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HEAVY MEDIA SEPARATION IN AGGREGATE BENEFICIATION

by

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ABSTRACT

The importance of using high quality aggregates in concrete and road construction is now well recognized. More rigid aggregate specifications and depletion of existing resources, however, have created a serious supply problem in many areas. Beneficiation of poor quality sand and gravel by use of heavy media separation has proved a remedy in a number of cases.

A laboratory investigation is described which illustrates both benefits achieved and problems encountered in heavy media separation of gravel aggregate. Aggregate evaluation studies were completed on the gravel before and after heavy media separation (HMS), including petrographic examination, physical tests, and concrete durability studies. Concrete beams containing the aggregate products were exposed to accelerated freezing and thawing for a period of about 700 cycles between 0 and 40°F. Separations were made at media densities of 2.51 and 2.55 on a feed sized between 1/4 and 1 1/2 in. The chief deleterious constituents proved to be argillaceous limestone, clay and shale, and highly weathered schists. The argillaceous limestone was found particularly troublesome to remove by HMS because of porous weathered surfaces and sound interiors.

Results of the investigation showed that it was possible to obtain a marked improvement of the aggregate by HMS. However, sufficient deleterious constituents remained in the beneficiated product to render questionable its use in concrete exposed to water saturation and freezing conditions.

Heavy media separation has proved an inexpensive and effective method of improving the quality of gravel aggregate since it was first used commercially for this purpose in 1948, and its use is expected to increase greatly as demand for high quality aggregates grows. The results of the investigation reported herein serve to show the importance of careful laboratory study before a decision is reached on the applicability of HMS to a particular problem.

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*This bulletin, in essence, was presented as a paper at the Fourth Triennial Mineral Conference, held at the University of Otago, Dunedin, New Zealand, September 1-3, 1959.

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INTRODUCTION

The need for high quality aggregates to provide long-lasting durable structures of adequate strength is recognized. Many years of research and study of service records have shown that a large proportion of concrete deterioration can be attributed directly to certain characteristics of the constituent aggregates, namely, high absorption, surface coatings, structural weakness, and chemical reactivity when related to environmental conditions. The same may be said to some degree for aggregates used in bituminous road construction and other applications. As a result, specifications for aggregate have been tightened, and this, coupled with a greatly increased demand, has created a serious supply problem in many instances. Sources of suitable sand and gravel near centres of population have become depleted. This situation has become further aggravated by zoning restrictions of cities and municipalities which have placed otherwise suitable deposits out of bounds.

The solutions to the problem of satisfactory sources of aggregate, depending on location, have been to go farther afield, to use crushed stone where available, or to improve the quality of inferior sands and gravels by the removal of deleterious constituents. It is mainly this last field, or the beneficiation of gravel by heavy media separation, that is dealt with in this bulletin. The contents are based on Canadian, and to some degree on American, experience and practice in aggregate production, as well as on laboratory research.

AGGREGATE CONSUMPTION

It is appropriate at this point to emphasize the importance of aggregate processing by considering very briefly some consumption figures and trends in the use of aggregates in North America. In Canada, total production of aggregates of all types for 1957 amounted to 193 million tons, valued at $137 million. This is more than four times the production of ten years ago. Of the total 1957 production, close to 20 percent consisted of crushed stone. For the same year, production in the United States, as reported by the Bureau of Mines, was 627 million tons of sand and gravel and 439 million tons of crushed stone. Consumption of aggregates in both countries has increased almost continuously each year since World War II.

The great expansion in the aggregate industry since the war can be accounted for by large increases in all types of construction. In Canada, total value of construction jumped from $3280 million in 1950 to $7231 million in 1958, according to the Dominion Bureau of Statistics. Of the total value of construction, the portion being spent for roads is worthy of special mention - in 1958 it was in excess of $1000 million. In the United States current spending on roads is running at the rate of about $6000 million per year. Cement production in Canada has grown 2.5 times over the past ten years to more than six million tons in 1958. This also serves to indicate the greatly increased amounts of concrete aggregate now required.

These figures are sufficient to draw attention to the fast rate at which our aggregate deposits are being depleted. The supply of suitable raw materials for aggregates varies geographically, of course, but it is generally true that scarcities occur in the industrialized areas where they are needed most. In a number of cases, the use of heavy media separation to improve the quality of inferior gravel to meet specifications for both road and concrete aggregate has overcome a serious problem and resulted in reduced costs of construction by eliminating high transportation charges of aggregate from distant points.

DELETERIOUS CONSTITUENTS IN AGGREGATES

The need for aggregate beneficiation is, of course, first determined by the use of several different acceptance tests, including petrographic examination. Those most commonly used are the sulphate soundness, abrasion, absorption, and accelerated freeze-thaw tests, all of which are well known and are described in American Society for Testing Materials (ASTM) procedures.[1]

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[1] References are listed at the end of the paper in the order in which they are numbered in the text.

These and other such empirical tests are used to reject or accept aggregates according to local specifications, but they do not tell what the deleterious constituents consist of. To obtain this information a detailed petrographic examination must be made in which the mineral and rock constituents are determined, together with certain of their properties. It is then possible to assess the possibilities of various methods of removing the undesirable constituents contained in the raw materials.

The deleterious constituents in aggregates have been classified in a number of ways, and more often than not by simply naming them, e.g., coal, clay lumps, opal, soft fragments or material finer than 200 mesh. One of the more recent classifications, which appears to be the most comprehensive and useful, is that proposed by Swenson and Chaly,[2] shown in Table 1. It will be noted that the deleterious constituents are classified by characteristics, divided into two main classes, physical and chemical.

For heavy media separation to be effective it must be possible to separate the deleterious constituents from the sound aggregate on a gravity basis. Fortunately, many of the materials which have been found to be deleterious in concrete have a lower specific gravity than good quality aggregate. Among these are many shales, clay lumps, unsound cherts, coal, highly porous and weathered rocks, and organic materials. Some specific examples investigated at the Mines Branch are described further on.

TABLE 1

Deleterious Characteristics of Concrete Aggregate Materials*

Physical		Chemical	
External	Internal	Reaction With Cement	Independent of Cement
Encrustations	Undesirable pore characteristics	Alkali reactivity	Oxidation
		Organic impurities	Hydration
Highly weathered surfaces	High volume change with wetting-drying	Salt impurities	Carbonation
			Air-entraining impurities
Highly polished surfaces	Lamination and cleavage	Base exchange	
			Solubility
Undesirable shape	Soft and weak particles		
Extreme fineness	Unfavourable thermal expansion		

*From Swenson, E.G., and Chaly, V., "Basis for Classifying Deleterious Characteristics of Concrete Aggregate Materials". Jour. American Concrete Institute, vol. 27 (1956), No. 9, pp. 987-1002.

METHODS OF AGGREGATE PROCESSING

After having determined the type and amount of deleterious constituents to be removed in upgrading the aggregate to meet specifications, there remains to consider how this may be done. The treatment given coarse aggregate differs in most cases from that given the sand, as a consequence both of the size difference and of the relative amounts of deleterious constituents in each fraction; investigations have shown extreme cases where the sand differed markedly in composition from the coarse aggregate. In some cases the sand was of such good quality that it could be used directly in concrete without any treatment other than classification, whereas, in other cases, unsound material constituted such a high proportion of the sand that all of it had to be wasted.

If the material to be removed from gravel consists of clay lumps, soft weathered particles, or particles with easily removed coatings, it may be that revolving scrubbers or log washers will prove suitable. If, however, coal, lignite, some varieties of chert, porous rock particles, shale, or other low-specific-gravity but relatively hard materials are present, heavy media separation is the best solution to the problem. It may well be that heavy media separation should be preceded by scrubbing or log washers. In any case, washing on a 10 mesh to 3/8 in. screen is essential to remove fine sand and clay which would interfere with the proper operation of the heavy media separation.

The beneficiation of sand, until very recent years, has been accomplished entirely by various classification methods which amounted to simply washing and a certain amount of attrition. Within the last five years, jigs[3] have come to play an important role in removing unsound constituents of low specific gravity. Very recently, the first heavy media separation application to the treatment of sand was reported.[4] However, it has been applied only to the coarser sizes, i.e., 1/4 to 1/8 in.

HEAVY MEDIA SEPARATION

The first application of heavy media separation to the removal of unsound constituents in gravel was at Rivers, Manitoba, in 1948, on a construction project for the Royal Canadian Air Force.[5] Gravel deposits in the area contained from five to 20 percent shale, and up to 10 percent weathered granite. Both of these constituents were determined as deleterious for use in concrete for runway construction, so an alternate material had to be considered. The nearest source of a known good quality aggregate was at Winnipeg, 165 miles away, which meant a transportation cost of $2.81 per cu yd. One of the officers in charge of the project, J. D. Shannon, who had a mining engineering background, suggested applying the heavy media separation process, well known in the mineral dressing field, to the problem. Preliminary laboratory tests proved the feasibility of the process and subsequently a Wemco No. 3 Mobil-Mill unit was placed in operation. Since 1948, about 20 heavy media separation plants have been installed in Canada and the United States for the beneficiation of aggregate.

Types of Equipment

There are at least four types of equipment which incorporate the heavy media principle of operation. Diagrams of these are shown in Figure 1. In each type of equipment a medium is circulated consisting of a suspension in water of finely ground high gravity solids, such as magnetite or ferrosilicon. The effective specific gravity of the medium is controlled by altering the type and proportions of the solids. Most gravel operations use specific gravities of media between 2.4 and 2.6. Brief descriptions of the common types of heavy media separation equipment follow:

1. Drum, Western Machinery Company.

In the Wemco drum separator the medium is circulated through a horizontal rotating drum. The feed entering at one end either floats through to discharge on a vibrating screen at the opposite end, or sinks and is collected by lifters fastened to the inside of the drum which discharges the sink product into an inclined launder running the length of the drum. The sink is flushed down the launder by the medium to the same screen as the float, but division of the screen throughout its full length keeps the sink and float separate. Underneath the screen are tanks to catch the medium, which is recirculated through the system by pumps. The aggregate is washed on the lower portion of the screen. The washings are circulated to a magnetic separator for recovery of the medium, then to a de-watering screen to densify it, finally to a demagnetizing coil, and back to the drum separator.

2. Cone, Western Machinery Company.

In this case, the separating vessel is a cone. The sink passes to the bottom or apex of the cone and is removed by a down-pipe and then elevated by air-lift to a screen system as described for the drum. The float passes to the periphery of the cone and is overflowed to a tangential launder and then to the same screen as above. A mechanism is rotated in the cone to assist in keeping the solids in suspension.

3. Spiral-type Separator, Colorado Iron Works Company.

This is simply an Akins spiral classifier in which heavy medium is circulated. The sink is removed by the screw at the top of the machine and the float passes over a side weir.

4. OCC Vessel, The Ore and Chemical Corporation.

The feed is introduced at one side of the vessel, and the float is carried across and discharged over a weir on the opposite side. The sink going to the bottom is removed at the other two sides by an oscillating, pendulum-type rake. Barrier screens near the sink discharge sides of the tank prevent float from being discharged

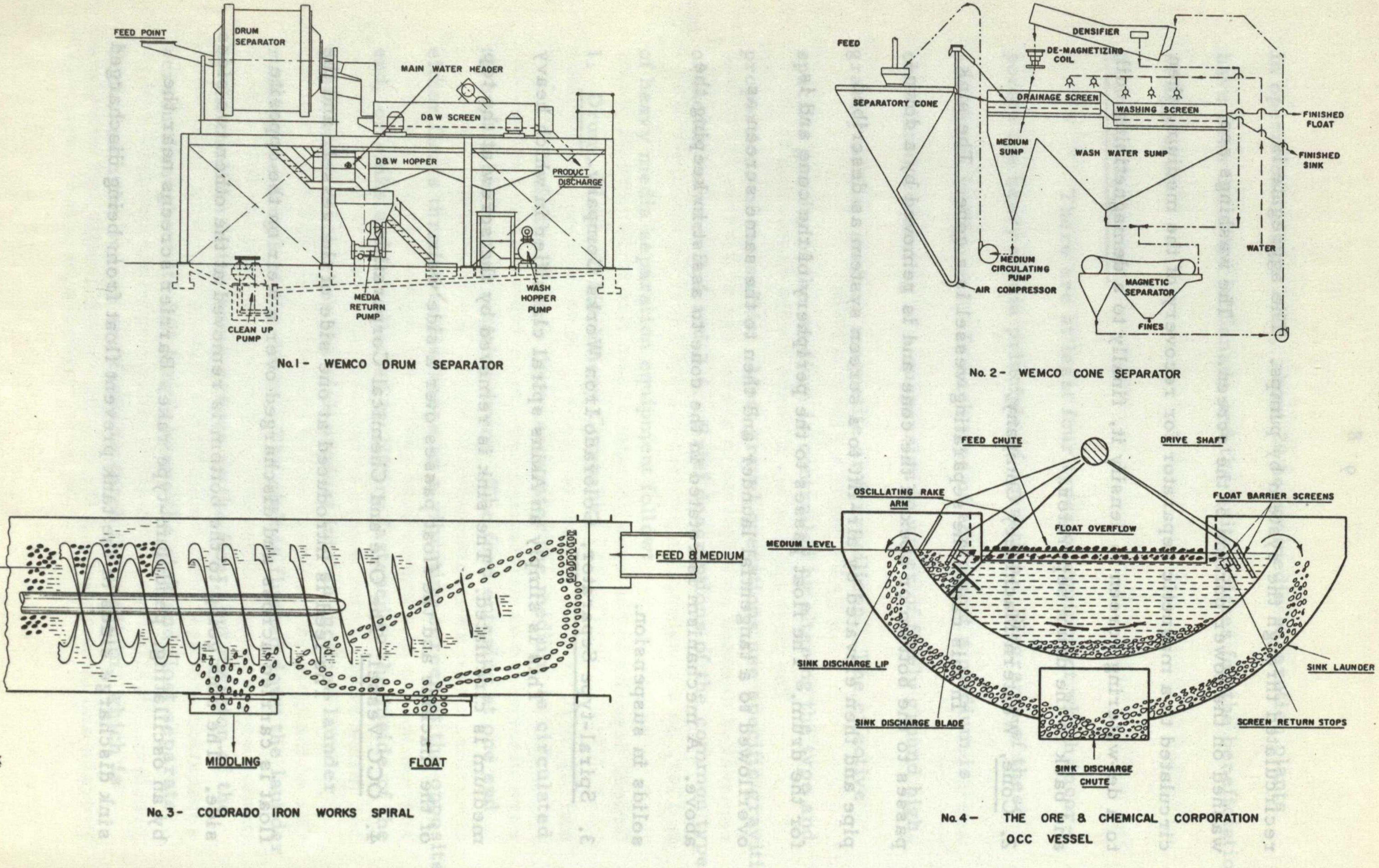

Figure 1. - Types of Equipment

with the sink. The cross-section of the vessel is semi-circular, to permit removal of the sink product at the bottom of the vessel by the oscillating rake.

There are other shapes and mechanisms of heavy media units, but those described are believed to be the most common.

According to company literature the Wemco cone, rather than the drum, is used in cases where the difference in specific gravity between the sound and unsound constituents is small. The greater area, depth, and separating volume of the cone allow greater retention time for the separation to take place. It should be noted that compressed air has to be supplied to provide an airlift to raise the sink, and that capacity per unit of separating volume is less than for the drum. Up to early 1958, eight drums were placed in operation compared to four cones.

Feed Preparation

Screening and washing are necessary before introducing feed to heavy media separation. The lower limit of feed size in most aggregate plants is 1/4 in., and the upper limit is usually governed by aggregate requirements which are normally not above three inches. Washing is necessary to avoid contaminating the circulating medium with clay and fine sand which increase viscosity and decrease efficiency of separation.

LABORATORY INVESTIGATIONS

Several pilot plant heavy media separation investigations have been conducted during the past few years in the laboratories of the Mines Branch in Ottawa. One, completed in 1955, resulted in the adaptation of the process at the Beechwood power dam project in New Brunswick.(6) Several have been undertaken for industry in western Canada, and one has just been completed for the Quebec Hydro-Electric Commission in connection with a power development on the lower Ottawa river. These investigations were carried through from the initial appraisal of the raw materials, to the processing by HMS, and to the final evaluation of the concrete made with the treated aggregate.

DETAILS OF A REPRESENTATIVE PILOT PLANT HEAVY MEDIA SEPARATION INVESTIGATION AT THE MINES BRANCH LABORATORIES (POINTE FORTUNE, P.Q., COARSE AGGREGATE)

A description of the Quebec Hydro investigation will illustrate the general approach used, the problems, and the results achieved. The location of the projected power development is at Carillon, about 70 miles down river and southeast of Ottawa. Substantial gravel deposits occur near the dam site at Pointe Fortune, but field examination indicated the presence of unsound constituents. The Commission requested an investigation to determine the feasibility of heavy media separation to remove the unsound constituents, and also, durability studies of concrete containing the treated gravel as aggregate. This work was started in September 1958 and completed in April 1959.

Evaluation of Aggregate Received

A 2-ton sample of sand and gravel obtained from the deposit consisted of material ranging from sand size to boulders up to eight inches or more in diameter. The sample was quartered to obtain representative portions for physical acceptance tests and petrographic examination. The sand was removed, as only the plus 4 mesh material was of interest for the investigation. The gravel was crushed and screened through 1 1/2 in. to provide the maximum permissible feed size for the pilot-plant heavy media separator.

1. Petrography

The results of the petrographic examination are shown in Table 2. The sample was first sized and the petrographic examination conducted on each of the fractions. The results shown, however, are for the composite sample, the rock types being grouped to include minor amounts of related materials.

TABLE 2

Petrography of the Pointe Fortune Coarse Aggregate

Rock Type	%	Description	Remarks
Limestone	53	Fine-grained, dark-grey, dense, tough, sub-rounded	Satisfactory
Argillaceous limestone	17	Soft and porous at and near surface, with hard, sound interiors	Doubtful
Clay lumps and shale	9	Soft clay lumps and weathered shaly fragments	Deleterious
Porous sandstone	4	Medium-grained, buff, impure, porous	Fair
Granitic rocks	16	Medium-grained, pink granite and gneisses; hard and tough	Satisfactory
Decomposed schists, etc.	1	Highly weathered, friable, of low strength	Deleterious
	100		

An examination of Table 2 will show that only 69 percent of the gravel--the limestone and granitic rocks--is considered satisfactory. The porous sandstone is not likely to cause trouble, but the clay, shale, and decomposed schists are highly deleterious for any use, and portions of the argillaceous limestone are certainly unsound and likely to prove troublesome.

Partly altered particles, such as the argillaceous limestone type described in Table 2, present a difficult problem for HMS alone, but scrubbing before HMS may prove adequate if the altered material is soft and easily removed.

2. Physical Acceptance Tests

The usual acceptance tests carried out on gravel aggregates include: sulphate soundness, absorption, and Los Angeles abrasion. The results of these tests are compared, in Table 3, with the maximum permissible limits commonly specified. The tests were conducted according to ASTM standard procedures. The gravel on which the tests were conducted consisted of the crushed and screened material between 3/4 in. and 4 mesh. A portion of the deleterious materials described in Table 2 was removed in the course of crushing and screening.

TABLE 3

Acceptance Tests on Pointe Fortune Gravel as Received

Test	Results	Range of Specifications
Magnesium sulphate soundness	18.2% loss	Permissible loss, 12-15%
Absorption	2.86%	1- 2%*
Los Angeles abrasion, 'A' grading	38.4% loss through 10 mesh	25-35%*

*Aggregates for surface courses in highway construction.

It is evident, from these tests, that the gravel does not compare favourably with aggregates generally considered suitable for concrete and road construction.

Preliminary Test Work

Preliminary test work with heavy liquids, or an Ericksen cone[7] (shown in Figure 2), should be conducted prior to a full-scale pilot plant run. This permits an initial evaluation of the HMS process on small samples, and assists in determining operating conditions for the pilot plant. Using heavy liquids, any specific gravity between 2.96 and 1.59 can be obtained by mixing tetrabromoethane with carbon tetrachloride. Heavy liquids are particularly useful when dealing with sand below 4 mesh in size. Sink and float products can be examined petrographically at several different gravity separations to determine at

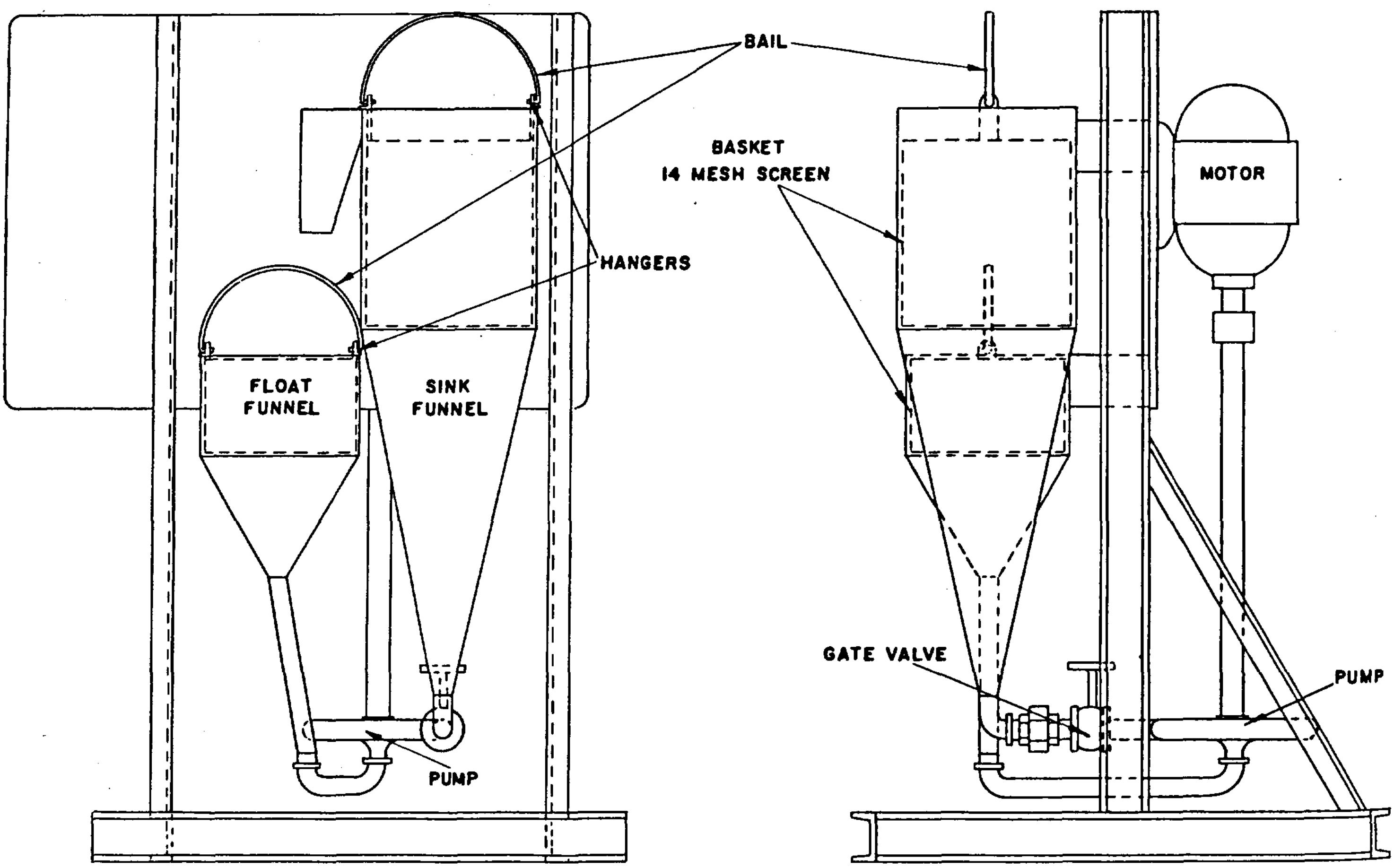

Figure 2. - Ericksen Cone.

what point the deleterious constituents are floated. The Ericksen cone is more suitable for handling larger samples and uses the same media as do the larger pilot plant and commercial units. It should be noted, in its use, that the upward surge of medium in the sink cone where the separation takes place contributes an increment of effective specific gravity to the actual specific gravity of the media. Normally an allowance of about 0.15 is made, which means an effective specific gravity of 2.60 using a medium specific gravity of 2.45. Preliminary tests with the Pointe Fortune gravel indicated that the media density should run between 2.50 and 2.55 to remove an appreciable amount of the unsound constituents and at the same time achieve a reasonable recovery.

<u>Pilot Plant Runs</u>

The pilot plant runs were made in a Wemco 20 x 36 in. drum separator. It is essentially the same as a commercial unit in all respects except size. No arrangement is made, however, for cleaning the media, as this is not considered necessary for runs of two or three days or less, such as are normal in pilot plant work. The cone under the first section of the screen receives the media circulated through the drum and most of the media which drain off the sink and float products. The second cone catches the washings resulting from the cleaning of the products by high pressure water jets. These washings contain some media that are wasted in laboratory work, and additions of fresh media are made to compensate for these losses. A 3-hp solids pump circulates the media from the first cone around through the drum, with a portion going directly to the launder inside the drum to help flush the sink product out and on to the screen. The screen is divided longitudinally to separate the sink from the float.

The preparation of the feed consists of sizing between 1 1/2 in. and 4 mesh, with careful washing to avoid contamination of the media.

The operation of the HMS drum unit is very simple, although the laboratory unit with its small volume of circulating media is sensitive to changes caused by losses of media or by addition of water in the feed. Checks are made about every 20 minutes on the specific gravity, by weighing a known volume on a tared balance, and adjustments are made, as necessary, by small additions of fresh media. The feed rate is normally maintained at about 500 lb per hour, but this could probably be increased to 1000 lb or more per hour, without any difficulty, if the size of feed was reduced slightly. The speed of drum rotation is important--too high a speed results in "eddy currents" within the drum and in a sideways motion of the float, which should pass directly through and out the other end. The rotation must be fast enough to remove the sink and provide sufficient agitation to keep the media in suspension. The unit can be shut down over-night without draining the drum, although the pump and valves below the cones are kept free of settled media by draining. If the wet medium is stored in drums or tubs for several days, lime is added to keep the solids dispersed.

In this investigation, the media consisted of 50 percent magnetite and 50 percent ferrosilicon in water, to provide an initial specific gravity of 2.55, which was later reduced to 2.51. It has been found quite easy to control the specific gravity within ± 0.01 in the laboratory. Up to specific gravities of 2.40, magnetite alone is adequate and costs about $40.00 per ton in Ottawa, compared with $130.00 per ton for ferrosilicon. Above 2.40 and up to 2.80, increasing proportions of ferrosilicon are used, and at 2.80 or higher, ferrosilicon alone is used. However, a media specific gravity of over 2.60 would rarely be used in the beneficiation of gravel. The size distribution of the media is also important--on the one hand, fine sizes result in more viscous conditions and poor separation, and on the other hand, the coarser sizes settle out at a faster rate, resulting in high differentials of specific gravity between the upper and lower parts of the separating pool. Different mixtures of the gradings shown in Table 4 have been used with success in pilot plant work, higher proportions of the coarser grade, A, of ferrosilicon being used for the higher specific gravities.

TABLE 4

Grading of Solids in Heavy Media

Mesh	Magnetite % Retained	Ferrosilicon % Retained	
		A	B
On 48	-	3.5	-
65	-	11.0	2.0
100	1.7	15.0	5.0
150	2.7	15.0	15.0
200	15.3	11.0	17.0
325	32.6	17.5	28.0
-325	47.7	27.0	33.0

Evaluation of Results

The results were evaluated in terms of the physical acceptance tests and the petrographic examination, and by making concrete beams with the HMS products as aggregates and exposing them to accelerated freezing and thawing, noting the deterioration of the concrete with continued exposure.

TABLE 5

Distribution of Sink-Float Products

Spec. Gravity of Separation	% Sink	% Float
2.51	83.0	17.0
2.55	57.5	42.5

The figures given in Table 5 show that recovery of sink drops off rapidly with an increase of media specific gravity above 2.51.

1. Petrography

The composition of the HMS feed, described in Table 6, is slightly different from that of the head sample as reported in Table 2. This is accounted for by the crushing and screening that the gravel received prior to its preparation for feeding to the heavy media separator.

TABLE 6

Petrographic Description of Sink-Float Products

Rock Type	HMS	G = 2.51		G = 2.55	
	Feed %	Sink %	Float %	Sink %	Float %
Limestone	55	58	41	66	40
Argillaceous limestone	15	15	15	8	25
Clay and shale	10	4	38	4	18
Porous sandstone	4	5	0	4	5
Granitic rocks	15	17	6	18	10
Decomposed schists, etc.	1	1	0	-	2
	100	100	100	100	100

An examination of the sink columns in the above table shows that some unsound and doubtful material remains in the beneficiated product. It is also apparent that there is a considerable loss of sound constituents in the float.

2. Physical Tests

The sulphate soundness test was conducted according to ASTM procedure C88-56T, using five cycles in magnesium sulphate solution. The samples consisted of sized fractions of aggregate between

3/4 in. and 4 mesh. The loss reported in Table 7 is a weighted loss for the graded aggregate used in the concrete.

The Los Angeles abrasion loss test (ASTM, C131-55) was carried out using a 'B' grading - 2500 grams each of 3/4 - 1/2 in. and 1/2 - 3/8 in. sized gravel.

The absorptions were measured on a 24 hr immersion basis according to ASTM procedure C127-42.

TABLE 7

Results of Physical Tests on Sink Products, Compared with Feed

	Feed	Sink at G =.2.51	Sink at G = 2.55
Sulphate soundness loss, %	18.2	13.4	7.5
Los Angeles abrasion loss, %	38.4	30.2	30.1
Absorption, %	2.36	1.50	1.42

The benefit achieved by HMS is readily apparent on the basis of the results of the tests shown in Table 7. Both sulphate soundness loss and absorption have been reduced sufficiently at a media specific gravity of 2.51 to meet most specifications for aggregate in concrete and roads. Further improvement can be obtained by making the separation at a media specific gravity of 2.55, but at considerable expense in recovery. The Los Angeles abrasion loss has also been reduced appreciably and would probably meet most highway specifications.

3. Concrete Durability Evaluation

The most revealing method of evaluating aggregates for colder climates is to use them in concrete exposed to accelerated freezing and thawing. Standardized concrete mixes are used for this purpose in order to relate any variations in performance of the concrete to the quality of the coarse aggregate.

In this investigation the 3 1/2 x 4 x 16 in. concrete beams containing the aggregates under investigation were exposed to about 700 cycles of freezing and thawing. The beams were examined and tested during and at the end of the exposure, by (1) noting the surface deterioration in the form of 'pop-outs', (2) weight change, (3) change in ultra-sonic pulse velocity, (4) compressive and flexural strengths compared with standard moist-cured specimens of the same age, and (5) microscopic examination of sections of the exposed concrete.

Mix data and the concrete strengths and densities are given in Table 8. Results of the freezing and thawing are shown in Table 9, which also gives the percent decrease in compressive and flexural strengths of the exposed beams as compared with companion moist-cured beams.

TABLE 8

Concrete Proportions and Strengths

	Coarse Aggregate			
	Std Gravel[1]	Pt. Fortune[2] Gravel	Sink at G = 2.51	Sink at G = 2.55
Cement, lb/cu yd	486	484	491	490
Sand, lb/cu yd	1186	1135	1152	1150
Coarse aggregate, lb/cu yd	2110	1975	2044	2062
W/C Ratio	0.53	0.53	0.53	0.53
Slump, in.	2.00	2.00	1.75	2.00
% Air	3.0	6.0	4.5	4.7
lb/cu ft 103 d	152.3	148.2	151.1	149.8
Comp. str., 103 d psi	5070	4720	4900	4785
Flex. str., 103 d psi	850	725	825	806

1-High-quality gravel of known performance.
2-Sample as received after crushing and screening.

The properties of the hardened concrete are given at 103 days because it was at this point that the freezing and thawing cycles were ended and all specimens, both standard cured and exposed, were broken.

TABLE 9

Results of Freezing and Thawing Concrete Beams

	Coarse Aggregate			
	Std. Gravel	Pt. Fortune Gravel	Sink at G = 2.51	Sink at G = 2.55
Number of 'pop-outs'	64	186	87	115
Wt. change, %	-0.31	+0.27	+0.17	+0.17
E_d, % loss[1]	1.2	15.6	13.1	11.1
% Loss in comp. str., psi	25	22	23	21
% Loss in flexural str., psi	34	64	65	55
Internal failures[2]	30	290	177	101

1- E_d - dynamic modulus of elasticity calculated by using Poisson's ratio of 0.24

2- Internal failures represent number of aggregate failures, bond failures, and cracks in mortar as determined on eighteen 3 1/2 x 4 in. beam sections by microscopic examination.

The plus values in weight change shown in the table are explained by the absorptive aggregates taking in water as the cycling progressed. It is particularly interesting to note the small difference in loss of compressive strengths between all four aggregates after the freeze-thaw exposure. The differences in loss of flexural strength are more indicative of the aggregate quality. All other results shown in both Tables 8 and 9 indicate the degree of improvement in aggregate quality achieved by heavy media separation.

Whether the beneficiated aggregate in this investigation is of suitable quality for exposed concrete structures is questionable, and at the time of this writing is still under study. The problem of removing all deleterious constituents from the Pointe Fortune gravel by HMS proved to be very difficult, as may be seen from the results described. However, the investigation serves to illustrate several features of interest in the process, not excluding its limitations. Other gravels investigated have proved to be completely amenable to heavy media separation, all unsound constituents having been more or less completely removed by this gravity process.

COMMERCIAL INSTALLATIONS

From the beginning of its use in the aggregate industry, in 1948, heavy media separation has come to be widely accepted in Canada and the United States as an effective and inexpensive method of beneficiating aggregate. One equipment company reports that it had installed 15 HMS units for this purpose up until 1958, and it is known that a number of others are in operation.

Operating costs are of particular interest. Losses of medium are reported to run about 1/3 lb per ton of feed, which would result in a cost of 3 1/2 to 4 cents for a medium composed of 50 percent each of ferrosilicon and magnetite. Total operating costs vary between 12 and 20 cents per ton, depending on size of unit; the lower figure for operations of 250-300 tons per hour, and the upper for 50-60 tons per hour. Commercial operators are able to command a premium price of

25 percent above normal for HMS beneficiated aggregate in some areas, and in addition they can market the float product for applications not requiring sound aggregate.

CONCLUSIONS

With the greatly increased rate of consumption of aggregates in recent years, and the problem of facing tougher specifications, aggregate beneficiation has become a necessity in a number of areas. The use of heavy media separation has proved to be the solution to many such problems and its use will no doubt increase greatly in the future. However, careful laboratory investigation of each problem should be made before a decision is reached on the applicability of the heavy media separation method.

ACKNOWLEDGMENTS

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REFERENCES

1. American Society for Testing Materials Standards, Vol. 4, Aggregates, 1958.

2. E. G. Swenson and V. Chaly, Basis for Classifying Deleterious Characteristics of Concrete Aggregate Materials. Jour. American Concrete Institute, vol. 27 (1956), No. 9, pp. 987-1002.

3. W. L. Price, Current Developments in Gravel Beneficiation. Mining Congress Journal, Nov. 1957, pp. 68-73.

4. W. B. Lenhart, HMS for Sand Pioneered at Glen Canyon. Rock Products, vol. 62, No. 5 (May, 1959), pp. 134-141.

5. C. V. Trites and J. D. Shannon, Acceptable Aggregates from Low Grade Deposits. Rock Products, vol. 53, No. 2, Feb. 1950.

6. I. D. MacKenzie, Heavy Media Processing of Gravels. Jour. American Concrete Institute, vol. 30 (1958), No. 1, pp. 133-138.

7. S. E. Ericksen, How to Simplify Testing for Sink-Float Separation. Engineering and Mining Journal, vol. 152, No. 6 (June 1951), pp. 88-89.

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