Holbrook.

A Study Of Screen Sizing With Special Reference To Illinois Mining Practice.

A STUDY OF SCREEN SIZING WITH SPECIAL REFERENCE TO ILLINOIS MINING PRACTICE

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A STUDY OF SCREEN SIZING WITH SPECIAL REFERENCE TO ILLINOIS MINING PRACTICE.

I. INTRODUCTION

That branch of mining engineering which concerns itself with the preparation of mineral for the market in a more concentrated form or more available state than in which it was mined is called ore dressing, of which coal preparation is a part. In ore dressing it is axiomatic that the ore must be separated into a series of sizes during or subsequent to crushing and before it is treated for separation of valuable mineral from the waste or gangue rock. In coal preparation, market convenience, custom and efficiency in combustion compel the separation of the mined coal into various sizes, even though no subsequent separation of coal from contained refuse is attempted. All ore dressing and coal preparation plants consequently contain screening or sizing apparatus.

For such an important subject the published literature is meager. It is true that considerable data are available for certain screens used under the special conditions found in ore dressing. Concerning their use in modern coal preparation practice, most of the information published has been as scattered articles in the mining press during the last ten years and often as a partly disguised advertisement of some manufacturer of the particular screening machinery described.

The writer for a number of years had experience in operating various screening devices and was able to observe at first hand foreign practice, later he carried out experimental work relating to screen sizes and ratios. During the past three years

he has spent part of his time studying coal preparation in Illinois under the direction of the Mining Department and the Engineering Experiment Station of the University of Illinois. Considerable data relating to screening practice has been gathered first hand in this work.

The intent of this thesis is to outline the present practice in screening coal, especially in Illinois, supplemented by such theoretical considerations as are necessary to illustrate basic points of design and operation. Since most coal preparation apparatus, including screens, have been evolved from similar appliances first applied in ore dressing, the discussions may rightly include references and data concerning screens used in ore dressing, especially where these may supplement the present available data. In addition the different materials used for the screening surface itself are discussed and a bibliography appended.

II. HISTORY

Screens may be older than civilization itself. The coarsely woven baskets or the rough cloth used by the ancients to carry loose materials may have suggested the idea, or more primitive yet, picking up a handful of loose unassorted beach sand and allowing it to sift gently through the fingers would, on need, quickly furnish the idea for a bar screen.

In the middle ages Agricola[1] (1556) describes the application of screens in mining work, used both wet and dry. Illustrations show hand screens employed not unlike the common hand riddle used today, excepting as metals were scarce, the screens were often holes bored in a wooden trough. The translation describes the process as sifting.

One of the first references to mining screens in modern times gives this interesting information for the year 1740. "In this year the mischievous practice of screening coals was first introduced at Willington colliery by Mr. William Brown. The screens were first made very narrow, but were a good deal enlarged towards the year 1770."[2]

Since differences over the use of screens for the past 30 years has been a prolific source of trouble between coal operator and miner in this country, it is of interest that more than 150 years ago the term "mischievous" was applied to the practice of screening coal and record made of the enlargement of apertures.

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[1] De re Metallica. (Hoover's English Translation.) Book VIII, pp. 287, 293, 310 and 321.

[2] Chronicles of the Northern Coal Trade. Trans. N. of E. Inst. of Ming. Eng. Vol. 15 (1865-6) p. 205.

Without doubt, the simple gravity screen, used with both wet and dry material, especially in separating sand from gravel in placer mining and the hand shaken screen have for an unknown time been the common possession of miners.

The introduction and development of movable screens took place in connection with ore dressing, rather than coal preparation. As has been the case with many other classes of mining machinery, the greater value per ton and the consequent economic possibility of expending greater labor and care in ore preparation naturally leads to experimentation and development of machinery, which afterwards is adopted by the coal industry as necessity arises. Thus movable sieves were in use at the German metal mines in the first part of the 18th century,[1] although it was more than a century afterwards before they were generally introduced into the coal mines of the same country (1880). In 1828 revolving screens or trommels were in use in the tin mining districts of Cornwall, being turned by women laborers.[2]

In a description of an early ore dressing plant of the French in Algeria[3] a bumping screen is mentioned, suspended by iron chains and operated by manual labor. "The capacity depends on the strength of the worker" is the only engineering data given.

The general introduction of the steam engine in the first part of the 19th century made possible greatly improved practice

1 Schennen, H. und Jüngst, F. von. "Lehrbuch der Erz und Steinkohlenaufbereitung".

2 Proc. Civil Eng. Vol. 17, 1857, p. 208.

3 Bull. de la Soc. de l'Industrie Minerale, Vol. 3, 1857, p. 376.

in the breaking of ores, and the consequent need for screens, power driven and of large capacity. The shaking and gyrating screens soon became common, especially for the larger sizes of ore, and threatened to replace the trommel. Within the last 25 years, however, a reversal towards the trommel may be noted, especially where used with the finer sizes and for wet work in general.

In the coal industry abroad, one of the first deviations from the simple rigid gravity bar screen was a screen in which the spaces between the bars could be quickly increased or decreased. Although patented in 1834 by an Englishman named Hall, it was as late as 1864 called an "unnecessary refinement"[1] in the coal trade.

In France, Berard,[2] who is remembered as having developed successful coal washing machinery, first used, about 1851, a flat bumping suspended screen for the separation of small sizes of coal preparatory to washing.

Briart's moving grate screen,[3] first installed in 1872 at a Belgian colliery marked the beginning of an important development in European coal preparation. The bars moving alternately forward and backward, screened and conveyed friable coals with little breakage. It was generally adopted, and even at the present day is widely used in France and Germany for coarse screening work.

For a time, a German screen, Schmitt's revolving spiral screen,[4] brought out in the seventies, was popular, but probably

1 Jüngst, F. "Steinkohlenaufbereitung".
2 Groves and Thorp. Chemical Technology, Vol. 1, p. 128.
3 Bull. de la Soc. Min. Vol. 14, 2s, 1885.
4 T. N. of E. Inst. Min. Eng., 1878-79, p. 183.

owing to its complicated construction, resembling in cross section a concentric spiral, recent writers give it but little attention.

About 1895 the English Vibrometer screen,[1] having a gyratory motion was invented and for exact screening has acquired wide use.

Compared with American coal screens, the European ones are generally designed for more exact sizing with a minimum of breakage of the higher priced coal. The tonnage handled is much less than in America.

The coal preparation industry was first developed in America in the anthracite region of Pennsylvania, where about 1840 the first coal screens run by power were erected in connection with crushing rolls. These were "circular" revolving screens with cast iron perforated plates. Before this time coal was broken on perforated plates by men, until small enough to drop through.[2] In this same industry the gyrating screen of Coxe[3] was introduced about 1890 and within the past twenty years the shaking screen for the smaller sizes of coal has been greatly improved by the introduction of the Parrish flexible arm shaker, which reduces slope, weight, vibration, and coal breakage as compared with the older forms.

In the bituminous coal fields, following a long period when a rough screening of the coal had taken place underground by the use of forks, etc., separation of the coal at the surface was generally by the use of gravity bar screens. At practically all bituminous coal mines, even in the early nineties, this was the

1 Catalog, Hardy Patent Pick Co., Ltd., Sheffield, England.

2 Stoek, H. H., History of the Preparation of Anthracite, M. & M., May, 1906, p. 428.

3 Coxe, E. B., T. A. I. M. E., Vol. 19, p. 402.

common practice[1] and is still followed in many districts.

In Illinois the first mention noted of any excepting bar screens is of a reciprocating screen for washing slack coal installed in the Wilmington field[2] (1884). Revolving screens for resizing bar screened coal must have been introduced somewhat before this time, as by the middle of the eighties there were several in operation in the State, especially at mines near cities, where there was a demand for the smaller sized coal for domestic purposes. In the Bureau of Labor Statistics Report for 1890 (page 355) it is mentioned that the Consolidated Coal Company at its Gillespie colliery, had installed a shaker screen to take the place of the regular bar screen on the larger sizes of coal. It was reported to be a new and successful departure in screening at Illinois mines, and certain to be adopted at other of the larger mines. Since that time shaking screens have multiplied rapidly until today they are in use for coarse coal screening at more than 90 per cent of the shipping coal mines in the State. In the preparation of the finer sizes of coal the revolving screen continued to hold the field until about 1910, when a modified shaking screen (the Parrish) was adopted from the Pennsylvania anthracite field, and since then has been rapidly displacing the revolving screen.

In 1913 a new type of shaking screen, the Marcus, was introduced into Illinois from English practice. It is horizontal, and has a peculiar jerking motion which causes the coal to move forward rapidly over it.

It must not be supposed that the brief historical list

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1 Mineral Industry, Vol. 1, 1892, p. 80.

2 Illinois State Bur. of Labor Statistics, 1884, p. 452.

mentioned outlines the full development of screening practice, either abroad or in this country, for magazines and patent files reveal literally hundreds of patents granted to inventors of coal and ore screening devices. Most of these have had but a single trial, lacking the simplicity and strength necessary to withstand the great strain of handling large quantities of material, others have found a limited use and have been replaced by improved and simplified types, while a few are favored in special cases or because of the peculiarity of ores or coals in some one district. Since an ore dressing or coal preparation plant frequently involves a long flow sheet or continuous movement of material, the failure of one part involves the idleness of the whole plant. Ruggedness in screens is more essential than perfect screening.

It is safe to say that for all general classes of mineral screening the three simple types, bar, revolving and shaking, have and will continue to be the most used. Abroad, F. Jüngst has summarized the screen question as follows: "Only material of a very difficult nature justifies deviation from the greatest possible simplicity."[1]

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1 Jüngst, F. "Steinkohlenaufbereitung".

III. GENERAL CONSIDERATIONS OF SCREENS AND SCREEN PRACTICE

Factors Affecting Screening: The theory of screening, sizing, sieving, as it is variously called or the separation of unassorted material of a wide range of sizes into divisions, the individual pieces of which are of approximately the same size or diameter, or range between maximum and minimum diameters, is at first sight simple, depending merely on the obvious facts that an individual particle will drop through a hole larger than itself and will not pass through a hole smaller than its least dimension. In attempting to apply this consideration a great number of complicating factors are introduced of which the following is a general introductory list:

1. The shape or shapes of the particles being screened. In a mass of broken ore or coal possibly no two particles are of the same shape, they may tend to be oval, flat, cubical or rectangular, making the real sizes and quantities that will pass a hole of given diameter quite different with different materials.

2. The relative sizes being screened, or proportion of coarse and fine material present. A given quantity of unsized material containing a relatively small percentage of undersize or material passing through a given screen in proportion to the oversize or material too large to pass the screen will affect both the time and the amount of screen area necessary for complete separation.

3. The amount of moisture present in the material. Screening may be done with either dry or wet material, i. e., dry enough to be dusty or drenched with and flowing in a stream of water. In the intermediate state of damp or moist material screening is well nigh impossible. Not only does the finest and most sticky materi-

al clog or blind the holes in the screening surface so that it can not pass through the holes, but the oversize, especially if of small size, refuses to slide over the screen to make room for new material. As many engineers have found to their cost, there is no exception to this rule.

4. The screen holes, meshes or apertures may be of different shape. Round holes, square holes, slotted, rectangular or oblong holes situated in different positions with respect to the longitudinal axis of the screening surface may be used, and finally parallel bars which size the material with reference to its least diameter only may compose the screening surface. Thus different screens of apparently the same diameter may pass different amounts and sizes of material.

5. The slope of the screen. To have capacity and to remove the sized products, material is caused to pass continuously over the screening surface. This is usually accomplished by giving this surface a slope or inclination. A particle which is just small enough to drop vertically through a hole in a horizontal screen, has, when the screen is inclined, only approximately the horizontal projection of the hole presenting itself, and can not pass through. The greater the slope the smaller is the size of this horizontal projection.

6. The velocity of the material over the screen. Material sliding over the screen has velocity along the plane of the screen. The instant a particle reaches the edge of a hole and slides into the space, it describes a trajectory whose path depends on the slope of the screen, the velocity with which the particle is moving, and the force of gravity. Thus instead of falling vertically

through a hole of nearly its same dimension, a particle may strike the other side of the hole and be turned back on the screen again. The thickness of the plate or screening surface is correlary to this in that a thick plate diminishes the space in which a free trajectory of the particle can take place.

7. Coefficient of friction between material and screening surface. As is well known, different ores and different coals have different coefficients of friction with respect to the same or to different screening surfaces. For example, coarse ore may have a different coefficient of friction from fine ore on steel plate, or coals may have different coefficients of friction on screen surfaces depending on size, shape, cleavage, state of aggregation, etc., of the individual pieces. This consequently affects the velocity and in turn the slope of the screen over which they must pass. In all cases it is important to distinguish between the angle at which a particle will start to slide from rest (coefficient of static friction) and the angle at which it will continue in motion (coefficient of kinetic friction).

8. Motion of the screen. Certain types of screens in operation have a shaking motion which gives velocity to the moving particle with less slope of the screen surface than is ordinarily necessary to overcome static friction. This motion may be harmonic, irregularly accelerated, or gyrating. Thus the question of distance and number of vibrations enter into the resultant velocity imparted to the particles and in turn these affect the ease of separation.

9. Temperature. The temperature of the moving particles or of the screen surface affects the velocity of the particles.

Probably high summer temperatures tend to increase the coefficient of friction, especially between coal and screen and render apparatus installed for cold weather conditions unfavorable without some change of slope.

From the foregoing, the practical application of screening introduces a great number of independent variables, with laws and relations whose solutions have received but little attention. Design usually is based on the results obtained from the experimental adjustment of screening apparatus until found satisfactory with one set of conditions, and the copying of this practice in the next design under similar conditions. That this does not always lead to maximum efficiency is evident.

In the great number of designs of screens that have been evolved three general types can be recognized.

1. The gravity screen, called a grizzly in ore work, where the screening surface is stationary and set at an angle great enough to allow the material being screened to run over it by gravity. The drag screen, where material is forced to pass over the stationary screening surface by means of scrapers or drags, may be regarded as a modification of this type.

2. The revolving screen, sometimes called a roller screen or in ore work a trommel (German for drum) in which the screening surface forms the envelope of a revolving cylinder. Material fed into this cylinder is carried up the inside during part of a revolution, and rolls to the bottom, these steps succeeding each other until the material falls through a hole in the screen or if too large is carried out of the lower end of the screen. Modifications exist which are known as conical screens, double or triple

jacketed screens, etc.

3. The shaking screen, where the screening surface is given an oscillating motion, the material being screened moving over it, finding new chances for passing through the screen, or being discharged at one end if too large; also new material can be fed constantly. In this type a great variety of mechanical movements have been introduced to give various paths over which the screen surface oscillates. Outside the simple shaking screen, which is usually moved from an eccentric by a simple harmonic motion, this class includes the Parrish, bumping, knocker, impact, vibrating, gyrating, and the differential motion screens and a number of minor types.

Methods of Screening: With any screen of any class, the screening operation may be simple or compound. In simple screening one size of holes only is used, and there results two products, one called an oversize, and the small or undersize. The usual screening operation is compound, that is, a number of different sizes of holes are used and the difference in the diameter of the successive ones is called a screen ratio. Each screen used in succession produces an oversize, of which the size, excepting from the first screen is limited both in maximum and minimum dimensions. Such a material is known as a sized product. The final screen also produces an unsized undersize. For example, run of mine Illinois coal is often prepared for market by using screens having the following holes and making the corresponding products:

Screen (round holes)	Size of Product	Trade Name	Average per cent of run of mine coal of this size
On 6 inch	6 in. and larger (oversize)	6 in. lump	25 %
" 3 "	3 " min. and 6 in. max.	3 in. egg	17
" 2 "	2 " " " 3 " "	2" or #1 Nut	18
" 1 1/4 in.	1 1/4" " " 2 " "	No. 2 nut	11
" 3/4 "	3/4" " " 1 1/4" "	No. 3 "	9
" 1/4 "	1/4" " " 3/4" "	No. 4 "	7
Thru 1/4 "	1/4" to zero	No. 5 "	13

The first difficulty in the screening operation comes from the question, where shall the sizing operation begin? In general there are three methods of sizing in vogue as follows:

1. The first screen of a series has the smallest holes, so that the undersize of this screen is the smallest material and the series of screens are arranged in the order of finest to largest.

2. The first screen of a series has the largest holes, so that the finished oversize of this screen is the largest material and the series of screens are arranged in the order of largest to finest.

3. The first screen of a series has an intermediate size of holes so that the oversize of this screen contains the larger material as yet unsized, and the undersize contains the finer material also in itself unsized. Both products can now be sized by either method 1 or 2.

Many writers who have urged some one of these systems have failed to consider that any one system may at times be the best, depending chiefly on size, kind of material, and room available.

Considering the material as Illinois coal, method 1 has the advantage that all the sizes of holes can be placed on nearly the same level. It is the oversize that is rescreened in succession, and the undersize immediately becomes a finished product. It has the disadvantages that the whole tonnage to be screened falls on and blinds the finest holes, which require, even under equal conditions, more area and time for their work, and unless the area of this first screen is made excessive, poor screening results. The larger coal, which is most valuable, is kept longest on the screen and considerable breakage results. This method is often improved by placing a larger screen, called a relief screen, above the finest holes, so that the largest material is carried over the first part of the fine screen to a point where the screen is not so crowded.

In method 2 the whole tonnage is thrown on the largest screen which is best able to handle it and which passes as undersize all but the largest and most valuable coal and this is loaded immediately without further screening. The disadvantage of the method is the extra head-room required, for the product falling through a screen must be handled on the next screen.

Where method 3 is used the oversize from the first screen usually follows method 1; these larger holes being arranged in ascending order of their size, while the undersize usually follows method 2, the screens used being arranged in the descending order of their size. This method has the advantage of keeping the fine screens free from an excessive load and follows a logical arrangement with the succeeding products. It has, however, the disadvantages of complication, two or more sets of screens being required.

In practice, where the smaller sizes of coal, say under 1 1/4 or 2 inches are not made, method 1 is usually followed, although at some mines method 2 is used and reported satisfactory, as it is claimed that a larger tonnage can be handled for the same area of screens. At mines where the small sizes of nut (under 1 1/4 or 2 inches) are made, method 3 should be and usually is used. The undersize from the first screen is elevated into a separate building called a rescreener and there prepared into successively smaller sizes.

In ore screening work it is more common to let the medium or the largest size be screened out first, as wear on fine screens by large particles of ore is excessive.

Materials for the Screening Surface: Little attention has been given by writers to the material of the screen surface or to the nature of its holes, perforations, or apertures and their bearing on the resulting product. The slots in a gravity bar screen are a part of the screen itself and will be considered with it. With other screens the screening surface may be composed of bars with spaces between, giving a long narrow hole for the material to pass through. It may be plate of any metal punched or bored with holes that may be round, square, rectangular, tapered, oblong, diamond, or other shape. Finally it may be composed of screen cloth woven with wires of different metals or in the finest sizes of some fabric, and the opening between these wires may be square or rectangular in shape.

The same material passed over screens of differently shaped holes but of the same diameter or width and consequently of the same rated size exhibits wide differences in amounts, and

true sizes removed. Thus on an average Illinois run of mine coal screened over bar screens having 7/8 inch spaces will produce the same amount of undersize as a round hole screen with perforations 1 1/4 inches in diameter, while a wire screen with a square hole of one inch on a side will produce the same amount as a 1 1/4 inch round hole screen, although in each case the shape of the maximum pieces will be different. Comparing round and square holes of the same rated size, the area of a circle inscribed in a square is 0.7854 of the area of the square and the respective amounts passed follow fairly closely this ratio. In commercial work considerable confusion exists regarding this, as a 1 1/4 inch product from a bar screen may be of quite different size than a 1 1/4 inch product from either one of the other screens, although all are called 1 1/4 inch screenings.

The most perfect screening is obtained from round holes as they have only one dimension; a square hole has two unequal dimensions, the side and diagonal, while a rectangular hole has three, two unequal sides and the diagonal. With bar screens the hole forms a continuous line down the screen, with wire screen the successive holes are in line with each other in both directions, while in plate the successive rows of holes may be in line in one direction and staggered in the other, or they may be staggered in both directions. English coal plate screens often have square holes set with one diagonal parallel to the flow of coal, and presenting the maximum size of opening to the particles.

Another comparison between screens may be made as to the percentage of space or opening in screen surfaces; bar screens are unrestricted in opening in one direction, while the percentage of

opening in a wire screen varies with the size of the wires used, but is generally over 60 per cent and may reach 90 per cent. With punched plate the percentage of opening is much smaller and although it varies somewhat among makers and according to size and position of the holes, the usual range is from 30 per cent with small holes, to 50 per cent with the large holes, since the thicker metal used in large hole plate makes more hole space possible.

Combining the two comparisons gives an idea of the efficiency of a given area of bar, wire or plate screen, or on the chances of a given small particle of material to fall through in a given area of screen. In general the chance is greatest with the bar screen, next with the wire screen cloth and poorest with the screen plate. Conversely, the areas of these plates for the same chance of screening must be in reverse order. Wiard, in his "Theory and Practice of Ore Dressing" (p. 264) gives a mathematical demonstration of the chances of a particle of given size approaching an opening of greater diameter than itself and dropping through, and shows that when the particle is small compared with the diameter of the hole the chances are infinitely great, but as the diameter of the particle approaches that of the hole they become infinitely small and the chances between these points when platted form a hyperbola. This illustrates the increasing difficulty of successfully screening out particles of only slightly less diameter than the hole and also of what great length a screen would have to be to pass these sizes. Especially with the friable coal, too much screening surface or too long screening simply means more slack coal formed.

Area of Screen Surfaces: A general mistake made in

screen design is to assume for a given capacity of a given size an area of screen surface that has worked successfully and attempt to apply this without reservation to another material and to different sizes. Screens of the same character should differ somewhat according to the proportions of oversize and undersize in a given tonnage. Data for these conditions have not been collected. A decided increase in area of screen is necessary for the same tonnage as the size of hole decreases. So much difference exists in the proportionate area of large holes and small holes in coal mine screens used in Illinois that any design must have been largely empirical. As a guide the simple theoretical discussion following may be helpful.

A ton of theoretical cubes of any material as coal of a given length of edge or size X contains A pieces. A ton of coal of smaller size Y contains $\left(\frac{X}{Y}\right)^3$ A pieces, since each piece of the large size is split each way to make the smaller cubes.

Let there be an area L x d of screen plate perforated by enough holes of diameter X satisfactorily to screen the material of this size. A piece of the coal of size Y should have equal chances of screening on a plate having holes of diameter Y; in other words the number of holes for any size should be in proportion to the relative number of pieces in that size. Therefore size Y should have $\left(\frac{X}{Y}\right)^3$ times the holes that were necessary for size X.

Consider the area of screen having holes of size X: ignoring thickness of wires, in a given area of screen where the holes are of size X there may be $\left(\frac{X}{Y}\right)^2$ holes of size Y. Therefore the increased area of plate necessary to screen the smaller sizes under equally favorable conditions is $\dfrac{\left(\frac{X}{Y}\right)^3}{\left(\frac{X}{Y}\right)^2} = \dfrac{X}{Y}$. If the screens are of

the same width, as they usually are, the length must be increased to obtain $\frac{X}{Y}$ times the original screening area. Therefore on theoretical grounds alone, the length of screen necessary to obtain equal screening increases in direct proportion to the decrease in size of the material.

The following example will show how this ratio may be used in practice.

Given a mine producing 2000 tons of coal per day. It is desired to produce 2 inch screenings, 2 x 3 inch nut coal, 3 x 6 inch egg coal and 6 inch lump coal. A screening test on a fair sample of the coal shows the following results:

Size	Per cent	Total tons per day
2 inch screenings	40	800
2 in. x 3 in. nut	20	400
3 in. x 6 in. egg	20	400
6 inch lump	20	400

It is required to design a screening plant. Assume from experience that a length of say 20 feet of 2 inch screen plate is necessary to prepare the 2 inch screenings. To calculate the length of the other screen plate necessary to give equal screening proceed as follows:

The 2 inch hole plate receives 2000 tons per day and requires 20 feet of screen plate. The 3 inch hole plate receives 1200 tons per day, requires $\frac{2}{3} \times \frac{20}{1} = \frac{40}{3}$ feet of plate for the same tonnage, but the tonnage handled = $\frac{1200}{2000}$ of the 2 inch plate, therefore, the necessary length of plate will be $\frac{40}{3} \times \frac{1200}{2000} = 8$ feet long. In the same way, the 6 inch plate is required to be $\frac{20}{3} \times \frac{800}{2000} = 2\ 2/3$ feet long.

It may be argued that the difficulties of screening increase with an increase of the percentage of undersize screened out. In the example given 40 per cent of the material on the first screen is undersize; the second screen receives 1200 tons of material and screens out 400 or 33 1/3 per cent and the 6 inch screen has 50 per cent undersize. Based on the first screen the length of the second should be decreased $\frac{6-2/3}{40}$ and the third screen increased by $\frac{50}{40}$. Making these corrections, the required lengths of screens become

for 2 inch - 20 feet.

for 3 inch $8 \times \frac{33-1/3}{40} = 6\ 2/3$ feet.

for 6 inch $\frac{8}{3} \times \frac{50}{45} = \frac{50}{15} = 3\ 1/3$ feet.

The same results can be arrived at by calculating the screen lengths directly on the respective amounts of undersize. This checks closely with some of the better designed screens used in practice. The usual screen, however, has too little area in the small sizes and too much in the large sizes. In practice the individual screen plates as purchased are usually about 4 feet wide and placed crossways on the screen frame, therefore the length used might have to be slightly greater than that calculated.

The thickness of plate screens varies from the thinnest sheets up to plate 1/2 inch in thickness. The standards vary with the maker. In Illinois coal practice 3/16 or 1/4 inch plate is used with small sizes of holes up to 1 1/4 inches; 1/4 to 3/8 inch plate with sizes up to 4 or 5 inches and 3/8 or 1/2 inch plate above this size. For ore work no general rule can be given, as the small sizes used and the particular local conditions make it necessary to consult a manufacturer's catalog and to use ones

judgment. Commonly the United States standard gauge is followed in listing the thickness of steel plate for small holes. For plate with holes less than 1/4 inch a common rule is that the thickness of the plate is about the diameter of the hole. Sometimes thin screens with small holes rest directly upon a plate with much larger holes, whose only purpose is to give stiffness to the thin plate. A good rule to follow in buying is that perforated plate should not have to support more than half the load which would be readily borne by a plain one and that the area of perforations should be about 40 per cent of the total area.

With wire screens almost any size of wire can be obtained with any size of hole and again the particular condition determines the choice.

Screen material of all kinds is usually mild steel, but for wet screening or when the holes are small brass or copper is used, recently in wet screening work, especially where dealing with acid waters, the Monel metal cloth and plate has been introduced. For ore work, where the wear is great, manganese steel plate is favored. Too high carbon steel although hard, will frequently crack between the holes.

In considering screening material one is sometimes attracted by special trade names of screens preporting to do special work and usually at a special price. Some of these screens have the advantage of an extra percentage of space, thereby giving larger capacity for a given area. Wire cloth sometimes is given a special weave, which leaves one surface of the screen quite smooth and thus decreases wear, while the smooth surface does not obstruct the flow of material. Recently screen plate recommended for coal

work has been put on the market with its surface pressed so as to form a series of low waves. This is said better to distribute the material, to impart a rolling movement to the coal, to stiffen the plates and to prevent bagging. These specialties are to be recommended only if the tonnage exceeds the capacity of an ordinary screen. In most cases good design will admit using common standard screens.

With coal screen plate or cloth the life is varied and indefinite. Some plate screens have been discarded as worn out in two years as a minimum. In this time the holes had become elongated and did not admit of close enough sizing. In other cases screen plate has been in use 5 or 6 years. Ore screen surfaces wear much faster and in some cases their life is measured by days or weeks especially those having small holes. The wearing action in screens run wet is greater than when run dry.

Materials Commonly Used: The screening surface used on shaker screens in Illinois is always punched or drilled plate, with the holes staggered and the alternate rows in line. If the centers of two holes in one line are connected with each other and each with the center of the hole in the line above, an equilateral triangle is formed. This form is supposed to give maximum strength and offer the greatest chance for a piece of material to find a hole to drop through. It is very seldom that any but round holes are used. On account of roughness which hinders the sliding of material over the screen, wire cloth is never used.

With the revolving or trommel screen both punched and wire cloth are used. The wire cloth, giving the greater percentage of openings, is often used, but the punched plate gives the more regu-

lar size of product and is a favorite, especially in ore work. At Illinois coal preparation plants, plate revolving screens are more common in the larger sizes and wire screens are confined to the smaller sizes, 3/4 inch and less.

With the vibrating screen, a type of shaking screen for screening ores in fine sizes, and which depends on the vibration of the screen to keep the meshes open, wire cloth is always used, as it vibrates more freely than plate.

Screen Ratios and Mesh. With any compound system of screening, shall the succeeding sizes of screens be of random diameters or shall they follow some definite ratio? In the sixties, Rittinger advocated that the succeeding diameters of the holes in any screening system should follow some definite ratio, and proposed a ratio equal to the $\sqrt{2} = 1.414$, and this simple ratio is generally known as Rittinger's ratio. The successive sizes of this sieve scale form a geometrical series. Starting, for example, with holes of 1 mm. diameter, the next larger hole should have a diameter equal to $1 \times \sqrt{2} = 1.414$ mm., the next smaller hole than 1 mm. should have a diameter of $\frac{1}{\sqrt{2}} = 0.71$ mms. The area of successive screen holes doubles under this ratio.

R. H. Richards in his "Ore Dressing" (Vol. 1, page 366) discusses the sieve scale thus proposed and advocates adherence to its general principles, at the same time recognizing that for certain work every third or fourth size is sufficient, and that some other ratio also may be satisfactory.

In ore dressing where it is necessary to size the material present day practice follows some sieve scale, but owing to the different principles of the different machines treating coarse and

fine ore, the same sieve scale is not necessarily followed through the whole range of sizes.

Another factor complicating the true size and consequent ratio of one particle to another is the difficulty of understanding the meaning of the word mesh. Where round hole screens are used, as with sizes down to about 1/4 inch, mesh means the diameter of the hole. With wire screen cloth which is standard from this size down to smaller than 200 mesh and usually having a square hole, mesh generally means the number of holes in a linear inch of the screen. For example 20 mesh does not mean that each hole is 1/20 of an inch across, but that there are 20 holes in a linear inch of the screen, consequently each is less than 1/20 of an inch by the thickness of the wire used. As almost any size of wire can be used for almost any mesh, confusion of what size is represented by a 20 mesh product results. Other wire screens are designated as mesh by the fraction of one inch represented by a side of the hole. This is always true for holes larger than 1 inch.

The W. S. Tyler Screen Company have placed on the market a standard set of testing screens where the successive sizes are controlled by Rittinger's ratio and where the size of wire is standard for each size of hole, and the width of hole is the measure of the screen size. This screen scale has as its base an opening of 0.0029 inch which is the opening in 200 mesh 0.0021 inch wire, the standard sieve as adopted by the Bureau of Standards of the United States Government, the openings increasing in the ratio of the square root of 2 or 1.414.

In metal mining circles the subject of screen mesh has been recently discussed, particularly in England by the Institute of Mining and Metallurgy and in America by the Mining and Metallurgi-

cal Society of America. Various standards have been recommended, without however entirely clearing up the situation. The writer believes that the persistence of manufacturers to follow old individual standards is responsible for much of the confusion. In any comparative testing work, the same standards and the same sieve scale should be followed, otherwise the results are useless.

The question has been asked, why not use round hole screens and do away with this uncertainty. The probable answer is that in ore dressing much work is carried on with screens of 50, 100, and even 200 mesh and finer. The finest needle punched holes in thin brass plate that can be made at the present time are about 1/64 inch in diameter, consequently a standard wire sieve scale is necessary, at least below this size.

Proposed Coal Sieve Scale: In coal preparation, excepting in a very few cases with fine coal where washing is subsequently performed, no attempt has been made to follow any sieve scale. For example, at Illinois mines there are produced at least 37 different sizes of coal, and as the same trade names often refer to different sizes, some standardization of sizes is desirable. F. C. Lincoln,[1] for washed coals, has proposed a set of sizes made by round hole screens, varying by a ratio of two. The writer would go further and suggest that all coal prepared be made to fit this ratio. Starting with a one inch round hole as a basis, and working up and down from this point, the common nut coal sizes would have 2 and 4 inches as maxima, egg coal would be made over 4 inch and through 8 inch holes and lump coal over an 8 inch hole.

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1 Coal Washing in Illinois. Bull. No. 69, Engineering Experiment Station, University of Illinois.

In laboratory coal testing work involving sizing, because commercial screens are round hole, while most laboratory screens are square mesh wire, results are often meaningless. Some sizing work of this character even has been carried out with a haphazard sieve scale, odd sizes of screens being used because easily available. Results from work like this are useless as regards future correlation.

The writer, in laboratory coal testing work is using a set of round hole screens, starting with a one inch diameter as a standard and the larger screens have round holes of 2, 4, and 8 inches in diameter, and below 1 inch the plates have 1/2 inch, 1/4 inch, 1/8 inch, 1/16 inch, 1/32 inch and 1/64 inch diameter round holes. The scale is proposed as a standard for all coal testing work.

It is true that it adds another standard set into the already complicated field, and for reasons previously stated the smallest screen is limited to 1/64 inch in diameter. It is granted that special tests made with coal dust 100 mesh and finer require the standard wire screen.

The arguments for such a scale are: (1) It would place all coal testing work on the same basis for comparison; (2) it follows a simple ratio; (3) it needs for the results obtained no conversion of sizes to be immediately applicable in practical work; (4) the screens are cheap and of long life; (5) coal is screened and used in larger sizes than ore and 1/64 inch represents the minimum diameter necessary in commercial coal testing work. For example, coal 1/64 inch in diameter and smaller will not settle in water and can, therefore, be regarded as are slimes in ore work.

IV. GRAVITY SCREENS

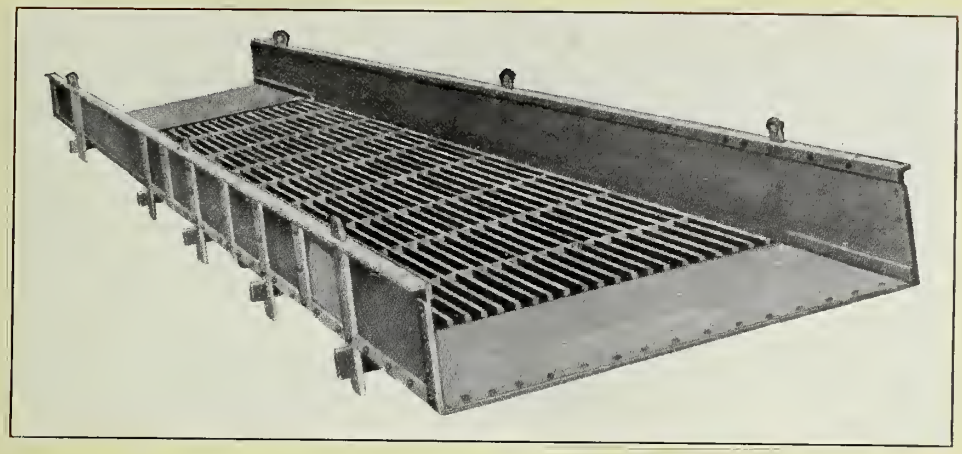


Fig. 1. A Gravity Bar Screen

Gravity Bar Screens: Fig. 1 illustrates a type of the ordinary gravity bar screen. It consists of parallel bars spaced equally and over which material to be screened is passed. If used in ore dressing work it is generally called a grizzly, often in coal work the terms grids or grills (Gr. Reibseibe) are applied. A bar screen generally has a head or dump chute attached at the upper end and a tail or bottom chute at the lower. They are set at the same angle as the bar screen and are joined to it. In this discussion the term chute where used will refer to these parts of the screen.

The explanation of the screen depends on the obvious fact that if set at a great enough angle, material will slide over the bars and screen itself without further handling. This angle depends on the coefficient of friction between the material of the

bars and the material being screened and must be carefully considered. If the screen is set at a lower angle than this the material will have to be pulled or dragged over the screen, if set at too great an angle, the material is accelerated during its passage and its velocity may become so great that the smaller particles are carried too swiftly down the screen and indifferent screening results. If coarse ore is being screened the velocity acquired by the large pieces, often weighing several hundred pounds, may cause breakage to the chutes or bins below or danger to the attendant. In the case of coal the trouble usually comes through breakage of the large lumps of coal and the consequent reduction in size and production of fines, which are less valuable than the lump sizes.

Difference in Slope: The angle with the horizontal at which a screen must be inclined to cause a particle resting on it to start sliding is called the angle of static friction and tan α = the coefficient of static friction. The angle is greater than the angle θ required to keep a sliding particle in motion. Tan θ is the coefficient of kinetic friction. No known work has been carried out in America on the relative values of tan α and tan θ for ores or coals on metal surfaces. With English bituminous coal and steel plate

$$\frac{\alpha = 30^{\circ}}{\theta = 26^{\circ}}, \quad \frac{\tan\alpha}{\tan\theta} = \frac{0.577}{0.488} = 1.182$$ [1]

Some confusion has arisen in designing the proper slope for bar screens owing to these two different coefficients. In general since ore or coal is nearly always dumped on a screen with con-

[1] Louis, Henry. "The Dressing of Minerals", p. 13.

siderable force and consequently is in motion, design should be with reference to kinetic friction rather than static. Moreover, particles may either roll or slide down a screen. Most rock particles have flat or oval sides, and in a properly designed screen, sliding rather than rolling takes place and sliding and not rolling friction should be considered.

The application of the above simple theory is complicated because the coefficient of kinetic or sliding friction is different in the following cases:

1. Between the material sliding and different screen materials.
2. Between the same screen material and different ores or coals being screened.
3. If the screen surface is bright or rusty.
4. If the screen surface is smooth or irregular.
5. If the material is dry or moist.
6. For different conditions of the atmosphere, causing the screen surface to be either moist or dry.
7. According to size of material and percentages of various sizes in the material.
8. With different temperatures of material or screen.
9. With the shapes of the top of screen bars, i. e., width of riding surface.

Considering the thousands of coal and ore chutes and gravity screens in daily use, it is surprising that more definite data on the subject are not available. The general practice seems to design against an average condition, hoping that one extreme set of conditions will not give too much velocity to the material or

that it may be slowed down in some way, and that an opposite set of conditions may be met by helping the material over a screen with rakes or shovels. As flow sheets for ore plants and coal tipples are usually designed to make the material flow or run from one process to another by the force of gravity and with the expenditure or loss of as little head room as possible, a screen once installed may not be changed without disarranging the flow sheet of a considerable part of the plant. Therefore each of the variables mentioned will be detailed in order.

1. Difference in friction between a given material and different screen materials.

Gravity screen surfaces and chutes have been of cast iron, steel, copper, brass, bronze or other alloys, glass and wood, although steel is the common material. As a rule, the harder the material, the smoother its surface wears and the combination usually offers less resistance than softer materials. The Coal and Metal Miners' Pocketbook, page 443, lists a table comparing the slopes on which anthracite will continue in motion with different chute or screen materials from which the following is taken:

If the anthracite be of egg size, between 3 1/4 inch and 2 5/16 inch then the following table will be applicable:

Material of Chute or Screen	Minimum slope in inches per foot to allow coal to continue to slide	Slope in degrees
Glass	2 1/4 inches per foot	10° 37'
Manganese Bronze	2 5/8 " " "	12° 20'
Sheet Iron (mild steel)	3 " " "	14° 3'
Cast Iron	3 1/2 " " "	16° 15'
Wood	Not given	

No comparative tests between other coals and ores and different chute materials are available. In a general way they follow the above order, although the slopes when using anthracite are less than when using bituminous coals and they in turn are lower than when ores are considered. The writer's notebook lists a quartzose ore which would run on steel chutes set at a 35° slope, but not on wooden chutes until they were inclined 50°.

2. Difference in friction between the same screen material and different ores or coals being screened. Since steel is the common screen bar material, the various sliding angles that are required to move different materials over it when bright will be discussed. Differences noted here are due not only to the inherent difference of the ores and coals being screened, such as hardness, specific gravity, etc., but to the way they break, i. e., the shape of their fragments. Thus some ores and coals tend to break into cubical pieces, some into flat and some have oval or conchoidal faces. Even the development or lack of development of cleat or cleavage in coals influences their ease of sliding. These all complicate the practical solution of the problem, since a large piece resting on a small surface will undoubtedly have more weight per unit of area resting against the screen bars, i. e., an apparently lower sliding angle and a less coefficient of friction. On an average the following list fairly well represents the sliding angle between bright steel and various ores or coals of lump size:

Material		Sliding Angle on Bright Steel Plate	Authority
1. Anthracite	=	14° 30'	C & M M Pocketbook
2. Ill. bituminous coal	=	22° 30'	Writer's Data.
3. W. Va. " "	=	26°	" "

Material	Sliding Angle on Bright Steel Plate	Authority
4. Slate =	20° - 30°	Writer's Data
5. Quartz gangue ores =	35°	" "
6. Limestone " " =	36°	" "
7. Iron ore =	38°	" "

Among different ores and even among different ores of the same metal there is a considerable difference in sliding angle due principally to the different gangue material which usually constitutes the bulk of the material. Figures on iron oxide ores, and ores having a large amount of exposed sulphides would be valuable. Some ores have a greasy feeling and seem to carry a surface lubricant which reduces greatly their coefficient of friction.

Frequently the ore being screened is not of one gangue material, but may be a mixture of several, thus coal may be mixed with shale or slate, which gives a higher coefficient of friction to the mixture and ores may be mixed with various sedimentary or igneous wall rocks, which may change the calculated angle. Altogether the available data are rather incomplete.

3. The consideration of whether the screen surface is bright or rusty falls partly under discussion 1, since a rusty surface (iron oxide) acts like an entirely different material than steel. Because the writer has experienced annoyance from having to slow down a plant just starting up after a shut down in order to rake material over a screen previously in good working order, special reference is made to the difficulty, with the recommendation that all screens and chutes be protected from the weather, or greased before a shut down. The saving in time will more than pay for the additional cost.

4. Differences if the screen surface is smooth or irregular. Most gravity screens are built of longitudinal bars. Sometimes however, punched hole screens and wire mesh screens are used. The wire mesh gravity screen is a favorite where sized coal, to remove the last trace of adhering fines, is rescreened when drawn from a bin. The very irregularities of the cross wires of the screen (woof) cause a jarring of the coal which accomplishes the desired end. A screen of this type, called a degradation screen requires an unusually high angle of slope depending on the relative irregularity of its surface. The slope may be 35° as against 26° with a smooth screen.

A punched plate gravity screen furnishes still another case from irregularity of surface caused by sharp pieces lodging in the screen holes. No definite rule can be given for the extra angle necessary to overcome this defect, but unless provided against by an extra slope it is certain to cause trouble. Even with a bar screen otherwise properly designed, pieces lodging between the bars may hang up succeeding pieces and ultimately cause a choked screen. With coal the tendency of lodged pieces to be sheared by succeeding pieces is a positive factor in coal breakage. When screening certain irregular ores where the succeeding free pieces do not slide with sufficient velocity to free the lodged pieces, part of the duties of a screen attendant are frequently to inspect and free the screen by means of a heavy iron hook.

5. Difference of friction in dry and moist material and (6) different conditions of the atmosphere, making the screen surface dry or moist. Since moisture, either on the material or on the screen decidedly increases the coefficient of friction and the slid-

ing angle, 5 and 6 will be discussed together.

While a dry quartz ore may slide on an angle of 35°, moist pieces may require 45° and even 50°. The same statement of great increase in the coefficient of friction with increased moisture can be applied to coal.

An interesting report on this subject comes from an Indiana mine. Here the engineering construction company erecting a bituminous coal tipple gathered data from other tipples where coal from the same seam was being treated and came to the conclusion that a slope of 27° for the bar screen would suffice for the extreme conditions. The tipple was designed and erected, using this slope as a basis for required tipple height. The mine, however, was just being developed, and the fresh coal near the bottom of the shaft was wet, in addition the air current could only circulate a short distance underground, consequently it did not become heated and absorb the moisture there. Under these conditions a rather moist coal had to be handled, although the extra moisture was not apparent to the eye. The coal lodged on the tipple screens and greatly handicapped the preparation work. At considerable trouble and expense the engineering firm increased the slope of the screens to about 30°, which remedied the defect. After a time, the mine becoming drier, complaint was made that the screens were sliding the coal too fast. Not enough fines went through and the coal was being badly broken, so the screens were changed to the original slope and have worked well since.

In general, ore mines are at times and in places wet and this condition must be provided against, even at the trouble of having too great a slope for the usual condition. The writer

operated an open cut rock mine at Zortman, Montana. Here in the summer and fall the ore, dried out by months of cloudless skies, would run so fast over chutes and grizzlies as to cause serious damage by breakage of screen gates, etc. When, however, the rainy winter weather came on, the mill crew were often half employed in pulling the ore over these same chutes and screens.

The above discussion refers only to material in a moist state. If so thoroughly wet as to be dripping, the water has the effect of a lubricant, and as in the case of an ordinary machinery bearing, greatly reduces the coefficient of friction. The extreme case is wet screening where the material flows in a stream of water and more common with the small sizes. Here, however, the slope given is not a function of the coefficient of friction, but of the velocity of the water, the carrying power of the water varying as the sixth power of the velocity. Bar screening work, excepting in placer mining is rarely done wet, and for the reasons stated every effort should be taken to keep the material as dry as possible.

If the screen surfaces are colder than the atmosphere, which may happen in a plant in summer time, moisture may deposit on them and increase the sliding angle. Although at first sight a theoretical consideration it may be the explanation of trouble with screens at certain irregular times.

7. Differences in friction according to size of material and percentages of various sizes in the material. Of the differences noted this is most generally known and easily recognized. With perfect cubes of a material sliding over a bar screen or in general any inclined surface, the coefficient of friction should be the

same for any size of cube of the same material, i. e., independent of size, (Coulomb's second law of friction); nevertheless ores or coals of large size have a smaller coefficient of friction than the same material in the smaller sizes, and bar screens built to handle the smaller material must have a greater slope than those for the large. The increase of slope necessary is definite with each smaller size, although small until the finer sizes are reached when it increases rapidly. An explanation is as follows: Large pieces of ore and coal although of irregular shape, approach in total volume the theoretical cube of material, one side of which is represented by the surface of the piece in contact with the screen. If this size be broken into smaller irregular pieces, the amount of surface exposed in the small irregular piece per unit of volume or weight tends to increase, although this increase is small until the smaller sizes are reached when it increases rapidly, as a limit reaching colloidal material like clay where the amount of surface exposed per unit of volume is so great that particles will not sink in water. Recent experimenters[1] on sliding friction have recognized that friction may vary according to proportionate rubbing surface, and that with greater pressures the friction is somewhat smaller. With fibrous substances also friction is increased by an increase of surface, and considering coal as of a somewhat fibrous nature, this might offer additional explanation. The general effect then, of a reduction of size is to increase the ratio of the surface to the weight, therefore the force tending to cause motion is less per unit of surface, and a steeper angle is necessary to allow the material to slide by gravity. The following data

[1] Lanza, G. "Notes on Friction". 1903. pp. 115 and 128.

which is frequently used in design will illustrate the point:

Practical Slopes Necessary for Different Sizes of Dry Anthracite to Slide on an Inclined Plane[1]

Size, (round hole, diameter in inches.)	Glass Chute: Minimum slope in inches per foot for sliding to begin.	Glass Chute: Minimum slope in inches per foot for sliding to continue.	Steel Plate Chute: Min. slope in. per ft. for sliding to cont.
Broken coal, 4 1/2-3 1/4	2 5/8	2 1/4	2.75
Egg " 3 1/4-2 5/16	2 5/8	2 1/4	2.94
Stove " 2 5/16-1 5/8	3	2 1/2	3.12
Chestnut" 1 5/8-15/16	3	2 1/2	3.50
Pea " 15/16-5/8	3 1/4	2 1/2	4.50
Buckwheat #1, 5/8-7/16	3 5/8	3 1/8	5.25
" #2, 7/16-1/4	3 3/4	3 1/4	6.00
" #3, 1/4-3/32	4 3/8	3 3/8	7.50
" #4, 3/32-0	4 7/8	4 1/8	8.00 ±

With Illinois bituminous coal, using steel surface the required angle is slightly different for different coals, those from the northern part of the state probably requiring a little more angle than those from the southern. The following are averages of measurement taken by the writer at Illinois mines and show general practice in chute and bar screen slope for

Lump coal 25°

Egg coal 26°

Nut coal 27°

Screenings 32-37°, average 35°, depending on relative amount of coarse and fine. It is often made 45°

[1] After Sterling, Paul. "Preparation of Anthracite". T.A.I.M.E. 1911, p. 788.

to avoid possibility of trouble, and because breakage here is not important. Run of mine 26 1/2° - 29°. To start run of mine on steel may require 38°.

For New River, West Virginia, steam coals which have up to 60 per cent slack through a 1 inch bar screen, in common practice for bar screen and chute design the following slopes are allowed:

For lump coal	26° - 28°
" egg "	30°
" run of mine coal	32° - 33°
" slack, up to	45°

This coal is softer than Illinois coal and needs a somewhat greater slope for the corresponding sizes. In either case some knowledge and judgment as to the probable percentage of coarse and fine coal in any mixture of sizes is necessary. Run of mine, a combination of all sizes, has its individual angle, and screenings which are frequently 1 1/2 inches or 2 inches down to zero in size also requires its special angle, differing slightly in each coal. A special coal is No. 5 nut, which is from 5/16 or 1/4 inch to zero in size. Screens or chutes for such coal may have to incline as much as 35°.

While most ores required to pass over bar screens are raw ores, i. e., all sizes as mined mixed together, yet from analogy some allowance must be made if the ore contains a preponderance of fine sizes. Ores require a greater slope than coals and one finds ordinary ore grizzlies set at 40 - 45° slope; with coarse ore or a sized ore this may be lessened to 36 - 40° while with very fine material the angle may have to be increased to 50°.

8. Temperature of material of screen.

Almost no data are available as to the effect of temperature on the coefficient of kinetic friction, in other words, as to whether a body will slide more easily over another when one or both are hot or cold. Following the seeming analogy of an oiled bearing, as a car axle, it would appear that the coefficient of friction decreases as the temperature increases. In this case, however, it is because the lubricant becomes less viscous as the temperature rises, and the friction is between oil and metal rather than between two metals. In the case of a coal or ore sliding over a bar screen, other conditions being the same, there is undoubtedly a considerable difference between the velocity of material on a very cold and a very hot day, and it is believed that coal moves more slowly over a screen on a hot day than on a cold one, or when any set of conditions make either screen or material comparatively warm. This is contrary to popular supposition. To support this conclusion, the writer's data reveal an exposed coal screen in Illinois that worked perfectly under ordinary conditions, but on which the coal would stick on the hot days in summer.

Similar interesting conditions are to be found at two coal mines at Gillespie, Illinois, owned and operated by the same company. At these mines the same coal seam is worked only three miles apart, and they are the largest mines in Illinois, if not in the world, hoisting from single shafts, as the output of each frequently reaches 5000 tons per 8-hour day. Mine No. 1, is equipped with a 1/2 inch space bar screen 10 feet wide by 12 feet long, set at 27°. Using puncher machines, the coal produces 17 per cent of screenings.

Mine No. 3 has identical screening equipment, but set at 29°, and as electric machines are used only 11 per cent of screenings is produced.

Both screens work well under ordinary conditions, if anything the coal has a tendency to move too fast. At a mine producing 5000 tons per day, however, for several hours at a time 12 tons per minute must slide over the chutes and screens and the heat generated by the coal rubbing over the screen is considerable, as it is sometimes impossible to hold ones hand on the screen. This screen temperature would, of course, be a maximum on the hottest summer days. It is on these days that trouble and annoyance has been experienced through the finer coal sticking on the screen chutes at No. 1 mine, but not at No. 3. Since No. 1 mine screen has the lower angle and the greater percentage of screenings, difficulty should appear here first.

One explanation of the difficulty is that the coal starts to "stew" (fuse and exclude volatile matter) on the hot screen, but as the coal only requires 4 or 5 seconds to pass chutes and screen this could hardly be the correct explanation. The theory advanced above of increase of friction with temperature would appear to fit the case.

The remedy applied was simple and efficient. A thin stream of cold water was allowed to flow down the chutes constantly, thus carrying away the heat as fast as formed, and as in a bearing, possibly offering a lubricant between coal and screen. At the time the screens were inspected the "boss" in charge said that boiling hot water from the engine exhaust was more available at the mine than cold water, and that he had at first tried the hot

water as a remedy but it had not stopped the trouble as well as the cold water. If this statement can be relied upon, it strengthens the theory just advanced. When coal screens, then, are to be used under such severe conditions, knowledge of this temperature factor is important.

Ore chutes and screens are seldom required to perform service requiring the close adjustment necessary with coal, and a slight increase in friction is not easy to notice. Occasionally hot roasted ore is conducted by gravity chutes or screened on gravity screens. The angle of slope ordinarily used, since breakage is immaterial usually conceals any error in design. Philip Argall, a well known mining engineer, says that ore screens more rapidly when hot than when cold.[1] This statement, however, presumably applies to actual ease of separation of the particles through drying, rather than from more rapid motion through contained heat.

9. Shape of top of screen bars. The upper side or surface of the screen bar has been made flat, inclined, pointed at different angles, and variously curved and of many widths. The object is to present a narrow surface for the lumps to ride on, that a slight change in direction may cause them to tip over and loosen adhering fines. For large sizes of material especially, it is believed that wide flat bars increase somewhat the coefficient of friction through increase of rubbing surface, and even though the weight per unit of rubbing surface is less in this case it does not entirely compensate for the increased amount of friction. A parallel case might be that on a hard pavement a narrow tired wagon is preferred, while on a very soft road, the reverse is true. In

[1] Min. Ind. Vol. 6, 1897, p. 370.

general, most bar screens are so shaped as to present scarcely more than a line down the bars for a rubbing surface.

It is hoped in the Mining Department of the University of Illinois to carry out a series of tests to ascertain the relative importance of these various factors in influencing the sliding angle required for coal and ores.

Design of Gravity Coal Screens: Fig. 2 illustrates some of the many designs of screen bars that have been tried in England[1] and indeed most of them in this country.

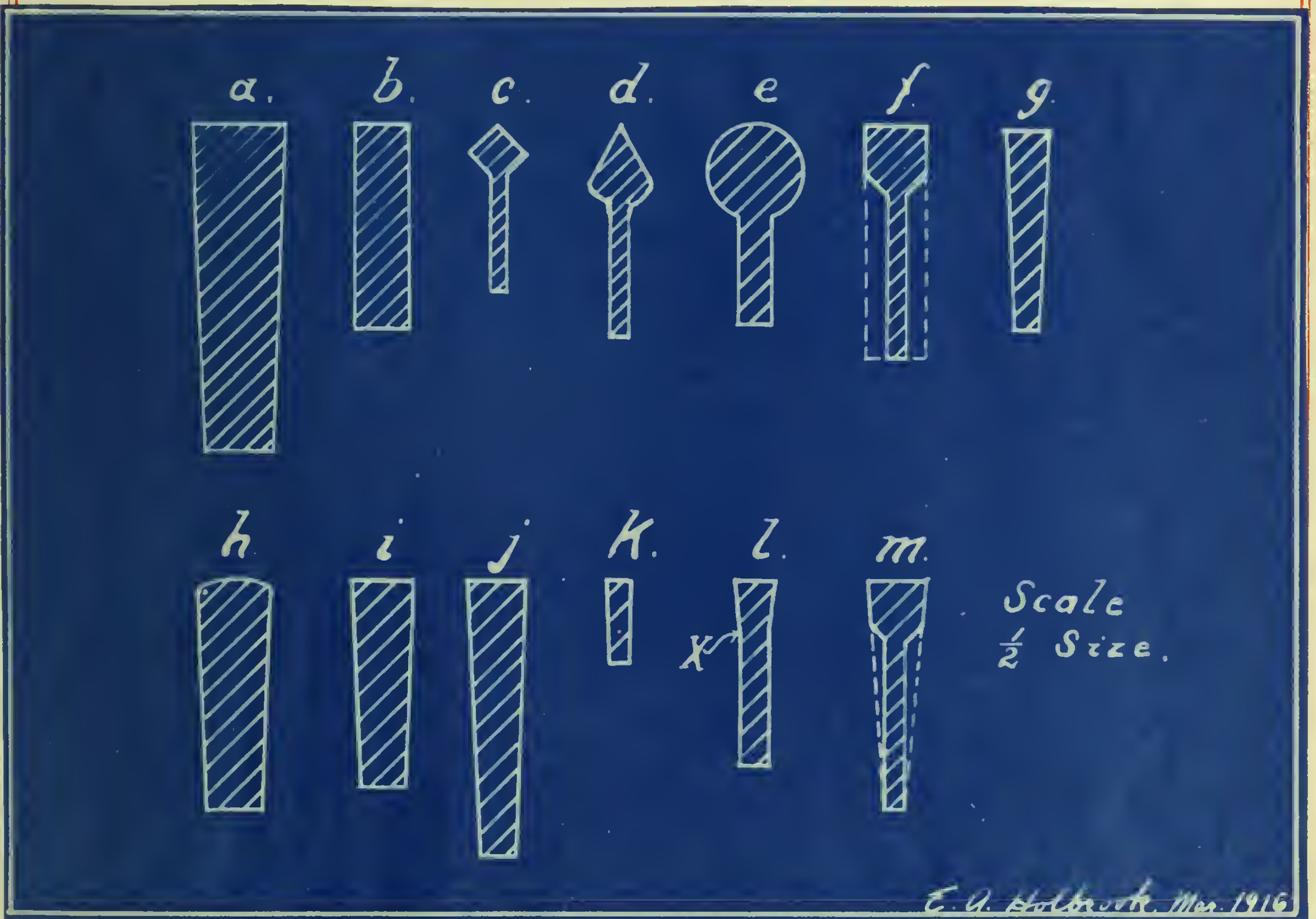


Fig. 2. English Bar Screen Sections

1 Riggs, James, Inst. of C. E. of London, 1896-97, Vol. 127, p.163.

These may, of course, be spaced any distance apart, depending on the amount and size of oversize desired.

Riggs criticises the shapes as follows:

(a) "Slack will not clear itself, and soon reduces screening area."

(b) "A wrot iron section with same criticism as for (a)."

(c-e) "Devised to faciliate entrance of slack into the spaces."

(f) "Recommended, as the upper parts of the sides are parallel and there is no unnecessary metal."

(g-h) "Slightly rounded surfaces which do not attain the best advantage, either in screening or for weight of section."

(i-k) "These bars have unnecessary weight."

(l) "The high acute angle of the side (X) makes for rapid wear."

(l) Recommended. "The obtuse bevel reduces the liability to wear, and secures a free passage for the slack."

He also recommends that bar screens receive coal at their upper end from chutes which slope 23° and discharge on chutes sloping at 28°. Evidently the first chute slows the coal that it may be well screened, while the latter angle increases the speed that it may be taken away rapidly. English screens are from 4 to 6 feet wide and from 6 to 20 feet long.

In America the bar lump coal screen used up to the present time in the bituminous coal mining districts of Pennsylvania, Ohio and Indiana, has been governed by an agreement between operators and miners as follows:

"Screens hereby adopted for the state of Ohio, Western Pennsylvania, and the bituminous district of Indiana shall be uni-

form in size, 6 feet wide by 12 feet long, built of flat or akron shaped bar of not less than 5/8 of an inch surface with one and one-fourth inches between bars, free from obstructions, and that such screen shall rest upon a sufficient number of bearings to hold the bars in proper position." The run of mine coal is dumped over this screen and the miner receives pay only for the oversize. The cross-section of the standard Akron bar generally used is illustrated in fig. 3, (section d).

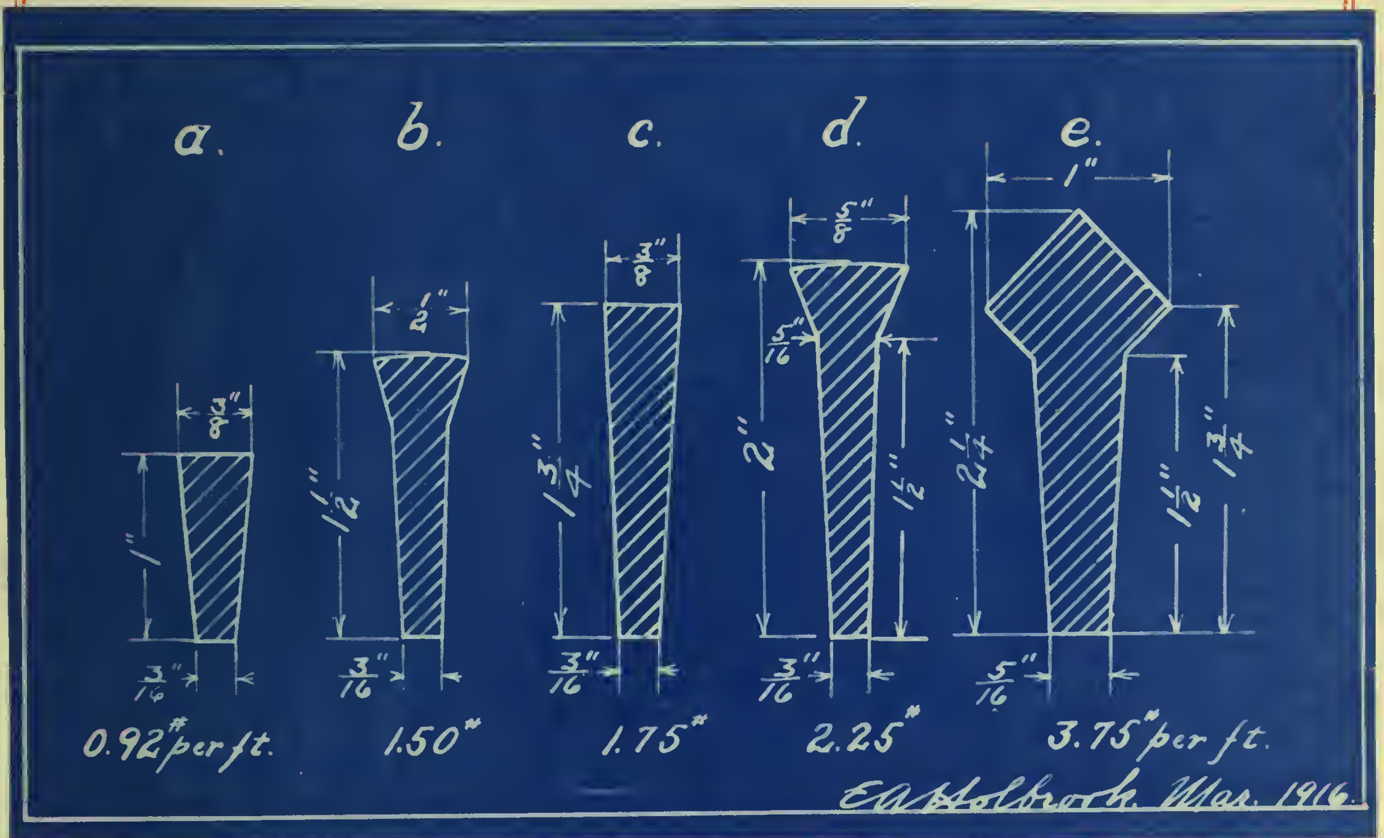
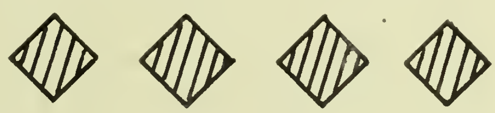


Fig. 3. American Standard Bar Screen Sections

The name Akron Bar given to a screen bar of this particular cross-section has reference to the city of Akron, Ohio, where it originated. A corruption of this term to "acorn" bar from the fancied resemblence of the cross-section to an acorn is sometimes

heard. Such a bar fulfils the requirements of wear, clean screening, and freedom from clogging. The weight of the section is 2.25 lbs. per foot. Where not intended as a standard screen it is also bought and used in lengths of 12 feet 2 1/2 inches, 14 feet, 15 feet, and 16 feet, depending on the cleanness of screening required. This same standard screen is to be found at all mines in the districts mentioned whether the daily output is measured in hundreds of tons or in thousands. For convenience in the larger mines two screens are used, one for each compartment of the hoisting shaft. Fig. 3, a, b, c and e represent a number of popular bar screen sections used in the bituminous sections of America, either for secondary bar screens following the standard one or for any screening work in districts where the bar screen agreement is not in force. (a) is a wedge-shaped bar used for small sizes of coal. (b) is of the standard shape, but is particularly adapted to small coal. Its usual dimensions are as given, 1 1/2" x 1/2" x 3/16". (c) is a wedge bar used on large coal. At Illinois tipples a frequent auxiliary bar screen is provided at the side of the tipple over which mine run coal can be dumped and screened for wagon or local trade. The wedge bar is frequently used here as it is a somewhat cheaper section than the Akron.

Section (e) is often known as a diamond bar screen, from the shape of its head. At a number of mines in Illinois the diamond bar used has no lower extension being a row of simple square rods set on edge as follows:



When used as coal screens, the bars noted are generally held in position by a set of cross-bearing bars, notched to carry

the screen bars. The standard bearing bar for the standard bar screen is a section 4 inches by 3/4 inches, cut by notches about 1 1/2 inches deep for the bars to rest in. The operators-miners agreement requires the screen bars to rest in a "sufficient number of bearing bars to hold the screen bars securely in place". In practice a bearing bar is placed at the upper and lower ends of a bar screen and about every three feet between. From the standpoint of security this may seem unnecessarily rigid, but pieces of coal or slate often become wedged between the bars and are struck by succeeding pieces, producing the same spreading action as though a wedge had been driven between. For practically the same reason the bars are made wedge-shaped and with the widest part of the wedge at or near the top. In the older bar screens where the section was made rectangular irregular pieces of material frequently lodged half way through them. By using the wedge-shaped section, any piece able to pass the widest part of the bar immediately falls away without further obstruction.

Bar screens, as a rule, are never used to their full capacity as dumping takes places at irregular intervals from a car and material is screened in sudden rushes. Under these conditions a screen 4 to 6 feet wide may be used, either for a few hundred or up to 2 or 3 thousand tons per day. One bar screen 10 feet wide treats 5000 tons of run of mine coal per 8-hour day, another 6 1/2 feet wide only 800 tons. A rule for maximum tonnage is 500 tons of run of mine coal per foot of width of screen per 8 hour day. Practically their capacity may be made unlimited by increasing their slope.

The length of a bar screen is regulated by the cleanness

of screening desired rather than capacity, as a short screen will pass as many tons as a long one, but not screen it so thoroughly. Screens are usually 12 to 16 feet long irrespective of tonnage. This point is made because many engineers quote capacity of gravity bar screens in square feet of screening area used per ton per hour. This gives little idea of the actual work unless width and length are stated as well.

Design of Ore Grizzlies: In ore dressing the grizzly is built much stronger than the bar screen used for coal, and the cross section of the bars is usually a simple wedge. Fig. 4 shows the common bars used.

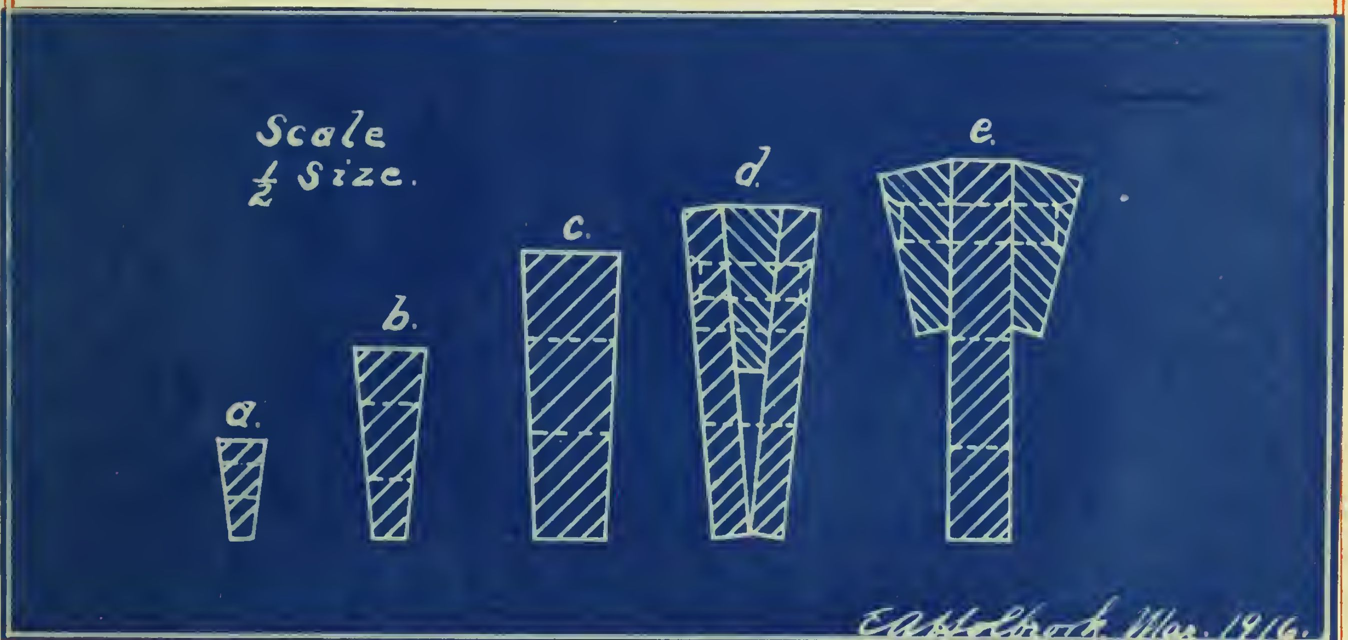


Fig. 4. Standard Grizzly Bar Sections

Old steel rails, inverted and fastened together are a common form of grizzly. Much harder and heavier material must be handled on a grizzly than on a coal screen and they are constructed unusually strong. Instead of the bearing bar, the bar section is pierced by a number of holes, through which rods are passed, the distance apart of the bars being kept constant by spacers or washers on the rods. The usual fault with grizzlies comes from a general use by the manufacturing firms of an insufficient number of these cross rods or bolts. Apparently a grizzly bolted together every 4 or 5 feet is rigid, strong and secure. The tremendous pressure, however, exerted by the wedge pieces which become lodged between the bars soon bends the bars and widens the space between them. This serious defect, which leads to large pieces of undersize, should be remedied by making all ore grizzlies with tie rods spaced not over 2 feet apart.

Life of Bar Screens: With either ore or coal, the life of a properly constructed bar screen is long, often with coal screens the life of the mine; with the harder ore the wear is greater, especially at the top end of the screen, where the material first strikes. The writer has in mind a grizzly that handled 500,000 tons of ore and was still in fair shape. Most grizzlies replaced have failed through bending of their bars due to insufficient number of spacing rods, rather than from wearing out.

Advantages and Disadvantages: The gravity bar screen is the simplest and cheapest of all screening devices to instal and operate. From $50. to $100. covering the whole cost of one of regular size, with often no expense for repairs or renewals for years. It is of almost unlimited capacity, requires no power and

little attendance, and for the roughest and coarsest work has not been excelled.

Its defects may be discussed as follows:

1. Difficulty of changing size of product. Coal market conditions frequently require a sudden change in the size of product which can be made only by putting in an entirely new screen or by changing the spaces between the bars, either of which schemes is troublesome. Many bar screens have been invented in which the bar spaces may be quickly changed by movement of a control lever or similar device. Even as early as 1834 an Englishman named Hall patented such a device. They all lack the prerequisites that have made the bar screen a favorite, namely, simplicity and wearing qualities, and none of them has been generally adopted.

2. Difficulties due to change in the coefficient of friction between screen and material. These difficulties have been outlined. That due to breakage at the end of the screen through excessive velocity should be emphasized. This tendency toward breakage for the same velocity probably increases as the cube of the diameter of the material being treated, an important point when designing for coarse material.

3. Lack of exact sizing. The bar screen is primarily intended for coarse or rough sizing and when fine and exact sizing are needed the results are unsatisfactory. Theoretically, a piece of material whose minimum thickness is the width of the bar spaces and whose maximum dimension might be several feet will pass the screen if it falls on the screen at a favorable angle. In practice the results of this are that a mineral which tends to break into cubical blocks will receive exact sizing over a bar screen.

Minerals as slate, shale, lignite coal and others, which tend to break into flat pieces, will frequently allow large uneven pieces to pass into the undersize. As an example in the Mining Laboratory of the University of Illinois, coal which had passed a one inch bar screen was rescreened over a one inch round hole screen and 24 per cent was oversize, some pieces which were mostly flat shale and bone coal, would not even pass a two inch round hole screen. Moreover when dealing with mineral under 1/2 inch in size on a bar screen the pieces become so numerous that excessive choking of the spaces results, and on such sizes a slight spreading of the bars changes considerably the size of the product. Roughly 1/2 inch represents the minimum size that is successfully screened through a bar screen.

4. Difficulty encountered in obtaining clean screening. With bar screens, the lumps slide down the screen rather than roll. Thus a dirty lump may carry considerable fines into the oversize. This is sometimes prevented by hanging loosely above the bar screen and about half way down, logs, wires or chains, against which the lumps strike and turn over, freeing themselves of the adhering fines. A similar result is obtained by breaking the bar screen into two or more sections in steps, the coal falling from one step to another is jarred and releases the fines. Either of these devices has the disadvantage of breakage of any tender mineral.

Recommendations. It seems feasible in the design of any flow sheet involving the use of bar screens to inquire closely into the nature of the material, its possible changes, the need for close sizing, and to allow sufficient head room to make necessary changes possible.

Finally, particles moving down the ordinary bar screen have either a positive or negative acceleration, causing either excessive velocity or the necessity of pulling the material over the screen by hand. It is here suggested that a theoretically perfect bar screen could be made by having the plane of the bars and chutes curved approximately in the form of a cycloid. Such a curve would allow material to traverse the length of the screen in minimum of time, therefore, with the greatest average velocity and conversely with the average flattest slope, making more perfect screening possible. The upper and lower points on a cycloid curve connected, form an angle of 32° 28' with a horizontal line. Therefore, with slight variation an approximate cycloidal curve could replace the straight bar screen. Moreover increased velocity and fall would be given the particles at the head of the screen where most needed and so decrease the velocity at the lower end of the screen that the breakage would be reduced to a minimum. On a long screen requiring a steep slope, the saving in mill height or head room would be considerable. With modern steel bending rolls, the additional expense of the bent bars should be small. The writer is not aware that the scheme has been suggested previously.

Other Gravity Screens: Another class of gravity screens of quite different properties from those having bars are the stationary inclined gravity screens having either wire mesh cloth or punched plate surfaces. Due to restriction of size of opening in two directions and to the slope of the screen as well as to the trajectory of the moving particle, these screens produce an undersize the maximum of which is considerably less than the dimension of the opening of the screen, and which in every case is a function

of the slope, although this maximum size is considerably increased by an elongation of the holes in the direction or path of the moving particle. Thomas A. Edison[1] has investigated and devised such stationary gravity screens, and points out not only the necessity of having the length of the holes in the plate at least 1/2 inch if any material is to get through but also the long life of such a screen, although an increase of one per cent of moisture in ore increases the wear on the screens by seven.

As a rule, such screens are used for the finer work, it being exceptional to see a gravity wire or punched screen passing material larger than 1 inch size. They are mostly used for producing sizes under 1/2 inch, where accuracy is required and where to prevent blinding it is desirable to use large holes, and still obtain a finer undersize than is indicated by the diameter of the holes.

The writer recently saw gravity wire screens being used in experimental work in an effort to get a sized coal under 1/8 inch mesh. The screens were 6 inches wide and 15 feet long set at an angle of 45°. The wire cloth had 1/4 inch meshes. Although covers were necessary over the screens to keep the material from bouncing out, they each were handling satisfactorily 3 tons per hour. As the finer sizes of coal become better understood and more valuable, the cheapness, capacity and absence of any power required should make this type a favorite over the power screening machinery.

In coal screening, the use of wire mesh cloth for degradation screens has been considered (p. 38). Round hole and elongated

[1] T.A.I.M.E. Vol. 19, 1890-91, p. 656.

hole screens also are often used as secondary or degradation screens. For example in storing a sized coal in a bin, crushing and rubbing takes place with a production of up to 5 per cent of fine sizes. As this dust interferes with the appearance and consequent sale of the coal its removal is necessary before loading the final car or wagon. The chute leading from bin to the car has its bottom formed for part of its length of a screen plate with round or elongated holes, for illustration:

#1 Nut coal 3 in. - 2 in. has a degradation screen with 3/4 in. r.h.
#2 " " 2 in. - 1 1/4 in. has a " " " 3/4 in. ""
#3 " " 1 1/4 in. - 3/4 in. has a " " " 3/8 in. ""
#4 " " 3/4 in. - 1/4 in. " " " " " 3/16 in. ""

These screens slope at 35° more or less, and at this angle, the maximum diameter of coal removed is about two-thirds the diameter of the hole mentioned. At the coal crushing plant of the Illinois Steel Company, at Joliet, lump coal is reduced to 1 1/2 inch round hole size with Bradford breakers and from here to 1/4 inch size with swing hammer pulverizers. Wishing to take out material already below 1/4 inch round hole size, before pulverizing, and relieve the machines of extra work, the bottoms of the chutes leading to the pulverizers are of 1/2 inch round hole punched plate for a length of about 15 feet, on a 45° slope. The undersize produced has a maximum size of about 1/4 inch.

Elongated hole plate screens are illustrated by the patented flanged lip screen or step screen, fig. 5, which is frequently used as a degradation screen. Not only does it handle the sized coal on less slope than the wire cloth screen, but the steps aid in turning over the coal. The perforations are 12

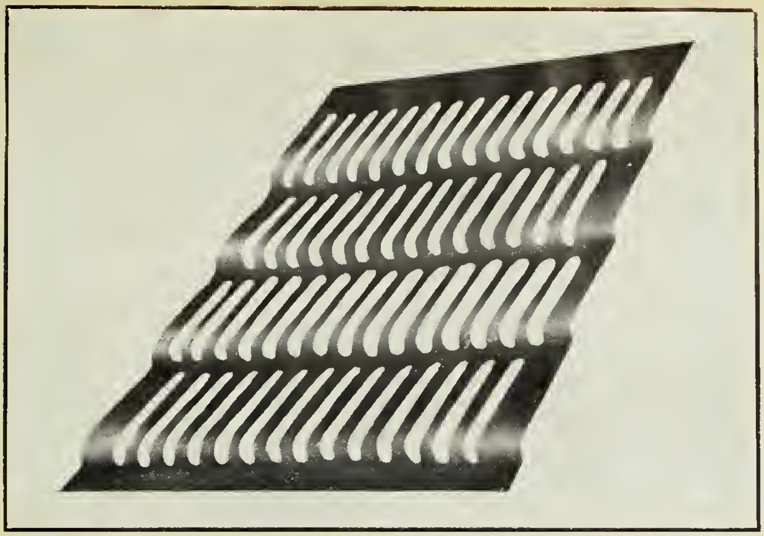


Fig. 5. A Lip Screen

inches long and are slightly wider at the lower end. Wedged pieces slide out at the lower end of the perforations. For Illinois practice with lip screens, the following slopes are recommended:
For 6 in. to 3 in. egg coal (slot 3/4 in. x 1 1/4 in. x 12 in.), 30° slope. For 3 in. to 1 1/4 in. nut coal (slot 1/2 in. x 3/4 in. x 12 in.) 32° slope.

Wire mesh cloth and perforated plate gravity screens have a distinct use in ore dressing. In some processes it is necessary to screen with as fine as 100 meshes per linear inch, or 10,000 holes per square inch; screening of sizes above 10 mms., about 3/8 inch is considered as coarse work. For reasons stated gravity bar screens can not be used below this size. Their place is sometimes taken by the gravity wire or punched plate screen. Considerable difference exists in the ratio of the maximum size of piece in the undersize to the diameter of hole in the screen, depending on the same variables as mentioned with similar coal screens and in addition on the shape of the grains of mineral being treated. One case is recorded where a 30 mesh wire screen set at

45° gave a maximum size of grain of 50 mesh in the undersize. In general, as in fig. 6, let a be the side of a square hole in a gravity screen set at an angle of x°, then the horizontal projection b of the side a, or b = a Cos. x, is the theoretical maximum grain that may pass the screen hole. This is a limiting condition and may only be approached when the particles have nearly a vertical trajectory, i.e., a low velocity, and approach spheres in shape. For the case where $x = 45^{\circ}$ and a = 1/4 inch, b = 0.17 inches.

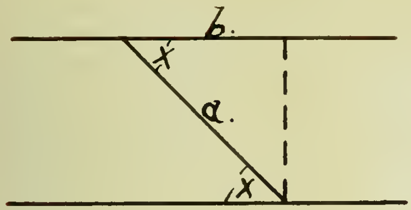


Fig. 6. Effect of Inclined Screen Surface

Unskilled mill men who have discovered that the inclined wire screen produces a small undersize in proportion to the size of hole and also its comparative freedom from blinding have imagined the inclination could be increased enough so that very fine sizes could be produced while still retaining the large holes. Practically, on exceeding a slope of about 55°, the velocity of the particles becomes so great that they jump over the screen, and even if it is 15 or 20 feet long they will touch at a few points only, and the chances for screening are reduced to a minimum.

As gravity plate or wire screens are used on the finer sizes, perhaps under 1 mm., a new condition arises, for the holes soon blind with irregular pieces. Why this does not occur with the coarser sizes can be explained by the fact that the coarser sizes rattling over set up enough vibration in the screen to cause the lodged pieces to bounce out of the holes, while with the smaller

sizes the screens seem to be "dead" or to lack vibration. If the material contains a larger percentage of oversize vibration is increased or sometimes very light wire screens are used which vibrate more easily; on the whole the only remedy has been to subject the screen to artificial vibration, which case will be discussed under Vibrating Screens (p.105).

Another feature with these screens is that two or three per cent surface moisture, an amount that will not be noticed when screening coarser material will cause the dust to adhere to the wires and in a short time blind the holes. For example with a hot dry barite ore coming from a calciner the writer was able to produce a clean 20 mesh undersize (using a somewhat larger rectangular hole), while such an ore in its slightly moist raw state could not be separated with these screens.

Drag Screens: A minor type of stationary screen, although the passage of the material over it is not by gravity, is the so-called drag screen. The material to be screened is dragged over the screens by means of scrapers, which are usually fastened to an endless chain or belt passing continuously in one direction. Material may move up the screen or down the screen or the screen may be set horizontal, and the screening surface may be bars, wires or plate. This screen is a favorite for rescreening washed coal, especially where much water is present, for besides ridding the coal of the finer sizes, it drains it of excess water. F. C. Lincoln[1] lists a drag screen 2 feet wide used in sizing raw coal 3 3/4 inches - 0 containing 1 3/4 inch slot holes and 3/8 inch

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1 Coal Washing in Illinois. Bull. No. 69, Eng. Expt. Sta., U. of I.

square holes, having respectively lengths of 16 feet and 8 feet, capacity 40 tons per hour or 0.2 square feet per ton per hour. Five other drag screens listed as sizing washed coal, have round holes varying from 1/8 to 5/16 inch and average 1 square foot per ton per hour capacity. At one rescreener in the state a 1 1/2 inch space bar drag screen 5 feet wide and 30 feet long first drags to coal up a 26° incline and then horizontally. The capacity is 600 tons per 8 hours with a scraper speed of 80 feet per minute. Round holes for any size above 1/2 inch are not favored with these screens on account of the pieces lodging in the holes and being broken by the scraper. They have the decided advantage of being able to elevate the coal while screening it, and are the only screens where height is gained during screening. With coal, the wear of scrapers and screens is inconsiderable, but no record of worn out screens is available. The speed of the scrapers is from 60 to 100 feet per minute, so slow that the coal moves over the screen without jar or tipping of the lumps, making clean dry screening unlikely. The real place of this screen is as a washery dewaterer, especially where the plant design needs headroom.

In ore dressing the drag type of screen is occasionally used as a dewaterer. Since few coarse ore products require rescreening or resizing after wet treatment, some form of bucket elevator is more useful as a dewatering device.

A modification of the drag screen in ore work called the Chain Grizzly[1] has been introduced at the iron ore mines in Minnesota. Here parallel endless chains passing over pulleys at each end form the screening surface and at the same time convey the coarse oversize over the screen.

[1] Eng. & Min. Jour. Apr. 1, 1916, p. 600.

V. REVOLVING OR TROMMEL SCREENS

Of the three main classes of screens, the revolving screen or roller screen of the coal tipple, generally called a trommel or drum screen by the ore dressing writers has been the most studied and described, and it is the main type of screen in ore dressing practice, where perfect screening is more important than speed, and where, as in the sizes ranging from 15 mms. to 2 mms. wet screening is the rule. In coal preparation on the contrary its breakage of the tender coal has resulted in an unfavorable opinion towards it especially for coarser work and it is not being installed in the new plants.

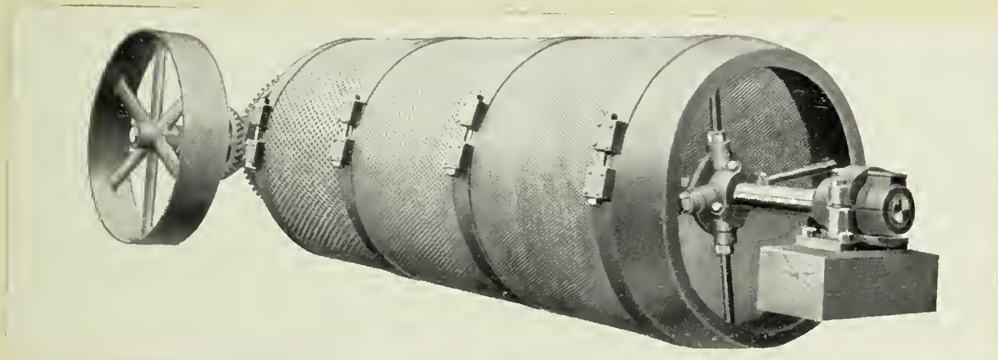

Fig. 7. A Revolving Screen

The Common Revolving Screen: The revolving screen, fig. 7, in its simplest elements is a cylinder with its envelope a screening surface of wire mesh cloth or perforated plate or occasionally of bars. With its longitudinal axis set at a slight

angle it receives material at the upper end and discharges oversize at the lower. The screen revolves slowly and carries the particles inside around until a point is reached where the force of gravity overcomes the friction of the particle against the screening surface plus whatever centrifugal force the particle may have due to its rotation. It rolls down hill until equilibrium is reached and then is carried up the slope again. Since the axis of the screen is set at a slight slope, the path of steepest descent which the particle will follow, will not be in the plane of an element of the screen surface. If fig. 8 represents part of a revolving screen, the particle (a) will be carried by the rotation up to (b) when it will fall or slide down to point (c) to be again raised to (d), etc. This path of a theoretical particle in a revolving screen is known as the saw tooth path. R. H. Richards[1] calls the angle ABC the pitch angle of a particle and directs attention to its relation to the slope of the screen as regulating the length of time a particle is retained, which in turn is a function of the capacity of the screen and its cleanness of separation. Rittinger[2] shows the effect of centrifugal force on a particle being screened. As the revolutions per minute of a trommel increase, i.e., its peripheral speed, the particle is carried higher up the sides of

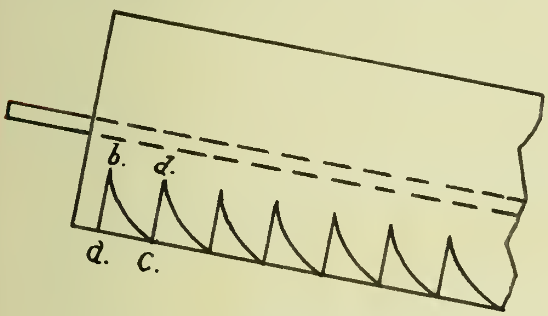

Fig. 8. Path of a Particle in a Revolving Screen

1 Ore Dressing, Vol. 1, p. 375.

2 Aufbereitungskunde, p. 260.

the trommel before sliding, rolling, or dropping down. This speed may be increased until the particle is carried around the screen and no screening then takes place. If the coefficient of friction of coal is assumed to be 30°, the following table shows, for screens of different diameter, the r.p.m. at which this case would result and also the usual working speed:

Diameter of Screen	R.p.m. at which no screening takes place	Good Practice	
		Ore R.p.m.	Coal R.p.m.
30 inches	63	16-20	30
36 "	56	16-20	26
48 "	48	15-17	20
60 "	43	12-15	16
72 "	40	12-15	13
84 "	35	10-12	11

In general the efficiency of a revolving screen is low at very slow speeds, increasing with an increase of speed until the particle is carried roughly one-fourth of the way up the screen as a maximum on each revolution. It is often claimed that for best results with a revolving screen, the speed of revolution should be so slow that the particles will slide down the screen rather than roll. It is difficult to see how this aids screening, although it may produce less attrition of the coal than when the particles roll constantly in their passage through the screen, yet such a slow moving screen must necessarily be of low capacity. Revolving screens designed for coal average from 200 to 250 feet per minute peripheral speed, although English practice is much slower, 90 to 180 feet per minute. Screens in operation in Illinois washeries

vary from 126 to 471 feet per minute.[1] Evidently many arc not running under the best conditions.

With ore trommels the peripheral speed is somewhat less, due to its greater friction against the screen. In both cases the other variables of slope, diameter, length and size charge somewhat the correct peripheral speed.

For cylindrical revolving screens used with coal, the standard angle of slope of the long axis is about 5°, often 0 - 7/8 inch or 1 inch slope in 12 inches. Wire screen revolving screens require slightly more slope than those using plate screen. A slight increase in slope angle greatly increases the capacity of the screen by increasing the pitch angle of the particles, but makes for less thorough screening unless the length of screens is increased. A screen designer has stated that 5° is the standard inclination, if the coal contains a large proportion of oversize the angle is made a little greater, since not so much is to be screened out. If the proportion of undersize is large, the angle is decreased slightly.

Most cylindrical coal screens in Illinois used as re-screeners range from 4 to 7 feet in diameter, usually 6 feet on the large sizes, or where large capacity is required. The length of a screen is governed by the number of sizes to be produced in the same screen or by the cleannes of screening desired. Length has no definite relation to the capacity of the screen, but for the ordinary work certain lengths which have been found satisfactory are generally adopted.

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1 Lincoln, F. C. Coal Washing in Illinois, Appendix E.

Revolving screens rotating empty consume little power, but when loaded power is expended in constantly lifting the load and the amount required is directly proportional to the load. Since a change of slope, speed, screen size and diameter greatly change the capacity it is difficult to find average capacity and power required for the average screen. A screen 10 feet long, 6 feet in diameter, with a 5° slope, making 12 r.p.m. will handle up to 100 tons of oversize per hour. It takes about four revolutions for a particle entering to be discharged. The screen lifts the particles at the rate of 6 x 12 x 2 = 144 feet per minute. Therefore, the total lift on each particle = 144 x 4/12 = 48 feet. $\frac{100}{60}$ tons x $\frac{2000}{1}$ lbs. x $\frac{48}{33000}$ = approx. 5 H.P. (theoretical) to drive the screen. If the screen stops with a full load of coal, about twice the power is necessary to start as is required to keep it in operation, so that most screens are overpowered. The usual design is to allow twice the theoretical H.P. or in this case the motor would be 10 H.P.

Variations of Standard Type. The cylindrical screen with central shaft is the standard type used for coal and for fine ore work. When the length of the screen exceeds 20 feet or the material is large or heavy, or the slope considerable, the central shaft needed becomes too large or the thrust on the lower bearing is excessive. In these cases the screen is supported and driven from trunnion wheels or rollers. Revolving screens also vary widely in the shape of the envelope. For example, it may have the shape of a truncated cone, the slope of an element being about 5° or equal to the slope of the axis of the ordinary cylindrical screen. The axis or shaft of this screen may be horizontal, avoid-

ing end thrust on the bearings while its cone shape allows material to work forward as easily as in the standard type. The disadvantage of its conical shape is that special cutting of the screen cloth is necessary.

Revolving screens are often made of hexagonal or other polygonal cross section. This obviates the necessity of bending the screen cloth covering, but lifts the material higher and considerable damage may result from breakage. With hard ores this shape is said to make superior products.

Where a number of sizes are required to be produced with one screen, the finest holes must come first, followed by the others according to increasing size (see method 1, p. 18). This is a disadvantage as it requires the finest screens to take the greatest tonnage and wear and since fine screens need more screen surface than coarse for the same tonnage, the chances for imperfect screening are greatest where they should be the least. Moreover, large pieces which are more susceptible of breakage than the small, are kept longest in the screen and are subject to the greatest abrasion. To overcome these defects, screens have been made double jacketed and triple jacketed, where the successive sizes of plates are concentric, one outside the other. In this way the largest holes can be put on the inside cylinder, and the largest pieces discharged immediately as oversize from this cylinder, and in succession the decreasing sizes are discharged as soon as formed. This is according to method 2, p. 18. These screens are compact and require little headroom. They have two serious defects, namely, that to change the inside screens or to repair them, it is necessary to remove the outside screens, and that the correct peripheral speed of

the outside screen limits the work of the inside one. Thus if the outside envelope is 9 feet in diameter, the whole screen may not make more than 8 r.p.m. at which speed the inside cylinder of perhaps 4 feet diameter can not work to capacity, hence additional screens are required for a given capacity. As a choice in coal work between long single cylindrical screens and short multi jacketed screens, preference is usually given the former, although in special cases, where compactness is a factor the latter is used.

An interesting modification of the multi jacketed screen is the Schmitt[1] mentioned in the historical outline, which has found considerable use in Germany, although it has not been adopted in this country. The cross section of the screen is a concentric spiral with successively smaller screen holes, and with a dam or barrier in each turn. It would seem that the complicated structure and evident trouble in making interior repairs would be fatal defects.

The cost of revolving screens varies with the factors of size, weight, and nature of screen cloth. For a 6 foot diameter screen, 20 feet long, with shaft, the cost of the frame f.o.b. should not exceed $250.00. Ordinary punched plate costs about $6. per section 3 feet x 6 feet, therefore, between 75 and 100 dollars is a fair allowance for screen cloth, a total of $325. and upward for the completed screen. For bituminous coal practice it has been estimated that the life of a revolving screen is 5 years, or a necesary yearly allowance for depreciation of 20 per cent, although one case reported showed a life of only one year. Life in these cases is assumed to be the length of time until repairs and

1 Jungst, F. "Steinkohlenaufbereitung", p. 598.

renewals have equalled the original cost of the machine.

General Criticism of Revolving Screens: The most unfavorable criticism that can be made of the revolving screen in coal work is its undue breaking of the coal. This is such a positive factor that it has led to its abandonment for coarse work. The maximum size of coal treated in such a screen in Illinois is 3 inches. Even with bituminous coal of a smaller size than this, the loss resulting from the production of small coal as a degradation product is so great, that they are being abandoned in favor of the more modern shaking screens. Recently a rescreening plant in Illinois installed a new revolving screen. This so interested the writer that particulars were asked for. The facts presented by the engineering firm were that for years the coal company had specialized with their trade name "Roller Screened Coal" and could not at the present day afford to lose the market that had been built up. The coal in question from long attrition in the screen has its corners worn off, and when ready for market the shape resembles an egg. A similar action is found in the rattler testing machine used for road material, etc. From an efficiency standpoint the wastage is large. Even in anthracite preparation practice where the harder coal withstands breakage better, this screen has been replaced by the shaking screen.[1]

When the revolving screen is used as a wet screen the conditions are somewhat different. In sizing fine coal before or after washing from 3 inches to zero, and especially under 1 inch, the material is often flowing in a stream of water, and particles tend to clog the apertures. As the screen rotates the screen

1 "Preparation of Anthracite", Mines and Minerals, Vol. 25, 1904-5, pp. 280-382.

plate is placed in an inverted position, and the offending piece drops out, or is forced out with a stream of water. By using this screen wet coal has been separated in as small as 1/8 inch mesh size, which is somewhat smaller than is usual with other types of screens. For wet screening on fine sizes, then, the revolving screen has held its own.

A coal particle in a revolving screen is turned and presented to a maximum number of openings, i.e., its chances of being thoroughly screened are great, which produces the most exact sizing and thorough screening possible. This is not always of prime importance in coal work. On the other hand only about one-sixth of the perimeter is covered with coal at one time, which means low capacity per square foot of screening surface. For illustration, a revolving screen frequently averages for 1 1/2 inch size, 2 square feet per ton per hour, while a shaking screen with its whole screening surface constantly covered may do equal work with 0.5 square foot per ton per hour. An advantage of the revolving screen is its uniform rotating motion, with consequent absence of vibration to the building. This factor often determines its use, especially at the top of a building, or above bins in a rescreening plant. Most other types of movable screens impart noticeable vibration to the supporting structure.

As a rule, revolving screens require more space than other screens having the same capacity, and finally they do not admit of hand picking while the coal is being screened. All these points weighed, for coal work, the revolving screen has passed the day of its most general use.

The Trommel for Ore Work: The trommel is and has long

been the most general screen used in the sizing of most kinds and sizes of ores. For this reason it has been exhaustively discussed by various writers and consequently it is not necessary to investigate it here. Those interested may consult the following authorities:

Richards, R. H. "Text Book on Ore Dressing", p. 207.

Wiard, E. S. "Theory and Practice of Ore Dressing", p. 263.

Louis, Henry "The Dressing of Minerals", p. 55.

Rittinger, P. R. von "Aufbereitungskunde", p. 260.

Callon, J. "Cours d'Exploitation des Mines", Texte 3, p. 27.

A few points connected more with the practical operation of trommels, as taken from the writer's note book and which have escaped most of the above writers are noted below:

Ore trommels do not differ in appearance or construction from the revolving coal screen described. Because the average specific gravity of ore or rock is about 2.65 as compared with 1.30 for bituminous coal, screens must be made heavier and more rugged. The wear on the screen surfaces is much greater, screening surfaces with small holes often requiring renewal in three or four weeks.

With ore exact sizing of very fine material is a necessity therefore for sizes down to 2 mm., the trommel screen has held its own. Within the last ten years large heavy trommels mounted on trunnions have steadily replaced the grizzly for the coarse rock work in size 1 inch and greater without limit as required. These sizes of hard rock are not subject to breakage and the objection to the screen from this source heard in coal work is not valid here. Trommel screens generally work dry on ore above 1/2 inch size, for finer work wet screening is favored, as the use of water in the

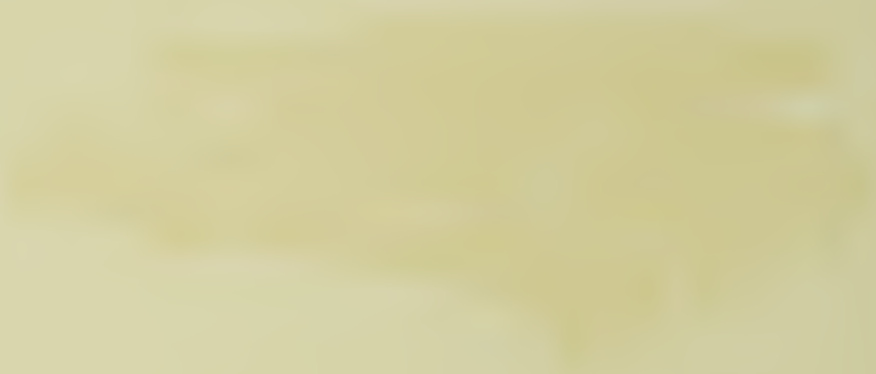
screen is of great aid in cleaning the meshes as the screen revolves, and also prevents dust.

As the size of the meshes decreases below 2 mm., a new condition arises. The number of pieces in a ton of material enormously increases and the small screen holes used are in a screen plate which, to secure wear, must be of proportionally greater thickness. Under these conditions even wet screening fails or where partially successful, involves a frequent beating of the screen to keep the meshes open. While local conditions may vary the figure, 1 mm. holes are given as the minimum size that can be used in wet or trommel screens. Below this, classification in water is usually resorted to for separation.

A mill superintendent complained of the blinding of certain of his fine trommel screens and placed the blame on the screens as a type. The real trouble came from placing certain of the screen plates wrong side out. To the eye both sides of a fine screen plate look the same. The holes, however, have been punched from one side, which is smooth and the holes are of a little larger diameter than on the other side, which is slightly rough and burred where the die has torn out the metal. If the burred side is placed on the inside little blinding will be noticed as any piece caught in the burr falls through the hole. If the other side is placed inside, these small pieces wedge in the holes and can only be removed at considerable trouble. Knowledge of such apparently trivial points in screens may mean their success or failure.

Compared with revolving coal screens ore trommels are usually of smaller diameter and proportionately are longer and

have greater slope, while the speed is somewhat less and the horsepower needed is greater. A single trommel usually has but one size of holes, if more sizes are required separate and independent trommels are used.



VI. SHAKING SCREENS

Description and Variables for Coal Work: The growing use and importance of the shaking screen in coal preparation in the last twenty years threatens to eliminate other types of screens where coal is intended for the general market. First came a general replacement of the bar screen by the shaker screen for coarse coal preparation, as a rule in sizes over 1 1/4 inch or 2 inch, and during the last 5 years even the revolving screen used in preparing coal below these sizes has given way to special forms of shaking screens. The usual type is illustrated by fig. 9.

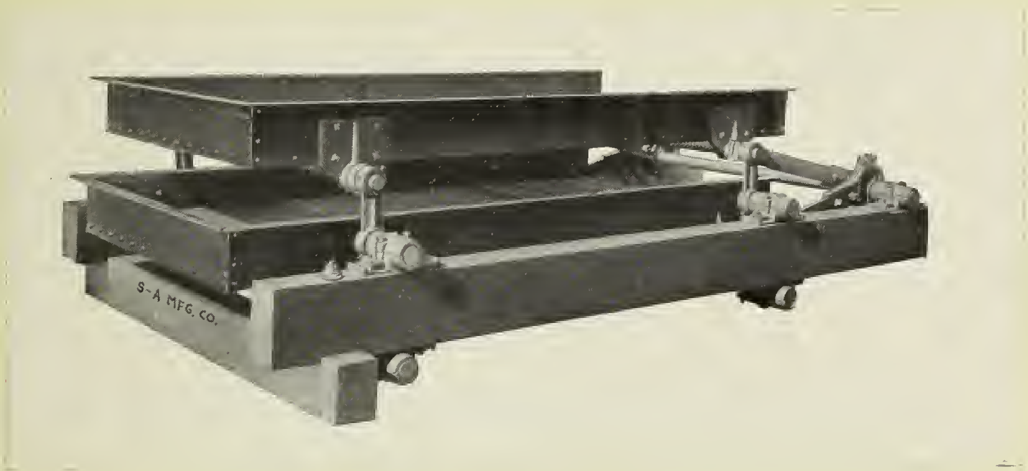


Fig. 9. A Shaking Screen

It is a rectangular screen inclined at a low angle and suspended from or supported by loose rods. The frame is attached by a connecting rod to an eccentric or other mechanical device for giving an oscillating movement. Material fed on the top end of the screen slides down, especially on the back stroke, the finest

sizes falling through the screen perforations. In nearly every case, the screening surface is round hole plate, although bars and wire cloth have been used. If the screening surface is replaced or covered by blank plate, the screen is said to be veiled. To avoid vibration from the reciprocating motion, screens are hung in pairs from the same driving shaft and their direction of motion is opposite. Apparently such a mechanical appliance is of extreme simplicity; but theoretically and practically it is complicated by the variables following, any one of which may affect its work and capacity.

1. Material of screen, size of particles, moisture and other conditions affecting the coefficient of friction between moving coal and screen plate. These have been discussed under Gravity Screens, Part IV.

2. Angle of inclination of the screen which affects the velocity of the particles. Greater slope gives greater velocity, and more capacity, but lessens the cleanness of screening.

3. Length of throw and revolutions per minute of the eccentric which measure the amount and intensity of movement of the screen frame and the particles on it.

4. Size of perforations. With large perforations rough pieces of coal which lodge in the holes have to be removed by giving the screen such an effective throw that they will be lifted out. Large pieces require more force than small ones, since $F = \frac{W a}{g}$, or for the same force applied the small pieces receive the greater acceleration. As the size of the particles increases, then, greater force must be applied to the screen to keep the holes clean, that screening may be continuous. Theoretically, increased speed or

throw will accomplish this, practically the large hole plate is given an increased inclination. As an illustration a screen at an Illinois mine had plate with maximum holes of 6 inch diameter. When these were replaced by 8 inch hole plate the holes blinded. The slope of the particular plate was increased several degrees and gave no further trouble.

This explanation is necessary since in the discussion of bar screens it was stated that fine coal required a greater slope than coarse. While this is equally true on a shaker screen if the screening surface is bars, yet with the usual perforated plate surface used the large particles lodging in the holes makes a greater slope necessary for them and more than balances the difference of friction with size.

5. Direction of motion. Shaking screens may have a more or less pendulum like motion or they may have an upward and forward and a downward and backward motion, or some combination of these which will give a forward jerk to the coal. These will be considered under special types p. 88.

Theoretical Consideration of the Action of a Shaking Screen: The theoretical considerations connecting these different variables of shaker screen action have not been studied previously, as by adjustment it has been usual to make a certain shaking screen work well. Other screens are designed from this one, trusting to flexibility of adjustment after installation to produce passable work for the different conditions. Speed or revolutions per minute of the driving shaft is the variable most easily changed. An examination of coal tipples in Illinois revealed that many of them contained shaker screens working under unfavorable conditions.

Some imparted excessive vibration to the structure through poor balancing of the reciprocating parts, others moved the coal so fast that only imperfect screening took place, while still others had been equipped with special knockers to keep the screen openings free, a doubtful improvement which soon wears holes through the screen. Some of the newer tipples contain well designed screens, one especially was seen in northern Illinois of which the superintendent said "That screen always worked so well that several engineers have been here to take measurements before designing others."

While recognizing that a subject complicated by so many variables is difficult of a complete theoretical solution, yet it is believed that the discussion of shaker screens on the following pages will given an insight into their action.

Reduced to its elements, a shaker screen is an inclined suspended perforated plate, to which is imparted a reciprocating motion by means of a rod connected to an eccentric, fig. 10. Material such as coal, to be screened, is fed on the upper end of the inclined plate, and under the reciprocating motion mentioned, moves down the plate, the smaller sizes falling through the perforations, the larger sizes passing over the end.

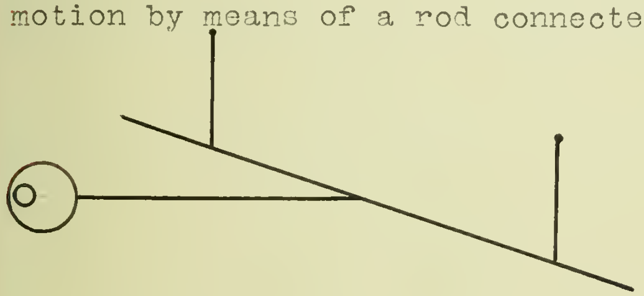


Fig. 10. Elements of a Shaking Screen

For any given material, screens will always have three of the variables previously mentioned. (1) Slope or inclination of the plate. (2) Speed or R.p.m. of the shaft giving the eccentric

throw. (3) Amount or length of throw. Friction between the plate and moving particle with two standard materials such as Illinois coal and smooth bright steel screen plate, may be assumed to be a constant, if in the discussion one size only of coal is considered. The variable caused by the necessity of throwing lodged particles out of the holes will not be considered, excepting to recognize that it increases the angle of the screen somewhat in practice. For a given size of coal this may be represented by a factor.

The usual practice in the design of screens is to assume a combination of throw, speed and inclination that has worked well in previous practice. For example, with an inclination of 3 1/2 inches per foot (about 16° 16') a shaker screen with 100 six-inch throws or complete shakes per minute will work well if the screen is in good condition, especially if having no lost motion in the eccentrics. This combination of variables holds for coal ranging in size from at least 1 inch diameter up, provided the largest holes are not over 6 inches in diameter. This is the rule used by one American engineering firm in the design of shaker screens. It will be noticed that R.P.M. x throw in inches = 600, and this is also often taken as a general rule for practical design, especially among English engineers. For slope they have a general rule of 14° for coarse coal and running up to 18 - 20° for the finer sizes. That this slope rule is erroneous and should be reversed for coarse and fine coal has been proven. (p.76).

Rittinger recommends 200 three-inch strokes per minute, which is not favored in America, since the rapid reciprocating motion gives more vibration than fewer strokes of greater amplitude.

Considering the elements of the problem mathematically, and limiting the variables to slope, R.p.m. and throw, as defended above for any given size and variety of coal.

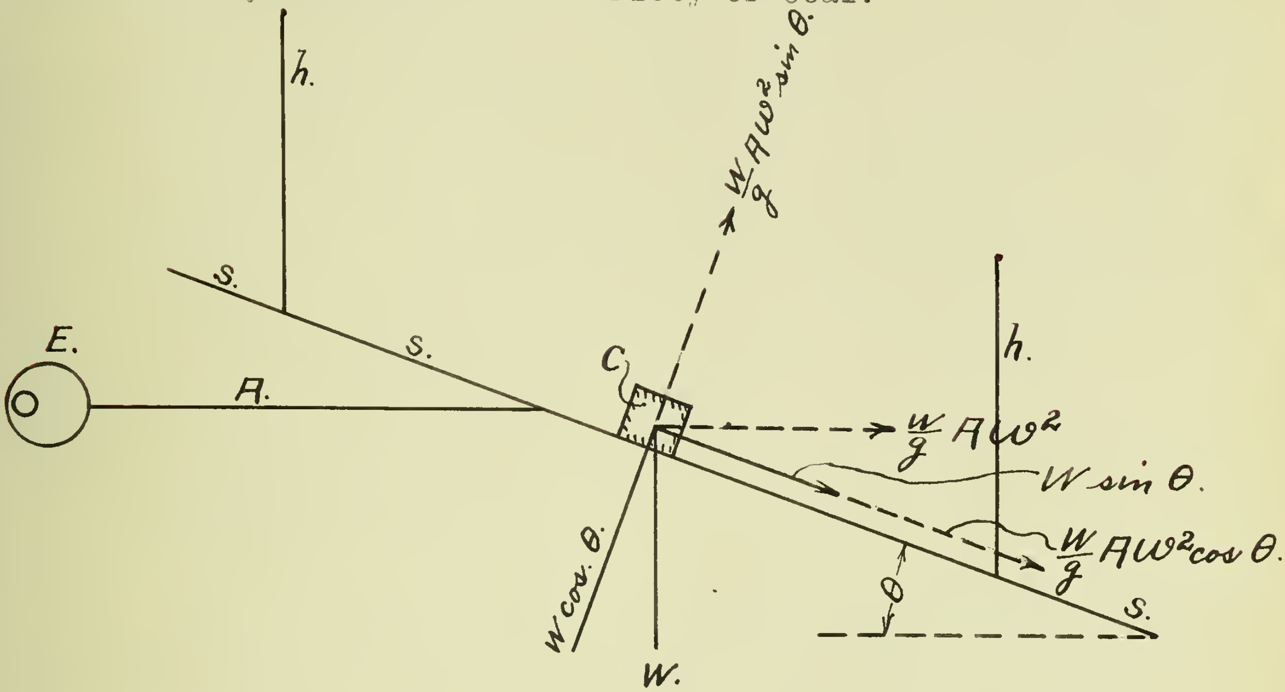


Fig. 11. Forces Acting on a Particle on a Shaking Screen

Let S = Shaker Screen
R = Connecting Rod
E = Eccentric
h = Suspension Rods

A particle (C), fig. 11, of weight W resting on the screen of inclination θ, may have this weight resolved into the two components W cos θ, and W sin θ respectively perpendicular and parallel to the screen frame.

Suspended from the rods hh, the screen, in its movement, describes the arc of a circle whose radius is h, but as this movement is only a few inches, and as the rods h are assumed to be 6 feet or more in length, the oscillating path of the particle C may

be taken as a straight line.

On the forward or right hand movement of the screen, the particle will be at rest, on the backward or left hand movement, if the acceleration of the screen plate be great enough to overcome friction, the particle will slide down the screen plate, coming to rest again when the next forward movement takes place. Thus the withdrawal of the screen from beneath the particle is equivalent to the action of a horizontal force F to the particle.

The measure of this force is $F = \frac{W\ a}{g}$

Where F = horizontal force acting
M = Mass of particle
W = Weight of particle
a = Maximum acceleration

From the properties of an eccentric, the maximum acceleration takes place when the velocity is zero, that is, at the beginning of each return stroke and this maximum acceleration will impart maximum tendency towards movement of the particle. This acceleration is measured by $a = R\omega^2$

Where R = radius in feet of the eccentric

ω = angular velocity = $\frac{\text{radians}}{\text{seconds}}$

Whence $F = \frac{W}{g}\ a = \frac{W}{g} R\omega^2$ = Max. horizontal force acting on the particle.

This horizontal force may in turn be resolved into two components, one acting normal and one parallel to the inclined screen.

The force normal to the screen = $\frac{W}{g} R\omega^2 \sin\theta$

The force parallel to the screen = $\frac{W}{g} R\omega^2 \cos\theta$

If α = angle of starting friction of the coal particle (with Illinois coal and a clean bright screen, α is assumed to be 30°; coefficient of friction = $\tan 30^\circ$): the particle will move

down the screen when

$$\frac{W}{g} R\omega^2 \cos\theta \text{ plus } W\sin\theta \geqq \tan q\left(W\cos\theta - \frac{W}{g} R\omega^2 \sin\theta\right)$$

In other words when the sum of the forces down the plane are greater than the opposing forces. Simplied, the above expression becomes

$$\omega^2 R \geqq \frac{[q\cos\theta - \sin\theta]\, g}{[\cos\theta + q\sin\theta]}.$$

(I.) = Minimum conditions for downward movement of a coal particle on the backward stroke of the screen.

Thus for any given slope of screen and material

$\omega^2 R$ = a constant

also $\frac{60\omega}{2\pi}$ = Rev. per minute

and 2 R x 12 = inches throw or travel of eccentric, or $(\text{R.p.m.})^2$ x throw of eccentric = a constant for any given slope of screen.

Therefore, the action of a shaking screen varies directly with the throw or total travel of the eccentric, and directly with a simple function of the angle of inclination also inversely as the coefficient of starting friction of the material, but varies directly as the square of the revolutions per minute.

When the values are worked out by expression (1) the particle barely moves down the screen. As the acceleration of the throw is increased, a speed may be reached great enough to cause the particle to slide up the screen on the forward stroke, as well as down the screen on the backward stroke. As such a movement slows the particle in its passage over the screen, such a speed is not desirable. The maximum down speed of the particle will come just before this point is reached. Thus as for (I) a particle will slide up the screen as well as down when $\omega^2 R \geqq$

$$\frac{[q\cos\theta + \sin\theta]\, g}{\cos\theta - q\sin\theta}. \quad (2.)$$

These then, must be the maximum conditions for successful screening. Also that the nearer this condition is approached, the greater will be the capacity of a screen. For this most efficient condition of screening $(\text{R.p.m.})^2 \times$ throw of eccentric = constant. Thus, with screens to be designed

For 8°	slope	$(\text{R.p.m.})^2$	x	throw	in	inches	= 55050	= C_1
" 12°	"	"	x	"	"	"	= 63500	= C_2
" 16°	"	"	x	"	"	"	= 73100	= C_3
" 20°	"	"	x	"	"	"	= 84000	= C_4

These values are maximum and should not be exceeded.

Using equations (1) and (2) a graphic logarithmic plat has been made, fig. 12, illustrating maximum and minimum values under any conditions of speed, slope and throw. The minimum values platted represent a theoretical limiting condition only. Commercial screens must have capacity and for this reason, the probable greatest forward speed without any backward travel will be found at a point close to the maximum lines in the plat.

Referring to page (81), it is seen that the Force causing motion of the particle down the screen is a maximum at the beginning of each stroke. Poor mechanical connections, such as a loose connecting rod, or a worn and loose eccentric reduces this acceleration and would necessitate in practice a set of values somewhat above or to the right of the maximum values platted. This also explains why screens frequently work well when new and cause trouble after running a short time. Neglect to keep dirt away from the eccentric and failure to take up the natural wear by the class of labor usually found in a coal preparation plant may result in serious loss of capacity of the screen. Even the best eccentric

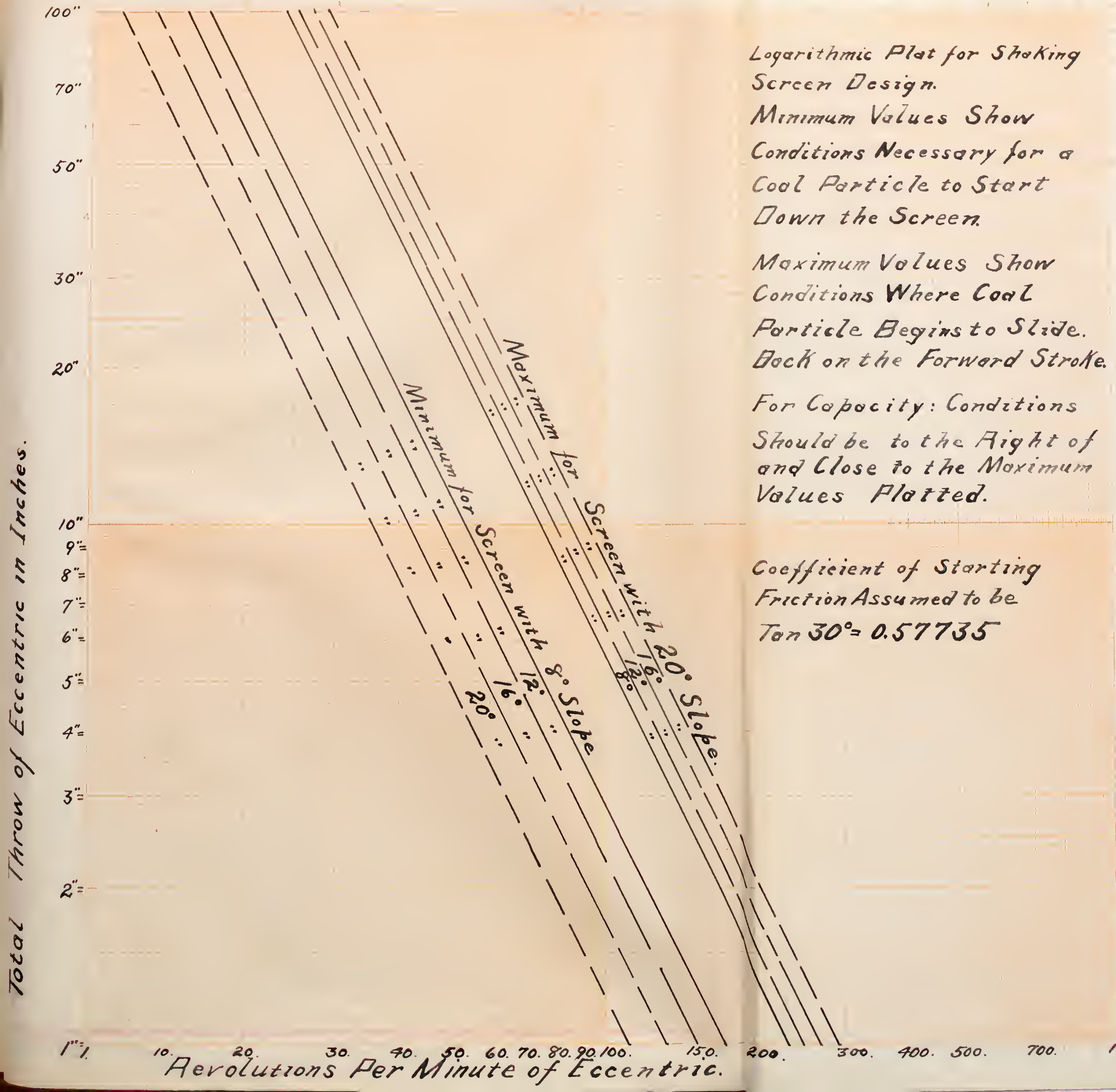


Fig 12.
Plat of Shaking Screen Design.

must be slightly loose when running ("have a little play") and the variables as platted should be increased accordingly.

Discussion. The conclusions above have been submitted to several mining engineers who agree with them excepting as to the point where the maximum or best screening takes place. The assumption was that as a maximum a particle moved down the screen on the back stroke and was stationary on the forward stroke, and that the maximum speed down the table was reached just before the combination of variables was great enough to cause movement up the screen on the forward stroke. One engineer maintains that with a particle moving on the back stroke only, screening takes place only 50 per cent of the time and hence the screen is only 50 per cent efficient. He therefore favors a condition of screening where particles move both ways, but further down the screen on each double throw. There are two objections to this. With large heavy screens the high value necessary for $(R.p.m.)^2$ x throw to effect this motion both ways makes for excessive vibration, and the velocity of the particles become so great that close effective screening is impossible. Therefore on large heavy screens, practice calls for movement over the screen in one direction only. With the lighter screens and loads handled in the smaller sizes, it is admitted that a slight backward throw may help screening. For instance, a fine screen noted gave the particles a forward throw of about 5 inches and a backward throw of about one inch; at 150 R.p.m. this means an average velocity of the coal on the screen of 50 feet per minute.

A writer in Coal Age[1] recommends for coarse screens also an

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[1] Pfening, H. F. "The Design of Coal Screens", Coal Age, Sept. 14, 1912.

average velocity of the coal of 50 feet per minute. This agrees with personal observations made on screens in Illinois that appeared to be doing good work. Other screens noted, however, gave much greater or much less velocity. This factor would bear a direct relation to the capacity or duty of any screen.

Another engineer favors high velocity and steep slope with his screens, claiming that with flat screens a lodged piece of coal is sheared by a succeeding piece, while with steep slopes the succeeding piece rides over the lodged particle.

Special Types of Shaking Screens. (a) The Parrish Screen: Mention has been made of special shaker screens for fine coal, of several types the most effective is the Parrish screen. It is different from the ordinary shaker screen in that it is of lighter weight and lower slope and instead of swinging loosely from rods, it is either supported by or rests on rigidly fastened hard wood strips, usually 1 inch x 12 inch boards about 6 to 8 feet long and placed perpendicular to the length of the screen. As the screen swings to and fro the boards are bent after the manner of spring boards. The popular explanation of this screen is that it has a whip like action and throws the coal. An examination while in action revels no such throwing or jerking motion. A better explanation of the action is as follows:

As the screen eccentric reaches the end of its stroke, considerable bending stress is developed in the wooden side arms. At the instant the eccentric starts on its return stroke, all lost motion, whether in eccentric, connecting rod, bearings or driving belt, is done away with by this bending of the side boards. The instant the dead center is passed the tightened parts deliver the

maximum acceleration possible in the eccentric to the screen, ($R\omega^2 a$). Such a screen must approach more nearly than any other the theoretical conditions illustrated by the plat, fig. 12, on page 84. Consequently it works well with a very low slope, often only 7°. Any other arrangement of drive which secures the initial rapid acceleration would give the same advantage. For example, it should be possible to fasten steel springs to a screen, or weights hanging from a rope over a pulley, for the purpose of getting full advantage of the maximum acceleration. These schemes have been tried by several inventors. The steel springs soon crystallize, and the extra weights lifted, add vibration. The ash or hickory side boards where securely bolted leave little to be desired for continued resiliency and long life.

The original Parrish had the connecting rod between eccentric and screen made of wood and tightly fastened at each end so that slight bending of the rod took place on each stroke. This was supposed to aid screening by a slight throw of the coal. Spring board screens fitted with ordinary connecting rods free to keep aligned, appear to work with equal success.

Owing to the weight of coarse coal screens and contained coal, the use of the Parrish has been confined to coal requiring a 3 inch screen perforation as a maximum and down to 1/4 inch as a minimum. It replaces the revolving screen perfectly in every case excepting possibly in fine wet work.

An added advantage of the Parrish is the ease with which hand picking can be performed on it. Sometimes the screen is lengthened at the lower end by the addition of 8 or 10 feet of blank or dead plate. The oversize passing over this plate can

[illegible]

readily be cleaned of refuse by hand-picking. In one case where the screen is so wide (8 feet) that hand-picking from the sides becomes difficult, the screen is split in the middle by a protected opening large enough for a man to sit in. In this way he can watch the coal coming down the center of the screen and pick efficiently. Especially where increased headroom is an object the Parrish type of screens will probably be designed strong enough to treat the large run of mine coal.

(b) Other Modifications of the Simple Shaking Screen: The simple shaking screen described as a model was assumed to be hung from long loose rods or chains and to have practically a horizontal path backward and forward. By shortening this suspension considerably the screen has a considerable rise on its forward stroke and a drop on its back stroke, i.e., an upward and forward and a downward and backward motion. The action of such screens is equivalent to increasing momentarily the angle of inclination in that on the return or backward stroke the screen has an additional tendency to draw away from the particle. Such a screen should be so hung that the supporting rods only swing to the vertical when the screen is at the end of its backward stroke, for if swinging freely as a pendulum the advantage of the downward and backward stroke is lost.

A modern shaking screen of this type is the Morrow, recently placed on the market by the Morrow Manufacturing Company of Wellston, Ohio.

O. G. Peterson[1] has designed a short suspension arm shaking screen for use in a concrete tipple, using the assumption that a

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[1] Coal Age, Vol. 3, p. 958.

swinging screen should have a ratio between length of arm and time of a complete swing corresponding to that of a pendulum of equal length.

From the properties of a pendulum

$T = 2\pi\sqrt{\frac{l}{g}}$ where T = time of a complete swing

l = length in feet

or for a screen of 60 R.p.m.

= 9 3/4 inches approx.

By making the suspension about one foot long, and increasing the R.p.m. to 90 or 100, a pull is given to the screen which draws it away from the coal. In this design the usual horizontal vibration is partly replaced by a vertical one which makes concrete tipple design more simple.

The same effect of an upward throw on the forward stroke may be gained by having the screen supported from beneath by rods or plates which are inclined backwards from the vertical when the screen is at the backward end of its stroke. In this case the effect of the up-throw may so increase the apparent angle of the screen that the screening surface itself may be horizontal. Such a screen is the Dodge Zimmer, made by the Dodge Manufacturing Company of Mishawaha, Indiana. Owing to the weight of coal being lifted on the forward stroke, screens of this type have a tendency to become unbalanced, and are said to require more power than the ordinary shaking screen. Their great advantage is their low slope.

It must be admitted that these special screens are not original ideas, but have been developed from similar English and German screens. Supporting shaking screens on rollers, which may run either on a horizontal or inclined track has come into vogue

during the last few years. Screens supported by rollers running on a horizontal track or bearing plate, fig. 13a, have a horizontal motion, while screens supported on inclined bearing plates, fig. 13b, have the upward and forward and downward and backward motion,

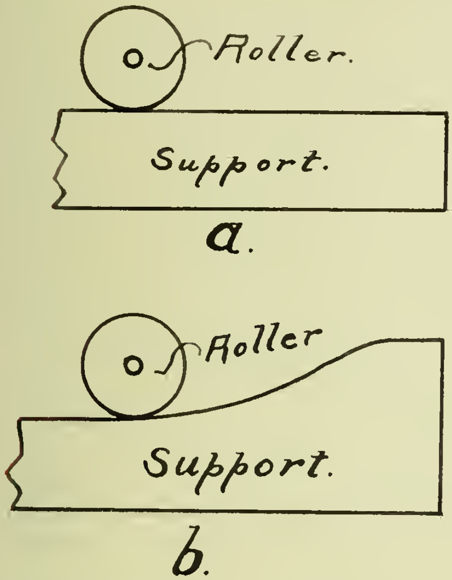

Fig. 13a & b. Rollers and Supports for Shaking Screens

thus requiring less slope to obtain the same screening effect, but tending to cause more vibration and to require more power. Variations from these types are found where the rollers are split and the bearing plates have tongues fitting into the space. This precaution prevents the screens from wabbling. In other cases the shaft of the roller is fixed into a bearing at each end, and the bearing plates, instead of being fixed below the roller, rest on the roller and are attached to the screen. This arrangement is said to be effective as it offers little chance for the ever present dust to find lodgment on a wearing part.

Balancing. Especial attention should be given to the question of balancing shaking screens. The standard type is always made in two sections driven from the same shaft, and moving in opposition to each other with eccentrics 180° apart. Occasionally three screens with eccentrics spaced at 120° are on the same shaft. At one or two old installations in Illinois only a single screen is used, an ineffective effort being made to avoid vibration by a heavy fly-wheel on the shaft. In one case this fly-wheel was reported to weigh two tons. These balanced screens may be tandem,

one following the other, or may be top and bottom, superimposed, and either of them may be single, double or triple deck.

Where two screens are in balance, the same diameter of eccentric is generally used, therefore the moving parts have the same moment arm, and the total weights vibrating, including each screen with its average load of coal should be approximately the same. Past practice gave little attention to this detail, one tipple being noted where the screens when in action threatened to shake down the structure. A rapid estimation of weights showed the top screen to weigh with load about 12 tons and the bottom screen about 3, an unbalanced load of about 9 tons. Under such conditions as these shaking screens were set in special and separate frame work from the rest of the tipple. Some of the more recent designs have been so well balanced that this separate structure has been done away with. Some construction companies, however, still use the independent shaker structure, claiming that as the load on the screens may vary by several tons, balancing for every condition is not possible.

Engineering Data: Size of screens for run of mine coal. An inspection of about 50 Illinois mine tipples reveals a wide difference in size of the screens used for different capacities and for the same capacity.

The width of a shaker screen is the measure of its capacity to take and discharge material. Average widths used for different capacities are about as follows:

	8-hour capacity	Width of screen
	1000 tons and less	6 Ft.
Between	1000 - 2000 tons	7 Ft.

Between 2000 - 3000 tons	8 Ft.
" 3000 - 4000 "	9 Ft.
Over 4000 "	10 Ft.

The length of the screens is a direct measure of the cleanness of separation of the different sizes. The usual tipple screens have three sizes of holes, 1 1/4 or 2 inch holes on the upper screen, followed by 3 inch and 6 inch holes on the lower screen, thus 4 sizes of products are made.

1 = 0 - 1 1/4 inch or 2 inch screenings

2 = 1 1/4 inch or 2 inch - 3 inch nut coal

3 = 3 inch - 6 inch egg coal

4 = 6 inch lump coal

Again there is a wide difference in practice, coming from two causes, (1) Difference of design, both in area of plate for a given quantity and from the fact that either the small, medium or large holes may come first and have to take most of the tonnage. (See Methods of Screening p. 17). Most often the small holes come first. In this case it is not infrequent to place "relief" screens with large holes, 12 - 18 inches above the small screen. This device may add 20 per cent to the capacity of a screen. Often commercial reasons keep a producer from doing complete screening, since in general the more fine coal he produces, the less average price will he receive for a ton of run of mine coal. The following figures have been gathered for the average case in Illinois practice.

Table showing details of first screening surface on shaking screens

No. of Screens Examined	8-Hour Capacity	Average Width of Section	Average Sq. Ft. per ton per hour	Av. area of this screen	Average length of screen in ft.	Remarks
5	Under 1000 tons	6 Ft.	0.84	105 sq. ft.	17.5	
12	1000-2000 tons	7 "	0.54	135 " "	19.3	
14	2000-3000 tons	8 "	0.46	172.5 " "	21.5	Relief screen occasionally
8	3000-4000 tons	9 "	0.35	175.0 " "	19.5	Relief screen usual
4	Over 4000 tons	10 "	0.30	187.5 " "	18.8	Relief screen generally

Running Variables: The average tipple screen slopes about 3 1/2 inches per foot of length or 16° 16', certain ones have slopes as great as 21° and others as small as 12°.

One hundred revolutions per minute with an eccentric having a 6-inch throw represent average movement and the extremes recorded are 65 revolutions per minute and a 9-inch throw, and 120 revolutions per minute with a 4 1/2 inch throw. From the theoretical grounds previously discussed, it is impossible to criticise these single variables without more thorough examination of the other variables than it was possible to give.

Power. The ordinary drive is from a steam engine situated under the tipple and usually of about 35 rated horse power. As the screen shaft is usually above the engine at a high angle an unfavorable condition for a belt drive is brought about. The writer recommends the simple expedient of an idler pulley placed on the loose side of the belt and about one-fourth way from driver to driven pulley as a remedy for these troubles. A frequent difficulty is the stopping of the screens on the dead center of their

eccentrics; especially if they happen to contain a load of coal trouble may be encountered in starting from this position. In one case this has been done away with by connecting the screen drive shaft to two small steam engines with crank pins set at an acute angle and either engine may start the load.

More recently, the direct current electric motor with chain or belt drive has been installed for tipple screens. By using a controller considerable latitude in revolutions per minute of the screen may be obtained. Warren, Biesecker and Powell[1] have recently made power tests on shaking screens driven from motors. They found that where opposing each other at 180° on the same shaft the screens gave minimum vibration, but a maximum variation of load on the motor, and recommend the installation of a fly-wheel on the motor shaft to compensate these load fluctuations. The motors noted in Illinois tipples varied from 25 to 50 horse-power according to the size of the screen. Two 10 foot x 28 foot tipple shaking screens on a recent test in Illinois consumed 26 horse-power running full. A French test on a Briart shaking screen showed that 35 per cent of the horse-power was absorbed by engine and belting, 38 per cent in moving the screen, and 27 per cent in moving the coal.

Methods of Obtaining the Reciprocating Motion. In nearly every case the eccentric is used to give simple harmonic motion to the screen. In some cases objection has been made on account of excessive wear, large bearing surface, and difficulty of controlling lost motion. This has led to the use of the crank pin in several cases and recently an installation using an offset crank

[1] Bull. A.I.M.E., Feb., 1916, p. 181.

shaft has met with success. One or two rather complicated bell crank mechanisms for obtaining harmonic motion have been tried, but owing to their many joints with accumulating lost motion, they will not come into common use. English practice[1] in shaker screen design causes eccentric to act on the screen near its center of gravity in order to prevent jerk. American practice does not follow this, and its value is doubtful.

Operating Variables with the Parrish Screen. The separation of the small coal with this screen generally takes place in a rescreener or building separate from the main tipple. The slope of the screen is about 7°. The number of revolutions of the driving shaft 130 - 160 per minute and the length of throw 5 - 6 inches. This is a greater speed than can be used with the tipple screen and is made possible by the light weight and low slope.

To illustrate capacity, a successful installation in Illinois is quoted. Capacity 2400 tons in 8 hours of 2 inch - 0 screenings; width of screens 8 feet; top screen 1 1/4 inch round hole plate (protected by a relief screen) 24 feet long, or 0.64 square feet per ton per hour: middle screen 3/4 inch round hole plate, 24 feet long or 0.87 square feet per ton per hour; bottom screen 3/8 inch round hole plate, 24 feet long or 1.42 square feet per ton per hour.

Sizes made (round holes)	2 inch - 1/4 inch	No.	2	nut =	26.5	per cent
	1 1/4 inch-3/4	"	3	" =	21.7	" "
	3/4 inch - 3/8 inch	"	4	" =	13.8	" "
	3/8 inch - 0	"	5	" =	38.0	" "

[1] Jour. Soc. Chem. Ind. Vol. 30, p. 662.

Power tests made at this rescreener show 4 1/2 horse-power consumed in driving the screens empty and 12 horse-power when loaded. A 15 horse-power direct current motor furnishes the power. Other modern installations have about the same area per ton per hour for the same sizes, and vary the area for different tonnage chiefly by a change in the width of the screen. A suggested formula[1] for horse-power consumed in driving these hanger supported screens is

$$H. P. \quad 0.00000000112 \times W R^3 S^2$$

where W = weight of reciprocating parts, including coal 4 to 6 inches deep on all screen surfaces.

R = revolutions per minute

S = stroke in feet equal to the throw of the crank.

In some washeries, the Parrish screen is reported in use for sizing wet coal, but no special difference in the running variables is reported from those used for dry sizing. For wet sizing under 1/4 inch, however, the writer is inclined to still favor the revolving screen.

Cost of Shaking Screens Installations: The cost of shaker screen installations has been reported at from $1000. to $8000. This usually includes cost of screens, driving power, and supports, but not their installation. An average life, arrived at from calculating when the cost of renewals equalled the first cost of the screens, is 7 - 8 years, and with an allowance of 13 1/3 per cent yearly for depreciation, although one installation had a life of only 2 years.

The Marcus Type of Screen: Within three years a new type of tipple shaking screen, the Marcus screen, manufactured by

[1] McGann, W.H. COAL AGE, Feb. 26, 1916, p. 368.

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Roberts and Schaefer Company, Chicago, Illinois, has been installed at least at three Illinois coal mines and at various places in other states.

This screen is horizontal, resting on rollers and is given a differential reciprocating motion from a novel differential head motion drive. The stroke is 10 to 12 inches and with about 70 R.p.m. Starting from the extreme backward position the screen moves forward with a constantly increasing velocity, reaching a maximum at about three-fourths of the stroke. The velocity now decreases rapidly and the screen stops and starts back moving with fairly uniform velocity until near its first position when it is brought to an easy stop and then begins a new stroke. The result is that the coal on the screen is thrown forward near the forward end of each stroke, and without being thrown back on the return stroke. The velocity of the coal on the screen is about 50 feet per minute. A diagram of the head motion is given in figure 14.

The great advantage of the screen is its horizontal position on which any number of sizes of coal can be prepared without having undue height of the tipple and moreover, the prepared coal has only a low drop into the railroad cars below. An added advantage is the ease with which hand-picking can be conducted on the screen while it is in motion. A disadvantage is its jerking motion which is unbalanced and which must be absorbed to prevent vibration. In practice this motion is absorbed by placing the head motion on a heavy block of concrete extending to the ground. In the average case this concrete block weighs 150 tons.

Engineering Data: A Marcus table 6 feet wide is designed to handle 1600 tons per 8 hours, one 7 feet wide will handle 2000 tons and costs about $7000. in place. When a greater tonnage is

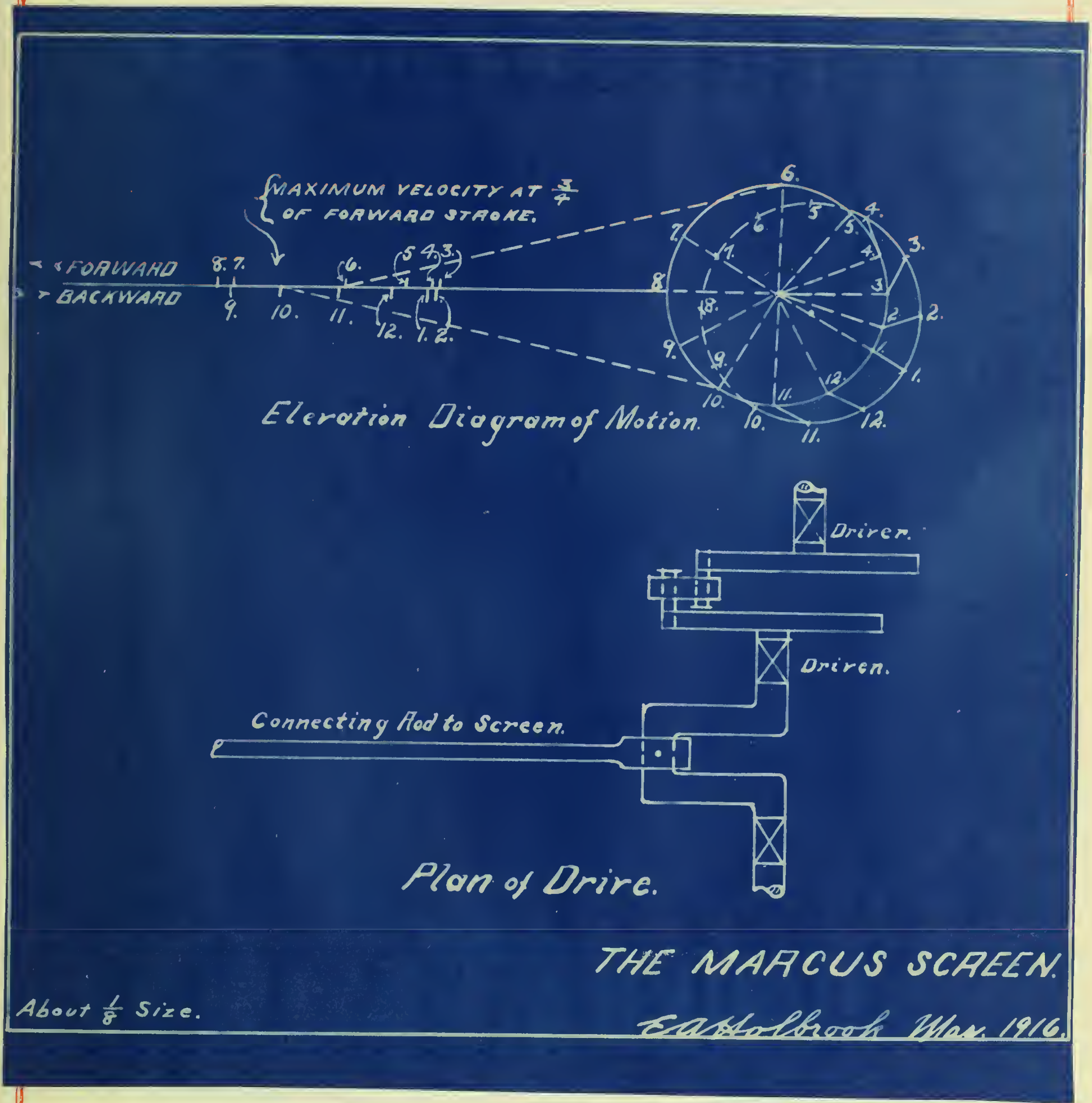

Fig. 14. Diagram of Marcus Screen Head Motion

to be treated, two separate installations are used. From the screens installed the average number of square feet of screen used per ton per hour for the different sizes are as follows: Average 8 hour tonnage = 1730 tons. Average width 6 1/3 feet.

	1 1/4 inch size	2 inch size	3 inch size	6 inch size
Area Square Feet	84	50	40	24
Sq. Ft. per ton per hr.	0.39	0.23	0.18	0.11

The Marcus screen is not an American invention, having been used and described in English coal preparation work several years before being brought out in this country. There has been this difference, however, that where English engineers were satisfied with a duty of 500 tons per day, American engineers have so improved and strengthened it that up to 2200 tons have been prepared per screen per 8 hours.

There are a number of other screens of this type in use abroad, that is, having differentially accelerated motions on the forward and back stroke. As they have not been introduced into this country and as their differences consist in different mechanical head movements to obtain the desired motion, they will not be described.

Other Shaking Screens: One of the most successful European shaking screens for large coal is the Briart[1] which was developed in Belgium in the seventies and has been used increasingly in the other European countries. In principle like the shaking

1 Bull. Soc. Ind. Min. Series III, Vol. XI, 1897, p. 745.

screen, it consists of a number of parallel bars which may form a true bar screen, or they may be wide and flat and contain holes as an ordinary plate screen. Alternate bars are attached to one eccentric, the other half to another spaced 180° on the same shaft underneath the screen. The coal is lifted forward first by one set of bars rising and then by the other. German writers praise the screen highly, especially for tender or friable coarse coals. Outside the anthracite field in Pennsylvania, the writer has only one record of an installation in America of a similar screen, that of the Acme Coal Company, Sheridan, Wyoming, installed by the Ottumwa Iron Works Company, Ottumwa, Iowa. In the anthracite field they are called oscillating or movable bar screens. They are used there for handling very heavy lumps of coal. Paul Sterling[1] says their advantages are: (1) Heavy construction to handle large pieces of lump coal; (2) Their action as a regulator and feeder for other machines; (3) Saving in slope and, therefore, in height of the structure; (4) The slow speed, 50 R.p.m. of the shaft, prevents vibration.

A similar screen is the finger bar screen, in appearance like the opened fingers of a hand and attached to the lower end of a shaking screen or chute where it overhangs the railroad car being loaded. Poorly screened or unscreened coal sliding over these fingers has the small coal passed as undersize, while the lumps discharge over the lower end of the fingers. In this way the fine coal falls into the car first, and as the car is moved along slowly, the coarse lumps fall on top, which gives a lumpy appearance to the whole load. Curious local slang phrases are used to designate these

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1 Preparation of Anthracite. T. A.I.M.E. Oct. 1911, p. 767.

screens.

Certain types of shaking screens have been invented where the motion is from side to side which causes the coal to zig-zag slowly down the inclined screen; although the slow rate of travel makes for low capacity yet the screening under these conditions is complete. No data are available on their work.

Bumping Screens: In the earlier days of coal preparation the bumping screen or "knocker" screen as it is sometimes called was a favorite. The principle of action is that the moving screen is suddenly brought to a stop by striking a bumping post, or is struck a blow by a rapidly moving cam. In either case the coal is thrown forward on the screen. Their advantage is in the low slope that can be used, and that they do good work at very slow speeds. A modification of this type is the screen lifted at one or both ends by a cam and allowed to drop suddenly.

The disadvantages of all these screens are that their jar tends to break the coal. Especially with coarse coal, the load on the screen may become so heavy that the impact of screen and bumping post is excessive and the vibration rapidly wears out both screen and machinery. It has been reported that a number of knocker screens are used as fine coal screens in Kentucky tipples. At the best they were an effort to get away from the use of roller screens on fine coal, a problem that has been solved by the Parrish.

Vibrating Screens for Coal: The final class of coal screen may be called vibrating screens, which are divided into: (a) Gyratory screens, which follow an irregular path and (b) True Vibrating screens, which travel in the same vertical, horizontal or inclined plane. Class (b) are used almost wholly in ore work

and will be discussed under that heading p.104).

(a) Gyratory screens. In this class are included all screens that have such an irregular motion as to cause the coal to assume an irregular path in ellipses of varying eccentricity in its passage over the screen. A common hand riddle is the best example of this type, and a few moments work with one will convince that theoretically at least, such a motion will screen material more quickly and cleaner than any other motion possible. The irregular rolling path which must be followed by any particle turns it over and over and presents a maximum number of positions to any perforation.

In this country on coal work the one successful screen of this type is the Coxe[1], which has a circular combined with a rocking motion. It fulfils the expected advantages of correct sizing and large capacity, but as compared with shaking screens, which have in a measure replaced them, they cost more, both in original price and maintenance, they are more inaccessible, and are hard to balance properly. As it was first used in the anthracite preparation and in America, has been mostly confined there, a fuller description is not attempted. It is interesting to note that it has been copied in the European field for both bituminous coal and for ore work.

Abroad the two principal vibrating screens are the English Vibrometer and the German Karlik Pendulum screen, now or formerly in common use at Westphalian collieries.

The Vibrometer[2] is slightly inclined and suspended by four

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1 Coxe, Eckley B. T.A.I.M.E., Vol. 19, 1890, p. 398.

2 Correspondence with Hardy Patent Pick Co., Makers, Sheffield, England.

flexible rods. The vertical central driving shaft or spindle is also flexible, and attached to it is an adjustable lever on which a weight is fixed. This unbalanced load, when revolving around the spindle creates a peculiar motion of the particles on the screen which can be best described by calling it a series of loops within a larger loop. The largest size, 12 feet long x 4 feet wide, costs $825. f.o.b. and with a one-inch screen has a capacity of one ton per square foot of screening area per hour. Revolutions per minute of shaft = 350. H.P. required 5. Apart from its perfect screening these figures do not compare with the American Parrish in duty.

The Karlik Pendulum screen or nest of screens, is hung from above by a long suspension frame which has a ball and socket joint. A loose eccentric drive from underneath imparts rotation and from the looseness of suspension, a tipping motion is given the screens, closely imitating the motion of the ordinary hand screen when correctly used.

An efficient gyratory hand laboratory coal screen was installed recently in the mining laboratory at the University of Illinois under the writer's direction. Here a nest of coal screens is placed in a frame, which is suspended from above by a long chain. Protruding downwards from the center of the bottom of the frame is a pipe several inches long, which fits loosely around a lug fastened to the floor. The top of the nest can be given a horizontal motion, while the bottom can only move vertically. The effect of a push on the top of the nest is to displace the center of gravity and when released, the nest returns to its original position with a jerk. If used in commercial sizes such a screen would put tremendous vibra-

tion on any supporting structure.

Shaking Screens in Ore Work: For reasons outlined gravity bar screens have given real satisfaction in coarse ore work and trommels hold first place from medium down to the rather fine sizes. In special cases the shaking screen has taken their places. Thus in rough screening before or after a coarse rock breaker, where sufficient head room for a gravity bar screen or length of space necessary for a trommel can not be obtained, the shaking screen may be substituted with good results. This condition often exists where the rock crusher discharge is in a pit below the general ground level. With the exceptions that as ore is twice as heavy as coal and therefore only half the screen area for the same tonnage is required, and that the coefficient of starting friction for ore is somewhat greater than for coal, requiring a slightly greater slope for the same conditions of speed and throw, the design of shaker screens for ore work does not differ greatly from that of coal screens. They should be made much stronger for the same size of material. In operating the wear of screen plate and holes will be found much greater than with coal.

For the medium and fine sizes of ore, both wet and dry, the trommel seems to fulfil every required condition. For example, in Germany a large ore dressing plant at Clausthal which had been equipped with shaking screens for this material in the eighties, had within ten years replaced them with trommel screens. The writer had experience with a half inch hole shaker screen while operating a Montana mill. While the ore was dry the screen did good work. On days when the ore was damp the screen would invariably blind. Under similar conditions trommels would have kept

open, especially as wire screening with a large percentage of spaces could have been used with trommels, while the shaker, which required a smooth plate screen had a much lower percentage of openings.

Vibrating Screens for Ores: There is one class of shaking screens which have a large field of usefulness in ore work, the inclined vibrating screen, class (b) p. 102. It has been shown previously that trommels fail, either wet or dry to screen material under 1 mm. diameter and that in sizes as large as 2 mms. trouble occurs. Furthermore, in considering gravity screens composed of plate or of wire cloth the statement was made that the screens must be of great length in the fine sizes and that here trouble comes from the blinding of the screen holes with the fine particles of ore. If these inclined gravity screens are subjected to a rapid vibration, even though it be of very small amplitude, the screen keeps open and works rapidly, furthermore since they may slope at about 45° the screen surface opening can be large in proportion to the maximum particle of undersize. This class of screens are the most successful yet devised to handle in a dry way the finest sizes of ore from about 1/2 inch to even as small as 180 mesh.

On the American market four makes of these screens have been successful, all doing about the same class of work. They are the Newago, the Kent, the Jeffrey, and the Impact screens.

Fig. 15 represents the Newago screen and details its principle of action. Little hammers worked mechanically keep the wire screen cloth in rapid vibration, and allow up to three sizes of product to be made at once. Owing to the great number of pieces in a ton of, say 1 mm. and finer material, the tonnage handled by this screen is much less than with screens handling

Fig. 15. A Vibrating Screen

larger sizes. A screen 6 feet by 6 feet with 1 mm. holes handles upwards of 5 tons per hour. The Kent and Jeffrey screens are similar in construction, differing only in the manner of applying the vibration. The horse-power is nominal, probably 1/2 - 1 H.P. per screen.

In practice the size of product produced by using various sizes of square hole screen cloth is about as follows:

Mesh of Cloth	Maximum Mesh of Product
10	16-18
14	26
18	32
24	40
40	65
60	100
100	200

A double Kent screen 3 feet by 6 feet with a 45° slope as installed in the mining laboratory, University of Illinois, gave the following results with a limestone gangue ore.

Product on a 14-mesh and through 3-mesh (1/4-inch opening).

Maximum size of grain = 0.178 inch, minimum remained on 28-mesh standard wire screen. This shows an average size of grain slightly more than half the average size of the holes used.

The Impact screen differs from these in that the inclined screen frame is suspended from a spring on each side which are pressed down slightly by toothed wheels or multiple cams fastened to a shaft. When the highest point of the cam is passed the spring causes the screen to fly back about 3/4 inch to the lower point on the next tooth. In this way 200 to 400 vibrations per minute are given the screen, causing fine ore passing over it to have a path resembling corn in a corn popper. The result is efficient screening. One of the first of these screens was installed by the writer. Within a week the vibration had shaken it to pieces, necessitating its temporary disuse. Its efficient work during its short life so impressed the management that the screen was entirely rebuilt with double its former strength, and satisfaction resulted. Later screens from the manufacturers have been of equal strength.

Without doubt, when it becomes necessary to prepare coal dry in sizes under 1/4 inch this type of screens will find extensive use in the industry.

Conclusions. In summarizing the work of the various coal screens two points must be emphasized. (1) The choice of a coal tipple screen should depend, first of all on its simplicity, for in a practical way coal preparation has not reached the stage which requires absolute separation of one size from another and relative quantities alone are considered. (2) All other engi-

neering features are of minor importance compared with absence of vibration. A screen producing vibration not only requires more power, but shakes itself and the supporting structure to pieces, necessitating frequent renewals and repairs.

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