# Development of a new ultra low-$NO_x$ burner for fiber and gypsum board dryer

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*With emission legislation becoming more strict and in the same time requirement for more efficient burners, there is a need for clean burners with high efficiency. The Linnox burner is a ultra low $NO_x$ properties in combination with the possibility to have a strong heat distribution. The Linnox burner can distribute the heat so efficient because of the fact that the burner can be built of modules with practically any capacity from 24 kW to 720 kW per stretching 300 mm.*

Generally, three primary sources of $NO_x$ formation in combustion processes are documented:

- thermal $NO_x$
- fuel $NO_x$
- prompt $NO_x$

Thermal $NO_x$ formation, which is highly temperature dependent, is recognized as the most relevant source with combustion of natural gas. Fuel $NO_x$ tends to dominate during the combustion of fuels, such as coal, which have significant nitrogen content, particularly when burned in combustors designed to minimise thermal $NO_x$. The contribution of prompt $NO_x$ is normally considered negligible.

## Thermal $NO_x$

Thermal $NO_x$ refers to $NO_x$ formed through high temperature oxidation of the nitrogen molecule found in combustion air. The formation rate is primarily a function of temperature and the residence time nitrogen at that temperature. At high temperatures, usually above 1600 °C, molecular nitrogen ($N_2$) and oxygen ($O_2$) in the combustion air disassociate into their atomic states and participate in a series of reactions.

The three principal reactions, described by Zeldovic, producing thermal $NO_x$ are:

$N_2 + O \rightarrow NO + N$

$N + O_2 \rightarrow NO + O$

$N + OH \rightarrow NO + H$

all three reactions are reversible. Zeldovich was the first to suggest the importance of the first two reactions. The last reaction of atomic Nitrogen with Hydroxyl radical, OH, was added by Lavovie, Heywood and Keck to the mechanism and makes a significiant contribution to the formation of thermal $NO_x$.

## Fuel $NO_x$

The major source of $NO_x$ production from nitrogen-bearing fuels such as certain coals and oil, is the conversion of fuel bound nitrogen to $NO_x$ during combustion. During combustion, the nitrogen bound in the fuel is released as a free radical and ultimately forms free $N_2$, or NO. Fuel $NO_x$ can contribute as much as 50% of total emissions when combusting oil and as much as 80% when combusting coal.

Although the complete mechanism is not fully understood, there are two primary paths of formation. The first involves the oxidation of volatile nitrogen species during the initial stages of combustion. During the release and prior to the oxidation of the volatiles, nitrogen reacts to form several intermediaries which are then oxidized into NO. If the volatiles evolve into a reducing atmosphere, the nitrogen evolved can readily be made to form nitrogen gas, rather than $NO_x$. The second path involves the combustion of nitrogen contained in the char matrix during the combustion of the char portion of the fuels. This reaction occurs much more slowly than the volatile phase. Only around 20% of the char nitrogen is ultimately emitted as $NO_x$, since much of the $NO_x$ that forms during this process is reduced to nitrogen by the char, which is nearly pure carbon.

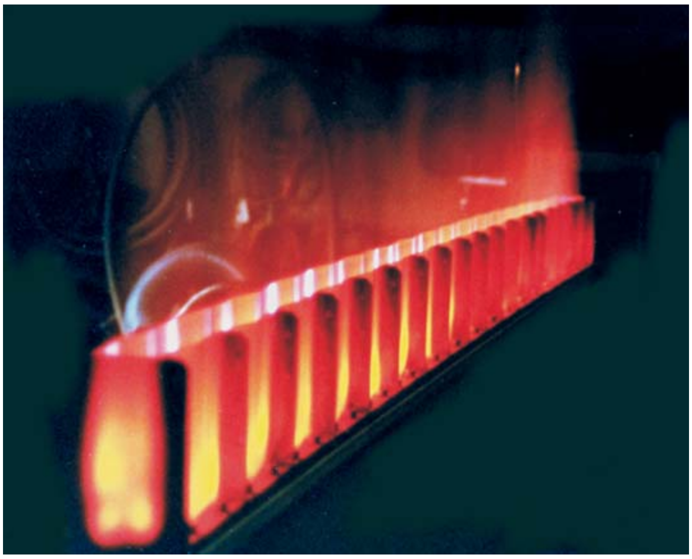

**Fig. 1:** Linnox burner in operation

## Prompt $NO_x$

This third source is attributed to the reaction of atmospheric nitrogen, $N_2$, with radicals such as C, CH, and $CH_2$ fragments derived from fuel, where this cannot be explained by either the aforementioned thermal or fuel processes. Occurring in the earliest stage of combustion, this results in the formation of fixed species of nitrogen such as NH (nitrogen monohydride), HCN (hydrogen cyanide), $H_2CN$ (dihydrogen cyanide) and CN-gas which can oxidize to NO. In fuels that contain nitrogen, the incidence of prompt $NO_x$ is especially minimal and it is generally only of interest for the most exacting emission targets.

## Low-$NO_x$ gas burners

Low-$NO_x$ technology is mostly based upon preventing thermal $NO_x$ being formed, because this has the most effective potential. This can be done by keeping the flame temperature low. In flames of conventional burners regions are formed where temperatures are higher than in other regions. Especially in the regions with high temperatures the Thermal $NO_x$ is being formed. Different methods are being used to decrease the flame temperature in combustion technology.

- flue gas recirculation in the burner (external)
- flue gas recirculation in the flame (internal)
- staged combustion
- premix in combination with excess air

## Linnox Burner

The Eclipse Linnox burner is using the later technology to create a low $NO_x$ combustion system (**Fig. 1**). This technology is very effective and can create ultra low $NO_x$ levels in flue gases. The Linnox burner uses a integrated mixer for premixing the gas and air. The quality of the combustion is highly depended on the quality of the gas / air mixture. Eclipse has developed a mixing system for these kind of burners, which is able to make high quality mixtures. This mixer is also flexible enough to be able to create this mixture with a high turn down of at least 1:10. Over this turn down the mixture is of consistent quality and therefore the low $NO_x$ – qualification can be given from 1:10.

## History

The burner is started as a development to create a Low $NO_x$ version for the Line burner, which was one of the burners from Eclipse. This Line burner is a burner built from 1 ft length burner elements which were also fed with a premixed gas / air mixture. The burner had a line shaped flame and per 1 ft module different inputs were available. A German customer who used many Line burners from Eclipse required a Low $NO_x$ version. Eclipse Gouda developed a technology (Minnox system) for a Ultra Low $NO_x$ air heat burner. This technology won the DSM-enviromental technology prize in 1992. In 1996 Eclipse combined this technology with the modular built of the Line burner and the Linnox was born. The first burners were commisioned in 1998.

## Burner Construction

The burner has a straight mixture feed duct where burner modules are mounted on. This mixture duct with modules is the actual burner and is normally mounted in the process duct. Outside the process duct the mixture is produced by mixing an exact controlled amount of air and gas.

## Modular Built

By creating 1 ft modules, or in European terms 300 mm, Eclipse was able to make a flexible burner which fitted perfectly in the requirement for the original customer. The burner modules are made as such that by using the same parts, the module can delivered with 24, 36, 48, 60, 72, 96, 120 or 144 kW per 300 mm. Burners can be constructed with up until 20 modules (6 meter) with any element and in any sequence. Because of this flexibility we are able to spread the input of the burner over the whole length, so creating an optimal heat flux distribution for any application. This makes it possible to place the burner close to the process without any complicated distribution methods to spread the heat evenly over the process.

All of these modules have the same width and because of a very smart construction of the burner these elements can be exchanged if necessary. If a customer for one reason or the other needs to change an element from one input to another input, it is possible without exchanging the whole burner.

The product line was further extended by making an element with larger widths. Since 2003 burners were built with 240, 360, 600 and 720 kW per module with a length of 300 mm. Even these large elements have ultra low $NO_x$ emission of smaller than 3 ppm $NO_x$ related to 17% $O_2$ over the whole turn down of 1:10.

In this way it is theoretically possible to built a burner for 720 kW with a total length of 9 meters or with a total length 300 mm or anything in between. In this way it is possible to spread out the desired input over practically any duct size.

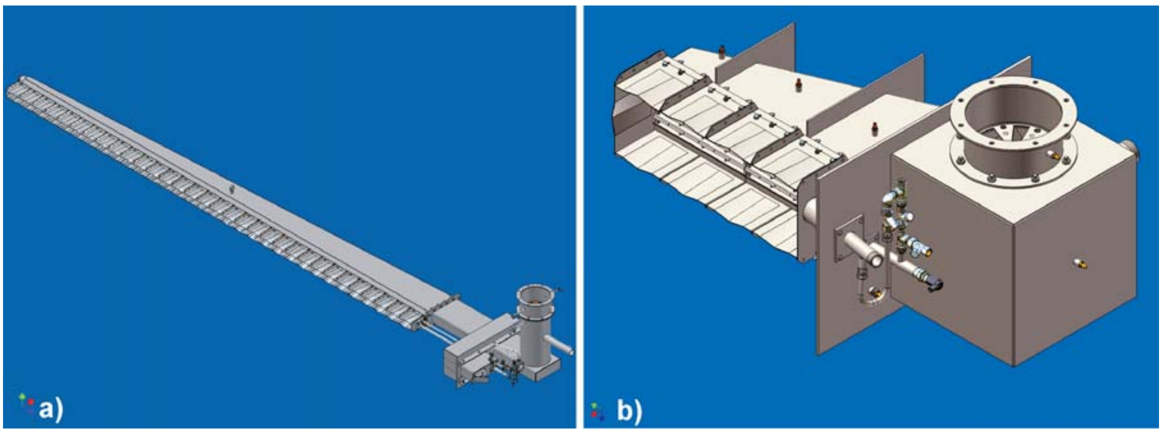


**Fig. 2:** Examples of a Linnox HC and a Linnox LC

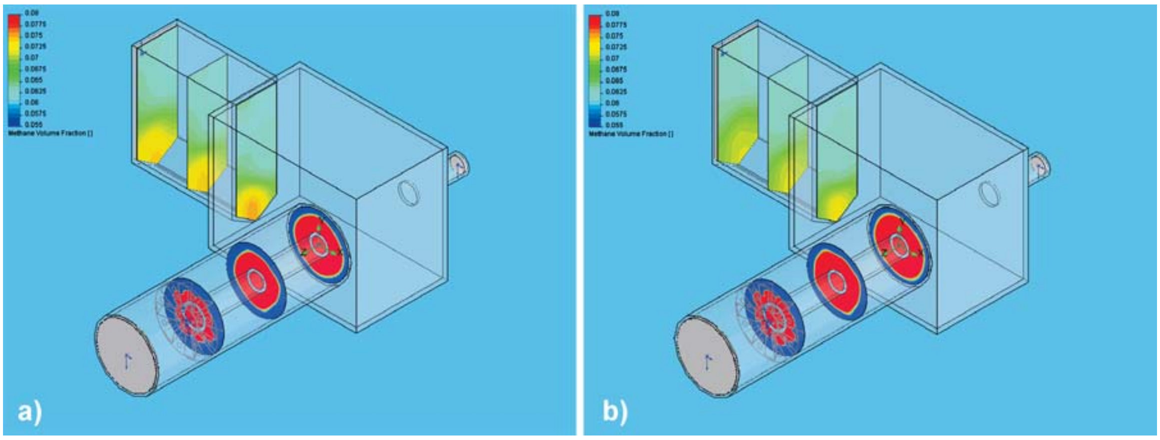


**Fig. 3:** a) simulation at 10% input
b) simulation at 100% input

The Linnox burner (**Fig. 2**) with inputs of 144kW / 300mm and smaller are called the Linnox-LC ans the Linnox burner with inputs of 240 kW and larger are called the Linnox-HC. In praxis burner capacity of 80 kW/m up to 2.400 kW/m can be build.

## Safety

Especially with premix burners safety is a very important issue. The fear of back firing into the mixture duct is quit large and in many cases even entitled. With the Linnox burner this has been one of the focus points with the development. During the experiments the temperature of the burner modules was constantly monitored. Even with a burner adjustment close to stoichiometric, with the highest flame temperature, and at minimum input, with the lowest cooling by mixture, the temperatures do not come close to dangerous levels.

The construction of the burner module acts as a flame arrester. The high mass of the modules are too difficult to heat up.

## Gas / Air Mixer

The Linnox burner's heart is the mixer. The quality of the combustion is mostly defined by the quality of the mixture. It is necessary that the mixer provides a constant quality of mixture with a deviation of less than 5% over a burner turn down of 1:10. This means that a injector mixer can not be used, because the turn down would not be sufficient. The present design is based on a swirl-and-distribute principle, which has proven to be an extremely efficient and reliable design. Since the burners are modular built and therefore extremely flexible, the mixer has to be equally flexible. The design is made as such, that it is possible to have 3 basic mixers for inputs from 120 kW to 2000 kW. Before building the burners and mixers, the design of the mixers are modeled in a fluid dynamics program to ensure the best possible mixing. These models are sometimes confirmed by tests in our test laboratory. Bad quality mixing would compromise the specifications of the burner, so ensuring this part of the burner is essential. **Fig. 3** is shown the results of one of those calculations.

From the calculation the mixer shows a very good quality over the complete turn-down of the burner.

The design of the mixer is partly defined so the burner can be controlled by proportionator. The pressure drop across the mixer is relative high, to create swirling movement of the air flow and a second effect is that the air pressure is sufficient to drive the proportionator. This gives the mixing plate a double purpose. Preliminary tests have been done with low pressure drop mixers. These had the same turn down, but without the necessity for a high air velocity. These mixers can be used in applications with the Linnox controlled by parallel valve positioning or any other electronic linked valve system.

## Emission

The emission **figures 4 and 5** of the Linnox are shown below. Obviously when a burner is developed as a Low-$NO_x$ burner, the CO emissions still need to be excellent as well. With a burner as the Linnox, which uses excess air to cool the flame, there is a danger that the flame is cooled too much and CO emissions occur. During tests it was found that the emission levels can be achieved at an optimum gas / air ratio of 40 to 50% excess air.

The emission levels of the HC burner are on a different level then the LC burner,

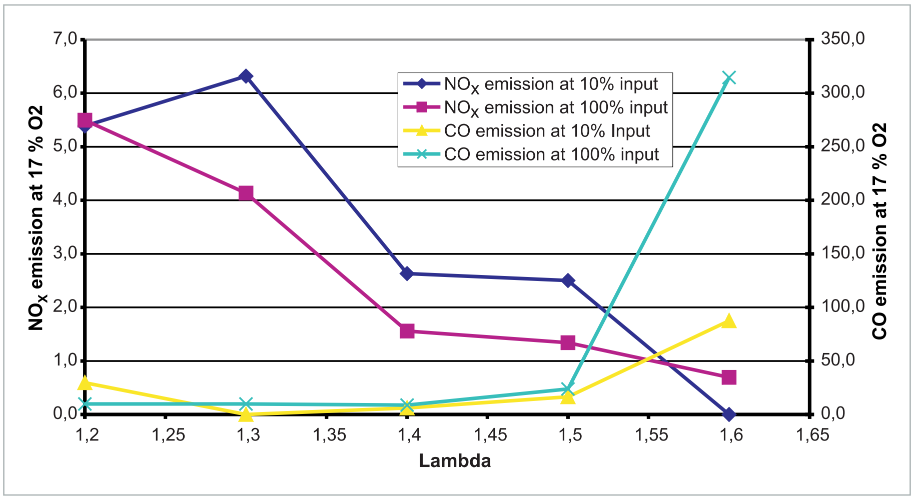


**Fig. 4:** Test data of emission levels measured with the Linnox-LC burner in a dryer

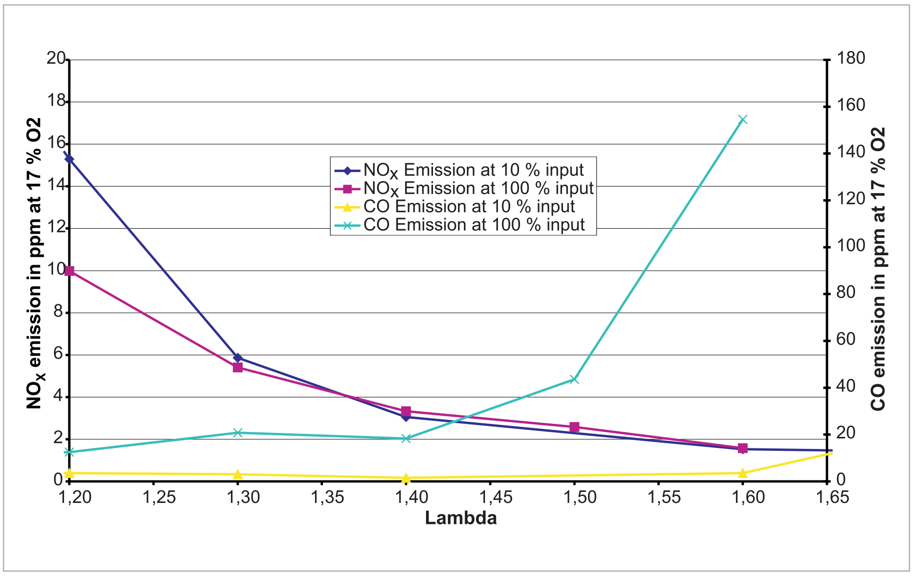


**Fig. 5:** Test data of emission levels measured with the Linnox-HC burner

**Fig. 6:** Linnox burner mounted in the gypsum and fiber board dryer

but the optimum region is the same. With both types the best emissions are found at a excess air of 40 to 50%.

## Heat recovery

Because of the fact that the burner modules act as flame arresters and can not reach dangerous temperature levels, it is possible to provide the burner with preheated combustion air. A successful demo project was started 3 years ago with over 200 °C combustion air. This makes it possible to recover approximately half of the energy which is lost by the use of excess air which was needed for the Low $NO_X$. However, increasing the temperature of the combustion air will result into an increased $NO_X$ level. Estimates predict an increase of 50% more $NO_X$.

## Applications

The original application for which the Linnox was developed is a fiber and gypsum board dryer (**Fig. 6**). The burner proves to be very suitable to create the most optimum temperature distribution across the length of the burner, which is mounted vertically from top to bottom.

The Linnox has been proven to be an excellent burner for air heat applications and is therefore used in many of those installations. Up until now gypsum board, paper, textile, luandry and soja flower are products which are dried with Linnox burners. Specially all applications where huge air-volumes have to be heated up and a good temperature distribution by the source (burner) is required. Even on drum dryer applications the Linnox-burner can be adapted perfectly. The burner could even be used in incinerators.

The reasons to choose this specific burner is because of the two previous mentioned qualities: the more than excellent emission figures and the possibility to have a very good heat distribution along the length of the line-burner. ■

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