TECHNICAL REVIEWERS' COMMENTS

LRC-LXXII(73)-A: "Demonstration of Multipollutant Reduction Using a Lextran 3-in-1 Wet Scrubber"
Submitted by: Energy and Environmental Research Center; Request for: $67,200; Total Project Costs: $199,050; Project Manager: Jay C. Almlie; Project Duration: 10 Months.

1. **OBJECTIVES**

The objectives or goals of the proposed project with respect to clarity and consistency with Industrial Commission/Lignite Research Council goals are: 1 - very unclear; 2 - unclear; 3 - clear; 4 - very clear; or 5 - exceptionally clear.

Reviewer 12-01 (Rating: 4)

General and specific objectives are very clear. The general objective is to conduct pilot-scale combustion testing of the Lextran 3-in-1 gas cleaning technology using lignite-fired flue gas conditions at the EERC. The work proposed is Phase I. Phase II, field demonstration of the technology, is not included in this proposal. The specific objectives are: 1) to establish > 90% SO_2 removal across an ESP/wet scrubber and FF/wet scrubber, 2) to establish 60% to 90% NO_x removal across an ESP/wet scrubber and FF/wet scrubber, 3) to quantify the removal efficiencies of HCl and Hg across the ESP/wet scrubber and FF/wet scrubber, 4) to characterize the SO_3 emissions, 5) to determine optimum operating conditions, and 6) to compare Lextran with lime-based wet scrubber technology.

RESPONSE: Phase II only mentioned in this proposal to convey to the LRC reviewers that a plan is envisioned for advancing this technology to field demonstrations in North Dakota. However, the EERC is currently only interested in objectively evaluating the Lextran technology relative to the claims made by the company, thus providing an objective, scientific assessment of the technology's applicability to North Dakota lignite power generation. We felt that any more discussion of Phase II intentions in this proposal would be have been presumptive and might have indicated a lack of focus on the first evaluation steps.

The general and specific objectives are consistent with LRC & NDIC goals and objectives. An explanation relating the proposal objectives and LRC/NDIC goals and objectives is not clearly shown in the proposal.

RESPONSE: We agree that an explicit linkage between project objectives and LRC/NDIC goals was not written. We are happy that you agree that the project objectives match LRC/NDIC goals and objectives. We hope that the evaluation of this technology will be successful, and that it will demonstrate an effective multi-pollutant control tool that ND power generation utilities can cost-effectively employ to enable increased utilization of an important North Dakota natural resource – lignite.

Reviewer 12-02 (Rating: 4)

Abstract talks about 99% SO_x removal, but best plan discusses targeting 90% SO_2 removal. Test plan and abstract should match and some in industry are required to have >95% removal.

RESPONSE: Although Lextran claims a potential to remove 99% of SO_2, irrespective of inlet concentration, the EERC prefers to take a more conservative approach at this early stage of evaluation. We listed what Lextran claims is possible in the abstract, then listed greater than 90% removal as an objective. As part of the test methodology, we will naturally determine the maximum removal, but listed 90% as something we thought was an achievable goal. Some in industry are required to have >95% removal, but the EERC felt the right approach was to declare goals of lower removal rates in a proposal to evaluate such a new technology, then exceed the conservatively proposed evaluation target, if possible.

Reviewer 12-03 (Rating: 4)

The development of an economical and effective technology to achieve high removals of different emissions without adversely affecting plant operations would be very valuable for utilities burning lignite. Such a technology should assure meeting existing and anticipated regulatory requirements and be compatible with future control of CO_2. In particular a technology that is capable high removals of NO_X, consistent with SCR performance is important for utilities burning Fort Union lignite, because of the problems that have been demonstrated for SCR. 99% SO_X removal is consistent with the requirements of downstream CO_2 capture and 98% reduction of mercury would be a very important

development for lignite burning coal plants.

2. **ACHIEVABILITY**

With the approach suggested and time and budget available, the objectives are: 1 - not achievable; 2 - possibly achievable; 3 - likely achievable; 4 - most likely achievable; or 5 - certainly achievable.

Reviewer 12-01 (Rating: 4)

Given the approach, time and budget presented, the objectives of the proposal are most likely achievable. The capability and experience of EERC and EPRI are well known. The parties should successfully evaluate the specific objectives.

Reviewer 12-02 (Rating: 2)

Hard to determine how successful it will be without test data.

EERC RESPONSE: We agree with your assessment. Prior to submission of the proposal to the LRC, we had been provided with only limited data. Lextran had informed us that this data has been obtained in pilot-scale testing, but we had little additional information on the details of this testing. This data did show impressive levels of multipollutant control. We hope to validate this data at the EERC with ND lignite.

As a result of your appropriate points regarding lack of data, Lextran has since provided us with additional data, contained in the attached reports.

Reviewer 12-03 (Rating: 2)

Very little information is given about the company that is developing this technology, nor is any of its staff included in the key personnel. Enough information should be given about this company and the staff that is working on developing this technology so that a judgment can be made as to whether they have the capacity continue the development of this technology to the point where it can be installed full-scale on a lignite-fired power plant.

Information on the technology, itself is very limited. The proposal claims that this technology has been demonstrated for SO_x/NO_x/Hg capture, but no further information is given. It would be useful to know the kind of application where the demonstration has occurred, at what scale and duration and whether any issues have been identified that need to be addressed in order to achieve further application of this technology.

EERC RESPONSE: The EERC has been told that this technology is being installed at two locations in China. At both locations, construction activities are being completed soon. As such, no data exists from these installations. Lextran has shared with the EERC and with GRE several sets of test data that were developed in Lextran's pilot-scale facilities in Israel. This data is presented in the attached Lextran reports.

Ozone is proposed for oxidizing NO. Ozone handling poses several challenges and the release of ozone from the stack would be problematic. An explanation should be give of why ozone was selected vs. other potential oxidants and how the ozone would be manage safely. There should be some discussion of whether there are other reactions that can consume ozone instead of oxidizing NO and how these would be dealt with.

LEXTRAN RESPONSE: In order to oxidize NO, there are several chemical oxidizers, where Hydrogen Peroxide and Ozone are the common ones. When using H2O2 as an oxidizer, high temperatures (above 660°F) should be applied for oxidation. Furthermore, Ozone as an NO oxidizer is much more selective than H2O2. Ozone as an oxidizer can react with NO, SO2, Hg and other materials that exist in the flue gas emitted. However, It's known from literature that oxidation of NO to NO2 is highly selective due to its rapid reaction rate (1.8E-14) compared with SO2 oxidation (2.2E-22). Thus, it is expected that most Ozone will react with the NO. If Ozone will react with SO2 to oxidize it to SO3, it will probably be transformed into sulfate using our catalyst (this is a reliable safeguard for any possible o3 spillover). We should measure the SO3 at the outlet of the scrubber and the aqueous phase should be checked for the presence of sulfite as well. Regarding Heavy metal oxidation, it will help to capture it in our catalyst. Regarding the Ozone handle and stack release, because Ozone is highly reactive, we assume that it will react/dissolve/decompose before leaving the stack. However, an Ozone analyzer can be used for leakage detection.

Lastly, as to ozone handling, the procedure of using ozone is not from a stored reservoir which could have placed an operational hazard. We use an ozone generator which produces exactly the 1 to 1 quantity required.

There have been several multi-pollutant control technologies proposed where high levels of SO_2 and NO_x removal have been proposed. Generally, the NO_x reductions have been disappointing; there should be more discussion of how this process assures the desired NO_x reduction.

Little information is given about the catalyst. A potential four year life time is cited for the catalyst. There should be some discussion about the cost of catalyst make-up requirements and whether there are any environmental/health concerns associated with the catalyst use or its disposal.

LEXTRAN RESPONSE: Four year lifetime refers only in the case of mercury capture, and that as well is a minimal figure (we expect the regeneration period for Hg saturation to be longer). If referring only to SO_x/NO_x removal the catalyst is used as a catalytic material and can be used without any regeneration. To the thus far collective data we are of the belief that the shelf life of the catalyst is longer than 10 years, and we have guaranteed such in our commercial deployments in China. Equally, the functioning lifetime of the catalyst is above 10 years.

The catalyst itself has no health issues as indicated in the MSDS.

As to regenerating the catalyst after it reached Hg saturation, Lextran is responsible for the leaching of the Hg out of the decomposed organic catalyst. Therefore, the required volume for disposal is very limited (few ponds).

The process diagram shows two by-product streams. One is described as small particulate matter, but the nature of this is not discussed or whether there is any catalyst present in this stream. The effect of varying particulate levels entering the scrubber result should be discussed, particularly on whether this may affect catalyst losses.

LEXTRAN RESPONSE: The scrubber is not being used as a PM remover. Thus, we expect that the incoming stream will comply with the local regulations (typically 50 mg/Nm³). The more PM is entering the scrubber the more sludge will have to be filtered out, meaning more catalyst loss with the sludge and possible yield reduction.

Any environmental concerns with this material should be mentioned. The other stream is described as liquid fertilizer, but it is not clear how would this stream would be processed to result in saleable fertilizer. Lime is proposed as an alternative reagent to ammonia. If this is explored there should be some discussion of how the nitrate by-product be dealt with.

LEXTRAN RESPONSE: We can say that process is well defined in the fertilizer production industry. It should be adopted from this industry and either way, each region has its own specification. One of the thus far hard confirmations the Lextran process enjoys is that the aqueous fertilizer and the crystalized derived fertilizer, Lextran have received from all its pilots and commercial deployments have been sent to the agriculture faculty of the Hebrew U. and has received highest clean bill of health as well as from other institute in the respective pilot countries.

The potential for secondary emissions such as ozone and ammonia and how they would be handled should be discussed.

3. **METHODOLOGY**

The quality of the methodology displayed in the proposal is: 1 - well below average; 2 - below average; 3 - average; 4 - above average; or 5 - well above average.

Reviewer 12-01 (Rating: 5)

The quality of the methodology displayed in the proposal is well above average. EERC and EPRI are seasoned in writing successful proposals. The general and specific objectives are clearly related. The specific objectives lead logically to specific tasks and subtasks. The statement of work is clearly presented.

EERC's track record of qualifications and research activities is impressive.

Reviewer 12-03 (Rating: 4)

The approach proposed is suitable for the work considered and has proven effective in past test work.

Part of the test work is proposed adding ozone at different locations upstream of the scrubber to oxidize NO. There should be some discussion of how good mixing of the ozone in the flue gas is assured and the role of ozone vs. the process catalyst in oxidizing NO. Since the proposal places some emphasis on the role of the catalyst in oxidizing NO, it is not clear why the ozone would be introduced to the system at different locations upstream of the scrubber where the catalyst is.

EERC RESPONSE: As a result of the small internal diameter (4 inches) of the flue gas pipe used in the pilot unit at the EERC, thorough mixing of ozone with the flue gas is ensured. The EERC has conducted numerous studies to verify this. The function of ozone is to oxidize NO to water-soluble NO_2 that will be scavenged by the wet scrubber. The catalyst emulsion will then further oxidize the dissolved NO_2 to NO_3^- to drive the formation of nitrate.

Consideration should be given to monitoring ozone and ammonia at the PTC outlet as well as the O_2, CO_2, CO, SO_2, NO_x, HCl and SO_3 that are proposed.

EERC RESPONSE: Ozone and ammonia monitoring at the PTC stack were considered, but were rejected based on cost. Although we agree that this would be valuable data, we were constrained by what the technology provider could afford in test costs. We therefore focused on SO2/SO3, NOx, HCl, and Hg. We will be able to infer some information on ammonia emissions from the SO3 measurements and the Hg measurements since these are wet chemistry measurements.

4. **CONTRIBUTION**

The scientific and/or technical contribution of the proposed work to specifically address Industrial Commission/LRC goals will likely be: 1 - extremely small; 2 - small; 3 - significant; 4 - very significant; or 5 - extremely significant.

Reviewer 12-01 (Rating: 4)

The proposal addresses several environmental rules presenting economic challenges for the North Dakota lignite industry. If the proposed economic and environmental goals are achieved, then the contribution of the proposed work could be very significant.

Reviewer 12-02 (Rating: 3)

Extremely significant if abstract is met; smaller if only goals are met.

Reviewer 12-03 (Rating: 4)

Should the work proceed as proposed and the results are as expected, this would be very important to lignite using utilities as an option with good potential will be identified for successful long-term emissions management.

5. **AWARENESS**

The principal investigator's awareness of current research activity and published literature as evidenced by literature referenced and its interpretation and by the reference to unpublished research related to the proposal is: 1 - very limited; 2
- limited; 3 - adequate; 4 - better than average; or 5 - exceptional.

Reviewer 12-01 (Rating: 4)

Reference to published and unpublished research is limited in the proposal. However, the work of the organization and

PIs is well known. Review of U.S. Patent 6881243, “Method for removing acidic gases from waste gas” is a crucial element in understanding the Lextran process. There exist prior demonstrations of the technology and existing installation in the US and China. Results and information from these operations would be helpful.

The PI has the EERC as support.

Reviewer 12-03 (Rating: 4)

The principal investigator demonstrates high awareness of emissions management issues and work that is occurring elsewhere to deal with this.

6. **BACKGROUND**

The background of the investigator(s) as related to the proposed work is: 1 - very limited; 2 - limited; 3 - adequate; 4 - better than average; or 5 - exceptional.

Reviewer 12-01 (Rating: 5)

The individuals and organization have exceptional backgrounds.

Reviewer 12-02 (Rating: 5)

Again, EERC has an excellent track record supporting the ND lignite industry through research. EERC's track record is impressive.

Reviewer 12-03 (Rating: 4)

The principal investigator(s) have demonstrated a solid background in the proposed work. However, better definition of the company developing the technology being investigated would be helpful.

EERC RESPONSE: Biographical information on the Lextran technical team is attached. Also, further information on Lextran can be reviewed at http://www.lextran.co.il/Technology.html

7. **PROJECT MANAGEMENT**

The project management plan, including a well-defined milestone chart, schedule, financial plan, and plan for communications among the investigators and subcontractors, if any is: 1 - very inadequate; 2 - inadequate; 3 - adequate; 4 very good; or 5 - exceptionally good.

Reviewer 12-01 (Rating: 5)

The elements of the proposal and SOW are exceptionally good.

Reviewer 12-02 (Rating: 3)

Test plan discussed one week of testing; project timetable shows 1.5 months. What else will be going on?

EERC RESPONSE: Although only one week of pilot-scale test operations is planned, data reduction, results interpretation, and post-test analysis activities will continue for a few weeks after the test. The overall project is conservatively scheduled to last up to 10 months. Reporting activities will occur during the post-test period. The EERC always allows adequate time in proposed schedules for reporting and review of data and reporting by participating entities.

Reviewer 12-03 (Rating: 4)

The project management plan is clear and appears achievable.

8. **EQUIPMENT PURCHASE**

The proposed purchase of equipment is: 1 – extremely poorly justified; 2 – poorly justified; 3 – justified; 4 – well justified; or 5 – extremely well justified. (Circle 5 if no equipment is to be purchased.)

Note: Reviewer 12-01 provided no comments.

Reviewer 12-02 (Rating: 4)

Not much equipment necessary.

Reviewer 12-03 (Rating: 5)

The proposed work of project will largely be performed with already available equipment.

9. **FACILITIES**

The facilities and equipment available and to be purchased for the proposed research are: 1 – very inadequate; 2 – inadequate; 3 – adequate; 4 – notably good; or 5 – exceptionally good.

Reviewer 12-01 (Rating: 5)

The facilities and equipment available to the participant are exceptionally good.

Reviewer 12-02 (Rating: 4)

Have been used for other lignite testing effectively.

Reviewer 12-03 (Rating: 5)

The facilities and equipment proposed for this work is of high quality with a well-established track record.

10. **BUDGET**

The proposed budget "value"[1] relative to the outlined work and the financial commitment from other sources[2] is of: 1 -very low value; 2 - low value; 3 - average value; 4 - high value; or 5 very high value.

Reviewer 12-01 (Rating: 4)

The proposed budget is of high value.

Reviewer 12-02 (Rating: 4)

Above the min. 50% will be funded elsewhere.

Reviewer 12-03 (Rating: 4)

The proposed budget is consistent with other successful projects of this nature that have been supported by NDIC.

[1] "Value" – The value of the projected work and technical outcome for the budgeted amount of the project, based on your estimate of what the work might cost in research settings with which you are familiar. [2] Financial commitment from other sources – A minimum of 50% of the total project must come from other than Industrial Commission sources to meet the program guidelines. Support greater than 50% from Industrial Commission sources should be evaluated as favorable to the application.

OVERALL COMMENTS AND RECOMMENDATION: Please comment in a general way about the merits and flaws of the proposed project and make a recommendation whether or not to fund.

Reviewer 12-01 (Rating: FUND)

General comments: **FUND**

The strengths and merits of this proposal are:

- The experience and strengths of EERC and EPRI
- GRE is an experienced industry sponsor with excellent engineering capability
- The technology is new but not "unproven"
- The technology offers the potential of significant economic and environmental rewards
- The proposal is carefully crafted
- The proposal team is outstanding
- The proposal present clearly defined specific objectives, and
- the standards of success are clearly defined measureable benchmarks

The weaknesses and flaws of this proposal are:

- If successful the proposal carries an undefined Phase II with uncertain costs
- The technology if successful may mean coal, subbituminous or lignite but not necessarily ND lignite
- The "Lextran Catalyst" is of unknown or undefined composition, character, cost or availability
- The experience, results, data and status of the existing Lextran installations are not defined

LEXTRAN RESPONSE: Unfortunately, Chine licensee does not act very transparently and we do not have performance data. This is a second reason why we seek US based pilot program.

- Industry commitment for Phase I and Phase II

My greatest concern are: 1) lack of detailed information from existing installations, and 2) information on the nature, availability and cost of the organic sulfoxide Lextran catalyst. With these concerns, I recommend the proposal for funding.

Reviewer 12-02 (Rating: FUND)

Not much discussion of activity relating to Hg reduction. That is now an important issue. I hope the project target for SO_2 removal is increased to at least 95% and believe as high as possible should be gone after for NO_x reduction as well. I recommend to fund.

Reviewer 12-03 (Rating: FUNDING MAY BE CONSIDERED)

The proposed work is high risk, high reward and relatively low cost and something that should be seriously considered. Successful completion of this project would provide lignite-burning utilities an important option for successful long-term management of its emissions, allowing the continued operation of lignite-burning power plants well into the future. However, there are several questions/concerns that should be addressed before a funding commitment is made.

Evaluation of Lextran, Ltd. Proprietary Material for Elemental Mercury, SO_2, and NO_X Removal

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Introduction

Lextran Ltd. is an Israeli company that is developing a technology to treat flue gas for control of SO_2, NO_X, and mercury emissions. This technology is based upon an organic liquid (named Lextran) that is deployed in an aqueous emulsion in a wet scrubber. Flue gas SO_2 and NO_X are captured in the aqueous phase and recovered as saleable fertilizer components (ammonium sulfate and ammonium nitrate). Lextran Ltd. envisions this technology employed as a stand-alone scrubber in new plant installations or as a retrofit to limestone-based scrubbers at existing plants.

Pilot tests conducted by Lextran Ltd. at diesel and oil-fired power plants in Israel indicate greater than 99% removal of SO_2 and 50-85% removal of NO_X. Laboratory tests conducted by Lextran Ltd. with the Lextran material showed that elemental mercury was captured by the organic phase. These tests were performed with a simple gas consisting of elemental mercury in nitrogen.

The Lextran material was tested in URS Corporation's Austin, Texas laboratories during December 2003 and January 2004. The purpose of the URS tests was to evaluate the ability of Lextran to capture elemental mercury from simulated flue gas and to simultaneously remove SO_2 and NO_X. The tests were conducted in simulated flue gases containing the major acid gas components, at flow rates ranging from 0.85 to 1.9 liter/minute. The spent Lextran solution was analyzed for mercury concentration and sulfate, nitrate, and ammonium ion concentrations in order to conduct a mass balance on the scrubber system. The results from the URS laboratory tests are intended for use in the preparation of larger-scale tests.

Testing Apparatus and Analytical Methods

The performance of the Lextran liquid was evaluated by passing simulated flue gas through a contacting vessel that contained a known amount of the Lextran solution. A series of parametric tests were conducted in which the gas residence time in the Lextran solution was varied. The effect of residence time on mercury, SO_2, and NO_X removal was studied. The treated Lextran solutions from selected tests were analyzed for mercury and sulfate, nitrate, and ammonium ion concentrations. This section describes the testing apparatus and the analytical methods employed in the investigation of the Lextran solution.

Testing Apparatus

Simulated flue gas was mixed from a variety of compressed gases, using calibrated rotameters. The dry simulation gas contained SO_2, NO, NO_2, HCl, CO_2, oxygen, and nitrogen. Moisture was added to the simulation gas by feeding dry nitrogen gas through a water saturator, which was maintained at a predetermined temperature. Mercury was added to the simulation gas in the elemental form by passing a portion of the dry nitrogen gas makeup through a mercury diffusion tube (Hg^0) maintained at a controlled, elevated temperature. Figure 1 illustrates the simulated flue gas test apparatus.

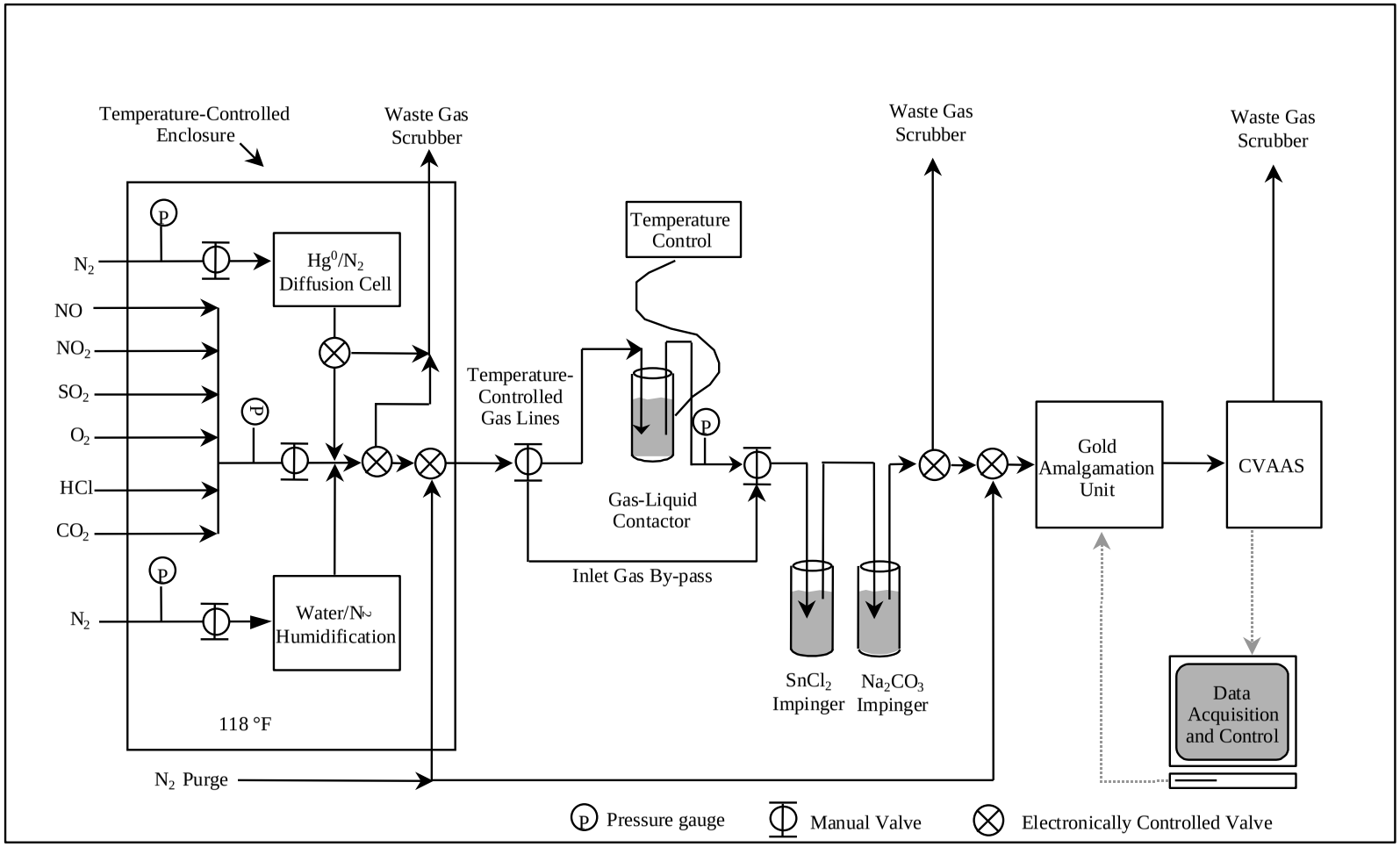

Figure 1. Bench-scale flue gas simulation unit and mercury analyzer.

The gas contacting vessel was a deep-well impinger bubbler, shown in Figure 2. The bubbler was filled with pyrex glass beads in order to enhance contact between the Lextran liquid and the simulated flue gas. Two different-sized contactors were used. A smaller contacting vessel held up to 90 mL of liquid, while a larger contacting vessel held up to 150 mL of liquid. Changing the gas flow rate and/or liquid volume in the contactor varied the residence time of the flue gas through the contactor. The contactor was equipped with ports for insertion of a pH probe and configuring a gas-tight septum through which ammonium hydroxide was injected for pH control.

Figure 2. Bench-Scale Gas Contacting Vessel.

Flue Gas Mercury Measurements

Mercury measurements were made using a semi-continuous mercury analyzer originally developed by URS for EPRI, illustrated in Figure 1. Flue gas was sent from either upstream of the contactor or from the contactor outlet through a gas treatment system consisting of a series of impingers containing various solutions. Gas exiting the impingers flowed through a gold amalgamation column where the mercury in the gas was adsorbed at less than 100°C. After adsorbing mercury onto the gold for a fixed period of time (typically 1-2 minutes), the mercury concentrated on the gold was thermally desorbed (>700°F) from the column under a nitrogen purge. The desorbed mercury was sent as a concentrated stream to a cold-vapor atomic absorption spectrophotometer (CVAAS) for analysis. The total flue gas mercury concentration was measured semi-continuously, typically with a 1-minute sample time followed by a 2-minute analytical period.

To measure total mercury in the flue gas, the impinger solutions consisted of stannous chloride ($SnCl_2$) followed by a sodium carbonate (Na_2CO_3) buffer. The $SnCl_2$ solution reduced all flue gas mercury species to elemental mercury. After passing through the $SnCl_2$ impinger, the gas flowed through the Na_2CO_3 solution to remove acid gases, thus protecting the downstream, analytical gold surface.

To measure elemental mercury in the flue gas, the stannous chloride impinger was replaced with an impinger containing tris(hydroxymethyl)aminomethane (Tris) solution. The Tris solution has been shown to capture oxidized mercury while allowing elemental mercury to pass through without being altered. Mercury passing through the Tris solution to the gold is analyzed as described above and assumed to be elemental mercury only. The difference between the total mercury concentration (stannous chloride solution) and elemental mercury concentration (Tris solution) is the oxidized mercury concentration.

Flue Gas SO_2 and NO_X Measurements

For the sampling of SO_2 and NO_X, gas detector tubes were used; the flow rates used in bench scale tests were insufficient for use of automated CEMs for performing these measurements. The gas detector sampling method consists of collecting flue gas in a 1-liter Tevlar bag and then pumping the collected flue gas through SO_2 or NO_X gas indicating detector tubes.

The NO_X gas detector tube has interferences with many of the species present in flue gas; therefore, NO_X removal across the Lextran scrubber was tested with a stream of NO_X in nitrogen with no other acid gases were present. This test provided information about the ability of Lextran to remove NO_X from gas stream; however, it provided no information about competition with other species for absorption by the Lextran liquid.

Liquid-Phase Measurements

The Lextran aqueous phase was measured for dissolved levels of sulfate, nitrate, and ammonium ion by ion chromatography (IC).

The Lextran aqueous and organic phases were measured for mercury concentration using standardized digestion/measurement methods. The organic phase was prepared for analysis using ASTM D3684, which is the method typically used for analyzing coal mercury concentration. A small portion (0.4g) of the organic phase is combusted under pressure in the presence of an absorbing solution (10% nitric acid). Upon sample combustion, the mercury vaporizes and absorbs into the nitric acid. The absorbing solution is recovered and analyzed with a Flow Injection Mercury System (FIMS). The FIMS converts liquid phase mercury into the vapor phase and detects the mercury with a cold vapor atomic absorption spectrometer.

The aqueous phase was mixed with water to obtain a 1:100 dilution and then digested using EPA Method 7470; here, sulfuric acid, nitric acid, permanganate, and potassium persulfate are added to the solution in order to unbind the mercury from the sample matrix, oxidize it and hold it in solution. The digested aqueous phase was then analyzed with the FIMS analyzer.

Bench Scale Test Procedures

The scrubber contactor was loaded with a known volume of the Lextran solution and placed into a heated water bath (55°C). After allowing at least 20 minutes for the Lextran solution to achieve thermal equilibrium, flue gas was passed through the contactor. During the equilibration time, the mercury, SO_2, and NO_X concentrations of the inlet flue gas were measured.

Tests were carried out in batch mode. The pH was monitored using a pH probe and meter and was manually adjusted, as needed, by adding drops of ammonium hydroxide.

Tests were initiated by flowing simulated flue gas at a specified rate, ranging from 0.85-1.9 L/min, across the scrubber contactor. The effluent gas stream then flowed through heated lines to a semi-continuous mercury analyzer for analysis. The outlet total and elemental mercury concentrations were monitored semi-continuously, with data points generated approximately every 3 minutes. Each test was run long enough to obtain a steady-state outlet mercury concentration for at least fifteen minutes (at least 5-7 data points). These steady-state points were averaged to determine the removal efficiency of the Lextran solution.

Once steady-state outlet mercury measurements were obtained, a grab sample of the outlet flue gas was taken. The SO_2 and NO_X concentrations in the outlet gas were measured with gas detector tubes.

The simulated flue gas conditions tested are summarized in Table 1. Mercury concentrations are not reported in this table, as they varied with the flow rate of the flue gas. Because the mercury stream was maintained at a fixed flow rate, the mercury concentration decreased as the flow rate of the simulated gas increased. At 1 liter/minute of total flue gas flow, the mercury concentration was 26 $\mu g/Nm^3$. Flue gas flow rates and corresponding mercury concentrations are provided in the results section of this report for the specific tests.

Table 1. Flue Gas Conditions Tested

Species	Flue Gas Condition A	Flue Gas Condition B	Flue Gas Condition C	Flue Gas Condition D	Flue Gas Condition E	Flue Gas Condition F
CO_2	0%	12%	12%	12%	12%	12%
H_2O	7%	7%	7%	7%	7%	7%
O_2	5%	5%	5%	5%	5%	5%
NO	0 ppm_v	0 ppm_v	0 ppm_v	0 ppm_v	75 ppm_v	75 ppm_v
NO_2	0 ppm_v	0 ppm_v	0 ppm_v	0 ppm_v	0 ppm_v	75 ppm_v
SO_2	0 ppm_v	0 ppm_v	100 ppm_v	1400 ppm_v	2000 ppm_v	2000 ppm_v
HCl	0 ppm_v	0 ppm_v	0 ppm_v	0 ppm_v	0 ppm_v	5 ppm_v
N_2	balance	balance	balance	Balance	balance	balance

A separate set of tests were conducted for the purpose of determining how mercury partitions between the Lextran and aqueous phases. For these tests, it was necessary to accumulate sufficient amount of mercury in the Lextran liquid to enable detection by the analytical method employed. The tests were performed with a flue gas elemental mercury concentration of approximately 2300 $\mu g/Nm^3$, which is two orders of magnitude higher

than typical coal-fired flue gas mercury concentrations, in order to build appreciable levels of liquid-phase mercury; thus the higher concentration enabled a shorter run-time needed to accumulate a detectable amount of mercury in the Lextran solution.

At the beginning of the mercury accumulation test, the outlet mercury concentration was measured in order to confirm that total mercury removal was achieved at the high inlet concentration. The test then proceeded for 1.5 hours. The scrubber was controlled at a pH between 6.0 and 6.5 using ammonium hydroxide reagent. In previous tests, it was determined that ammonia interferes with the operation of the mercury analyzer, so the exit gas from the scrubber was sent to waste and was not analyzed for outlet flue gas mercury concentration.

At the conclusion of the mercury accumulation test, the Lextran liquid was transferred to a separation funnel. The aqueous fraction of the Lextran was collected and analyzed for ammonium, sulfate, and nitrate ions by ion chromatography (IC). Both the aqueous and organic phases were analyzed for mercury using the method described above.

Test Results

Scrubber Removal of Mercury

Two batches of Lextran liquid were tested for mercury scrubbing capacity. One batch demonstrated near-complete removal of elemental mercury under a variety of test conditions. The other batch, which was later determined to be an expired solution, performed poorly with respect to mercury removal. The test conditions and results for experiments conducted with these two batches of solution are described in this section.

Initial tests performed with a solution provided by Lextran showed initial elemental mercury removal of approximately 50% from the simulated gas stream followed by immediate breakthrough to 100%. Several different tests were performed with this solution in an attempt to improve the performance including the following: (1) Increasing the amount of solution in the bubbler, (2) increasing liquid-gas contact by adding glass beads to the bubbler, (3) testing scrubber operation at room temperature, and, (4) testing at 55°C. None of these efforts resulted in improved mercury capture. Lextran subsequently determined that the originally sent solution had been used in other testing situations and may have expired. This solution was subsequently sent back to Lextran for analysis in order to further ascertain the cause of its poor performance.

A fresh Lextran solution was then received and the testing regime was repeated with it (tests #6-11). The results of these tests are summarized in Table 2. Test #6 was begun with 50 grams of pure Lextran organic phase. This solution was used in subsequent tests #7, 8, 9, 10, and 11. All tests were run with the contactor situated in a heated bath maintained at 55°C.

The first test with the fresh solution was performed using a synthetic flue gas containing elemental mercury in oxygen, nitrogen, and water (test #6). A mercury removal efficiency of 99.7% was measured during the test. In the next test (#7), CO_2 was added to the synthetic gas. Again, 99.7% removal of mercury was measured. The flow rate of the flue gas was increased to 1.55 L/min (test #8), thereby decreasing the contact time between the gas and the Lextran. Once again, high mercury removal was achieved indicating good reactivity of the liquid. In tests #9 and 10, SO_2 was added to the flue gas at two different concentrations, 100 ppm and 1400 ppm, respectively. In both cases, the Lextran liquid removed at least 99.0% of the mercury in the inlet gas. For test #11, water was mixed into the Lextran in order to form an emulsion typical of what is intended for use in an SO_2 scrubber. The mercury removal remained at 99.0% with the addition of the water. Inlet mercury concentrations for these tests ranged from 14 to 31 $\mu g/Nm^3$, depending upon the flue gas flow rate. In each of these tests, the measured outlet mercury concentration was below 0.4 $\mu g/Nm^3$, with the majority of the data below 0.1 $\mu g/Nm^3$.

Table 2. Mercury Removal by Lextran Liquid at Various Test Conditions

Test #	Mass Lextran (g)	Mass Water (g)	Gas Composition (see Table 2)	Gas Flow Rate (liter/min)	Inlet Hg^0 Concentration ($\mu g/Nm^3$)	% Removal of Hg^0 (%)
6	50	0	A	0.85	31	99.7
7	50	0	B	0.85	31	99.7
8	50	0	B	1.55	17	99.1
9	50	0	C	1.90	14	99.7
10	50	0	D	1.90	14	99.0
11	50	12	D	1.90	14	99.0

In the previous tests, the pH of the Lextran was not controlled. The ability of the Lextran emulsion to remove SO_2 and NO_X from flue gas is a function of the pH of the emulsion. The liquid should be maintained above a pH of 5.0 for appreciable acid gas removal. Thus, for the next set of tests, the Lextran liquid pH was controlled by manually adding ammonium hydroxide. The effect of pH on mercury scrubbing ability of the solution was then measured.

For test #12 a fresh solution, composed of 15 g of H_2O and 60 g of Lextran, was loaded into the vessel and heated (and maintained) to 55°C. Flue gas composition E, which contained 2000 ppm SO_2 and 75 ppm NO, was then prepared. The synthetic gas, which contained approximately 26 $\mu g/Nm^3$ mercury was then flowed across the vessel at a flow rate of 1 liter/min.

The pH of the "fresh" (untested) Lextran solution was approximately 3.5. Prior to the start of the test, ammonium hydroxide was added to the solution to increase the pH to 8.25. After twenty minutes of flue gas exposure, the outlet mercury concentration was monitored. Figure 3 shows the outlet mercury concentration (represented by solid diamonds on the plot) and pH (represented by open circles) as a function of time. From a time of 20 minutes to 70 minutes, the outlet mercury concentration varied between 0.6 and 2.12 $\mu g/Nm^3$. These levels are higher than the outlet mercury concentrations measured during testing when pH was not controlled. However, it still represents an average mercury removal as high as 95%. During this period the pH fell from 8.25 to 4.5, as acid gases were captured by the solution.

At a time of 70 minutes, ammonium hydroxide solution was spiked into the Lextran solution to bring the pH up to approximately 7. Immediately upon spiking the solution with the ammonium hydroxide, the outlet mercury concentration correspondingly spiked to a high of 5.3 $\mu g/Nm^3$. The mercury concentration quickly fell and returned to the concentrations seen prior to the ammonium hydroxide spike.

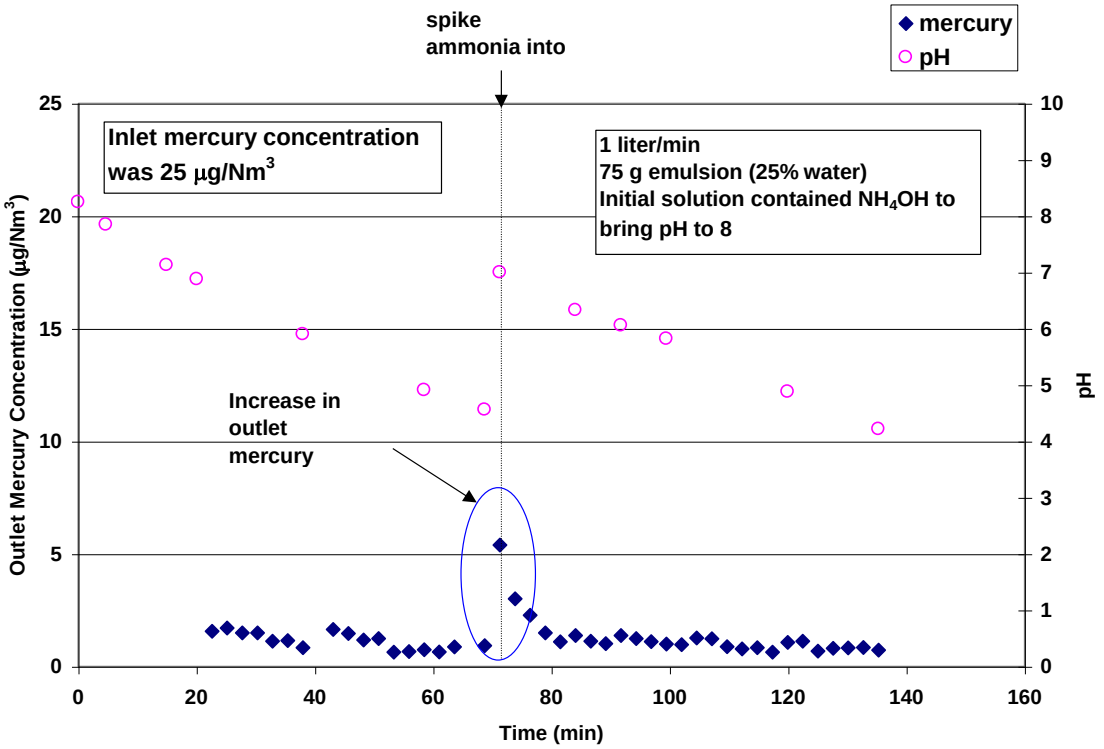

Figure 3. Mercury outlet concentration and pH variations with manual pH control using ammonium hydroxide addition.

At conclusion of the pH control test, the integrity of the mercury analytical system was checked by measuring the inlet mercury concentration. The measured values were half the expected inlet concentration, indicating a loss of calibration of the gold amalgamation column. The mercury flow was diverted to a waste stream, and the analytical system responded quickly, returning to a zero baseline concentration. This result indicates that the system was able to detect the presence of mercury in the flue gas, but it was not able to provide quantitatively accurate values of mercury concentration. This behavior was further verified by the poor recovery of calibration spikes of elemental mercury into the flue gas.

The mercury analytical system had remained within 10% of calibration for the first two days of testing with the Lextran material. It was only upon introduction of ammonia into the scrubber that the analytical system lost calibration. The corruption of the (analytical) gold surface by ammonia has been documented in previous tests involving SCR systems employing liquid ammonia addition. However, mercury measurements have been successfully performed on other processes employing ammonia. The effect of ammonia on the mercury analytical system is not well understood, and at this time cannot be easily predicted.

The gold amalgamation column was cleaned and subsequently re-calibrated successfully, and the Lextran scrubbing tests proceeded. Additional investigations of the effect of ammonium hydroxide on the mercury scrubbing performance of Lextran liquid were

desired. In an effort to prevent corruption of the gold amalgamation column, modifications were made to the testing procedure. First, a bubbler containing 0.1 N sulfuric acid was placed downstream of the analytical stannous chloride impinger. It was believed that the sulfuric acid would capture any evolved ammonia gas, thereby preventing it from reaching the gold amalgamation column. Secondly, it was decided to add the ammonium hydroxide slowly enough to keep the pH of the Lextran solution below 7.0. It was thought that as long as the Lextran solution was kept slightly acidic, the injected ammonium hydroxide might not break through the solution.

The next set of tests was performed with an increased liquid volume and decreased flow rate in order to increase residence time. Increased residence times are necessary for SO_2 and NO_X removal. The Lextran solution was composed of 120 grams of Lextran liquid and 30 grams of water. The gas flow rate was 1.1 liter/minute. Gas composition F, which included 2000 ppm SO_2, 75 ppm NO, 75 ppm NO_2 and 5 ppm HCl, was used.

After the reaching equilibrium, ammonium hydroxide was added to the Lextran scrubber until the pH reached 5.4. No mercury release from the scrubber was observed during this procedure. The pH was allowed to fall to 4.0 during flue gas exposure, then another spike of ammonium hydroxide was added to increase the pH to 6.35. The outlet mercury concentration increased from 0.5 to almost 2 μg/Nm^3 as shown in Figure 4. However, this increase in outlet mercury concentration was smaller than seen in the previous test. The pH was allowed to fall to 5.5, and then ammonium hydroxide was spiked into the scrubber to bring the pH to 6.4. No corresponding increase in outlet mercury concentration was observed.

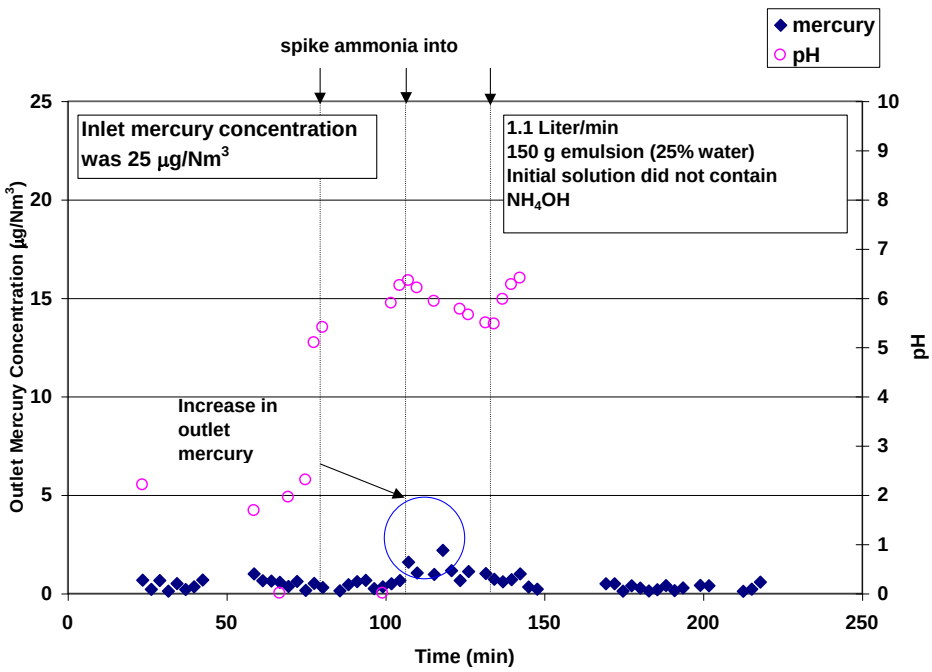

Figure 4. Mercury outlet concentration and pH for slower addition of ammonium hydroxide.

Although analytical difficulties were encountered when ammonia was present in the system, test results appear to indicate that the addition of ammonium hydroxide to the Lextran solution can cause an increase in the scrubber's outlet mercury concentration. It is unclear whether the increase in the outlet mercury concentration is attributable to temporarily reduced scrubbing efficiency or due to a release of mercury captured in the Lextran solution. Addition of the ammonium hydroxide in a slower and more controlled manner may reduce or eliminate this problem. Because the addition of ammonium hydroxide was performed by hand with a very concentrated solution, the behavior observed in the laboratory may not be indicative of the behavior that might be seen in a full-scale application with appropriate controls and feed systems.

SO_2 Scrubbing Ability

The SO_2 scrubbing ability of Lextran was measured during tests #12-15, described above. The SO_2 concentration of the inlet gas was 2000 ppm. The ability of Lextran solution to scrub SO_2 increased with increasing pH of the emulsion. A 20% water solution was tested at two different residence times. The results are summarized in Table 3. At an approximate pH of 4.5, approximately 62.5% of the SO_2 was captured. Addition of ammonium hydroxide to raise the pH resulted in higher SO_2 removals. In the pH range between 4.9 and 5.9, 95-96.5% of the SO2 was removed. At pH above 6.0, the outlet SO_2 was undetected with the gas tubes, indicating greater than 99.5% removal.

Table 3. SO_2 Scrubbing Results

pH	% SO_2 Removal	
	Flow Rate = 1 lpm Emulsion Mass = 75 g	Flow Rate = 1.1 lpm Emulsion Mass = 150 g
4.55	62.5%	
4.90		95.5%
5.65		95%
5.90	96.5%	
6.20		>99.5%
6.25		>99.5%

NO_X Scrubbing Ability

The ability of Lextran to scrub NO_X was evaluated using a synthetic gas composed of NO, NO_2, and nitrogen. The other flue gas components were not included because of their interference with the gas detector tube (analytical) method. The flow rate of the gas stream was 1.1 liter/min, and the solution was composed of 150 grams of a mixture containing 20% water in Lextran solution. The pH was maintained between 6.1 and 6.4 for these tests.

Two relative concentrations of NO and NO_2 were tested. In the first case, the gas was composed of 40 ppm NO, 100 ppm NO_2, and nitrogen. The Lextran solution scrubbed

70% of the NO_X from this stream. In the second case, the flue gas contained 70 ppm NO and 70 ppm NO_2, and the Lextran solution scrubbed 40% of the NO_X. In both tests, the amount of NO_x removed from the flue gas was very near the percentage of NO_2 as NO_X in the gas. Speciation of the outlet gas was not possible with the gas detector tubes. Further tests would be needed to determine whether the Lextran solution removes primarily NO_2 (by solvation) or whether NO is also removed.

Mercury Partitioning between Aqueous and Organic Phases

As described in the Test Procedures section, a known amount of mercury was loaded into a Lextran emulsion. The emulsion was separated into aqueous and organic phases by allowing the solution to settle in a separation funnel. The goal of the experiment was to determine the quantity of mercury in the aqueous phase and the quantity of mercury in the organic phase.

Two mercury loading experiments were performed using two identically prepared Lextran solutions and identical procedures. These two experiments are called L1 and L2. A water-only scrubber was also tested as a baseline case. Neither Lextran emulsion separated neatly into the aqueous and organic phases. In both tests L1 and L2, a clean organic phase formed, with an inter-phase above it. The inter-phase appeared to contain both aqueous and organic phases. In experiment L2, a small amount of inter-phase was also present on the very bottom of the separation funnel. It was necessary to centrifuge the inter-phase at high speed for twenty minutes in order to obtain a sufficient quantity of aqueous phase for analysis. Even after the centrifuging, a significant portion of the inter-phase material remained.

The extracted aqueous phase and the organic phase were analyzed by URS for mercury content. The samples were digested and prepared according to the methods outlined in the Test Procedures section. The purpose of digesting the sample was to release the mercury from the sample matrix and solvate it into the aqueous phase.

As part of the quality assessment procedures, a known amount of mercury was spiked into the aqueous solution after the dilution but before the digestion step. This spike serves as a check for the presence of any interference between the sample matrix and the analytical system. The measured amount of mercury in the spiked samples was significantly lower than the actual spike amounts. Subsequent spiked digested samples were analyzed, with even lower recovery. Once the Lextran solutions were allowed to clear the FIMS system, the detection of mercury returned to normal. This behavior indicates that the Lextran sample matrix interferes with the ability of the AA to detect mercury. Additional analytical development will be required to quantitatively characterize the mercury levels in the Lextran liquid.

Ion Balance

The aqueous phases from the two mercury loading experiments were analyzed by ion chromatography (IC) for the concentrations of ammonium, nitrate, and sulfate ions. These measurements were compared to the amount of SO_2 and NO_X in the inlet flue gas that passed through the Lextran emulsion during the mercury loading experiments. An experiment using only water was run in the same manner as the Lextran emulsion loading experiments. The water blank results are provided for comparison.

Table 4 compares the IC measurements to a mass balance for the sulfate ion. The theoretical sulfate value represents the amount of sulfate ion that would be present in the aqueous phase if 100% of the SO_2 was captured. The theoretical concentration is calculated as the mass of sulfate ion passed through the system divided by the starting amount of water in the emulsion.

The aqueous phases L1 and L2 had nearly the same sulfate concentration, approximately 14000 ppm. However, the analyzed aqueous phase contained only 70% of the theoretical sulfate. Likewise, the water blank contained 76% of the expected sulfate. The pH of the Lextran emulsion and the water blank was maintained between 6.0 and 6.5 for the duration of the loading experiment. In this pH range, it is expected that the Lextran emulsion would remove greater than 95% of the SO_2 from the inlet flue gas. The missing sulfate may be present in the inter-phase. Alternatively, some of the sulfate may have partitioned to the organic phase. Neither the inter-phase nor the organic phase was amenable to IC analysis due to their organic matrix.

Table 4. Mass balance analysis of sulfate ion.

Sample	Measured SO_4^{2-} [ppm]	Theoretical SO_4^{2-} [ppm] (assumes 100% capture)	Percent Recovery
L1	14758	20700	71
L2	13760	19700	70
Water	4549	6000	76

The results for the nitrate ion mass balance analysis are shown in Table 5. The nitrate concentration was almost four times higher for aqueous phase L2 than aqueous phase L1, while the ammonium concentration was lower in L2. However, the sum of the nitrate and ammonium ions for L1 and L2 are approximately equal (Table 7), indicating that some of the nitrate ion may be reduced to ammonium ion. The reduction of the nitrate ion would further explain why the measured nitrate concentrations are significantly higher than the theoretical nitrate concentrations. These results were not seen for the water blank sample, further indicating that the Lextran organic may facilitate transformation of ammonium ion to nitrate ion.

Table 5. Mass balance analysis of nitrate ion.

Sample	Measured NO_3^{2-} [ppm]	Theoretical NO_3^{2-} [ppm] (assumes 100% capture)	Fractional Recovery (assuming 100% capture)
L1	1291	940	137
L2	4536	890	510
Water	<100	270	<40%

Table 6. Analysis of nitrogen species.

Sample	Measured NO_3^{2-} [ppm]	Measured NH_4^+ [ppm]	NO_3^{2-} + NH_4^+ [ppm]
L1	1291	8215	9506
L2	4536	5563	10099

Conclusions

The results from bench-scale tests performed by URS indicated that the Lextran product is capable of achieving high removal levels of elemental mercury and SO_2, and appreciable removal of NO_X from synthetic flue gas. The Lextran solution was tested under a range of gas flow rates, liquid volumes, and acid gas concentrations. The material was tested as pure Lextran and as a mixture of Lextran and water. The elemental mercury scrubbing efficiency was greater than 99% in all tests except when ammonium hydroxide was added to the solution; the mercury scrubbing performance decreased slightly, but was still greater than 95%, when the system pH was controlled with ammonium hydroxide.

Gas-phase measurements indicated that the Lextran process liquid possesses a high capacity for mercury, enabling long-term removal to be achieved. Mass balance results for mercury are not available at this time due to analytical interference associated with the Lextran matrix. An alternate analytical technique is being investigated as a viable means to quantify of the Lextran liquid mercury levels.

The SO_2 removal by the Lextran liquid was a strong function of pH. At pH greater than 6.2, more than 99.5% of the SO_2 was removed from the flue gas. At pH below 5.0, the SO_2 removal was less than 60%. The NO_X removal was strongly dependent upon the relative speciation between NO and NO_2 it the flue gas. In the two experiments that were run, the NO_X removal percentage was approximately equal to the percentage of NO_X as NO_2. Liquid-phase analyses indicated that the amount of sulfate present in the aqueous phase was approximately 70% of the SO_2 introduced to the emulsion via the flue gas. Because the pH of the emulsion was maintained above 6.0, greater than 95% SO_2 removal should have been achieved. The “missing” sulfate may be in the organic fraction or more likely in an inter-phase that was present upon separation of the emulsion. This inter-phase possessed a mixture of organic and aqueous characteristics.

The nitrate concentrations measured in the aqueous phase were higher than expected, and the ammonium ion concentrations were lower than expected. For the two experiments that were run, the sum of the nitrate and ammonium ions were approximately equal. From these data, it is postulated that the Lextran may facilitate a transformation between the nitrogen species.

The results of this study suggest that the Lextran solution may be a viable option as a multi-pollutant control for coal-fired flue gas applications. The liquid is able to remove very high levels of insoluble elemental mercury from flue gas for extended periods of time. This may provide substantial improvements for wet absorbers that currently remove no elemental mercury or that suffer from mercury re-emissions. Additional tests are warranted to further evaluate the capacity of the Lextran liquid under more realistic gas and scrubber conditions, or in actual flue gas.

AviVoldman, MBA, B.Sc

Principal Areas of Expertise

Mr. Voldman's principal areas of interest and expertise include process scale-up, process engineering, new technologies introduction, air pollution control with an emphasis on SOx/NOx and mercury, pharmaceutical production, NPI, change management, environmental control, production management.

Professional Experience

2011 – Present: Technology Manager, Lextran LTD. Mr. Voldman responsibilities include leading technological development of the product, managing production, supervising lab and pilot activities. Mr. Voldman is also involved in engineering design of potential customer's facilities.

2010 – 2011: Project Manager, Operational Development, Operations Division, TEVA Pharmaceuticals. Mr. Voldman responsibilities included leading dozens of projects for raw material change resulting over 100M$ annual cost savings, supervising 2 teams of researchers (production and analytics) focused on material changes, coordination with the main disciplines involving production, RA, QC,QA, supply chain etc. Mr. Voldmanwas also managing projects of new technologies introduction including cutting edge production technology with a budget of 20M$.

2006 – 2010: Project & Process Engineer, Global R&D, API Division, TEVA Pharmaceuticals. Mr. Voldman responsibilities included process technologies evaluation, new technologies introduction to the R&D and production, product development projects at sub-contractors sites and TEVA sites. Mr. Voldman also managed the site engineering and led the site to be awarded 6 stars in the "Eretz Israel Yaffa" competition.

2005 – 2006: R&D Researcher, Lycored. Mr. Voldman responsibilities included formulation development, scaling-up lab processes to production lines. Mr. Voldmanwas also involved in production engineering.

Qualification

MBA, Business Management, Ben-Gurion University, 2010.

Managerial Development, TEVA Pharmaceuticals, 2009.

B.Sc, Chemical Engineering, Dual degree program in Nano-science and technology for outstanding students, Ben-Gurion University, 2006.

B.Sc, Chemistry, Dual degree program in Nano-science and technology for outstanding students, Ben-Gurion University, 2006.

Publication and Presentation

Presented at the IIChE (Israeli Institute of Chemical Engineers) annual meeting and Coauthored several professional publications.

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Curriculum Vitae

Date of birth: 25.07.1939

Birth place : Kiev, USSR

Education:

1961-1964: BA, Chemistry, Kiev University

1964-1966: Mathematics and Applied Science, Kiev Applied Mathematics Institute

1966-1970: PhD, Mathematical modeling of Industrial catalytic processes, Academy

Academic Appointments:

1979-1982: Consultant, Laboratory of Chemical Processes and Reactors, Chemical Engineering Science Fac., Technion, Haifa

1976-1978: Sr. Fellow Researcher, Chemical Engineering Science Fac., Technion, Haifa

1973-1976: Fellow Researcher, Hebrew University, Casali Institute of Applied Chemistry, Jerusalem

1970: Ph.D. in Chemical Technology, Academy of Science, Kiev

1970-1972: St. Lecturer, Institute of Heat and Mass Transfer, Kiev

1964-1970: Lecturer, Institute of Heat and Mass Transfer, Kiev

Industrial Experience:

1998- Chief Chemist, Lextran Ltd

1992-1998: Heading of R & D projects at the Golan Initiative Center, Katzrin

1980-1992: Group Leader, Research Laboratory, Haifa Chemicals Ltd, Haifa

1978-1980: Head of Research Laboratory, Haifa Chemicals Ltd, Haifa

1964-1971: Consultant Engineer, Chemical Industrial Complex, Severodonetsk, USSR

1961-1964: R&D Engineer, Chemical Plant, Kiev

Research Activity:

1998-up to now: Inorganic compounds for agricultural and civil engineering, ecology, water and gas cleaning

1992-1998:	Developing Anticorrosive pigments based on slow release technology; Conductive ceramics; Salt separation in electrostatic field
1980-1992:	Development of new fertilizers and slow released fertilizers
1980-1982:	Inorganic Chemistry: new processes for obtaining nitrates and phosphates; liquid extraction; ion exchange
1976-1979:	Industrial catalytic processes; ion exchange synthesis; synthesis of fire resistant and ablative materials
1972-1976:	Heat and mass transfer into porous bodies; synthesis of catalysts
1966-1970:	Heterogeneous catalysts; hydration of acetylene; methane conversion
1964-1966:	Synthesis of various phosphates (Ca, Mg, Cd, Cu, etc.)

Published over thirty scientific and registered over sixty patents

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Education:

2010 -present: Postdoctoral Research Associate

Department of Chemistry, Stanford University. Supervisor: Prof. Robert M. Waymouth.

Research project: Design, structure, and catalytic α-olefin polymerization behavior of phenolate ether group IV complexes.

2003-2010: Ph.D. in chemistry (direct track).

Schulich Department of Chemistry, Technion – Israel Institute of Technology.

Supervisor: Prof. Moris S. Eisen.

Thesis: Hetero-aza-allyl Complexes of Li, Ti, Zr, and V: Structure, Reactivity and Catalytic Propylene Polymerization.

1994-1997: B.Sc in Chemical Engineering and Chemistry High School Teaching Diploma.

Departments of Chemical Engineering and Education in Technology and Science.

Technion – Israel Institute of Technology. (Academic reservist).

Honors

2009: Schulich award for excellence in teaching.

2006-2009: Raymond Rosen Ph.D fellowship.

1993: Ramat-Gan B.Sc scholarship.

Professional Skills

Organic and organometallic synthesis: Preparation and purification of inorganic, organic, and organometallic compounds (organo-lithium, magnesium, group IV, and vanadium) using various organic, high vacuum, Schlenk, and glove-box apparatus and techniques. Characterization of the products by X-ray diffraction, NMR, ESR, ESI-MS, MALDI-TOF, FT-IR spectroscopy, GC/GCMS, HPLC, TLC, and elemental analysis.

Physical Organic techniques: Mechanistic investigations using structure-activity relationships studies and various spectroscopic methods.

Computational techniques: Development of a computer program for the stochastic (Monte-Carlo) modeling of polypropylene microstructures produced by fast-epimerizing octahedral catalysts.

Analytical techniques: experience in various one and two dimensional NMR techniques (with both Bruker and Varian spectrometers), GPC, GCMS.

Polymer chemistry: Catalyst design, Atmospheric and high pressure polymerization of α-olefins using complexes of transition metals and different Al or boron based activators, isolation and purification of polymer fractions, full polymer characterization (stereo- and regiochemistry, end groups, molecular weight and polydispersity).

Management skills: Maintenance of lab equipment and inventory, operation and maintenance of glove boxes, Parr and other high pressure reactors, supervision of graduate and undergraduate students, cooperation with group colleagues and with other researchers.

Chemical engineering: Project management, process design and operation research in the paper production and water purification plants. Assessment and prevention of risk from hazardous materials to life and property.

Computer skills: Certified computer technician. Proficiency in MS Office (moderate knowledge of VB), MS Access, MS Project, MS Visio, Chemoffice, Topspin/ACD, ORTEP/Mercury, Endnote.

Research Interests:

1. Structure and reactivity of organometallic complexes.
2. Design and synthesis of unique polymer architecture via Homo- or co-polymerization of α olefins by early transition metal complexes.
3. Homogenous catalysis in the broader sense, especially catalytic activation and functionalization of strong C-H or C-F bonds.
4. Organic synthesis.

Work Experience:

2001-2002: Process Engineer, process design department, American Israeli Paper Mills.
1998-2000: Advisor for civil defense against hazardous chemicals and chemical warfare. The Home Front Command, Jerusalm district, the Israeli Defense Forces.

Languages

English, Hebrew (native)

Miscellaneous

- Trained for first aid and life saving and handling with hazardous material incidents.
- Hobbies: History and Archeology, Scuba-diving (2 stars qualification), Cooking.

Publications:

1. Octahedral Complexes in the Polymerization of alpha Olefins. Aharonovich Sinai , Volkis Victoria, Eisen Moris S. *Macromol. Symp.* **2007**, 260, p. 165.
2. N,N′-Bis-silylated Lithium Aryl Amidinates: Synthesis, Characterization, and the Gradual Transition of Coordination Mode from σ Toward π Originated by Crystal Packing Interactions. Aharonovich Sinai, Kapon Moshe, Botoshanski Mark, Eisen Moris S. *Organometallics* **2008**, 27, p. 1869.
3. Group IV Octahedral Amidinates in Olefine Polymerization. Aharonovich Sinai, Eisen Moris S. *The Metallocene and Single-Site Catalyst Monitor*, **2008**, 16(4), p. 4.\
4. Synthesis of Lithium N-pentafluorophenyl, N'-trimethylsilyl 2-pyridylamidinate and its Cyclization to Lithium Tetrafluoro-2-(2-pyridyl) benzimidazolate Via a Me3SiF Elimination. Coordination Chemistry, Reactivity and Mechanism. Aharonovich Sinai, Botoshanski Mark, Eisen Moris S. *Inorg. Chem*. **2009,** 48, p. 5269.

5. Lithium Furyl and Pyridyl Amidinates as Building Blocks in Coordination Polymers, Ladder and Cage Structures. Aharonovich Sinai, Botoshanski Mark, Rabinovich Ziv, Waymouth Robert M., Eisen Moris S. *Inorg. Chem.* **2010,** 49, p. 1220.
6. Mono- and Bis-amidinate 2,6-xylylimido Vanadium Chlorides: Synthesis, Structure, and Reactivity. Aharonovich Sinai, Botoshansky Mark, Tumanskii Boris, Nomura Kotohiro, Waymouth Robert M., Eisen Moris S. *J. Chem. Soc., Dalton Trans*. **2010,** *39***,** p. 5643.
7. Thorium 2-Pyridylamidinates: Synthesis, Structure and Catalytic Activity Towards the Cyclo-oligomerization of ε-caprolactone. Rabinovich Elena, Aharonovich Sinai, Botoshansky Mark, Eisen Moris S. *J. Chem. Soc., Dalton Trans.* **2010,** *39***,** p. 6667.
8. Chemoselectivity Diversity in the Reaction of $LiNC_6F_5SiMe_3$ with Nitriles and the Synthesis, Structure, and Reactivity of Zirconium Mono- and Tris[2-(2-pyridyl)tetrafluorobenzimidazolate] Complexes. Aharonovich Sinai, Botoshansky Mark, Waymouth Robert M., Eisen Moris S. *Inorg. Chem.* **2010**, 49, p. 9217.
9. Deuterium Labeling and Mechanistic Insights in the Polymerization of Propylene Promoted by Benzamidinate Complexes. Volkis Victoria, Aharonovich Sinai, Eisen Moris S. *Macromol. Res.* **2010**, 18, No. 10, p. 967.
10. Elucidation of Substituent Effects in the Polymerization of Propylene Promoted by Titanium Amidinates. Aharonovich Sinai, Botoshansky Mark, Balazs Yael, Eisen Moris. *Organometallics* **2012**, Article ASAP DOI: 10.1021/om300068w

Submitted

11. Organoactinides in the polymerization of alpha-olefins: Why TIBA is a better co-catalyst than MAO? Rabinovich Elena, Aharonovich Sinai, Tumanskii Boris, Eisen Moris S.

In Preparation

12. Zirconium (IV) N,N′-Bis-Silylated Aryl, Furyl and pyridyl Amidinates: Substituent effects and mechanism in MAO Promoted Propylene Polymerization. Aharonovich Sinai, Botoshanski Mark, Waymouth Robert M., Eisen Moris S.
13. Lithium and Zirconium (IV) Complexes Bearing the N-trimethylsilyl 1-phenyl 2-(6-picolyl) ethenamide Ligand: synthesis, Coordination Chemistry Redox and Electrophilic Reactivity Toward MAO. Aharonovich Sinai, Botoshanski Mark, Eisen Moris S.
14. Titanium and Zirconium (IV) N,N′-bis-phenyl and perfluorophenyl Isopropyl Amidinates: Synthesis, Reactivity, and Substituent Effects in Propylene Polymerization. Elkin Tatyana, Aharonovich Sinai, Botoshanski Mark, Eisen Moris S.

15. Substituent effects and mechanism in Propylene Polymerization promoted by Titanium (IV) N,N′-Bis-Silylated Aryl, Furyl and pyridyl Amidinates activated by MAO and MAO\TTPB co-catalysts . Aharonovich Sinai, Botoshanski Mark, Eisen Moris S.
16. Titanium and Zirconium N,N'-bis-phenyl and *o*-fluorophenyl Triazenates and Formamidinates: Synthesis, Structure, and the Ring and Backbond Substitution Effect in Ethelene and Propylene Polymerization Promoted by MAO or TTPB. Torotko Andrey, Aharonovich Sinai, Botoshanski Mark, Eisen Moris S.
17. Structure and propylene polymerization reactivity of non-covalently bridged group IV phenolate ether complexes.
18. Covalently and non-covalently bridged Salane group IV complexes in the polymerization of propylene.

Oral Presentations

1. Substituent Effects in the Structural Chemistry of Lithium Amidinates and in the Catalytic Polymerization of Propylene Promoted by Titanium Amidinate Complexes.
   2nd Schulich Mini-Symposium, January 15 **2009**, Haifa, Israel.
2. Transition Metal-Promoted Activation and Functionalization of the C-F Bond. march 22 **2009**, Haifa, Israel.
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4. Hetero-aza-allyl Complexes of Li, Ti, Zr, and V: Structure, Reactivity, and Catalytic Propylene Polymerization. march 1 **2010**, Haifa, Israel.
5. Synthesis and propylene polymerization behavior of loosely bridged group IV phenolate ether complexes. BSF Workshop on Olefin Polymerization, September 23 **2011**, Stanford, California.

References:

Available upon request

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Mr Haim Sterenfine

Curriculum Vitae

EDUCATION

B.Sc in Chemical Engineering – BG UNIVERSITY, BEER SHEVA
M.Sc Industrial Engineering - BG UNIVERSITY, BEER SHEVA

PROFESSIONAL EXPERIENCE

2012- Lextran Ltd, COO

2003-2012 General Manager of Lextran
Company dealing with air pollution control. Removal of SO_2, Mercury and heavy metals from combustion flue gases - producing fertilizers (Ammonium Sulfate, Potassium Sulfate as by-product.

1999-2003 Manager of the Ecology & Safety Eng. At Ludan Engineering Group & General Manager of "Lextran" a start-up company dealing with combined removal of Sox & NOx from flue gases. (owned 38% by Ludan).

1993-1999 Marketing Manager for Ludan Engineering – Beer Sheva Branch.

1990-1993 General Manager of Building and Development in the Negev Company – a group of plants producing gravel by grinding and screening of stones. In addition, asphalt plants, ready made concrete producing plants and bricks manufacturing.

1984-1990 ***Plant Manager of Ramon Plant*** (part of Negev Ceramics- Israel Chemicals Group
Plant produces calcinate and ground clays for the refractory ceramics and fertilizers industry.

1977-1984	***Negev Phosphates (Rotem Fertilizers) in ICL Group*** Acting as process engineer, plant manager of granulated fertilizers, head of process engineering department, production manger (a plant of 270 employees).
1976-1977	***Makhteshim Chemical Works*** Process Engineer

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Lextran Pilot Plant Test Results

Conducted at CET Govora Power Plant in July 2009

Written by: Aaron Tager

Approved by: Haim Sternfine

Date: 22.7.09

T A B L E O F C O N T E N T

1. SUMMARY
2. SYSTEM DESCRIPTION
3. PROCESS OPERATING PARAMETERS
4. FLUE GAS PROPERTIES
5. TEST RESULTS
6. DeNOx
7. FERTILIZER BY-PRODUCT
8. APPENDICES

    8.1 DeSOx Results

    8.2 DeNOx Results

    8.3 Pilot Photos

    8.4 Data Lgging Sheets

    8.5 Fertilizer Lab Test Results

1. Summary

Lextran pilot plant was operated at CET Govora power plant during the period starting in 29.6.09 and ending in 9.7.09 including a continuous test run of 72 hours. The pilot was operated by a combined team of Lextran (A. Tager, R. Tkach, U. Barlevav, H. Sterenfine) and of Ludan SRL people (Zoltan Bartha and Octavian Stanculescu).

This operation had the following primary targets:

- ✓ To demonstrate the capabilities of Lextran process in reducing SO_2 concentration in the flue gas of Lignite fired boiler.
- ✓ To collect process data for design of a commercial plant at CET Govora.
- ✓ To produce a representative quantity and quality of the process byproduct for testing its suitability as an aqueous ammonium sulfate fertilizer.
- ✓ To identify any problems which need special consideration in the detailed design of the commercial plant to be installed in CET Govora.

A secondary target of the testing campaign was to demonstrate NOx reduction capability which may be of future interest for CET Govora.

All the targets were fully fulfilled.

SO_2 concentration in the flue gas, as measured by Lextran's gas analyzer, was reduced from 5,330 mg/dNm^3 to 60 mg/dNm^3 (90 mg/dNm^3 corrected to 6% O_2). This value is lower substantially than the required value of 200 mg/dNm^3 and corresponds to 98.9% removal rate. This was substantiated by the measurements taken by CET Govora's gas analyzer and by the measurements of a local independent third party assigned by CET Govora. Please see attached Appendix 8.1 DeSOx results.

In addition to SO_2 reduction the limited number of tests conducted for NOx reduction, which were not part of the 72 hours test, demonstrated an ability to reduce NOx concentration. Please see attached Appendix 8.2 DeNOx results.

2. System Description

The system is presented in the drawings in the following pages.

A slip stream of 40 – 70 am^3/h was drawn from boiler No 5 by ID fan (N° 2) installed at the outlet of the system.

Hot flue gas is filtered from fly ash in a bag filter (not shown) and then passes through a 6 kW heater which is used for NO oxidation by reaction with 30% hydrogen peroxide.

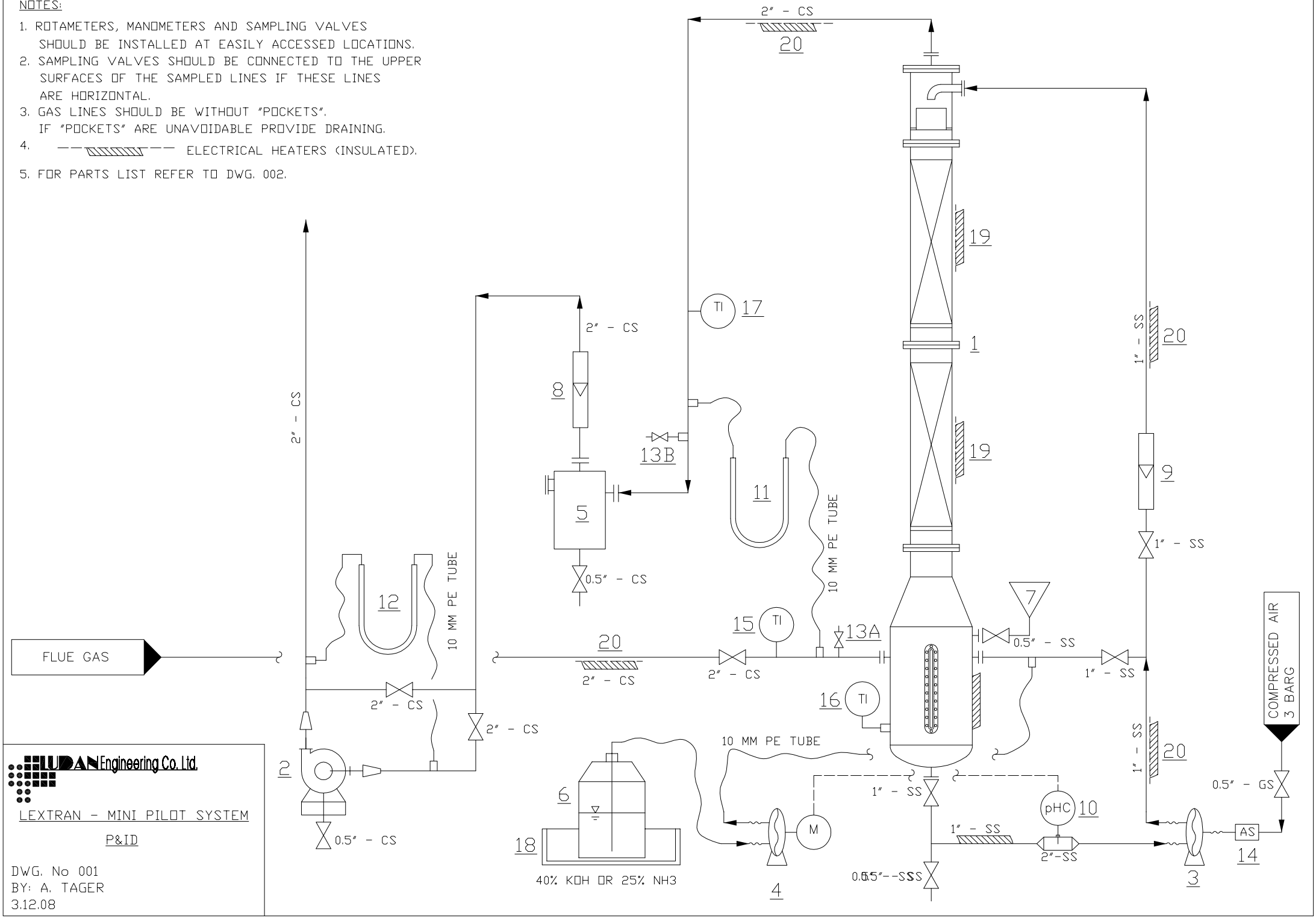
Flue gas is contacted in countercurrent flow with the scrubbing liquid in a 6" absorption column. The column (N° 1) is packed with two 1.2m sections of 1"/2 IMTP random packing.

Circulation pump (N° 3) provides the required flowrate of the scrubbing liquid (emulsion of water + Lextran catalyst).

The pH of the scrubbing liquid is controlled automatically by addition of 25% aqueous ammonia (parts 10, 4 and 6).

NOTES:

1. ROTAMETERS, MANOMETERS AND SAMPLING VALVES SHOULD BE INSTALLED AT EASILY ACCESSED LOCATIONS.
2. SAMPLING VALVES SHOULD BE CONNECTED TO THE UPPER SURFACES OF THE SAMPLED LINES IF THESE LINES ARE HORIZONTAL.
3. GAS LINES SHOULD BE WITHOUT "POCKETS". IF "POCKETS" ARE UNAVOIDABLE PROVIDE DRAINING.
4. —— ELECTRICAL HEATERS (INSULATED).
5. FOR PARTS LIST REFER TO DWG. 002.

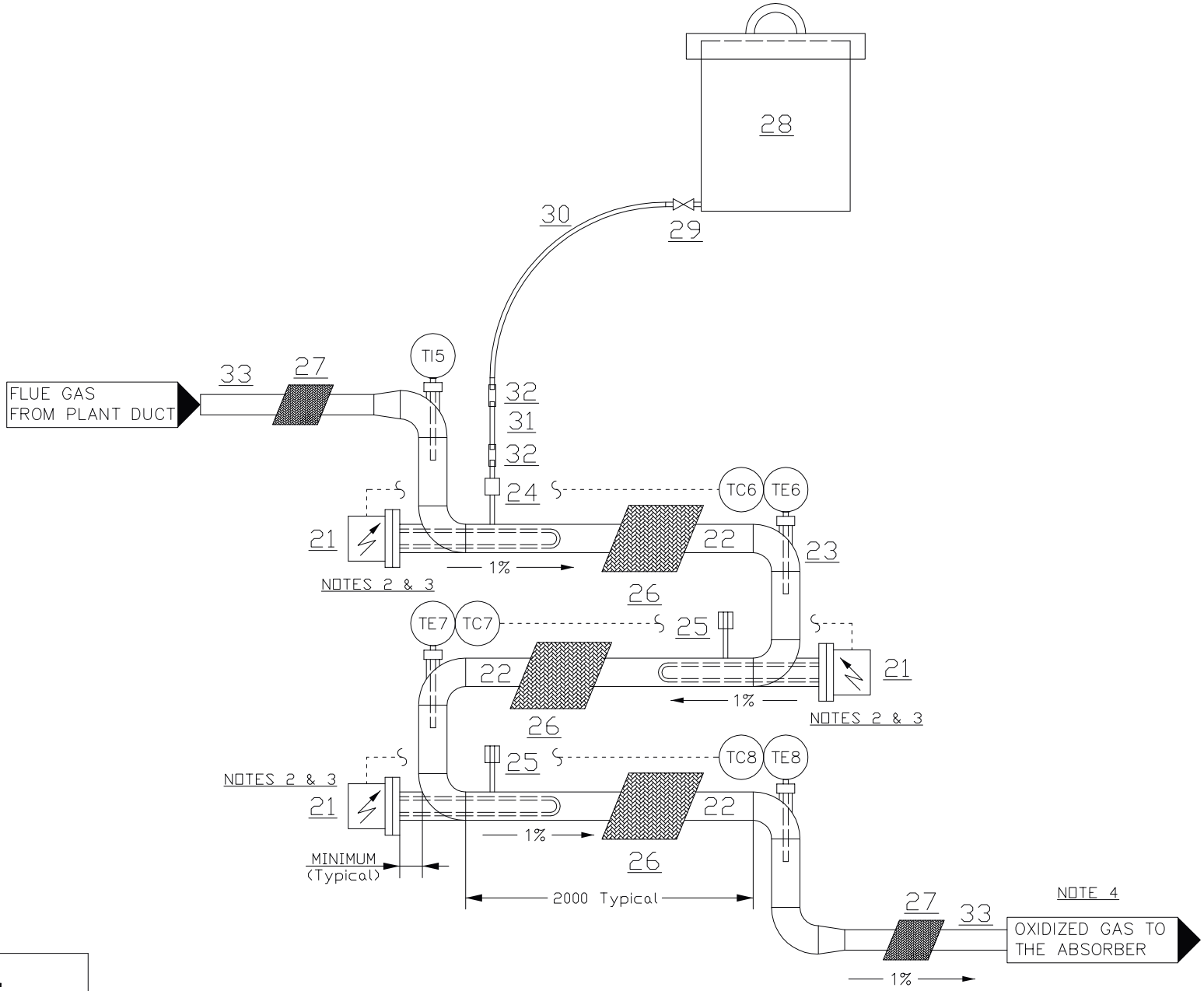


LUDAN Engineering Co. Ltd.

LEXTRAN - MINI PILOT SYSTEM

P&ID

DWG. No 001
BY: A. TAGER
3.12.08



LUDAN Engineering Co. Ltd.

LEXTRAN - MINI PILOT SYSTEM

H2O2 FEEDING & HEATING

DWG. No 004 REV. P0
BY: A. TAGER
26.2.09

NOTES:

1. FOR PARTS LIST REFER TO DWG. No 005
2. EACH HEATER SHOULD HAVE ITS OWN SWITCH.
3. THE HEATERS SHOULD BE ELECTRICALLY INTERLOCKED TO THE FAN SO THAT THEY WILL BE SWITCHED ON ONLY IF THE FAN IS WORKING.
4. ALL PIPINIG SEGMENTS SHOULD BE SELF DRAINING TO THE ABSORBER.
5. ALL PIPING ELEMENTS SHOULD BE THERMALLY INSULATED.

3. **Process Operating Parameters**

The following values are the calculated average figures of the main operating parameters of the pilot plant during the 72 hours continuous run.

- Flue gas flowrate: 43.6 am^3/h.

- Absorption liquid flowrate: 0.9 m^3/h.

- pH of the absorption liquid: 6.3

- Pressure drop on the absorption column: 75 mmWC.

4. **Flue Gas Properties**

The following values are representative of the flue gas properties:

- Flue gas temperature: 150°C.

- Flue gas humidity 30-45%.

- O_2 concentration: 10-12%.

- CO_2 concentration: 7.4%.

- Pollutants

The average values of the pollutants' concentrations in the flue gas before treatment are as follows:

Pollutant	Measured concentration (mg/dNm^3)	Normalized concentration to 6% O_2 (mg/dNm^3)
SO_2	5,343 (note)	7,810
NO	123	179 < 250 (required emission value)
NO_2	3	5
NOx expressed as NO_2	181	270
CO	65	96
Particulate matter	115	168

Note: For protection of the gas analyzer it was disconnected before reaching a stable reading value.

5. **Test Results**

5.1 The 72 hours continuous test yielded the following averaged results.

Pollutant	Measured concentration (%v/v or mg/dNm^3)	Normalized concentration to 6% O_2 (mg/dNm^3)
O_2	10.9	----------
SO_2	63**	90
CO_2	8.1	----------
CO	85	126
Particulate matter	was not measured	----------

** Excluding few exceptional measurements SO_2 outlet average is 36mg/dNm^3

5.2 Since the standard method of particulates concentration measurement is a gravimetric method it was not measured during the test.

5.3 Ammonia concentration in the outlet of the Lextran system was measured by Dräger tube and found to be 0-4 ppm. This value is lower than the allowed emission value for ammonia.

5.4 The absorption of SO_2 yielded aqueous solution of ammonium sulfate whose density was 1.140 g/cm^3. This value corresponds to concentration of about 27% ammonium sulfate in water.

6. **DeNOx Results**

6.1 The average normalized NO outlet value is 179 mg/dNm^3. It means that right now DeNOx is not required.

6.2 By injection of 30% H_2O_2 (Hydrogen Peroxide) to the flue gas at an average temperature of 240°C we oxidized part of the NO into NO_2. The average DeNOx value is 56% - please see attached Appendix 2.

6.3 Commercial plant will be equipped with the necessary equipment for DeNOx. Injection of H_2O_2 to reduce NO will be optional decision of CEt Govora management.

7. **Fertilizer By-Product**

7.1 Commercial Installation of Lextran technology for boiler C-7 will produce 17,910 kg/hr of Ammonium Sulfate solution containing 40% solids. This plant will consume 7,370 kg/hr 25% Aqueous Ammonia.

7.2 The by-product should be crystallized into a free flow solid.

7.3 The phase separation between the organic catalyst and the aqueous phase (fertilizer) was done manually. To avoid solid sedimentation and SOx emissions the by-product was changed with fresh water ahead of time and solid concentration reached 27%. In commercial plant the process is fully automatic and controlled and solid concentration will reach 40%.

7.4 Prof. Emeritus Uzi Kafkafi Email; kafkafi@agri.huji.ac.il

Phone: **972-54- 8820131** Fax: **972-8-948-9899**

Analytical analysis of experimental run of Lextran Proces in CET Govora Romania

The solution was bought for analysis to the credited Amino lab in Rehovot. Their lab reports are attached.

They identified 57.793 g per liter of N in ammonium form as determined by Kjeldhal method, in the solution brought by Mr Sternfine from Romania.

From the experimental run in Romania, (See COAFILE attached), and they detected 273 g per liter of solids in that solution.

From these data it is possible to calculate the percentage of nitrogen -N in the solid which is: (57.793/273)* 100= 21.17% N,

This value is exactly the percent of N present in commercial ammonium sulfate fertilizer.

I expect that proper crystalization of such a solution will produce an ammonium sulfate fertilizer with the composion formulae $(NH_4)_2SO_4$ that is a well known commercial N fertilizer. It should be noted that although in commercial markets the ammonium sulfate fertilizer is sold as an N fertilizer, it is containing also sulfate that is used by plants and is known as a "secondary nutrient element" since it's uptake by plants is about 10 to 15% of the amount of N taken up by plant. However sulfur is an essential element and have benefits to plant growth and production.

Appendices

APPENDIX-1

- SO_2 inlet (average) 5543 mg/m^3.
- SO_2 removal was 98% (normalized to 6% O_2), to 92 mg/m^3.
- Distribution of SO_2 (outlet) results:

SO_2=0 mg/m^3; 39 measurements.

0<SO_2<20 mg/m^3; 26 measurements.

20<SO_2<50 mg/m^3; 13 measurements.

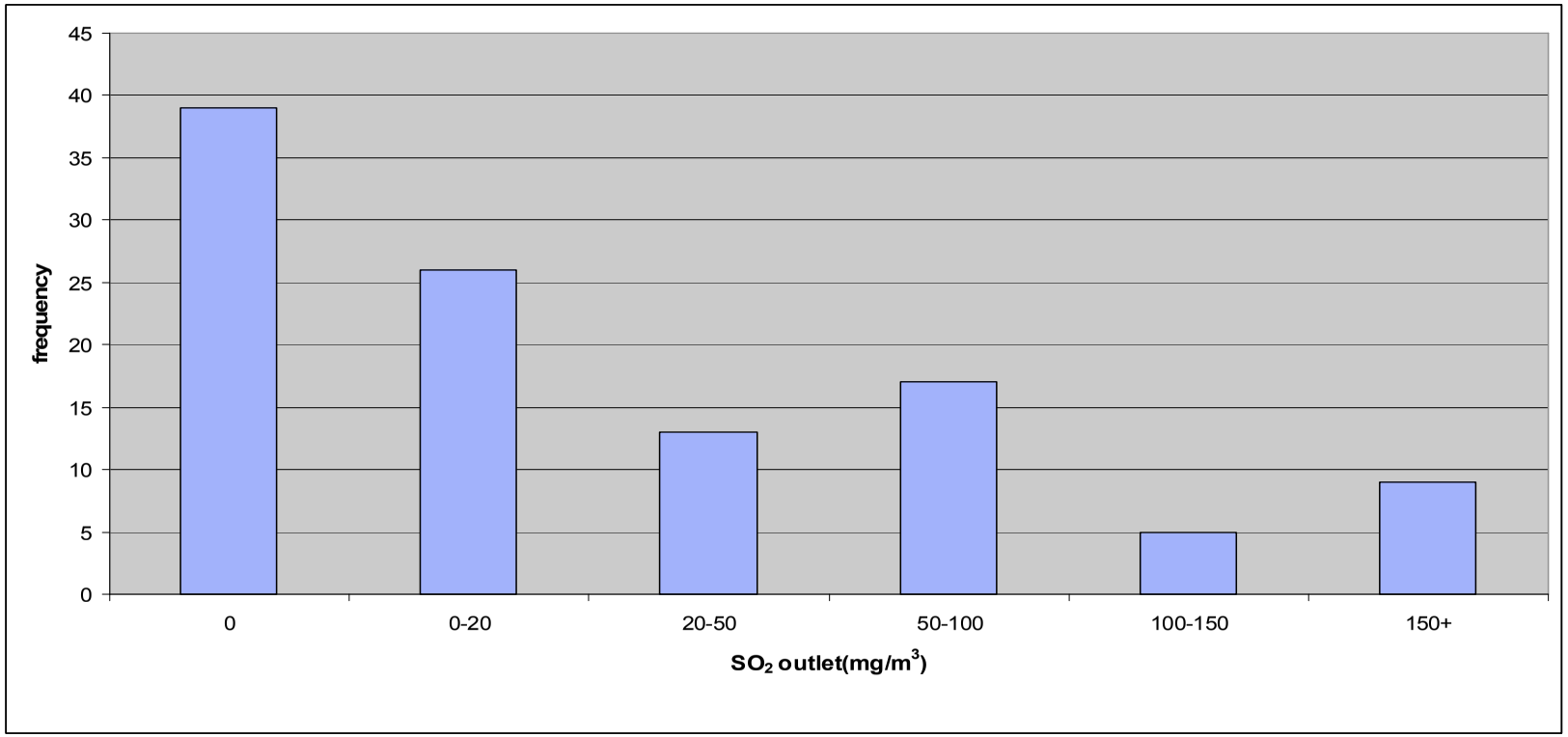
50<SO_2<100 mg/m^3; 17 measurements.

100<SO_2<150 mg/m^3; 5 measurements.

SO_2>150 mg/m^3; 9 measurements.

- Average O_2 measured concentration was 10.7%

Distribution of SO_2 (outlet) results:



APPENDIX-2

- NO inlet (average) 123 mg/m^3.
- DeNO removal was 56%, 55 mg/m^3.
- Distribution of NO (inlet) results:

$0<NO<90$ mg/m^3; 14 measurements

$90<NO<120$ mg/m^3; 29 measurements

$120<NO<130$ mg/m^3; 18 measurements

$130<NO<140$ mg/m^3; 18 measurements

$140<NO<150$ mg/m^3; 10 measurements

$NO>150$ mg/m^3; 13 measurements

- Distribution of NO (outlet results):

$0<NO<30$ mg/m^3; 2 measurements

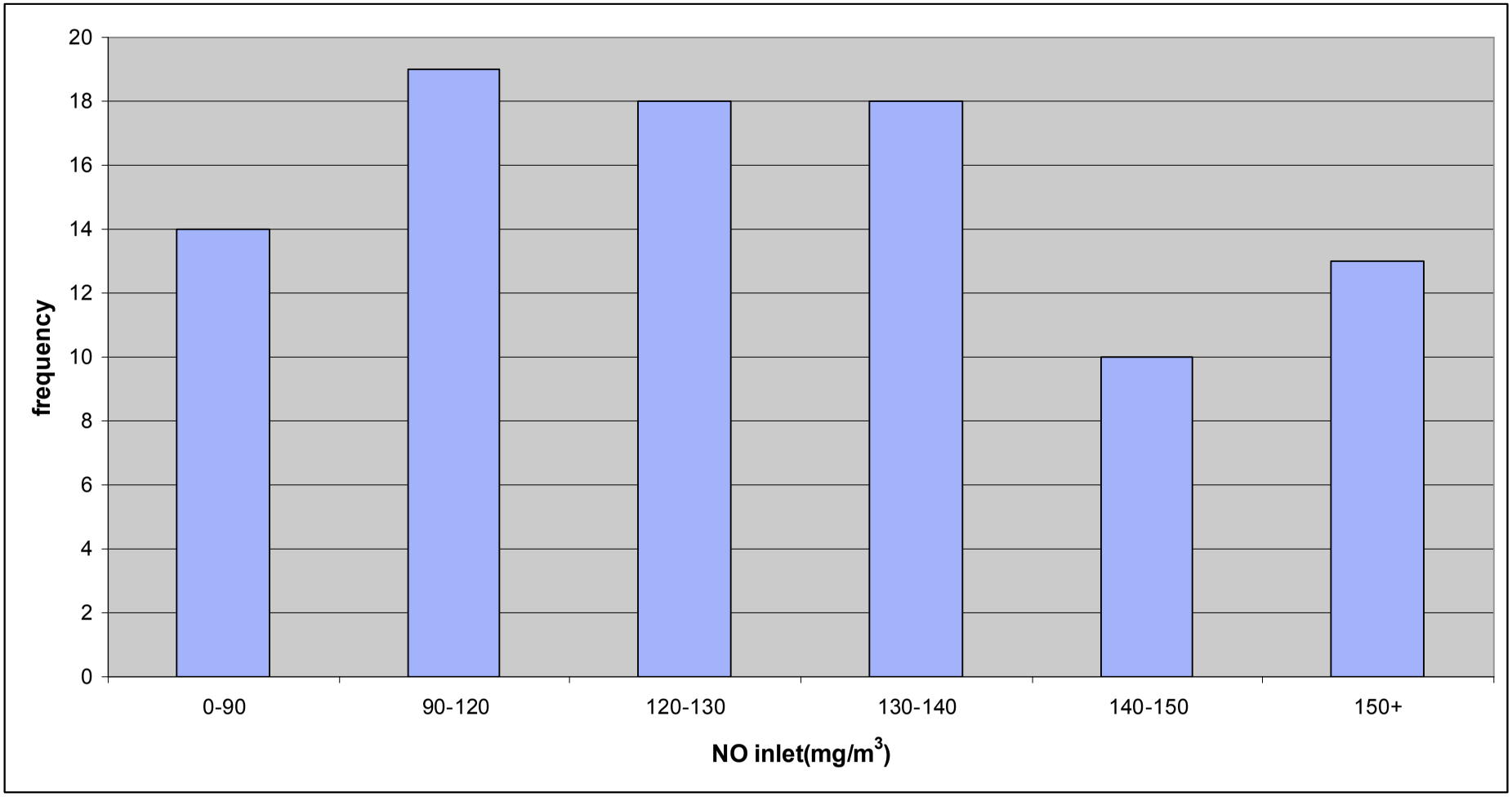
$30<NO<50$ mg/m^3; 4 measurements

$50<NO<70$ mg/m^3; 5 measurements

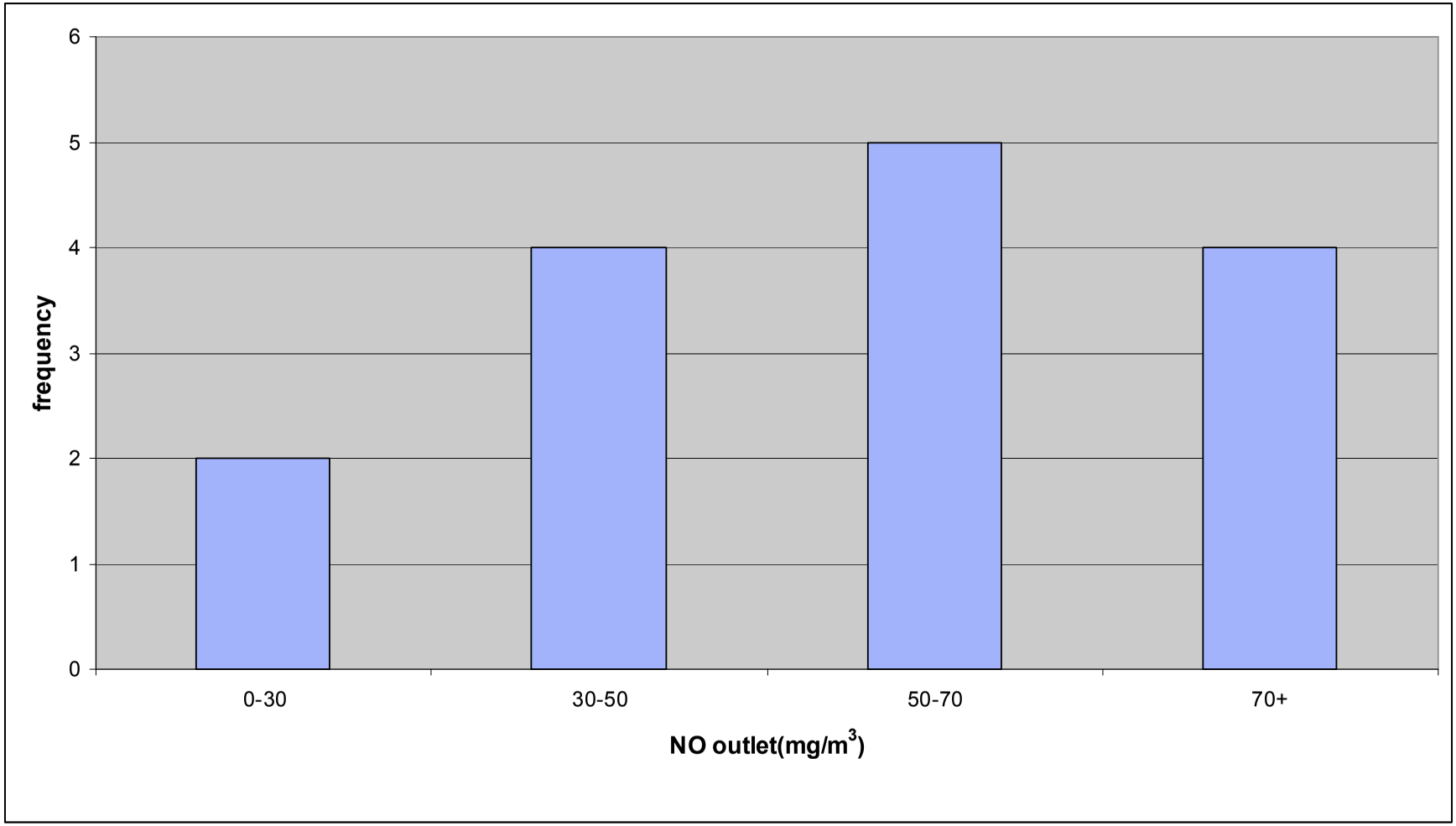
$NO>70$ mg/m^3; 4 measurements

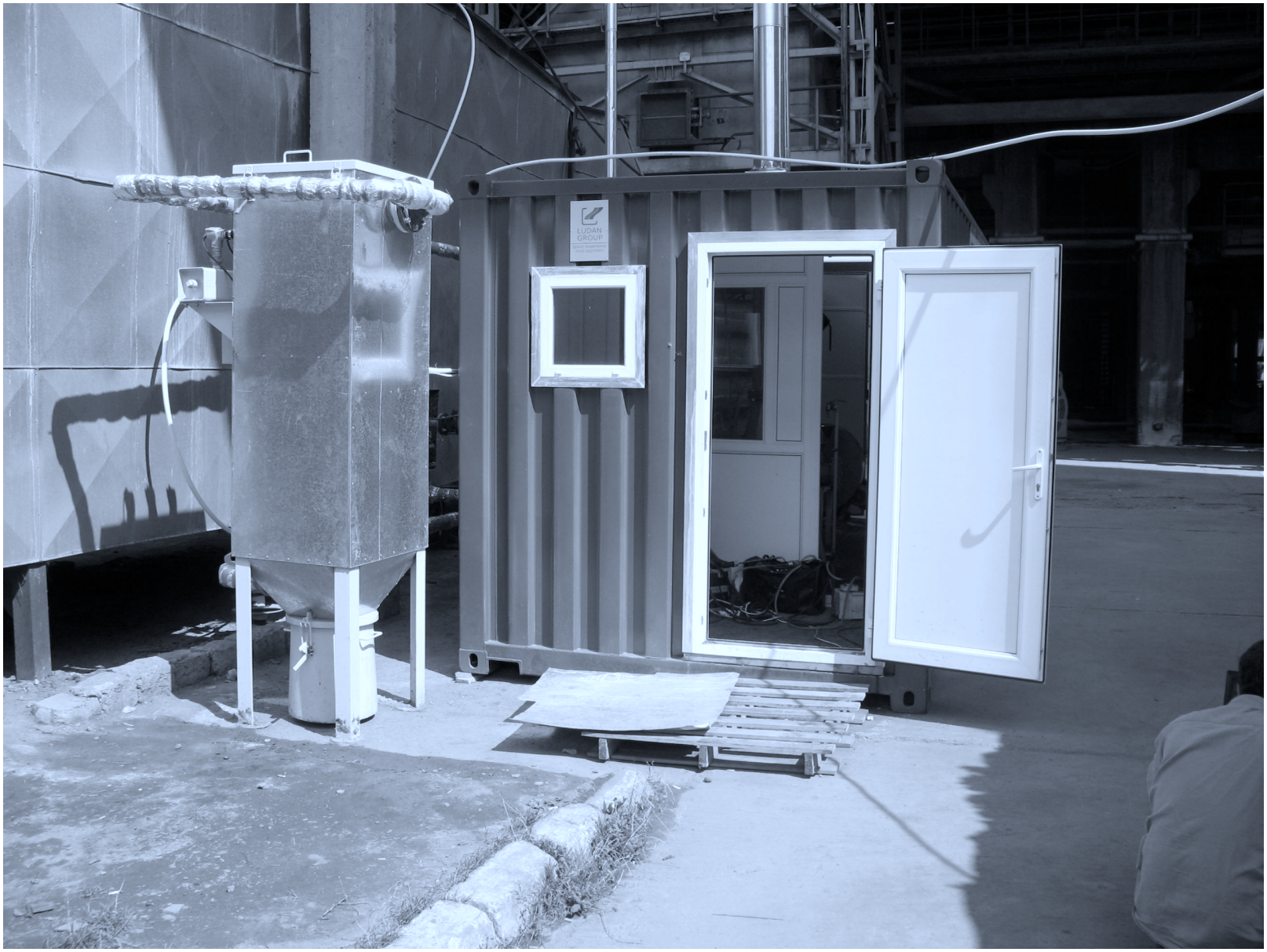
- Average O_2 measured concentration was 10.7%

Distribution of NO (inlet) results:



Distribution of NO (outlet) results:




LUDAN
GROUP

220 V

Data Logging Sheet - Part 1

Date: 2.7.09

Operators:Aharon;Haim;Udi

Page N°: 1 / 15

Time	FI-1 (m^3/h)	FI-2 (l/h)	PI-1 (mmWC)	pH	Inlet / Outlet	Concentrations (%, mg/dNm^3)						Notes
						O_2	SO_2	NO	NO_2	CO_2	CO	
11:30	29	1.5		6.36	out	10.2	14	128	2	9.15		
12:00	44	1.5		6.37	out	11.4	0	115	0	7.5	54	
12:30	49	1		6.2	out	10.2	15	125	2	9	68	
13:00	48	1		6.14	out	10.2	20	130	2	9.17		
13:30	53	0.9		6.13	out	10.5	10	135	2	9		
14:30	48	1		6.13	out	10.9	7	135	2	9		
15:30	50	1	200	6.18	out	10.3	20	136	2	9		
16:30	52	1		6.15	out	10.6	4	138	2	9.12		
17:50	48	1		6.23	out	9.8	144	117	2	9.51		
20:00	48	1		6.29	out	10	63	126	2	9.4		
20:30	49	0.9	100	6.37	out	9.99	51	124	2	9.36		
21:00	30	1		6.38	out	10.1	15	132	2	9.29		
21:20	30	1		6.35	out	10	24	128	1	9.38		
22:20	40	1	60	6.35	out	9.8	120	121	3	9.46		
23:00				6.4	out	9.9	25	125	2	9.55		
23:20				6.35	out	9.7	55	112	2	9.6		
23:40				6.36	out	9.84	42	113	2	9.5		

Data Logging Sheet - Part 2

Date: 2.7.09

Operators:Aharon;Haim;Udi

Page No: 2 / 15

Time	T-1 (°C)	T-2 (°C)	T-3 (°C)	T-5 (°C)	T-7 (°C)	PI-2 (mmWC	LG-1 (%)	Water added	Notes
11:30	30	50	53	114	78.7				
12:30									
13:30	33	56	59.7	124	165.7		14		
14:30									
15:30	36	58	62.7	135	220	420	11		
16:30	35	57	62.4	136	224		11	2000 ml	
17:50	34	59	63.2	136	226	420	10		
20:30	33	59	63.1	137	225	420	13		
22:30	33	59	63.1	166	266.7	420	11		

Data Logging Sheet - Part 1

Date: 3.7.09

Operators:Aharon;Haim;Udi

Page N°: 3 / 15

Time	FI-1 (m^3/h)	FI-2 (l/h)	PI-1 (mmWC)	pH	Inlet / Outlet	Concentrations (%, mg/dNm^3)						Notes
						O_2	SO_2	NO	NO_2	CO_2	CO	
0:00	40	0.5	50	6.36	out	9.42	520+	103	6	9.92		
0:00	40	0.5	50	6.36	out	14.9	813	58	0	4.5		ecom;saturared aqueous phase by ammonium sulfate
1:00	40	0.5	50	6.36	out	10.3	400+	130	6	9		
1:00	40	0.5	50	6.36	out	16.2	110	55	0	3.5		
2:00	40	1	70	6.36	out	10.2	72	132	2	9.2		
2:00	40	1	70	6.36	out							
3:00	35	1	55	6.42	out	10.2	55	132	2	9.1		
3:00	35	1	55	6.4	out	10.1	15	132	2	9.2		
4:00	40	1	70	6.37	out	10.1	9	130	2	9.2		
5:00	40	1	60	5.89	out	9.9	40	120	6	9.3		
6:00	35	1	70	6.63	out	9.76	130	125	2	9.6		
7:00	30	1	60	6.28	out	10.1	95	128	2	9.3		
8:00	40	1	60	6.41	out	9.87	93	126	2	9.5		
9:00	34	1	50	6.36	out	10.8	22	125	2	8.91		
10:30	32	1	50	7.18	out	10.7	5	128	2	8.76		
11:30	70	1	190	7.06	out	10.4	3	131	1	9		
12:30	70	1	180	6.67	out	10.1	6	130	2	9.09		
13:30	70	1	190	6.36	out	10	7	135	2	9.4		
14:00	70	1		6.07	out	13.7	18	139	0	5.4		
14:00	25	1		6.15	out	13.6	7	100	1	5.4		
17:45	72	1	180	6.06	out	13.6	3	103	2	6.18		
19:30	69	1	180	6.07	out	10.3	6	141	2	9.02		
20:45	70	1		6.1	out	9.5	16		2			
21:00	70	1		6.08	out	10	17	150	1			
21:30	65	1		6.1	out	9.99	22	147	3	9.3		

Data Logging Sheet - Part 2

Date: 3.7.09

Operators:Aharon;Haim;Udi

Page No: 4 / 15

Time	T-1 (°C)	T-2 (°C)	T-3 (°C)	T-5 (°C)	T-7 (°C)	PI-2 (mmWC	LG-1 (%)	Water added	Notes
0:00	33	59	64.7	154	263	420			
0:00	33	59	65.8	152	260	410			
1:00	33	59	66	149	255	410			
1:00	33	59	66	149	255	410			
2:00	33	58	64	147	250	410		1000	
2:00	33	58	64	147	250	410		1000	
3:00	33	57	62.8	157	255.5	420	9		
4:00	33	58	68	152	256	420	9		
5:00	32	58	69	148	251	420	9	1000	
6:00	31	58	68	155	255	460	9		
7:00	31	57	68	162	262	430	9		
8:00	31	57	68	159	253	420	9	1000	
9:30	33	59	64.3	119	207	420	14	6000	
10:30	34	57	60.9	133	215	420	14		
11:30	34	58	60	134	220	420	14		
12:25	38	61	66	120	204	420	14		
13:30	40	59	64.4	122	196.5	420	14		
17:45	36	53	56	184	277	420	14		
19:30	39	60	66	133	230	420	13		
21:30	42	52	56.3	159	203				
17:00									
18:00									
19:00									
20:00									
21:00									
22:00									
23:00									
0:00									

Data Logging Sheet - Part 1

Date: 4.7.09

Operators:Aharon;Haim;Udi

Page N°: 5 / 15

Time	FI-1 (m^3/h)	FI-2 (l/h)	PI-1 (mmWC)	pH	Inlet / Outlet	Concentrations (%, mg/dNm^3)						Notes
						O_2	SO_2	NO	NO_2	CO_2	CO	
0:00	40	1	70	6.36	out	10.3	500	140	7	9		ecom;saturared aquoas phase by ammonium sulfate
0:00	40	1	70	6.1	out	11.7	501	101	0	5.9		
1:00	35	1	60	6.33	out	10.9	84	112	6	8.52		
1:00	35	1	60	6.42	out	11.8	72	126	0	6.7		
2:00	25	0.25	20	6.23	out	10.4	63	144	8	8.9		
2:00	25	0.25	20	6.62	out	11.7	57	68	0	6.7		
3:00	25	0.25	20	6.66	out	10.4	46	141	6	5		
3:00	25	0.25	20	6.52	out	11.5	80	130	6	6.6		
4:00	15	0.5	10	6.41	out	10.3	100	129	1	9		
4:00	15	0.5	10	6.25	out	14.3	127	83	0	5		
5:00	30	0.5	40	6.6	out	10.3	61	140	5	9		
5:00	30	0.5	40	6.47	out	16	25	58	0	3		
6:00	11	0.5	10	6.39	out	10.6	18	140	2	8.7		
6:00	11	0.5	10	6.65	out	11.7	3	131	0	6.9		
7:00	11	0.5	10	6.42	out	9.6	53	135	2	9.7		
7:00	11	0.5	10	6.83	out	11	61	121	0	7.4		
8:00	21	0.5	10	6.3	out	10	20	147	4	9.25		
8:00	21	0.5	10	6.51	out	11.2	20	134	0	7.1		
9:00	22	1		6.22	out	10.1		148	2			starting of addition of H2O2 30%
10:00	60	1			out	13		55	14			
11:30	60	1		6.1	out	9.88	42	132	1			
12:00	60	1		6.12	out	9.4	54	122	2			
13:30	60	1		6.1	out	9.56	28	129	2			
13:35	60	1		6.12	out	9.48	36	129	2			addition of H2O2 30%
13:45	60	1		5.96	out	9.47	24	100	2			
14:15	60	1		5.96	out	10.3	0	59	2			
14:15	64	1		6.18	out	10	13	140	1			
16:15	60	1		6.27	out	12.4	0	50	0	6.3		
16:15	60	1			Inlet		4436	99	0	7.3		

17:30	60	1		6.24	out	11.9	6	48	2	6.7		
17:30	60	1	160	6.3	inlet	10.8	5521	105	0			
19:00	60	1	160	6.1	out	11.2	0	32	0	7.2		
19:00	60	1	160	6.3	inlet	10.8	5229	101	0	7.4		
20:00	60	1	160	6.45	out	11.2	15	54	0	7.2		
20:00	60	1	160	6.4	inlet	10.7	5513	92	0	7.6		
21:00	60	1	160	6.36	out	12.2	0	71	4	6.4	40	
21:00	60	1	160	6.31	inlet	12	5500	70	25	6.7	73	
22:00	60	1	160	6.29	out	11.3	0	40	2	7.1	109	
23:00	60	1	170	6.35	out	13.4	0	96	2	5.6	156	

Data Logging Sheet - Part 2

Date: 4.7.09

Operators:Roman;Octavian

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Time	T-1 (°C)	T-2 (°C)	T-3 (°C)	T-5 (°C)	T-7 (°C)	PI-2 (mmWC	LG-1 (%)	Water added	Notes
0:00	36	52	55	254	207	450	11		
0:00	36	52	55	254	207	450	11		
1:00	35	56	60	178	260	410	9		
1:00	35	56	60	178	260	410	9		
2:00	36	53	61	179	274	420	13		
2:00	36	53	61	179	274	420	13		
3:00	35	53	62	190	282	420	15		
3:00	35	53	62	190	282	420	15		
4:00	35	53	62	191	290	420	15		
4:00	35	53	62	191	290	420	15		
5:00	36	57	63	196	300	420	14		
5:00	36	57	63	196	300	420	14		
6:00	37	52	57	217	295	420	13		
6:00	37	52	57	217	295	420	13		
7:00	35	50	55	253	310	420	13		
7:00	35	50	55	253	310	420	13		
8:00	35	56	61	242	343	420	13		
8:00	35	56	61	242	343	420	13		
9:00	36	56	60.5	231	340	420	13		
12:40	41	60	63.7	188	274		13		
13:35	44	61	64	184	273		13		
14:15	45	61	64.4	173	265		13		
16:15	49	61	64.3	166	246		13		
17:30	49	59	61.8	158	240		13	2000	
19:00	49	61	65.2	165	242	400	13		
20:00	48	59	4	164	244	400	13		
21:00	47	60	64	163	245	400	13		
22:00	47	60	64	163	245	400	12	2000	
23:00	45	56	60	167	249	420	11	1000	

Data Logging Sheet - Part 1

Date: 5.7.09

Operators:Aharon;Haim;Udi

Page N°: 7 / 15

Time	FI-1 (m^3/h)	FI-2 (l/h)	PI-1 (mmWC)	pH	Inlet / Outlet	Concentrations (%, mg/dNm^3)						Notes
						O_2	SO_2	NO	NO_2	CO_2	CO	
0:00	58	1	180	6.29	out	10.1	0	88	0	7.9	100	
1:00	55	1	130	6.5	out	11.5	4	60	2	8		
2:00	55	1	150	6.31	out	10.4	6	88	2	7.6	58	
2:00	55	1	150	6.3	inlet	10.3	4800	135	2	7.3	42	
3:00	55	1	170	6.3	out	11.1	0	64	16	7.4	41	
4:00	55	1	160	6.32	out	10.8	0	45	12	7.4	58	
5:00	55	1	160	7.61	out	10.6	0	76	6	7.6	80	
6:00	60	1	160	6.41	out	11.2	0	65	6	8.8		
7:00	35	1	210	6.05	out	10.6	0	92	6	7.6	56	
8:00	60	1	230	6.31	out	12.7	0	106	0	6.2	45	
9:00	60	1	230	6.2	out	10.3	0	28	6	7.8		
9:00	60	1	230	6.04	inlet	10.6	5554	137	0	7.6	90	
10;00	60	1	230	6.27	out	11.3	0	11	31	7.1	33	
11:00	60	1	230	6.17	out	10.6	0	36	16	7.6	71	
11:00	60	1	230	6.2	inlet	10.3	5852	135	0	7.8	126	

Data Logging Sheet - Part 2

Date: 5.7.09

Operators:Roman;Octavian

Page No: 8 / 15

Time	T-1 (°C)	T-2 (°C)	T-3 (°C)	T-5 (°C)	T-7 (°C)	PI-2 (mmWC	LG-1 (%)	Water added	Notes
0:00	46	59	63.4	168	252	410	13	3000	
1:00	44	53	54	161	225	440	12		
2:00	44	53	54	161	225	410	14	3000	
3:00	43	52	60.8	160	237.4	410	11	3	
4:00	43	52	60.9	161	240	410	11	2	
5:00	42	58	62.1	160	239	410	11	2	
6:00	41	58	63	155	234	410	11	2	
7:00	41	55	60	154	233	410	11	2	
8:00	41	55	59	157	233	410	11	2	
9:00	42	59	63	159	236	410	11	2	
10:00	44	60	63	159	236	410	11		
11:00	46	61	64	161	239	410	10		
12:00									
13:00									
14:00									
15:00									
16:00									
17:00									
18:00									
19:00									
20:00									
21:00									
22:00									
23:00									

Data Logging Sheet - Part 1

Date: 6.7.09

Operators:Aharon;Haim;Udi

Page N°: 9 / 15

Time	FI-1 (m^3/h)	FI-2 (l/h)	PI-1 (mmWC)	pH	Inlet / Outlet	Concentrations (%, mg/dNm^3)						Notes
						O_2	SO_2	NO	NO_2	CO_2	CO	
9:00	55	1	280	6.2	out	12.8	6	119	0	6.2	45	ecom
10:00	55	1	250	6.15	out	10.4	0	157	0	7.8	66	ecom
11:00	55	1	250	6.18	out	10.3	0	150	0	8	91	ecom
12:00	60	0.8	220	6.15	out	10.4	0	155	0	7.8	81	ecom
13:00	58	0.8	210	6.18	out	11.6	15	111	0	6.9	36	ecom
13:00	58	0.8	210	6.21	inlet	11.2	5276	154	0	7.2	31	ecom
13:00	58	0.8	210	6.19	out	11	64	82	0	7.3	1	ecom
14:00	50	0.8	130	6.14	out	10.5	12	161	0	7.6	40	
14:00	50	0.8	130	6.15	out	10.7	44	55	0	7.6	35	
15:00	50	0.7	120	6.14	out	10.2	6	163	0	7.8	38	
16:00	65	0.7	120	6.17	out	10.2	0	157	0	7.8	38	good interfase
16:00	65	0.7	280	6.2	out	10.9	47	62	4	7.4	29	d(1.15 gr/cm3)

Data Logging Sheet - Part 2

Date: 6.7.09

Operators:Roman;Octavian

Page No: 10 / 15

Time	T-1 (°C)	T-2 (°C)	T-3 (°C)	T-5 (°C)	T-7 (°C)	PI-2 (mmWC	LG-1 (%)	Water added	Notes
9:00	32	49	59	102	110	440	12	2	
10:00	35	57	60	146	179	420	14		
11:00	37	59	62	161	214	420	14		
12:00	41	61	65	173	233	420	12	2	
13:00	44	61	63	165	249	420	13	1	
14:00	46	61	65	165	248	420	13		
15:00	48	61	65	176	255	420	13		
16:00	48	61	66	180	265	420	13	2	

Data Logging Sheet - Part 1

Date: 7.7.09

Operators:Aharon;Haim;Udi

Page N°: 11 / 15

Time	FI-1 (m^3/h)	FI-2 (l/h)	PI-1 (mmWC)	pH	Inlet / Outlet	Concentrations (%, mg/dNm^3)						Notes
						O_2	SO_2	NO	NO_2	CO_2	CO	
8:00	50	1	120	6.28	outlet	10.8	0	142	0	7.6	9	
9:00	50	1	270	6.57	outlet	10.7	0	150	0	7.6	35	
10:00	50	1	270	6.54	outlet	10.7	0	154	0	7.8	43	
11:00	60	1	280	6.09	outlet	10.6	0	155	0	7.6	31	
11:00	60	1	280	6.3	inlet	10.2	5600	150	6	7.6	31	
12:00	60	1	280	6.24	outlet	10.8	0	43	0	7.5	33	
13:00							0					
14:00							0					
15:00	60	1	300	6.06	outlet	9.4	0	94	0	8.4	256	
16:00	60	0.7	280	6.13	outlet	9.2	0	90	0	8.7	450	d=1.03(gr/cm3)
17:00	60	0.7	280	6.36	outlet	9	0	82	0	8.9	450	

Data Logging Sheet - Part 2

Date: 7.7.09

Operators:Roman;Octavian

Page No: 12 / 15

Time	T-1 (°C)	T-2 (°C)	T-3 (°C)	T-5 (°C)	T-7 (°C)	PI-2 (mmWC	LG-1 (%)	Water added	Notes
8:00	28	43	43	63	69	450	12	2000	
9:00	31	54	57	121	145	420	14		
10:00	33	57	60	147	190	420	14		
11:00	36	57	60	173	236	420	12	1000	
12:00									
13:00									
14:00									
15:00	46	61	64	193	240	400	12	2000	
16:00	46	61	65	184	282	400	13	2000	
17:00	46	61	65	180	273	400	16		

Data Logging Sheet - Part 1

Date: 8.7.09

Operators:Aharon;Haim;Udi

Page N°: 13 / 15

Time	FI-1 (m^3/h)	FI-2 (l/h)	PI-1 (mmWC)	pH	Inlet / Outlet	Concentrations (%, mg/dNm^3)						Notes
						O_2	SO_2	NO	NO_2	CO_2	CO	
9:00	50	1	390	6.3	out	9	0	137	0	8.8	400	
10:00	50	1	320	6.23	out	9.6	0	154	0	8.4	155	
11:00	60	1	320	6.17	out	9.3	0	145	0	8.7	420	
12:00	60	1	310	6.24	out	9.5	0	143	0	9.4	240	
13:00	60	1	310	6.06	out	9.5	0	141	0	8.4	200	
not possible to take measurement												
15:00	50	1	310	5.93	out	10.2	0	153	0	7.8	48	
15:00	50	1	310	6.01	inlet	10.1	5500	153	0	7.8	73	
16:00	60	1	310	5.94	out	10.6	0	172	0	7.8	38	
17:00	60	1	310	5.93	out	10.5	0	162	0	7.7	40	

Data Logging Sheet - Part 2

Date: 8.7.09

Operators:Roman;Octavian

Page No: 14 / 15

Time	T-1 (°C)	T-2 (°C)	T-3 (°C)	T-5 (°C)	T-7 (°C)	PI-2 (mmWC	LG-1 (%)	Water added	Notes
9:00	30	49	51	67	74	470	14		
10:00	32	55	59	134	158	420	15		
11:00	35	59	63	171	233	410	13		
12:00	38	60	64	181	257	420	11	4000	
13:00	41	61	64	183	269	420	13		
15:00	47	58	61	192	253	420	14		
16:00	47	57	60	184	263	420	12	2000	
17:00	48	60	63	182	267	420	13		

Data Logging Sheet - Part 1

Date: 9.7.09

Operators:Aharon;Haim;Udi

Page N°: 15 / 15

Time	FI-1 (m^3/h)	FI-2 (l/h)	PI-1 (mmWC)	pH	Inlet / Outlet	Concentrations (%, mg/dNm^3)						Notes
						O_2	SO_2	NO	NO_2	CO_2	CO	
9:00	60	8	250	6.3	OUT	10.6	0	148	2	7.6	31	
	60	8	250	6.3	INLET	10.9	5000	145	30	7.4	38	
10:00	60	8	250	5.98	OUT	10.6	0	140	0	7.7	51	
												d(1.062 gr/cm3)

Aminolab Ltd. **Analytical Laboratory Services**
Main Branch: Weizmann Science Park, Ness-Ziona, Israel. Tel: 08-9303333, Fax: 08-9303300
North Branch: P.O.B. 1033, Karmiel 20100, Israel. Tel: 04-9586916, Fax: 04-9582154

21/07/2009
Report No: C4993 R_1

To:
Mr. Haim Shtranfain
LEXTRAN LTD
Granit 6 Kiriat Aria
Petach Tikva 49130
Tel: 052-2341345, 08-6258300#263
Fax: haim@ludan.co.il/03-9182028

CERTIFICATE OF ANALYSIS

Aminolab No.: **30577.09-C**
Sample: Liquid 04/07
Sampled by: The Customer
Sampling type: Random

Sample reception: 09/07/2009
Order No: DOC3H-112

Analyses Results:

Analysis	Units	Results	Remarks
Total Keldhjahl Nitrogen	mg/L	57793	-
Total Solids 105°C	%	27.3	-
Total Suspended Solids 105°C	mg/L	<1	-

Analyses Remarks:
(-)=No remarks

Quality Assurance:

Analysis	Method / Standard	Remarks
Total Keldhjahl Nitrogen	SM - 4500-Norg B	a,b
Total Solids 105°C	SM - 2540 B	a,b
Total Suspended Solids 105°C	SM - 2540 D	a,b

Accreditations / Certifications:
The laboratory is accredited under ISO/IEC 17025 with standard operating procedures.
a. Aminolab is accredited to perform this analysis under ISO/IEC 17025 by ISRAC.
b. Aminolab has the recognition to perform this analysis by the Israeli Ministry of Health.

Analyzed By: Dina Brudner Signature: _____

Approved by: Dr. Zadok Shabi - Lab. Manager Signature: _____

This certificate is valid only when it is presented in its complete format, and it is not permitted to extract part for inclusion in any other document. The data presented accurately expresses the results for the sample received only. It is not permitted to use Aminolab Ltds' name or its reputation in respect to the above - specified results, without Aminolab written consent.

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Sampling type: Random

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Order No: DOC3H-112

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Analysis	Units	Results	Remarks
Total Keldhjahl Nitrogen	mg/L	57793	-
Total Solids 105°C	%	27.3	-
Total Suspended Solids 105°C	mg/L	<1	-

Analyses Remarks:
(-)=No remarks

Quality Assurance:

Analysis	Method / Standard	Remarks
Total Keldhjahl Nitrogen	SM - 4500-Norg B	a,b
Total Solids 105°C	SM - 2540 B	a,b
Total Suspended Solids 105°C	SM - 2540 D	a,b

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