

COMBINED DeNO_x/DeSO_x AND ADDITIONAL NO_x REDUCTION BY CLEANING FLUE GAS CONDENSATE FROM AMMONIA

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1. SUMMARY

Mixing of combustion gases inside the furnace is of greatest importance to achieve optimum combustion. A good intermixing is also essential to achieve high efficiency of any chemical used.

A new intermixing system has been developed and comprises of the following steps:

1. ROFA®. Rotating Over Fire Air. This is an improved Over Fire Air system that assures a good intermixing throughout the whole furnace volume. The result is a more efficient combustion process, i.e. higher efficiency and lower NO_x.
2. ROTAMIX®. ROTating MIXing. This is a second generation SNCR. Thanks to the good intermixing created by the ROFA, the SNCR or other chemicals can be more effectively used. The chemicals are injected through the ROFA air nozzles and as a result are mixed very good with combustion gases in the entire furnace.

The system called MobotecSystem™ (ROFA & ROTAMIX) has been proved in more than 15 plants using different kinds of fuels. Two examples are presented.

1. The Jordberga boiler generates 78 MW with a spreader stoker using coal as fuel. Before the installation of ROFA and ROTAMIX (DeSO_x), Jordberga emitted 0.24 lb of NO_x/MBtu and 0.393 lb. of SO_x/MBtu to the atmosphere. After installation the emissions were reduced to 0.14 lb. of NO_x/MBtu and 0.039 lb. of SO_x/MBtu. These reductions were 40% and 90% respectively. The NO_x reduction was achieved without using chemicals, SO_x was reduced by using dry limestone. As an extra benefit the excess oxygen was reduced from 5.5% to 2.3% after the ESP, resulting in increased operating efficiency by over 1%, without increasing CO and unburned carbon in fly ash.
2. Boiler #3, Söderenergi generates 80 MW and is equipped with a flue gas condensation system generating 20 MW extra. The boiler is a fluidized bed burning mostly wood refuse. The NO_x reduction system is ROFA combined with ROTAMIX (SNCR), using ammonia as

reducing agent. The NO_x level without any reduction measures was 0.39 lb/MBtu. After the installation of ROFA, the NO_x emission was 0.21 lb/MBtu and combined with ROTAMIX, 0.10 lb/MBtu at an ammonia slip less than 4 PPM.

By using twice as much ammonia the NO_x emission was further reduced to 0.04 lb. of NO_x/MBtu. Through the use of reverse osmosis the ammonia slip is recovered and reused as a SNCR chemical. By this technique almost no ammonia is released into the atmosphere or to the receiver.

Rotating Over Fire Air creates a horizontal rotation in the flow of air and combustion gases inside the furnace. This rotation increases the flue gas velocity and allows for delayed combustion. It also assures for good admixture of air without increasing CO levels. As a result, the furnace temperature is reduced and the "hot spots", where most of the thermal NO_x is generated, are minimized. Also, laminar flow which is always found in furnaces is almost eliminated. Through the ROFA ports, i.e. ROTAMIX, the injection of chemicals into the furnace is easily made and is more efficient than other injection techniques. As a result, the chemicals are thoroughly mixed in the flue gas allowing the reducing agent to be used more effectively resulting in higher reduction levels.

2. COMBINED DeNO_x/ DeSO_x IN A COAL FIRED BOILER. DIRECT DESULFURIZATION IN COMBINATION WITH PRIMARY TECHNIQUE AT JORDBERGA SUGAR MILL.

2.1 Introduction

2.1.1 Background

Jordberga Sugar mill is owned by Danisco Sugar AB and produces raw sugar, which is used as raw material in the production of sweetening products at the company refinery. The production period lasts from September to January. During the rest of the year extensive maintenance and new installations are made.

ROFA was installed at Jordberga Sugar mill during 1995. The system was prepared for ROTAMIX, i.e. intermixing chemicals for DeNO_x and/or DeSO_x.

During startup of ROFA, a positive side effect was noticed. The introduction of rotating air affected the existing desulfurization system in a positive way. The sulfur level was further reduced by approximately 50%. Since the boiler is coal fired, and harder regulations were expected, Danisco decided to proceed with injection of limestone via ROTAMIX.

2.1.2 Goal

The goal with installation of ROFA was to achieve as low NO_x level as possible together with an increase in efficiency without deterioration of the combustion, i.e. without increasing CO or unburned carbon in the fly ash.

The goal with the reconstruction of the limestone injection system was to get well below 0.11 lb. of SO_x/MBtu, even with the use of a high sulfur coal.

Further, the sulfur reduction was to be achieved with the use of dry limestone and not hydrated lime, which is more expensive.

2.2 Description of the plant

2.2.1 Distribution of energy

Steam is generated in a coal fired boiler, with the following data:

Startup	1989
Thermal output	78.4 MW
Steam data	60 bar/ 480 °C
Firing equipment	Spreaderstoker
Boiler type/ Manufacturer	Eckrohr/Kvaerner

At present, the boiler is fired with coal from Poland, but it can also be fired with wood chips or other bio-fuels. If bio-fuel is used, the power output is reduced to about 70 MW.

2.2.2 Fuel

Table 2.1 Fuel specification.

	Typical coal	Fuel band
Low heat value (as received) (MJ/kg)	29.7	27-30.5
Moisture content on raw coal (wt. %)	6	5-9
Ash content (wt. %)	4	3-8
Ash softening temperature (° C)	1350	1200-1400
Ash melting point (° C)	1400	1300-1450
Volatile components (%)	30	25-40
Nitrogen content (wt. % on dry substance)	1.3	max 1.5
Sulfur content (wt. % on dry substance)	< 0,60	max 0.65
Sulfur content/energy content (mg/MJ)	< 200	max 240
Swelling index	1	1-2.0

2.2.3 Grading analysis

Normally, the coal is distributed as follows:

Table 2.2 Grading analysis of a normal coal.

(mm)	(%)
< 30	100
< 25	99
< 20	98
< 15	95
< 10	89-45
< 5	74-32
< 3	63-23
< 1	34-15
< 0.5	20-10
< 0.2	10-5

Remark. Coal consisting of rougher fractions have a tendency to increase NOx.

2.2.4 Original equipment for desulfurization

Original equipment for desulfurization consists of 12 air nozzles placed at the front of the boiler above the grate, Figure 2.1. In 1991 the nozzles were modified to ejector nozzles. This solution provides some flexibility with 2 fixed levels to blast lime into a calculated temperature window.

After measuring the furnace temperature, the result shows irregularities during power changes, causing laminated flow in the furnace, convection and economizer parts.

Extensive documented tests using different lime types were done. Spreading angles from existing ports for optimal coverage in the furnace have been tested. Crushed limestone 0-0.2 mm gave best results.

2.2.5 Furnace and combustion air

The furnace is 5.8 m deep and 9.5 m wide. The total height from grate to boiler roof is 15 m.

Primary air is introduced under the grate on the right and left side, and is divided into different zones. Primary air is mixed with about 25% of recirculated flue gas.

Previously, secondary air was introduced on three different levels at the back and front of the furnace. With the ROFA installation, all secondary air was redirected to the new system. Approximately 40% of the total amount of combustion air is introduced via the ROFA system.

In addition, separate air systems for the spreader is needed.

2.2.6 System for limestone injection

After reconstruction, the limestone is distributed via ROTAMIX, using two injectors, one on each side of the furnace. If desired, some of the limestone can be injected through the old system.

The amount of injected limestone is regulated by the control system.

2.3 Performed tests

After completed startup of ROFA, tests were performed introducing a part of the limestone via ROTAMIX. With a relatively small reconstruction, about 1/3 of the limestone could be injected via ROTAMIX. The tests were so successful that Danisco decided to go along with the new configuration during the rest of the campaign, Figure 2.2.

During the maintenance period 1996 the limestone system was reconstructed in order to fully introduce limestone via ROTAMIX.

At the campaign startup October 10th 1996 the same configuration as the recent campaign was used, i.e. 1/3 of the total amount of injected limestone was directed via ROTAMIX. The only difference was that the limestone was introduced into the furnace on a higher level. After a few days the level was moved to the same level as the first season tests.

Later, during October 1996, a test were performed to clarify the needed temperature and amount of limestone injected to achieve maximum reduction. The test were performed according to Table 2.3.

Table 2.3 Distribution of total amount of limestone.

ROTAMIX right:	ROTAMIX left:	Older system, front:
1/6	1/6	4/6
2/6	1/6	3/6
3/6	1/6	2/6
3/6	2/6	1/6
3/6	3/6	0

In addition, tests to determine the temperature dependence and sulfur reduction were performed.

During these tests a constant amount of limestone were injected, 1250 kg/h.

In order to compare data, the total amount of injected limestone was increased to 1450 kg/h, which was the average amount of injected limestone during the latest campaigns, Figure 2.3.

2.4 Results and discussions

2.4.1 Reduction of SO₂

The tests show that the original injection procedure totally reduces SO₂ with approximately 60%. The reduction depends very much on the furnace load and the amount of injected limestone.

When using ROFA for rotary intermixing of air into the furnace, the sulfur emitted to the atmosphere was reduced by an additional 50%. The total reduction rate was increased to about 80%. The comparison is done using the same amount of limestone at corresponding load.

With introduction of 100% limestone via ROTAMIX into the furnace the sulfur emitted to the air was reduced by another 50%, i.e. the total sulfur reduction was 90%.

Further sulfur reduction can be achieved at reduced loads, i.e. with relatively increased injection of limestone. However, the total amount of injected limestone into the furnace is limited to the capacity of the ESP, which is about 1500 kg/h of limestone.

2.4.2 Reduction of NO_x

The total NO_x reduction was accomplished by the use of ROFA, i.e. without using any chemicals. The NO_x was reduced from 0.24 lb/MBtu to 0.14 lb/Mbtu, i.e. by 40%.

2.4.3 Improvement in efficiency

The total increase in efficiency was over 1 % due to the positive effects of ROFA. ROFA allows for lower excess oxygen and increases the heat transfer to the furnace walls. The amount of unburned content in the fly ash was reduced from 26 to 15 %. The unburned content in the bottom ash was not affected.

The furnace was cleaner after the campaign compared to earlier years.

No negative consequences have been noticed with the introduction of ROFA and ROTAMIX at Jordberga Sugar mill. For further information, see Figure 2.4 and 2.5.

2.4.4 Maintenance cost and availability

The operating time is 2500 h per year. The maintenance cost has been extremely low. Since 1995 only flexible hoses for the calcium transport system has been replaced.

The availability for the MobotecSystem has since 1995 been 100%.

3. ADDITIONAL NO_x REDUCTION BY CLEANING FLUE GAS CONDENSATE FROM AMMONIA

3.1 Introduction

3.1.1 Background

Söderenergi mainly delivers district heating to Södertälje and the south part of Stockholm. The main production facility is Igelstaverket.

Boiler #3 was a tangential fired unit for coal/oil originally producing 120 MW, built 1982 by Maskinverken. The boiler was rebuilt 1994 by Foster Wheeler to a Fluidized Bed, (FB) using bio fuels. A SNCR-system was also installed by Foster Wheeler. After the rebuilding to FB, the boiler produces 80 MW. During the reconstruction a flue gas condensation system was installed, generating 20 MW extra. ROFA and ROTAMIX was installed by Mobotec 1996.

The NO_x level with no SNCR is 0.39 lb/MBtu. With the old SNCR system the NO_x level was 0.20 lb/MBtu. The major problem was the very high and varying ammonia slip levels up to about 30 PPM in the flue gas. Most of the ammonia slip was washed out by the flue gas condensation system, resulting in non acceptable high levels of NH₄ into the receiver.

After startup of ROFA/ROTAMIX the NO_x level over a long period was 0.070 lb/MBtu at an ammonia slip less than 4 PPM, see Figure 3.1. (Test run average was 0.051 lb. of NO_x/MBtu, ammonia slip 3.7 PPM, CO 64 PPM, N₂O 1.6 PPM and O₂ 2.4 %).

The amount of ammonia used is controlled by the actual ammonia slip.

Due to the change of fuel to a mix with higher nitrogen content during the last two years, the NO_x levels has increased to 0.099 - 0.110 lb/MBtu. Also the large variation in moist content has negatively influenced on the NO_x.

3.1.2 The goal

The goal for cleaning the flue gas condensate from ammonia is to obtain NO_x level as low as possible, at least below 0.077 lb/MBtu without getting any negative side effects, but also to minimize ammonia released into the atmosphere or to the receiver.

3.2 Description of the plant

3.2.1 The boiler

Four fuel inlets (two on each side) is placed approximately 3 feet above the sand bed. The fuel is transported to the boiler by screws and falls in to the sand bed. The sand bed temperature is regulated by recirculated flue gas and is normally kept at 850°C.

Three oil burners are mounted. These are normally used only for startup.

Dimensions for the upper part of the furnace is 7.42 m (W) x 6.78 m (D). The new lower part of the furnace has the dimensions 7.42 m x 8.16 m. The total height is 20.5 m, Figure 3.2.

The unit is equipped with an ESP, sulfur reactor, bag filters and flue gas condensation. At full load, the flue gas condensation gives an additional 20 MW.

The combustion air is moisturized to 25%.

Six thermal elements controls the temperature in the sand bed. The furnace temperature is measured at the nose before the outlet.

3.2.2 The ammonia system

A redundant system completely in stainless steel including tank, pumps, filters, piping, valves etc. is installed.

As chemical for NO_x reduction, 25% aqueous ammonia is used.

ROTAMIX is used as SNCR system.

3.2.3 Combustion air

The combustion air is separated between primary, lower and upper secondary, tertiary and ROFA.

The primary air goes through a booster fan to a maximum pressure of 15 kPa. The primary air is used for fluidization of the bed. The primary air flow varies between 8.5 and 16 Nm³/s.

The primary air flow is controlled by the pressure in the bed.

Excess oxygen is regulated via the ROFA system.

3.3 Performed tests

The amount of ammonia was successively increased at full load where the NO_x, ammonia slip and ammonium (NH₄) in condensate was measured continuously. Tests on the fly ash from the ESP and bag filters were frequently taken.

Further, large amounts of ammonia was injected during 18 and 10 hours periods respectively.

3.3.1 Results of performed tests

Increased amount of injected ammonia through ROTAMIX gave a major additional reduction of NO_x. The tests also show that further NO_x reduction decreases at a certain amount of ammonia used, i.e. very large flow of ammonia gives only a marginal extra reduction of NO_x. This is fully in accordance with previous studies, (Figure 3.3).

The amount of ammonium in the fly ash increased, but never reached any dangerous level for the boiler. In the bag filter the ammonium level increased slightly to a maximum of 18µg/g, while in the ESP the maximum level was three times as high as normal (maximum 35µg/g was measured).

Twice as much ammonia gave approximately 50 % additional NO_x reduction. The ammonia slip was between 30 to 40 PPM (normal <4 PPM). The corresponding ammonium in the condensate varied between 200 to 300 mg/l.

The 18 hour test period gave a NO_x level of 0.073 lb/MBtu at an ammonia usage of 0.016 kg/s at a slip of 10 PPM. The 10 hour test period gave a NO_x level of 0.055 lb/MBtu at an ammonia usage of 0.022 kg/s at a slip of about 18 PPM.

The normal usage of ammonia is 0.009 to 0.010 kg/s.

3.4 Description of the system used for cleaning flue gas condensate from ammonium

3.4.1 Reversed Osmosis, RO

The system planned to be installed consists of a neutralization tank, sand filter, buffer tank, activated carbon filter and a RO unit.

The RO system is dimensioned for 95 % recovery of ammonia.

3.4.2 Structure of the system

The flue gas condensate is transported to a neutralization tank. From the tank the condensate is pumped through a sand filter and further to a buffer tank. From the buffer tank the condensate is pumped through an activated carbon filter to the RO unit. From the RO unit, the permeate is reused for example as process water.

The reject from the RO is either used directly injected into the furnace or sent to an evaporator, where the ammonia is evaporated and sent to the furnace, while the residue is discarded, Figure 3.4.

3.5 Dosing

3.5.1 Assumptions

Based on load, moisture- and energy content of the fuel, the calculated flow of condensate is 26.25 m³/h. The ammonium content in the condensate is assumed to be 200 mg/l.

The RO is dimensioned for 3.75 m³/h reject. With 90% efficiency the NH₄ content increases to 2000 mg/l, Figure 3.5.

3.5.2 Introduction of the reject as gas.

The ammonium reject can be evaporated and via a duct system intermixed into the furnace via the ROFA air.

3.5.3 Introduction of the reject as a liquid.

The reject can also be injected into the furnace as a liquid.

The total amount of reject is 3.75 m³/h, equals to approximately 1 l/s. From a day tank the reject is pressurized and transported to each side of the furnace and introduced to the furnace through the ROTAMIX system.

By introducing the reject through the ROTAMIX system a good intermixing is assured. Lowering of the furnace temperature caused by vaporizing of the reject, will be evenly distributed throughout the entire furnace volume.

Reusing the reject as liquid will result in a simpler installation, lower total investment but also simpler maintenance. Possible problems are discussed below.

3.5.4 Vaporizing the reject

Needed energy to increase the temperature of 1000 kg liquid from 20°C till 1000°C steam has been calculated as follows:

Liquid 20 – 100 ° C	0.09 MWh
Evaporation	0.63 -"-
Steam to 1000°C	0.54 -"-
Total	1.26 -"-

Our assumption of a total flow of reject results in an energy consumption of approximately 4.7 MWh, which is recovered through the flue gas condensation system.

3.5.5 Potential practical problems

The obvious practical problem is clogging of pipes and spraying nozzles for the reject. This can be solved by a periodical flushing of the system with citric acid etc.

3.6 Results and discussion

3.6.1 Reduction of NO_x by ROFA and ROTAMIX

By introducing the SNCR chemical through ROTAMIX a better intermixing is assured, allowing for as many ammonia molecules as possible to react with NO_x molecules. By this the usage of ammonia can be reduced together with higher NO_x reduction.

3.6.2 Reduction of NO_x by overdosing ammonia.

Overdosing the ammonia through the ROTAMIX system gives an additional NO_x reduction of 50 %. By using the flue gas condensation and cleaning the condensate by RO, the reject can be reused as a SNCR chemical, either as liquid or in vapour phase.

Given amount of reject and ammonium in condensate means that 7 kg of anhydrous ammonia per hour may be reused. 7 kg of ammonia can theoretically reduce $7 \times 46/17 = 18.9$ kg NO_x.

3.6.3 Combustion improvements

The ROFA reduces the laminar flow which in turn allows for lower excess oxygen together with lower CO. Also spikes of CO caused by variation in the fuel, are minimized.

4. CONCLUSIONS

To achieve good combustion and high efficiency together with low emissions of unwanted gases, a good intermixing of the combustion gases are very important.

A homogeneous mix of for example, limestone or ammonia and combustion gases is crucial for receiving high reduction levels. Good admixture of air and flue gas also reduces the amount of chemical needed for reduction.

Conventional direct desulfurization and SNCR techniques are based on injection via a large number of nozzles placed to cover the cross section of the furnace. System ROTAMIX is a technique that creates turbulence in the furnace, resulting in good admixture of the flue gas and chemicals used. In total the number of injection nozzles can be fewer. This means that the installation of mechanical and controlling equipment can be made less complex, resulting in lower costs and easier maintenance.

With the ROTAMIX installation the production of unwanted byproducts can be kept to a minimum. The rotation of the air prevents laminar flow, i.e. the temperature in the cross section of the furnace is more homogeneous and the ammonia slip is minimized. When intermixing chemicals through the ROTAMIX, the reducing agent is used more effective, resulting in higher reduction levels.

By overdosing the SNCR chemical very high NO_x reduction is achieved. The procedure results in high ammonia slip. By removing the ammonia slip in a wet step, (flue gas condensation or scrubber together with a RO) the ammonia slip can be recycled and reused in the SNCR. Besides very large NO_x reduction the described technique means that almost no ammonia is released into the atmosphere or to the receiver.

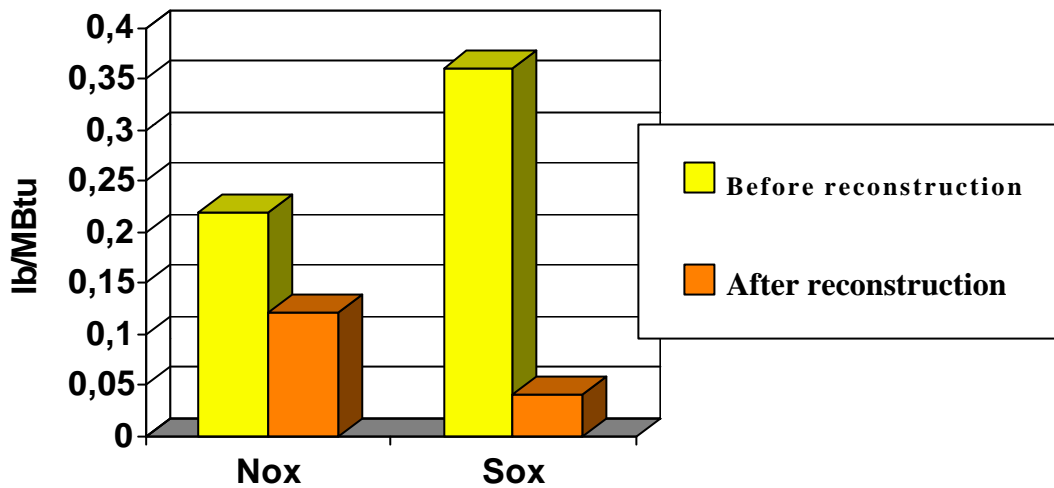


Figure 2.3 Jordberga, comparison NOx and SOx before and after reconstruction.

Year	SOx (In/Out)	NOx (lb/MBtu)	O ₂
1991	- / 0.295	0.364	5.5
1992	0.555 / 0.279	0.332	5.5
1993	0.470 / 0.216	0.221	4.4
1994	0.505 / 0.186	Urea tests 0.142	4.0
1995	0.393 / 0.088	ROFA 0.154	2.4
1996	0.393 / 0.075	0.150	2.3
1997	0.367 / 0,079	0.148	2.3
1998	0.411 / 0.079	0.143	2.4

Figure 2.4 Jordberga, yearly average of NOx, SOx and O2.

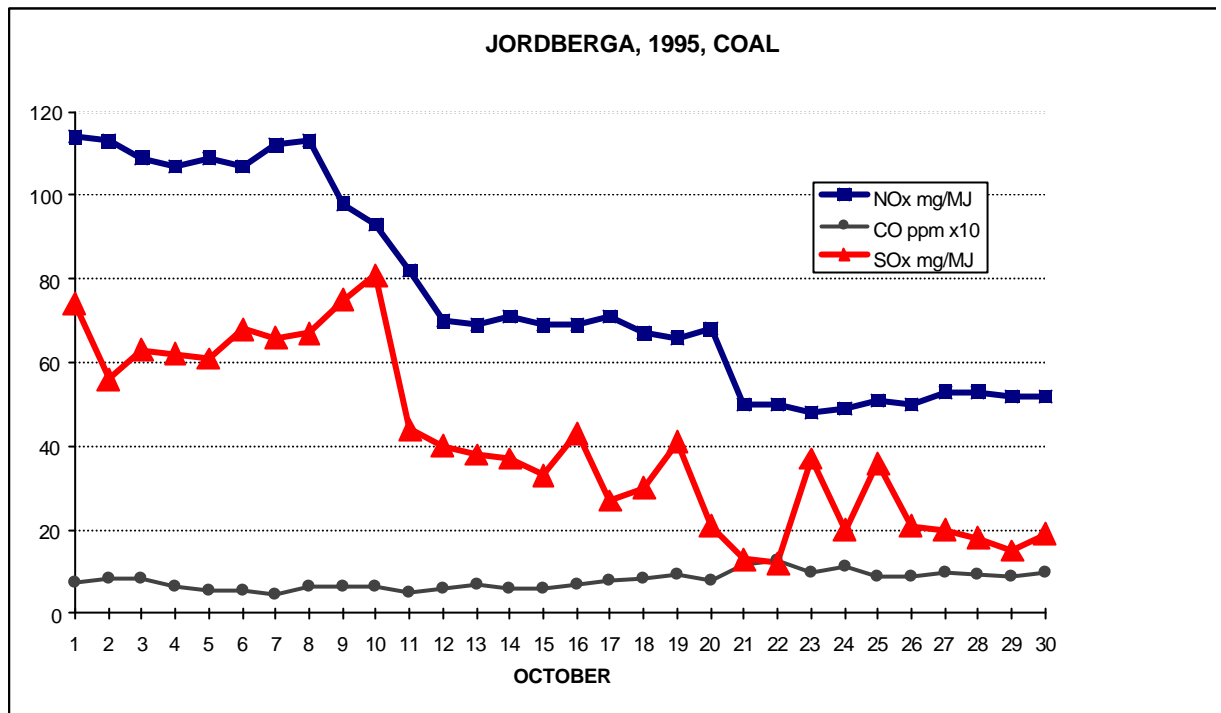


Figure 2.5 Flue gas composition at startup of ROFA installation.
100 mg/MJ≈0.22 lb/Mbtu.

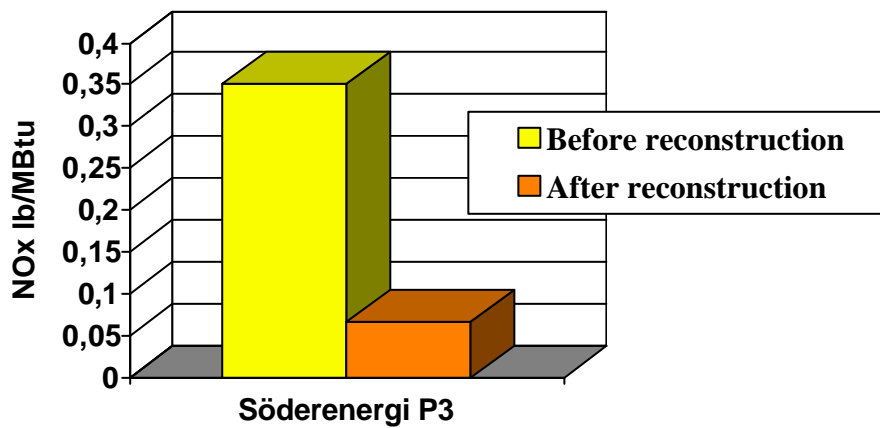


Figure 3.1 Boiler # 3 Söderenergi, comparison with and without MobotecSystem.

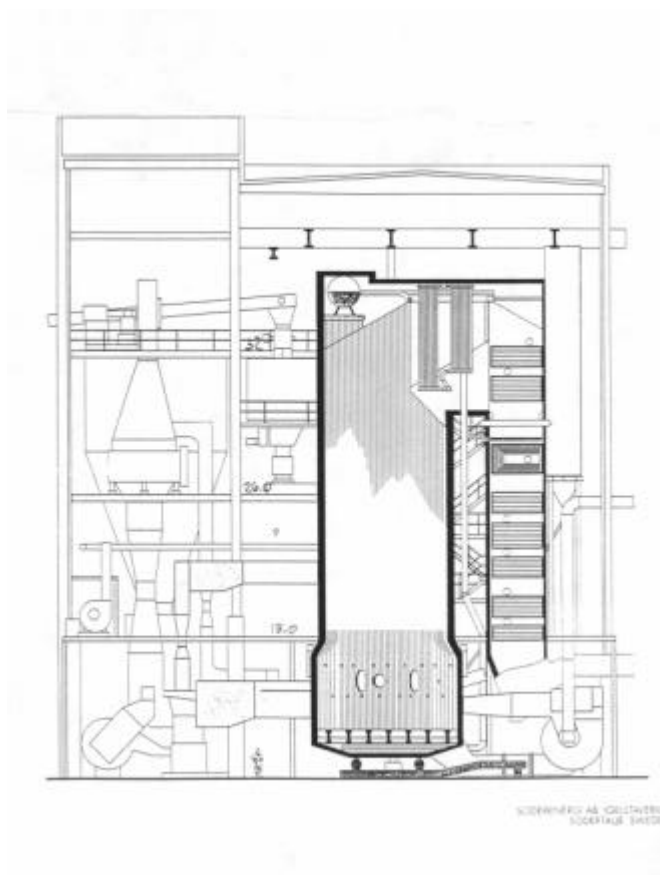


Figure 3.2 Boiler # 3 Söderenergi.

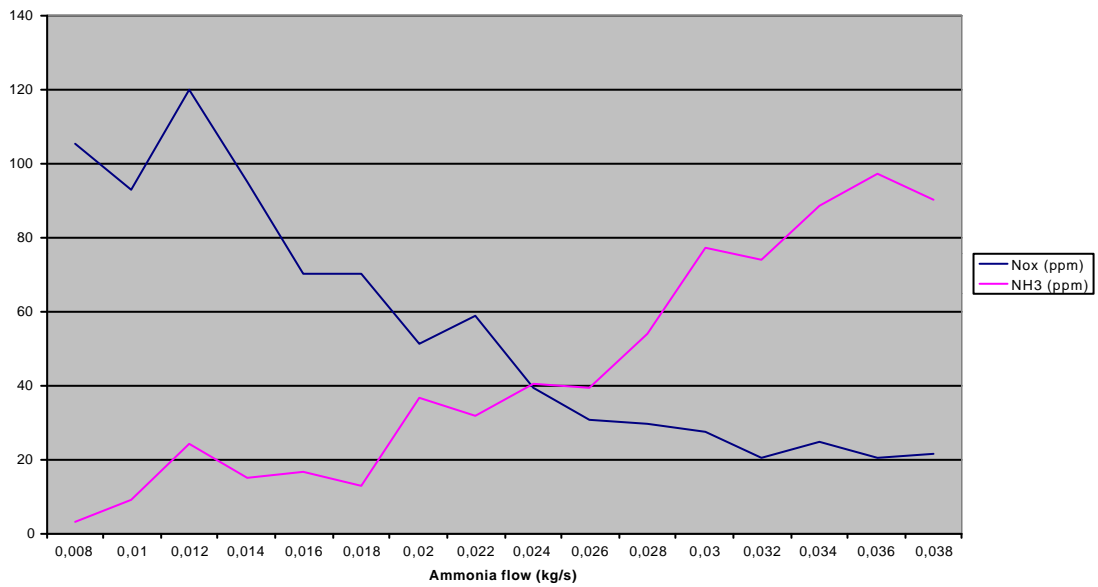


Figure 3.3 Boiler # 3 Söderenergi ammonia flow versus NOx and Ammonia slip.

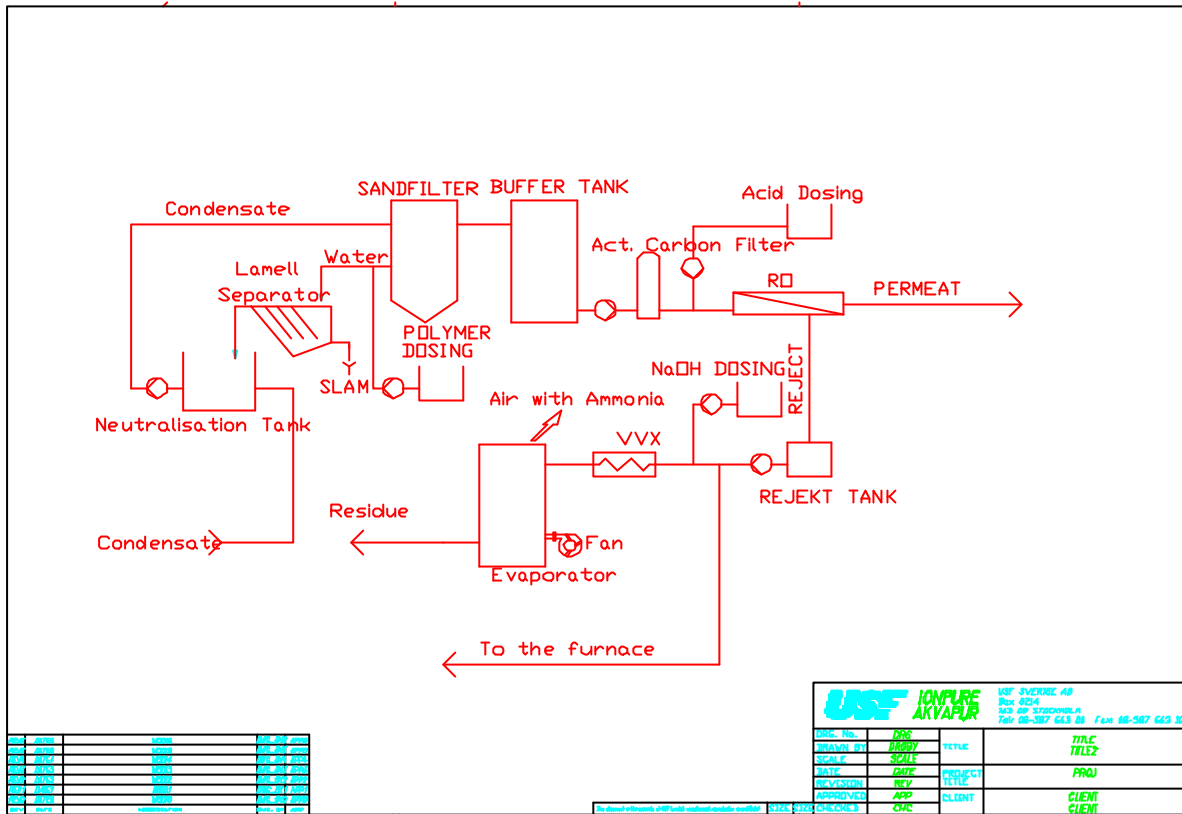


Figure 3.4 Schematic illustration of the installation for condensate cleaning

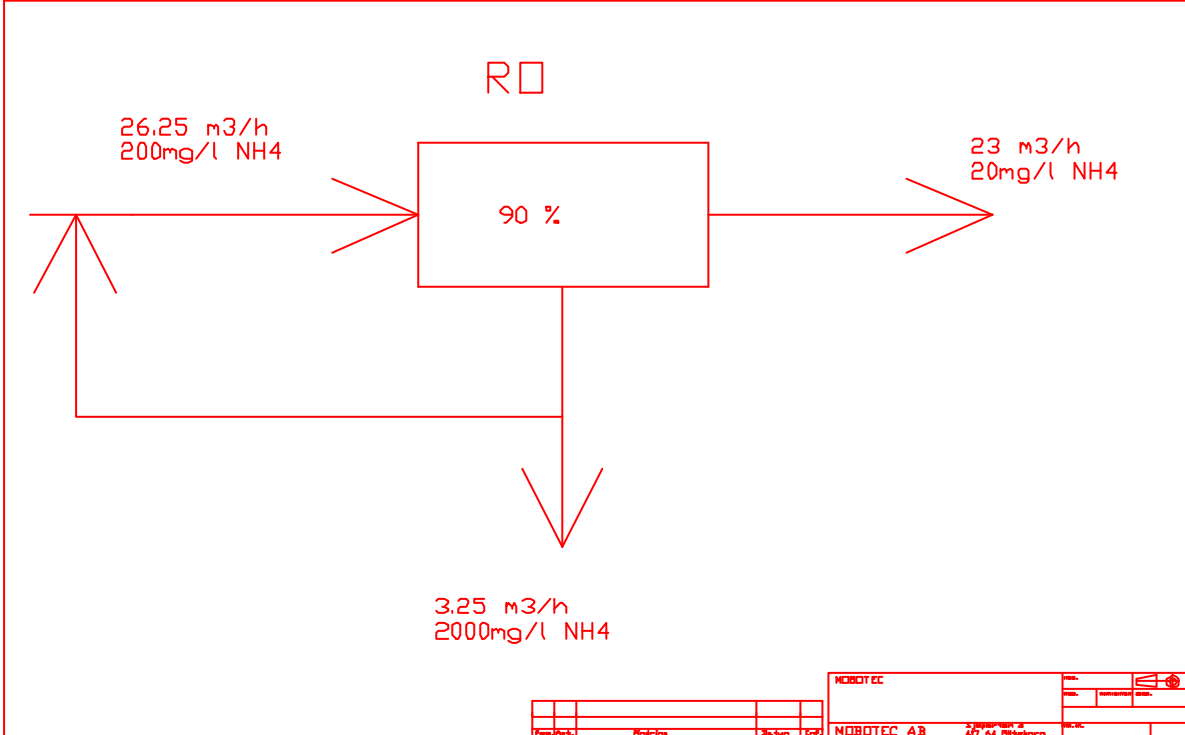


Figure 3.5 Schematic illustration of RO system.