bulk solids handling Volume 2, Number 1, March 1982

A New Dust-Free Spout for Barge Loading

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Summary

After a thorough discussion of the causes for dust emission and ways and means to reduce dust emission during the loading of barges, details on a new speed regulating device incorporated in the loading spout are given. In practical operations this new loading device showed excellent results.

1. Introduction

The object of this report is:

1. to trace the causes of dust emission when loading barges.
2. to clarify the way in which this dust emission can be reduced and
3. to give the mathematical possibilities to assess the advantages of speed regulating devices at the end of the loading spout.

Calculations of speeds are based on a loading capacity of 1,000 m³/h, equal to 700 t/h in grains.

2. Origins of Dust Emission

As practice has shown, it is possible to have a dust-tight handling system up to the point when the product leaves the loading spout.

From that point onward, the following causes of dust emission can be differentiated:

2.1 Dust Entrained by the Air in the Spout

The sectional area of the spout is defined by the situation at the beginning of the spout where the velocity of the product is low, so, e.g., for a capacity of 700 t/h a circular spout needs a diameter of about 500 mm as with smaller diameters the capacity of 700 t/h cannot be reached.

As the spout normally is a telescopic one, the diameter at the end must be larger than at the beginning and will reach a value of about 550 mm.

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Calculations show that at 700 t/h, specific weight 0.75 and a spout diameter of 500 mm, the speed of the product should be at least 1.32 m/s at which speed the sectional area is completely filled-up.

As will be calculated later on, the exit-speed out of the spout amounts to about 15 m/s and the product at that speed needs a sectional area of 173 cm², the spout, however, has 2,376 cm² and therefore the product uses only about 7.5 % of the area.

The turbulent movement of the product in the spout can saturate up to a certain extent the air that fills the 92.5 % of the sectional area and even if the air does not move with a high speed, calculations show that even with an air speed of only 2 m/s, about 1,600 m³/h of dusty air can escape from the spout (Fig. 1).

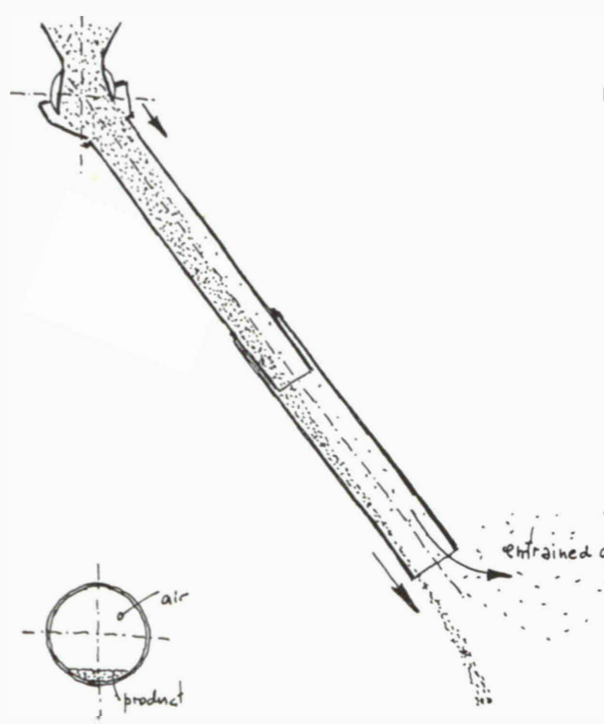

Fig. 1

2.2 Dust Caused by Displacement of Air

As the product loaded represents a certain volume, the same volume of air will be displaced and entrails the dust, generated by other causes.

At a loading capacity of 700 t/h, the volume of this air amounts to 1,000 m³/h and as it enters the environment at the location where the product enters the barge, this dusty air very much reduces the effect of the flexible skirt constructions that are used to prevent the action of the wind on the falling product (Fig. 2).

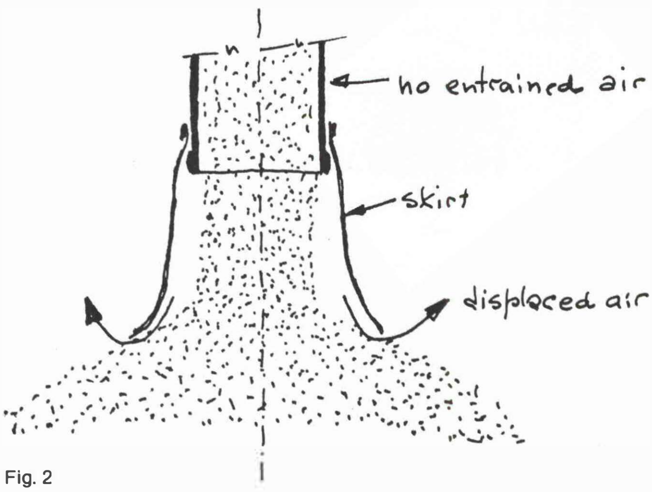

Fig. 2

2.3 Dust Generated by the Impact

The falling product has a certain velocity at the moment it hits the foregoing product that has already been loaded into the barge. This velocity represents a certain amount of kinetic energy that causes breakage of the product and therefore generates dust at the point of impact (Fig. 3).

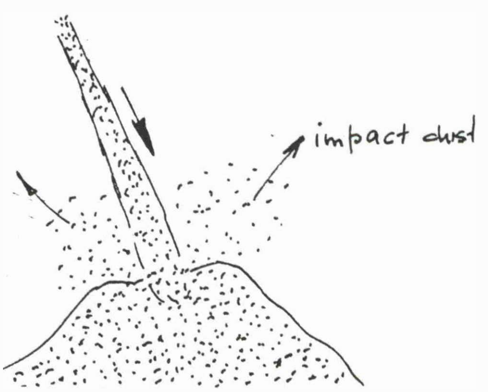

Fig. 3

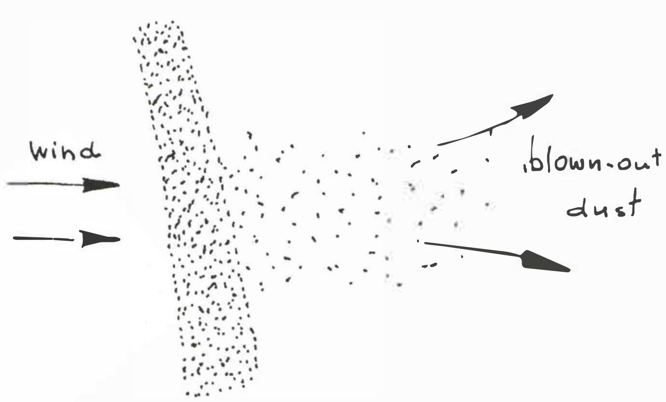

Fig. 4

2.4 Dust Blown Out by the Wind

As soon as the product leaves the spout, the wind can blow through the falling stream of product and will blow out the smaller and lighter particles (Fig. 4).

2.5 Dust Generated by the Product Flowing Down

As soon as the impact energy has been dissipated, the stopped product starts flowing down the hill type configuration that has been formed by the product already loaded; this flowing down often entails a rolling movement of the particles and generates dust (Fig. 5).

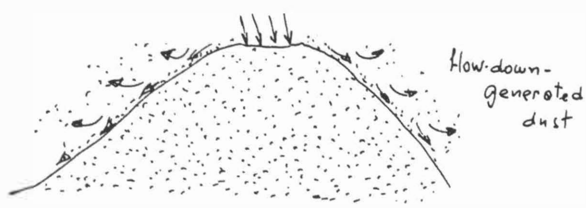

Fig. 5

2.6 Dust Blown Up by the Wind

Even at the moment the loading has stopped, a sudden gust of wind can blow up some dust from the product that has been loaded and is completely at rest (Fig. 6).

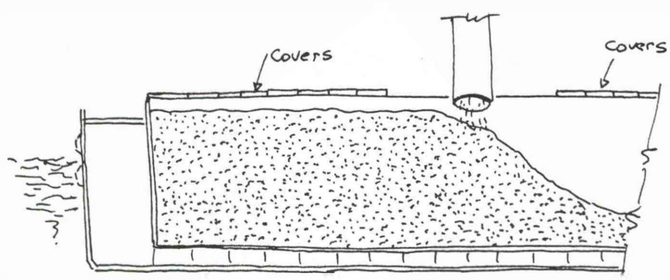

Fig. 6

3. Measures for Dust Abatement

As is to be expected, the different origins of dust emission lead to different measures to be taken for dust abatement.

3.1 Dust Entrained by the Air in the Spout

The escape of dusty air out of the opening of the spout can be counteracted by closing off this opening to such an extent that only the product to be loaded can escape.

This can be realised in different ways:

1. A flap can be installed to close off the opening completely and can be opened by an outside mechanism when the level of the product in the enclosed spout reaches a certain height. At that moment, the flap is opened automatically and gives free way to the product to start flowing out but as soon as the level of the product comes near to the opening of the spout, the flap is closed again.

The problem is that most dusty products also have a tendency to stick and often they do not start flowing out as the flap is opened; and if they start flowing out, many times only the lower part of the column of product comes down but the upper part remains undisturbed even when the spout at the down level is completely empty.

The upper level tester still indicates a full spout and the flap remains open until the moment that the complete column of sticky product has fallen out by bits and pieces.

Because of the intermittent working of the flap giving rise to completely stopping the product, this system can give operational problems with sticky products.

2. A number of triangular flaps can close the opening of the spout and, by rotating around radial shafts, can open up gradually.

   This system also works automatically by means of level testers and as the flaps do not have to close completely, the product is not completely brought to a stand-still.

   Operationally speaking, this system works more satisfying than the former one but is somewhat expensive because of the six to eight flaps that have to be automatically brought in the desired position by means of air-cylinders with a rotating outgoing shaft. Up to now this system has been incorporated in vertical spouts and it is not known if it can also be used for inclined spouts.

   This can be interpreted as a disadvantage as the vertical spout cannot be hinged above the quay side but must be hinged on the end of an outrigger that is provided with a conveyor for the horizontal transport; that is to say a vertical spout is more expensive than an inclined spout because of the crane-type loading machine and the foundations for this machine.

3. A rotating gate device can be located at the end of the spout and its rotations per minute can be regulated automatically in such a way that a certain amount of the product remains at the lower end of the spout, thereby closing off the opening of the spout against escaping air.

   As the radial walls of the rotating gate move back, they are empty of the product but they entrain air backward, thereby also eliminating the problem of the dust caused by displaced air.

4. At the end of the spout a dead box is constructed to brake the speed of the product.

5. At the end of the spout a swivel flap is mounted, weighed down by a spring or a weight, resting on the outgoing stream of the product, thereby closing off the escaping air.

6. At the end of the loading spout, a vertical screw is installed in a skirt-like steel hood.

   This hood is placed on the product already loaded and the screw forces the product from the loading spout down into the product already loaded.

   The air displaced by the product, however, is trapped beneath the hood and also forced down and tends to escape upward in the product outside the hood, giving rise to dusty air bubbles.

7. At the end of the loading spout a short conveyor is located that drops the product down with a minimum of speed.

3.2 Dust Caused by Displacement of Air

As already indicated, the rotating gate device has the advantage of not only closing off the opening of the spout in such a way that only the product can escape but it also copes with the displaced air as the rotating gate, while transporting the product down the spout, at the same time transports the equivalent volume of air upward where it is brought into separate ducts, closed off by filter cloth. The dust-free air can escape upward and the trapped dust can be brought back into the stream of the product (Fig. 7).

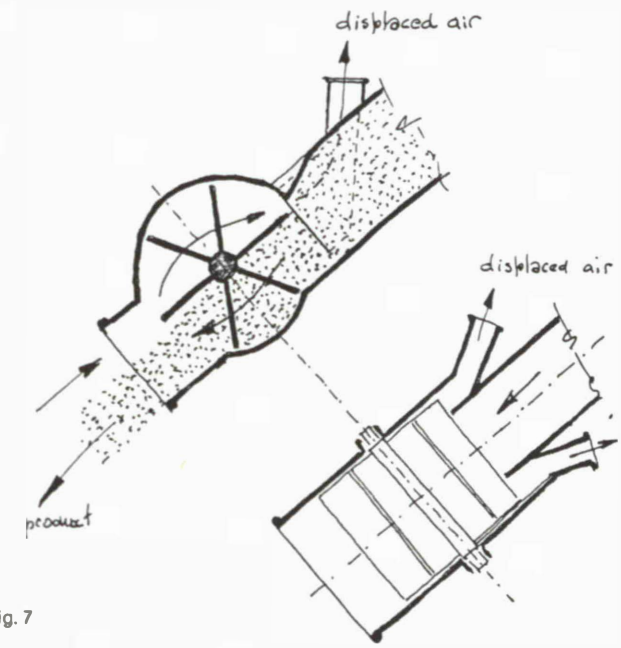

Fig. 7

3.3 Dust Generated by the Impact

The kinetic energy at impact should be kept as low as possible.

As the spout is working, the impact speed is composed of two components (Fig. 8):

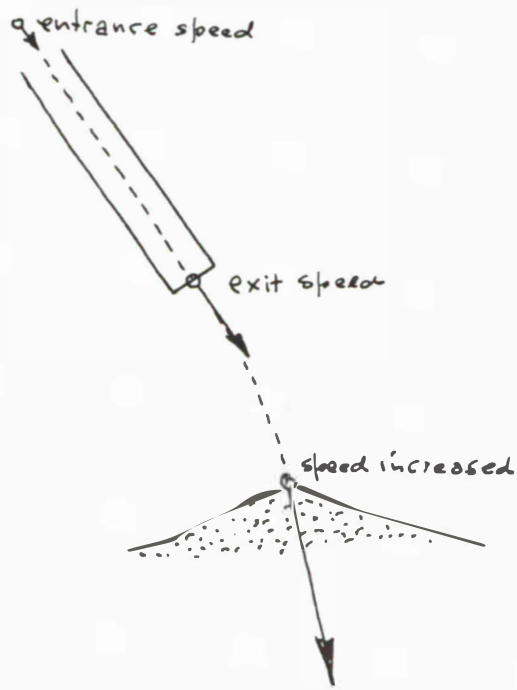

Fig. 8

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1. The exit-speed out of the spout.
   Calculations show that reducing the exit-speed is of prime importance and this can be attained by special devices at the end of the spout.
2. The increase in speed due to free fall from the end of the spout up to the point of impact. This will be diminished by keeping the spout close to the product already loaded.

3.4 Dust Blown Out by the Wind

Practice has shown that a rather thick stream of product is less liable to have the lighter particles blown out than a thin stream. To get a thick stream it is of course necessary to have a low exit-speed of the product and this is a point for consideration when evaluating constructions at the end of the spout. Furthermore it is clear that the stream of product should be as short as possible to give the air less area of attack; operationally speaking this can be translated into: keep the spout close to the product already loaded (Fig. 9).

Also a flexible skirt around the spout, reaching down on the product already loaded is to be recommended but can only give satisfying results if the displaced air is taken away.

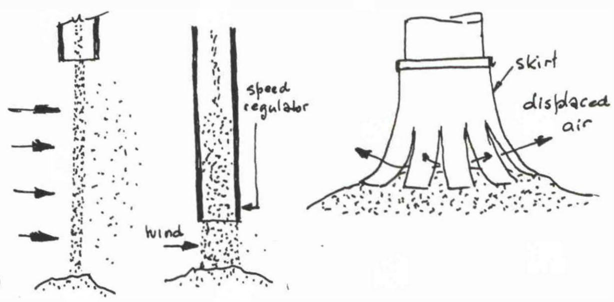


Fig. 9

3.5 Dust Generated by Flowing Down

Of course the easiest way to load a product is to keep the spout in a fixed position up to the moment that the top of the hill reaches the opening; then to move it away to a new location and work in the same way again. To avoid the dust from this cause it is necessary to work in such a way that the flowing down does not occur; that is to say one should avoid the formation of hills by moving the opening of the spout forward/backward and left/right with the opening near to the level already existing (Fig. 10).

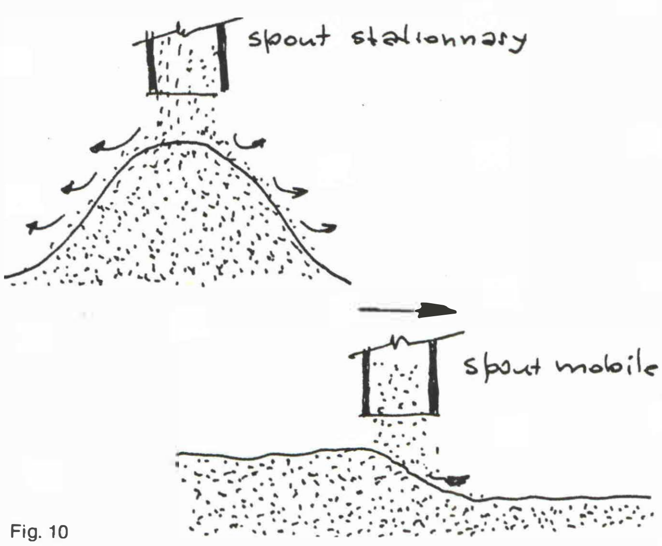


Fig. 10

3.6 Dust Blown Up by the Wind

This can be minimized by opening the hold as late and closing the hold as soon as possible.

It is clear that with only a small opening between the covers of the hold, the recommendation as mentioned before to the effect of not making hills, cannot be followed.

Practice must show which of both recommendations should be followed, depending on wind force, wind direction and type of product to be loaded (Fig. 11).

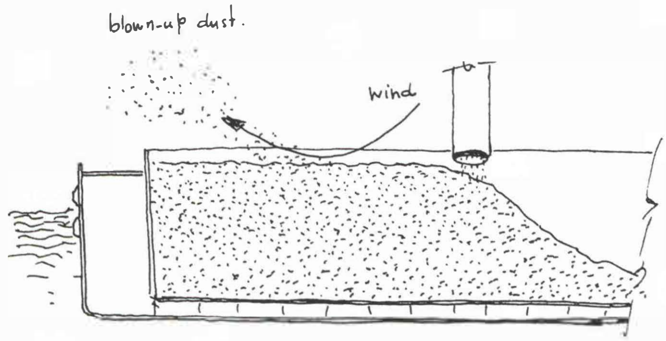


Fig. 11

4. Summing-Up of Measures to Be Taken

1. Installing a device at the end of the spout that is capable of:
   — preventing the product-entrained dusty air to escape from the spout;
   — diminishing the exit-speed of the product in order to minimize the energy of impact as well as to enlarge the volume of the downward stream in order to minimize the dust blown out by the wind; however, without intermittently bringing the product in the spout to a complete stand-still to avoid the danger of blocking the spout;
   — taking-up the displaced air and to clean this air before bringing it outside the device.
2. Protecting the stream of product that leaves the spout against the wind by means of a flexible skirt reaching down.
3. Keeping the outlet of the spout as close as possible to the level of the product already loaded, thereby attaining:
   — smaller impact speed, therefore smaller impact energy and less impact generated dust;
   — shorter length of product stream, therefore less dust blown out by the wind.
4. Trying out the best way of deposition of the product:
   — by having the hold open and spreading the product in layers (moving the spout);
   — by having the hold nearly closed and making hills (not moving the spout).

5. Speeds and Energy of Impact

The product, entering the spout with a speed v_0, flows down in the spout over a distance l under the influence of the component $g \sin \alpha$ of the gravity and of the friction $fg \cos \alpha$ in which α is the angle between spout and horizon while f is the coefficient of friction. The product leaves the spout with the exit-speed v_e. From this point onward, the product falls down over a vertical distance k up to the point of impact where it meets the product (already loaded) with the impact speed v_i, while this impact speed is dissipated the impact energy E_i is released (Fig. 12).

In the following calculations metric dimensions are used.

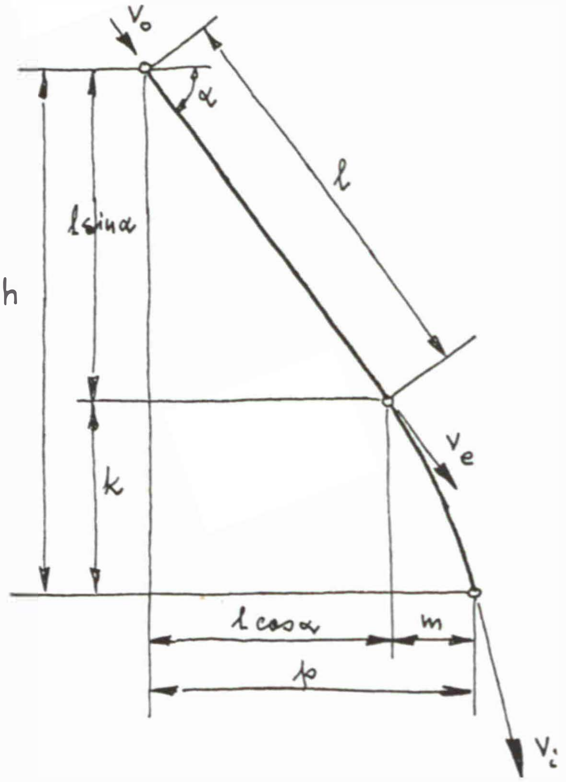


Fig. 12

5.1 Speed in the Spout (Fig. 13)

Eliminating t from the well-known formulae

$$v_t = v_o + at$$

and

$$S = v_o t + 1/2\, at^2$$

gives

$$v_t = \sqrt{V_o^2 + 2aS}$$

in which

v_o	= entrance speed	m/s
v_t	= end speed	m/s
a	= acceleration	m/s²
S	= distance travelled	m

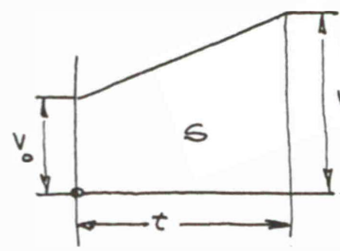
As the acceleration equals $a = g\,(\sin\alpha - f\cos\alpha)$ the exit speed amounts to

$$v_e = \sqrt{V_o^2 + 2gl\,(\sin\alpha - f\cos\alpha)}$$

in which

v_o	= entrance speed	m/s
v_e	= exit speed	m/s
g	= acceleration of gravitational field	m/s²
l	= length of spout	m
f	= coefficient of friction	
α	= angle of spout against horizon.	

In case the exit of the spout is provided with a speed reducing device, the exit speed is defined by this speed reducing device.



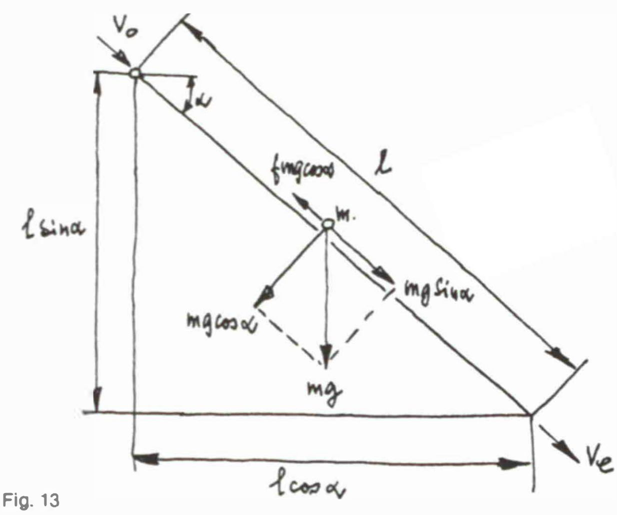


Fig. 13

The values of the coefficient of friction f can be found by bringing the spout in such a position that the product does not flow out anymore with an exit speed that is higher than the entrance speed; practically speaking, hoisting the spout to such an angle that the product does not come out anymore.

Fig. 14

Putting the value of this angle equal to β and, as there is no acceleration anymore, $(\sin\beta - f\cos\beta)$ equals zero and f equals $\tan\beta$ (Fig. 14).

5.2 Speed Outside Spout

Not taking into account air resistance, the horizontal component of the exit speed $v_e \cos\alpha$ remains constant and equals the horizontal component of the impact speed. The vertical component of the exit speed $v_e \sin\alpha$ increases to

$$\sqrt{\{v_e^2 \sin^2 \alpha + 2gk\}}$$

k being the vertical distance travelled from the point of exit to the point of impact (Fig. 15). Therefore the impact speed can be calculated to be

$$v_i = \sqrt{\{v_e^2 + 2gk\}}$$

in which

v_e	= exit speed	m/s
v_i	= impact speed	m/s
g	= acceleration of gravitational field	m/s²
k	= vertical distance	m

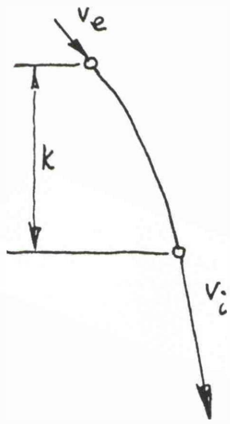


Fig. 15

5.3 Energy of Impact

At the capacity of C tons per hour, every second C/3.6 kg arrives at the point of impact with the speed V_i and represent an energy of $\frac{1}{2}Cv_i^2/3.6$ Nm.

The energy of impact therefore can be calculated at

$$E_i = Cv_i^2/7.2$$

in which

E_i	= energy of impact in W
C	= capacity in t/h
v_i	= impact speed in m/s

5.4 Distances Travelled

When falling down over the distance k, the product has a begin speed of $v_e \sin\alpha$ and an end speed of $\sqrt{(v_e^2 \sin^2 \alpha + 2gk)}$, the average vertical speed equals to $\frac{1}{2}\{v_e \sin\alpha + \sqrt{(v_e^2 \sin^2\alpha + 2gk)}\}$ and the travelling time amounts to

$$t = 2k/\{v_e \sin \alpha + \sqrt{(v_e^2 \sin^2 \alpha + 2gk)}\}.$$

As the horizontal speed $v_e \cos \alpha$ remains constant, the horizontal distance travelled can be calculated (Fig. 16) to be

$$m = 2kv_e \cos \alpha/\{v_e \sin \alpha + \sqrt{(v_e^2 \sin^2 \alpha + 2gk)}\}$$

in which

m	= horizontal distance outside the spout	m
k	= vertical distance outside the spout	m
v_e	= exit speed out of spout	m/s
g	= acceleration in gravitational field	m/s²
α	= angle of spout against horizon	

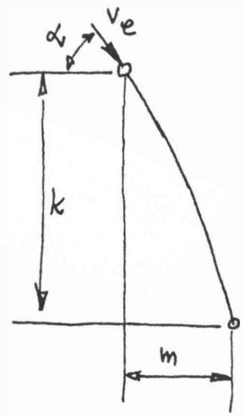


Fig. 16

6. Example of Calculation

We assume the following specifications:

diameter of entrance of spout	=	0.50 m
diameter of exit of spout	=	0.55 m
length of spout	=	20.5 m
angle of spout/horizon	=	68°
height of exit above product	=	0.75 m
loading capacity	=	700 t/h
specific weight of product	=	0.75
blocking angle of spout	=	30°

To calculate the entrance speed we assume the product flowing out of a surge bin and completely using the cross-section of the spout, being $\pi \times 0.5^2/4 = 0.20\,m^2$.

As the volume equals $700/0.75 \times 3600 = 0.26\,m^3/s$, the entrance speed $v_o = 0.26/0.20 = 1.32$ m/s.

The coefficient of friction f equals tan 30° = 0.58 and the exit speed out of an open spout can be calculated to be $\sqrt{\{1.32^2 + 2 \times 9.8 \times 20.5 \times (\sin 68° - 0.58 \times \cos 68°)\}} = 16.95$ m/s.

Dropping down over 0.75 m, the impact speed amounts to $\sqrt{(16{,}95^2 + 2 \times 9.8 \times 0.75)} = 17.38$ m/s and the impact energy will be $700 \times 17.38^2/7.2 = 29{,}393$ Nm/s or 29.4 kW.

The horizontal distance from swivel axis of spout to the point of impact is

$$20.5 \cos 68° + 2 \times 0.75 \times 16.95 \cos 68°/\{16.95 \sin 68° + \sqrt{(16.95^2 \sin^2 68° + 2 \times 9.8 \times 0.75)}\} = 7.98 \text{ m}$$

In case the exit speed of the spout is defined by a speed reducing device, it is again assumed that the cross-section is completely used by the product.

This cross-section being $\pi \times 0.55^2/4 = 0.24\,m^2$ the exit speed amounts to 0.26/0.24 = 1.09 m/s.

Now the impact speed amounts to $\sqrt{(1.09^2 + 2 \times 9.8 \times 0.75)} = 3.99$ m/s and the impact energy is $700 \times 3.99^2/7.2 = 1{,}546$ Nm/s or 1.5 kW. The horizontal distance from swivel axis of spout to the point of impact is in this case

$$20.5 \times \cos 68° + 2 \times 0.75 \times 1.09 \cos 68°/\{1.09 \sin 68° + \sqrt{(1.09 \sin^2 68° + 2 \times 9.8 \times 0.75)}\} = 7.80 \text{ m}.$$

Comparing the calculations, one finds

		without device	with device
exit speed from spout	m/s	16.95	1.09
impact speed	m/s	17.38	3.99
impact energy	kW	29.4	1.5
horizontal distance	m	7.98	7.80

So in this example, by installing the speed reducing device at the exit of the spout, the impact speed drops to 23% and the impact energy drops to 5% of the original values without device.

7. Conclusion

It should be kept in mind that the speed regulating device not only diminishes the impact energy to the amount calculated but also diminishes the dust blown out by the wind — and when using a skirt can even avoid this dust completely.

To resume the advantage of a speed regulating device at the end of the spout:

1. It completely avoids the dust entrained by the air in the spout by closing-off the free exit;
2. in the case of the rotating-gate device it also avoids the free entrance of dust-containing displaced air by bringing this air back into a controlled space;

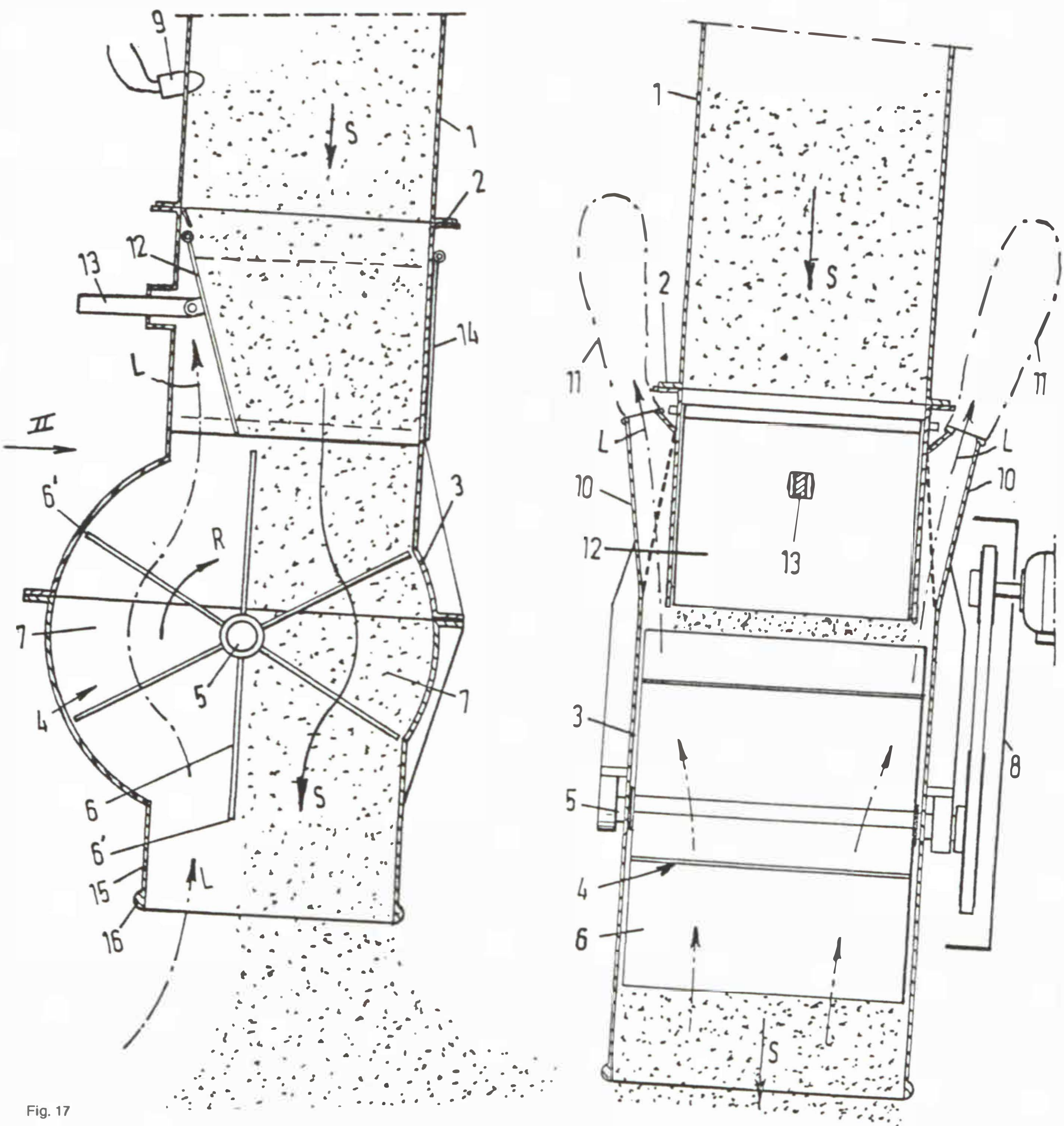


Fig. 17

3. it diminishes the impact energy as calculated and thereby the dust that is generated by this impact, especially in case a skirt is used as than the dust can be trapped under the product that is being loaded;
4. it diminishes the dust blown-out by the wind by augmenting the cross-section of the product stream and even can avoid this dust completely in case a skirt is used.

Fig. 17 shows the speed regulating device as presented in the patent application and in Fig. 18 the dust-free loading spout is shown. In Fig. 19 can be seen that the only dust present is being generated by the man shoveling the tapioca. Fig. 20 shows the tremendous dust generation created by using the so-called "fish-mouth" loading spout, and Fig. 21 demonstrates clearly the dust-free loading process with the speed regulating device presented here.

Fig. 18

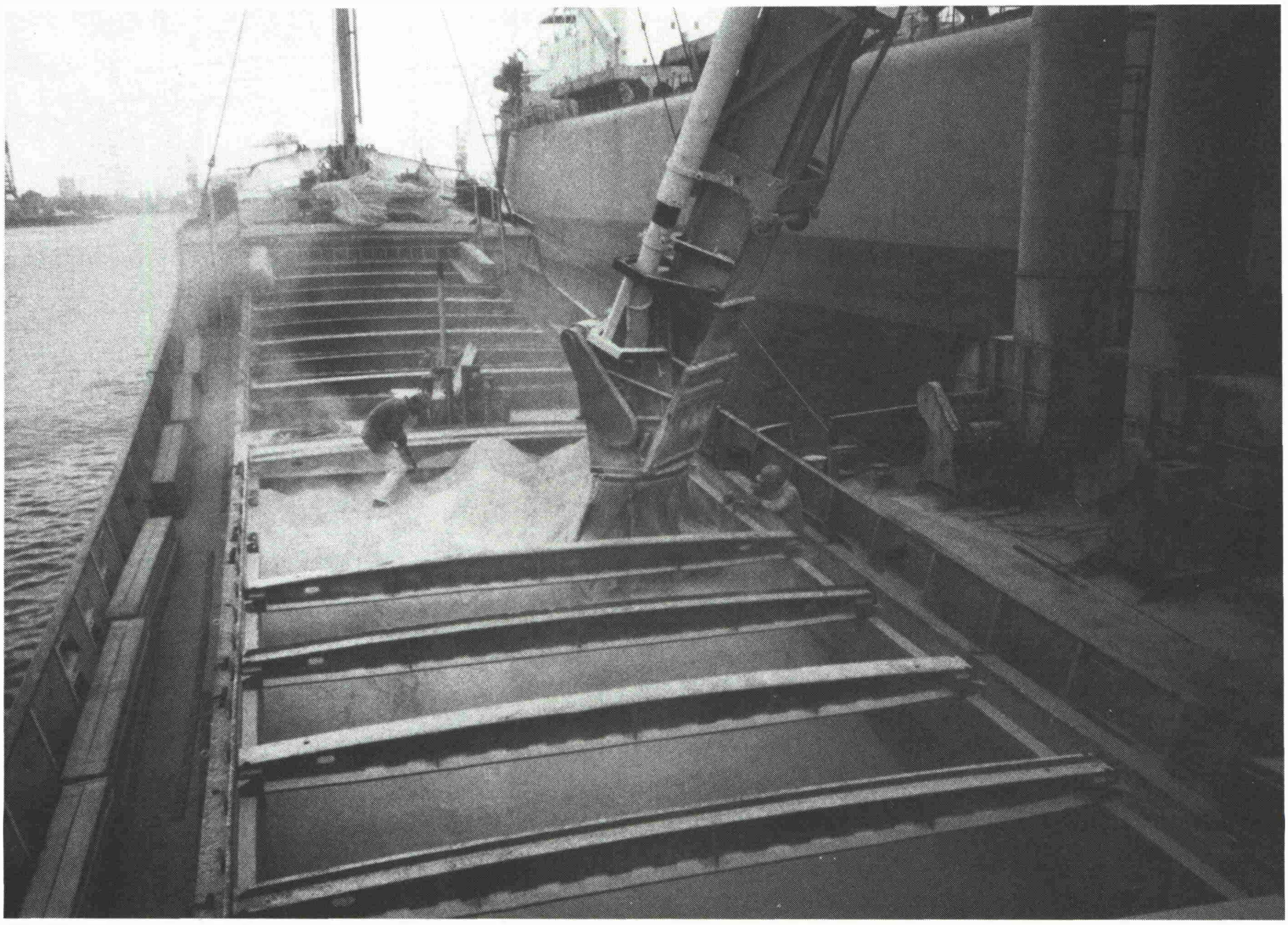


Fig. 19

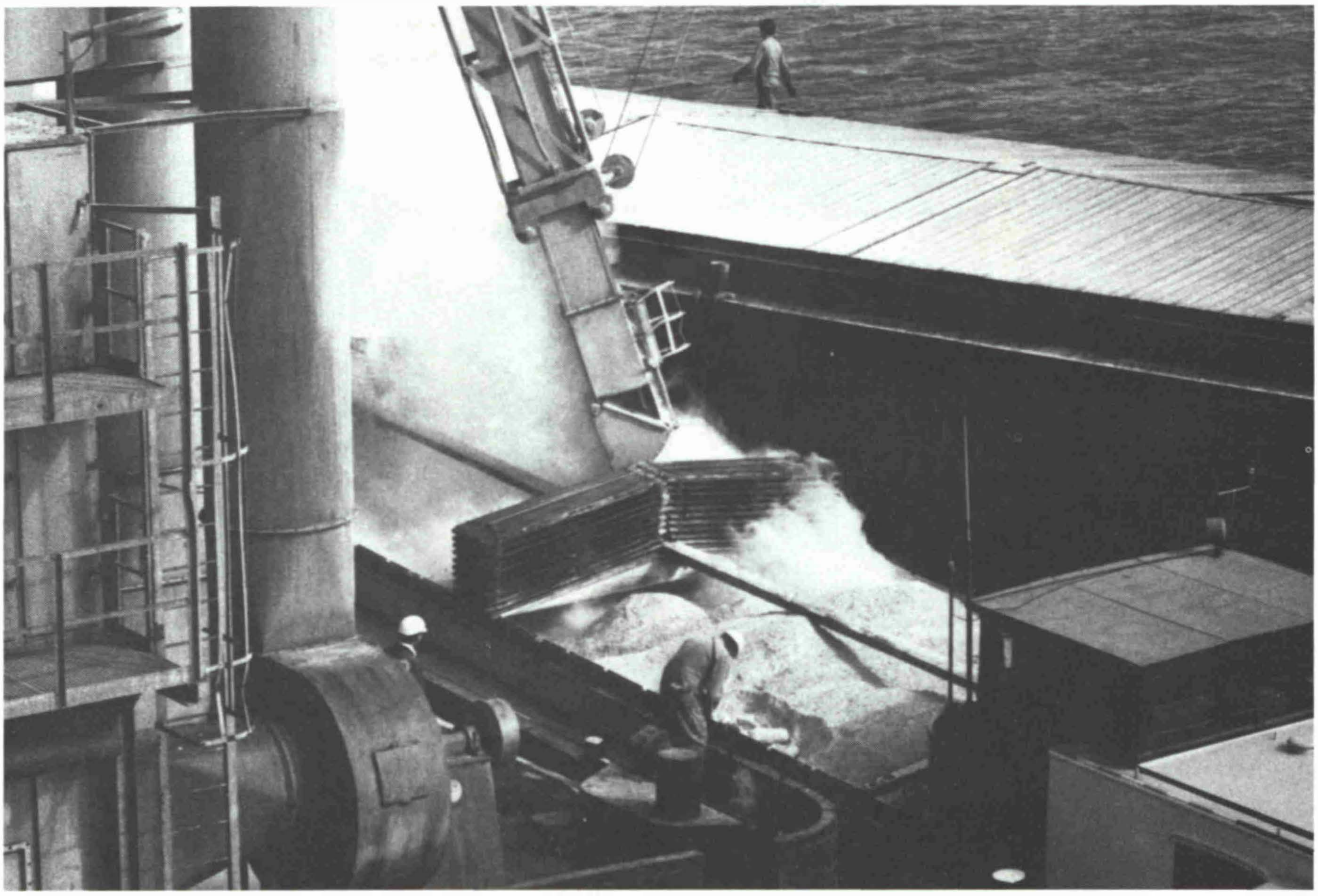


Fig. 20

Fig. 21