REF #4756

Summary

In the new flue gas desulphurizing process described, fine liquid droplets of NaOH or Na_2CO_3 are sprayed as absorbing chemicals into the flue gas within a spray drying tower. The SO_2 and CO_2 gases present in the flue gases are quickly absorbed by these liquid droplets to form Na_2SO_3 and Na_2CO_3. Simultaneously, the water contained in the droplets is vaporized by the heat of the flue gas. After the Na_2SO_3 and Na_2CO_3 concentration in the droplets has reached the saturation point, the droplets crystallize and become dried. Thus dry dust particles consisting of Na_2SO_3 and Na_2CO_3 are produced by these steps. Subsequently, these dust particles are sufficiently separated as by-products from the flue gas by an appropriate dust collector such as an electrostatic precipitator. It is a remarkable advantage of this new process that both the desulphurization of flue gas and the production of Na_2SO_3 and Na_2CO_3 powders are simultaneously accomplished within a single spray drying tower without any gas pre-cooling.

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725.4.051.8:613.155

The Dispersion of Air Pollutants in a Work Hall by Convection Currents*

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1. Introduction

Since dust particles and gases liberated by a manufacturing process and dispersing through the factory hall can be troublesome and sometimes toxic to the workers in the factory, research is being carried out in an attempt to counter this dispersion as far as possible. The most effective method is control at the source, e.g. by shielding or extraction. Frequently, however, this is impossible, so that when the lowest possible dust concentrations must be reached the solution seems to be good ventilation. How should such ventilation be achieved? By the term effective it should be understood that as many dust particles as possible are led directly from the dust source to the air vent opening, so that as few as possible can spread into the factory hall. For this purpose it is necessary to know how the air moves through a given factory hall, and which factors cause this motion. In general, air motion in a hall is primarily caused by the motion of external air – i.e. the wind – and the air in side halls. In addition, heat generation by machinery in the hall can play a significant role. At a certain point in time an air flow pattern – which can be designated as the natural air flow pattern – arises due to these two causes. In the case that the dust and gas concentrations become too high, investigations are undertaken on how to influence this pattern in the most satisfactory way by blowing or exhausting air at certain places in the hall. The question then arises of how much air should be blown or exhausted at which places. An answer to this question is possible only with model experiments in which planned changes in the hall are simulated on a model. Even a semi-theoretical calculation of this problem appears impossible, in the first place because of the complexity of the descriptive differential equations and in the second place because of the complicated geometry of the factory hall.

A model technology must start from the actual situation in the factory hall to be investigated. Thus it must be possible in the model to simulate precisely air speeds and temperatures as well as dust and gas concentrations in the hall.

Before a model can be constructed, it is therefore necessary to know precisely the situation in the factory hall. For this purpose, measurements were undertaken by the Research Institute for Health Technology TNO, Delft in a factory hall of Hoogovens IJmuiden BV. This hall is connected to side halls and through windows to the outside air. The machinery causes a convective air flow by heat generation. The hall is principally contaminated by very small oil droplets which originate from the oil mist lubrication system of the machinery. Solid particles, i.e. dust, play almost no part here.

The measurements should serve

a) to determine the air flow pattern in the hall as well as the factors which cause this pattern;

b) to establish the temperature distribution in the hall and to reveal the relationship with the air flow pattern;

c) analogous to (b) to plot the dust concentration distribution.

For this purpose, measurements must be made at a large number of places within a short time. This was made possible only by the cooperation of a large number of coworkers from our and other institutes. The investigation was made possible by a subsidy from the European Coal and Steel Community.

2. The Factory Hall

Measurements were performed in the S-hall of the electrotinning plant of Breedband N.V. This hall contains two machines on which rolled steel sheet is tin plated by an electrolytic procedure. A bird's eye view of the hall is shown in Figure 1.

The principal dimensions of the hall are: length: 176.65 m; width: 32.00 m; height: 17.31 m (of the low part); 21.04 m (of the high part).

Figure 2 shows the floor plan of the hall and the form of the side walls.

3. Location of the Measuring Points

Figure 2 shows the points on the floor and on the machinery at which measurements were made. The points lay along three straight lines in the longitudinal direction of the hall. Specifically, these are the lines through the centers of the machines and the line in the

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center of the space between the two machines. Seen in the transverse direction, measurements were made under the high and low parts of the roof instead of in the center. The measuring equipment was lowered from a crane by means of cables and tubes.

Figure 3 shows a vertical view of the measuring points.

4. The Measuring Assembly

The measuring equipment was assembled on the crane so that it was positioned precisely over the machines and on the line between them.

a) Measurement of the air speed and flow direction

The overall flow direction was determined by means of smoke experiments. For this purpose, smoke was blown in a perforated plastic tube with a smoke generator. Each tube was constructed from tubular sections approximately 3 m in length, which were coupled to each other so that the total tube length was variable.

Above the machines it was often necessary to take measurements with a shorter tube, whereas between the machines it was always possible to work with the entire tube length. For the measurements under the high section of the roof each tube could be lengthened with a tubular section. An anemometer, with which the air speed was measured, was attached to each tube section. This anemometer was a thermoanemometer developed by our Institute.

b) Temperature measurements

The temperatures were measured with copper-constantan thermo-elements. Both air speeds and temperatures could be read directly by means of an electrical functional system. The thermo-elements were attached to cables which were always lowered to the correct height.

c) Particle concentration measurements

The diameter of the oil drops was – as the management confirmed – less than 2 µm. Therefore it was possible to use two methods for the concentration measurements, namely:

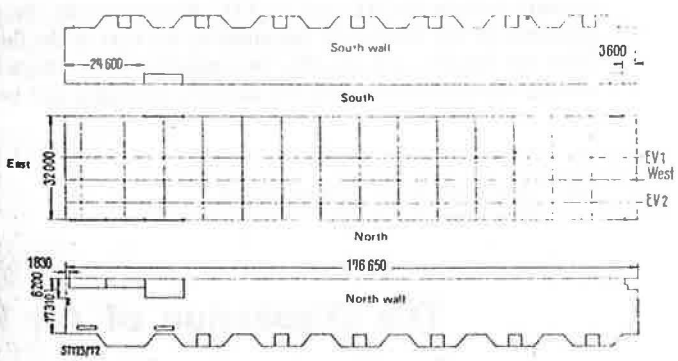

Figure 2. Dimensions of the work hall

1. Measurements with thermal precipitators;

2. Measurements with the Sinclair Phoenix aerosol photometer.

In the former method, the droplets sucked in are precipitated on glasses. It was necessary to photograph the samples as rapidly as possible through a microscope, since changes in the sample appeared after even fairly short times. The photographs were later analyzed by means of a Quantimet, so that a cumulative particle size distribution was obtained for each measuring point. The Sinclair Phoenix apparatus operates according to the principle of light scattering by particles in the air sucked in. The signal therefore depends on the physical properties of the aerosol sample, and especially on the particle size distribution. In the present case – as is evident – the physical properties of the particles were approximately equal for all measuring points. Thus the Sinclair Phoenix instrument could be used successfully here. A signal is obtained from which the concentration can be determined. During the measurements the Sinclair Phoenix instrument was mounted on the floor, and the intake tube was drawn upwards by the crane so that the intake port could be brought to any desired measuring point.

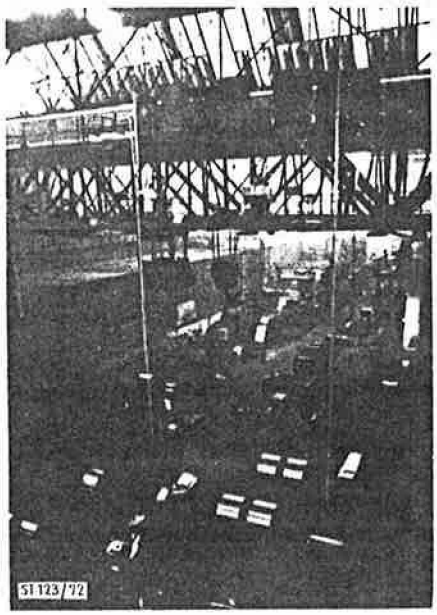

Figure 1. Bird's eye view of the hall

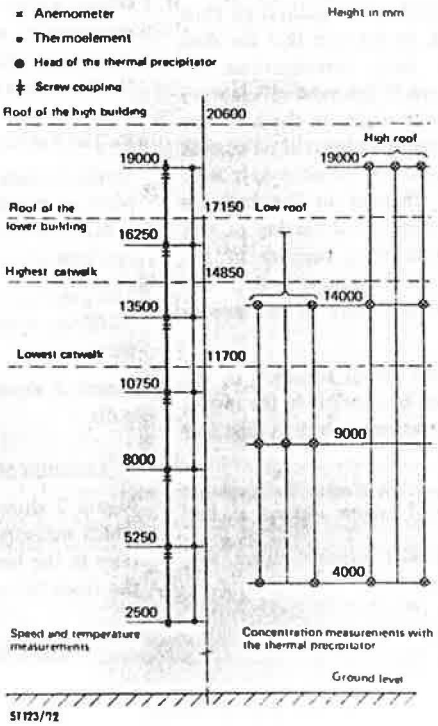

Figure 3. Height of the measuring points

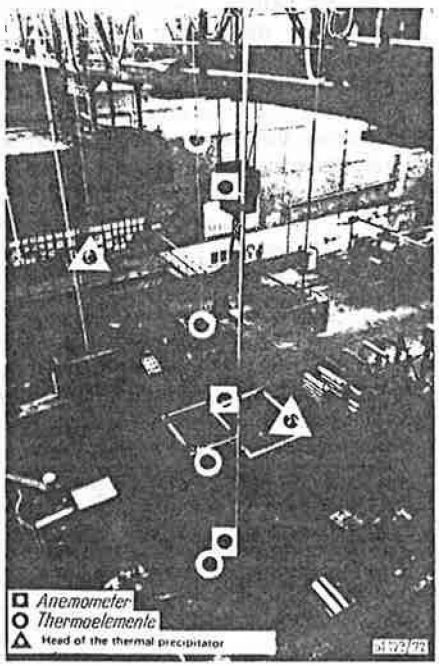

Figure 4. Measuring instruments suspended from the crane

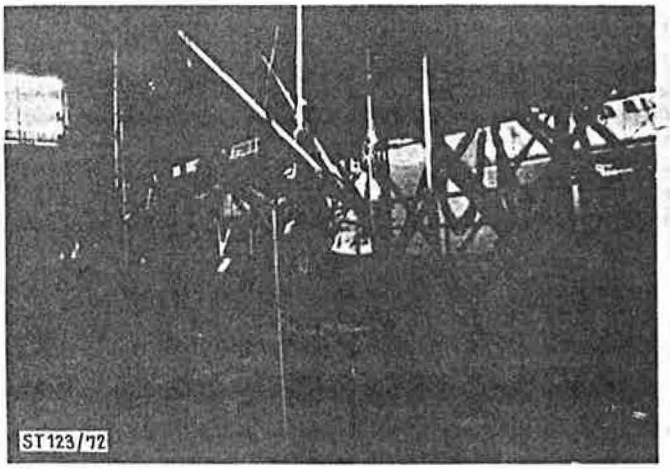

Figure 5. Unscrewing a tube section to change a measuring position

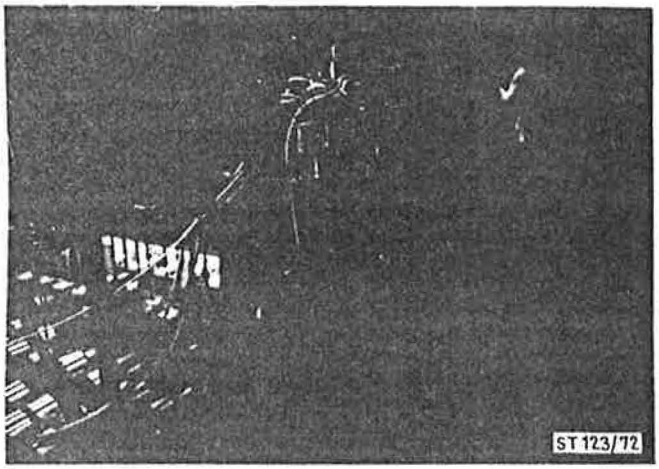

Figure 6. Intake chambers of the thermal precipitator on the crane

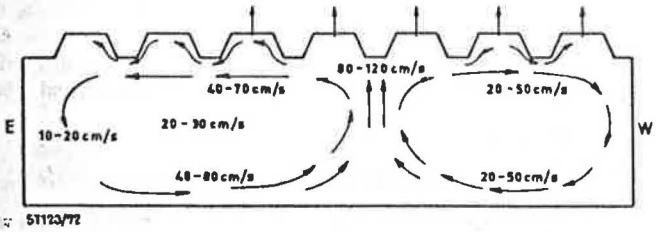

Figure 7. Air flow profile in the hall

Figure 4 shows how the smoke tube with the anemometer was suspended. The cable with the thermo-element was suspended beside it. In Figure 5 it can be seen how a tubular section is screwed from the tube. Figure 6 shows four intake chambers for the thermal precipitator, which was mounted on the crane.

5. Measured Results

a) Air flow pattern

The air flow pattern in the hall could be clearly determined from the smoke experiments and the anemometer measurements. West of the center of the hall a strong local heat development was observed due to the machines, which gave rise to a strong upwards convection flow. This in turn produced two eddy currents, of which one was stronger than the other. Figure 7 shows this flow pattern and the measured air speeds. In the high part of the roof were five ventilators, each of which extracted 30000 m^3 air per hour. It was evident that the eddy pattern in the west section was somewhat less well-defined than in the east part.

Figures 8, 9 and 10 provide an impression of the smoke experiments. The air flow direction can readily be seen. During the measurements four windows in the south wall and two in the north wall were opened, while the wind direction was east to southeast and the wind speed was 3 to 5 m/sec. In the vicinity of the opened windows and the connecting openings to the side halls this flow pattern was distorted by air flows from the outside.

It is clear that this air flow pattern occurs in all weather conditions, because influences from outside could distort this pattern only locally.

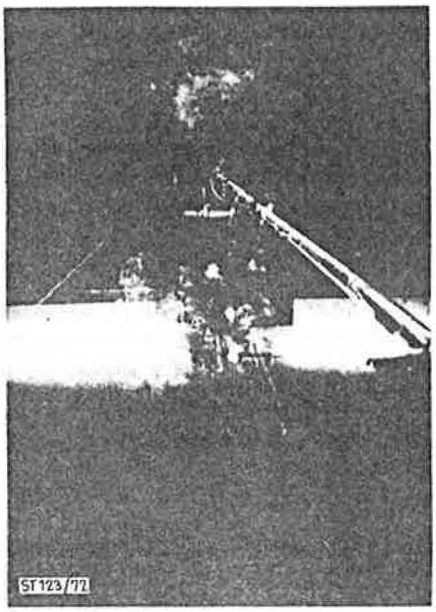

Figure 8. Smoke experiment

Figure 9. Smoke experiment

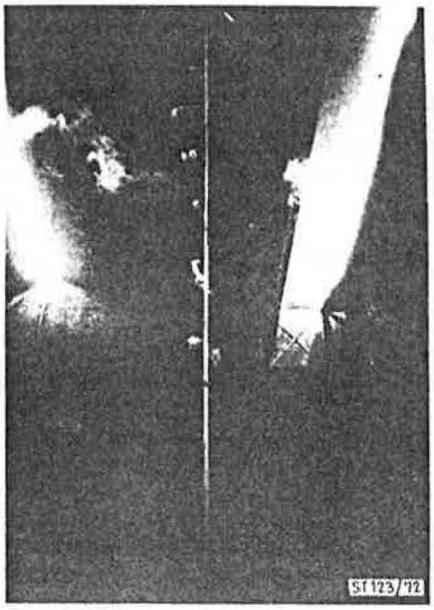

Figure 10. Smoke experiment

b) Temperatures

The temperature measurements gave the temperature distribution (Figure 11, temperatures in °C).

During the measurements the outside temperature was fairly constant at 4 to 6°C. A clear relationship was observed here between the air flow pattern and the temperature distribution. The circulating air reached its maximum temperature above the heat sources of the machines. Thereafter, the air gradually cooled as it flowed under the roof and along the east or west wall to a minimum value which was reached at the connecting openings to the side halls. There it became mixed with air from outside, after which its temperature gradually increased again, i.e. as it flowed along the machines.

c) Concentrations

Measurements were carried out in the hall over a two-day period using thermal precipitators. Both the concentration of oil droplets in the air and the particle size distribution could be determined in each measuring point by the Quantimet analyses. The shape of the distribution curve was actually approximately similar in most points, but the levels were very different. Moreover, it was proved that the particle concentrations on the second day of measurement were on average three to four times lower than on the first day.

On each day it was only possible to measure the concentrations at 50 points, which is therefore substantially less than could be obtained for the speed and temperature measurements. For each day of measurements a mean distribution and in turn the corresponding mass concentrations were determined from 50 size distributions. For this calculation it is necessary to convert the diameter of flattened drops on the glasses to the diameter of a sphere of equal volume. The mass concentration determined in this way was on average $6.4 \cdot 10^{-4}$ g oil per m^3 air on the first day and $1.4 \cdot 10^{-4}$ g oil per m^3 air on the second day.

The number of points in the hall for which the concentrations could be determined with the thermal precipitator was too small to plot a concentration pattern for the whole hall as was done for the air flow and temperature patterns.

It was proved that it was readily possible to measure the concentration at a point very rapidly with the Sinclair Phoenix aerosol photometer. This was due to the fact that the impurities in this hall consisted almost exclusively of oil droplets possessing a

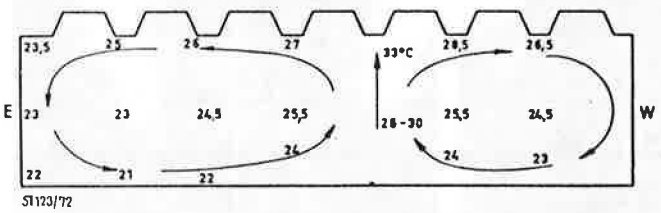

Figure 11. Temperature distribution in the hall

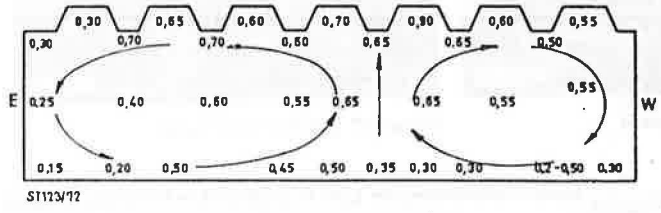

Figure 12. Concentration distribution in the hall (Mass concentrations in mg oil/m^3 air, measured with the Sinclair Phoenix apparatus)

diameter < 2 µm. Droplets with a diameter >. 2 µm were precipitated in the tubes of the lubricating system of the machines and therefore rarely entered the air. This means that the falling velocity of the particles is negligibly small, which in turn explains why the shape of the cumulative particle size distribution was approximately equal at all points. The signal of the Sinclair Phoenix apparatus is a measure of the intensity of the light falling on the photocell. This intensity is determined by the oil droplet concentration in the air of the measuring point, and consequently by the level of the cumulative particle size distribution.

By calibrating in the hall at different concentrations the relationship between the signal of the Sinclair Phoenix apparatus and the mass concentration of the droplets could be determined. Moreover, it was proved that the relationship between the mass concentration and the intensity of the light falling on the photocell was fairly linear, as expected from theory. This confirmed the reliability of the measuring method.

Figure 12 shows the concentration pattern obtained under the following measuring situation:

During the measurements all windows on the north and south side were opened. Here also – as in the case of the temperature distribution – the relationship between the air flow pattern and the concentration distribution was obvious. The concentrations reached their lowest values at the connecting openings (east and west) with the other halls.

Thus, looking in the flow direction, the concentrations increased. The air flowed over the floor along the machines and was driven upwards by convection. The concentrations remained practically constant under the roof. A little to the west of the convection current, however, the concentration under the roof was somewhat higher, whereas at the extreme east side under the roof it was much lower. This was supposedly due to the fact that an east wind was blowing at the time of the measurements. As the air flowed downwards the concentration decreased due to mixing with air flowing in through the connecting openings. In this regard there was a distinct difference to the air temperature under the roof, since the temperature still decreased gradually during the flow. This was probably caused by heat transmission through the roof, which would influence the temperature but not the concentration.

A mean mass concentration can also be determined from the measurements with the Sinclair Phoenix apparatus. For 251 measuring points a mean concentration of $4.9 \cdot 10^{-4}$ g oil per m^3 air was found. This is in good agreement with the mean mass concentration which was found on the first day of measurements with the thermal precipitator. The latter concentration was somewhat higher than the former because during the measurements with the Sinclair Phoenix apparatus more windows were open than during the measurements with the thermal precipitator, so that the air exchange was somewhat greater. From this it is evident that the mean concentration on the second day of measurements ($1.4 \cdot 10^{-4}$ g oil per m^3 air) must be too low.

6. Mass and Heat Balances of the Hall

On two different days, namely December 15, 1971 and May 10, 1972 the temperatures and air speeds were measured at the windows, the wall openings and the ventilators. In addition, the relative humidity was recorded. The roof ventilators were in operation during the measurements on December 15, 1971, but not on May 10, 1972. Tables 1 and 2 give a summary of the air masses flowing in and out, along with their heat flows.

The mass and heat balances agree fairly well considering the circumstances under which they were measured. The difference between the air masses flowing in and out was determined as 16.5%

Table 1: Mass balance of the air flow

Date	12/15/71		5/10/72	
Mass flow, kg/sec	In	Out	In	Out
Windows	65,0	32,5	43,2	28,3
Wall openings	90,1	19,8	97,2	78,1
Roof ventilators	–	65,5	–	11,3
Air extractors	–	15,4	–	15,4
Total	155,1	133,2	140,4	133,1

Table 2: Heat flow in the hall

Date	12/15/71		5/10/72	
Heat flow, kJ/sec	In	Out	In	Out
Windows	2000	1991	1299	1675
Wall openings	5071	1071	4229	3668
Roof ventilators	–	5904	–	942
Air extractors	–	1254	–	1254
Total	7071	10220	5528	7539
Heat development of the machines	1982	–	1982	–
Transmission loss	–	386	–	435
Total	9053	10606	7510	7974

on December 15, 1971 and as 5.5% on May 10, 1972. The corresponding values for the heat flow were 14.5 and 5.8%. An outgoing mass flow of 133 kg air/sec means a volume flow of 410000 m^3 air per hour. The volume of the hall is 108000 m^3, so that the air turnover rate was 3.8. For a mean oil droplet concentration of $6.4 \cdot 10^{-4}$ g/m^3 air this means that 49.5 liters oil were passed out, i.e. consumed, per week. For a mean concentration of $1.4 \cdot 10^{-4}$ g/m^3 air the corresponding oil consumption would be 11.2 liters per week. The difference between these two values is actually large, although in terms of order of magnitude they certainly agree with the estimate of oil consumed by the machine due to operation.

Final Conclusions

1. A well-defined and logically explicable air flow pattern is evident in the hall. It is caused most of all by the generation of heat by the machines in the hall. Influences from the outside, for example from windows and from openings in the wall leading to other halls can influence this flow pattern only locally.
2. A clear relationship can be distinguished between the air flow pattern on the one hand and the temperature and concentration distributions on the other. This relationship can also be logically explained.
3. It was proved that it is possible to accurately determined the air turnover number in the hall by means of measurements. The withdrawal of oil calculated from this agrees approximately with the calculated oil consumption of the lubrication system of the machines.
4. The results appear to be suitable to serve as the basis for model studies in this hall.

Acknowledgement

A word of thanks is first offered to the European Coal and Steel Community for the subsidy by which this investigation was made possible. We thank Messrs. Loos and Lasdrager of the Occupational and Environmental Health Division of Hoogovens IJmuiden BV for their valuable help and for making arrangements with the management of the tin plating plant. Finally, we thank the management of the tin plating plant for their cooperation in this investigation and for permission to use the crane, without which these measurements would not have been possible.

Summary

Air contaminants, i.e. gases as well as fine particles having a neglible falling velocity are mainly transported by movement of air. If there are sources of contaminants in a factory hall it is necessary to know the air currents inside the hall in order to foresee the spreading of these contaminants. Measurements carried out at different points inside a factory hall gave information on air speed, temperature and particle concentration. These measurements, and the determination of the air flow by means of smoke, have shown that the air current was caused by the local evolution of heat due to machines. Disturbances occur at the windows and at the connecting openings to adjacent halls. The temperature and concentration distributions are given.

Patent Report

Patent Applications

Announced December 14, 1972:

12 3 2-01 (B 01 d 47-02). 1807327. App Date: 11/6/68. Pub Date: 10/16/69. Priority: 11/16/67 Sweden 15724. Title: Device for Separation of Airborne Particles from a Gas. App: Alfa-Laval AB, Tumba, Sweden. Rep: Ruschke, H., Dr.-Ing.; Agular, H., Dipl.-Ing, Patent Attorneys, 1000 Berlin and 8000 Munich. Inv: Gramer, Erik Allan, Spaanga; Javorsky, Bronislav Stefan, Huddinge, Sweden.

12 e 3-02 (B 01 d 53-02). 1544084. App Date: 10/27/66. Pub Date: 1/7/71. Title: Process for Desulfurization of Gases. App: Metallgesellschaft AG, 6000 Frankfurt. Inv: Herbert, Wilhelm, Dr., 6000 Frankfurt; Bratzler, Karl, Dr., 6360 Bad Homburg; Storp, Klaus, Dr., 6000 Frankfurt; Hohne, Reinhard, Dr., 6078 Neu Isenburg.

12 e 5 (B 03 c 3-70). 1801143. App Date: 10/4/68. Pub Date: 4/23/70. Title: Device for Passing a Voltage Supply Conductor through the Cover of an Electrostatic Precipitator to be Used for Phosphorus Manufacture. App: Knapsack AG, 5033 Hurth-Knapsack. Inv: Muller, Fritz, Dipl.-Ing., 5033 Knapsack; Kampmann, Friedrich-Wilhelm, Dipl.-Chem. Dr., 5042 Liblar; Niermann, Hermann, Dipl.-Chem. Dr., 5045 Bliesheim; Werner, Hugo, 5030 Hermulheim.

14 k 3-04 (F 01 n 3-04). 1601450. App Date: 2/16/68. Pub Date: 3/19/70. Priority: 2/17/67 Australia 17892-67. Title: Cleaning Device for Exhaust Gases. App: E. M.