stop significantly on the examined engines. However, these experiences cannot be extrapolated to other engine types directly, as it depends on e.g. the design of the air and fuelling system of the engine.

7. ACKNOWLEDGEMENT

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