STUDY OF THE MINERAL PHYSICS OF THE FERRUGINOUS MANGANESE ORES OF THE VISAKHAPATNAM DISTRICT

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Introduction

In a series of articles, R. S. Dean and others (1934) have pointed out the importance of the study of mineral physics and showed that such studies can greatly help in the magnetic separation of economically important minerals. They have also announced the remarkable discovery that the hysteretic characteristics of minerals with even very feeble magnetic properties are susceptible to development, modification, and control through the development of interfacial area and mechanical and heat treatment. Thus today, in all advanced countries the beneficiation by magnetic separation of low grade minerals by alternating current treatment, preceded by modification of its magnetic properties by sizing, heating and packing to different sizes, temperatures and densities has now been adopted as a standard method of separating useful economic minerals.

The application of these ideas to a similar study of the physics of minerals occurring in our country has been engaging the attention of the authors for some time. They have confined their attention in this paper to the studies on the manganese ores of the Visakhapatnam district only.

The purpose of the present paper is thus a preliminary study of the mineral-physics of the ferruginous manganese ores of the Visakhapatnam district. The hysteretic parameters determined in the present studies will be coupled with the results of heat treatment and application of alternating current magnetic separation in the later investigations and then it will be possible to show how far these studies are useful in actual beneficiation.

Accordingly ferruginous manganese ores from two different localities (*a*) Garividi, and (*b*) Garbham (Visakhapatnam district) are collected. Of these, two representative samples are powdered and washed in running water. They are then chemically analysed for the total iron and manganese percentages by the usual methods (Low, 1927).

The average of five analyses for Garividi ore and six analyses for the Garbham ore are given in the table below, along with the average values of the previous workers.

	Present analyses	Average values of (Krishnan, 1951) the previous workers
(*a*) Garividi ore—		
Iron	18%	11·22%
Manganese	41·2%	42·96%
(*b*) Garbham ore—		
Iron	5·3%	9·99%
Manganese	46·9%	45·39%

The powdered samples are passed through sieves of various meshes and the mean sieve size is taken as being representative of the grain size for each fraction. Each fraction is labelled according to its grain size. In all, four different grain sizes for the ore from Garividi and five grain sizes for the ore from Garbham are studied.

Apparatus for the measurement of hysteresis

The apparatus of Bruckshaw and Rao (1950) is employed for the measurement of the magnetic properties of these ore powders. This is an inductive method employing the oscillographic technique. The specimen to be examined is placed in a uniform magnetic field, and the secondary field induced into it, which is proportional to the energising field is then investigated.

Fig. 1 shows the principal parts of the apparatus. The two energising coils *B* and *D* are designed to give a magnetic field of 250 oersteds per ampere. The maximum safe current that can be passed is 1·5 amperes giving a field of 375 oersteds at a point midway between the coils *B* and *D*. Alternating current is employed and this induces e.m.f.s in the three nearly identical coils *A*, *C* and *E*. The specimen in the form of a two-centimeter cube is placed within the pick-up coil *C* with its centre coinciding with the geometrical centre of the coil system. Without the specimen in place, the number of turns of these detecting coils is adjusted so that the e.m.f. in *C* is balanced by the sum of the e.m.f.s in *A* and *E*. When the specimen is introduced, the flux through *C* is modified accordingly and an out-of-balance e.m.f. is set up, its magnitude depending on the magnetic characteristics of the specimen.

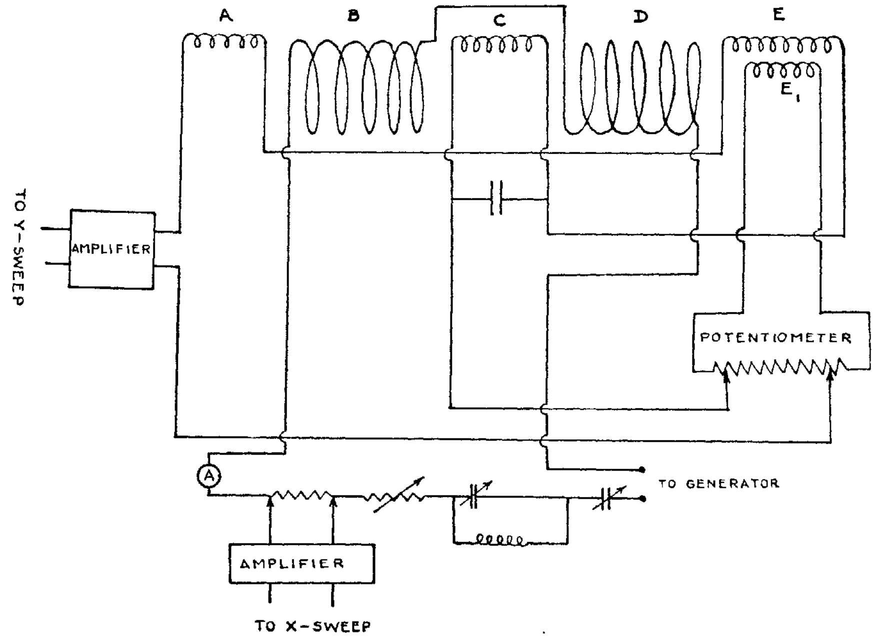

Fig. 1.

The induction at any instant in the specimen is given by $B = H+4\pi I$. The contribution arising from the term H is identical with that obtained without the specimen and is compensated by the initial balance. The out-of-balance e.m.f. is proportional to $4\pi \frac{dI}{dt}$ or $4\pi \frac{dI}{dH} \times \frac{dH}{dt}$. This e.m.f. after amplification is impressed on the vertical deflection plates of the cathode-ray oscillograph, the horizontal plates of which are joined to the ends of the resistor in the energising circuit. The instantaneous deflection, is then proportional to the field. Thus a combination of the vertical and the horizontal forces gives a graph on the oscillograph between $\frac{dI}{dH} H_0 \cos \omega t$ and $H_0 \sin \omega t$, where H_0 is the peak field.

This graph on the oscillograph is photographed on a 36 mm. film. The following exposures are taken for each specimen:—

(a) with the specimen inside the coil C,
(b) without the specimen,
(c) with the Y-sweep removed, giving a horizontal reference axis, and
(d) with the X-sweep removed, giving the Y axis.

METHOD OF MEASUREMENT

The photographs are enlarged to ten times their original size and the X axis of the enlarged picture is divided into twenty equal parts. This X axis is taken as representing the field axis and the twenty equal parts are named as 0, $0{\cdot}1\ H_0$, $0{\cdot}2\ H_0$, ... H_0. At each of these points ordinates are erected and the difference in ordinates between the trace with the specimen and the trace without the specimen, after correcting for the non-linear magnification in the oscillograph, is a measure of $\frac{dI}{dt}$ or $\frac{dI}{dH} \times \frac{dH}{dt}$ or $\frac{dI}{dH} \cdot H_0 \cos \omega t$. So, these values divided by $\cos \omega t$ are proportional to $\frac{dI}{dH}$ and are plotted on the Y axis against the field. The curve is then integrated from 0 to H and this gives I at various values of H. The I and H curves are drawn from these values and the arbitrary units of I are transferred into absolute units from a previous calibration of the oscillographic deflections.

The chief advantages of this method are:

1. The apparatus readily gives the hysteresis loop at any desired field strength and from this all the magnetic properties can be read.

2. The laborious calculations are very much simplified.

3. The packing density of the powder on which the magnetic measurements mostly depend is readily determined and can be varied over a considerable range by mixing with a magnetically inert material.

4. This method can conveniently be used in the case of rock specimens as well as in the study of mineral powders.

5. This requires comparatively small amounts of powder (10 to 15 gms.) and can be used with advantage for minerals available in small quantities.

The ore fractions of the various grain sizes are weighed and mixed with known quantities of plaster of Paris, used here as a magnetically inert material and also as a cementing agent. This mixture is wetted slightly and the paste is put in a two-centimeter cube mould. By weighing the prepared cube and by knowing the amounts of the ore and the plaster of Paris used, the packing density is calculated.

By varying the amount of plaster of Paris, various packing densities are obtained. Apart from the nine fractions of varying grain sizes mentioned previously, six fractions with different packing densities for Garividi ore and four for Garbham ore are also studied.

EXPERIMENTAL RESULTS

Employing the above method, I and H curves for all the nineteen fractions of the ferruginous manganese ores from Garividi and Garbham, are drawn at a peak field of 375 oersteds. The I-H curves obtained by the above method have been omitted from the list of figures given here, but the magnetic properties read from those curves have been tabulated.

Tables 1(*a*) and 1(*b*) give the values of $4\pi I$ and permeability at various field strengths differing by 37·5 oersteds, for various grain sizes. Table 2(*a*) gives the values of $4\pi I$ and permeability for $(-20+40)$ mesh at six packing densities for the Garividi ore and Table 2(*b*) gives the same data for $(-40+60)$ mesh Garbham ore, at four packing densities. All the values for the magnetisation per unit area of cross-section in the above four tables are expressed as 4π times the intensity of magnetisation, as has been done by Gottschalk and Wartman (1935). $4\pi I$ has been called by Gottschalk and Wartman as magnetisation density corresponding to the intensity of magnetisation I.

The curves in Figs. 2 to 6 pertain to the ore from Garividi area and the curves for Garbham ore can be obtained from the data available in Tables 1(*b*), 2(*b*) and 3(*b*). They are found to be similar to the curves in Figs. 2 to 6 and so are omitted. Fig. 2 represents the variation of permeability with grain size. These values of permeability are corrected for a standard value of packing density. Fig. 3 shows the variation of 'magnetisation density' with packing density at different field strengths. Examination of Fig. 3 shows that the variation of the magnetisation density with packing density is more linear for higher fields than for lower fields.

TABLE 1(*a*)

Variation of magnetisation density and permeability with field strength
(Garividi Ore)

H Oersteds	Fraction 1. $-20+40$ mesh		Fraction 2. $-40+60$ mesh		Fraction 3. $-50+80$ mesh		Fraction 4. $-120+140$ mesh	
	$4\pi I$ Gausses	Permeability	$4\pi I$ Gausses	Permeability	$4\pi I$ Gausses	Permeability	$4\pi I$ Gausses	Permeability
0	52·3	..	60·98	..	60·98	..	21·79	..
37·5	91·6	3·4	91·47	3·2	91·47	3·44	39·42	2·05
75·0	117·6	3·2	113·20	2·55	113·20	2·51	63·17	1·82
112·5	148·1	2·32	135·10	2·21	135·10	2·21	82·77	1·75
150·0	174·3	2·16	156·80	2·05	156·80	2·05	104·60	1·70
187·5	196·0	2·05	174·30	2·00	174·30	2·00	119·80	1·64
225·0	217·8	1·98	191·70	1·90	191·70	1·90	135·10	1·60
262·5	235·3	1·90	209·00	1·81	204·70	1·78	150·30	1·57
300·0	252·6	1·84	222·20	1·74	215·60	1·71	161·20	1·54
337·5	270·1	1·80	235·30	1·70	226·60	1·67	169·90	1·50
375·0	283·1	1·75	239·60	1·64	235·30	1·63	174·30	1·47
Fe gms./cm.^{3}	0·415		0·320		0·1806		....	
Mn gms./cm.^{3}	0·9443		0·7283		0·4111		....	
Grain size in microns	476		264		211		63	

TABLE 1(*b*)

Variation of magnetisation density and permeability with field strength
(*Garbham Ore*)

H Oersteds	Fraction 1. −20+40 mesh		Fraction 2. −40+60 mesh		Fraction 3. −60+80 mesh		Fraction 4. −80+100 mesh		Fraction 5. −100+120 mesh	
	$4\pi I$ Gausses	Permeability	$4\pi I$ Gausses	Permeability	$4\pi I$ Gausses	Permeability	$4\pi I$ Gausses	Permeability	$4\pi I$ Gausses	Permeability
0	16·2	..	22·7	..	19·80	..	20·5	..	17·0	..
37·5	44·3	2·18	42·6	2·14	32·40	1·86	30·7	1·82	23·9	1·64
75·0	54·5	1·72	52·8	1·70	34·10	1·46	37·5	1·50	28·97	1·39
112·5	64·8	1·57	63·1	1·56	40·90	1·36	47·7	1·42	34·08	1·30
150·0	75·0	1·50	71·6	1·48	49·40	1·33	52·8	1·35	39·20	1·26
187·5	83·5	1·45	78·4	1·42	56·20	1·30	59·6	1·32	42·60	1·23
225·0	90·3	1·40	85·2	1·38	61·30	1·27	64·8	1·29	44·30	1·20
262·5	97·2	1·38	90·3	1·34	66·50	1·25	68·2	1·26	49·40	1·19
300·0	102·0	1·34	95·4	1·32	71·60	1·24	71·6	1·24	51·10	1·17
337·5	107·4	1·32	98·8	1·30	74·98	1·22	75·0	1·22	54·58	1·16
375·0	110·8	1·295	102·2	1·27	80·10	1·21	77·5	1·21	57·90	1·15
Fe gms./cm.^{3}	0·0848		0·1056		0·0829		0·0798		0·0694	
Mn gms./cm.^{3}	0·7500		0·9344		0·7336		0·7062		0·6142	
Grain size in microns	476		264		185		143		114	

TABLE 2(*a*)

Variation of magnetisation density and permeability with field strength at various packing densities
(*Garividi ore* −20+40 *mesh*)

H Oersteds	Fraction 1.		Fraction 2.		Fraction 3.		Fraction 4.		Fraction 5.		Fraction 6.	
	$4\pi I$ Gausses	Permeability	$4\pi I$ Gausses	Permeability	$4\pi I$ Gausses	Permeability	$4\pi I$ Gausses	Permeability	$4\pi I$ Gausses	Permeability	$4\pi I$ Gausses	Permeability
0	69·7	..	52·3	..	34·9	..	22·2	..	15·05	..	10·00	..
37·5	100·9	3·90	91·6	3·4	65·3	2·74	47·9	2·3	45·08	2·15	30·85	1·82
75·0	148·1	2·97	117·6	3·20	91·5	2·22	69·7	1·93	69·70	1·92	47·95	1·64
112·5	182·9	2·63	148·1	2·32	113·2	2·09	82·8	1·78	82·80	1·74	60·98	1·54
150·0	217·8	2·45	174·3	2·16	139·4	1·93	101·6	1·72	101·90	1·67	69·69	1·48
187·5	248·3	2·32	196·0	2·05	156·8	1·84	122·2	1·65	113·2	1·60	82·77	1·44
225·0	274·5	2·23	217·8	1·98	178·6	1·82	139·4	1·63	126·30	1·577	91·47	1·41
262·5	300·5	2·15	235·3	1·90	191·7	1·73	156·8	1·60	139·40	1·53	101·90	1·38
300·0	318·5	2·09	252·6	1·84	209·0	1·70	173·8	1·58	148·10	1·49	108·90	1·36
337·5	335·8	1·99	270·1	1·80	217·8	1·65	182·9	1·54	161·20	1·48	117·60	1·35
375·0	339·8	1·89	283·1	1·75	226·6	1·60	196·0	1·52	169·90	1·45	122·00	1·33
Fe gms./cm.^{3}	0·35		0·32		0·2740		0·2125		0·175		0·134	
Mn gms./cm.^{3}	0·7968		0·73		0·6236		0·4837		0·3982		0·3050	

TABLE 2(*b*)

Variation of magnetisation density and permeability with field strength at various packing densities (*Garbham ore* $-40+60$ *mesh*)

H Oersteds	Fraction 1.		Fraction 2.		Fraction 3.		Fraction 4.	
	$4\pi I$ Gausses	Permeability	$4\pi I$ Gausses	Permeability	$4\pi I$ Gausses	Permeability	$4\pi I$ Gausses	Permeability
0	39·08	..	30·7	..	27·3	..	17·04	..
37·5	47·70	2·27	42·6	2·14	37·5	2·00	25·60	1·68
75·0	61·30	1·82	52·8	1·70	46·0	1·61	34·08	1·45
112·5	73·30	1·65	63·1	1·56	52·8	1·47	40·90	1·36
150·0	83·50	1·56	71·6	1·48	59·6	1·40	46·00	1·31
187·5	94·02	1·51	78·4	1·42	66·5	1·35	51·10	1·27
225·0	102·20	1·45	85·2	1·38	71·6	1·32	56·20	1·25
262·5	108·10	1·41	90·3	1·34	76·7	1·29	59·60	1·23
300·0	115·90	1·39	95·4	1·32	81·8	1·27	64·80	1·22
337·5	120·8	1·36	98·8	1·30	85·2	1·25	69·90	1·21
375·0	124·40	1·33	102·2	1·272	92·6	1·24	73·30	1·195

Fe gms./cm.^{3}	0·0825	0·0787	0·0742	0·0636
Mn gms./cm.^{3}	0·7000	0·6965	0·6566	0·5628

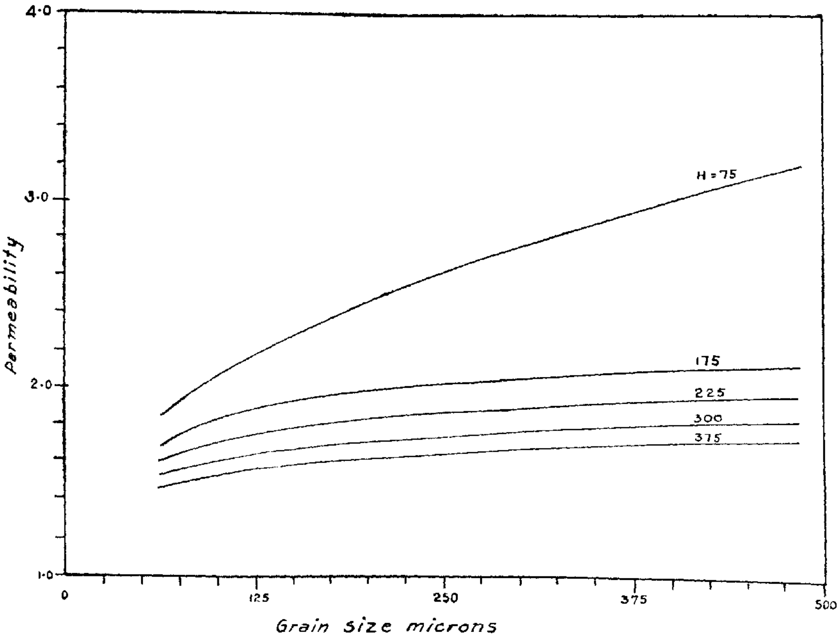

FIG. 2.

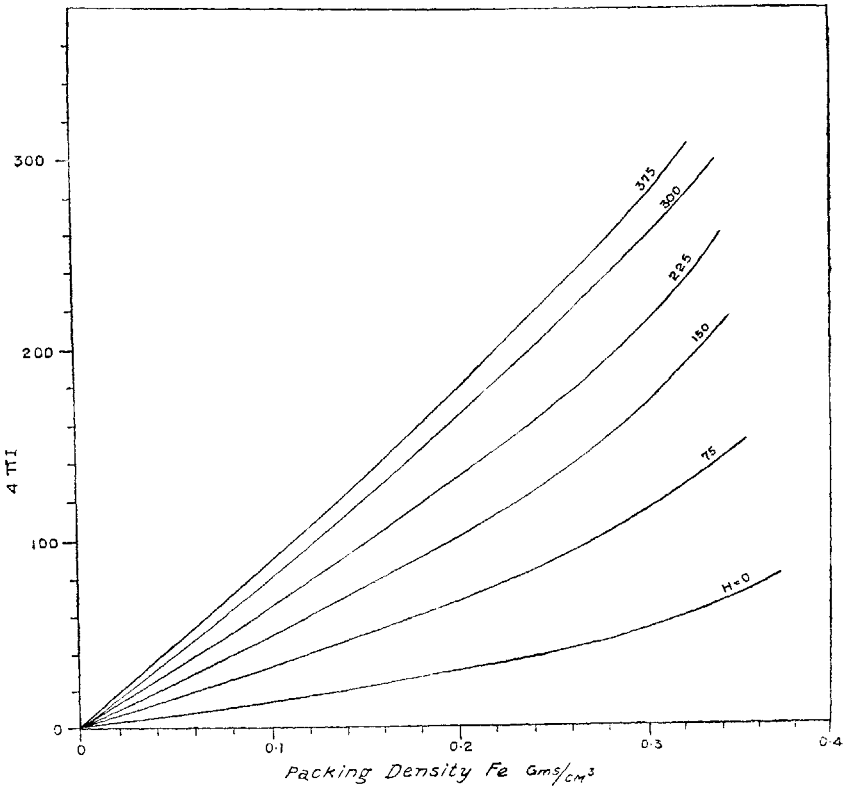
300
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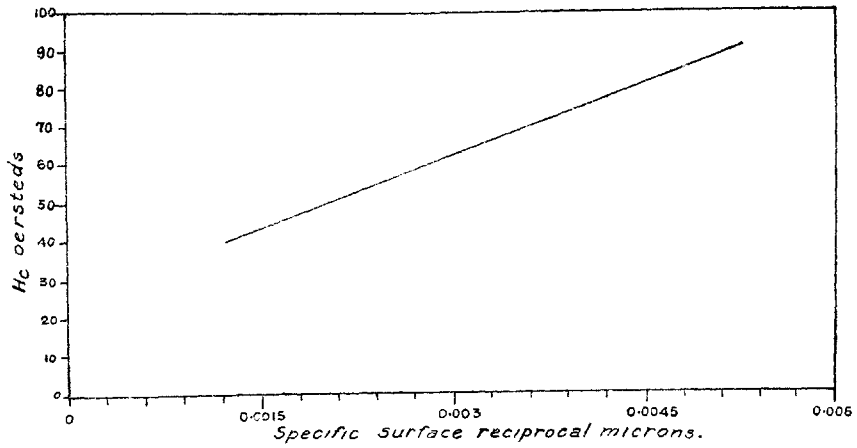
Fig. 3.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Specific surface reciprocal microns.

Fig. 4.

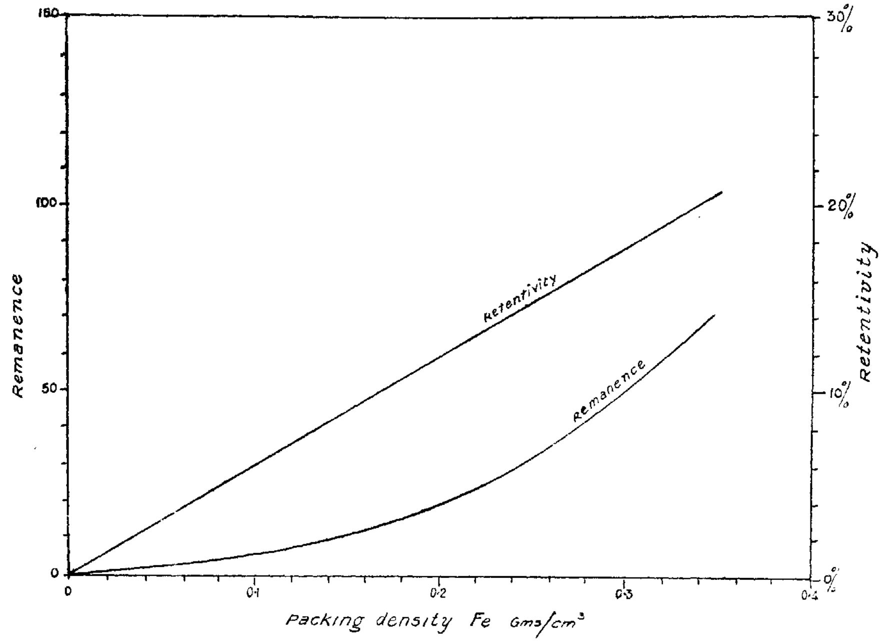

Fig. 5.

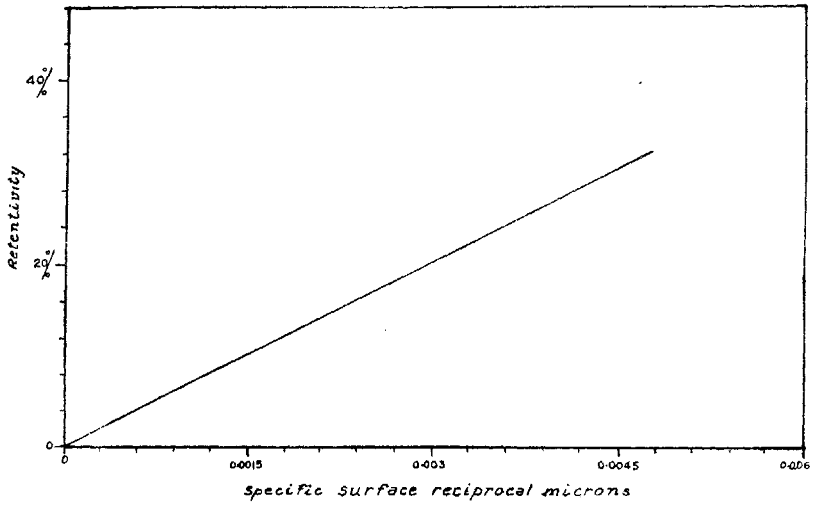

Fig. 6.

Table 3(*a*) gives the coercive force and remanence values for four fractions from Garividi and Table 3(*b*) for five fractions from Garbham. The average grain size in microns and the packing densities at which the measurements are made, are also shown in these tables.

TABLE 3(*a*)

Variation of coercive force, remanence and retentivity with grain size and packing density (Garividi ore samples)

Grain size in microns	Coercive force in Oersteds	Remanence in Gausses	Retentivity* %	Packing density Fe gms./cm.^{3}
476	50·0	52·3	13·0	0·4150
264	72·5	60·98	25·45	0·3200
211	82·0	60·98	32·0	0·1806
63	..	21·79	..	..

TABLE 3(*b*)

Variation of coercive force, remanence and retentivity with grain size and packing density (Garbham ore samples)

Grain size in microns	Coercive force in Oersteds	Remanence in Gausses	Retentivity* %	Packing density Fe gms./cm.^{3}
476	70·75	16·2	8·3	0·0848
264	71·25	22·7	12·5	0·1056
185	78·75	19·8	17·56	0·0829
143	84·40	20·5	23·1	0·0798
114	86·25	17·0	29·25	0·0694

As can be seen from the Tables 3(*a*) and 3(*b*), the coercive force increases as the grain size decreases and that this relation is linear can be seen by plotting the values of H_c against grain size. However, it is found more convenient (Gottschalk, 1935) to plot the coercive force against the specific surface of the powder. Specific surface is the area of the surface divided by weight. For spherical particles, it is $\pi d^2 \Big/ \frac{m(\pi d^3)}{6} = \frac{6}{md}$ and for cubic particles $6d^2/md^3 = 6/md$ where m is the density of the particle, d the diameter or the length of the side, as the case may be. The specific surface can thus generally be taken to be inversely proportional to the grain size (k/d).

The nature of the relationship between the coercive force and specific surface can be seen from the fig. 4 where the coercive force is plotted as ordinate against specific surface expressed in reciprocal microns. In fig. 5 is plotted the remanence against the packing density for the $(-20+40)$ mesh fraction from Garividi. The remanence increases with packing density and it is found that the retentivity expressed as $4\pi I$ at zero field divided by $4\pi I$ (max.) expressed per cent, is more linear with the packing density. The retentivity per cent is also plotted in Fig. 5.

A relation between specific surface (expressed in reciprocal microns) and retentivity is shown in fig. 6 after correcting for the variation of packing density. It can be seen from figure 6 that retentivity is a linear function of the specific surface.

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* This column gives the retentivity per cent after reducing for fixed packing density (Fe is 0·32 gms./cm.^{3} for Garividi ore and 0·0694 for the Garbham ore).

DISCUSSION ON RESULTS

The results obtained are summarised as follows :—

(1) The permeability decreases as the field strength increases;
(2) The coercive force increases with decrease in particle size;
(3) The remanence increases with decrease in particle size ; and
(4) With the packing density, the remanence and the intensity of magnetisation both show an increase.

The above results are in conformity with those of earlier workers (Gottschalk and Wartman, 1935).

In the curve showing the variation of permeability with grain size at 40 microns a sudden increase in permeability is observed by Gottschalk and Wartman (1935). This sudden kink is predominant between thirty to hundred oersteds and above that field, the permeability curve is almost horizontal to the grain size axis. In the present investigation the minimum grain size obtained is only 114 microns in the case of the Garividi ore and 63 microns in the case of the Garbham ore. Smaller grain sizes could not be obtained as the proper sieves are not available. So the knee in the permeability grain size curve, which is predominant in Gottschalk's measurements cannot be expected to appear in the curves of the present investigation.

The dependence of the coercive force on the grain size has been proved by the dispersion theory (Dean, Gottschalk and Davis, 1934) of magnetic hardening and also by the magnetic measurements of Nagaoka (1896) on iron amalgam. The observed decrease in coercive force with increasing grain size constitutes additional evidence in favour of the above-mentioned dispersion theory.

The linear variation between retentivity and specific surface is significant and is in conformity with the results of Gottschalk (1935).

These values of magnetic hysteresis measured at low fields represent the lower limits, since the saturation has not been obtained. Another apparatus working on the same principle and suitable for measurements at saturation fields of approximately 1,500 oersteds has been constructed and, it is hoped, it will yield more interesting results.

The nature of the relation of heat treatment and chemical composition to magnetic properties of these ores is also under investigation and the results will be published shortly.

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ABSTRACT

The magnetisation properties of ferruginous manganese ores of Garividi and Garbham mines of Visakhapatnam district have been examined initially, to investigate the possibilities of developing a method for separation of these ores by alternating current magnetic techniques. The method of measurement used here is the oscillographic technique of Bruckshaw and Rao. The results obtained show, in conformity with those of earlier workers, that the hysteresis properties of the mineral powders are susceptible to development, modification and control through the development of the interfacial area of the powders.

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