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Theory and Operational Characteristics of the Magnetic Value for Solids

Part I: Grate Design

The operational characteristics of the grate-type MVS with screen were studied in detail. First, theory was developed to predict how the current needed to operate the valve was related to the valve geometry. Then experiments were made to see how bed height, screen aperture, grate spacing, the presence of nonmagnetic solids in the mixture all affected the current needed to operate the valve and on the mass flux of solids. The response time of the valve was also determined.

The experiments were compared with the predictions of the theory.

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SCOPE

Magnetism has long been used to separate magnetic solids from nonmagnetic solids and fluids. More recently this technique has been extended to the removal of very weak paramagnetic particles from gas streams, by using high-gradient magnetic filtration. All of this is well known, and these techniques have been well developed. In recent years magnetism has also been used to transform fluidized beds into magnetic stabilized beds which have some interesting properties.

Magnetism can also be used to stop the flow of a dense stream of magnetic particles and by turning the field on and off one can then control the movement of this stream of magnetic particles and thus approach any desired contacting pattern in a gas/solid reactor.

This new type of valve, called magnetic valve for solids (MVS), presents important advantages over conventional devices for controlling the flow of a stream of flowing particles: (1) it does not use moving parts; (2) it can reliably act as a distributor-downcomer for multistage fluidized beds without the problems of bypassing, plugging, etc., previously mentioned; (3) its time response is practically instantaneous; and (4) it can be used either with pure magnetic particles or with mixtures of magnetic and nonmagnetic solids.

There are three main designs of the MVS: the grate-MVS, the collar-MVS, and the adjacent-MVS. Each one presents some advantages and some disadvantages. This work was undertaken to study the operational characteristics of the grate design. The main objectives of this study are:

(1) To develop a simple theory to explain the functioning of this type of MVS.

(2) To measure its operational characteristics so as to obtain useful information for design and for comparison with other designs to be tested.

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CONCLUSIONS AND SIGNIFICANCE

The main findings of this study are:

1. The theory of particle buildup around an electrical conductor, developed by Wang et al. (1982), and given as Eq. 1, was tested in the device of Figure 7, and verified in experiments reported in Figure 8.
2. Placing a screen near the current carrying grate reduced the current needed to operate the valve. The best location for the screen is directly below the grate. Above the grate the screen did no good.
3. The current needed to freeze a stream of flowing particles, the capture current, I_c, is greater than the release current, I_r, the ratio varying between 1.3 to 2.2 (Table 1).
4. The effect of grate spacing and screen aperture on the current and flow rate of solids are shown in Figures 9 and 14.
5. Theory developed here predicts that the current needed to operate the valve should be related to grate spacing and screen aperture by Eq. 12 in one extreme, and Eq. 13 in the other extreme. Experiments (Figure 9) fitted neither of these extremes.
6. Beyond a certain minimum height, the height of solids resting on the valve had no effect on the mass flux of solids through the valve.
7. The response time to opening and closing of the valve was very rapid, in the order of 0.2 s, Figures 11 and 12.
8. Increasing the value of the working current, I_w, did not affect the mass flux of solids through the MVS, Figure 13, except for very high electric currents.
9. Even with a large fraction of nonmagnetic particles in the mixture (up to 90%), the valve operated satisfactorily. However, the operating current rose as the fraction of nonmagnetic material is increased, Figure 15.
10. The response time to opening and closing of the valve in the case of magnetic-nonmagnetic solid mixtures was very rapid, in the order of 0.2 s, Figure 16.
11. The mass flux of mixtures of magnetic and nonmagnetic solids depended on the percentage of magnetics in the mixture, Figure 17.

These experiments show that the grate-type MVS can effectively, positively and very rapidly stop the flow of a stream of magnetic solids. It also operates satisfactorily with mixtures of magnetic and nonmagnetic material. Thus it represents a new tool for reliable trouble-free control of the movement of streams of solids with possible uses in countercurrent moving bed contactors of large solids with gas, or in multistage fluidized bed contactors of fine solids with gas.

CONCEPT OF MAGNETIC VALVE FOR SOLIDS

Wang et al. (1982) recently reported on preliminary studies on a new class of valves designed to control the flow of a stream of fine solids. These valves operate by properly creating a strong magnetic field in a narrow slice of flow channel such that the flowing solids freeze in place and block the flow channel. The only requirement for these valves to operate is that the flowing solids are magnetizable or contain at least some small fraction of magnetizable particles. The attractive feature of the MVS is that it has no moving parts or mechanical action; it requires modest power to operate, while the response of the flowing solids to a turning on and off of the magnetic field is rapid, consistent and reproducible.

The MVS can be used to control the flow of solids from hoppers, in downcomer pipes from fluidized beds and in moving beds. Thus these valves may become the key to a new class of countercurrent fluid-solid contactor through which solids flow at a controlled rate in close to plug flow.

There are three broad types of MVS's: the grate, the collar and the adjacent coil design, Figure 1.

In the grate design, Figure 1a, the current carrying electric conductors which create the strong local magnetic field intercepts the flow path of the solids in the form of a grate of spacing L_g. A screen of aperture L_s located directly below the conductors is helpful in that its presence reduces the power needed to operate the valve.

In the collar design, Figure 1b, the current-carrying conductors are coiled around and at a narrow slice of the flow tube, while an ordinary screen, grate or other partial obstruction is placed within the flow channel at or just below the collar.

The adjacent coil design, Figure 1c, has the electric conductor by the side of the flow channel, while the magnetic field it gener-

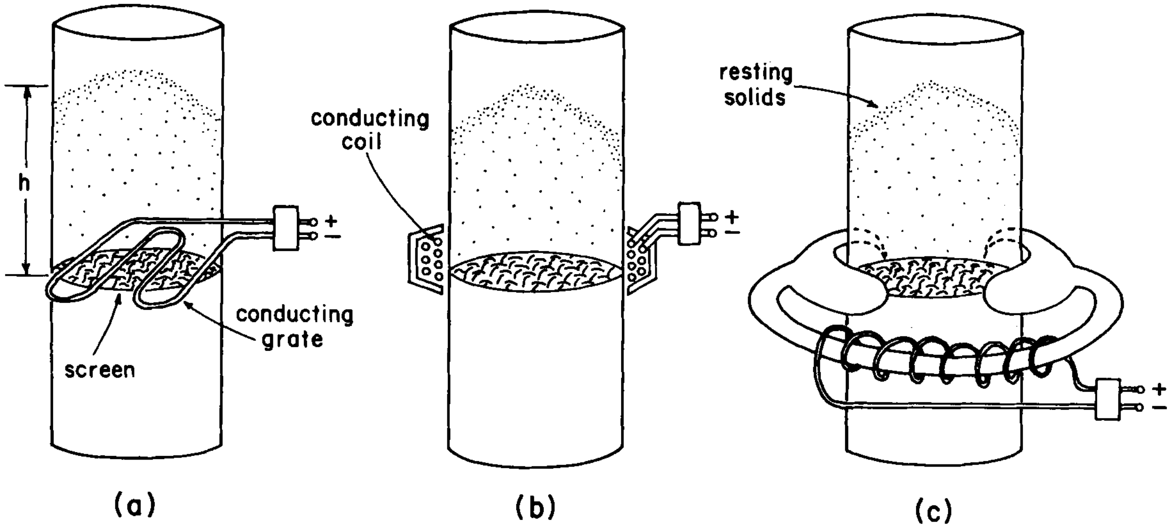

Figure 1. Three types of MVS: (a) the grate (b) the collar and (c) the external collar.

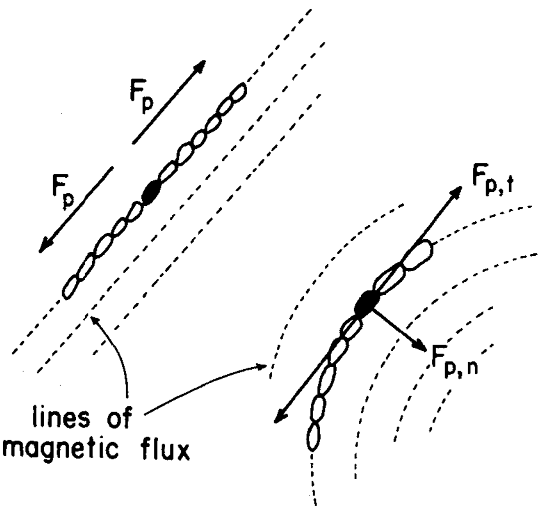

Figure 2. Forces on magnetic particles in a magnetic field.

ates is guided across a narrow slice of flow channel which contains a screen, grate or similar partial obstruction.

The presence of a screen, grate, current-carrying copper conductors or other partial obstruction within the flow channel is essential to the operation of the MVS.

In all these devices, when the current is turned off, the solids fall freely and the valve is in the "open" position. The time periods when the current is off and on are designated as t_{open} and t_{closed}. In addition, the current needed to stop and freeze a stream of flowing solids is called the capture current I_c, while the current below which the particles are no longer held in place is called the release current, or $I_c > I_r$.

This paper reports on the grate type of MVS. First, theory is developed to predict how the release current I_r should be related to grate spacing and screen aperture, and how the flow rate of solids should be related to t_{open} and t_{closed}. Then experiments are reported which give the actual operating characteristics of the valve and provide a comparison with the predictions of the theory.

THEORY

Principle of Action of an MVS: Qualitative

When magnetizable solids find themselves in a strong magnetic field generated by an electrical conductor, they want to line up in chains along the magnetic flux lines with a particle to particle force F_p, Figure 2a. If the flux are curved, Figure 2b, this force can be split into its tangential component $F_{p,t}$ and its normal component $F_{p,n}$. This normal component is always directed towards the center of curvature of the flux lines, in effect towards the region of higher flux density.

Figure 3a shows an electrical conducting grate with its surrounding flux lines. In this neighborhood, a stream of falling particles will form chains, be attracted to the conducting grate, rest on the grate, build up and bridge from bar to bar of the grate thereby blocking off the flow channel.

If a nonmagnetic screen is placed directly below the grate this becomes an additional resting place and support for these clumps and chains of particles. If the screen is of magnetic material it will also distort and concentrate the flux lines in its vicinity, acting as a "sticky" support for the particles and lowering the current needed to operate the valve.

Finally, consider the MVS in the closed position, with solids frozen in place and supporting additional solids above. Figure 3b shows the flux lines for this situation. The presence of magnetic material above the valve and the sharp difference in magnetic permeability above and below the valve will result in both an amplification of the flux and a very tight curvature of the flux lines near the screen. This will increase the holding forces on the particles.

MVS Using a Grate Alone: Quantitative

The theory which relates the release current I_r to the spacing of the conducting grate L_g was developed by Wang et al. (1982). Their results are given as

$$I_r = K_1 L_g^{1.5} \tag{1}$$

where k_1 is a constant which depends on the magnetic permeability of the particle/fluid medium. Theory and experiment agreed well.

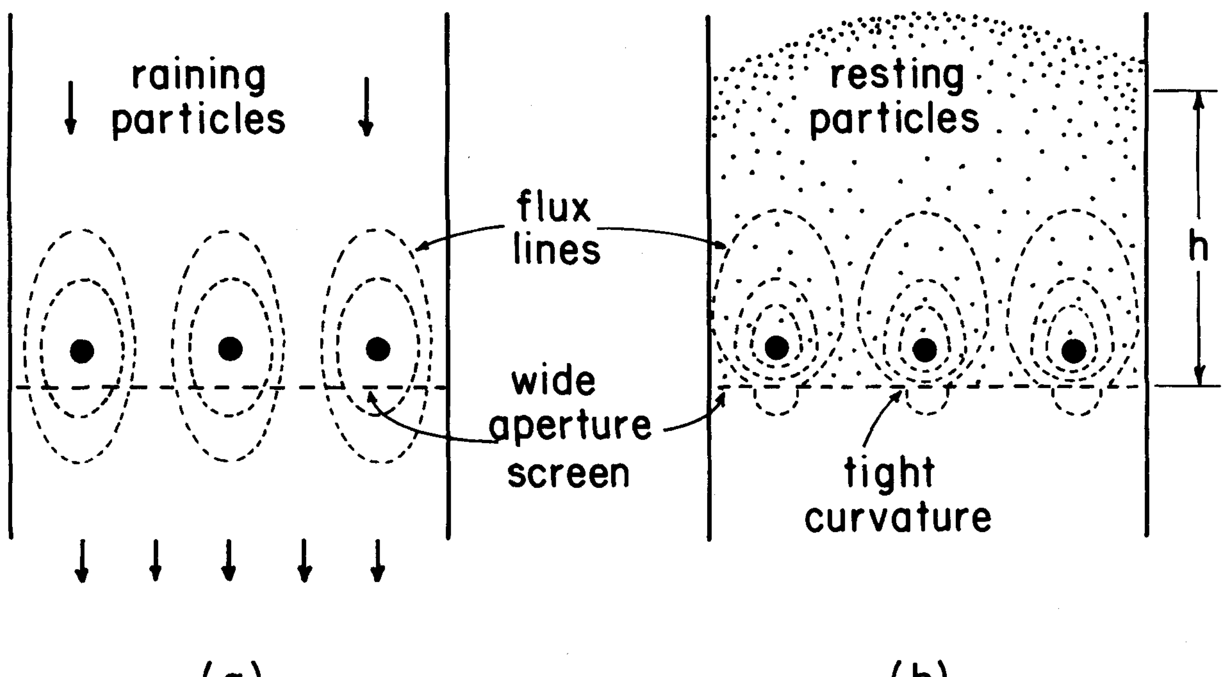

Figure 3. Magnetic flux lines in the neighborhood of a grate type MVS: (a) with free falling particles, and (b) with a bed of magnetic solids held up by the valve.

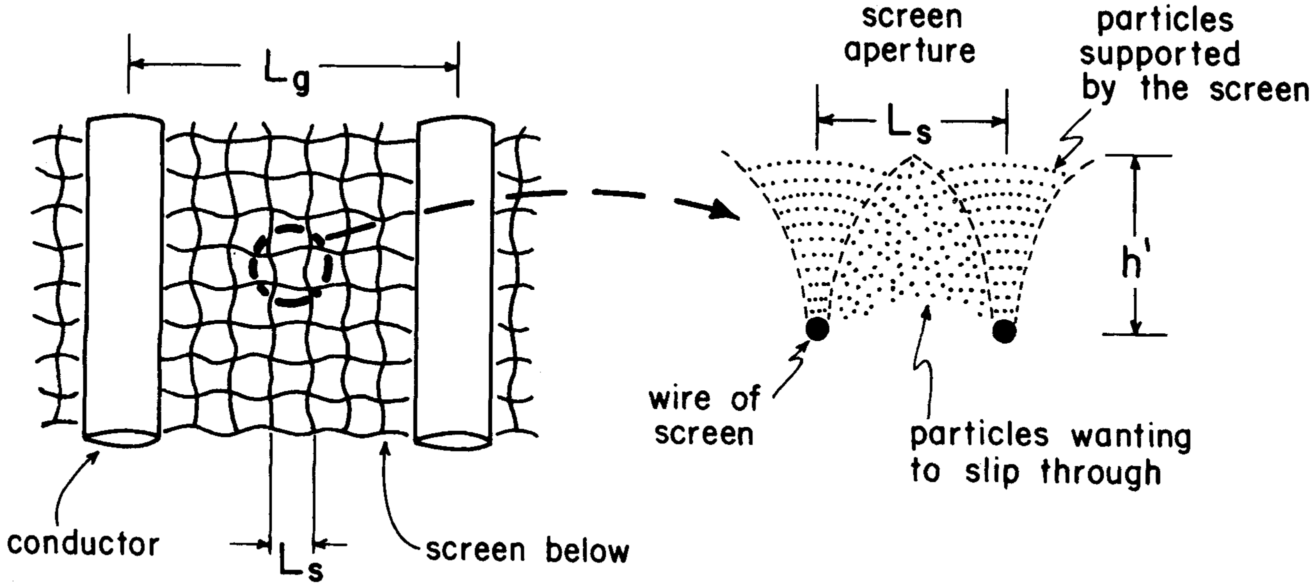

Figure 4. Forces on particles ready to slide through an aperture of the screen.

MVS Using Grate-Plus Screen Directly Below

Consider a MVS wherein the screen aperture is much smaller than the grate spacing, or $L_s < L_g$. Figure 3b sketches this valve in the closed position and holding up a batch of solids.

The current passing through the conducting grate and the nature of the particle/fluid medium determine the magnetic forces acting on the particles. This plus the physical support of the screen and grate counter gravity and keep the particles suspended.

Let us develop a simple model to relate the release current to the pertinent geometric factors of the MVS; since the magnetic field is weakest at the midpoint between conductors, consider the forces acting only on particles at a typical aperture of the screen at this location, Figure 4.

At this aperture of the screen a volume V of particles tend to slide downward, opposed, however, by the frictional force of the adjacent facing particles which are supported by the wires of the screen.

The weight of the particles which tend to slide downward is given by

$$W = (\text{volume})(\text{bulk density}) = k_2 L_s^2 h' \tag{2}$$

where h' is the effective bridging height. Then the total frictional drag force is given by

$$F_{p,\text{friction}} = \begin{pmatrix}\text{number of pairs}\\ \text{of facing particles}\end{pmatrix}\begin{pmatrix}\text{friction force between}\\ \text{pairs of facing particles}\end{pmatrix} = k_3\left(\frac{4L_s h'}{d_p^2}\right)\begin{pmatrix}\text{horizontal component of}\\ \text{force between adjacent particles}\end{pmatrix} \tag{3}$$

The particles are just held up against gravity when the above two forces are equal. Thus combining Eqs. 2 and 3 gives the force just needed to hold the particles in place, or

$$F_{p,\text{horiz}} = k_4 L_s d_p^2 \tag{4}$$

Let us now evaluate $F_{p,\text{horiz}}$. If we consider the particles to be magnets in the presence of a magnetic field generated by the conductor, the force of attraction between two touching particles on the same flux line is deduced from Eisenstein (1977) and from Fink and Beatty (1978) as

$$F_p = k_5 d_p^2 M^2 \tag{5}$$

where k_5 depends on the magnetic properties of the medium bathing the particles and M is the magnetization of the particles.

From electromagnetic theory

$$M = \frac{B}{\mu_0} - H \tag{6}$$

where B is the magnetic flux density through the particles, H the magnetic field strength and μ_0 the magnetic permeability of air or a vacuum. Combining Eqs. 5 and 6 gives

$$F_p = k_5 d_p^2\left(\frac{B}{\mu_0} - H\right)^2 \tag{7}$$

Then the horizontal component of this force of attraction is

$$F_{p,\text{horiz}} = k_5 d_p^2\left(\frac{B}{\mu_0} - H\right)^2 \cos\theta = k_6 d_p^2\left(\frac{B}{\mu_0} - H\right)^2 \tag{8}$$

where θ is the angle of the flux line to the horizontal.

Now the field strength H at a distance r away from a straight line conductor passing a current I is given as

$$H = \frac{I}{2\pi r} \tag{9}$$

Also by definition, the flux density and field strength are related by

$$B = \mu_{\text{eff}} H \tag{10}$$

where μ_{eff} is the effective permeability at that particular field strength. Replacing Eqs. 9 and 10 in Eq. 8 and combining with Eq. 4 gives

$$I^2 = \frac{4\pi^2 k_4}{k_6}\cdot\frac{r^2 L_s}{\left(\frac{\mu_{\text{eff}}}{\mu_0} - 1\right)^2}$$

and at the midpoint between bars of the grate, where $r = L_g/2$,

$$I = k_7\frac{L_g L_s^{1/2}}{\left(\frac{\mu_{\text{eff}}}{\mu_0} - 1\right)}$$

Now, in all but superconducting materials, $B \gg \mu_0 H$, or $\mu_{\text{eff}} \gg \mu_0$, hence we can safely write

$$I = k_7\frac{L_g L_s^{1/2}}{\left(\frac{\mu_{\text{eff}}}{\mu_0}\right)} = k_8\frac{L_g L_s^{1/2}}{\mu_{\text{eff}}} \tag{11}$$

This is the situation of concern here.

At this point let us consider μ_{eff}. Figure 5 sketches the B-H curve for iron or any typical magnetizable material. As can be seen, at

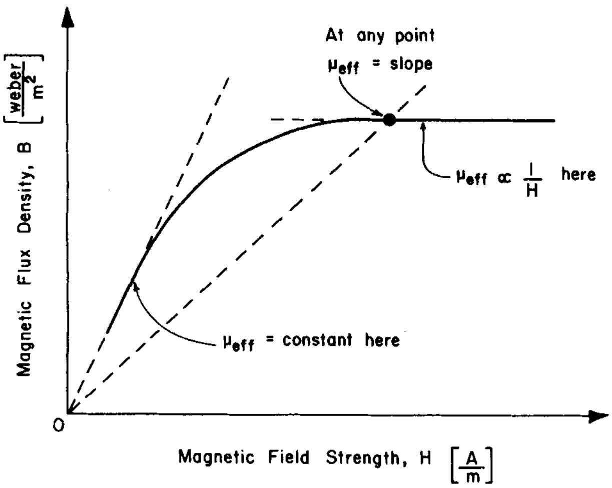

Figure 5. A typical *B-H* curve for a magnetizable solid.

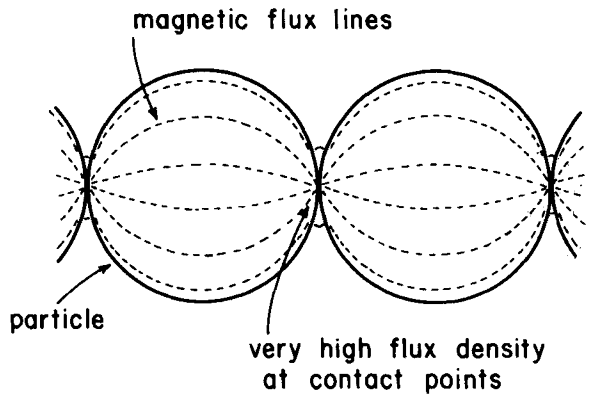

Figure 6. Magnetic flux lines within and around a magnetizable particle aligned along a magnetic field line.

low field strength where the particles are not saturated, B is proportional to H, so μ_{eff} stays constant and Eq. 11 becomes

$$I = k_9 L_g L_s^{1/2} \qquad (12)^*$$

Note that when the screen aperture approaches that of the grate, Eqs. 12 approaches Eq. 1, that for a grate alone.

On the other hand, at high field strength, where the particles are saturated, B becomes constant and independent of H and of r, Figure 5. In this situation Eqs. 9 and 10 give

$$\mu_{eff} \alpha \frac{1}{H} \alpha \frac{r}{I}$$

in which case Eq. 11 becomes

$$L_s = L_{s,\max} = \text{constant} \qquad (13)$$

This means that at very high currents some maximum screen spacing is reached beyond which one cannot hold the particles, irrespective of the current applied.

Equations 12 and 13 represent the extremes of low and high field strength, and experiments, reported below, are compared with the predictions of these extremes.

It is appropriate to ask which extreme, if any, to expect to occur. Figure 6 sketches the magnetic flux lines at the touching particles, and shows extremely high flux at the points of contact. Thus we may expect saturation to occur there first, and then spread with increasing current, hence increasing field strength.

Thus the MVS should behave somewhere between these extremes. Theory for this intermediate situation is yet to be developed.

Mass Flux of Particles through a MVS Opened for a Period t_{open}

When the current is switched off the MVS behaves as a set of ordinary obstructions to the flow of solids. The characteristic size of opening L associated with these obstructions should be taken as the smaller of the grate spacing L_g or screen aperture L_s if one of these is very much smaller than the other. Normally the screen aperture is much smaller (otherwise why have a screen present?) hence is taken as L.

According to Resnick (1966), the mass flux of granular solids through orifices—when the pressure drop across the orifice is zero—is given by

$$G \alpha L^{1/2} \qquad (14)$$

However, because of bridging of particles we modify this expression to give

$$G = k_{10}(L^{1/2} - L_0^{1/2}) \qquad (15)$$

where L_0 represents the size of opening at which bridging is likely to occur to stop the flow. Experiments show that this size is strongly dependent on particle shape and ranges from 4 to 12 particle diameters.

Applying this expression to the MVS suggests that a plot of G vs. $L_s^{1/2}$ should give a straight line which cuts the abscissa at a point which represents the bridging aperture. The use of Eq. 15 assumes in addition that when the valve is opened (current off) the time needed to accelerate the particles to their terminal velocity is negligible, and when the valve is closed (current on) the time needed for the particles to build up and block the flow channel is also negligible.

EXPERIMENTAL

The experiments reported in this paper were designed to study the effect of a number of controlled variables on the release current I_r and the mass flux of solids G. These controlled variables were height of solids h resting on the valve, t_{open} and t_{closed}, grate spacing L_g and screen aperture L_s, and finally the percentage of magnetic solids in the mixture $(\%)_m$.

The equipment consisted of an adjustable D.C. (200 A 5 V) power supply, a digital ammeter, and electric circuit to switch off the continual flow of current through the grate and a counter to control the number of these pulses.

The flow channel for solids was made of 6 in. (152 mm) Pyrex pipe, and the grates consisted of ¼ in. (6.35 mm) copper tubes in various spacings. Since high currents were needed to freeze the solids, water cooling of the tubes was used to keep the temperature, hence resistance of the grates unchanging with time. In addition, in all these experiments screens of various apertures were placed just below the grates so as to reduce the current needed to operate the valve.

The following procedure was followed:

1. In order to check theory a preliminary experiment was made, Figure 7, in which a U-shaped conductor with small disk-like platform on one arm was placed in a container. Magnetic solids were poured in to fill the container, the current was turned on and the conductor with its attached solids was withdrawn. The asymptotic thickness of conductor with its attached solids was recorded for different current I.
2. For all other experiments the flow tube with grate and screen were used. At first the current through the grate was raised to a high value, then particles were poured onto the grate. Some fell through but soon the whole flow channel was blocked with frozen particles. Additional particles were poured in until a height h was reached; as shown in Figure 1. Then two kinds of experiments were run.

a. To determine the release current, the current passing through the grate was reduced until particles started to fall from the grate. This gave the release current I_r. Then with current off and solids falling freely through the grate the current was raised until the flow of solids was stopped. This gave the capture current I_c. The working current I_w used in subsequent runs was picked slightly higher than I_c.

b. To determine the mass flux of solids a working current was selected, the valve was closed (current on), solids were poured onto the valve to a suitable height, the open time and pulse counter were set, the counting was started (usually 20 pulses) and the solids passing through the valve were collected and weighed.

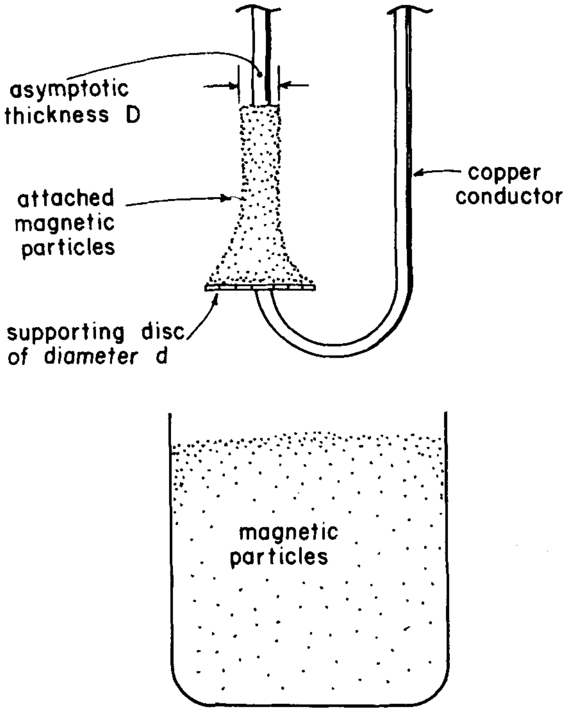

Figure 7. Experiment designed to determine the thickness of particle layer frozen to an electrical conducting wire or rod.

RESULTS AND DISCUSSION

Grate Without Screen

We would expect that particles cling to a conductor of a grate without a screen in the same way as to the single conductor of the experiment of Figure 7. Thus we may expect that the relationship of Eq. 1 holds equally for both setups.

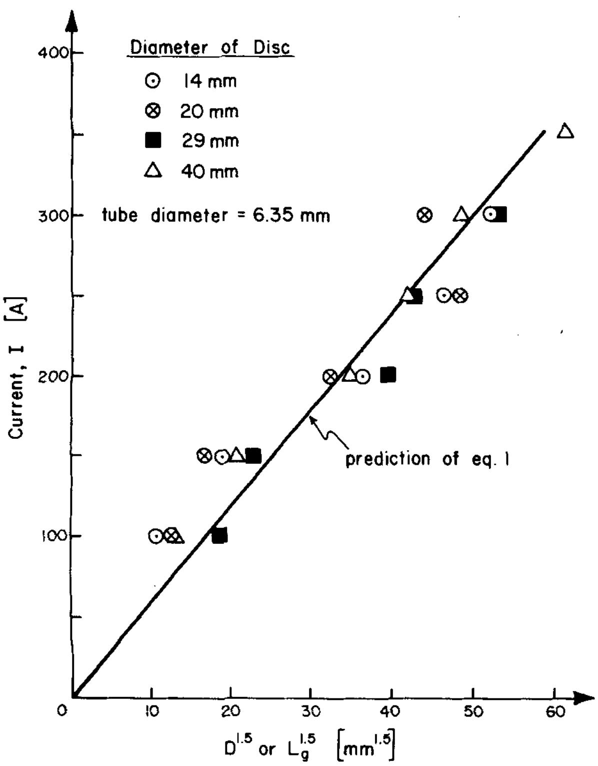

Figure 8. U-tube experiments (Figure 7) confirm the predictions of Eq. 1 for the grate type without screen below.

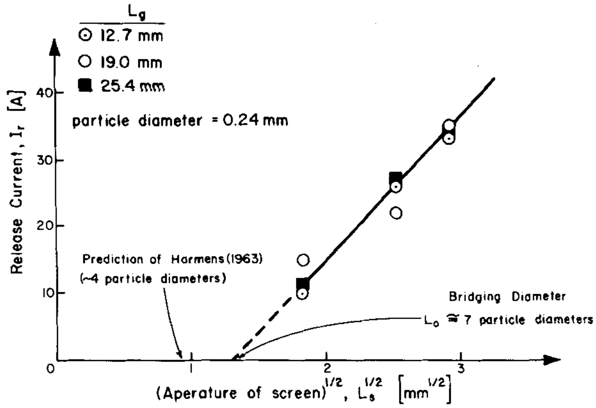

Figure 9. Test of the screen aperture prediction of theory.

Figure 8 shows results of experiments on the U-tube which do agree with Eq. 1. Note that the asymptotic thickness is independent of the dimensions of the supporting disk.

Effect of Screen Aperture and Grate Spacing on the Release Current

In attempting to correlate the data it was found that a plot of I_r vs. $L_s^{1/2}$, Figure 9, gave a straight line through the data which extrapolated to a bridging aperture of about 7 d_p. This limiting value can be compared with the findings of Harmens (1963) on the flow of solids through an orifice, in which he showed that the orifice was likely to block due to bridging when the orifice size is $\leq 4\ d_p$. Thus we may write

$$I_r = 630(L_s^{1/2} - L_{so}^{1/2}), \quad L_s = [\mathrm{m}]$$

The data indicated that grate spacing L_g did not affect the release current.

These results do not match either extreme of theory, Eq. 12 or 13. However the L_s effect matches one extreme, the L_g effect matches the other. Further experiments should be done to clarify this curious finding.

It should also be noted that a plot of I_r vs. L_s also gives a good straight line fit to the data.

Capture, Release and Practical Working Current

One may expect the capture current to be higher than the release current for two reasons. First, besides holding the particles the capture current has also to overcome the kinetic energy of falling particles. Secondly, a stream of falling solids has a lower mean density than a packed bed of resting particles, hence a lower magnetic permeability.

Table 1 shows typical values of the capture and release current found in this study, and also the practical working current chosen. Note that the capture current is very much higher than the release current at small screen apertures. This finding may be explained in terms of the bridging phenomena. Since bridging becomes dominant at smaller screen apertures it will cause a greater reduction in release current for small aperture screens than for the large aperture screens.

Effect of Bed Height on Mass Flux of Solids

Figure 10 shows that above a small minimum height the bed height does not affect the mass flux of solids. This result is consistent with previous studies on the flow of granular solids through orifices which also found no effect as long as the bed height was more than a few orifice diameters (Harmens, 1963). Once this fact was verified all further runs were made using bed heights beyond this minimum so as to be in the height-independent regime.

TABLE 1. TYPICAL VALUES OF RELEASE, CAPTURE AND WORKING CURRENTS.

		Screen Aperture 3.3 mm	Screen Aperture 6.4 mm	Screen Aperture 8.5 mm
Grate Spacing	I_r	10 A	26 A	33 A
½ in. (12.7 mm)	I_c	22	37	43
	I_w	26	40	45
Grate Spacing	I_r	15	22	34
¾ in. (19.0 mm)	I_c	21	33	46
	I_w	25	40	50
Grate Spacing	I_r	11	27	34
1 in. (25.4 mm)	I_c	24	40	57
	I_w	25	50	70

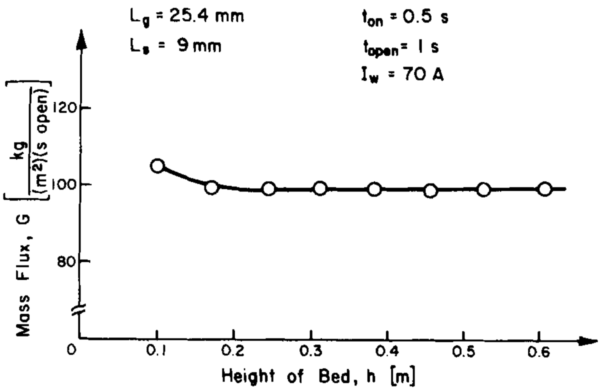

Figure 10. The height of solids resting on the MVS has no effect on the mass flux of solids, except maybe for very shallow beds.

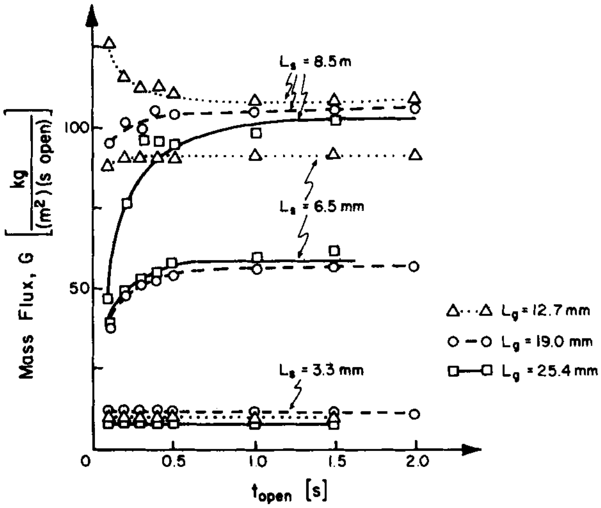

Figure 12. Only at short valve open times, t_{open} < 0.5 s, is the mass flux of solids not independent of t_{open}.

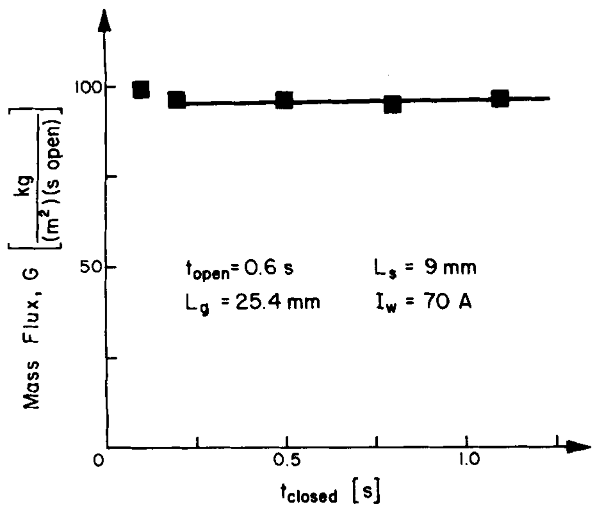

Figure 11. Even very short valve closing times do not affect the mass flux of solids when the valve is open.

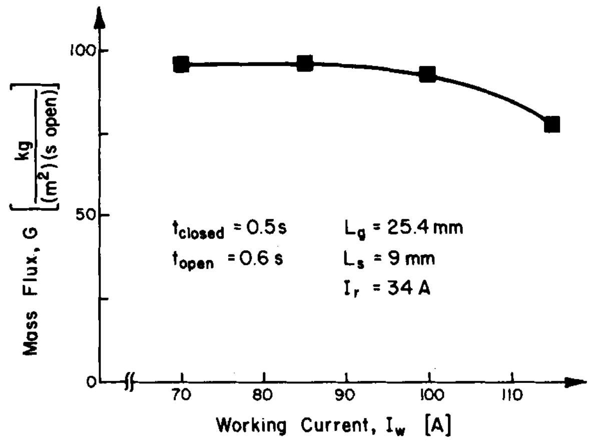

Figure 13. The mass flux is independent of the working current except at very high I_w.

Response Time of the Valves, and the Effect on Mass Flux of Solids

For very short switching times one may expect that time delays may affect the flux of solids through the valve. Figure 11 clearly shows no effect even for t_{closed} as small as 0.2 s, however Figure 12 shows that when $t_{open} < 0.5$ s the flow rate begins to be affected by this short time. These findings show that the response time is rapid, and that these are extremely fast acting valves.

Effect of the Working Current on Mass Flux of Solids

For a given geometry Figure 13 shows that the mass flux is practically independent of the working current, decreasing slightly at very high values, most likely because the residual magnetization of the particles at these higher working currents causes them to cling to their support before being dragged off.

Mass Flux vs. Screen Aperture

Figure 14 tests the prediction of Eq. 15 relating mass flux to screen aperture. The agreement suggests that a screen behaves as a set of side by side orifices, and that the larger spaced grate does not hinder the flow of solids.

Behavior of the MVS for Mixtures of Magnetic and Nonmagnetic Solids

Figure 15 shows that the capture and release current needed for mixtures increases slightly with an addition of small amounts of

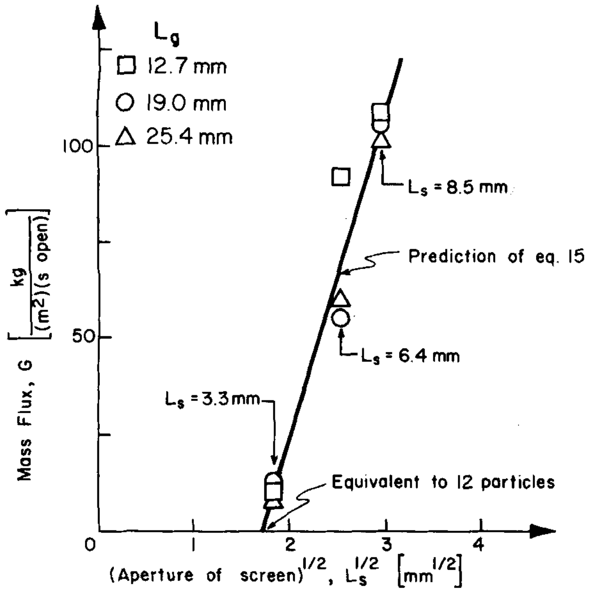

Figure 14. The mass flux of particles is strongly dependent on the screen aperture and is well represented by the orifice flow form of equation.

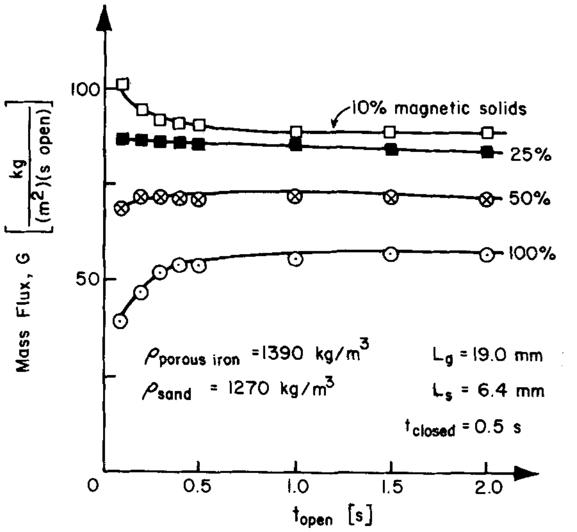

Figure 16. In mixtures with nonmagnetics the MVS experiences a time delay in its operation.

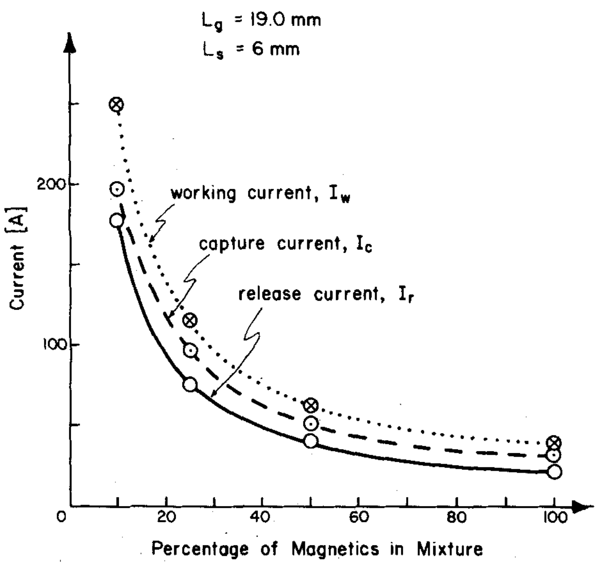

Figure 15. For small fractions of magnetic material the current needed to operate the MVS becomes very large.

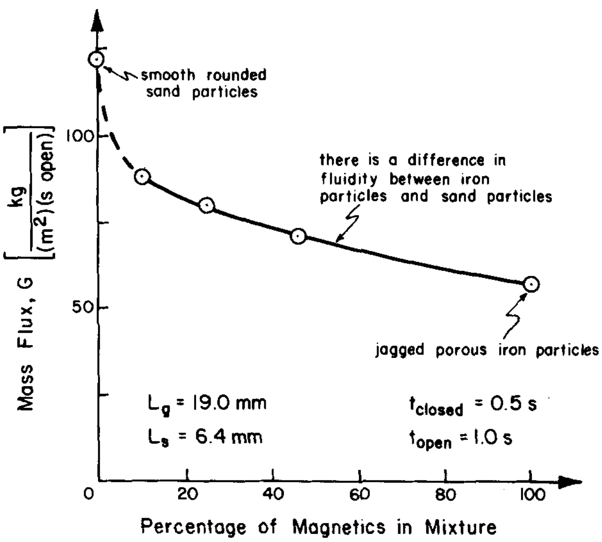

Figure 17. The volume flux of solids decreases as the fraction of magnetizable solids increases.

nonmagnetics, but that these currents increase sharply as the fraction of nonmagnetics in the mixture becomes large.

Figure 16 shows that the mass flux in mixtures stays independent of t_{open} for $t_{open} > 0.5$ s, similar to the findings with pure magnetics shown in Figure 12.

For particles of similar geometry the volume flux of mixtures should be independent of the mixture ratio. Since the density of the solids is different ($\rho_{porous\ iron}$ = 1,390 kg/m, ρ_{sand} = 1,270 kg/m³) the ratio of mass fluxes should be related to the density ratio of the components, or

$$\frac{G_{porous\ iron}}{G_{sand}} = 1.1$$

Figure 17 shows that this conjecture does not agree with experiment. It may be caused by residual magnetization of iron particles and will be investigated in further work.

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NOTATION

B = magnetic flux density, Wb/m²
d_p = particle diameter, m
D = diameter of disc in the experiment of Figure 7, m
F_p = particle to particle force, N
$F_{p,friction}$ = total frictional force acting on the lateral faces of an elemental volume of particles, N
$F_{p,horiz}$ = force needed to keep the particles in place, N
$F_{p,n}$ = normal component of F_p, N
$F_{p,t}$ = tangential component of F_p, N
G = mass flux of particles, kg/m²·s
h = effective bridging height of solids resting on a MVS, m

h' = height of bridge, Figure 4, m
H = magnetic field strength, A/m
I_c = capture current, A
I_r = release current, A
I_w = working current, A
$k_1, \ldots, k_{10}$ = constants
L = characteristic size of opening, m
L_g = grate spacing, m
L_s = screen aperture, m
$L_{s,max}$ = maximum aperture of screen beyond which particles cannot be stopped and held, m
L_{so} = size of screen opening at which bridging occurs naturally, m
r = distance away from a straight line conductor, m
t_{open}, t_{closed} = time period when the current to the MVS is off and on, respectively, s
W = weight of particles, N

Greek Letters

θ = angle between F_p and the horizontal
μ = magnetic permeability, H/m
μ_{eff} = effective permeability, H/m
μ_o = magnetic permeability in air or in a vacuum, H/m

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Theory and Operational Characteristics of the Magnetic Valve for Solids

Part II: Collar Design

This paper reports on the operating characteristics of the collar type MVS which uses either orifice plates or screens as supports for the solids.

The optimum placement for the support (screens or orifice plates), the current needed to operate the valve as a function of vessel size (up to 0.55 m) and screen or orifice opening, and the response characteristics of the valve were all determined. These findings were then compared with theory.

Finally, the operational characteristics of the MVS (magnetic valve for solids) when handling a mixture of magnetic and nonmagnetic solids were briefly examined.

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SCOPE

This paper as well as Part I explore the characteristics of a new class of valve to control the flow of solids in pipes and vessels. They operate by properly developing a strong magnetic field in a narrow slice of flow channel. These valves have no mechanical action and are very rapid acting, however they do require the presence of at least some small fraction of magnetic material in mixture of solids.

There are numerous possible designs for these devices. In contrast with the grate design, this paper deals with the design in which the electrical conductor does not protrude into the flow channel for solids but is coiled around it. Each design has its particular characteristics and advantages.

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