DUST AND FUME PROBLEMS IN GREENSAND PLANTS

Of all sand systems used, greensand is potentially the dirtiest. This is because it contains large amounts of fines as clay and dead clay and, in ironfoundries, live and dead coaldust or substitutes. The use of coaldust or black substitutes is the reason why ironfounderies appear to be dirtier than foundries casting other metals, which do not need to use coaldust or substitutes, though measured dust levels may be little lower in the latter foundries.

So far as ironfoundries are concerned the biggest single visual improvement which could be made would be the elimination of coaldust or any black substitutes.

We are concerned in this section with dust and fume from greensand plants. Silica sand is used with very few exceptions in greensand plants, and none of these exceptions are in the UK. A very few foundries, mainly in Scandinavia and the US, use clay-bonded olivine sand, but the cost of the material compared with that of cheap readily available silica sand precludes its use except in unusual circumstances which do not obtain in the UK. The use of silica sand must, therefore, be accepted, with the result that silica-containing dust will be generated and needs to be controlled to acceptable levels by process or engineering controls.

Dust limits

The substance of most concern in greensand foundries is silica. Silica exists in a number of allotropic forms, i.e. different crystal arrangements.

These forms are:

- Quartz: most foundry silica dust is of the quartz form
- Cristobalite: minor amounts of cristobalite dust can be found but it is confined to those foundries making large castings and, particularly, to those foundries using one of the silicate hardening processes. In greensand foundries cristobalite is found only in trace amounts, since greensand is not used to make large castings
- Tridymite: this allotropic form of silica has not been found in foundries

The maximum recommended amounts of dust depend on its size and how much quartz or cristobalite it contains.

The effect of airborne dust is modified by its size. Approximately, dust over 7 μm size is trapped in the nasal passages before it reaches the lungs and, therefore, does
not affect the lungs. Below about 7 μm particles can enter and be retained by the lungs - this is the so called 'respirable dust'.

If all the particles present in airborne dust are sampled, the sample is called a 'total dust sample' and may contain respirable dust. Where an instrument is used which rejects the heavier particles over 7 μm the sample is one of respirable dust only.

In the UK, the Health and Safety Executive uses Occupational Exposure Standards (OES) and Maximum Exposure Limits (MEL) to provide guidance on the amount of substances allowable in an operator's breathing-zone.

Occupational exposure standards are guidance levels (concentrations usually referred to in parts per million, ppm, or mg/m³) which should not be exceeded. If higher concentrations are measured then consideration must be given to reducing exposures to acceptable levels either by process modification or by installation of or improvement of local exhaust ventilation. Maximum exposure limits are concentrations which must not be exceeded. To do so, can lead to prosecution by the health authorities. There is also a duty to reduce exposures to as low a figure as possible below the maximum exposure limits by use of best practicable means.

The limits referred to above are referred to either as 10 minute (short term) or 8 hr (long term) exposure value.

For dusts generated from greensand the component of major concern is silica, the remainder being generally inert. The respective limits for dusts are:

<table>
<thead>
<tr>
<th></th>
<th>8 hr T.W.A.</th>
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<tbody>
<tr>
<td>Total inhalable dust</td>
<td>10 mg/m³</td>
</tr>
<tr>
<td>Respirable dust (&lt;7 μ)</td>
<td>5 mg/m³</td>
</tr>
<tr>
<td>Respirable silica (as quartz, cristobalite and tridymite)</td>
<td>0.4 mg/m³</td>
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Effect of moisture on sand dustiness

Every time sand is distributed or moved it is a potential dust source, and because about 10 tonnes of sand are required to be handled to make 1 tonne of castings, there are many opportunities for dust generation.

The amount of dust generated when sand is disturbed depends on its moisture content; dry clay-bonded sands generating obvious dust clouds, whereas no dust is generated by wet clay-bonded sand. Work carried out at BCIRA has shown that foundry sand containing not less than one-third of its working moisture level, which is evenly distributed, is unlikely to be a source of appreciable dust. Fig 1 shows the relation found between the amount of dust generated and moisture content of a typical greensand. The evenness of distribution is important, as sand containing an
average of 2 per cent moisture can contain pockets of wet and dry sand and the latter will generate dust if disturbed.

The practical implication of this work is that moulding-sand does not give rise to dust during its passage from the mill right up to the pouring-station. It is only when sand in the moulding condition is allowed to dry out that it becomes a source of dust. If the sand-conveying systems allow sand to drop onto the floor from belts, transfer points, etc., the sand dries out and is disturbed by traffic (human and mechanical) and results in airborne dust.

Dust is always generated at the knockout, and from this operation onwards the object should be to get sufficient well-distributed moisture back into the sand as quickly as possible, to suppress dust.

Sand-handling plant design

Use of subsidiary mill

One method of introducing water is to fit a subsidiary continuous pan-mill immediately after the knockout, as shown in Fig 2. The mill is not intended to develop the greenstrength of the sand, but merely to distribute sufficient water into the sand to make it non-dusting. In spite of the obvious disadvantages of such a system - the extra plant required, more maintenance, increased space requirements, tramp iron problems, etc. - such plant has been installed. Not only is dusting suppressed, but a useful degree of sand-cooling is obtained, as the moisture can partially evaporate and thus cool the sand in subsequent parts of the sand plant (particularly the screen). An aerator can serve a similar purpose, and may be easier to accommodate.

Water additions to sand on conveyor belts

Water added to a knockout belt should be added on the basis of the sand flow, its temperature and its moisture content. In practice, the sand temperature after the knockout provides a sufficiently accurate indication of the moisture content, and thus the amount of water to be added can be based on sand throughput and temperature only. Various units for adding water to sand belts are available, throughput being based on the measurement of sand height by means of a mechanical arm and temperature measured by one or more thermocouples trailing in the sand. Water is added by sprays over the belt (Fig 3) actuated from a control-box which decides, according to the sand flow and temperature, the amount of water to be added. Water added in this manner is not evenly distributed, and dry pockets will result, but they can be reduced by ploughs or fingers mounted over the belt to mix the sand and added water; these, however, can also act as sources of dust.
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The addition of damp sand

An alternative method of adding water indirectly to knocked-out sand is by addition of prepared moulding-sand. An excess of sand may be deliberately milled, greater than is needed for mould-making, as in the Schumacher process. A layout of a sand plant using this system is shown in Fig 4. Depending on the metal : sand ratio, extra sand is milled amounting to about the same as that required by the moulding-line. The surplus sand is diverted from the mill into the return-sand system. The knocked out sand is thus buried in damp non-dusting sand, and until disturbed no dust will be generated. At the earliest possible moment the two sands are mixed. Normally, magnetic separation is first required, after which mixing is accomplished by one or more aerators mounted over the sand belt. Note that even distribution of moisture in the mixed sand is essential, and plant to ensure the sand is well mixed in a necessary part of the dust-suppression system. An aerator is shown after a magnetic separator, and it would be expected that dust is suppressed after this point. As with other methods of dust suppression, extra costs are involved. In this system, the extra costs are due to the need for increasing the milling capacity and providing the larger belts required. It is also essential that milled sand is available for addition to the knockout sand during the whole period that knocking-out takes place. The results of 'before' and 'after' airborne dust surveys, in suitable UK foundries installing the Schumacher or a similar system, are awaited with interest. It should be noted that a milled-sand addition is intended not only to reduce dust but also to provide cool sand at the moulding-line.

Clay and coaldust additions

The addition of dry coaldust and clay to a sand mill or to sand on a belt generates dust. Where possible the addition of both materials should be made as a slurry. The use of slurry additions is possible when:

- The amount of water added, as an unavoidable component of the slurry, is not in excess of that required to bring the sand up to moulding moisture-level. In practice this means that the sand-to-metal ratio needs to be low
- A continuously agitated slurry tank is installed with a recirculating main to prevent settling out of the slurry
- A non-gelling clay is used, e.g. calcium montmorillonite, otherwise the amount of clay it is possible to use in the slurry is restricted to about 6 per cent w/w

In most cases slurry additions will not be possible, and in any case a small amount of dust is still generated on mixing of slurry and sand in the mill, so that even under the most favourable conditions, dust extraction is recommended. Where dry clay additions are made dust control is essential. Mills can be well enclosed and allow only small open areas for sand and other additions. Good enclosure allows low extraction rates for:
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- Batch mills with skip loading (additions in skip). The extraction rate can be 1 m/s, assuming the mill opening is closed after skip filling.

- Continuous mills (screw or vibration addition feeders). The extraction will normally be in the range of 0.5 to 1.5 m/s.

- Mills with sand-cooling by forced air. The makers' blowing and extraction rates should be adhered to.

Belt conveyors

A major reason why most mechanized foundries quickly become dirty is that sand is spilt from belt conveyors and falls onto gangways, overhead walkways, etc. Even if the sand is dustless as it falls from the conveyor, it quickly dries out. Operators walk on the dried sand or transport drives over it, and the result is the generation of dust which spreads throughout the factory and collects on all horizontal and near-horizontal surfaces. Removal of this deposited dust by non-vacuum sweeping methods gives rise to yet more airborne dust, and often results in part of it being dislodged from one place only to deposit again in another.

A reduction of belt spillage depends primarily on belt design. For the type of conveyor most used in foundries there are sufficient data available to enable the belt and its ancillaries to be economically designed. Table 1 gives recommended belt sizes for various capacities of belt. Capacities vary for different sands because of varying bulk densities, e.g. sand in the moulding condition is less dense than knocked-out sand, and a belt will, therefore, carry a lower flow of moulding-sand than of knocked-out sand.

Some design points which need to be considered, to reduce spillage, are given below:

- A belt must be designed for the maximum capacity required of it, even if this is only needed for short periods. Whenever possible, surge hoppers should be used to even out sand surges and so allow smaller and less expensive belts to be used. In practice, the estimated peak loading is often taken as double the maximum sand flow needed for moulding.

- Troughed belts are normally run at speeds up to 1.25 m/s. Speeds above this make the operation of ploughs and magnetic separators less satisfactory.

- The trough angle has been limited in the past to 20°. The development of the nylon belt allows steeper angles - up to 45° - to be used. The steeper the angle, the higher the carrying capacity of the belt and the lower the spillage for a given throughput.

- Where flat belts are used, or where troughed belts are run flat in some parts of the system (e.g. to allow ploughs to be fitted), the capacity of the belts should be taken as half that of the equivalent width of a 20° troughed belt, otherwise spillage will occur.
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- Belt inclination affects the amount of slipping and roll-back which take place. Excessive inclination leads to spillage and reduced belt capacity.

The maximum belt inclination should be:

17° for knockout sand carried by 20° troughed belts. Even at this angle there may be some difficulty with sand lumps rolling back down the belt and eventually falling off. It may be prudent, therefore, to restrict the maximum inclination to 15° for knockout sand, and 18° for prepared moulding-sand.

Special belts, with moulded cross-bars and frilled edges forming a troughed section until the belt goes round a pulley, may be used at inclinations up to 50°. Such belts may sometimes be used to supersede bucket elevators.

- Belt cleaners should be used whenever sand sticks to the belt. If they are not, sand will be dislodged from the return strand of the belt and give rise to a secondary form of spillage. Fig 5 shows a static scraper, and Fig 6 a rotary cleaner driven by its own motor. A modified trough conveyor where the belt runs in guides to retain its trough configuration is shown in Fig 7. Covers to enclose the top are available, which results in nearly complete enclosure.

- Pulleys often build up with sand, and belt wander results. Self-cleaning pulleys help to prevent this, and one such design is shown in Fig 8. Belt wander is one cause of sand spillage from conveyors.

- The efficient sealing of hopper exits onto belts reduces spillage. One method of sealing is shown in Fig 9. Poor hopper-to-belt sealing is a frequent cause of spillage, especially in underground pits where maintenance is unpleasant and often neglected.

- Beneath hoppers, where rollers are subject to impact from sand falling on the belt, impact-resistant rollers are sometimes used. These also help to clean the underside of the belt.

- The type of belt fastening used affects sand leakage. Only a vulcanized joint is leak-proof, and should be used in preference to mechanical belt fasteners.

Belt enclosure

Even with good design, some sporadic spillage of sand is likely to occur, especially from the underside of the return strand. It is possible to enclose a belt conveyor completely (Fig 10). The enclosure must be easily removable and replaceable for inspection and maintenance purposes. The system shown uses fabric stretched over a frame, but other systems are available.

Enclosure hinders the removal of spilt sand and some means of getting rid of it is necessary. This can be effected by fitting shallow hoppers beneath the belt, equipped
with nozzle outlets to which can be attached flexible exhaust tubes connected to a central vacuum-cleaning system.

Where unmilled sand is being transported (i.e. from the knockout, storage hoppers, etc.) some extraction from the belt enclosure is advisable but with good enclosure the airflow need be no more than that required to maintain a negative pressure within the enclosure. About 1 m/s for each 10 m of enclosure should be sufficient.

Pneumatic conveying

Pneumatic conveying is a dust-free conveying system for all types of sand. Sand is conveyed by air pressure through small pipes, which provide complete enclosure for the material being conveyed. Apart from being dustless (or at least very easily dust-controlled), pneumatic conveying allows complicated plant layouts and takes up little space. One possible layout is shown in Fig 11. The main advantage of the system, apart from its cleanliness, is the flexibility it permits in plant layout. Flexibility is not always possible with conveyor belts.

The disadvantages of pneumatic conveying are:

• Power consumption: The conveying medium is air, which is initially compressed to approximately 6 kgf/cm². Depending on the vertical and horizontal distance of the sand conveyed, and number of bends in the conveyor, a power consumption of 3 to 5 kW per tonne per hour capacity of sand conveyed can be expected. For example, to convey 20 t/h of sand, approximately 80 kW will be needed at the compressor. A conveyor belt, in comparison, will only need some 11 kW or less for conveying sand at the same flow rate for a distance of 80 m horizontally and 10 m vertically.

• Maintenance costs may be higher than for equivalent belt systems. This is because pipe bends and diverter valves wear out, and the air compressor needed to supply the motive power needs more maintenance than the electric motors fitted to belt systems

• Capital cost is likely to be higher than for a conveyor-belt system, unless spare compressor capacity already exists.

Bucket elevators

Bucket elevators are widely used to raise sand from one level to another. They are frequently underdesigned, and sometimes run at the wrong speed; both faults cause spillage. The capacity of the elevator should be the maximum capacity ever required. If necessary, surge loads can be reduced by surge hoppers.
The capacity of the elevator should then be obtained by means of the following formula:

\[
\text{Capacity, kg/h} = \frac{66.66 N D}{P}
\]

Where \( B \) = bulk density, kg/m\(^3\)
\( V \) = total bucket volume, m\(^3\)
\( N \) = speed of head pulley, rev/min
\( D \) = diameter of head pulley + 2 (belt thickness) m
\( P \) = pitch of buckets on belt, m

The bulk density varies quite widely with the type and condition of sand (Table 2).

The fact that average bucket-filling may only be 35\% of total capacity has been allowed for in the capacity design-formula. Wherever sand below a temperature of 100\(^\circ\)C is being handled, nylon buckets are recommended instead of those made of metal. The service life of nylon buckets is longer, and sand sticking is less - thus providing some capacity margin and reducing the possibility of spillage.

The speed of the top pulley should ensure that sand is not carried round again by the bucket (too high a speed) or does not fall back down the elevator (too low a speed). Both these faults reduce elevator capacity.

The correct speed is given by:

\[
N = \frac{42.3}{D}
\]

Where \( N \) = rev/min of pulley
\( D \) = diameter of pulley + 2 belt thickness + 1 bucket projection, m

The inlet boot and outlet chute from an elevator should be enclosed as far as possible, and extracted at a rate of 0.3 to 0.5 m/s.

**Knocking-out**

**Automatic knockouts**

Vibrating knockouts can be contained in an enclosure, provided that they are made automatic, and this allows dust control to be effective with relatively low exhaust-air flows.
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No successful automatic knockout has yet been made which can deal with a variable box size combined with bars in one or both halves. However, an ever-increasing number of mechanised foundries now use standard-size barless boxes, and for these enclosed automatic knockouts are both economical and improve working conditions by:

- Removing the operators from a hot unpleasant job
- Allowing efficient dust control to be installed
- Providing the possibility of noise control

Fig 12 shows a typical automatic knockout layout and Fig 13 illustrates a successful early 1950s mechanised plant (now superseded) which had an enclosed automatic knockout.

It is even possible to build such plants where floor excavation is not possible. Fig 14 is a photograph of an above-floor-level knockout where the operators simply feed the unit with boxes via a lift.

Boxless moulds such as those produced by DISA machines readily lend themselves to automatic knockout, and a good example is shown in Fig 15. Here the moulds at the end of the strand enter a rotary drum, which is well enclosed and discharges sand and castings separately.

Note the heated and insulated extraction duct to prevent condensation and consequent build-up inside the duct.

Floor knockout

A decreasing number of foundries still knock out over large areas of the foundry floor. Generally speaking production rates in such foundries are low and the dust generated per unit area of floor is not high. To capture this dust as it is generated and keep it away from the operators is virtually impossible, so a high standard of general ventilation is relied on to improve conditions. Where this is unacceptable there is no real alternative to mechanisation, so that all knockout operations take place at one point where dust control can be applied. In other words, mechanical handling has to be installed to make a satisfactory solution possible.

Manipulators for knockouts

Where existing manual knockout grids are used, automatic handling may be considered as an alternative which allows full access to the grid, since exhaust hoods are not then required. The operator may be housed in an air-conditioned cabin and handles castings and boxes by a manipulator (Fig 16). It does not, however, eliminate the need for dust control. The knockout and the operator cabin need to be put inside an enclosure from which dust is extracted to prevent its reaching other
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unprotected operators in other parts of the foundry, and in order to keep the foundry clean.

**Downdraught knockout**

In the early days of knockout ventilation it was common to draw air from beneath the grid in an effort to control dust and fume. Only where very shallow boxes were knocked-out on a grid about four or more times the box area could such systems provide reasonable dust control, and even then high air speeds of some 2.5 m/s (500 ft/min) into the grid (calculated over the full grid area) were required. High air flows were thus necessary, and all this air had to be drawn through or close to the falling sand-stream from the box, resulting in an excessive draw-off of sand fines, clay and coaldust. The only advantage of down-draught ventilation was that it allowed access to all sides of the grid.

**Side-draught knockout**

If a knockout grid has to employ manual box and casting handling, the most effective way of applying dust control is by side-draught ventilation. An extraction hood is placed on one of the longer sides of the grid if it is rectangular. This is because the distance of dust generation to the hood is shorter and requires less air flow for control. Design points include:

- A gap can be left under the hood for pushing boxes through, on to the grid from a conveyor.

- The air speed through slots in the hood should not exceed 5 m/s, in order to reduce friction losses. It is a myth that high slot-speeds are an advantage.

- The bottom of the extraction slot should be at about the height of the largest box used.

- The hood should overhang the grid as far as possible without interfering with any hoists used. Reinforcement is advisable, to prevent damage by hoists.

- Side shields should be used as far as possible.

- The extraction rate will depend on the grid size and amount of shielding that can be applied. For grids up to about 2 m x 2 m with at least an overhanging side-draught hood, an extraction rate of (grid area, m² x 2.5) m³/s should be adequate. Larger grids need treating on their merits - disproportionately larger air flows may be needed unless extra shielding can be provided.
Sand screens

Sand screens (usually of the rotary type, but flat-bed screens have been used) perform two useful purposes - they sieve out oversized sand lumps and tramp metal, and can provide an appreciable degree of sand-cooling. To obtain the maximum amount of sand-cooling the sand must be damped and air drawn through it by the screen extraction. The extraction rate is governed more by sand-cooling considerations than by dust-control requirements. Fig 17 shows a rotary screen designed for maximum sand-cooling, and its air-flow requirements. Unless carefully designed, the extraction air will carry with it a great weight of fines. This happens when the extraction is taken off very close to the screen top. The design shown includes an extension of about 1 m with a tapered offlake to reduce the air speed within the screen and offlake, thus reducing fines carryover. Exhaust air from screens is often warm and saturated with water vapour; condensation in ducting is, therefore, likely. Condensation leads to fines blocking up the ducts. All ducts should be designed so that they can be cleaned, e.g. bends should have capped ends to allow flue brushes to be inserted. It will be noted in Fig 17 that a stub duct is provided and fitted with a damper; this allows perhaps 25% of dry air to enter, to reduce condensation. If this dry air can be taken from a hot part of the foundry, such as over a holding furnace, so much the better.

Storage hoppers

Knockout sand after screening is usually put into storage hoppers which act as a buffer system to even out sand supply to the mill. Plough-off points on a conveyor running over the top of the hoppers direct sand as required into particular hoppers. The plough-off points themselves generate dust and the sand falling into the hoppers pumps air into the hoppers which emerges carrying dust with it. The usual method of control is to box in each plough-off point (or pair of points) to include the hopper inlet and to extract at 0.5 to 1.0 m/s. Another tried system with much to commend it uses a tunnel built over the hopper tops enclosing the feed conveyor. The tunnel can be large enough for a maintenance man to stand up in, and should be provided with lighting. Access is by removable doors. Such a system provides better dust control with lower extraction rates, and will depend on how closely the tunnel seals the hopper tops, but about 0.2 m/s per metre length of tunnel can be expected.

Dust control after the mills

Between the mills and the moulding-machines, sand contains enough moisture to make dust control unnecessary. Only at and after the knockout is dried sand disturbed, to become a dust source.

Pouring and cooling fume

When metal is poured into greensand containing carbonaceous volatiles (coaldust substitutes, or wood flour) some smoke is generated, but if no cores are used and the castings are of small section (up to 10 mm, say) so little smoke is evolved that it can
be ignored. Where sections are heavier and cores (other than CO₂/silicate) are used, appreciable smoke and fume are evolved and control is required. If moulds are poured all over the floor or on a multiplicity of roller conveyors, local exhaust ventilation is impossible and general ventilation has to be relied upon. This is often unsatisfactory, but the best that can be achieved. Ventilation rates of 8 m/s per tonne of metal cast per hour should be used as a starting point in the design of such a system. It should be remembered that air extracted by roof ventilators needs to be replaced, and floor level louvres or inlet fans are necessary for maximum efficiency.

If moulds are transported on powered conveyors, the provision of ventilation becomes easier. Pouring-hoods can be used for pouring, taking the form of hoods at the back of and as close to the track as possible, with extraction slots set at the height of the largest box. To reduce resistance losses, slot air speeds should not exceed 5 m/s. Extraction rates need to be in the range of 0.8 to 1.5 m/s per metre of conveyor to be covered, the recommended flow depending largely on box size.

After pouring, the moulds continue to smoke and fume for some time, so cooling-tunnels should be used after the end of the pouring-track. If fully sealed except for entrance and exits, an air flow of 0.15 m/s per metre of tunnel provides control. Sometimes the bottom of the tunnel is left with a gap to pull in cold air over the full length of the tunnel, and the extraction is by a plenum chamber along the top of the tunnel. For this design 0.23 m/s per metre of tunnel is suggested.

Collectors

Fume and smoke from pouring-hoods and cooling-tunnels are blown to atmosphere without collection because collection, though technically possible, is economically unacceptable. Dust from all other parts of the plant should be removed from the exhaust before discharge. Various designs of collector exist:

- Cyclones or multicyclones: not considered to have high enough collection efficiency for this application, and liable to blockage owing to condensation

- Fabric filters: not acceptable for this application, because of 'blinding' of filter media by condensation and clay

- Wet collectors: many designs of wet collector exist, but the one most used is of the induced-spray type. Dust-laden air is drawn through specially shaped channels in a water-bath/settling-tank. The passage of air causes water turbulence, and dust is wetted by the water and falls back into the settling tank. This and other designs of wet collector have been successfully used for greensand plant dust collection
Sludge

Clay is contained in the dust-laden air from greensand plants. Some is caught in the collector and enters the collector water from which, since it is a colloid, it will not settle. The water, therefore, becomes thicker and thicker, and often ends up as a thin mud before it is changed. Normal tips will not always accept this sludge and more expensive specialised tips may have to be used. Sludge disposal is, therefore, an expensive nuisance. 'Mud' in the collector also blocks up the eliminator plates (if fitted) and leads to the emission of 'black rain'. Moreover, the sludge contains valuable and unused clay and coaldust (or substitute).

Sludge treatment with flocculants to settle out clay has not proved practicable; nor has pressure filtering. Since the sludge contains clay and coaldust (or substitute) the obvious way of getting rid of it is to put it back into the mill (Fig 18). It is known that this is possible and successful systems are now in use. Where sludge is recirculated there is a saving in:

- Clay, coaldust (or substitute) and water

- Maintenance of the collector - it stays cleaner

- Disposal costs - this is usually the largest of the savings that can be made
Fig. 1. Dust generated by typical used greensand.

Fig. 2. Use of Pan mill at knock-out.

Fig. 3. Water additions to sand on knock-out belt.

Fig. 4. Schumacher System.
Fig. 5. Stationary belt scraper.

Fig. 6. Rotary belt cleaner.

Fig. 7. Formed trough conveyor.

Fig. 8. Self-cleaning pulley.
Fig. 9. Section through conveyor showing a 25° and 45° troughing idler, chute and sealing skirt, with idler guard.

Fig. 10. Enclosure of belt conveyor.

Fig. 11. Pneumatic conveying of moulding sand.
Fig. 12. Automatic knock-out plant.

Fig. 13. Automatic knock-out of 1950s.

Fig. 14. Above-ground automatic knock-out.

Fig. 15. DISA plant using rotary drum knock-out.

Fig. 16. Manipulator used at a knock-out.
Exhaust air rate = 1.25 \left( L \times \frac{D_1 + D_2}{2} \right) m^3/s

Area of vents plus area of sand inlet and tailings outlet.

\[ = \frac{\text{Exhaust air rate (m}^3/\text{s}) \times m^2}{1.5} \]

Fig. 17. Rotary screen dust control.

Fig. 18. Recirculation of wet collector sludge to sand mill.