Rapport SGC 132

EVALUATION OF A NEW TYPE OF CATALYTIC IR-RADIATOR

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FOREWORD

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Conclusions

The subject of this project was to test the new kind of catalytic net, which can be used in the radiant burners. Two main configurations were investigated in the project: the SUNKISS burner, where the combustion takes place in the fiber catalysts and the Catator burner with the catalytic nets. The fiber catalysts require a special system of secondary air flow to avoid too high temperatures inside the catalysts material during combustion. This solution seems to be not adequate for the catalytic net where the combustion of the premix (gas and air mixture) is more suitable. During the experiments with this material higher emissions of CO and VOC were measured which means that the combustion was not complete. Due to this fact also the radiation efficiency was lower than in the case of SUNKISS catalysts (about 20 %). The experiments conducted for the decreasing area of the fan inlet, suggest that the catalytic net has a potential to work satisfactory without the secondary air flow and the future work should focus on this issue.

Tested catalysts materials offer great possibility for highly efficient devices and even now their radiation efficiencies (45 – 65 %) are higher than the reported efficiencies of catalytic radiant burners (26 - 40 %, (Howell et al., 1996)) and the classical gas radiant burners (30 – 40 %, (Petterson, 1999)).

It is believed that the lower radiation efficiencies and the higher emissions can be eliminated with a design where a pre-mix of air and gas is fed to the catalytic burner. Both Sunkiss and Catator are positive to a further development of the new design in order to develop it into a commercial design which can replace existing but also can be used for new process applications.

The power levels for the new design using the Catator net range between 20 and 300 kW/m^2 which enables the application of this design both for low energy transfer applications such as painting and lacquering, as well as for high energy transfer applications such as in the drying of coated papers.

The future development should focus on the following topics:

- replace the secondary air system with a design using a pre-mix of air and gas. Determine the most suitable excess air ratio for the unit.
- enable even gas distribution over the whole burner surface.
- enable easy and quick start up and shut down of the unit.
- make sure that security is maintained at the required level.
- investigate what size and power levels are most suitable for the design depending on the different process applications.

List of contents

1 INTRODUCTION

The aim of this project was to investigate the possibility to use the wire mesh based catalyst developed by Catator in Lund in IR-burners. Catalytic burners are very attractive and have potential to enhance the efficiency of heat transfer and reduce the environmental impact due to pollutant emissions: the greenhouse gas CO_2, the toxic gases CO and NO_x and unburned hydrocarbons HC. These burners have to find applications in the lacquering and painting industries to dry and cure powder paints and in the food industry. The most common elements in these dryers are burners emitting infrared radiation from a surface at 800-1000°C to a painted surface.

The most important advantages compared to other types of dryers are the high heat fluxes (100-400 kW/m^2) and that the heat transfer is performed without contact with a hot surface. Some disadvantages for this kind of dryers are the low energy efficiencies (typically between 30-40 %) and that the spectral distribution of the radiation does not match the wavelengths where the product has a high absorptivity.

In the catalytic burners combustion of natural gas or propane takes place in a porous bed impregnated with some catalyst. The fuel is oxidized at lower temperature resulting in lower emissions of NO_x.

The difference between the burner developed in this project compared to traditional constructions is that the combustion is performed over a thin net coated with a catalytic material. This design should offer the following advantages:

a) Larger range over which the power can be controlled. Normally a range of 1:3 is achieved while this new type of dryer could be expected to operate over the range 1:10.
b) The oxidation occurs over a thin net with a very low-pressure drop. This will be an important feature in new future designs.
c) The amount of mass in the net is much lower compared with traditional designs, which results in a very fast dynamics for the radiator. This will be important for a rapid starting up and closing down of the unit limiting the risk for fire hazards.
d) A lower temperature in the unit results in lower emissions of NO_x.
e) Larger fuel flexibility for all gas fuels.
f) Fewer problems with clogging of pores resulting in more even distribution of the gas-mixture and thus also even combustion over the surface of the burner.

The project goal is to test the principles, determine some key-parameters which can be compared with existing designs and evaluate for which applications this kind of design is best suited. The participants in the project are the Department of Chemical Engineering I, Lund Institute of Technology, Catator AB in Lund and SUNKISS in Lyon.

Measurements have been performed for the existing Sunkiss design and the new design both by Lund Institute of Technology, in the Catator laboratory and by SUNKISS in their laboratories in Lyon.

2 EVALUATION OF THE SUNKISS BURNER EQUIPPED WITH SUNKISS FIBER PAD CATALYST

In the first stage of the project the RX 500 Thermoreactor® – catalytic IR-burner from SUNKISS was tested to measure the radiation efficiency, emissions and pressure drop. The burner operates normally in the range of 5.1 to 11.1 kW and its emitting area is 50x50 cm. The burner consists of a few layers of insulation and fiber catalysts and all layers are 1 cm thick (Figure 1).

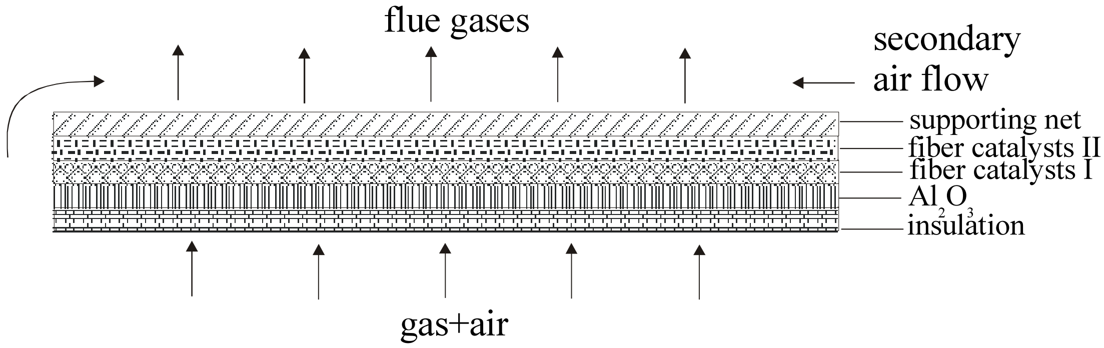

Figure 1. Insulation and fiber catalysts layers in the SUNKISS burner

Detailed SUNKISS burner design is presented in the figures below. The first layer is the wool insulation (Figure 2).

Figure 2. Insulation layer in the burner

The catalytic combustion of the natural gas takes place in the refractory panel. The panel consists of two layers of the refractory fibers in which particles of platinum-based catalysts are distributed (Figure 3). The catalysts initiate and accelerate the natural gas catalytic combustion, which heats the refractory panel without a visible flame to 550-700°C. The outer layer is a supporting net which protects the catalyst material against falling down from the panel (Figure 4).

Figure 3. Fiber catalysts

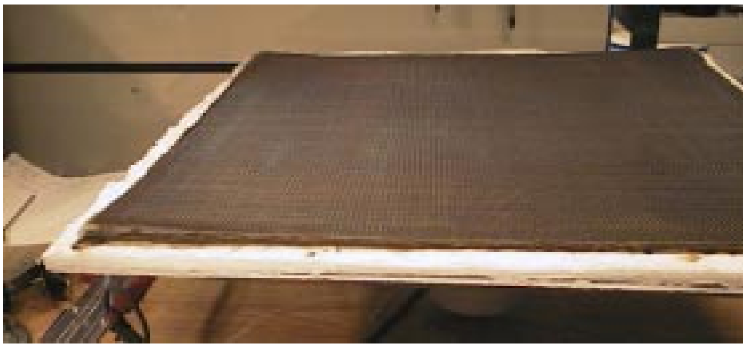

Figure 4. Supporting net

In this burner a venturi mixing tube is used to provide a partial premix of air and gas, which flows from the premixing chamber through the refractory panel. The premix is air-deficient (20-30% gas). A choke solenoid is used for 1 minute at the start of the catalytic combustion to enrich the mixture with gas. The fan blows the secondary air against the radiating surface of the panel, which diffuses through the mass of the refractory panel and meets the partial premix and contributes to the catalytic oxidation of the natural gas. The burner operates as follows:

1. A preheating resistor element heats the panel to around 400^{o}C during 10 minutes.
2. The gas solenoid valve and the choke solenoid valve open simultaneously and the operating temperature is rapidly attained by the catalytic combustion of the gas.
3. The fan starts and delivers the secondary air to the surface of the refractory panel. The burner is operating under steady conditions. From this moment it is possible to work with the inlet gas pressure in the range between 30 and 140 mbar.

3 RESULTS

During the experiments the burner was operated in the range between 40 and 140 mbar, that is equivalent to 6.6-12.4 kW of gas power (Danish natural gas)? The radiation efficiency, emissions in the flue gases and the pressure drop were measured in the burner. The efficiency measurements were conducted using the calorimetric method. The water-bath was built and the thermocouples were installed at the inlet and outlet of the bath (Figure 5). The water-bath was painted black, so all radiation from the burner was absorbed inside of it. The water-bath could be placed near the burner surface, because its set-up was mobile and the distance between burner – water-bath was easy to adjust.

Figure 5. Water-bath used for efficiency measurements

This bath was installed below the burner inside the chamber where the flue gases were collected and then transmitted to the chimney (Figure 6). The side-walls of the chamber were easy to remove, so it was possible to e.g. change the distance between the burner and the bath.

Figure 6. Water-bath in the flue gas-collecting chamber

Finally the burner was placed on the top of the chamber in the horizontal position and the burner-emitting surface was facing the water-bath. The area of water-bath was slightly higher than the burner area to catch all radiation emitted by the burner. The experimental set-up is shown in the Figure 7. Hoses delivered water to and from the water-bath. The water flow was controlled by the flow meter and was kept on high enough level (around 0.15 kg/s) to hold the constant water highness (5-6 cm) inside the bath and achieve moderate water temperature increase between 5 to 12 degrees.

Figure 7. Experimental installation

The water flow and temperatures were measured and the amount of heat used to warm the water in the bath was the scale of the burner efficiency. During these experiments water-bath was placed 1 cm below the burner and the distance between the water surface and the burner-emitting surface was 4.5 cm. The results are presented in Figure 8.

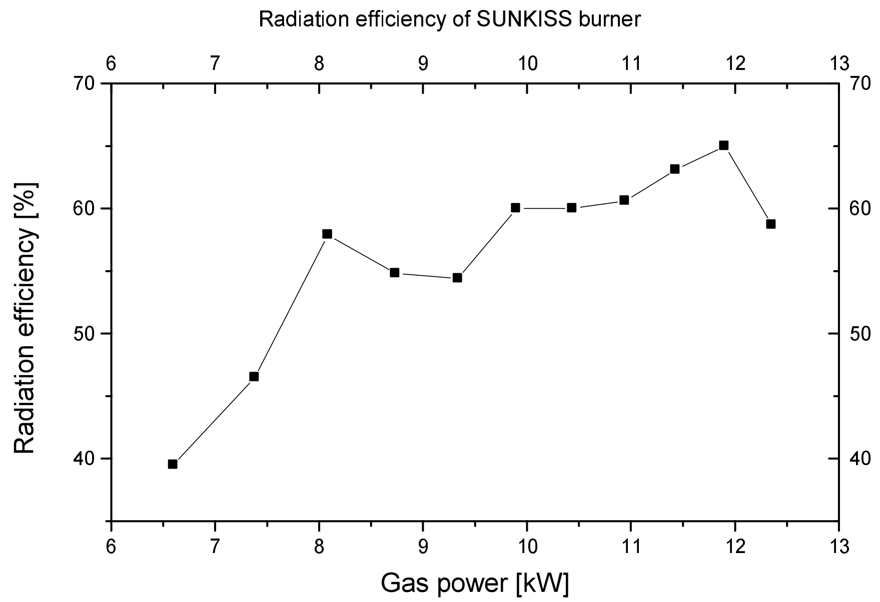

Figure 8. Measured radiation efficiency of SUNKISS burner

The radiation efficiency for the tested burner ranged between 33.7 and 66.2%. It was observed that the efficiency increased with the increasing gas power and after the efficiency has achieved the maximum value for 11.9 kW it decreased again.

The emission measurements were conducted as well. First O_2, NO, NO_2, NO_x and CO contents in the flue gases were measured near the burner surface in the middle and in the corner of the burner. During this measurement the chamber where the burner was placed was opened on the sides. Then the chamber was completely closed and the measurements were conducted in the chimney where the flue gases were collected. Also the content of the volatile organic compounds was measured then. The results are presented in the graphs below.

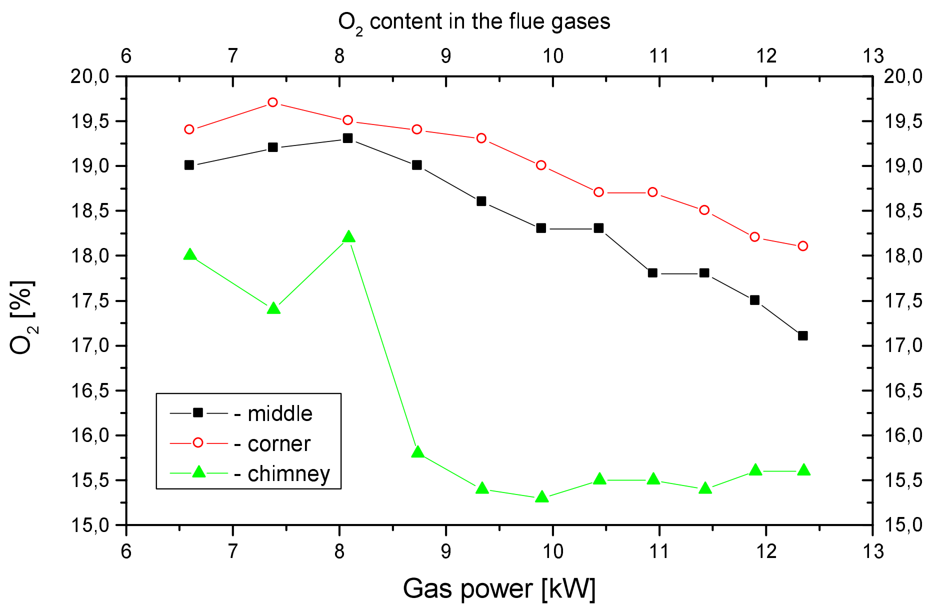

Figure 9. O_2 content in the flue gases

One can observe that the O_2 content in the flue gases was decreasing with the increasing gas power and that the combustion was less effective in the burner corner than in the middle (Figure 9).

Results obtained for CO content are presented in Figure 10. Lowest CO amounts were measured in the middle of the burner where combustion is most effective. It is difficult to obtain the even combustion in the burner and due to fact that air and gas are delivered in the middle of burner surface it is a point where the combustion is most effective and lowest emission of CO is measured there. Very similar results were obtained for measurements conducted in the burner corner and in the chimney and they show the total CO emission from the burner. For highest gas power of 12.4 kW the CO content was around 190 ppm. One of the aims of the further burner development is to decrease the CO emission in the flue gases.

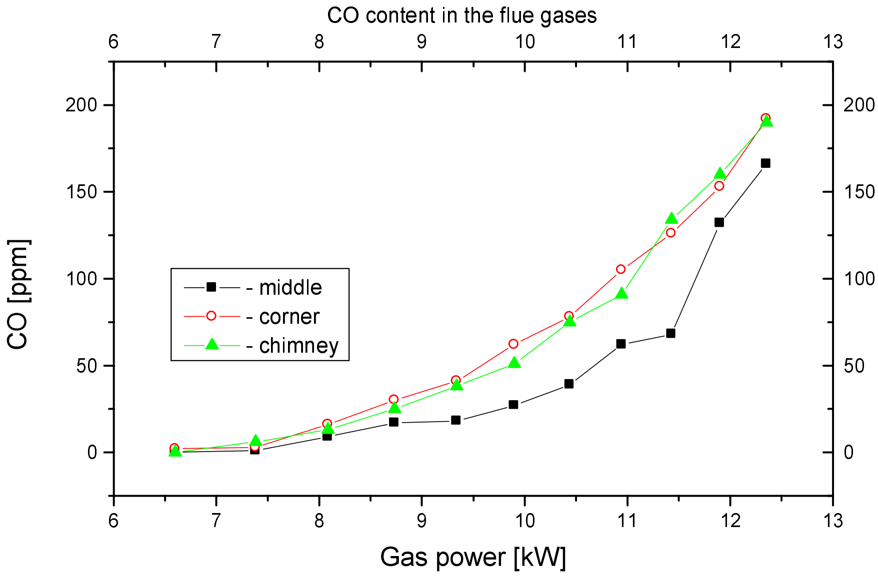

Figure 10. CO content in the flue gases

The content of the volatile organic compounds (VOC) (equivalent for propane) in the flue gases was measured in the chimney and the results are presented in the Figure 11. The amount of VOC increased for the higher gas power and achieved around 220 ppm for 12.4 kW.

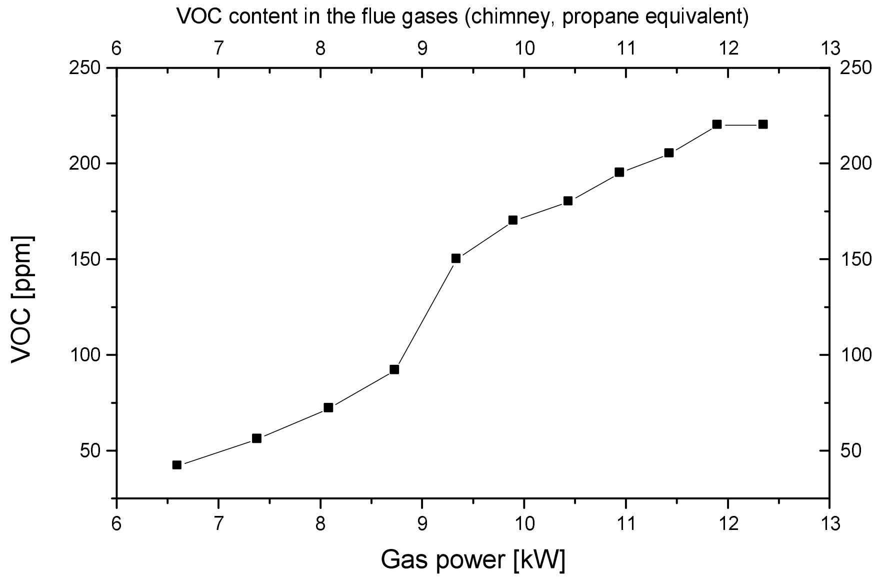

Figure 11. VOC content in the flue gases

The pressure drop in the burner as a function of gas power is presented in the Figure 12. The pressure drop ranged between 23-53 Pa and was increasing with the gas power.

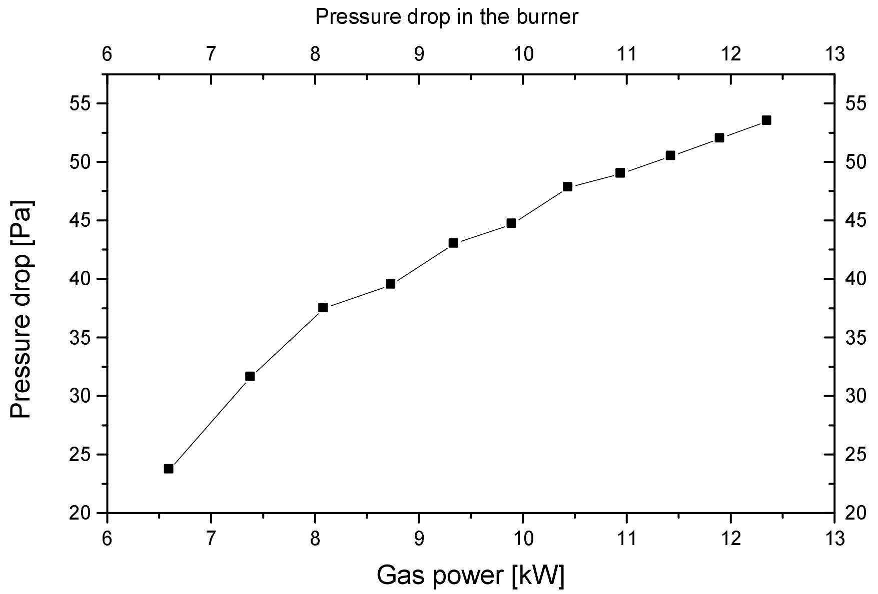

Figure 12. Pressure drop in the burner

4 EVALUATION OF THE SUNKISS BURNER EQUIPPED WITH CATATOR'S WIRE MESH CATALYST

In the next stage of the project the fiber catalysts of SUNKISS was exchanged and the catalytic net made by Catator was tested in the burner. A few configurations were investigated and the number of nets and their localization were changed. At the beginning the net with the catalyst was placed just after the insulation layer (Figure 13). It was covered with the supporting net.

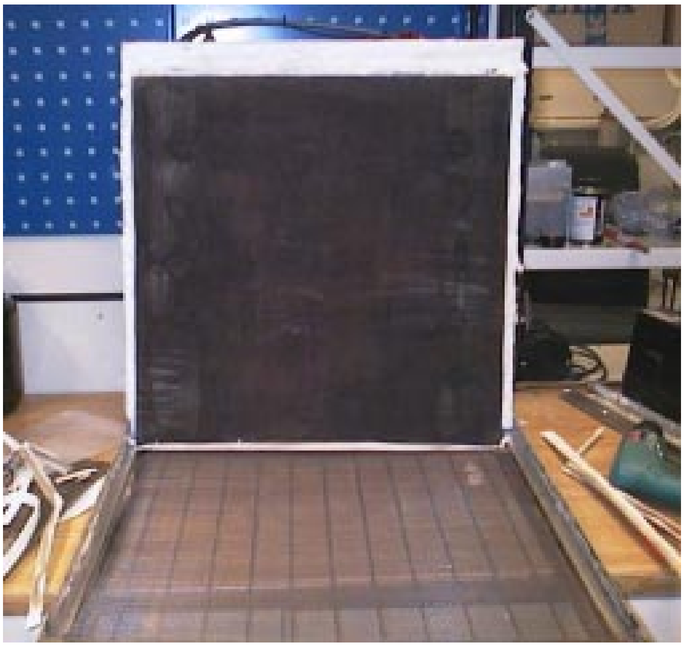

Figure 13. Catator's catalytic net

During tests the problems with the ignition and combustion propagation where observed. It seems that the method used by SUNKISS to heat the catalyst by means of electrical resistors is not working well with the catalytic net. In the next stage the catalytic net was placed over the SUNKISS catalysts to activate the combustion on the net. After this experiment the SUNKISS catalysts were removed and the places where the catalysts were burned was observed on its surface. It may suggest that the combustion temperature achieved in this burner was too high, even when it was operating for low gas power (6.6-8.1 kW).

In the next trial the folded distributing metallic net was placed rectangular to secondary air panel between the insulation and catalytic net (Figure 14).

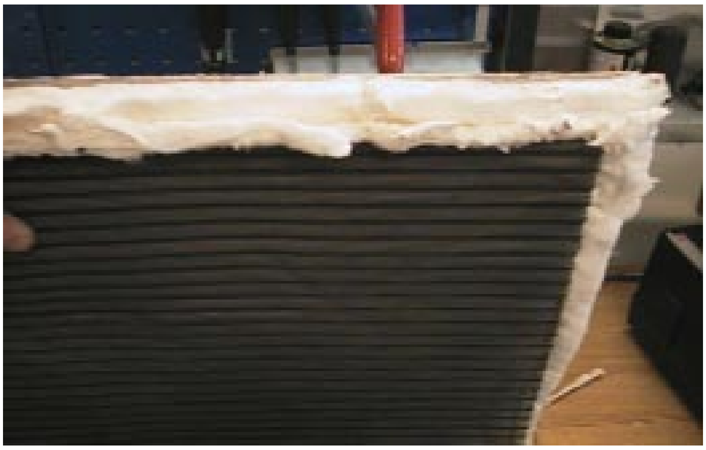

Figure 14. Folded catalytic distribution net

This configuration is later called "two nets – rectangular". A number of measurements were conducted for this burner and the results are presented below. Then a position of the distributing net was changed so it was parallel to the secondary air panel and this configuration is called "two nets – parallel". Finally a new configuration was built and tested. In this configuration a porous mat was placed on the insulation layer, then a catalytic net was laid. It was covered with the folded catalytic distribution net (in the parallel to the secondary air position). Then the third catalytic net was done and it was covered with the supporting net (Figure 15). This configuration is later called "three nets" or "Catator".

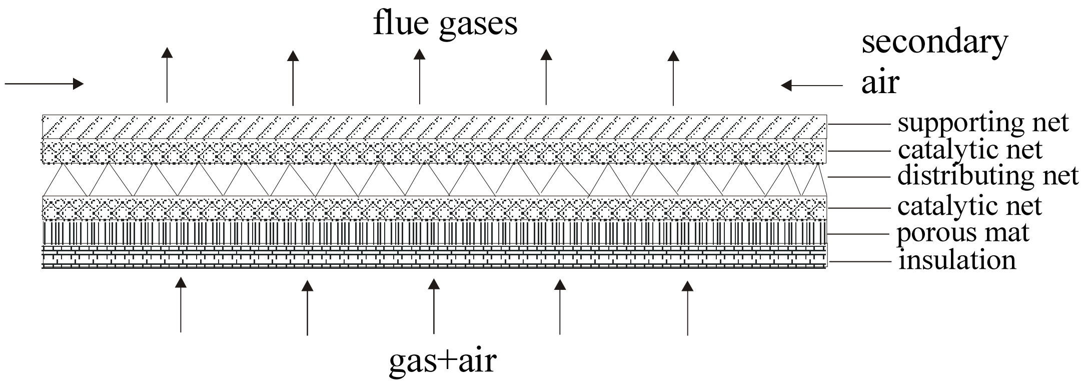

Figure 15. Scheme of the "three nets" configuration

Measurements were conducted for these three configurations for gas powers 6.6-11.4 kW and the comparison of the results obtained for the catalytic net and fiber catalysts are presented in chapter 5.

5 COMPARISON OF THE RESULTS

The comparison between the results obtained for burner with fiber catalysts and catalytic net is presented in Figures 16-25.

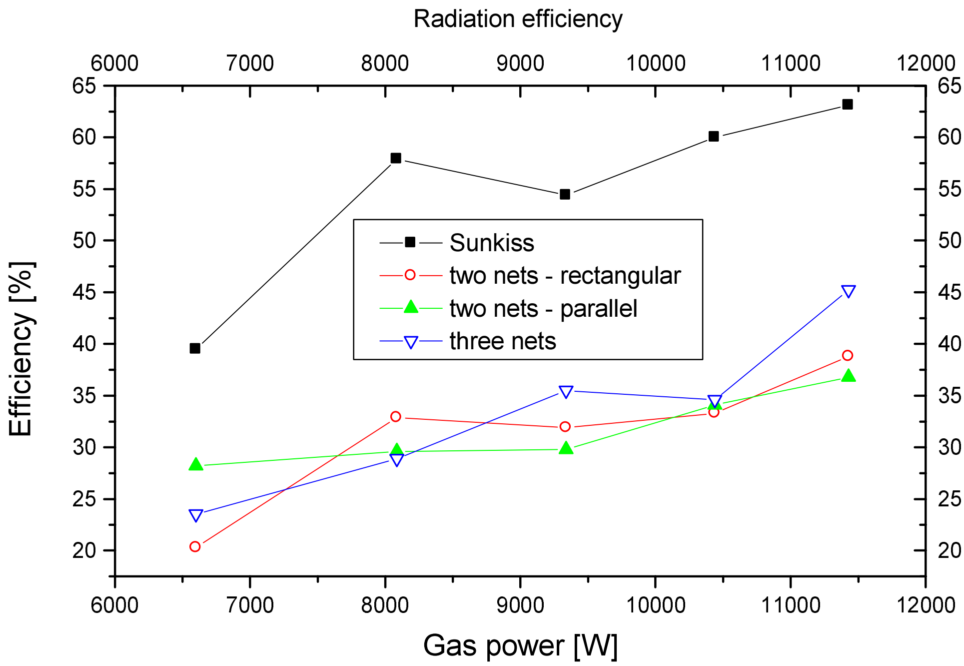

Figure 16. Measured radiation efficiency for catalytic burners

Highest radiation efficiency was measured for the SUNKISS burner and the difference between the efficiencies achieved for the burners with catalytic nets is 15-20 %. It is a bit surprising looking at the burner surface temperature, where the temperature measured for the burner with three nets is higher than in the SUNKISS burner (Figure 17).

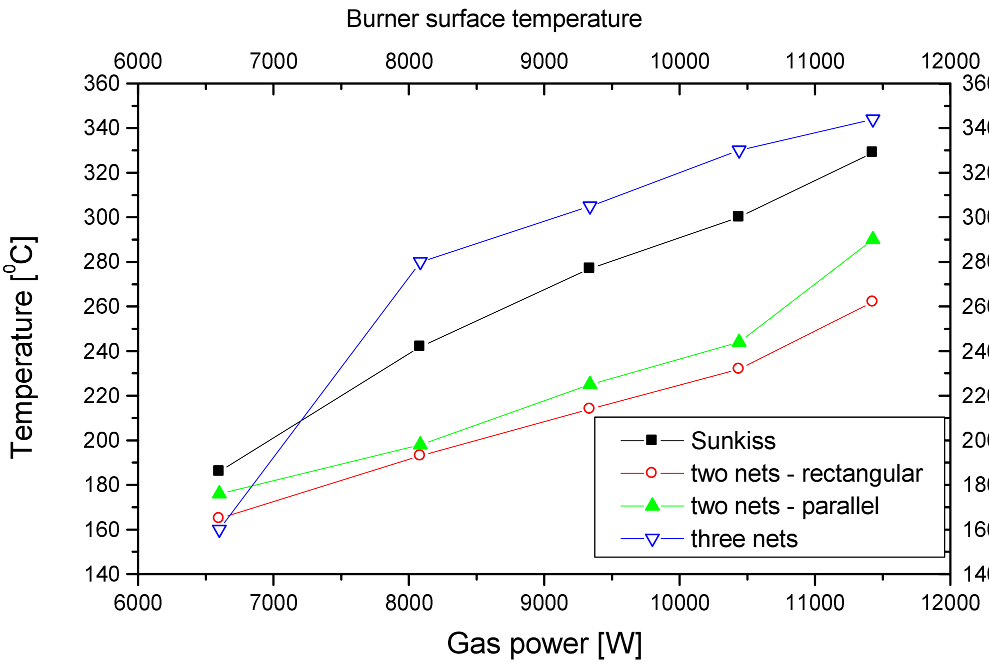

Figure 17. Burner surface temperature for catalytic burners

The amounts of the radiation calculated for the SUNKISS and Catator catalysts using the measured surface temperature are:

SUNKISS: $\varepsilon \cdot \sigma \cdot A \cdot T^4 = 1 \cdot 5.67 \cdot 10^{-8} \cdot 0.25 \cdot (330 + 273)^4 = 1874\ W$

Catator: $\varepsilon \cdot \sigma \cdot A \cdot T^4 = 1 \cdot 5.67 \cdot 10^{-8} \cdot 0.25 \cdot (344 + 273)^4 = 2054.3\ W$

The amount of heat, which is exchanged as convection between the burner surface and water in the bath, is:

SUNKISS: $h \cdot A \cdot (T_s - T_w) = 20 \cdot 0.25 \cdot ((330 + 273) - (20 + 273)) = 1550\ W$

Catator: $h \cdot A \cdot (T_s - T_w) = 20 \cdot 0.25 \cdot ((344 + 273) - (20 + 273)) = 1620\ W$

The total amount of the energy, which is emitted from the burner surface and exchanged as a convection is about 30-32% of the total gas power. This value is much lower than the measured radiation efficiency. A possible explanation is that the burner temperature was measured in just one point and the uneven combustion on the burner surface was observed in all cases. Looking at the results obtained for the flue gases leaving the burner much higher temperatures were measured for the SUNKISS burner (Figure 18). Generally the more even combustion was also observed in this burner. This is a reason that the radiation efficiency for the burner with the fiber catalysts is much higher than for the burner with the catalytic net. Also the burner temperature used in the calculations is the temperature measured on the surface of the supporting net. The actual temperature of the catalyst material was not measured, but it was estimated to be around 600^{o}C.

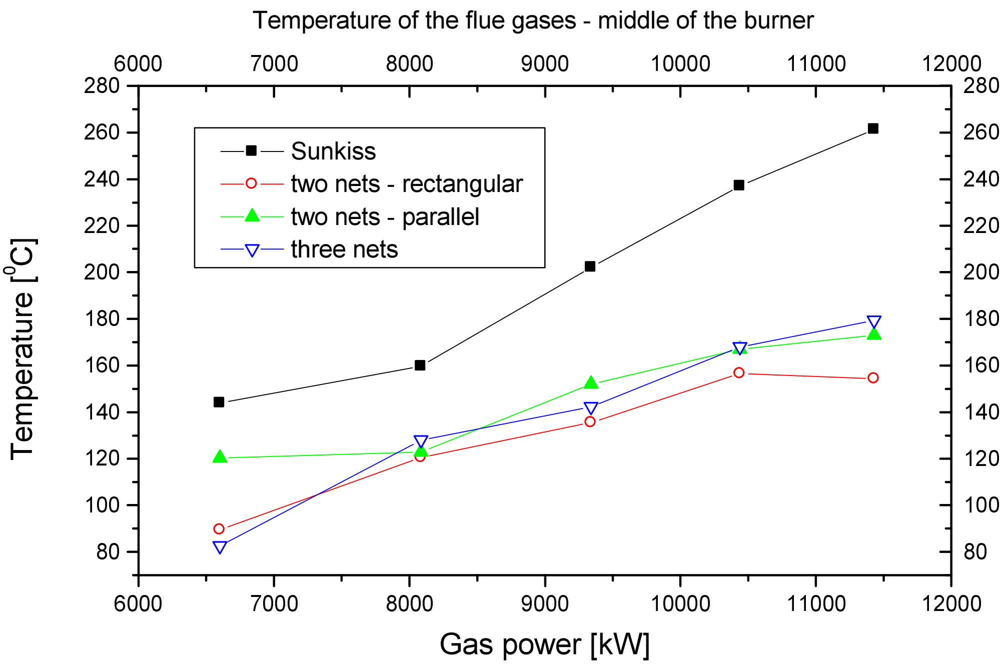

Figure 18. Flue gases temperature for catalytic burners

The results obtained for CO emission suggest that the combustion is not complete in the burner with the catalytic nets. For the high gas powers the difference ranges between 200-500 ppm. And the same situation was observed both for the measurements conducted in the middle and in the corner of the burner (Figures 19 and 20).

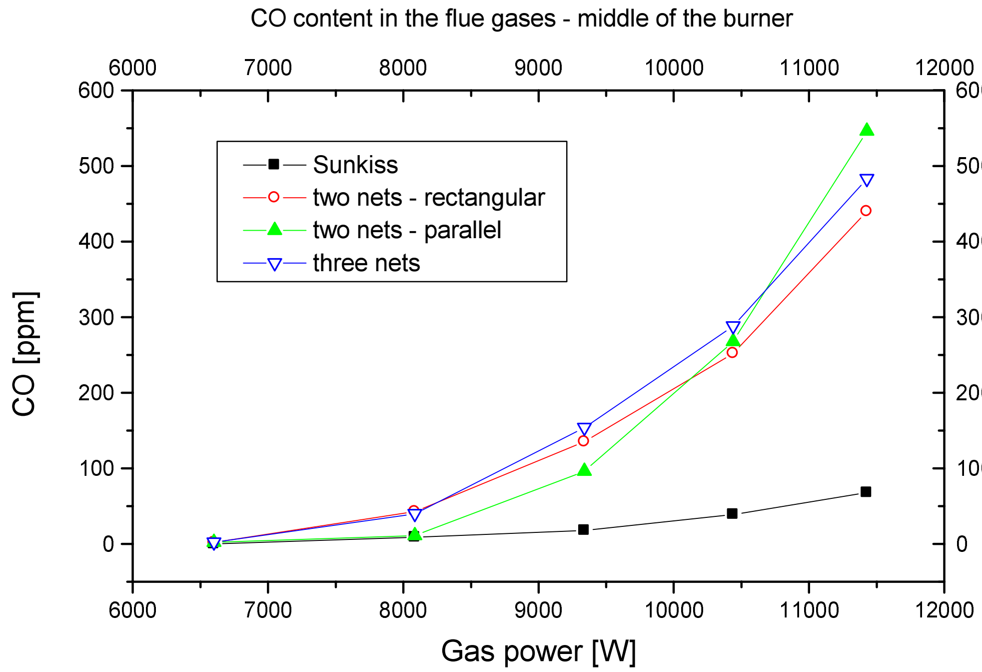

Figure 19. CO emission in the flue gases in the middle of the burner

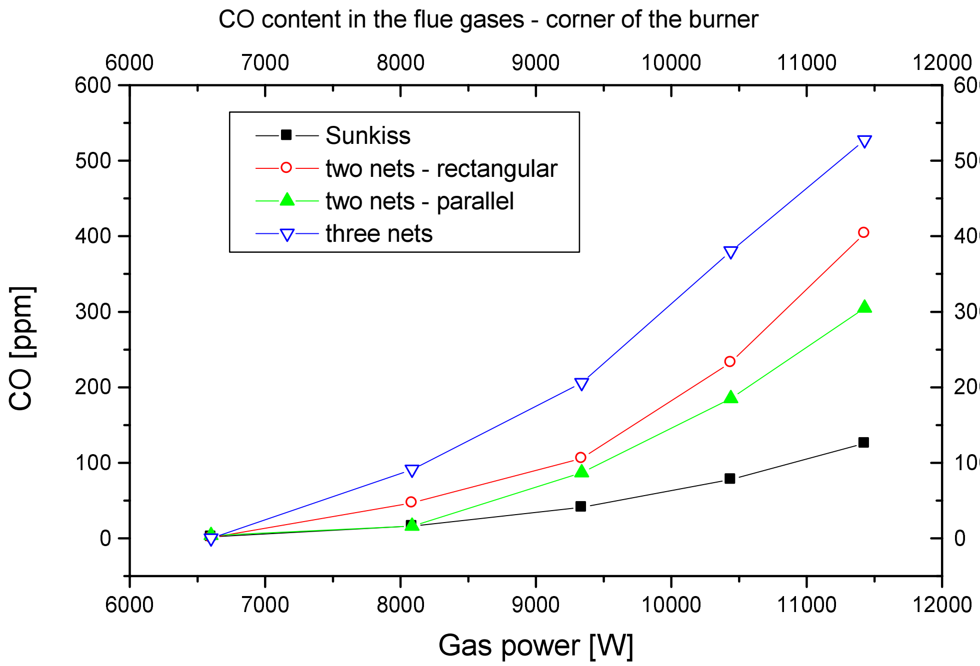

Figure 20. CO emission in the flue gases in the burner corner

More information about the combustion in the catalyst material can be found comparing the VOC content in the flue gases as a propane equivalent.

Measurements were conducted in the chimney when the burner was closed in the chamber to collect the flue gases. The results obtained for Catator catalytic nets are about 600 pmm higher than for SUNKISS catalysts (Figure 21). The combustion in Catator nets must be optimized, probably the SUNKISS solution with the secondary airflow is not suitable for this kind of catalyst.

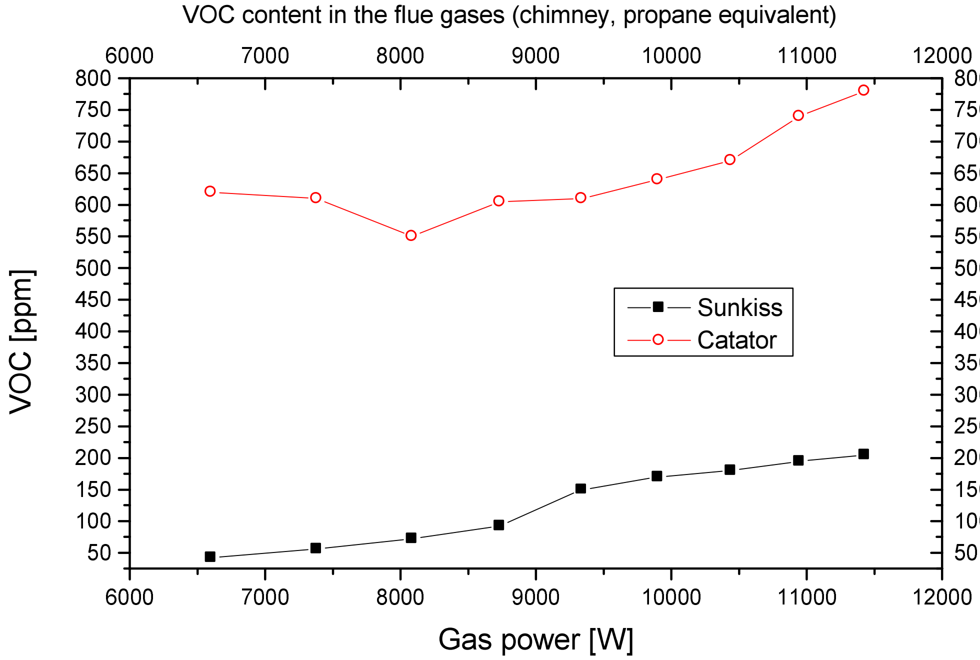

Figure 21. VOC emission in the flue gases

The same conclusions may be drawn from the O_2 content in the flue gases (Figures 22 and 23). The O_2 content is about 1 % higher for the Catator catalysts than for the SUNKISS material.

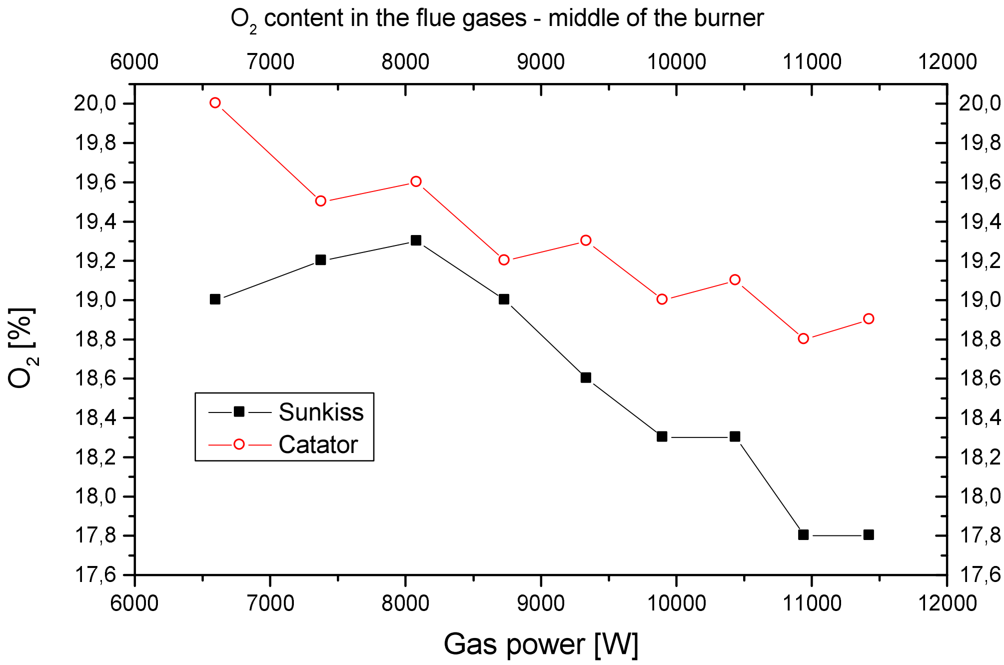

Figure 22. O_2 emission in the flue gases in the middle of the burner

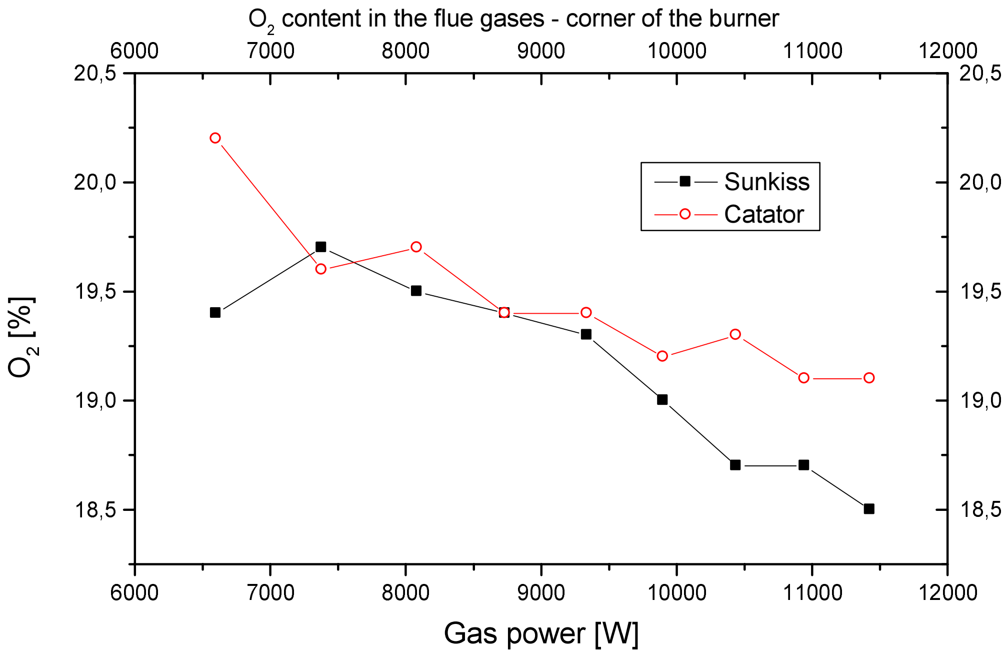

Figure 23. O_2 emission in the flue gases in the burner corner

The CO content in the flue gases in the chimney was also measured. The emissions are very similar for low gas powers, but for highest gas power the difference between the results obtained for SUNKISS and Catator catalysts is about 350 ppm. The higher emissions were observed for Catator material (Figure 24).

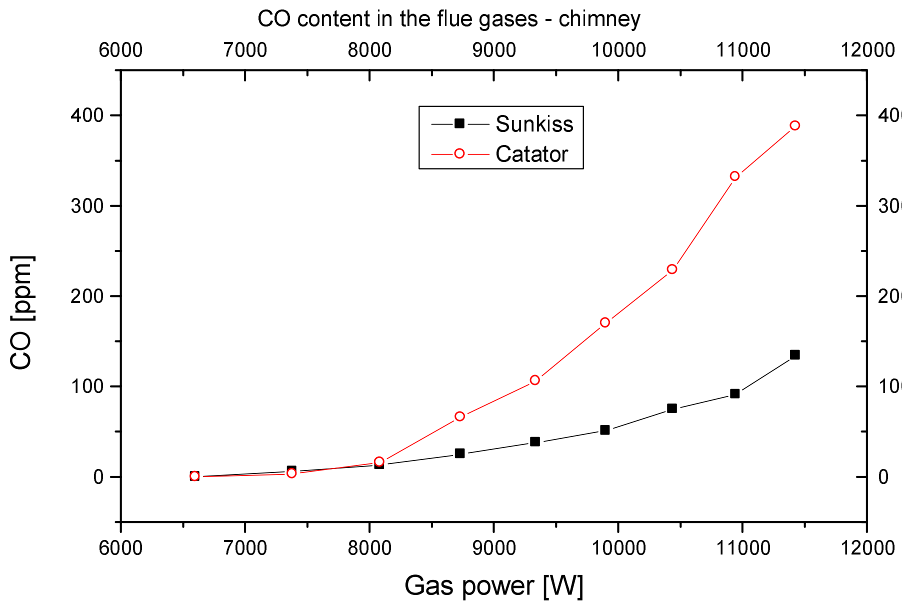

Figure 24. CO content in the flue gases

Pressure drop in the catalytic burner for SUNKISS and Catator materials were also measured. The results are presented in the Figure 25. The difference between the results is 5-10 Pa and slightly higher-pressure drop was observed for Catator catalysts.

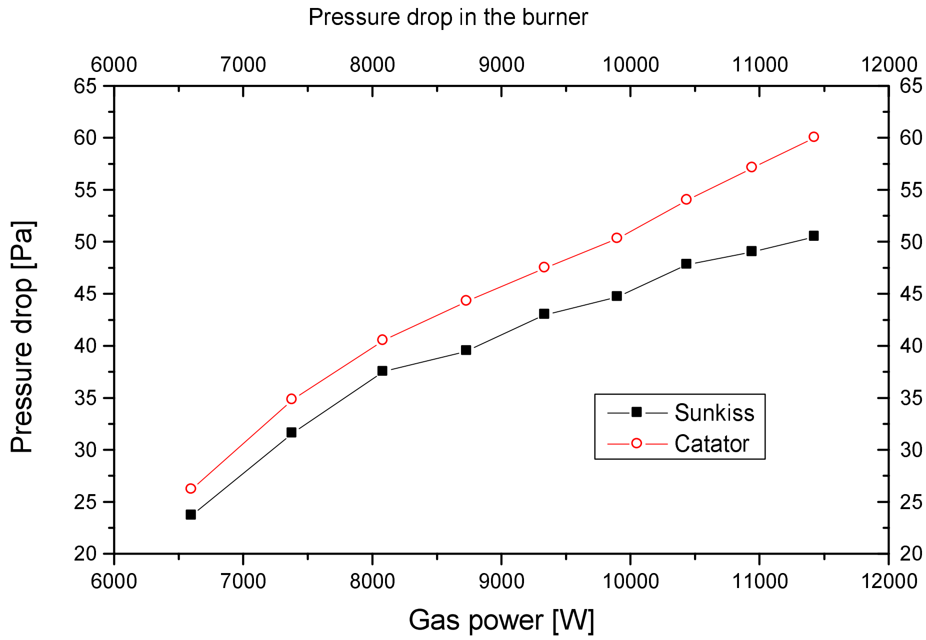

Figure 25. Pressure drop in the catalytic burners

The comparison between these two kinds of catalyst materials showed that in the existing burner construction with the secondary air flow, which was specially developed for SUNKISS fiber catalysts, the Catator catalytic net is not working at its optimal performance. This kind of material was designed for burners with the combustion of the premixed mixture of gas and air in the close to stoichiometric ratio. Future development should be concentrated on the trials to eliminate the fan and the secondary airflow and replacing it by the premix delivery system.

6 TESTING OF SECONDARY AIR INFLUENCE ON COMBUSTION

A number of trials with gradually decreasing amount of secondary air from the fan were done. During the experiments the area of fan inlet was gradually decreased until it was completely covered, so no air was sucked to the system. These tests were performed using the burner with the Catator catalytic net (the "three nets" configuration). Results are presented below.

During the experiments the water-bath was placed about 10 cm below burner surface and the chamber was opened. The first visible effect of this is much lower temperature of the surface burner in comparison with tests when the water bath was placed very close to the burner (Figure 26). The experiments were performed for one gas power equal to 8.1 kW while the ratio of the open area to the total inlet area was changing. The ratio of the areas equal to 0 means that the inlet of the fan was completely closed, while ratio equal to 1 means that the fan inlet was opened. Due to the fact that the water-bath was not influencing the burner and the mixing with the ambient air was easier, the burner surface temperature was about 55 degrees lower. When the fan was completely closed the whole system was stopped and the temperature went down.

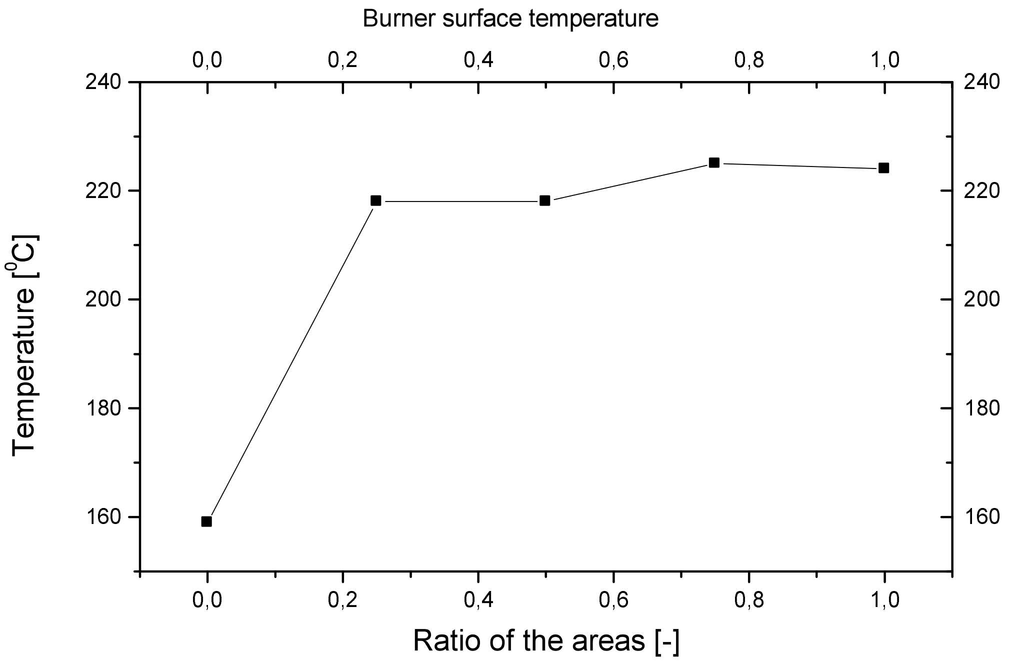

Figure 26. Burner surface temperature

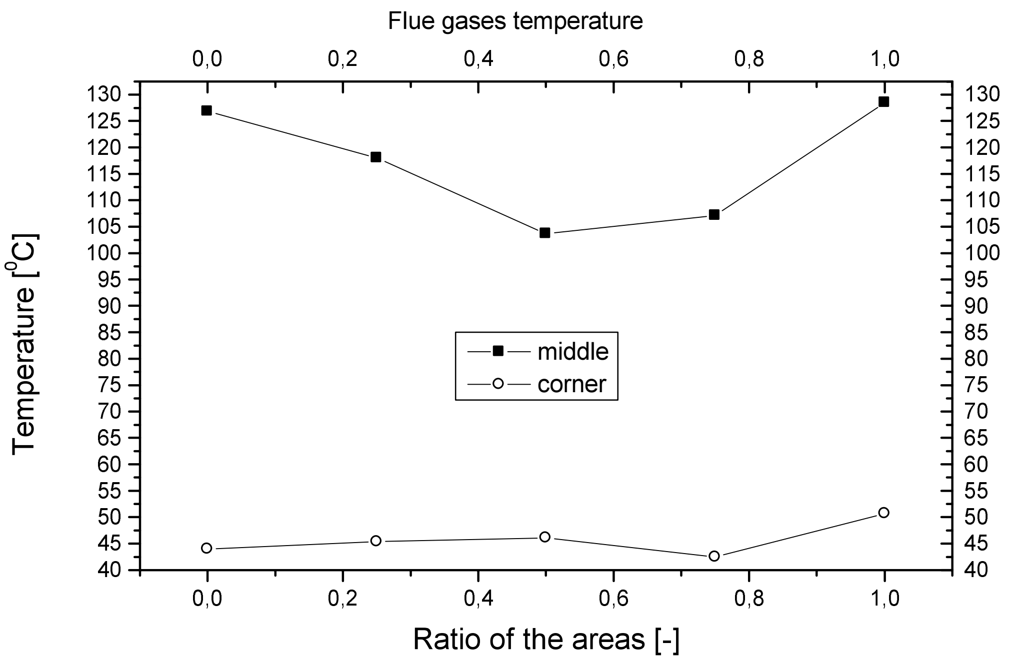

Figure 27. Flue gases temperature

Similar cooling effect was observed for flue gases temperatures, especially the temperatures measured in the burner corner, which were about 40-45^{o}C lower than previously (Figure 27).

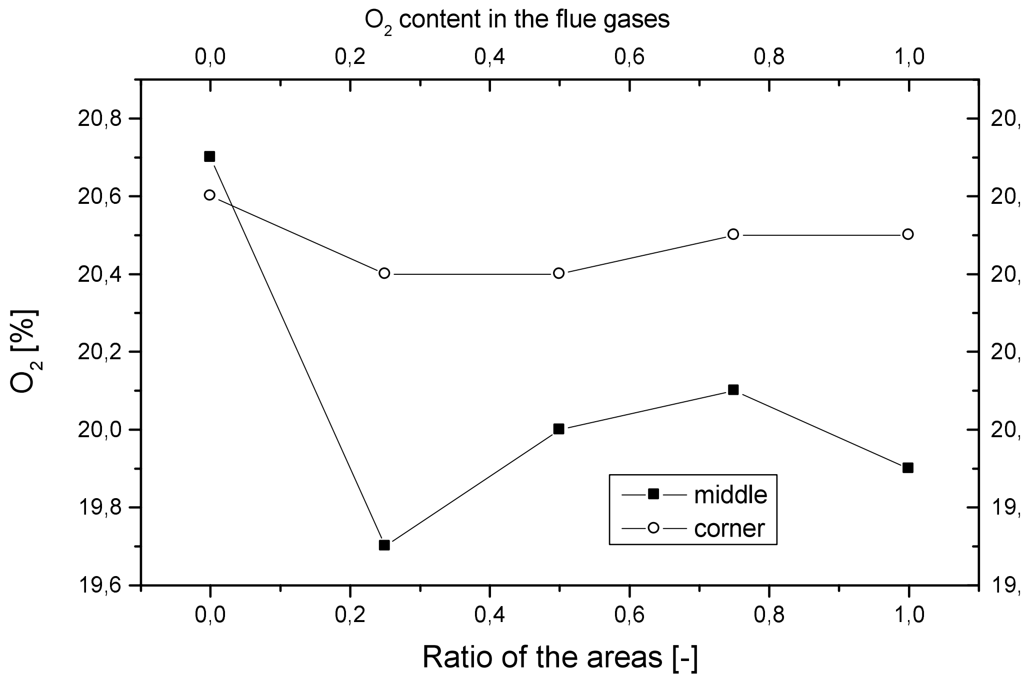

Figure 28. O_2 emissions in the flue gases

Emissions in the flue gases were measured and the higher content of O_2 was observed (previously 19.6% in the middle of the burner and 19.7% in the burner corner). The CO emissions were lower than in the test with the water-bath (Figure 29). The combustion process was more effective in the tests without water-bath. The emissions were quite low even when the half of the fan inlet was closed, a bit higher emission of CO was measured when 75% of the fan inlet was closed, but still it was lower than in the case with the water-bath (respectively 25 and 40 ppm).

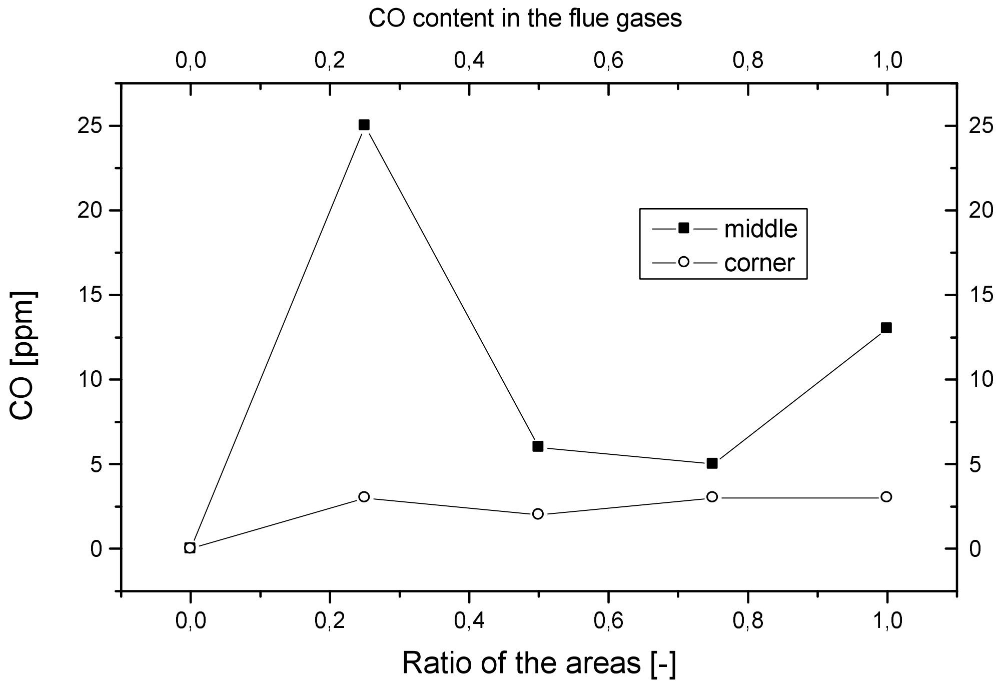

Figure 29. CO emissions in the flue gases

7 EVALUATION BY SUNKISS

7.1 INTRODUCTION

The aim of the Catator project was to investigate the possibility of using the wire mesh based catalyst developed by Catator in Lund on the Sunkiss' Thermoreactor® RX.

Sunkiss was to replace the catalyst fiber used in Thermoreactor® by a solid and less noxious material of catalyst support (i.e. the wire mesh). The whole with an equivalent price and with minimum of modification on Thermoreactor®.

7.2 REMINDER

The Sunkiss' Thermoreactor® are mounted in ovens and furnaces to heat and cure the powder coating or liquid paint on industrial parts. Thermoreactor® are assembled in wall mounting systems.

7.3 PREVIOUS REPORT

The Lund Institute of Technology has written a report about the "Evaluation of a new type of catalytic IR-radiator" on May 31, 2002. It is based on the comparison between a Sunkiss Thermoreactor® with catalyst fiber and the same Thermoreactor® modified (by Catator) with the wire mesh.

The report gives measurements on both configuration in power, combustion (CO, O_2), temperature and radiation efficiency.

7.4 PURPOSE FOR SUNKISS TRIALS ON CATATOR'S WIRE MESH CATALYST

At the end of the Catator's trials Sunkiss wanted to test and see the Thermoreactor® modified to examine and study the possibilities to mount the wire mesh catalyst support on the Thermoreactor® range.

The purpose of Sunkiss wasn't to check the measurement results of Catator but to study the implementation of a new catalyst system for Thermoreactor®. Sunkiss has considered that the measurement carried out by Catator was correct.

7.5 TEST OF THE SUNKISS BURNER EQUIPPED WITH CATATOR'S WIRE MESH CATALYST

When Sunkiss received the burner, they noticed few anomalies relative to the mounting of the burner:

- assembly of the front bar face
- fastening of the cell in the cell enclosure

When Sunkiss started the burner for the first time they had difficulties with the burner. The wire mesh catalyst didn't warm up and they had many failings in the starting-up. Those problems have been noted in the Catator report.

After many start-ups the burner has run and heats the black sensor in front of the panel (see figures below of the testing configuration). The temperature reached was 60°C maximum.

We have noticed that the front bar face disturbed the flow of the fan in front of the panel. We decided to dismount the front bar face and put it in its initial position (in the same configuration that fiber as Sunkiss has mounted the Thermoreactor®).

We have taken the advantage to look at the wire mesh composition.

After those modifications we have restarted the burner and the flow of the fan had a lower disturbance on the burner's face. And the temperature on the black sensor was about 150°C.

The temperature on the same black sensor with a Sunkiss' Thermoreactor® RX is about 150°C too.

When we checked the CO rate with a manual CO-meter we measured the same level as Catator. Between 57 and 114 ppm (depending on the position on the middle or corner measurement and disturbing of the fan ventilation in front panel – Note all tests have been done with a 140 mbar gas pressure). But in all cases the CO rate is much higher than a Sunkiss' Thermoreactor®.

7.6 CONFIGURATION FOR THE TEST

Figure 30. Position of temperature captor

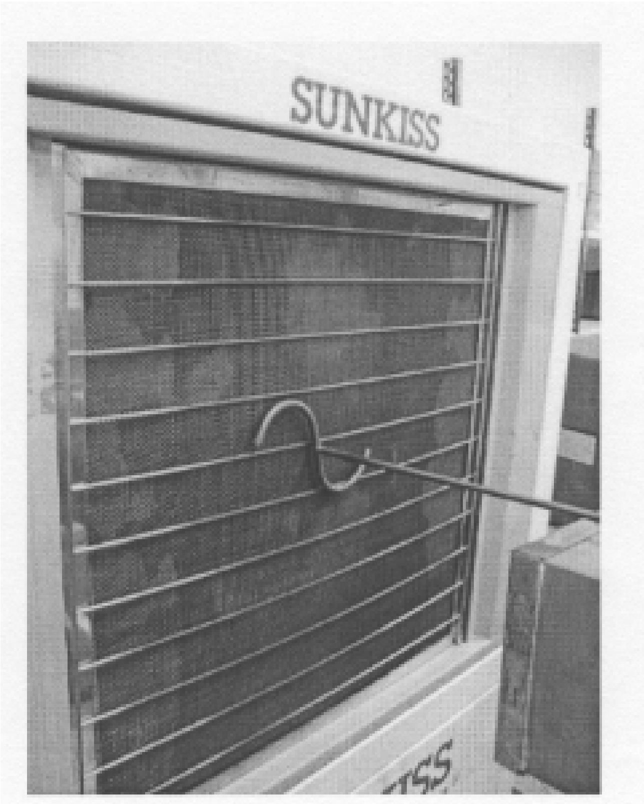

Figure 31. Position of sensor CO meter

7.7 CONCLUSION

The conclusions are the same as in the Catator's report. The Sunkiss' Thermoreactor® in its configuration is not adapted for the wire mesh catalyst. The following list point out the none suitable configuration for the wire mesh burner:

- Warming-up system.
- Second air ventilation fan.
- Mixing (venturi) air factor.

In conclusion, the wire mesh catalyst isn't directly transposable at the Sunkiss' Thermoreactor®. If Sunkiss want to introduce this new catalyst support, a specific development must be done (new conception, new tests and qualifications).

However the wire mesh catalyst has an important attract for Sunkiss products but not in this configuration. The main attraction is to use the wire mesh in static (without second air combustion) and/or a wide size burner.

For Sunkiss the interest is to substitute the fiber and to get a new product range.

7.8 OUTLOOKS AND QUESTIONS

Jean-Jacques Charmes and Patrick Parpette visited Catator and Lund Institute in September and a development for a partnership was considered. But the following questions remain about the wire mesh texture:

- What is the maximum rate for power/surface?
- What is the maximum size? And the minimum?
- What is the maximum temperature support by the wire mesh?
- …

All those points were mentioned in the September meeting.

8 NOMENCLATURE

A	area	m^2
h	heat transfer coefficient	W/m^2
T	temperature	K

Greek Symbols

ε	emissivity	-
σ	Stefan-Bolzmann's constant, $5.67 \cdot 10^{-8}$	$W/(m^2K^4)$

Subscripts

s	burner surface
w	water

9 REFERENCES

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