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EVALUATION OF THREE-WAY-CATALYSIS FOR NO_X-ABATEMENT IN LARGE GAS-FIRED APPLIANCES

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Summary

A study concerning the utilisation of three-way-catalysis (twc) for NO_X-abatement in gas-fired boilers has been performed on the requests of Swedish Centre of Gas Technology AB (SGC) and Perstorp AB. The boiler was a triple-pass Remeha OD15, fitted with a pre-mix burner (Dunphy). The load could be varied between 0.6 and 1.6 MW_t of heat input. A three-way-catalyst was installed as an annular wire-mesh segment in the turning section of the first pass. The conversion level (lambda= 0.99) with respect to NO_X ranged between 70 and 90%, depending on the load situation. In order to comply with the standards concerning CO-emissions, secondary air was injected downstream the twc to achieve an overall lambda-value of 1.1. An oxidation catalyst (oc) was installed further downstream to enable a purification of the flue gases with respect to CO.

The lambda-value-control was performed manually in this installation whereas automatic control is to be implemented in commercial installations.

A long-term-test during 1500 hours of continuos operation was performed without any losses in catalyst activities (twc/oc). Micro-reactor tests with reference catalysts and deactivated catalysts samples also indicated full catalyst activity for the deactivated samples. Characterisation revealed some thermal degradation of the morphology of the catalyst, although not serious enough to cause any losses in catalyst activities.

By-pass effects affected the obtainable conversion levels. It is of great importance to achieve a perfect alignment of the catalyst to the walls to avoid by-pass effects.

An economic evaluation of the twc-technology indicated typical pay-off-times of 2-3 years. The most important parameters in the economic evaluation are:

- The NO_X-emission (mg/MJ)
- The annual energy production in relation to the unit-size (h)
- The specific catalyst price (SEK per MWh)

The economic evaluation is based on the Swedish NO_x-legislation and current taxes concerning NO_x-emissions. To get an acceptable profitability of the installation the original NO_X-emission should be at least 60 mg/MJ. In addition the annual operation time should be as high as possible, i.e. industrial boilers are expected to show a higher profitability than municipal boilers. The specific catalyst price is, of course, another important parameter in the cost/benefit-calculations.

A full-scale test is expected to be carried out during the autumn of 1999. Commercialisation will be carried out during the next few years.

Sammanfattning

En studie avseende implementering av trevägskatalys (twc) i gaseldade pannor har utförts på uppdrag av Svenskt Gastekniskt Center AB (SGC) och Perstorp AB. Installationen utfördes på en tresträkspanna av fabrikatet Remeha (OD15), vilken var utrustad med en premix-brännare av fabrikatet Dunphy. Bränsleeffekten kunde varieras mellan 0.6 och 1.6 MW_t. En ringformad trevägskatalysator installerades i vändsektionen av första stråket. Reduktionsgraden m.a.p. NO_x varierade mellan 70 och 90% (vid lambda 0.99) beroende på lastförhållanden. För att uppfylla emissionskraven avseende CO skedde tillsats av sekundärluft i en position omedelbart efter trevägskatalysatorn. En oxidationskatalysator hade placerats nedströms sekundärluftstillförseln för att möjliggöra en effektiv rökgasrening m.a.p. CO.

Luftöverskottet vid förbränningen övervakades manuellt vid testerna medan avsikten är att utnyttja automatiska övervakningssystem i kommersiella installationer.

Långtidsförsök (1500 timmars kontinuerlig drift) visade att katalysatorn inte förlorade någon aktivitet. Denna iakttagelse stöddes av mikroreaktorförsök utförda med nytillverkad referenskatalysator respektive deaktiverad katalysator. Katalysatorkarakterisering påvisade effekter av termisk sintring, dock inte tillräckligt allvarlig för att förorsaka aktivitetsförlust.

Förekomsten av by-pass-effekter påverkade erhållna värden avseende reduktionsgrader negativt. Det är av stor vikt att tillse att by-pass-effekter undviks.

En ekonomisk värdering av twc-tekniken indikerar återbetalningstider för investeringen på 2 -3 år. De viktigaste parametrarna i den ekonomiska utvärderingen är:

- NO_x-utsläppets storlek (mg/MJ)
- Den årliga energiproduktionen i förhållande till anläggningsstorleken (h)
- Katalysatorkostnaden (SEK/MWh)

Den ekonomiska analysen bygger på det svenska avgiftssystemet för kväveoxidutsläpp. För att uppnå en rimlig lönsamhet bör den ursprungliga NO_x-halten i rökgaserna vara högre än 60 mg/MJ. Anläggningens utnyttjande (timmar/år) skall vara så högt som möjligt, vilket sannolikt gynnar industriella installationer. Katalysatorpriset är självklart en annan viktig parameter och ta hänsyn till.

Ett fullskaletest beräknas utföras under hösten 1999 och kommersialiseringen av tekniken förväntas sker under de närmaste åren.

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1. Introduction

Katator AB has performed a study concerning the utilisation of three-way-catalysis for NO_X-abatement in boilers for industrial heating. The design- and dimensioning work was based upon a preliminary study concerning three-way-catalysis in gas fired boilers performed during 1997 [1]. In that study experiments were performed in a gas-fired micro-reactor as well as in a gas-fired domestic boiler.

If the energy production of a boiler exceeds 25 GWh/yr, the owner of the boiler has to account for the annual NO_X-emission to the authorities. The owner is then assessed at 40 SEK per kg of NO_2 emitted. Implementation of NO_X-reducing measures thus creates an annual saving, which can be used to finance the catalyst installation.

It is believed that three-way-catalysis (twc) is an effective way to reduce the NO_X-emissions. To be able to commercialise the twc-concept it is, however, essential to demonstrate the durability of the catalyst in a large-scale application and to gather technical data to enable a cost/benefit-calculation.

The aim of this study is to demonstrate the twc-concept on an industrial boiler and to gather important technical information concerning installation, catalyst preparation and performance during prolonged times of operation. The project is financed by Swedish Centre of Gas Technology AB (SGC) in collaboration with Perstorp AB (PAB).

2. Previous studies

Katator AB has previously performed a study concerning three-way-catalysis in gas-fired boilers [1]. Tests were performed in a gas-fired micro reactor as well as in a domestic boiler (20 kW_t). The burners were adjusted to stochiometric or slightly under-stochiometric conditions. A three-way-catalyst (twc) was installed to reduce the NO_X-emissions through reactions between NO_X and CO/H_2/Hydrocarbons present in the gas mixture. To be able to comply with the emission standards concerning CO and hydrocarbons, an oxidation catalyst (oc) was installed down-stream the twc. In addition, secondary air was added in a position between the twc and the oc.

In order to achieve a high degree of NO_X-reduction when using twc in natural gas combustion, it is necessary to use slightly under-stochiometric conditions, as shown in Figure 1. The NO_X-conversion levels out at lambda values lower than 0.99. Thus, the lambda value during combustion should lie around 0.99, i.e. slightly under-stochiometric conditions. The three way catalyst also contributes to the combustion of carbon monoxide and hydrocarbons to some extent.

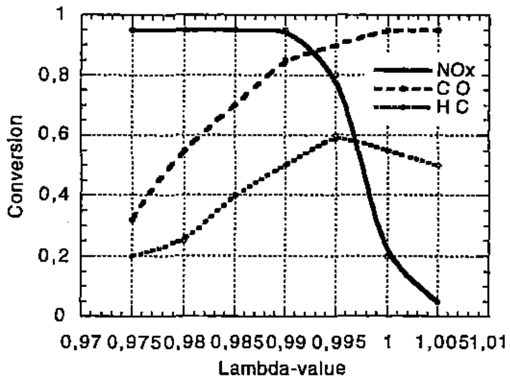


Figure 1 Conversion of NOx, CO and HC vs. the lambda-value, during three-way-catalysis (natural gas combustion), general trends.

The tests performed in the domestic boiler (Remeha OG9/Bentone BG100) verified the general trend concerning the influence of the lambda value on the NO_X-conversion. Figure 2 shows the NO_X-conversion and the boiler efficiency vs. the lambda value. As can be seen in the figure, the NO_X-conversion levels out at 0.98 at a lambda-value of 0.98 - 0.99, i.e. in perfect agreement with the general trend shown in Figure 1. The boiler efficiency increases as the lambda value is decreased. A decreased lambda value will lead to a lower flue-gas flow and consequently to lower flue-gas losses. At lambda values lower than 0.98, the flue gases will contain considerable amounts of CO, which will lead to a decreased boiler efficiency due to fuel slip (unburned CO/hydrocarbons).

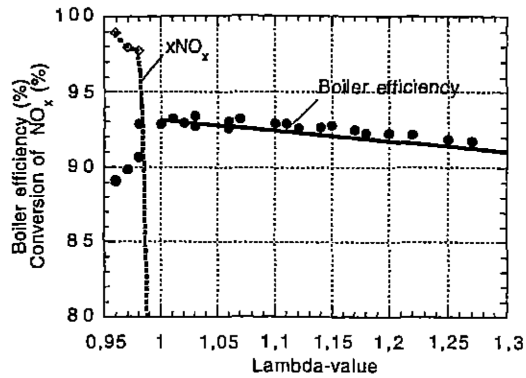


Figure 2 Boiler efficiency (•) and NOx-conversion (◊) vs. the lambda-value. Tests performed in a domestic boiler (20 kWt).

The study also contained a tentative cost/benefit-evaluation which clearly demonstrated a commercial potential of the technique. The most important parameters in the economic analysis were:

- NO_X-emission (mg/MJ)
- Energy production in relation to the maximum power output
- Catalyst price in relation to the life time of the catalyst

Most gas-fired boilers (municipal and industrial) have NO_X-emissions between 30 and 50 mg/MJ [2]. Industrial boilers are operated during a larger proportion of the year (often around 6000 hr/yr.) in comparison to municipal boilers (around 4000 hr/yr.). The catalyst price is another important parameter in the economic evaluation. The catalyst price relates the investment cost of the catalyst to the catalyst life time and might consequently be expressed with the unit [SEK/MWh].

The tentative economic analysis indicated typical pay-off-times of 2 -3 years.

3. Aim of the study

The overarching goal of this project can be expressed as follows:
"To demonstrate that three-way-catalysis can be used to reduce NO_X-emissions from gas-fired units to ultra-low levels in a technically, economically and environmentally advantageous way".

The term ultra-low emissions is used for emissions below 10 mg/MJ. The corresponding degree of NO_X-reduction is in most cases between 80 and 90%.

The advantages of the proposed technique for NO_X-abatement may be summarised as follows:

- Low pressure drop
- High conversion of NO_X
- Negligible emissions of CO/hydrocarbons
- Simple and compact construction
- Excellent catalyst durability expected
- Increased boiler efficiency

4. System design

4.1 Burner and furnace

The furnace used in this study was a triple pass Remeha OD 15B with a nominal heat input of approximately 2 MW_t. The chimney loss is, according to the manufacturer, around 18% at full load. The boiler is cooled by means of pressurised water and the temperature of the cast iron sections within the boiler will lie close to the water temperature (90 - 120°C).

The combustion-chamber-pressure-drop (at 20% excess air) is around 6 mbar at full load. Through installation of baffles in the flue-gas channel the heat-transfer-numbers are increased to obtain a higher boiler efficiency (natural gas appliances). The baffles will also result in an increased combustion-chamber-pressure-drop.

The boiler is built from standardised sections with a length of 140 mm. By fitting such sections together it is possible to build boilers with a nominal heat output ranging from 0.7 to 2 MW_t.

The combustion chamber has a circular cross section with a diameter of 720 mm.

The burner is a pre-mixed jet burner (Dunphy) with a turn-down ratio of 1:5. The load of the burner is controlled to obtain a certain temperature of the outlet water.

The lambda value is controlled by means of an air/gas-ratio controller and the lambda value is typically set to 1.1 - 1.2.

4.2 Catalyst installation

To enable studies concerning twc in gas-fired boilers a wire-mesh catalyst was installed at two positions along the flue-gas channel, see Figure 3. The three-way catalyst had an annular geometry and was fitted into the turning section of the first pass. The flue gas passed through the wire-mesh catalyst where reactions between NO_X, CO, H_2 and unburned hydrocarbons occured.

In order to comply with emission standards concerning CO/hydrocarbons an oxidation catalyst was installed downstream the twc. The oxidation catalyst was divided into four segments, each with a planar structure. The catalyst was placed in the turning section of the second pass, where the temperature still was high enough to facilitate an effective combustion of CO/hydrocarbons.

The installation contained around 1.5 m^2 twc and 3 m^2 oc (wire-mesh area). The twc was divided into three annular segments in series, each with a diameter of 720 mm and an effective length of 120 mm. The oc was divided into four segments, each with an effective area of 0.07 m^2. Each segment was equipped with six catalyst layers in series. Both catalysts were manufactured from a wire mesh with mesh no. 16 and a wire diameter of 0.5 mm. The wire material was FeCrAlloy (Kanthal AF).

The twc contained a combination of Pd and Rh as the active phase whereas the oc was supplied with Pt.

The combustion parameters were adjusted to obtain slightly under-stochiometric conditions in the combustion chamber, characterised by zero-concentration of oxygen and increased concentrations of CO/H_2/hydrocarbons. Secondary air was injected in a position between the twc and the oc to obtain an oxidising environment in the oxidation catalyst.

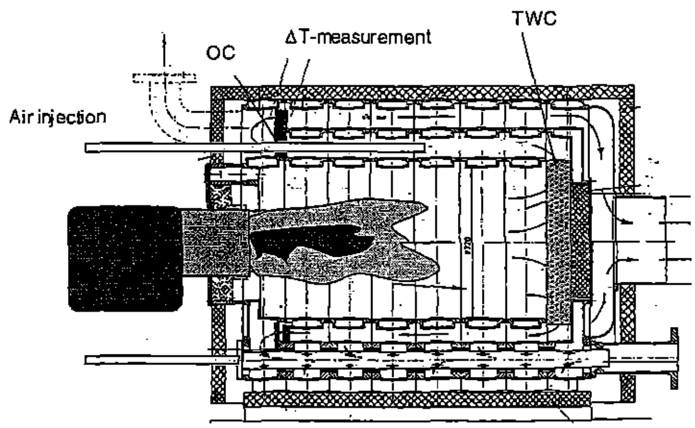


Figure 3 Catalyst installation. TWC= Three way catalyst. OC=Oxidation catalyst.

The temperature difference over the oxidation catalyst was measured continuously and was used as a control parameter for the deNO_X-process. A temperature difference of 10 - 20°C indicated that enough CO was present to facilitate an effective NO_X-reduction in the twc.

The flue-gas flow will vary linearly with the load, as indicated in Figure 4. At the maximum load, the flue-gas flow will lie around 1500 nm^3/h. The total pressure drop of the catalyst is expected to range from 0.3 to 3 mbar.

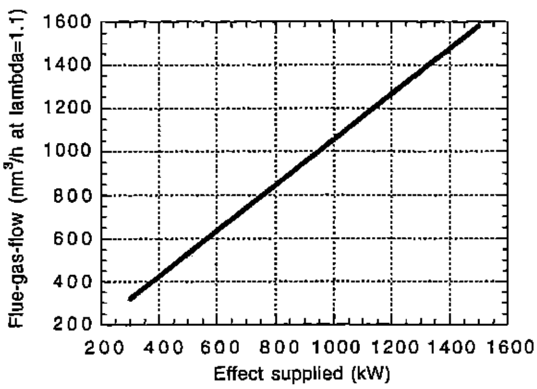


Figure 4 Flue-gas-flow vs. the fuel effect supplied.

4.4 Injection of secondary air

Secondary air was injected through lances fitted in positions between the twc and the oc. The air was supplied from a compressor-unit and was delivered to the air-injection system via a metering system.

The flow rate of secondary air was adjusted to obtain an excess-air ratio of 1.1 in the oc.

4.5 Test procedure

During the early stages of the project much concern was directed to the potential risks of causing damages to the boiler due to the neutral flue-gas atmosphere. If the protecting oxide layers prestent on the iron are reduced, severe corrosion from sulphur- and halogen compounds is possible. Natural gas does not contain such harmful components in concentrations high enough to cause any problems. Less pure fuels, i.e. sulphur containing oil, coal and bio-fuels, are likely to cause problems, especially at high metal temperatures (in the superheater portion of the boiler, if present).

Thermodynamical calculations (HSC, **TM** to Outokumpu OY) showed that cast iron is protected by oxides also in a neutral atmosphere at the temperatures prevailing in the boiler.

Even if the corrosion problems are negligible in this application, it was decided not to take any risks during the project. Consequently the burner was adjusted to stochiometric conditions only during the measurements. During normal operation the combustion was carried out at a normal excess air ratio.

The impact of thermal deactivation is not dependent upon the flue-gas composition. Indeed, the rate of catalyst deactivation is expected to proceed quicker in an oxidising environment due to evaporation of volatile metal oxides (Pd and Rh are more stable as the metals) from the catalyst. Consequently the test should be conservative with respect to catalyst deactivation.

5. Technical problems

5.1 lambda-value-control

In the experiments presented in this report, the lambda value was controlled manually. In a commercial installation, however, the lambda-value-control should be automatic.

The lambda value is easily controlled by a system including a lambda sensor, a control unit and a make-up gas valve. The lambda sensor measures the air-excess ratio and the control unit gives an open/close-signal to the make-up gas valve, based on the desired lambda value. The lambda sensor must be exposed to the atmosphere prevailing in the portion between the twc and the oc.

The control system is rather cheap (around SEK 20 000 for small-scale installations). Larger installations will require more expensive valves and perhaps a system redundancy.

5.2 Effective reduction of CO

Conventional combustion normally results in extremely low emissions of CO and hydrocarbons. The twc-concept is based on under-stochiometric combustion where the flue-gas is expected to contain 1000 - 2000 ppm of CO in the twc-position. In order to comply with the standards concerning CO-emissions, the oxidation catalyst must be rather effective (the conversion level must be close to 99%). The demand concerning high degrees of conversion also results in demands concerning the total absence of by-pass effects. This is, of course, a problem which must be handled during design and installation of the catalyst.

5.3 Fitting the catalyst into the furnace

As mentioned earlier in the report it is essential to avoid by-pass effects. In the twc-position by-pass effects will result in a lower reduction degree with respect to NO_X. By-pass effects are even more detrimental in the oc-position, since such effects will lead to high emissions of CO.

There is a large number of boiler designs on the market, each giving different possibilities of a successful catalyst installation. It is important to start the de sign work with an evaluation of the risks of by-pass effects.

5.4 Corrosion due to the neutral atmosphere

One of the major concerns during the project was corrosion, which might be caused by an oxygen free atmosphere in the boiler.

Corrosion is initiated by adsorption/fouling of corrosive compounds onto the metal surface. In an oxidising environment the corrosion processes are retarded by a protective oxide film prevailing on the metal surfaces.

Natural gas combustion does not result in the formation of corrosive components, since the fuel only contains very small amounts of sulphur (originating from the odorant added to the fuel). Also, the flue gases will not contain other harmful products as chlorine or alkaline compounds, normally found in coal- and bio-fuel combustion.

It is not correct to define the atmosphere as reducing since the metal still will react with oxygen containing compounds (water, carbon dioxide etc.) to form a protective oxide film at the metal temperatures prevailing in the boiler. Only at very high concentrations of CO/H_2, which only could be formed during partial oxidation or in gasification processes is the protective oxide film destroyed. Even if this was the situation we still lack the components which may cause corrosion in natural gas appliances.

It is however important to evaluate the possibility of corrosion phenomena when combusting less pure fuels, i.e. sulphur containing oil, coal and bio-fuels. Corrosion is most likely to occur in sections where the metal is hot, i.e. in the super-heater-section of the flue-gas-channel.

6. Preliminary tests

6.1 Temperature mapping

Since no reliable data concerning the flue-gas temperature along the flue-gas-channel existed a thermal calculation was performed prior to the catalyst installation. The thermal calculations were used to find suitable positions for the twc and the oc. The thermal calculations were verified during the preliminary tests of the installation, see Figure 5. As can be seen in the figure the experimental data (dots) rather well agree with the calculated data (lines). The temperature close to the chimney ranged from 150 to 250°C, depending on the load situation. The oc-temperature was close to 200°C at the lowest load and increased to 450 - 500°C at the highest load. The temperature of the twc varied between 600 and

1000°C. At temperatures above 1100°C rapid catalyst deactivation is expected.

The positions chosen for the twc and the oc will enable suitable operation windows with respect to the temperature. Problems with low CO-conversion at low loads as well as catalyst deactivation (twc) at high loads were, however expected.

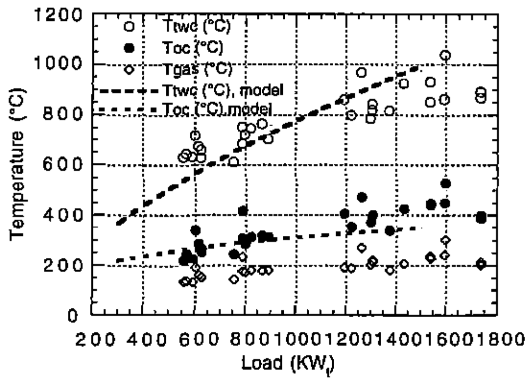


Figure 5 Temperature levels of the three-way-catalyst and the oxidation catalyst (dots) in comparison to estimated values (lines).

6.2 Pressure drop

The pressure drop of the catalyst installation was in good agreement with the expected values and ranged from 0.5 to approximately 5 mbar. The major portion of the pressure drop thus origin from the flow resistance in the boiler and the chimney.

6.3 Reduction of nitrogen oxides

The reduction degree with respect to NO_X was measured at different loads. NO_X-analysis was performed with an electrochemical technique as well as with chemiluminiscence (EMK AB). IR-instrument was used to monitor CO- and CO_2-emissions whereas the oxygen content of the flue gases was measured electrochemically.

Figure 6 shows the initial reduction degree with respect to NO_X (dots) vs. the load. The experimental data very well agree with the forecasted data (modelled data presented as lines).

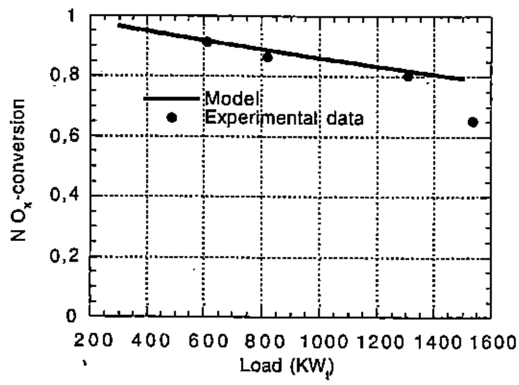


Figure 6 NO_X-reduction obtained in the boiler in comparison to estimated values.

At the highest load, the secondary air jet impinged on the twc, thus causing an oxidising environment in a portion of the twc. This effect resulted in an unexpected low reduction degree with respect to NO_X at that load.

Due to design constraints it was not possible to move the air lances to eliminate this problem.

The NO_X-emission was around 40 mg/MJ without the twc-installation. The twc-installation thus enabled ultra-low NO_X-emissions of 4 - 10 mg/MJ

6.4 Reduction of CO

The performance of the oc was expected to follow the graph presented in Figure 7. The experimentally obtained values are in fair agreement with the calculated data, especially at low loads. At high loads the experimentally obtained conversions are somewhat lower, which might be explained through by-pass effects; it was difficult to install the oc without obtaining a slot along the circumference.

It is obvious that the oc is under-dimensioned to be able to comply with standards concerning CO-emissions. Indeed, the CO-emission ranged from 100 - 500 ppm during the measurements. The CO-content at the twc-position was varied between 1000 and 5000 ppm, without significant effects on the NO_X-reduction. Consequently it is possible to postulate that the CO-concentration at the twc-position should be between 1000 and 2000 ppm. In order to comply with the CO-standards, the CO-conversion should be at least 95%.

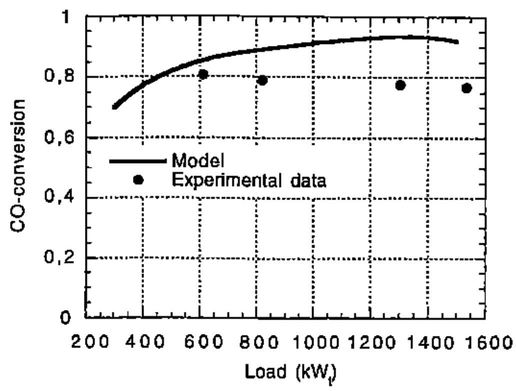


Figure 7 CO-reduction obtained in the boiler in comparison to estimated values.

The desired degree of conversion is only obtainable if by-pass effects can be eliminated through an improved alignment of the catalyst.

7. Long-term-tests

7.1 Trend analysis

In order to study the durability of the catalysts a long-term-test was performed during 1500 hours of operation. The NO_X-and CO-conversions were measured at different times during the long-term-test. As can be seen in Figure 8, the NO_X-conversion is rather constant during the course of the long-term-test. This indicates that the processes leading to catalyst deactivation and loss in activity are under control. Since no catalyst deactivation is observable after 1500 hours of operation, the catalysts is expected to manage at least 10 000 hours of continuos operation. The conversion level was measured by an independent company (EMK AB) at the end of the long-term-test. The EMK-measurements very well agreed with our own measurements, see appendix A. Although their analysis technique (chemiluminiscense) gave somewhat lower NO_X-emissions in absolute terms, the conversions were the same.

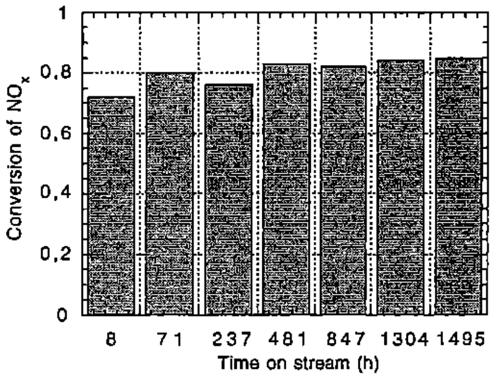


Figure 8 NO_X-reduction during the long-term-test, obtained at 1.2 MW_t input effect.

Also the oxidation catalysts was rather stable during the course of deactivation, as can be seen in Figure 9. There is however a tendency, although weak, to catalyst degradation. This phenomena might also be associated with increased by-pass-effects, which may arise from thermo-mechanic impact on the catalyst.

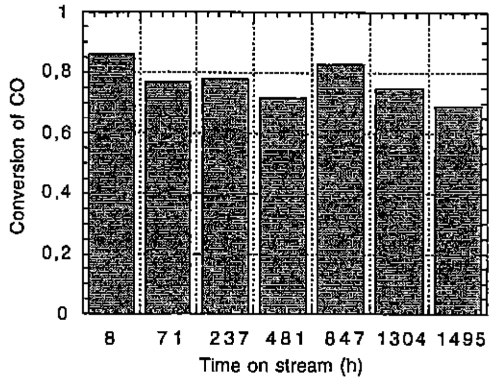


Figure 9 CO-reduction during the long-term-test, obtained at 1.2MW_t of effect input.

7.2 Discussion

To be able to separate the effects of true catalyst deactivation from effects caused through by-pass-effects it is important to perform activity tests with unused catalyst samples (reference samples) and catalyst samples subjected to the long-term-test. The catalyst installation was dismounted in June, after almost 2000 hours of operation. Catalyst samples were taken for micro-reactor tests and characterisation.

Physical inspection indicated some leaks between the twc/oc and the walls (imperfect lining). These leaks may be responsible for the suspected by-pass-effects.

8. Catalyst characterisation

8.1 Activity

In order to judge whether the catalysts had been deactivated during the long-term-test, micro-reactor-tests were performed. A gas mixture containing air/CO was used to study the activity of the oc whereas a mixture containing N_2/CO/NO was used for the twc.

The flow rates were accurately adjusted with mass-flow-controllers and analysis was performed with photoacustic IR (CO/CO_2) and chemiluminiscensce (NO/NO_2).

The reactor diameter was 35 mm and the total flow rate was 2 nm^3/h. 5 catalytically active wire meshes were placed in series in the reactor and the conversion with respect to CO/NO was measured at different temperatures.

Tests were performed with an empty reactor to ensure that no gas-phase reactions or wall-effects affected the results.

In Figure 10, the conversion of fresh and deactivated catalysts samples are compared during NO-reduction (200 ppm) with CO (2000 ppm). The results show that the activity of the twc only has decreased marginally (only at low reaction temperatures). These results very well agree with the full-scale measurements performed on the boiler installation.

The conversion was unaffected by the CO:NO-ratio, provided that the ratio was above 2. In a real boiler, the ratio need to be higher due to problems with flow- and concentrations gradients. During the full-scale tests, we used a CO:NO-ratio ranging from 10 to 20, to obtain an acceptable conversion of NO_x.

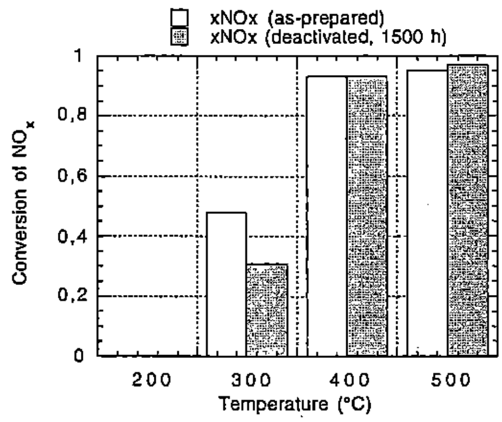


Figure 10 NO_x-conversion (as-prepared and deactivated catalysts).

Also the oc had maintained its activity during the long-term-test, as can be seen in Figure 11. The tendency of catalyst deactivation observable during the full-scale-test must thus be explained in terms of increasing effects of by-pass.

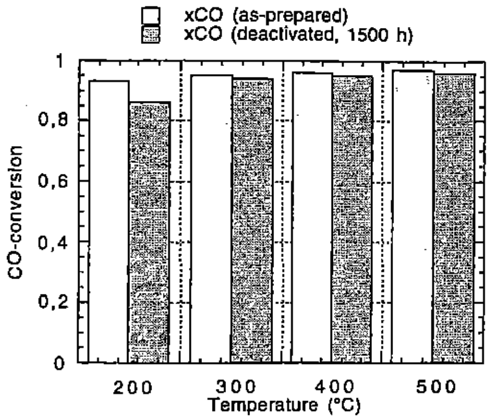


Figure 11 CO-conversion (as-prepared and deactivated catalysts).

8.2 Morphology

The twc and the oc were characterised with respect to the specific surface area through physisorption of N_2 (Micromeritics, TriStar). Table 1 summarises the results obtained for the references and the deactivated catalysts.

Table 1 Wire-mesh areas measured through physisorption of nitrogen.

Sample	Wire-mesh area (m^2/m^2)
twc, ref.	5980
twc, deact.	1040
oc, ref.	6610
oc, deact.	1510

From table 1 it is evident that catalyst sintering has occurred during the long-term-test. The oxidation/reduction-reactions in this application, however, are so quick that the effects of mass-transfer-limitations totally mask the effects of morphological degradation of the catalyst.

8.3 Conclusions

The long-term-test indicate an excellent durability of the catalyst. The activity of the catalysts is maintained for prolonged periods of operation even if some thermal sintering of the catalyst has occurred. The test conditions have been rather severe since the temperature of the twc often has reached 1000°C or more. The optimum temperature window for the twc is between 400 and 800°C. In such a case activity and stability can be guaranteed for 10 000 hours of opereation or more.

9. Technical and economical evaluation

9.1 Installation cost

The installation cost can be divided into four major items, i.e.:

1. Catalyst
2. Air-supply system
3. Control and safety
4 Installation costs

The specific catalyst cost is, of course, dependent upon the market price of the catalytic wire mesh as well as the expected life-time of the catalyst and might consequently be expressed with the unit SEK/MWh. A reasonable market price (in large-scale production) will be around SEK 50000/MW_t for 90% conversion. Taking the expected life-time of the catalyst as 16000 hours, the specific catalyst cost will be around 3 SEK/MWh for 90% conversion.

The catalyst cost for 99% reduction will be SEK 100000/MW_t whereas lower reduction degrees will demand less catalyst, e.g. the catalyst cost for 70% reduction will be about SEK 25000/MW_t.

The system for secondary air injection contains air lances and a fan. The cost of these components is low in comparison to the catalyst cost and is expected to equal SEK 10000/MW_t or less.

The control system for make-up gas contains a lambda-sensor-system, a control unit and a gas valve. The cost of the lambda-sensor/control unit is around SEK 20 000 whereas the cost of the gas valve will increase with the size of the unit.

A CO/hydrocarbon-sensor is installed down-stream the oc to detect disorder of the oc. If the concentration of CO/hydrocarbons increases, a solenoid valve will close the gas valve for make-up gas. The cost for the sensor, the control unit and the solenoid valve will be around SEK 30000.

It is difficult to specify the installation cost since it is dependent upon the boiler design. A rough estimation is that the installation cost will equal 30% of the total component cost.

As shown in Figure 11, the catalyst cost alone stands for approximately 2/3 of the total cost. The most effective way of decreasing the total cost and to make the cost/benefit-calculation even more favourable is to cut down the specific catalyst cost. This can be done in three different ways:

1. A cheaper way of production
2. Increased catalyst durability
3. Decrease the catalyst amount necessary

Since the reactions are highly mass-transfer-controlled it is necessary to decrease the mass-transfer-limitations to be able to reduce the amount of catalyst. The most effective way of increasing the mass-transfer-capacity of the catalyst is to use a higher mesh number and a wire with a smaller diameter. Calculations show that there is a potential of reducing the catalyst amount by a factor 2 or more in this way. The utilisation of higher mesh numbers although require the total absence of particulate matter in the flue gases.

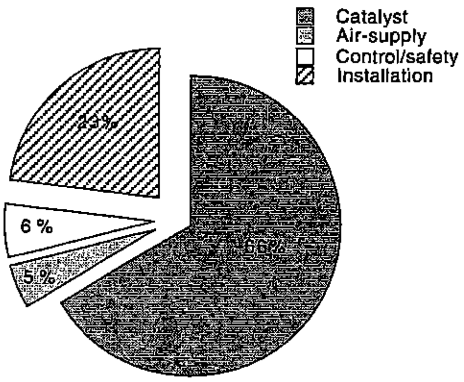


Figure 12 The importance of different items in the investment cost (20 MW_t-installation)

As stated before, the catalyst cost will be about SEK 50 000 per MW_t when using the standard wire-mesh catalyst (16 mesh/0.5 mm). The other investment costs (air-supply, control/safety and installation) are given as a function of the unit-size in Figure 13. The total investment cost of a 20 MW_t-unit will be about 1000 kSEK in catalyst cost and 500 kSEK in other investment costs. When using a higher mesh no. there is a potential of reducing the catalyst cost by a factor 2. Also the installation cost will be somewhat lower if the catalyst amount is decreased (smaller catalyst holders etc.).

The total investment cost (with the exception of catalyst costs) thus equals 20-30 SEK/kW_t for larger appliances (>10 MW_t).

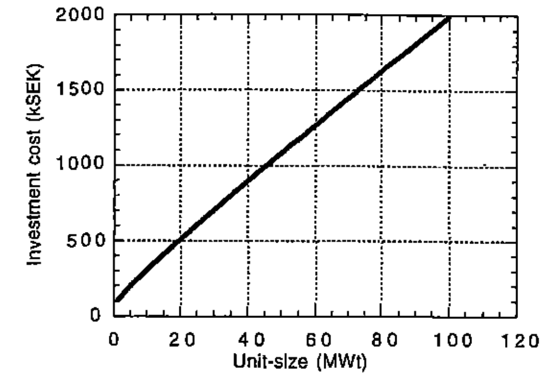


Figure 13 Investment cost (catalyst costs not included)

9.2 Other techniques to achieve NO_X-reduction

There are, of course, other techniques on the market for NO_X-abatement in gas-fired appliances, e.g. burner optimisation, SCR (Selective Catalytic Reduction of NO_X with Ammonia) and SNCR (Selective Non-catalytic Reduction with ammonia).

Relevant data concerning the performance and the installation costs of different NO_X-abatement-methods are summarised in a comprehensive report issued by Stiftelsen för Värmeteknisk forskning [2]. For gas-fired appliances, measures concerning the burner design and the combustion technique were generally performed when natural gas was introduced in Sweden during the 1980s. In most cases the NO_X-emissions from gas-fired installations are as low as 30 - 50 mg/MJ today.

The installation cost of the presented non-catalytic methods is around 25 SEK/kW$_t$. SNCR generally give a higher reduction level with respect to NO_x but will demand ammonia injection which increases the cost of operation.

The installation cost of SCR is around 90 SEK/kW$_t$ and the corresponding degree of NO_x-reduction is generally above 90%. Three-way-catalysis, which is described in this report, will give a total investment cost of ca. 70 SEK/kW$_t$, i.e. somewhat lower than SCR. SCR will demand ammonia injection to work, which will increase the cost of operation.

Figure 14 summarises the investment cost of different techniques for NO_x-abatement. Generic data concerning the degree of NO_x-reduction are given in the same figure

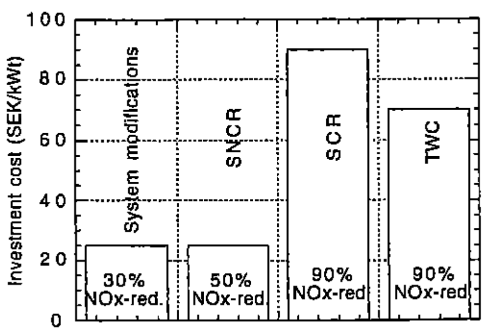


Figure 14 Investment cost of different techniques for NO_x-abatement.

9.3 Economic evaluation

Cost/benefit-calculations were performed to indicate the profitability of a twc-installation under different conditions with respect to:

1) Raw-emission of NO_x (mg/MJ)
2) Energy production (GWh/yr.)
3) Unit-size (MW$_t$)
4) Catalyst durability (hours in continuos operation)
5) Catalyst price (SEK/MW$_t$)

As indicated in Figure 2, the boiler efficiency could be increased by 1 - 2% due to the decreased flue-gas losses when reducing the air-excess-ratio during combustion. The increase in boiler efficiency, however, only marginally influence the outcome of the economic analysis.

Current legislation in Sweden states that combustion units with an annual energy production exceeding 25 GWh/yr. must account for the NO_x emitted to the atmosphere. The owner of the unit is charged with a fee of 40 SEK/kg of NO_2 emitted. Tax restitution is then obtained in relation to the annual energy output of the unit. The tax-restitution (SEK/MWh) is settled each year by the authorities.

In the cost/benefit-calculations the boiler efficiency was set to 90%, which is somewhat higher than the average efficiency of the boilers in Sweden. The value is justified by the fact that natural gas combustion usually facilities higher boiler efficiencies than other fuels.

The standard case is calculated with the following parameter values:

- NO_X-emission: 60 mg/MJ
- Annual energy production: 50 GWh/yr.
- Unit-size: 10 MW_t
- Operation time: 5000 hr/yr.
- Specific catalyst cost: 3 SEK/MWh

The calculations indicate an annual profitability of the installation of SEK 110000 at a conversion level of 90% with respect to NO_X. The investment cost (the catalyst cost is considered to be an operational cost) of the installation is SEK 300000. The pay-off-time will consequently be around 3 years for this installation.

Figure 15 shows the sensitivity of different parameters. The most important parameter is, as expected, the NO_X-emission (mg/MJ). If the NO_X-emission is 35 mg/MJ or less, the installation is unprofitable at all situations. On the other hand, if the NO_X-emission increases to 100 mg/MJ or more the pay-off-time will be as low as 1 year.

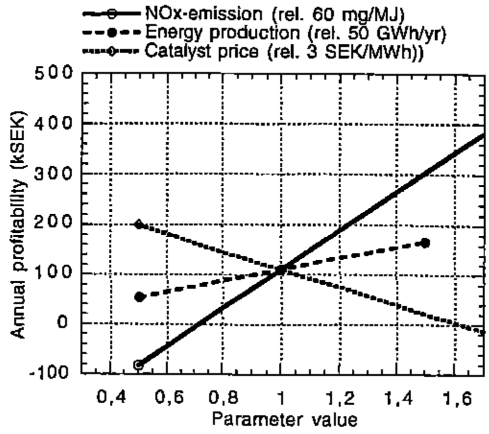


Figure 15 Evaluation of the parameter sensitivity (10-MW-unit).

The second most important parameter is the specific catalyst cost, which is expressed as the unit-catalyst-price in relation to the lift-time of the catalyst. A specific catalyst price higher than 5 SEK/MWh makes all 10-MW_t-installations unprofitable.

The annual energy production is another important parameter to take into consideration. The profitability monotonously increases with the annual time of operation. Consequently, one might expect a better profitability for industrial boilers than for municipal boilers.

10. Conclusions

A long-term test concerning three-way-catalysis in gas-fired boilers has been concluded. The technical outcome of study very well agree with the expectations. The conversion level with respect to NO_X ranged from 90 to 70%, depending on the load-situation, i.e. very close to the forecasted values. The conversion levels with respect to CO were somewhat lower than expected, which can be explained through by-pass effects.

There were no evidences of deactivation of the three-way-catalyst during the course of the long-term-test (1500 hours of continuos operation). The performance of the oxidation catalyst, however, declined somewhat during the long-term-test. This effect is associated with increased by-pass-effects since the alignment of the catalyst to the walls was destroyed by the thermo-mechanical impact. It is normally easier to achieve a perfect alignment of the catalyst to the walls in large-scale-units.

An economic evaluation of the twc-concept indicate typical pay-off-times of 2 - 3 years. In the pre-design-work it is essential to evaluate the following parameters:

- NO_x-emission (mg/MJ)
- annual energy production (GWh/yr.)
- Unit-size (MW_t)
- Current catalyst price
- Life-time of the catalyst

Even if the lambda-value-control was performed manually in this study, it is rather easy to automatize it. No corrosion problems are expected in gas-fired appliances. Corrosion problems might, however, be expected when fuels giving rise to corrosive flue gases are combusted, i.e. sulphur-containing oil, coal, bio-fuels etc. Corrosion is then most likely to occur in zones with high metal temperatures (i.e. in the in super-heater region).

The outcome of the study can be expressed in the following items:

- High conversion level with respect to NO_x possible
- By-pass effects might be a problem in some installations.
- High catalyst durability, no effects of catalysts deactivation during 1500 hours of operation
- Simple and straightforward installation
- Good profitability of the installation in many cases

Full-scale-tests are underway during the autumn of 1999 and commercialisation is expected during next few years.

11. Literature

1. F.A. Silversand, "Utveckling av katalytisk rening av avgaser från befintlig panna", SGC rapport 087, Svenskt Gastekniskt Center AB, Malmö, 1997

2. A.K. Hjalmarsson och K. Hedin, "Installationer av NOx-reducerande åtgärder", Värmeforsk rapport nr. 560, Stiftelsen för Värmeteknisk forskning, Stockholm, 1996.

Appendix A

Independent emission review performed by EMK AB

Load-situation	Thermal effect (kW_t)	Reduction degree of NO_x (%)
0	600	83
2	900	79
4	1200	84
8	1500	76

Rapport

NO_x-mätningar naturgaspanna vid Katator AB:s testanläggning Malmö

Utgåva 1
Onr IJ176

SWEDAC ACKREDITERING
1263
EN 45 001

Malmö 1999-06-30
EMK Energi Miljö Konsult AB

Mattias Johansson
Fältansvarig

Carl-G Kronström
Kvalitetsansvarig

EMK

Energi Miljö Konsult AB

Skrittgatan 8 A · 213 77 Malmö · Tel 040-94 04 00 · Fax 040-21 50 60 · E-post info@emk.se

Beställare	Katator AB Fredrik Silversand Ideon 223 70 LUND
Uppdrag	NO_x-mätning vid Nobelvägen i Malmö
Onr	IJ176
Utgåva	1
Bilagor	1 Provtagnings- och beräkningsmetoder 2 Provtagningsresultat, diagram

ÄRENDE

Katator AB utvecklar bland annat en katalysator för att reducera NO_x efter naturgaseldade pannor. Företaget har gjort interna mätningar liknande de som behandlas i rapporten. För att verifiera att företagets mätningar beslöt man att låta ett oberoende mätlaboratorium utföra NO_x-mätningar.

Provtagningarna utfördes av Mattias Johansson, EMK AB, under vecka 925.

ANLÄGGNING

Katator AB har en testanläggning vilken är placerad på Malmö Värme AB:s område vid Nobelvägen i Malmö.

Anläggningen består av en treстråkseldad naturgaspanna av fabrikat Remeha typ OD15B med en tillhörande brännare av fabrikat Dunphy. Pannan har försetts med en katalysator från Katator.

Katalysatorn bygger på ett speciell metallnätskonstruktion som rökgaserna passerar i pannans stråk.

EMK 93:24

PROVTAGNING

Mätningar har utförts vid mätuttag placerat i rökgasstråk 2 före oxidationskatalysatorn.

Mätningar har utförts vid driftläge 0, 2, 4 och 8. För varje driftläge har, förutom normalt driftläge, även extra primärluft och primärgas tillsatts.

Mätresultatet för de olika driftfallen framgår tydligt av bilaga 2.

Provtagnings- och beräkningsmetoder framgår av bilaga 1.

ACKREDITERING

EMK AB är ackrediterat för provtagningsmetoden.

Laboratorier ackrediterade av SWEDAC för provning och kalibrering uppfyller minst kraven i SS-EN 45001 och ISO/IEC Guide 25, vilket innebär att dessa laboratorier enligt ISO/IEC Guide 25:1990(E) i sin ackrediterade verksamhet också uppfyller de i sammanhanget relevanta kraven i SS-ISO 9002.

PROVTAGNINGS- OCH BERÄKNINGSMETODER

Provtagningsmetoder ackrediterade av SWEDAC. Vårt ackrediteringsnummer är 1263.

NO_x-halt

Ett delgasflöde utsugs, torkas och filtreras varefter gasen späds i en sond med ett EPM-utspädnings-system. NO_x analyseras i en Thermo Environmental 42 som halten i torra gaser. Totala onoggrannheten är mindre än ±3.0 procent av registrerat värde.

Metod enligt SNV:s Allmänna Råd 98:1, Svensk Standard SS 02 84 25 och Värmeforsks mäthandbok kapitel 4.1.

Dataloggning

För mätvärdesinsamling används en Intab AAC-2 och en bärbar dator. Mätsekvenser har valts till en mätvärdesinsamling var femte sekund. Toleranserna för dataloggern är inkluderade i ovan nämnda instruments specifikationer.

Laboratorier ackrediterade av SWEDAC för provning och kalibrering uppfyller minst kraven i SS-EN 45001 och ISO/IEC Guide 25, vilket innebär att dessa laboratorier enligt ISO/IEC Guide 25:1990(E) i sin ackrediterade verksamhet också uppfyller de i sammanhanget relevanta kraven i SS-ISO 9002.

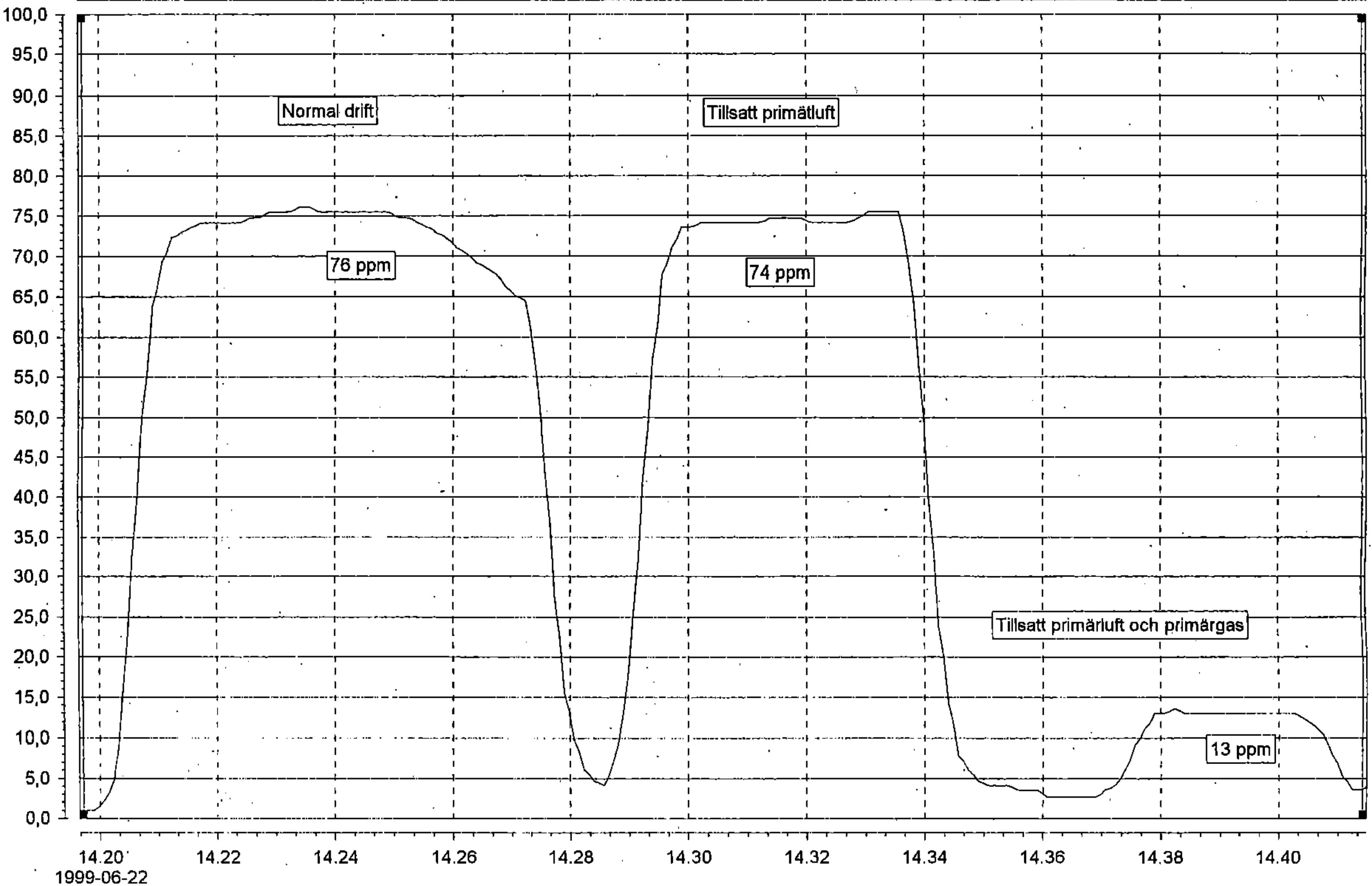
1999-06-30 MJ/UK

EMK Energi Miljö Konsult i Malmö AB, Skrittgatan 8 A, 213 77 Malmö
Tel 040-94 04 00 Fax 040-21 50 60 E-post info@emk.se
Organisationsnummer 556221-6779. Säte Malmö

	Färg	Enhet	Kommentar
G01		ppm tg	NOx-halt

Driftläge 0 (IJ176)

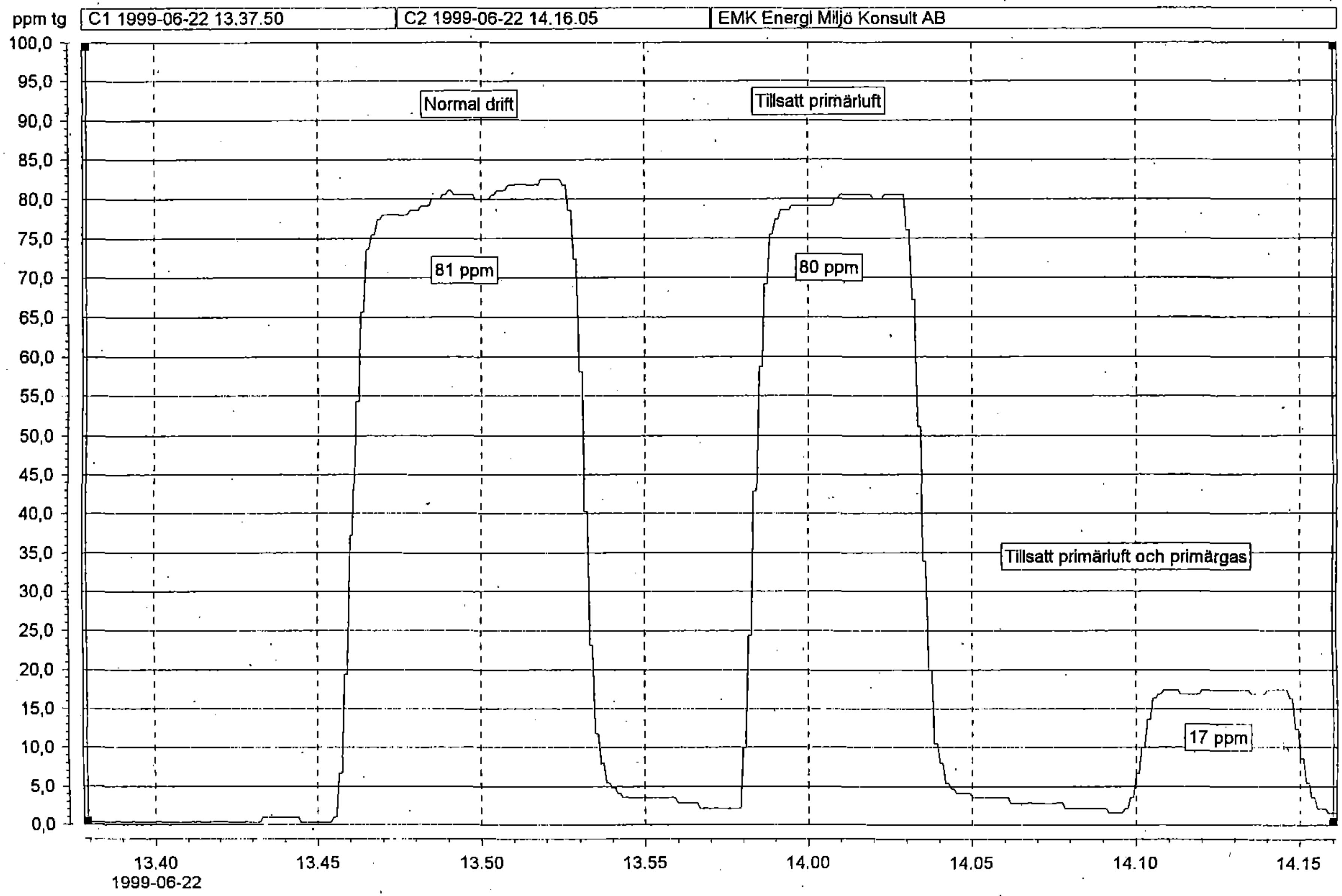
ppm tg	C1 1999-06-22 14.19.39	C2 1999-06-22 14.41.27	EMK Energi Miljö Konsult AB



Energi Miljö Konsult AB

	Färg	Enhet	Kommentar
G01		ppm tg	NOx-halt

Driftläge 2 (IJ176)



Energi Miljö Konsult AB

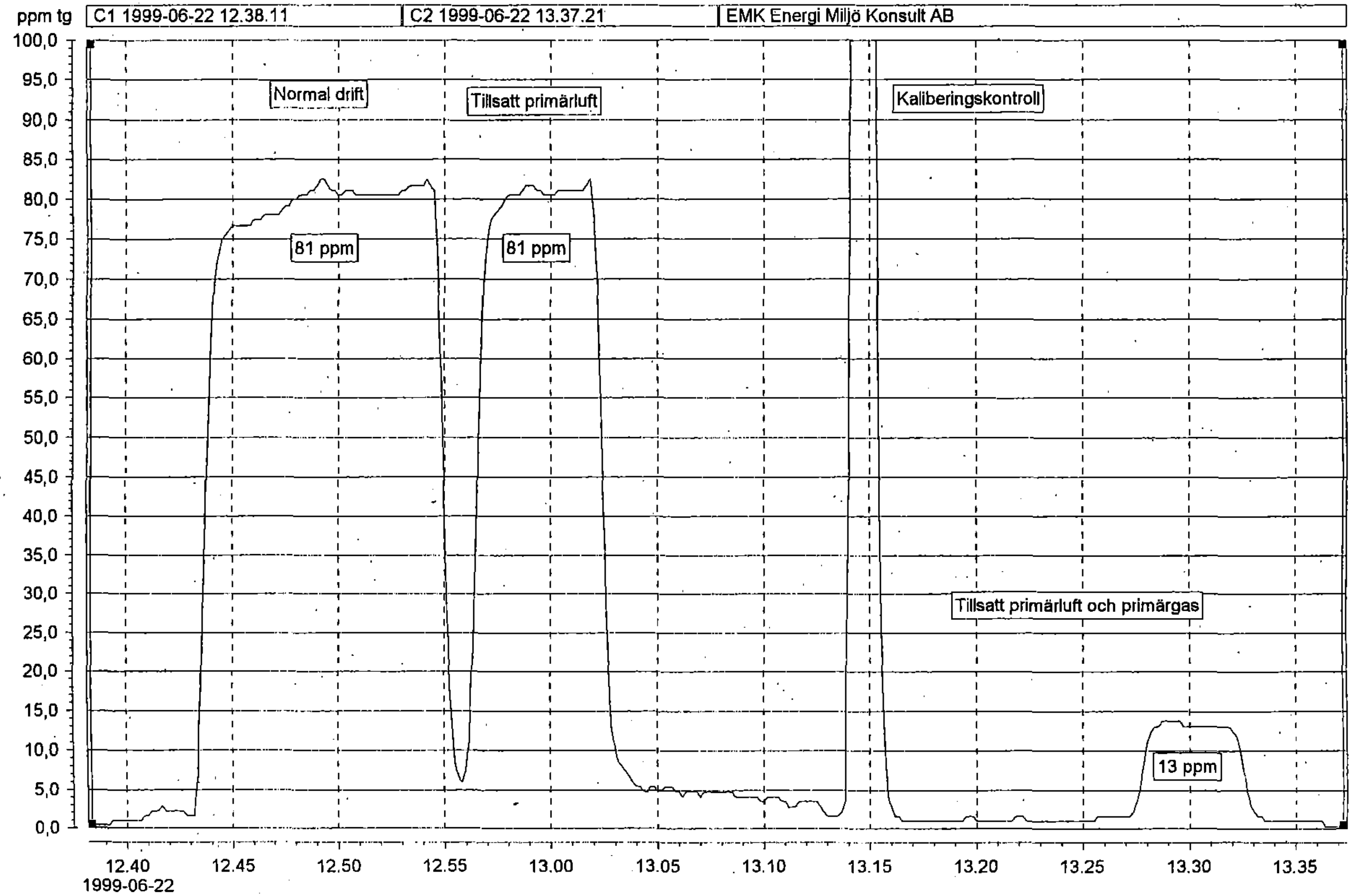
EMK

BILAGA 2
Utgåva 1

Sid 2 (4)
Onr IJ176

	Färg	Enhet	Kommentar
G01		ppm tg	NOx-halt

Driftläge 4 (IJ176)



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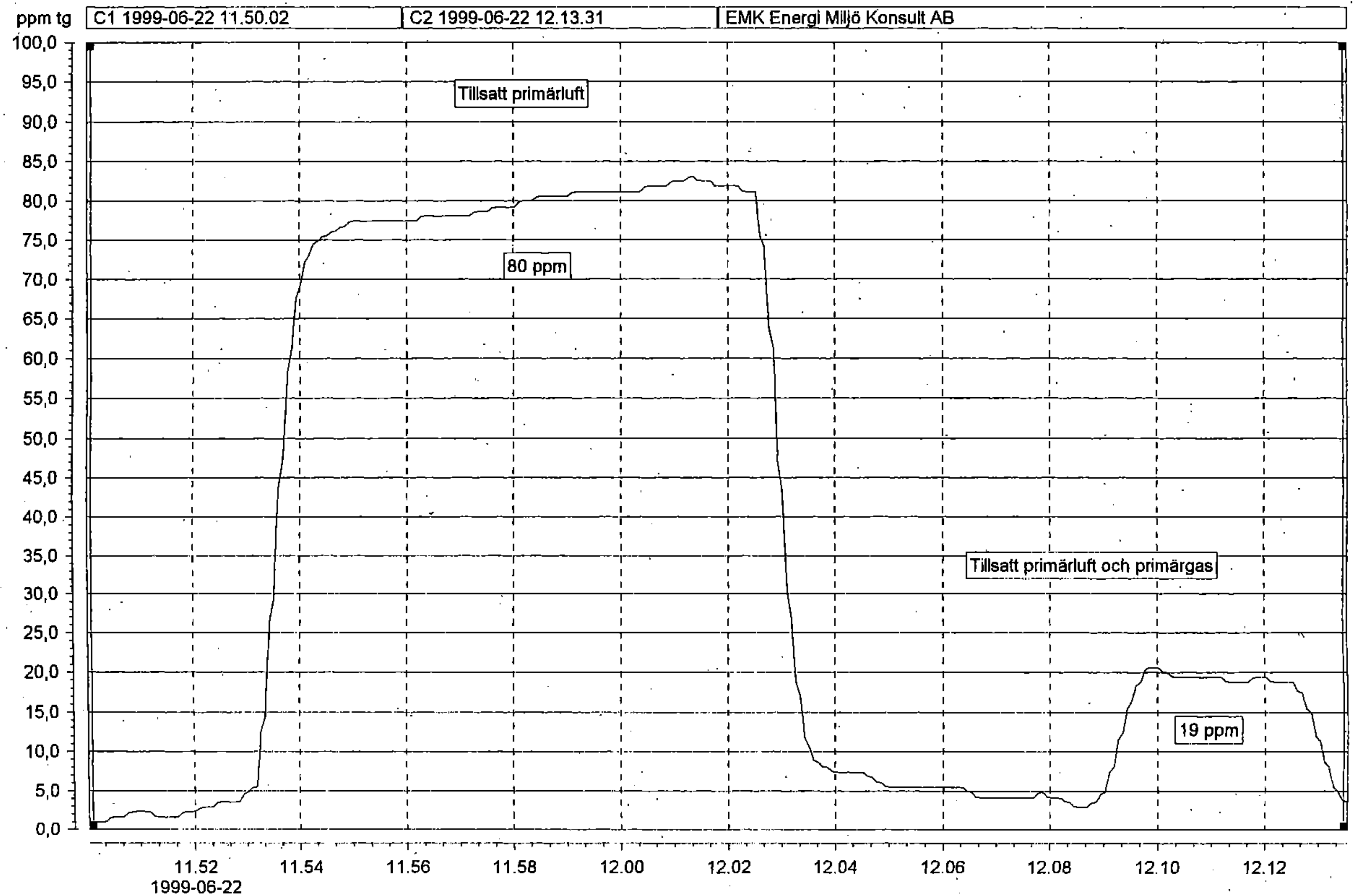
EMK

	Färg	Enhet	Kommentar
G01		ppm tg	NOx-halt

Driftläge 8 (IJ176)



Energi Miljö Konsult AB

EMK

99-12-27

RAPPORTFÖRTECKNING

SGC Nr	Rapportnamn	Rapport datum	Författare	Pris kr
001	Systemoptimering vad avser ledningstryck	Apr 91	Stefan Grudén TUMAB	100
002	Mikrokraftvärmeverk för växthus. Utvärdering	Apr 91	Roy Ericsson Kjessler & Mannerstråle AB	100
004	Krav på material vid kringfyllnad av PE -gasledningar	Apr 91	Jan Molin VBB VIAK	50
005	Teknikstatus och marknadsläge för gasbaserad minikraftvärme	Apr 91	Per-Arne Persson SGC	150
006	Keramisk fiberbrännare - Utvärdering av en demo-anläggning	Jan 93	R Brodin, P Carlsson Sydkraft Konsult AB	100
007	Gas-IR teknik inom industrin. Användnings- områden, översiktlig marknadsanalys	Aug 91	Thomas Ehrstedt Sydkraft Konsult AB	100
009	Läcksökning av gasledningar. Metoder och instrument	Dec 91	Charlotte Rehn Sydkraft Konsult AB	100
010	Konvertering av aluminiumsmältugnar. Förstudie	Sep 91	Ola Hall, Charlotte Rehn Sydkraft Konsult AB	100
011	Integrerad naturgasanvändning i tvätterier. Konvertering av torktumlare	Sep 91	Ola Hall Sydkraft Konsult AB	100
012	Odöranter och gasolkondensats påverkan på gasrörsystem av polyeten	Okt 91	Stefan Grudén, F. Varmedal TUMAB	100
013	Spektralfördelning och verkningsgrad för gaseldade IR-strålare	Okt 91	Michael Johansson Drifttekniska Inst. vid LTH	150
014	Modern gasteknik i galvaniseringsindustri	Nov 91	John Danelius Vattenfall Energisystem AB	100
015	Naturgasdrivna truckar	Dec 91	Åsa Marbe Sydkraft Konsult AB	100
016	Mätning av energiförbrukning och emissioner före o efter övergång till naturgas	Mar 92	Kjell Wanselius KW Energiprodukter AB	50
017	Analys och förslag till handlingsprogram för området industriell vätskevärmning	Dec 91	Rolf Christensen ÅF-Energikonsult Syd AB	100
018	Skärning med acetylen och naturgas. En jämförelse.	Apr 92	Åsa Marbe Sydkraft Konsult AB	100

99-12-27

RAPPORTFÖRTECKNING

SGC Nr	Rapportnamn	Rapport datum	Författare	Pris kr
019	Läggning av gasledning med plöjteknik vid Glostorp, Malmö. Uppföljningsprojekt	Maj 92	Fallsvik J, Haglund H m fl SGI och Malmö Energi AB	100
020	Emissionsdestruktion. Analys och förslag till handlingsprogram	Jun 92	Thomas Ehrstedt Sydkraft Konsult AB	150
021	Ny läggningsteknik för PE-ledningar. Förstudie	Jun 92	Ove Ribberström Ove Ribberström Projekt. AB	150
022	Katalog över gastekniska FUD-projekt i Sverige. Utgåva 4	Aug 92	Svenskt Gastekniskt Center	150
023	Läggning av gasledning med plöjteknik vid Lillhagen, Göteborg. Uppföljningsproj.	Aug 92	Nils Granstrand m fl Göteborg Energi AB	150
024	Stumsvetsning och elektromuffsvetsning av PE-ledningar. Kostnadsaspekter.	Aug 92	Stefan Grudén TUMAB	150
025	Papperstorkning med gas-IR. Sammanfattning av ett antal FUD-projekt	Sep 92	Per-Arne Persson Svenskt Gastekniskt Center	100
026	Koldioxidgödsling i växthus med hjälp av naturgas. Handbok och tillämpn.exempel	Aug 92	Stig Arne Molén m fl	150
027	Decentraliserad användning av gas för vätskevärmning. Två praktikfall	Okt 92	Rolf Christensen ÅF-Energikonsult	150
028	Stora gasledningar av PE. Teknisk och ekonomisk studie.	Okt 92	Lars-Erik Andersson, Åke Carlsson, Sydkraft Konsult	150
029	Catalogue of Gas Techn Research and Development Projects in Sweden (På engelska)	Sep 92	Swedish Gas Technology Center	150
030	Pulsationspanna. Utvärdering av en demo -anläggning	Nov 92	Per Carlsson, Åsa Marbe Sydkraft Konsult AB	150
031	Detektion av dräneringsrör. Testmätning med magnetisk gradiometri	Nov 92	Carl-Axel Triumf Triumf Geophysics AB	100
032	Systemverkn.grad efter konvertering av vattenburen elvärme t gasvärme i småhus	Jan 93	Jonas Forsman Vattenfall Energisystem AB	150
033	Energiuppföljning av gaseldad panncentral i kvarteret Malörten, Trelleborg	Jan 93	Theodor Blom Sydkraft AB	150
034	Utvärdering av propanexponerade PEM-rör	Maj 93	Hans Leijström Studsvik AB	150

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RAPPORTFÖRTECKNING

SGC Nr	Rapportnamn	Rapport datum	Författare	Pris kr
035	Hemmatankning av naturgasdriven personbil. Demonstrationsprojekt	Jun 93	Tove Ekeborg Vattenfall Energisystem	150
036	Gaseldade genomströmningsberedare för tappvarmvatten i småhus. Litteraturstudie	Jun 93	Jonas Forsman Vattenfall Energisystem	150
037	Verifiering av dimensioneringsmetoder för distributionsledningar. Litt studie.	Jun 93	Thomas Ehrstedt Sydkraft Konsult AB	150
038	NOx-reduktion genom reburning med naturgas. Fullskaleförsök vid SYSAV i Malmö	Aug 93	Jan Bergström Miljökonsulterna	150
039	Pulserande förbränning för torkändamål	Sep 93	Sten Hermodsson Lunds Tekniska Högskola	150
040	Organisationer med koppling till gasteknisk utvecklingsverksamhet	Feb 94	Jörgen Thunell SGC	150
041	Fältsortering av fyllnadsmassor vid läggning av PE-rör med läggningsbox.	Nov 93	Göran Lustig Elektro Sandberg Kraft AB	150
042	Deponigasens påverkan på polyetenrör.	Nov 93	Thomas Ehrstedt Sydkraft Konsult AB	150
043	Gasanvändning inom plastindustrin, handlingsplan	Nov 93	Thomas Ehrstedt Sydkraft Konsult AB	150
044	PA 11 som material ledningar för gasdistribution.	Dec 93	Thomas Ehrstedt Sydkraft Konsult AB	150
045	Metoder att höja verkningsgraden vid avgaskondensering	Dec 93	Kjell Wanselius KW Energiprodukter AB	150
046	Gasanvändning i målerier	Dec 93	Charlotte Rehn et al Sydkraft Konsult AB	150
047	Rekuperativ aluminiumsmältugn. Utvärdering av degelugn på Värnamo Pressgjuteri.	Okt 93	Ola Hall Sydkraft Konsult AB	150
048	Konvertering av dieseldrivna reservkraftverk till gasdrift och kraftvärmeprod	Jan 94	Gunnar Sandström Sydkraft Konsult AB	150
049	Utvecklad teknik för gasinstallationer i småhus	Feb 94	P Kastensson, S Ivarsson Sydgas AB	150
050	Korrosion i flexibla rostfria insatsrör (Finns även i engelsk upplaga)	Dec 93	Ulf Nilsson m fl LTH	150

99-12-27

RAPPORTFÖRTECKNING

SGC Nr	Rapportnamn	Rapport datum	Författare	Pris kr
051	Nordiska Degelugnsprojektet. Pilot- och fältförsök med gasanvändning.	Nov 93	Eva-Maria Svensson Glafo	150
052	Nordic Gas Technology R&D Workshop. April 20, 1994. Proceedings.(På engelska)	Jun 94	Jörgen Thunell, Editor Swedish Gas Center	150
053	Tryckhöjande utrustning för gas vid metallbearbetning -- En förstudie av GT -PAK	Apr 94	Mårten Wärnö MGT Teknik AB	150
054	NOx-reduktion genom injicering av naturgas i kombination med ureainsprutning	Sep 94	Bent Karll, DGC P Å Gustafsson, Miljökons.	100
055	Trevägskatalysatorer för stationära gasmotorer.	Okt 94	Torbjörn Karlelid m fl Sydkraft Konsult AB	150
056	Utvärdering av en industriell gaseldad IR -strålare	Nov 94	Johansson, M m fl Lunds Tekniska Högskola	150
057	Läckagedetekteringssystem i storskaliga gasinstallationer	Dec 94	Fredrik A Silversand Katator AB	150
058	Demonstration av låg-NOx-brännare i växthus	Feb 95	B Karll, B T Nielsen Dansk Gasteknisk Center	150
059	Marknadspotential naturgaseldade industriella IR-strålare	Apr 95	Rolf Christensen Enerkon RC	150
060	Rekommendationer vid val av flexibla insatsrör av rostfritt i villaskorstenar	Maj 95	L Hedeen, G Björklund Sydgas AB	50
061	Polyamidrör för distribution av gasol i gasfas. Kunskapssammanställning	Jul 95	Tomas Tränkner Studsvik Material AB	150
062	PE-rörs tålighet mot yttre påverkan. Sammanställning av utförda praktiska försök	Aug 95	Tomas Tränkner Studsvik Material AB	150
063	Naturgas på hjul. Förutsättningar för en storskalig satsning på NGV i Sverige	Aug 95	Naturgasbolagens NGV- grupp	150
064	Energieffektivisering av större gaseldade pannanläggningar. Handbok	Aug 95	Lars Frederiksen Dansk Gasteknisk Center	200
065	Förbättra miljön med gasdrivna fordon	Aug 95	Göteborg Energi AB	150
066	Konvertering av oljeeldade panncentraler till naturgas. Handbok.	Nov 95	Bo Cederholm Sydkraft Konsult AB	150

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SGC Nr	Rapportnamn	Rapport datum	Författare	Pris kr
067	Naturgasmodellen. Manual för SMHI:s program för beräkn av skorstenshöjder	Dec 95	Tingnert B, SKKB Thunell J, SGC	150
068	Energigas och oxyfuelteknik	Dec 95	Ingemar Gunnarsson Energi-Analys AB	150
069	CO2-gödsling med avgaser från gasmotor med katalysator	Dec 95	Bent Karll Dansk Gasteknisk Center	150
070	Utvärdering av naturgasförbränning i porösa bäddar	Mar 96	Henric Larsson Lunds Tekniska Högskola	150
071	Utvärdering av naturgasdrivna IR-boostrar i ugn för pulverlackering	Nov 95	Ole H Madsen Asger N Myken	150
072	Sammanställning av emissionsdata från naturgas-, biogas- o motorgasdrivna fordon	Jun 96	Hans-Åke Maltesson Svenskt Gastekniskt Center AB	150
073	Livslängdsbestämning för PE-rör för gasdistribution (EVOPE-projektet)	Jul 96	Tomas Tränkner Studsvik Material AB	100
074	Gasblandningar för fordonsdrift. Idéstudie.	Aug 96	Ola Hall Sydkraft Konsult AB	150
075	Gasbranschens miljöhandbok	Sep 96	Jörgen Thunell Svenskt Gastekniskt Center	500
076	Låg-NOx-teknik för gasdrivna processer - dagsläge	Okt 96	Mikael Näslund, LTH Inst.Värme- och Kraftteknik, LTH	150
077	Karakterisering av emissioner från naturgasdrivna lastbilar inom LB 50 -projektet	Dec 96	K-E Egebäck Roger Westerholm	150
078	Uppvärmning med gas i svenska småhus - erfarenheter och framtida teknikval	Nov 96	Mikael Näslund, LTH	150
079	Handledn. för inst av gaseldade IR -värmare. Rådgivning, analys och genomförande	Apr 97	Pär Dalin DITAB	150
080	Mikrokraftvärmeverk med Stirlingmotor	Jan 97	Tomas Nilsson Lunds Tekniska Högskola	150
081	Naturgasbaserad småskalig kraftvärme inom uppvärmningssektorn	Feb 97	Mats Nilsson LTH/MALMÖ	150
082	Kylning och klimatisering av byggnader och lokaler med hjälp av naturgas	Apr 97	Anders Lindkvist Vattenfall Energisystem	150

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083	Naturgassystemet i Sverige - en teknisk beskrivning	Jun 97	Ronny Nilsson, KM	150
084	Livscykelanalyser - Är det något för gasbranschen	Sep 97	Jörgen Thunell	150
085	Konvertering av direktelvärmda småhus till naturgasuppvärmning	Dec 97	Mikael Näslund Inst Värme- och Kraftteknik, LTH	150
086	Uppgradering av biogas . Fas 2, Praktiska försök med kondenseringsmetoder.	Jun 97	Ola Lloyd / BioMil AB Johan Nilsson / LTH	150
087	Utveckling av katatalytisk rening av avgaser från befintlig panna	Dec 97	F Silversand, T Hargitai m fl Katator AB	150
088	Technical Description of the Swedish Natural Gas Distr System (På Engelska)	Jun 97	Ronny Nilsson, KM	150
089	Rening av avgaser från en naturgasdriven lean burn motor i en förbr.växlare	Okt 97	Björn Heed Inst för Energiteknik, CTH	150
090	Utsläpp av oreglerade ämnen vid förbränning av olika bränslen	Jun 98	Jörgen Thunell	150
091	Nya metoder för att säkerställa mätnoggrannheten i naturgasnät	Nov 97	Ulf R C Nilsson Luleå TH, Inst Systemteknik	150
092	LB30-projektet - Introduktion av naturgasdrivna tyngre lastbilar	Jan 99	Owe Jönsson Svenskt Gastekniskt Center	150
093	Karaktärisering av emissioner från naturgasdrivna lastbilar inom LB50 -projektet	Sep 98	Karl Erik Egebäck	150
094	Gasdistribution och avgasinstallation i byggnader	Jan 99	Hans Christian Thiis Per Palm	150
095	Karaktärisering av emissioner från naturgasdrivna lastbilar inom LB50 -projektet	Okt 98	Karl Erik Egebäck	150
096	Lifetime of PE-pipes subjected to squeeze off	Nov 98	Tomas Tränkner	150
097	Svensk högskoleförlagd energigasforskning Nutid och framtid	Jan 99	Mikael Näslund, LTH Owe Jönsson, SGC	150
098	Metoder för snabb kvalitetskontroll av PE -rör för gasdistribution	Apr 99	Tomas Tränkner	150

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099	Gas co-firing for NOx-reduction in coal fired boilers	Apr 99	Fredrik Brogaard	200
100	Optimerad samrötning av restprodukter från stad och land	Apr 99	A Dahl, M Linné, L Andersson	150
101	Distribution av biogas i naturgasnät	Jul 99	Kaj Vågdahl	100
102	Evaluation of the efficiency face to the NOx -emissions from European plants	990901	M J Fourniguet, A Quinqueneau, B Karll, P Breithaupt, O Jonsson	150
103	Uppföljning av kvalitetsspecifikation för uppgraderad biogas som fordonsbränsle	Okt 99	Anders Dahl	150
104	Evaluation of three-way-catalysis for NOx -abatement in large gas-fired appliance	Jan 00	Fredrik Silversand	150
A01	Fordonstankstation Naturgas. Parallellkoppling av 4 st Fuel Makers	Feb 95	Per Carlsson Göteborg Energi AB	50
A02	Uppföljning av gaseldade luftvärmare vid Arlövs Sockerraffinaderi	Jul 95	Rolf Christensen Enercon RC	50
A03	Gasanvändning för färjedrift. Förstudie (Endast för internt bruk)	Jul 95	Gunnar Sandström Sydkraft Konsult	0
A04	Bussbuller. Förslag till mätprogram	Jun 95	Ingemar Carlsson Ecotrans Teknik AB	50
A05	Värmning av vätskor med naturgas - Bakgrund till faktablad	Okt 95	Rolf Christensen Enerkon RC	50
A06	Isbildning i naturgasbussar och CNG -system (Endast för internt bruk)	Nov 95	Volvo Aero Turbines Sydgas, SGC	0
A07	Större keramisk fiberbrännare. Förstudie	Jan 96	Per Carlsson Sydkraft Konsult AB	50
A08	Reduktion av dioxin, furan- och klorfenoler vid avfallsförbränning	Maj 96	H Palmén, M Lampinen et al Helsingfors Tekniska Högskola	50
A09	Naturgas/mikrovågsteknik för sintring av keramer	Maj 96	Anders Röstin KTH	50
A10	NOx-reduktion genom naturgasinjektion o reburning. Demoprojekt på Knudmoseverket	Apr 96	Jan Flensted Poulsen Völund R & D Center	50

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A11	Direkttorkning av socker med naturgas (Endast för internt bruk)	Jul 96	Rolf Christensen Enerkon RC	0
A12	Uppföljning, installation av gaspanna med avgaskondensor, kv Hornblåsaren 6, Råå	Sep 96	Bo Cederholm Sydkraft Konsult AB	50
A13	Klassningsplaner för gasinstallationer	Jun 97	Carl-Axel Stenberg Greger Arnesson	50
A14	Uppf av drift med natugaseldad kondenserande gaspanna i Rinnebäcksskolan	Okt 97	Bo Cederholm Sydkraft Konsult AB	50
A15	Undersökn o förstärkn av korr.skyddet på gasrör förl i skyddsrör - Delrapport 1	Nov 97	Åsa Marbe, C Johansson Sydkraft Konsult AB	100
A16	Ind - CO2-härdning av betong med naturgas	Feb 98	Åsa Marbe Sydkraft Konsult AB	50
A17	Reservförsörjning med fordonstransporterad LNG	Dec 97	Stig Johansen	50
A18	Emissions- och immissionsmätning vid en naturgaseldad villapanna	Mar 97	David Cooper IVL	50
A19	Katalytisk rening av gaseldade lean -burnmotorer etapp 1 - teoretisk förstudie	Aug98	Fredrik Silversand Katator	100
A20	Europeisk livscykelinventering för naturgas (endast för internt bruk)	Sep 98	Jörgen Thunell	0
A21	Naturgasdrivna järnvägsfordon - Förstudie	Dec 98	Rolf Öberg	100
A22	Catalytic abatement of CO- and UHC -emissions from Gas Fuelled Engines	Feb99	Fredrik Silversand	100
A23	Förläggning av gasrör av polyeten i befintliga massor	Mar 99	Gunnar Bergström Stefan Nilsson	100

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