Item 1
Dust-Removal
Pages 5-28
Report presented by Dr. Geister, Dec. 3, 1936

In 1936 many efforts were made to deal with the problem "Dust".* The reason is that the increasing quantities of dust, which are obtained by the use of large quantities of cheap solid fuels, by the combustion of powdered coal, by the increase of the throughput of dryers, mills and transportation devices cannot always be recovered satisfactorily or economically by the hitherto known processes of the "dedusting technique". It seems therefore to be very necessary to give a report which covers the latest development of the "dedusting technique".

The dust extracting devices can be divided into:
(1) Dedusting devices employing the force of gravity.
(2) Dedusting devices employing the centrifugal force.
(3) Electric precipitators.
(4) Devices applying molecular forces and the force of friction.

Employing the first 3 methods, the devices must be designed in such a manner that the dust particles leave the gas stream as quickly as possible at a specified point whereas if filters are employed which use molecular forces or the force of friction they remain in the gas and are hindered from further motion. Because the force of gravity is very cheap it should be always employed whenever it is efficient enough.

The force of gravity imparts an acceleration to every mass according to the law of gravity, but dusts differ from other solid particles in that their fall is nullified very quickly by the viscosity of the carrying gases. The accelerated fall is transformed into uniform fall, which with regard to dusts, is called "migration velocity". At first the "migration velocity" must be determined in order to be able to select the best dedusting method.

The following table #1 represents a compilation of the formulae dealing with the "migration velocity", the factors upon which it depends, and the conclusions which may be drawn from the formulae. The factors "specific gravity" and the "viscosity" should generally be known, whereas the equivalent radius of the dust particles must be determined.

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* January 1936:	Meeting of the "Dust committee", Berlin
January 1936:	Meeting of the "Association of the owners of Large Boilers" and the "Association of Electric Power Supply" held at Darmstadt with the single subject "Recovery of Flue-ashes".
February 1936:	Performance of guarantee tests of dedusting devices.
April 1936:	Number one of a periodical named "Dust".
April 1936:	Determination and composition of dust according to size and velocity of fall.
May 1936:	Meeting of the committee for the "Techniques of Dust".

The determination of the sizes of the particles is carried out by screening if the particles are larger than 60 microns; by sifting if the particles are smaller than 60 microns. Since sifting separated only particles down to a size of 5 microns, finer particles must be analyzed by elutriation. Dr. Krause and Dr. Zell described a method for the determination of the size distribution of particles between 20 and 0.5 microns. (Laboratory report of the Alizarine-division, July 16, 1936 #1054)

The result of all siftings is represented by a size distribution diagram, whereby we have to distinguish between uniform granulation, screen-sifted, non-sifted and air-sifted material. As shown in Table #2, the results are represented by diagrams of the oversize, undersize, and size-distribution curves.

Table #2

Uniform granulation	Screen-sifted	Non-sifted	Air-sifted
Residue	Residue	Residue	Lower limit for air-sifting
Undersize	Undersize	Undersize	
Size-distribution	Size-distribution	Size-distribution	Size-distribution diagram
	Dust precipitation in the dust chamber	Determination of the dedusting efficiency	Determination of the size of the dust-chamber

Note: The original German diagram and curves are not reproducable because the reduction in size made them illegible. The titles of the diagrams or curves are shown above.

The method to determine whether a gravity deduster or a centrifugal one is able to secure a suitable dedusting efficiency, depending on the composition of the dust, was published by Schultes and is represented by the lowest row of the diagram ("Views for the selection of a suitable dust extracting method". VDI-Meeting at Darmstadt).

Hitherto it was impossible to perform any calculations if a dust of different shape and different specific gravity had to be treated. If one has to deal with such a kind of dust the size-distribution curve is replaced by the curve of uniform fall which can be drawn according to the "Regulations for the determination of dust according to size and velocity of fall", (published in 1936 by VDI-Berlin). It is a well-known fact that dust particles which are carried away by the wind are precipitated again at definite places causing dust-drifts i.e. snow drifts.

It is obvious that with the cognizance of the regularity of this appearance it should be possible to design suitable dust precipitating devices. Dr. Sell has carried out numerous experiments concerning the motion and precipitation of dust particles in a field of flow with or without resistance bodies. He derived the most important formulae which could be confirmed by trial. (Dust precipitation by means of simple solids or air-filters. Research number 347, published by VDI-Berlin, Edition B, Vol. 2, 1931). At first he tried various resistance bodies applying the laws of hydrodynamics and aero-dynamics taking into consideration the weatherside (windward side) of the body which is responsible for any precipitation of dust. Small drops of Indian ink, (diameter 50 microns) which were blown against various resistance bodies applying a velocity of 9.2 meters per second served as dust particles. Picture #3 represents a cylinder which was employed as resistance body. All dust tracts which are passing the cylinder tangentially are called boundary tracks. They were drawn in afterwards. The respective dust extracting efficiency is represented by the distance of the parallel section of the boundary tracks in relation to the diameter of the resistance body. The cylinder (Picture #3) showed an efficiency of 0.60, the plate (Picture #4) of 0.75 and the "catching body" (Picture #5) of 0.82. (Picture #3: Dust tracks employing a cylinder with the boundary tracks drawn in (dotted lines). Air pressure 748 mm Hg, air temperature 17°C., flow velocity W_o=9.2 meters per. sec.). (Picture #5: Dust tracks employing the "catching body" with the boundary tracks drawn in (dotted lines), air pressure 748 mm Hg., air temperature 17°C., flow velocity W_o= 9.33 meters per. sec.). (Picture #4: Dust tracks employing a plate with the boundary tracks drawn in (dotted lines)., air pressure 748 mm. Hg, air temperature 17°C., flow velocity W_o = 9.08 meters per. sec.).

The "catching body" showed the most efficient relative dust extracting efficiency. In order to reduce its resistance against the flow of the air a streamlined catching body was employed.

Picture #6: Dust-tracks employing a streamlined body; 2/3 of natural size. Air pressure 750 mm Hg; air temperature 20°C., flow velocity W_o = 9.5 meters per sec.

In order to treat the dust tracks which are passing at the right and left side of the "catching body" some of them were arranged in staggered banks. (2/3 of natural size).

The second chapter of his report covers the deposition of dust by means of oil-wetted metal filters which replaced the cotton-bag filters since 1916 due to a shortage of textile tissues. By improving the design of the metal-filters a standard type which now governs the market could be developed. All designs are distinguished by particularly shaped metal sheets or by packing material which impart to the gas a frequent alteration of its direction; by doing this the dust particles are withdrawn from the flow threads and meet somewhere the oil-wetted deflection plates to which they are attached. Every driver is familiar with that kind of filter which must be refreshed from time to time. If large gas volumes must be treated, endless belts are often employed which are wetted and cleaned continuously.

The aim of Dr. Sell's experiments was to find out by trial such a shape of the deflection plates which had a low resistance against the flow of the gases but a very good efficiency with respect to the dust extraction. He found that a channel where an enlargement of the diameter follows a jet-like contraction showed 10 to 15% less resistance as if the radii r_1 and r_2 are of equal size. The resistance was increased for 25% when the direction of the flow of the air was reversed. (Compare picture 8) Picture 8: Depth of the filter equals 14 κ.b. Shape and sizes of the investigated corrugated sheet-iron channel.

Picture 9 represents the flow of the air through the channel. The pictures 10 and 11 show the course which led to the arrangement which is represented by the pictures 8 and 9. Picture 9: Air-flow through the corrugated sheet iron channel. RI= 1900; Inspite of the high Reynolds figure only small vortices can be observed and the flow is almost viscous.

The white parts in the pictures 10 and 11 represent the dust. It is easy to observe that the fewer vortices are formed the better is the dust precipitated. The deflection plates go just to the midst of the channel or a little farther. The plates in the upper part of the picture deflect the gas flow whereas the plates in the lower part are perpendicular with respect to the direction of the flow of the gases. The following plates serve as "catch pockets". A zigzag channel had no precipitating effect. A wave-like shaped channel showed the highest efficiency.

The cognizance of the migration velocity of the dust particles and the experiments dealing with the attitude of dust against the flow of gases render it feasible to judge the modern dedusting devices.

Picture #12 represents a couple of dry and wet gravity dedusters.
Picture 12: dry gravity deduster

Heimike design	Bartl design	Filtrex design
Velocity of the gases 1-2 meters per sec. Less of the draught 3-5 mm water column	Velocity of the gases 2 meters per sec.	Velocity of the gases 23-25 meters per sec.

Wet gravity deduster

Babcock design	Van Tongeren design	Finow design
Water consumption 0.5 cu. m. per 1000 cu. m. gas	Water consumption 0.5-1 cu. m. per 1000 cu. m. gas	Water consumption 0.05 cu. m. per 1000 cu. m. gas

The most simple dry working gravity deduster was a settling chamber. Such a device is efficient if the time of fall of the dust equals or is less than the time of passage of the gas. The time of fall is short if the distance of fall is short, the time of passage is long if the cross section of the device is large. The Heimike design complies with both requirements. The roof shaped baffles secures a

short way of fall maintaining at the same time a large cross section.
The dust particles are collected in pockets which are arranged at the right and left sides. The design and the operating costs are cheap but the apparatus requires much space, because the velocity of the gas is only 1-2 meter per sec. The Bartl design applies equally low gas velocities but its sizes are a little smaller. The total gas volume is subdivided into single streams and is several times deflected. By means of catching pockets the efficiency is similar to that of metal filters which are shown in picture #9. The Filtrex design applies an extremely good deflection of the gas. A cone-like arrangement secures a uniform gas velocity even after a withdrawal of a certain gas volume. Approximately 3-4% of the total gas volume together with the dust are drawn into a following dust extracting device, from which the purified gas is led back to the main gas stream. Several other designs employ the same principle of subdividing the total gas volume into a main stream free from dust and a dust carrying side track. This method has the advantage that only small dedusters are necessary.

The dry gravity deduster is able to extract only coarse or medium fine dust. By injecting water fine dust particles can also be extracted. The lower part of picture 12 shows three designs of this type. The Babcock deduster is equipped with water jets, the van Tongeren chamber employs wetted metal sheets. The Finow deduster is of similar design, it is the most remarkable deduster due to its extremely low water consumption. The wet dedusters have an efficiency as high as almost 100%. Due to this fact it should be advisable to employ only wet dedusters. Since many dusts are either spoiled by water or are hard to recover the application of wet dedusters is limited. The disposal of the dust-containing water offers sometimes a more difficult problem than the dust extraction itself if worthless dusts must be dealt with. A dry working method is therefore mostly applied and since the use of gravity dedusters is limited, the centrifugal force is mostly applied. The formula of the migration velocity of dust particles shows very clearly that the peripheral velocity must be as high as possible whereas the radius of curvature should be as narrow as possible. It is obvious that many of the formerly used designs do not comply with those requirements.

The table of the sizes of cyclones which is represented by picture #13 was published in 1931 by a periodical. Not only is the cross section of the inlet pipe with an increasing gas volume to be treated enlarged, but also all other sizes of the apparatus. With an increasing gas volume the apparatus complies less and less with the requirements of an effective centrifugal deduster. Should, nevertheless, a dedusting effect be observed it will be caused more by the force of gravity than by the claimed centrifugal force.

Picture #14 represents such an inefficient apparatus which consumes high amounts of material without giving satisfactory results. A water pipe is easy to recognize at the top of the apparatus which introduces water into the insufficient working apparatus. Often a choked disposal channel is the result of this bad sized deduster. Such failures would be impossible if the fundamental laws of dust extraction would always be observed.

Picture #15 represents some of the modern centrifugal dedusters.

~~Picture #15~~

Centrifugal deduster "Dry"

<u>Hartmann design</u>	<u>van Tongeren design</u>	<u>Lurgi design</u>
Particle size down to 5-10 microns. Resistance 75 mm. water column	Particle size down to 20 microns Resistance 12-49 mm. water column	Multiclone Resistance 70-1000, mm. water column

Centrifugal deduster "Wet"

<u>Raymond mill</u>	<u>Pfleiderer design</u>	<u>Frey design</u>
Centrifugal force and air sifting	Particle size down to 1-8 microns water consumption 0.8 cu. m. per 1000 cu. m. gas	31.5% 75 micron Resistance 20-50 mm Water column. Water consumption 0.1-0.4 cu. m. per 1000 cu. m. gas.

The Hartmanm design is shaped like a cyclone, it complies with the two main requirements of a modern centrifugal deduster. Even with large gas volumes the radius of curvature remains small wherever the peripheral velocity is so high in all cases that the centrifugal force is acting but not the force of gravity. Due to the high gas velocity the resistance is as high as 80-100 mm. water column, but the total efficiency is very good and dust particles down to a size of 5 microns can be removed.

The van Tongeren design has less resistance. Only particles down to a size of 20 microns can be removed. A dust carrying side track is separated from the main track, from which the dust is extracted by a very sharp deflection.

The Lurgi design "Multiklon" complies with the requirements of a centrifugal deduster even if large gas volumes must be purified. Since large gas volumes cannot be treated by cyclones which have a small radius of curvature, the main gas stream is subdivided into small streams which correspond with the capacity of one single unit. Such a subdivision is consequently made even if a complete purification system should consist of 100 single units.

In this connection such types of centrifugal dedusters should be mentioned which do not comply with the proper design, the poor efficiency of which is concealed by the manner of their utilization. I want to mention the air-sifters of our mills. The output of a mill increases if the finished product is removed as quickly as possible from the product to be ground. The most employed method for this purpose is "air-sifting" as shown in picture #15 in connection with the Raymond mill. The basic principle of air-sifting consists of removing particles of only such a size from a dust mixture which are carried away by an ascending wind, the velocity of fall of which is less than the velocity of the wind. The velocity of fall equals the migration velocity (Compare picture #1).

A continuous sifting of the material to be ground can be successful with respect to an increase of the output only if the finished product is properly removed, otherwise it comes back into the mill with the recirculating air thus decreasing the output. It was experienced that the output of a mill could be improved 50% by an improved separating system.

A water-wetting is employed for the operation of centrifugal dedusters, if a high percentage of very fine particles should be present as is the case if flue ashes must be treated. Picture #15 represents a flue dust catcher of the Pfleiderer design which is connected with the high pressure boilers of the Oppanpand Ludwigshafen plant. The Pfleiderer design resembles the metal filters with respect to the subdivision of the gas flow. The dust particles are projected from the gas track by deflection of the gas blow and adhere to a wetted surface.

With the Frey design, the dust carrying gases enter the device at the top, penetrate a water spray and are led to an impeller which has several blades which effect the extraction of the dust by projecting it against the wetted wall of the apparatus.

Picture #16-- Increase of the centrifugal force by centrifuging.

Babcock blower-deduster	Air-sifter	Hildebrandt-sifter
Space saving but low efficiency	Pfeiffer design	

Filter duster

Beth-filter	Homgmann filter	Traveling filter
Self-cleaning textile filter; without pretreatment.	Efficiency 94-98% Resistance 30-50 mm. water column	0.4 m^2 filtering area per 1000 cu. m. gas

The Babcock design by the utilization of the blower as a dust extractor saves space, but due to a turbulent gas flow the efficiency is low.

The remark which has been made concerning the air-sifters of the mills refers partly to the air sifters proper; that is to gadgets which have nothing to separate but coarse material from fine. With the application of such devices it sometimes happens, that the fine material is carried away by the recirculating wind and is mixed with the coarse one. (Picture #16 Pfeiffer design). By adding a centrifugal deduster the Hildebrandt design tries to prevent that danger and claims to be able to perform a proper separation.

Filters are employed if very fine and precious dust must be separated which cannot be recovered economically by the centrifugal force and which must be kept free from water or oil. Three kinds of filters must be distinguished: the tissues, the packings, and the sieves and porous bricks. Cotton tissues are very often applied because due to the presence of a natural oily surface they are capable of extracting even the smallest dust particles. But it must be mentioned that cotton is affected by heat, by various chemicals, and by the weather; and that it is inflammable. The Beth-filters are very often employed. The gas stream is subdivided and the single gas flows are led to the extracting apparatus. Since the dust is retained by the filtering material, the latter must be cleaned from time to time in order to maintain anuniform resistance. The Beth-filter applies a tapping device for the removal of the accumulated dust.

The Honigmann-filter consists of packing material which is moistened by water. It has been employed for the purification of flue gases. With a comparatively low water consumption (0.13 cu. m. per 1000 cu. m. gas to be purified) its efficiency is very remarkable. The injected water serves as cleaning agent of the packing.

The well-known "Traveling-filter" applies a packing and an automatically controlled purification system but does not inject any water. A wetting of such type of filters results very often in their complete choking. Dr. Kiesskalt (I.G. Hochst) tried to overcome this difficulty by the so called "Oscillating Gaswascher". It was possible to refresh such a filter within three minutes by oscillation when it was completely choked by leather dust after an operating time of 19 hours.

The report tries to submit a short review of the modern dust extracting devices which apply either the force of gravity or the centrifugal force of filters. The most efficient method is that of the precipitation of dust by means of electric current. It is much more expensive than the already mentioned methods unless large gas volumes are treated. It requires a comparatively large amount of space because gas velocities not exceeding 1-4 meters per sec. must be applied. It cannot be utilized for all types of dust but with respect to its separating efficiency it is superior to all known methods. Since the particle size and the spec. gravity of the dust is without any influence, even the most widely dispersed aerosols, as for instance cigarette smoke can be purified. It is not necessary to give further details of the design and the working method of the electric precipitators. The performance of 2 films explained the electric precipitating process.

The following pictures represent various dust extracting apparatuses of the Ludwigshafen factory. The right side of picture #17 shows a drum dryer for "Tanigan" the vaporized moisture of which carried away too much material to be dried. An almost complete dust extraction could be performed by the installation of a dust extractor of the Hartmann type (compare the left side of picture 17). The total gas volume is subdivided into three separate flows in order to maintain small radii of curvature. The apparatus is carefully insulated in order to maintain a temperature which is higher than that of the dew point.

An exhaust fan secures a high velocity of the gas resulting in high peripheral velocities of the vapors to be treated. (Picture 18) Picture 18 shows the common suction line which assembles the 3 separate lines. An additional moistening is possible by means of the small pipe which is introduced into the main suction line. Furthermore the following precipitator with the exhaust pipe can be easily observed. The precipitated dust is collected in several drums (See picture #17).

Distribution of the total extracted dust:

Drum #1: 36%
Drum #3: 47%
Drum #4: 16%

Drum #2 which was connected with the final dust extractor (Picture 18) remained empty.

It was not necessary to employ any wetting with water. Another Hartmann dust extracting unit was installed in connection with the new feed-installation of the high pressure boilers. The powdered coal is brought to the bunkers by means of freight cars and is discharged into the bunker openings. (Picture #20) The displaced air together with

dust particles is drawn off by means of suction pipes and is purified
by means of a cyclone (Picture #20). The purified air is sucked in by
a fan and disposed of.

The feeding arrangement is capable of handling 100 tons of coal
per hour. The dust extracting unit draws off 10,000 cu. m. air per
hour. The peripheral velocity of the air passing through the precipi-
tator is supposed to be 15 meters per second. The size of the dust is
supposed to give approx. 20% residue on sieve #230 (Standard screen
scale).

Efficiency of the cyclone: 85% ± 3%
Dust content of the air to be treated: 10 gram per cu. m.
Power consumption 15 k.w.
Cost: RM 5380 without installation

The plant has not yet been put in operation. It is not yet known
whether the suction pipes draw off nothing but the displaced air and
whether the air which leaves the bunker like the gases of an explosion
will be properly drawn off by the exhaust fan.

A quite modern installation is the electric precipitating unit
(Lurgi design) which removes the dust originating from the movement
of the slag. Formerly the dust carrying air was scrubbed by water, a
method which was by no means satisfactory due to the difficulties
which arose from the disposal of the mud. All suction pipes which are
coming either from the pyrites burners or from the loading station are
led to the electric precipitator which removes the dust almost com-
pletely as shown in picture #21. On the left side an almost invisible
dust cloud is to be observed if the current is turned off. With the
tapping device in operation a dark colored smoke leaves the stack
which becomes invisible as soon as the current is turned on.

Picture #21
Waste gases 7,200 cu. m. per hour

Without tapping device | Tapping device in operation | Tapping device in operation

Electric precipitator turned off | Electric precipitator turned on

Picture 22 represents a compilation of latest bids of dust ex-
tracting apparatus. The figures are only rough estimates. The last
column which contains the costs per 1,000 cu. m. gas to be treated
per hour can be used for rough calculations of the cost of a dust
extracting unit. The high costs of a Stroeder-washer compared with
the costs of all other systems should be noted. The decrease in cost
of an electric precipitator depending on the gas volume to be treated
is worth while mentioning too.

Summary:

The dust extracting technique made much progress during the last
years and the employed methods were greatly improved. The following
questions should be answered before installing a dust extracting unit:
Actual or possible size distribution of the dust
Specific gravity of the dust
Quantity of the dust per 1 cu. m. gas to be treated
Migration velocity of the dust (Apply the formulae of Picture 1)

Tablo #1

Classification according to the forces	The Migration Velocity of the Dust Particle from the carrying Gas depends on:		Conclusions which may be drawn
Gravity Deduster	$V = \frac{32}{g} \times \frac{\gamma_1 - \gamma_2} \times r^2$	Equivalent radius of the dust particle = r Spec. Grav. of the dust = γ Viscosity of the gas = η Spec. Grav. of the gas = γ	"V" decreases with the square of r; resulting in very large sizes of a grav. deduster if very fine dust must be extracted.
Centrifugal deduster	$V = \frac{2}{g} \times \frac{r^2 \times \gamma_1}{g \times \eta} \times \frac{u^2}{R}$	Peripheral velocity = u Equivalent radius of the dust particle = r Radius of curvature of the track = R Spec. Grav. of the dust = γ Viscosity of the gas = η	A high peripheral viscosity and narrow curvatures increase the efficiency of a centrifugal deduster.
Electric precipitator	$V = \frac{40^6 \times E \times e}{g \times \pi \times \eta}$	Field strength = E Elementary charge = e Viscosity of the gas = η	Size of the dust particles and spec. gravity of the dust are without influence All dust particles have an equal migration velocity No sifting of the particles
Filter deduster	Efficiency increases with the resistance of the filter	Molecular forces forces due to friction	Narrow, long, and curved channels increase the efficiency. Fine porous dense and irregular filters should be employed.

PICTURE 22
DEDUSTING APPARATUS

Deduster for department	Crude gas	Treated gas	Gas velocity	Power consumpt.	Design	Costs RM	Costs RM per 1000 cu. m. gas
Lu 150 Coal feeding plant 100 tons/hr. coal	10,000 cu.m./hr. 10 g/m^3 20% ÷ 60 micron 2-42,000 cu. m./hr.	86% ± 3% Size of the remaining dust 20 microns	15 m/sec.	15 KW	Hartmann multiklon	5,680.- 10,310.-	538.- 1,031.-
Phthalic acid Lu 300	5,000-6,000 m^3/hr. 6-0.5 microns	85-88%	14 m/sec. 15-20 m/sec.	52 KW 14.5KW	Buttner Hartmann	19,690 3,050	235.- 550.-
Slag Lu 353 70 ton/day Fe S [illegible] 4	15,400 m^3/hr. 40-100°C. 18 g/m^3	99%	20-25 m/sec. 310 mm. water column		Lurgi-cottr.	20,800	1,360
4 Pyrite burners Lu 253	96,000 m^3/hr. 450°C. 3 g/m^3	98% ± 1	15 KVA		Lurgi-cottr.	50,000	1,400
Flue gas Boiler house Lu	7.3 g/m^3 80,000 m^3/hr.	91.6%			Pfleiderer	30,000	375.-
Boiler House Me 203 Flue gas filter	1,060,000 m^3/hr. 200°C. 2-3 g/m^3	93% ± 1	4-30 KVA 120 KVA		Lurgi-cottr. incl. high tension eng.	266,400 331,200	250.- 332.-
Waste gases Lu 80	82,000 m^3/h 24,000 " 5,000 " 3,600 " 800 "	94-96% 70 g/m^3/250°C.	4 KW 3.5 KW		Honigmann Beth-filter Multiklon Hartmann Stroeder washer	25,000 7,720 1,000 2,010 6,340	300.- 380.- 200.- 560.- 8,500.-

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