THE PREPARATION OF STOKER COALS FROM IOWA SCREENINGS

By

H. L. Olin
Professor of Chemical Engineering

in collaboration with

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FOREWORD

In a very real sense the coal producing industry of Iowa is facing a crisis through which it must inevitably pass and for which it must grimly prepare if it is to emerge unscathed. The elements of the situation are many and complex; but chief among them is the fact that in all the midwest mining states save Iowa alone, mechanical cleaning has been adopted as a regular procedure by the larger and more important producers and washed coal quality has been set up as a standard to which the merits of their product are referred. In the highly competitive markets of today, even under the stimulus of the enormous demands of war industry, poorly prepared coals laden with refuse are often passed by in favor of cleaner fuels sold at a higher unit price but more economical in net results.

Possibilities for washing the general run of Iowa coals for commercial use are hedged about by economic difficulties, many of them based on the limited areas of workable seams, and each case must be judged on its own merits. But one fact stands out clearly; the small sizes designed for use in domestic stokers must be mechanically cleaned if they are to be accepted by the discriminating householder and accorded the recognition the inherent quality of the coal itself deserves. This monograph reports the results of extensive studies that indicate that with a modest investment the small Iowa producer can put out a domestic fuel of a quality comparable with most of those shipped in from other states; that this fuel can be developed from raw screenings that in many cases have little value. It is to him that this work is dedicated.

H. L. Olin

Iowa City, Iowa
August, 1942

THE MINERAL IMPURITIES OF COAL

This monograph is concerned with the removal of a part of the non-combustible matter of coal from the fuel portion with a view to making a product that shall meet the requirements of the discriminating household consumer. The evil effects of high ash content in any coal, industrial or domestic, are too well recognized by all concerned to need much discussion here. The wasted effort expended in transporting material of no value, the lowered furnace efficiencies due to the obstructive effect of inert rock, the nuisance of superfluous ash or the annoyance of mushy slag, all these and more, are counts of an indictment for which there is little defense.

But the problem of ash elimination from the average coal is far from being simple. It is complicated by the fact that coal is itself a complex substance both in composition and structure, and that from its beginnings in ancient Paleozoic time to the very present it has been a part of the earth's crust, contaminated with wind-borne dusts or by contact with soils and mineral bearing solutions. It is appropriate therefore, that we consider the nature and origin of the ash-bearing components to gain a better understanding of the possibilities and limitations of a given cleaning process, for it must be understood at the outset that in no case can ash be entirely separated from the pure coal; the practical and economic limits fall far short of that result.

In a general way the various kinds of impurities found in a coal seam may be classified as follows: (1) inherent or basic ash consisting of residual mineral matter present in the original vegetation from which the coal was formed but varying in composition not only with the floral types of a given age but with the evolutionary changes those types undergo over vast periods of time; (2) wind or water borne silts carried into the peaty mass and becoming intimately mingled with it; (3) finely divided pyrites resulting from the interaction of the organic matter of the seam with percolating waters carrying ferrous sulfate in solution; (4) water borne silts forming sharply defined sediments and finally hardening to shale or slate partings; (5) lump pyrites forming large irregular masses or spreading into horizontal partings more or less thick, and (6) crystalline salt deposits (in the main, calcium carbonate) separating from mineralized waters and usually lodging in the vertical cleavage planes. It is immediately apparent on inspection that the lump of Monroe County coal shown in Figure (1) contains much of the impurity listed under (6), laminar calcite lodged in the cleavage planes, in addition to other types of heavy mineral. Because of the discontinuity of the coal seams of Iowa in general, in which they differ basically from the great seams of southern Illinois and Pennsylvania, the kind and amount of impurities must be determined for each individual mine; marked variations are often observed within limited areas.

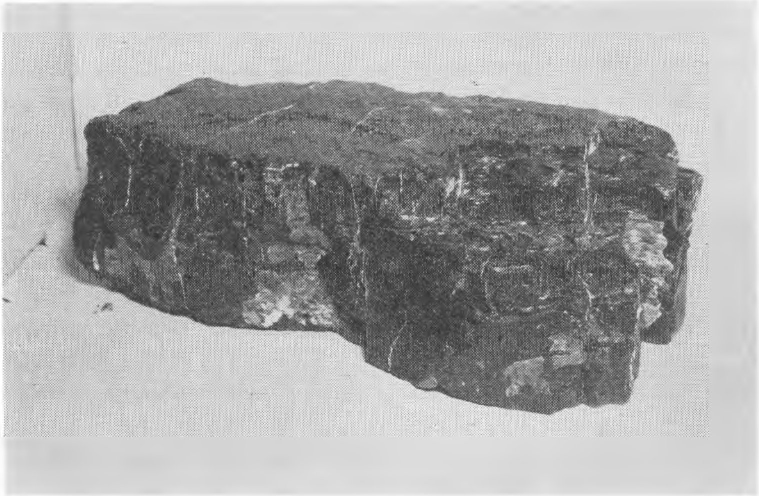

Fig. 1. Block of coal with laminar calcite in cleavage planes.

First in the list are those minerals that were inherent in the plant tissues from which the coals were derived and which are so intimately associated with the fuel substance as to make a physical separation impossible. Microscopic and chemical studies show that this original plant ash is in the main, contained in the bright, jet-black lenses or stripes lying parallel to the bedding plane and known to the coal petrologist as vitrain.* This type of coal material (See

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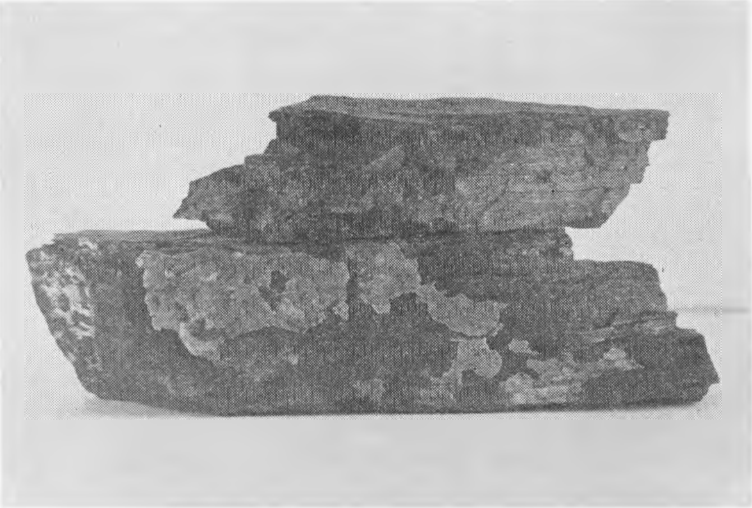
*From the Latin *vitrum*, glass, which it somewhat resembles because of its conchoidal fracture. In the American terminology it is called anthraxylon, from Greek roots signifying coalified wood.

Figure 2) represents the residuum of stems and branches or twigs of trees which after being somewhat softened in the original peat were buried and flattened and converted into coal. It is the component most active in the formation of coke and it therefore plays an important role in the metallurgical industries. Since the original woody material was naturally low in mineral content the vitrain residues are the most nearly pure of all the coal structures with ash percentages as low as three or less. Parenthetically, this fact explains the astounding analytical results often obtained when a

Fig. 2. Vitrain structures on base of fusain.

laboratory sample is hand picked for beauty of appearance rather than for overall uniformity of composition.

Durain, the dull hard component of coal was formed from a more or less complex mixture of finely shredded plant debris such as bark fragments, spores and spore cases (exines) and the like, intimately permeated with a certain amount of colloidal mud. It is the most resistant to lump degradation of all the coal structures, requiring nearly twice the energy needed to reduce vitrain to equal size. It breaks with a splinty fracture. The ash content of durain varies with the amount of silt picked up from the water in which it was formed but it is invariably higher in mineral matter than vitrain and in extreme cases it forms what is commonly called ''false bottom'', a bed of fine grained bituminous shale with an ash content of 30 per cent or more, difficult to separate from the good coal because of its low specific gravity. (See Figure 3). In general however, durain is moderately clean and it constitutes an important fraction of the coal mass. Its coking properties are inferior to those of vitrain.



3. Block of ''false bottom'' showing natural cleavage.

Fusain the third of the distinct coal types is known also as ''mother-of-coal'' or ''mineral charcoal''. It is soft and brittle with a pronounced smudge or streak and is responsible for most of the dust produced in the handling of coal. Although the residuum of an almost complete chemical reduction of wood to carbon (carbon contents range from 80 to 90 per cent) it retains better than any other type the cellular structure of the wood from which it was derived (Figure 4) and it is because of such open structure that percolating waters may deposit mineral matter in the absorptive cells and raise its normal ash content to values ranging from 4 to as much as 30 per cent.

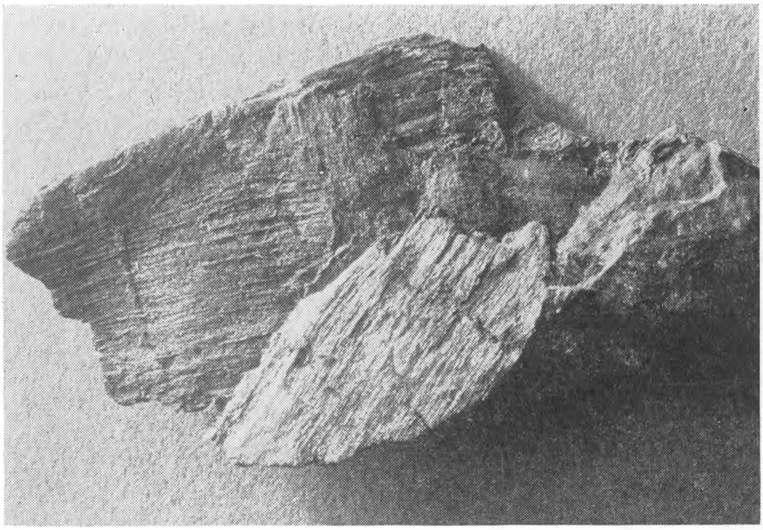


Fig. 4. Fusain or ''mineral charcoal''.

So far as the removal of pyrites or ''brasses'' is concerned the critical question is whether it is disseminated through the coal structure in small crystals or isolated in masses that may be easily detached from the coal lump. In the latter case its separation is extremely simple because of the wide difference in specific gravities of the two minerals; if it is highly dispersed the situation is hopeless.

Clay or shale partings almost invariably cleave sharply from the coal immediately above and below them and those of appreciable thickness are discarded in the hand loading operation. With mechanical loading in either shaft or stripping practice they are gathered in and remain with the fuel unless removed by table picking or washing. Crystalline deposits of lime salts that chip off easily in the degradation of the lump and accumulate with the fines are especially obnoxious slag formers if left with the fuel but are easily removed by gravity cleaning processes. On the other hand false bottom, with a high ash content that condemns it for fuel is particularly troublesome in mining operations not only because it so nearly resembles good coal as often to deceive the loader but because its specific gravity is so close to that of pure coal that a differential gravity separation is difficult or impossible to make.

Summarizing, fraction (1) contains the inherent mineral matter of coal; fractions (2) and (3) the accidental wind or water borne mineral coming from the outside. The combined mineral contents of fractions (1), (2) and (3) make up the fixed ash of coal which is the limiting ash content to which it can be cleaned. Fractions (4), (5) and to a certain extent (6) together with broken roof rock and floor cuttings contribute the free dirt in coal, that is, the mineral matter not intimately associated with the coal substance but mixed with it during mining operations and normally separable by coal cleaning methods.

COAL CLEANING IN PRINCIPLE AND PRACTICE

Practical application of gravity separation of values from waste doubtless goes back to that prehistoric occasion when some rustic genius first devised a way for winnowing the chaff from his meager crop of wheat. The essential element of that ancient operation, in simple, the sinking of two or more solids of different specific gravities through a fluid moving in a direction normal to the path of fall, is still the controlling principle of many of the important classification processes used in industry today. In the field of metallurgy and ore-dressing, to name only one, it dictates the fundamental design of most of the machines employed in concentrating and refining crude ores, but in other industries as well (not to mention the natural processes of sedimentation) its applications are legion. A full discussion of the mathematical theory of gravity separation is given in chapters III and IV of Chapman and Mott's "Cleaning of Coal"(5) but a simple outline of the principles involved will no doubt serve the present purpose.

Under the influence of gravity and in a perfect vacuum bodies starting simultaneously from rest fall with equal velocities regardless of size or density. However, in a fluid medium such as air or water the moving body encounters a resisting or frictional force that is proportional to the density of the fluid, the size of the body and to the square of the velocity at which it moves. Under normal conditions the body quickly assumes a rate of motion such that the frictional resistance equals the accelerating force and thereafter it drops with a constant "free settling" velocity. It is easily demonstrated that this constant velocity V, is related to the controlling factors by the equation

$$V = K[gD\ (s-a)]^{1/2}$$

where g is the accelerating force causing the body to move, D the diameter of the body and s its specific gravity. K is an arbitrary constant whose value depends upon the units of measurement employed and *a* is the specific gravity of the fluid (in the case of water it is 1). It follows then that of two bodies b_1 and b_2 of equal size but of gravities s_1 and s_2 (where $s_1 > s_2$), the first will fall the more rapidly since the critical factor $(s_1—a)$ is greater than $(s_2—a)$. Now let the fluid move at right angles to the line of fall and it is apparent that b_2 being exposed longer to the lateral force will be more widely deflected than b_1 and that when both finally come to rest they will be some distance apart. If s_2 is less than a, V_2 will have a negative value, that is b_2 will rise until it floats and separation may then be effected by means of a skimming operation. If the gravities of b_1 and b_2 are both greater than a, the fluid may be given an apparent or effective gravity of higher value than that of b_2 by applying force to give it an upward surge so controlled that the lighter object may ride away while the heavier remains at the bottom.

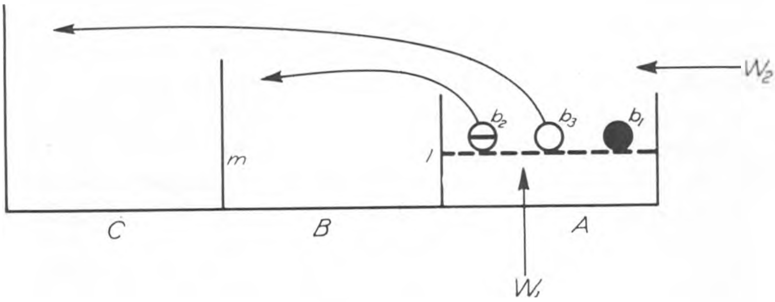


Fig. 5. Diagrammatic scheme of wash box separation.

The principle of the wash box or jig may be explained by means of a simple diagram. Figure 5 represents a horizontal tank with compartments A, B and C. In section A is a grid *g* on which the raw feed consisting of lumps of material with gravities s_1, s_2, and s_3 is delivered. As water surges into A from below, the lightest object, b_3, quickly follows the stream and although caught by the lateral wave W_2 it rises fast enough to clear the barriers l and m and falls into the product compartment C. The object b_2, say a lump of coal with adhering rock, has a slower pick-up and travels with a flatter trajectory. It succeeds in hurdling the low barrier l but is caught in the middlings compartment B whence it may be recovered for recrushing and another wash. The lump of shale or pyrite b_1 remains on the grid to form part of a stratum that gradually builds up until finally discharged by mechanical dumping.

The impulse necessary for causing the water surge may be produced by a mechanical piston as in the Luhrig jig shown in Figure

6 or by means of pulsating air currents as in the Baum jig illustrated in Figure 7. The latter type has certain practical advantages that have led to its almost exclusive adoption in jig plants, at least in American practice, although the Luhrig still finds a place in operations where pyritic rock is to be separated from lighter refuse

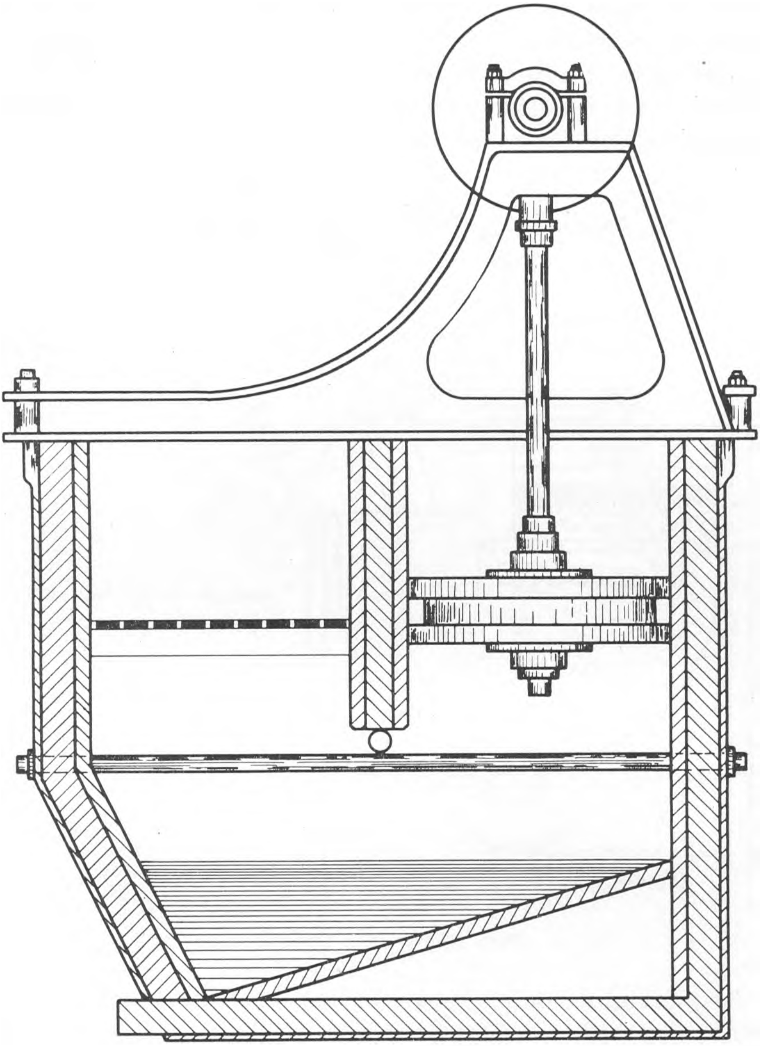


Fig. 6. The Luhrig jig.

for use in acid manufacture. Throughout the coal producing areas of Illinois, Indiana, Missouri and Kansas washing operations are rapidly becoming a part of standard practice, not only in fields where the seam carries considerable foreign matter but in the regions of better coals where normally high quality is depressed by mechanical loading. In most of the larger preparation plants all coal except the large hand-picked lump is washed and classified into the various steam and domestic sizes.

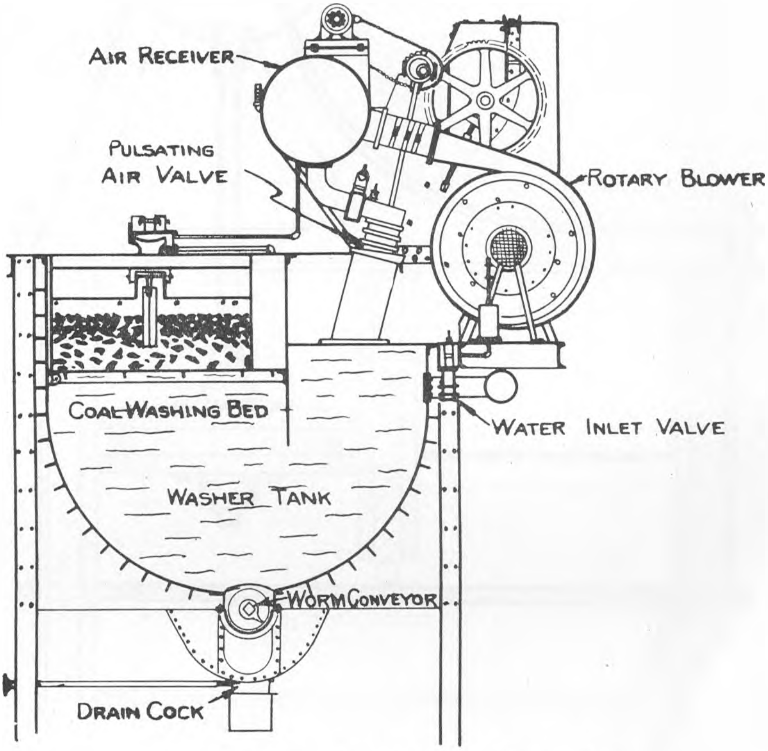


Fig. 7. Cross section of a typical Baum jig.

The principles described above in their relation to the jig washer govern also the launder type of which the Rheolaveur is one of the best known. This machine consists of a long trough divided into two sections, the first of which is steeply inclined and in which the entering water and raw feed quickly assume high velocities. In the lower section stratification takes place exactly as it does in a turbulent stream carrying a heterogeneous load of sands and gravel. On the trough bottom the heavy refuse settles first, to be discharged at intervals through "Rheo-boxes" (see Figure 8). A layer of lighter material making up the middlings fraction overlies the refuse while the top stratum floats along with the stream and runs off as product. Although its earlier use was limited largely to the cleaning of fines it has been developed to handle successfully all sizes up to five inches in diameter. A number of installations have been made in large mid-west preparation plants.

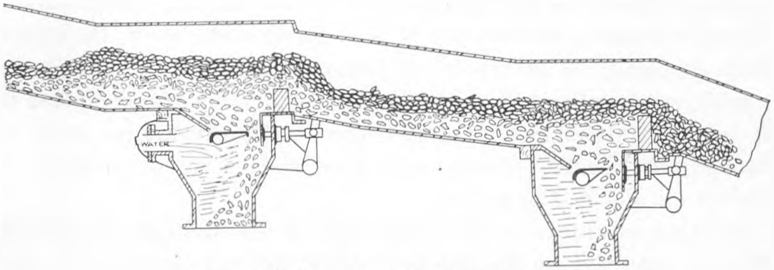


Fig. 8. Section of a Rheolaveur trough.

Somewhat radical in mechanical design is the type represented by the Chance washer shown in Figure 9. Its main feature is a huge cone 16 feet or more in top diameter equipped with a paddle agitator that serves to keep a quantity of fine sand in water suspension. The average density of this sand-water system can be so

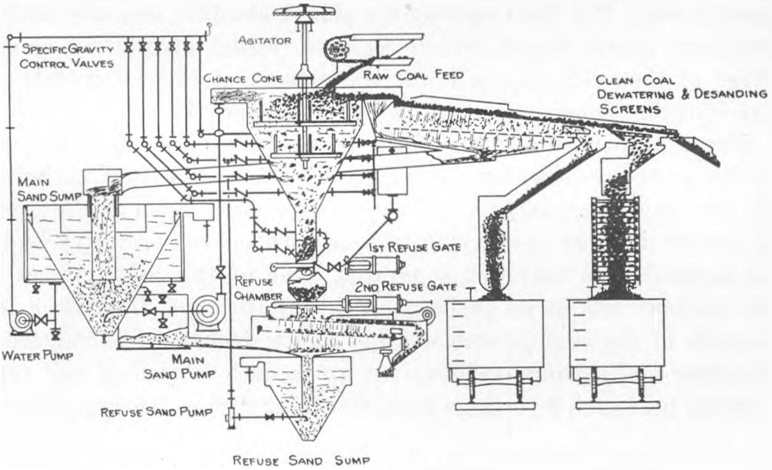


Fig. 9. Typical layout of the Chance sand-water process.

controlled by regulation of propeller speed, water rate and sand-water ratio as to make sink-and-float cuts of the raw feed possible at any desired set of values. The product floating over the rim is dewatered and desanded while the refuse drops to the cone bottom and passes a gate valve to waste. The sole representative of this cleaning system in the middle west is located at a large mine in Franklin County, Illinois but it is in fairly wide use in the eastern fields especially in anthracite preparation. The writer has observed a similar system employing a clay mud slurry as the float medium in use in Kansas but its rather obvious disadvantages involving mechanical recovery of the suspended clay, seem to stand in the way of its general adoption.

In other machines of this class such as the Menzies, the floating effect is obtained by the use of upward flowing currents of water alone without the addition of solid materials to raise its apparent density. A few systems like that used by the Old Ben Coal Corporation of West Frankfort, Illinois employs solutions of calcium chloride to raise the liquid gravity *a* to the desired value, duplicating on a large scale the laboratory sink-and-float technique. One only, designed by the du Pont Company, uses a heavy organic liquid in which pure coals will float without the application of wave forces. But the necessity for almost absolute recovery of this relatively costly liquid, which requires partial distillation at one stage of the cycle, makes it for the present at least, definitely an experimental scheme, interesting though it may be.

For a proper completion of the survey mention should be made of the processes in which a flowing bed of fine sand made turbulent by the upward passage of jets of air escaping from perforations in a table deck, so closely simulates the properties of a heavy liquid as to serve as a coal-rock separator. One of the chief virtues of the method lies in its delivery of a dry product free from the hazards of freezing in zero weather and independent of expensive drainage and drying systems. An up to date version of this type is being perfected by a large manufacturing firm in Aurora, Illinois.

THE PRINCIPLES OF TABLE CLEANING

Although the concentrating table has certain fundamental elements in common with the machines described in the preceding section it differs so greatly in design and operation as to merit separate treatment. Moreover, since the experimental work reported in the main chapter of this paper bears directly on the use of a machine of this type a somewhat detailed description of the device is appropriate.

Consider for a moment a slightly inclined plane surface to which is attached a low barrier (riffle) extending parallel to its major axis. Give this plane a complex reciprocating motion of such character that the backward thrust is a quick jerk while the forward movement is a relatively slow and easy push. If now a number of small irregular objects of different specific gravities are placed on the upper end of this plane (table) two effects may be observed, first a stratification of the objects in the order of their densities and second, a progressive movement down the table (under certain conditions the particles will move up-hill) at rates varying with their densities and their frictional grip on the table surface. Now let a broad stream of water flow across at right angles to the line of mechanical motion. The objects are all immediately pushed against the riffle but the lighter pieces riding high in the stratified pile are washed over the barrier to be collected at one side as product while the heavy low-lying chunks follow the fence row down to the end as tailings. Let these simple specifications be applied to a linoleum covered table or deck from 8 to 20 feet long and 5 or more feet wide provided not with one but with many thin wooden strips spaced at regular intervals on the surface; give it a motor driven head motion (from a separate mechanical unit) and we have the essential elements of the concentrating table. Machines of this kind have long played an important role in ore-dressing where a light worthless gangue is to be separated from heavy metal-bearing mineral and modifications of these metallurgical models have a record of high success in coal preparation.

In the mid-west coal industries the use of these machines is limited at present to small operations for the preparation of stoker coals but they have an important place in Alabama in the cleaning of coal for making metallurgical coke. In a typical case at a Birmingham plant a ½″ by 0″ slack running 27% in ash is yielding a clean product of 5.5 per cent impurities with a net loss of only 3 per cent combustible. Moreover they have proved highly successful in reclamation projects involving the reworking of old bituminous and anthracite waste banks containing salvage values. From the engineering standpoint the table system has the advantage of divisibility into more or less independent units and so has great flexibility in meeting capacity needs; in small operations a single unit may be profitably employed on a capital investment quite modest in comparison with those of other designs.

A drawing of the machine used in our experimental work is shown in Figure 11 and a description of the coal cleaning operation is presented in a later section of this paper.

THE PREPARATION OF DOMESTIC STOKER COAL IN THE MID-WEST REGION

In a study designed to bring out the possibilities of preparing high grade stoker fuels from our home produced coals it is well first to make a brief survey of the methods used in neighboring states to meet the demands of the domestic consumer as well as to anticipate them. In the sharply competitive market that prevails, the practice of the leading producers of a region must sooner or later set the standards of product for that region, and so it is the part of wisdom for the small producer to observe and imitate. To cite a striking example of the meeting and overcoming of natural disadvantages, many of the commercial seams of Kansas are less than 20 inches thick and normally of mediocre quality. Washing practice has long been established in that state however, and Kansas coals are successfully measuring up to the exacting specifications of metropolitan markets. From a long list of current operations a few typical examples have been chosen to indicate in some measure the trend of the movement and the methods employed.

It is natural that the state of Illinois with her vast coal resources and her highly developed mining industry should take a leading place in the art of coal preparation. Indeed, the student of fuel engineering who sets out to observe what is newest and best in coal cleaning equipment and practice in this country will do well to spend much of his time within that state. The Old Ben Coal Corporation working the great No. 6 seam in Franklin County cite the following steps in the preparation of their premium stoker fuel: first, a screening operation to provide uniformity of size and to insure the elimination of the extreme fines; second, a three point tramp iron removal with magnetic separators; third, a blending of high vitrain coals to promote a lively flame with a durain stock to depress coke formation; fourth, a dry cleaning with air tables and fifth, treatment with a pressure spray of a heated high viscosity oil to inhibit dust formation. Produced under standardized conditions it has the merit of a uniformity of quality that promotes high combustion efficiency and greatly reduces the necessary labor of firing and attendance.

Similar treatment is accorded the 1″ and 1 ½″ stoker coals put out by Peabody and by Sahara in the No. 5 seam of Saline County. Screening, elimination of tramp-metal and cleaning in huge Baum wash boxes are followed through in order and again the result is an almost absolute uniformity of high quality that only complete processing can attain. Bell and Zoller in the No. 6 seam in Williamson County employ two Chance cones, using the larger on 6″ by 1 ½″ and the smaller on 1 ½″ by 5⁄16″.

In the northern counties of Henry and Fulton where the major coal mining projects are stripping operations, the necessity for washing is even more pronounced because of the mechanical loading that is inherent in that type of mining. One of the older washing plants at the Atkinson mine in Henry County working a rather low-grade seam (La Salle No. 2) and the Middle Grove mine in Fulton (Seam No. 6) run their entire outputs through Baum machines while Buckhart No. 17 (United Electric) in Seam No. 5 in the same county is served by a Rheolaveur.

Trends in Indiana, Missouri and Kansas in general follow those of Illinois. In the latter state the McNally-Pittsburg Mfg. Corpn., manufacturers of wash boxes and mining machinery that have an international distribution have done much to make the coal industry of the Southwest conscious of coal quality and a number of first class plants are located west of the Missouri. In the Pittsburg, Kansas, region a group of operators have established a community or public utility washing plant and thus they secure the advantages of modern methods and equipment at moderate overhead cost.

It must be noted that the cleaning and washing activities sketched above are integral parts of large production projects involving considerable capital investment and supported obviously, by adequate financial backing. In none of the cases cited is the production of stoker fuel the major objective; rather does it usually involve a simple diversion from the main washed stream of a fraction within a given size range, in quantity sufficient to meet the demand. In effect, as stoker fuel it bears only its fair split of the washing plant overhead. It is evident then that the example of the large plant offers little help to the solution of the problem faced by the small producer whose output is below the volume that would justify the investment in complete cleaning but who finds nevertheless that he must do something to hold his stoker business. For such a situation some new projects now well beyond the experimental stage are of special interest.

The setup of the Peru Deep Vein Coal Company of Peru, Illinois operating in an old mine field of the LaSalle No. 2 seam is an excellent example of a small washing unit for producing stoker coal only. This plant, constructed at a cost of about $6,000, consists of a Super Duty No. 7 Deister-Overstrom table, a dewatering drag and pump, an elevator and two 50 ton steel storage bins for product.

Their raw material consisting of screenings and slack containing up to 20 per cent of refuse was definitely a slow mover in a strictly local market but after conversion to a 1¼″ by 0 or 1¼″ by 10 mesh washed stoker fuel the demand went up 250 per cent and at times exceeded the supply even with a step-up to 20 tons per hour instead of the rated 15. The plant is operated by one man and maintenance costs have been uniformly low. Make-up water is secured from the city supply but the recycling of wash water is so efficient as to reduce this cost item to a low figure. Ash contents of the project as determined in the writer's laboratory range between 7.0 and 8.5 per cent. Moisture is fairly high as it leaves the machine but the removal of the minus 5⁄16″ by screening which is done when necessary, reduces it to a satisfactory point. The general situation as it appears to the outsider is that this course of procedure marks the line between a relatively small but profitable business or little or no business at all.

The Paris Coal Washing Company of Paris, Arkansas was organized by a group of 10 small companies working the low volatile Paris ''anthracite'' seam, as a non-profit corporation to provide means for raising the quality of their coals. Increasing demands for stoker sizes, particularly since the enactment of smoke laws in their St. Louis market area, made it imperative that rock and machine cuttings be eliminated from their product.

This plant, operated by a crew of four men, treats 50 tons per hour of their 3″ by 0 cut which is first split by a Leahy screen into fractions of 3″ by 2″, 2″ by 1″ and 1″ by 0. The two larger sizes are put over two Deister-Overstrom No. 7 tables in parallel and loaded direct. The 1″ by 0 size is divided between another pair of similar tables and after being washed is rescreened wet to yield a 1″ by 3⁄16″ stoker and a 3⁄16″ carbon. Coal received by this plant coming as it does from eleven different mines, may run from 16 to 30 per cent of ash which puts it beyond the pale for stoker use;

an average product has approximately 4.5 per cent moisture, 9.8 per cent ash, 16 per cent volatile matter and a thermal value of 13,470 B.t.u. Obviously the cost of a plant of this size, about $40,000, places it beyond the reach of the small individual producer but that cost divided among ten requires only a modest investment from each. A brief description of this project appears in the August 1941 number of Coal Age. Figure 10 is a view of the plant set-up.

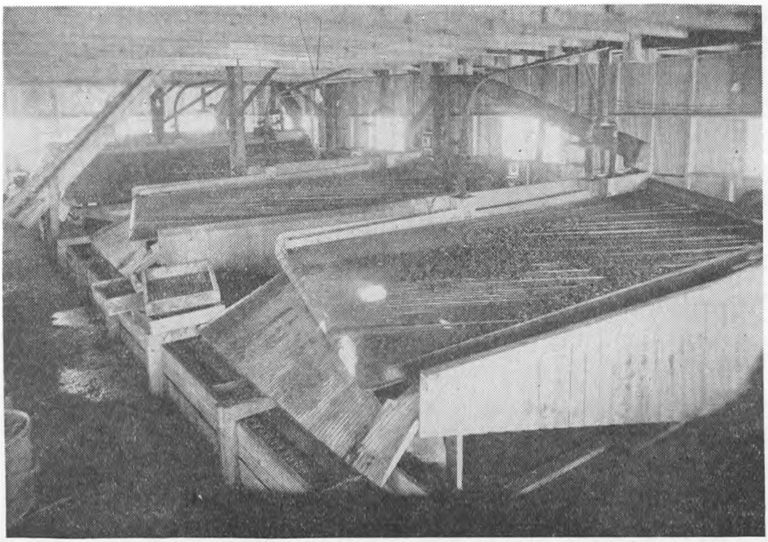


Fig. 10. View of the table equipment of the Paris Coal Washing Company.

In its general aspects the problem confronting the Farmers Coal Mining Co. of Higginsville, Mo. is similar to those cited above, with some variations in detail. The mine is small, yielding only about 150 tons per day but in screening and otherwise preparing the lump and smaller sizes for the local market they separate about two per cent of minus 1¼″ fines of a quality so low as to be unsalable. By the use of a No. 6 Deister table handling from three to four tons per hour this material containing 25 per cent waste yields a readily salable product of less than 9 per cent ash. In this case the question to be answered by the management was one of production and sale of straight run-of-mine versus classification into commercial sizes with complete separation of values from the waste. Cost data are not available but plant performance has apparently been highly satisfactory and the owners are pleased with the results.

Operations of the Elmira Coal Company's plant at Elmira, Mo. began in late August of 1941 and little detailed information is available as yet. A No. 7 Deister table is handling 10 tons per hour of 1 ¼″ by 0 dirty slack to produce a stoker coal. Again the key point of the situation is the conversion of what is practically a waste material into a valuable commodity.

A discussion of table cleaning in the Birmingham district of Alabama where the coal is used in by-product ovens would hardly be apropos here were it not that some of the results obtained there throw some light on the question under direct discussion. The Woodward Iron Company in the operation of their jig washers separate a 20 ton per hour refuse fraction running from 30 to 50 per cent of ash; for the recovery of the values from this waste it is recrushed to 1 ¼″ by 0 and tabled to yield a product with only 6.4 per cent ash. We shall take occasion in describing our own work on Iowa coals to point out an analogous case in which salvage values were recovered from picking table refuse.

THE PRODUCTION OF STOKER COALS FROM IOWA SCREENINGS

Pilot plant washing studies in the Department of Chemical Engineering at the University date back to 1933 when a 5 ton per hour McNally-Pittsburg jig was installed and put into operation in improvised laboratory space at the University heating plant. Facilities for work in this place were especially good because of the opportunity for use of the plant elevating equipment and bunker space, and in a period of two years time a total of some 50 carloads from 14 different Iowa mines were put through the machine for tests under varying conditions. An idea of the general nature of the results obtained may be gained from the following tabulated averages of 19 carload runs on 11 different coals:

TABLE I.

Averaged Results of Jig Washing Tests, (19 Runs).

Ash in raw coal	Ash in washed coal	Ash in refuse	Ash in sludge solids	Recovery of coal	Ash removal
18.7	11.3	64.2	44.8	84.2	49.0

(All figures are expressed in percentages on the dry basis.)

A more complete description of these studies may be found in Technical Paper No. 3 by H. L. Olin *et al* published in 1936 by the Iowa Geological Survey. They clearly proved that Iowa coals were little different from those from other states in their adaptability to washing processes; and that after being washed they differed little from those foreign coals in quality.

As our studies in coal cleaning progressed and particularly as closer contacts were made with the Iowa mining industry it became more and more evident that the critical problem of coal preparation lay in the situation of the small operator. For better or worse much of the mining of coal in this state (with a few notable exceptions of course) is small time business with operations as reported by the State Mine Inspectors in 1940 numbering 442 mines, only 67 of which have railroad connections. Some of these to be sure are almost literally dog holes with production for the year as low as 10 tons, but the average annual output of these 375 non-railroad mines for 1939 (again our data come from this report) was only 3,000 tons in contrast with 28,000 tons for the 67 railroad mines. The greater tonnage of the larger workings makes possible some latitude in the selection of a cleaning unit if and when the decision to install it is made, and in the meantime the amount of steam coal fines is usually ample to secure power plant contracts leaving the way clear for the marketing of the various domestic furnace grades. But the situation of the little fellow often verges on the desperate. Faced with the necessity for screening the run-of-mine, he is plagued with the accumulation of fines too dirty for domestic stoker use and too small in quantity to be of interest to the big consumer. For him an adequate salvaging of his by-product entails mechanical cleaning but only under conditions and at costs strictly consistent with the size of the job to be done. It was with his case in mind therefore, that we turned to the study of table cleaning as the type that seems to offer most opportunity for successful operation on the small scale and a new laboratory was designed and equipped accordingly.

Experimental Studies with the Deister-Overstrom Cleaning Table

The central feature of the new laboratory setup is a Deister-Overstrom No. 14 table with linoleum deck made by the Deister Concentrator of Fort Wayne, Indiana. Figure 11 is a plan drawing of the machine showing the line of the deck motion, the position of the driving mechanism with reference to the table, the feed and water receivers, the water distributing launder and the diamond shaped blocks that pivot on their centers to govern the water flow over the table. The table and drive are mounted on a double I-beam which extends longitudinally below the center line but the table deck, resting on blocks set in rectangular channels supported on a subframe, is free to vibrate with its characteristic reciprocating motion. Adjustment of the machine to varying quality of feed and to the desired degree of separation to be made involves mainly the changing the slope of the table with reference to both longitudinal and transverse axes but coal and water flow rates are likewise important elements to be controlled.

An automatic feeder designed and built especially for our use by Link-Belt delivers coal to the table by means of a tapered spiral conveyer with sprocket wheel and chain drive. It is powered with a one-horse single phase induction motor through a Link-Belt speed reducer of the variable pulley type; feed rates ranging from three quarters to two and one-half tons per hour may be maintained. A feed hopper of 600 pounds capacity is included in the assembly.

Although coal drying operations after washing are usually limited in commercial practice to the removal of excess surface moisture to insure against freezing troubles it was desirable in our experimental setup to provide means for a high degree of water removal and a tray drier of 500 pounds capacity, steam heated and equipped for forced air circulation was accordingly built. In general however, it was used merely for elimination of superficial moisture and this was accomplished with little loss of time. Because of limitations of space in our present laboratory location a vibratory wedge wire screen which is part of our regular operating equipment was unavailable for use in dewatering the wet coal but as opportunity is presented later for putting it in the line the drier will be relieved of much of its burden and the operating costs much reduced.

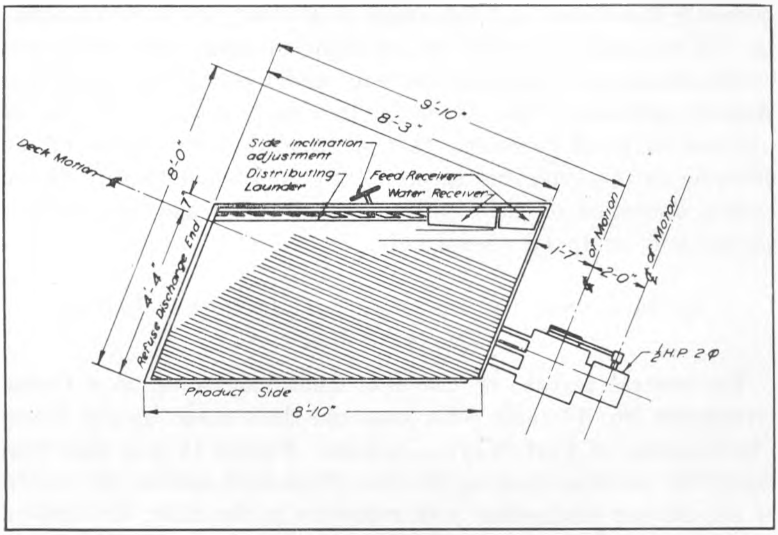


Fig. 11. Plan of the Deister-Overstrom table.

Results of preliminary work with many of our Iowa coals on the No. 14 table proved to us clearly that effective separation was possible only with a coal feed of ¾″ or less in diameter and this limitation applied particularly to those coals in which pyrite or other foreign rock was distributed through the coal mass in small particles or attached in thin laminar plates to the fuel proper. To provide the required degree of mechanical division of pure coal from rock previous to the washing operation use was made of a Sturtevant buhr mill of 1,000 pounds per hour capacity set to deliver the three-quarters inch maximum size and the 1 ½″ screenings as delivered to the plant were accordingly completely reprocessed without rejection of oversizes.

In addition to the equipment described above, accessories needed for making complete material balances were provided, such as water meters, platform scales, sludge sumps and the like. Raw coal bagged in burlap at the railroad dump pit was brought to the laboratory by truck and the washed and dried product was handled in a similar manner.

Laboratory Surveys of Coal Washability

Before undertaking actual experimental work with the pilot machine a broad groundwork was laid by plotting washability curves based on float and sink tests, for all the coals under investigation. Figure 12 for a shipment of screenings from Appanoose County is a typical example. Such a plot accurately drawn, indicates the theoretical limits of separation possible under various conditions and serves as a basis for computing actual washing efficiencies. The washing efficiency is the ratio of the percentage of float of a given coal actually secured with a definite machine setting to that obtained in a laboratory float test in a liquid whose specific gravity corresponds to that setting. Test liquids used are mixtures of gasoline and carbon tetrachloride in varying proportions to produce solutions with gravities ranging from 1.3, in increments of 0.1, up to 1.6 or higher. This technique is described in detail in Bureau of Mines, Information Circular 7,045 published in 1939.

Referring again to Figure 12 to illustrate its use, let us assume that the machine setting corresponds to a float liquid gravity of 1.49, i.e. all parts of the feed of this gravity or less will float. From the 1.49 point on the lower abscissa scale (specific gravity) now pass vertically to the intersection with the specific gravity curve, thence laterally to the "yield per cent" scale on the left and we see that the float under these conditions will constitute 80 per cent of the total feed. Moreover this lateral intersection with the cumulative ash curve (by reading down to the "ash per cent" scale) shows that the float fraction has an average ash content of something less than 10.0 per cent.

The "elementary ash" line mathematically, is the derivative of the cumulative ash curve and as such, indicates the rate at which the ash content of the float fraction rises with increasing float percentages as the gravity of the liquid is stepped up. Thus a flattening of this curve indicates only a slight change of ash percentage with increase of float product while a high slope of course shows that increased float yield can be effected only with rapid rise of ash content.

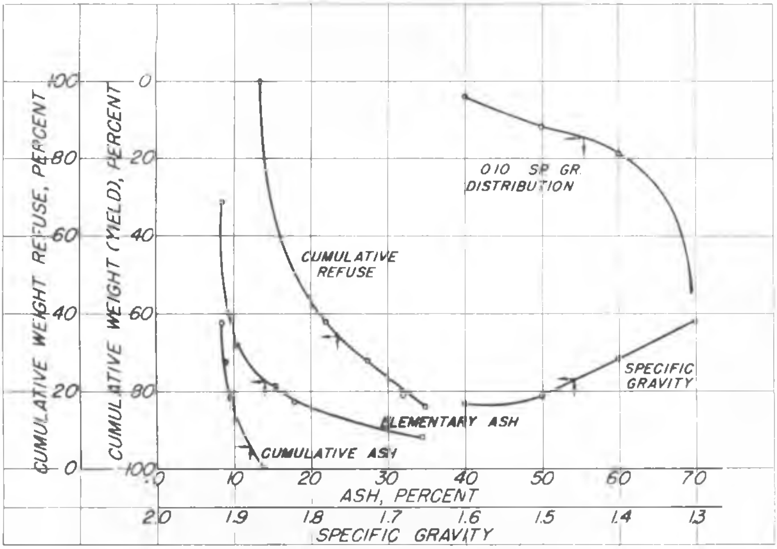


Fig. 12. Washing characteristics of Appanoose County screenings.

Some knowledge of the nature and scope of a formal preliminary investigation of coal washability may be gained from the study of a typical government report such as that covered in R. I. 3449 "A Washability Study of the Woodstock Coal Bed at Klondyke Mine, West Blocton, Ala." by B. W. Gandrud and G. D. Coe, published by the Bureau of Mines. In addition to complete analytical data both proximate and ultimate and a curve of screen sizing tests for the minus 3″, it contains a series of ten plots of the kind just described, on the various screen fractions ranging from through 3″ to through 100 mesh. It is obvious that such a survey is highly desirable or even mandatory in preparation for the design of a commercial washing plant to serve a given mine; in covering the general aspects of our broader problem we have been content to limit ourselves to one plot as fixed by the size of the coal actually washed.

THE LABORATORY WASHING PROCEDURE

The raw feed of approximately two tons (crushed to a maximum of ¾″) was sacked and weighed previous to the beginning of the run and delivered to the feed hopper as needed. Meanwhile the length of stroke and the table pitch were checked, the drive motor started and coal admitted to the table. Four distinct fractions were separated for analysis: the heavy refuse discharged from the end of the table, the middlings leaving at the corner, the main product coming off at the side and the fines being discharged with the water as sludge. During the run each of these was sampled at approximately one minute intervals and the aggregates then reduced down to laboratory size, the solids by coning and quartering and the sludge by proportioning. The following data were collected for each run: (1) side elevation of the table, (2) length of stroke, (3) weight of coal feed, (4) weights of product, middlings and refuse respectively and (5) water and coal feed rates.

RESULTS OF CLEANING TESTS, 1938-39, SERIES "A"

The first series of wash runs with the laboratory Deister was made in the academic year of 1938-39 by a crew consisting of W. D. Warinner, foreman, and L. H. Riggs, Eldon E. Bauer, Dick Duffey and E. R. Beverly. Since the method was untried so far as local conditions were concerned and since the equipment was new, much of the limited time available the first year after the completion of the installation was spent in determining the optimum operating conditions, i.e. the proper table setting, length of stroke, water and coal feed rates and the like. For most of the formal experimental work carried out during the year the following conditions were maintained: length of stroke ⅝″; longitudinal elevation of table 1 ⅞″; side inclination 4″ and water rate about 80 gallons per minute with a coal feed of approximately 1.25 tons per hour. Of a total of 21 runs made in this series on crushed run-of-mine and low grade screenings, the following on coals from mines in Appanoose County (A16 and A18), Monroe County (A20) and Mahaska County (A12) are typical of general conditions and results and they are described in the tables that follow.

INTERPRETATION OF ANALYTICAL RESULTS

The data presented in the following tables are simply expressed and need little explanation. It should be noted however, that ash, sulfur and thermal values are reported on the dry basis only, that is, they are calculated to the percentage distribution that would hold were no moisture present. Since Iowa coals have on the average under mine conditions about 15 per cent of moisture, "as received" values may be computed by multiplying the "dry" percentages by (1— .15) or by some similar factor based on a known moisture content.

Per cent loss quoted in negative values indicates an apparent gain in weight in computing the material balance. Percentage of ash elimination equals 100 times the weight of ash in the raw feed, minus the ash retained in the product, divided by the weight of ash in the raw feed.

TABLE II.

A 16, Appanoose County Screenings

	Dry wt. lbs.	Per cent ash	Per cent yield	Per cent S
Raw feed	531	21.9	......	5.0
Product	366	10.4	69.0	4.3
Refuse	102	70.2	19.2	
Fines and loss*	63	......	11.8	

Ash reduction, 67.2 per cent.

(All percentages on the dry basis).

*In the "A" series the fines in the sludge were not recovered.

The refuse from this run consisted largely of thin plates of calcite ($CaCO_3$) loosened from the vertical cleavage planes and of undercut shale, which accounted for its extremely high ash content. The striking reduction in mineral matter from nearly 22 per cent in the raw feed to less than 11 in the product leads to the conclusion that what was practically a waste material has yielded an acceptable domestic fuel (69 per cent of the total) and that its value less the cost of processing therefore represents almost clear profit. This lot is typical of the screenings from the long-wall mines of the

Mystic seam of Appanoose County where the machine cuts into the floor rock and where the fines almost invariably carry heavy mineral burdens. Perhaps on no other screenings produced in the state does the cleaning process offer so much promise of improvement as on those from this seam mined by the long-wall method. Washing characteristics shown in Figure 12 indicate that this test run was short of 100 per cent efficiency, i.e. a higher yield of product of 10 per cent ash was theoretically possible.

TABLE III.

A 18, Appanoose County Crushed Run-of-Mine.

	Dry wt. lbs.	Per cent ash	Per cent yield	Per cent S
Raw feed	493	13.7	—	3.72
Product	417	9.7	83.0	—
Refuse	43	39.5	8.7	
Fines and loss	33	—	6.7	

Ash reduction, 40.1 per cent.
(All percentages on the dry basis).

The refuse from this lot which came from a second Appanoose County mine was similar in character to that of A 16 but representing crushed run it was naturally much less in quantity. In general, Mystic coal exclusive of screenings, is fairly clean and the ash reduction was therefore only moderate; the product yield (83 per cent) is correspondingly high. Figure 12 serves to indicate the general cleaning possibilities of this coal as well as those of A 16.

TABLE IV.

A 20, Monroe County Screenings.

	Dry wt. lbs.	Per cent ash	Per cent yield	Per cent S
Raw feed	540	24.3	—	7.6
Product	406	13.2	75.5	4.8
Refuse	104	67.5	19.3	—
Fines and loss	37	21.8	6.9	—

Ash reduction, 59.4 per cent.
(All percentages on the dry basis).

In Run A 20 on screenings from Monroe County we processed a raw feed with nearly 25 per cent ash, well-nigh worthless from the standpoint of any direct utilization and unquestionably of no value as stoker coal. While the product with 13.2 per cent ash was not ideal in quality it was at least vastly improved and usable and the recovery was good (75 per cent). The refuse was gray, flaky and slate-like containing much granular calcite together with considerable quantities of finely divided pyrite. The practice of marketing screenings of a quality so low as this for power plant fuel is to be strongly deprecated; it does much to give the good coals of the state a bad name.

TABLE V.

A 12, Mahaska County Screenings.

	Dry wt. lbs.	Per cent ash	Per cent yield	Per cent S
Raw feed	331	18.6	......	8.4
Product	256	12.9	77.3	5.7
Refuse and loss	36	53.5	10.9	......
Sump fines	39	......	11.8	......

Ash reduction, 46.6 per cent.
(All percentages on the dry basis).

These Mahaska County screenings were unusually "bony", i.e. they had a high content of a highly mineralized coal-like structure of low specific gravity and were consequently difficult to clean as indicated by the relatively high ash content of the product. The washability plot is shown in Figure 13.

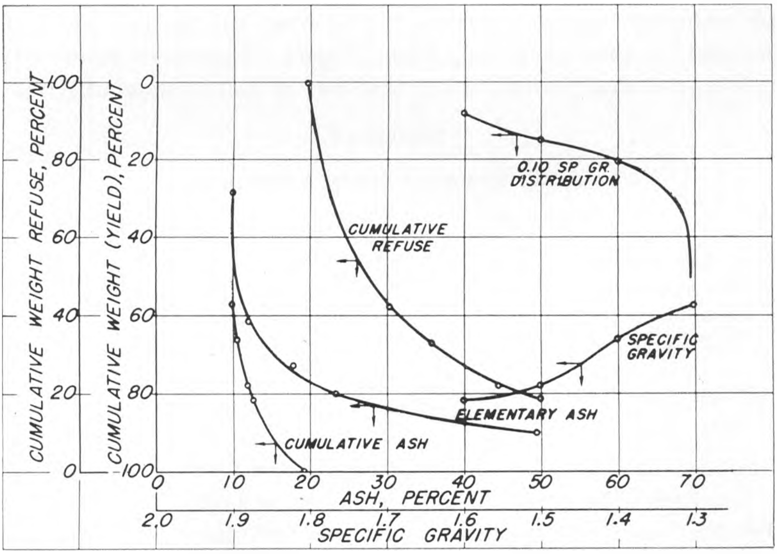


Fig. 13. Washing characteristics of Mahaska County screenings, Mine A.

RESULTS OF CLEANING TESTS, 1939-41, SERIES B

With the reorganization of the work in the fall of 1939 in preparation for tests on a larger scale than those made the preceding year a number of improvements in method and apparatus were made. A tank provided with drainage lines, screens and weirs and sufficiently large to receive the product from the side of the table was substituted for the smaller metal containers previously used. In addition a more effective scheme for sampling the sludge overflow from the weir box was applied with the result that a material balance accurate to less than one per cent could be computed. The crew in charge of operations consisted of Harold Bice and Walter J. Armstrong.

Observations made in previous tests indicated sharply the need for keeping the coal feed size to the No. 14 table at or below the ¾″ maximum and except for run B 75 the Sturtevant mill was set as before to meet that precise condition. Except where special qualities of the feed dictated a change the machine setting for runs in the "B" series was kept approximately constant at the following values: side elevation and length of stroke, 5.5″ and 1⅛″ respectively; elevation of discharge end above feed end, 1½″. Water rates varied somewhat with the adjustment of the machine; they were changed in general, only to meet special demands of the raw feed quality.

TABLE VI.

B 75, Monroe County Screenings

	Dry wt. lbs.	Per cent ash	Per cent yield	Per cent S	Thermal values B.t.u.
Raw feed	3,502	15.1	......	5.0	11,776
Product	1,828	7.6	52.2	3.4	13,045
Middlings	206	9.9	5.9	....	....
Refuse	1,270	25.1	36.3	....	....
Fines	100	19.6	2.9	....	....

Per cent loss, 2.7
Feed rate, 0.69 tons per hour
Maximum size of feed, 1 ¼″
Ash reduction, 74.0 per cent
(All percentages on the dry basis).

The results of this run demonstrate the adverse effect of working with a feed containing a fraction above the optimum size of ¾″ and they are reported here solely for that purpose. In any cleaning operation the heavy mineral must be broken from the coal before separation can be effected in the washer and a certain amount of preliminary crushing is usually mandatory. The product was of high quality with an ash content of only 7.6 per cent, but a refuse percentage of 36.3 with only 25 per cent ash is too high to be tolerated; the high percentage of ash removal was obtained at the expense of excessively high loss of coal in the refuse. Figure 14 indicates the theoretical possibilities of cleaning this coal.

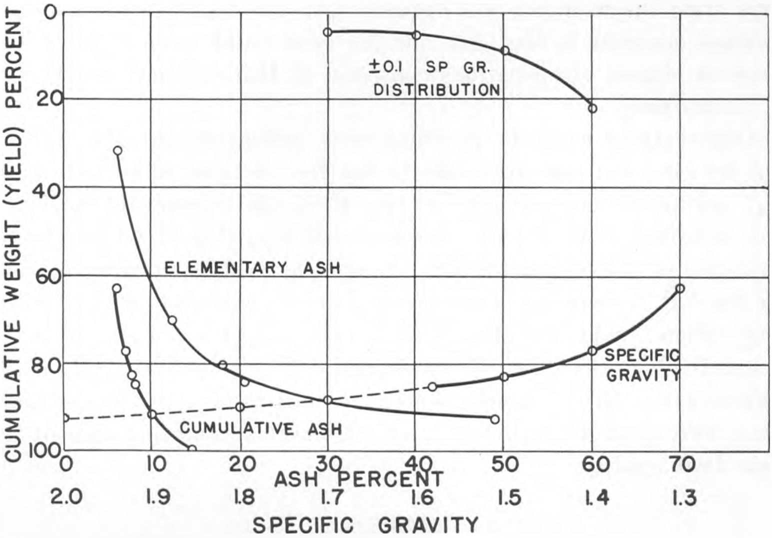


Fig. 14. Washing characteristics of Monroe County screenings.

TABLE VII.

B 77, Mahaska County Screenings

	Dry wt. lbs.	Per cent ash	Per cent yield	Per cent S	Thermal values B.t.u.
Raw feed	3,560	13.1	......	6.1	12,333
Product	2,691	9.0	75.6	4.5	12,912
Middlings	0	......	......	......	....
Refuse	744	25.6	20.9	......	....
Fines	87	18.3	2.4	......	....

Per cent loss, 1.0
Feed rate, 0.70 tons per hour
Water rate, 8.8 lbs. per lb. of coal
Ash reduction, 48.0 per cent
(All percentages on the dry basis).

This run was unsatisfactory from the standpoints of both yield (75.6 per cent) and ash elimination as indicated by the plots of Figure 15. Reference to the cumulative ash curve shows that with theoretically perfect separation about 85 per cent of a product with less than 9 per cent ash should be obtained. The low slope of the specific gravity curve shows it to be amenable to cleaning and later runs on screenings from the same mine gave better results.

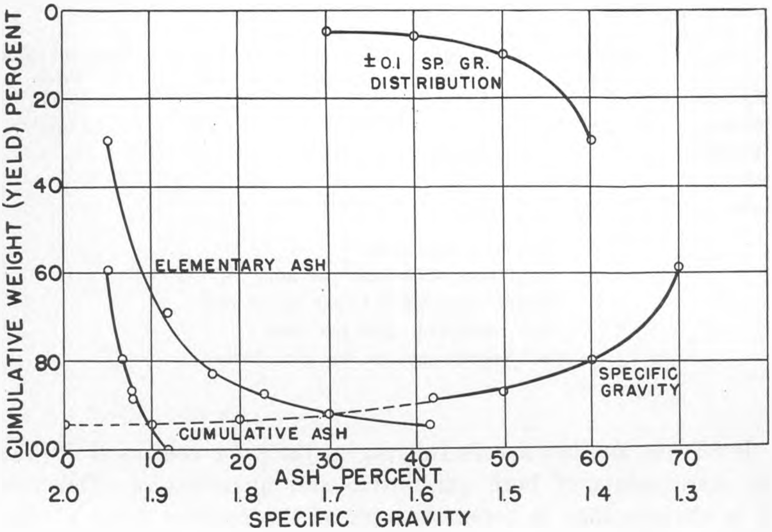


Fig. 15. Washing characteristics of Mahaska County screenings, Mine B.

TABLE VIII.

B 79, Mahaska County Crushed Run-of-Mine

	Dry wt. lbs.	Per cent ash	Per cent yield	Per cent S	Thermal values B.t.u.
Raw feed	3,638	11.7	....	7.0	12,397
Product	2,964	7.1	81.5	6.0	12,990
Middlings	67	21.0	1.8	......	....
Refuse	427	41.2	11.7	......	....
Fines	158	14.7	4.3	......	....

Per cent loss, 0.91
Feed rate, 0.78 tons per hour
Water rate, 8.9 lbs. per lb. of coal
Ash reduction, 50.1 per cent
(All percentages on the dry basis).

This run marked a successful separation of crushed run-of-mine from the same source as B 77. Reference to Figure 15 shows that a product of 81.5 per cent corresponds closely to the maximum yield possible if the ash is to be reduced to 7 per cent. By rejecting less than 19 per cent of the raw feed, 50 per cent of the waste mineral was removed.

TABLE IX.

B 83, Mahaska County Crushed Run-of-Mine

	Dry wt. lbs.	Per cent ash	Per cent yield	Per cent S	Thermal values B.t.u.
Raw feed	3,347	11.6	......	6.7	12,357
Product	2,841	8.1	84.9	4.2	12,731
Middlings	45	16.7	1.3	......	....
Refuse	328	39.6	9.8	......	....
Fines	109	12.3	3.2	......	....

Per cent loss, 0.73
Feed rate, 0.76 tons per hour
Water rate, 8.2 lbs. per lb. of coal
Ash reduction, 41.0 per cent
(All percentages on the dry basis).

B 83 was another successful run on the same coal as B 79 from the standpoints of both qualitative and quantitative efficiencies. It is obvious that in repeated tests of the product from a single mine, acquired familiarity with its characteristics is of great help in setting the machine for making an efficient separation.

TABLE X.

B 78, Mahaska County Oiled Stoker Coal

	Dry wt. lbs.	Per cent ash	Per cent yield	Per cent S	Thermal values B.t.u.
Raw feed	2,132	13.8	......	9.5	12,278
Product	1,739	8.9	81.6	6.0	12,982
Middlings	0	0	0	......	....
Refuse	371	37.3	17.4	......	....
Fines	0	0	0	......	....

Per cent loss, 1.0
Feed rate, 0.67 tons per hour
Water rate, 11.6 lbs. per lb. of coal
Ash reduction, 47.5 per cent
(All percentages on the dry basis).

A stoker coal marketed in Mahaska County, oiled to lay the dust but otherwise unprocessed except for screening, was put over the table with the results shown above. The high percentage of refuse of course indicates that in its original state it was of doubtful quality; a satisfactory stoker coal cannot be prepared by putting an oil film on dedusted screenings. It was obvious however, that in the washing process the added oil promoted a sharpness and completeness of separation not observed with any of the untreated coals. It seems evident that the oil film preferentially adsorbed by the coal particles inhibits wetting much as it does in froth flotation and with the same beneficial results. Particularly noticeable was the clarity of the waste water which carried only a light, gray mineral suspension instead of the usual black sludge made up of coal fines, due to selective wetting of the coal particles by the oil. Much of the oil applied before the cleaning operation appears to have remained in the product; it is possible that in cases where separations prove unusually difficult a light oil pretreatment may prove effective in producing sharper cuts. Comparison of results with the theoretical plot (Figure 16) shows the mechanical processing to be highly efficient.

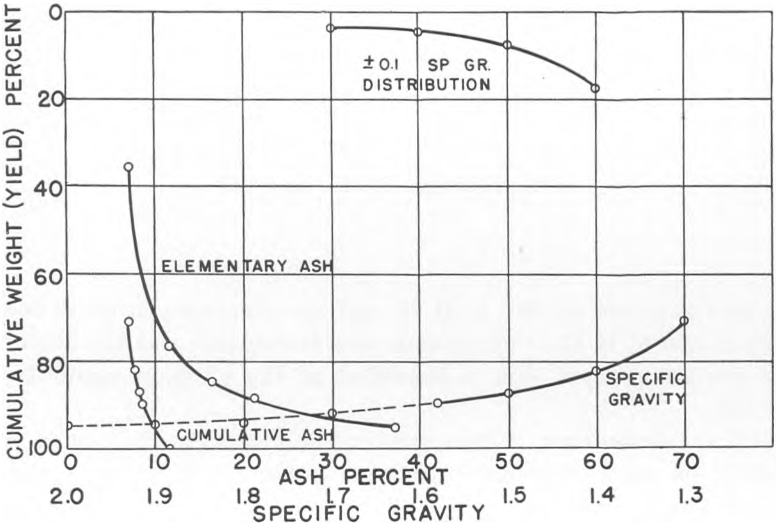


Fig. 16. Washing characteristics of Mahaska County oiled stoker coal.

TABLE XI.

B 81, Mahaska County Oiled Stoker Coal

	Dry wt. lbs.	Per cent ash	Per cent yield	Per cent S	Thermal values B.t.u.
Raw feed	3,101	12.5	.....	.....	....
Product	2,615	8.8	84.3	.....	....
Middlings	160	12.6	5.2	.....	....
Refuse	296	38.8	9.6	.....	....
Fines	0	0	0	.....	....

Per cent loss, 0.97

Feed rate, 0.63 tons per hour

Water rate, 9.9 lbs. per lb. of coal

Ash reduction, 41.0 per cent

(All percentages on the dry basis).

This run was similar to B 78 and the comments made thereon apply also to B 81. Conspicuous in this run also was the absence of fine sludge coal, due to the effect of the previous application of oil.

Of special interest in this series of studies were the results obtained on tests of material rejected in the picking tables in the usual tipple operation and normally wasted. Mechanical loading in any type of mining greatly increases the burden on the cleaning plant but in stripping operations the need for special methods for removing the gross impurities becomes especially acute. The obvious solution of the problem in a completely equipped modern plant is of course a rigorous separation at the picking table followed by the crushing and washing of the rejects; without the follow-up operation, coal picking resolves itself into a nice question of concession to the quality of product on the one hand or loss of valuable tonnage on the other.

Runs B 82 and B 84 were made on picking table rejects from a Mahaska County stripping operation, removed in the course of the preparation of marketable grades. It is the usual practice at this plant to reject from 9 to 10 per cent of the gross intake in this way, most of which is unsalvaged. Figure 17 gives graphic evidence of the economic advantage of reworking the rejects; the pile at the right carrying 11 per cent ash constitutes 73 per cent of the raw feed.

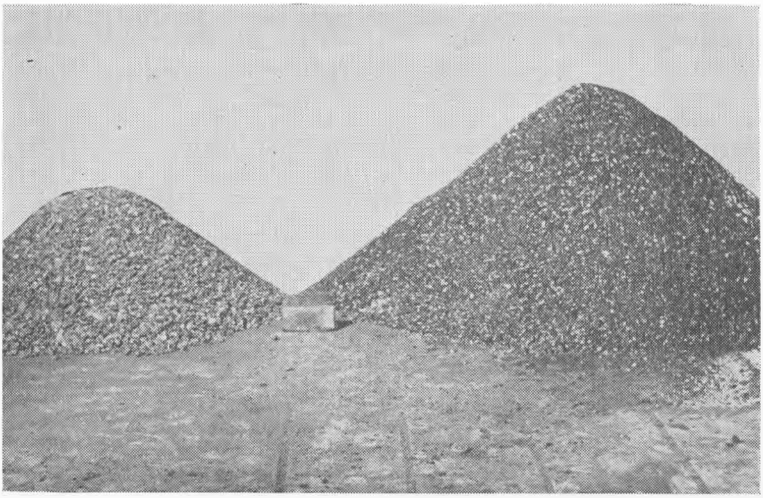


Fig. 17. Products from picking table waste; (left) refuse, (right) recovered product.

Figure 18 is a plot of the washing characteristics of the refuse processed in Runs B 82 and B 84.

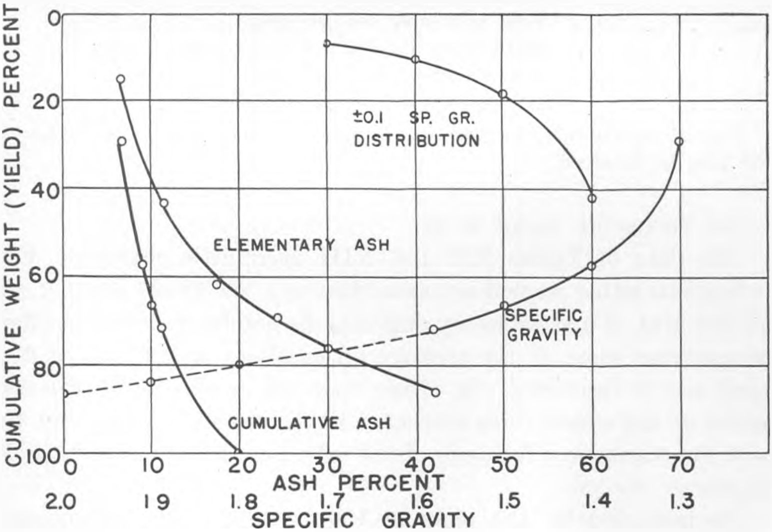


Fig. 18. Washing characteristics of crushed picking table refuse.

TABLE XII.

B 82, Mahaska County Picking Table Refuse

	Dry wt. lbs.	Per cent ash	Per cent yield	Per cent S	Thermal values B.t.u.
Raw feed	3,502	20.3	.....	11.9	10,532
Product	2,548	11.4	72.8	5.8	12,352
Middlings	85	26.9	2.4	.....	....
Fine refuse	502	46.6	14.3	.....	....
Heavy refuse	208	56.7	6.0	.....	....
Fines	92	12.8	2.6	.....	....

Per cent loss, 1.9
Feed rate, 0.77 tons per hour
Water rate, 7.8 lbs. per lb. of coal
Ash reduction, 59.0 per cent
(All percentages on the dry basis).

TABLE XIII.

B 84, Mahaska County Picking Table Refuse

	Dry wt. lbs.	Per cent ash	Per cent yield	Per cent S	Thermal values B.t.u.
Raw feed	3,114	20.6	.....	10.1	10,998
Product	2,267	11.9*	72.8	3.5	12,226
Middlings	64	31.4	2.1	.....	....
Fine refuse	456	50.5	14.6	.....	....
Heavy refuse	144	60.0	4.6	.....	....
Fines	180	13.9	5.8	.....	....

Per cent loss, 0.1
Feed rate, 0.92 ton per hour
Water rate, 7.0 lbs. per lb. of coal
Ash reduction, 58.0 per cent
(All percentages on the dry basis).

*By setting the table to produce a 60 per cent yield a product of 9 per cent ash may be obtained.

See comments under B 82.

The data of Tables XII and XIII need little comment. From a material either wasted or earmarked as a low grade product, over 70 per cent of a satisfactory fuel may be obtained, or by sacrificing 10 per cent more of the tonnage an excellent stoker coal of 9 per cent ash is recovered. In either case the product is better than many of the stoker fuels marketed in the state at the present time and the economic advantage of the salvaging of values of this kind is clearly obvious.

As indicated by the plots in Figure 18 a high percentage of theoretical recovery was obtained.

Inspection of Tables II to XIII inclusive will show that reduction of sulfur content by washing, while relatively great in some cases, is nevertheless far from ideal so long as percentages as high as six are retained in the product. While pyrite in mass is easily eliminated, its occurrence in fine flakes distributed through the coal presents an extremely difficult cleaning problem. Moreover much of the sulfur of Iowa coals is in the organic state, that is it is chemically combined with the carbon of the fuel substances itself; its mechanical separation in this form is of course hopeless. In any case the least that can be said in its favor is that in some degree it has heat value and that its presence in a coal does not unduly detract from its value as a fuel.

RESULTS OF CLEANING TESTS, 1942-4, SERIES C

Work along the same general lines was resumed in the fall of 1941 with the view to covering a number of coals from Iowa mines not previously studied in Series A and B. The completion of Series C by Messrs. S. J. Lawrence and Jens Anderson, with methods differing little from those that preceded brought the machine laboratory work to a close. The results shown in the following tables confirm the general trends of the earlier studies and altogether they demonstrate the possibilities for improving coal quality inherent in this type of treatment.

In the reports of runs that follow we have omitted washing plots except for two, one on a relatively good coal C 92 and another on a particularly bad one, C 90. They will serve to show the possible separations which the machine operator should seek to attain.

TABLE XIV.

C 85, Mahaska County Screenings

	Dry wt. lbs.	Per cent ash	Per cent yield	Per cent S	Thermal values B.t.u.
Raw feed	2,282	15.7	......	8.4	11,884
Product	1,704	9.0	74.7	4.7	12,923
Middlings	420	36.8	18.4	.....	....
Refuse	28	50.5	1.2	.....	....
Fines	130	25.9	5.7	.....	....

Per cent loss, 0
Feed rate, 0.76 tons per hr.
Water rate, 6.8 lbs. per lb. of coal
Ash reduction, 57.2 per cent
(All percentages on the dry basis).

This shipment was typical of Mahaska County screenings coal quality with a characteristically high pyrite content. A notable reduction in sulfur percentage was obtained since massive pyrite is easily removed.

TABLE XV.

C 86, Appanoose County Screenings

	Dry wt. lbs.	Per cent ash	Per cent yield	Per cent S	Thermal values B.t.u.
Raw feed	2,032	16.1	......	5.3	11,633
Product	1,548	7.2	76.2	3.5	13,034
Middlings	185	20.8	9.1	....	....
Refuse	278	57.2	13.7	....	....
Fines	74	38.7	3.6	....	....

Per cent loss, –2.61*
Feed rate, 0.84 tons per hr.
Water rate, 6.62 lbs. per lb. of coal
Ash reduction, 66.3 per cent
(All percentages on the dry basis).

*A negative "loss" indicates an apparent gain in weight in the material balance.

The Mystic seam in Appanoose County is fairly clean but the screenings produced in the long-wall mining are high in shale fines brought in by the undercutting machine. A good separation is obtained however, and the product is of exceptionally high quality. The high percentage of ash removal was due to the fact that in these screenings much of the waste mineral matter is "free" or unattached to coal particles.

TABLE XVI.

C 87, Marion County Screenings

	Dry wt. lbs.	Per cent ash	Per cent yield	Per cent S	Thermal values B.t.u.
Raw feed	2,334	18.6	......	4.8	11,386
Product	1,763	10.2	75.5	3.4	12,562
Middlings	153	26.1	6.6	....	....
Refuse	315	57.9	13.5	....	....
Fines	159	27.2	6.8	....	....

Per cent loss, –2.38
Feed rate, 0.91 tons per hr.
Water rate, 7.99 lbs. per lb. of coal
Ash reduction, 58.6 per cent
(All percentages on the dry basis).

This coal from a commercial slope mine was not only extremely dirty but it had a high percentage of fines. It is a typical example of a grade of fuel that can expect little consideration from the trade in its raw state. On being washed it gave a fair yield of a highly satisfactory stoker coal. It is significant that the location of this mine, not far from Des Moines, gives it an important advantage in disposing of any potential good quality stoker fuel that it might produce.

TABLE XVII.

C 88, Marion County, Crushed Run-of-Mine

	Dry wt. lbs.	Per cent ash	Per cent yield	Per cent S	Thermal values B.t.u.
Raw feed	2,082	17.0	......	5.2	11,446
Product	1,640	9.1	78.8	3.4	12,661
Middlings	176	29.4	8.5	......	....
Refuse	223	50.9	10.7	......	....
Fines	63	19.5	3.0	......	....

Per cent loss, –0.96
Feed rate, 0.78 tons per hr.
Water rate, 7.92 lbs. per lb. of coal
Ash reduction, 58.1 per cent
(All percentages on the dry basis).

This shipment, from the same mine as C 87, carried slightly less ash and yielded a somewhat better product. Shale and pyrite easily separable from the coal, made up the bulk of the refuse.

TABLE XVIII.

C 89, Mahaska County Crushed Run-of-Mine

	Dry wt. lbs.	Per cent ash	Per cent yield	Per cent S	Thermal values B.t.u.
Raw feed	2,192	19.3	......	5.9	11,674
Product	1,591	9.8	72.5	3.9	13,000
Middlings	185	34.0	8.5	......	....
Refuse	304	61.6	13.9	......	....
Fines	126	29.9	5.8	......	....

Per cent loss, –0.68
Feed rate, 0.91 tons per hr.
Water rate, 6.43 lbs. per lb. of coal
Ash reduction, 63.7
(All percentages on the dry basis).

This shipment is a typical small-mine product (1941 production 10,000 tons) put out by primitive methods with little consideration for quality. Nevertheless a remarkable reduction in ash content was obtained in washing.

TABLE XIX.

C 90, Mahaska County Screenings
(From same mine as C 89)

	Dry wt. lbs.	Per cent ash	Per cent yield	Per cent S	Thermal values B.t.u.
Raw feed	2,351	22.8	....	6.1	10,935
Product	1,820	10.8	77.4	4.3	12,781
Middlings	154	47.7	6.6	....	....
Refuse	270	68.3	11.5	....	....
Fines	137	34.1	5.9	....	....

Per cent loss, –1.26
Feed rate, 0.97 tons per hr.
Water rate, 9.39 lbs. per lb. of coal
Ash reduction, 63.3 per cent
(All percentages on the dry basis).

Screenings of a quality unfit for market when judged even by liberal standards yielded a product of less than one-half the ash content of the raw feed. The refuse fraction contained shale, soft clay, calcite (lime carbonate), pyrite and oxidized iron.

The plot of washing characteristics is shown in Figure 19.

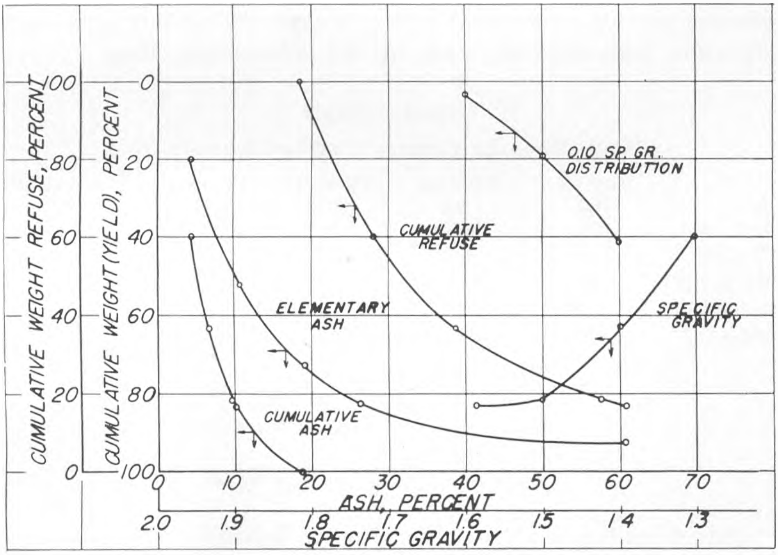


Fig. 19. Washing characteristics of Mahaska County screenings, Mine C.

TABLE XX.

C 91, Mahaska County Screenings

	Dry wt. lbs.	Per cent ash	Per cent yield	Per cent S	Thermal values B.t.u.
Raw feed	2,149	16.2	....	3.2	11,781
Product	1,675	9.0	77.9	2.2	13,029
Middlings	190	30.4	8.8	....	....
Refuse	244	52.5	11.4	....	....
Fines	21	50.6	1.0	....	....

Per cent loss, 0.87
Feed rate, 0.83 tons per hr.
Water rate, 10.4 lbs. per lb. of coal
Ash reduction, 56.7 per cent
(All percentages on the dry basis).

This shipment was from one of the smaller stripping operations of the county producing about 15,000 tons per year. It showed evidence of some care in preparation and the percentage of fines was exceptionally low.

TABLE XXI.

C 92, Monroe County Screenings

	Dry wt. lbs.	Per cent ash	Per cent yield	Per cent S	Thermal values B.t.u.
Raw feed	1,842	13.4	....	3.8	12,188
Product	1,579	8.2	85.8	3.0	13,105
Middlings	57	33.7	3.1	....	....
Refuse	135	54.4	7.4	....	....
Fines	52	21.1	2.8	....	....

Per cent loss, 0.96
Feed rate, 0.80 tons per hr.
Ash reduction, 47.2 per cent
(All percentages on the dry basis).

The coal from this mine (Blackstone) has long had a reputation for good quality and this shipment adds confirmation to that impression. The washed product is high in yield and low in ash content. Production at this mine in 1941 was 52,680 tons.

The washing plot is shown in Figure 20.

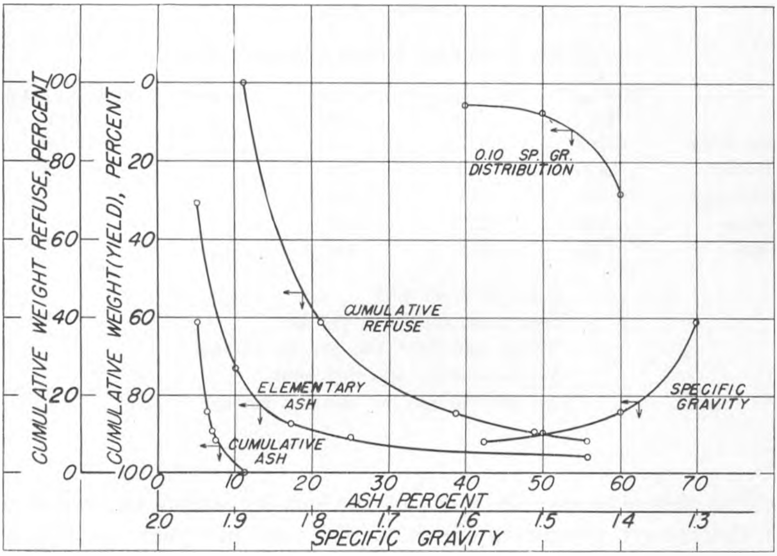


Fig. 20. Washing characteristics of Monroe County screenings.

TABLE XXII.

C 93, Marion County Screenings

	Dry wt. lbs.	Per cent ash	Per cent yield	Per cent S	Thermal values B.t.u.
Raw feed	2,079	16.3	.	5.3	11,822
Product	1,729	10.0	83.2	3.7	12,757
Middlings	77	40.0	3.7	.	.
Refuse	207	61.0	10.0	.	.
Fines	72	35.1	3.5	.	.

Per cent loss, –0.33
Feed rate, 0.74 tons per hr.
Ash reduction, 48.7 per cent
(All percentages on the dry basis).

This shipment represents the product from a mine putting out less than 500 tons per year. The quality nevertheless was not unduly low compared with that from some larger mines in the locality. While a "dog hole" works under severe handicaps in many respects it may sometimes yield a fairly respectable fuel.

TABLE XXIII.

C 94, Monroe County Screenings

	Dry wt. lbs.	Per cent ash	Per cent yield	Per cent S	Thermal values B.t.u.
Raw feed	2,379	22.2	.....	8.1	10,790
Product	1,769	10.0	74.4	4.4	12,872
Middlings	117	51.9	4.9	.....	....
Refuse	390	68.2	16.4	.....	....
Fines	72	48.6	3.0	.....	....

Per cent loss, 1.32
Feed rate, 0.96 tons per hr.
Ash reduction, 66.6 per cent
(All percentages on the dry basis).

This shipment coming from a small mine with an annual production of less than 5,000 tons reflects the low quality to be expected in operations carried out under primitive conditions with inadequate preparation equipment. In addition to a relatively high percentage of fines it carried much shale, calcite and pyrite which however, were easily removed to produce a 75 per cent yield of a fuel with only 10 per cent ash. There is little market for screenings of this quality in their raw state; some low-cost cleaning process seems to be its only means of salvation.

TABLE XXIV.

C 95, Marion County Screenings

	Dry wt. lbs.	Per cent ash	Per cent yield	Per cent S	Thermal values B.t.u.
Raw feed	1,966	16.1	.....	6.2	11,567
Product	1,749	10.2	89.0	4.4	12,587
Middlings	26	29.0	1.3	.....	....
Refuse	198	51.5	10.1	.....	....
Fines	7	24.9	0.3	.....	....

Per cent loss, –0.68
Feed rate, 0.76 tons per hr.
Ash reduction, 44.0 per cent
(All percentages on the dry basis).

The character of this coal was such as to make it rather difficult to clean. On the other hand a high yield of an acceptable stoker coal was obtained.

While the obvious limitations to which our experimental work was subjected made difficult or impossible any valid estimate of costs of processing our results do confirm the general statements made in a preceding section (page 34) regarding the advantages of table cleaning in situations where production and markets are limited and available capital is small. Thrifty use of second hand construction material and accessories, regulated of course by sound engineering, may do wonders in keeping down capital costs, as demonstrated by the case in Peru, Illinois, cited before. Power demands for table cleaning are inherently low and with careful recycling of water, operating costs including supervision, may easily be kept at moderate levels. Let it not be overlooked that to these costs whatever they may be, should be credited the weighty advertising advantage of applying to the product as it goes to market the qualifying term ''washed'', which in the coal markets of the country is rapidly becoming a significant trade mark of quality.

BURNING TESTS OF IOWA WASHED SCREENINGS

Confidence in the value of these coals as stoker fuels is amply supported by the results of burning tests carried out under practical conditions in one of the University cooperative dormitories provided with a Kol-Master domestic stoker. While formal heat balances were made in most cases, attention was centered mainly on the qualitative aspects of the investigation, i.e. the nature of the clinker formed, the coking and burning characteristics of the coal and the ease of control of the burning process in general. In the second series of such studies, made by Richard M. Markham and Doyon Pollock in 1937, approximately 5 tons of Iowa washed screenings were used in 11 test runs of 10 hours each, in addition to prepared coals from other states which served as reference material for comparison of fuel values.

Ash and sulfur contents of the test coals, prepared from typical screenings from Appanoose, Lucas and Mahaska mines, had been reduced by washing to average values of 8.5 and 4.5 per cent respectively, which closely approximate the theoretical limits beyond which, for the coals in question, mechanical cleaning has little effect. This superiority over the raw screenings from which they were derived—and this of course applies to all washed coals—was due to the following improvements: first, a material reduction in the total ash content; second, complete removal of free shale and other rock; and third, a certain degree of size classification with elimination of fine dust. All of these are of fundamental importance and collectively they constitute the elements of a code of standards that must sooner or later be adopted by all coal producers who hope to continue to provide domestic fuels.

The tests in question were made under moderate winter conditions with outside temperatures ranging from 7° to 40°F. and steam pressures were maintained at an average of 15.3 lbs. absolute. Average evaporation per hour, coal feed per hour and weights percentage of CO_2 in the flue gas were 443 lbs., 62 lbs., and 9.1 per cent respectively. The average overall thermal efficiency was 71 per cent.

In their summarized conclusions Markham and Pollock state that inspection of the stack revealed little smoke evolution, the maximum appearing in the ''off'' periods with a density that seldom exceeded No. 2 Ringelmann, and the minimum during the ''on'' periods, when it was only faintly visible. Air feed to the stoker was set at the lowest value consistent with clean combustion and minimum monoxide evolution during the ''on'' period.

No trouble was encountered from clinker fusion in the tuyeres; practically all the ash except that escaping on the fly fused into a ring around the retort that could be easily removed in the usual way. Absence of loose unclinkered ash on the dead plate often encountered in the burning of Eastern coals was due largely of course to the relatively low fusing points that characterize the coal ashes of this region. Perhaps in no other type of coal burning can this quality be considered a positive virtue.

The suppression of unduly high stack losses involves mainly the prevention of air channeling in the fuel bed. This in turn is dependent first upon the inherent qualities of the coal such as coking tendency and ash content, and second upon the technique of the firing operation, i.e. length of the cleaning interval, thickness of fuel bed and the position of the air setting.

Perhaps the most noticeable characteristic exhibited by all the coals tested was a tendency common to most of those of bituminous rank, of carbonizing and forming more or less troublesome ''coke trees'' that rise from the retort and extend over the dead plate. Contrary to general opinion the coals of Iowa are definitely of the coking type although this quality is not so highly developed as in those of the East. In hand firing this property is to be classed as a positive virtue since a moderate amount of sintering mats the fuel charge together and helps to ''hold the fire,'' but in mechanical stokers it may cause trouble in draft control through formation of air channels when developed to an excessive degree. Coals with especially strong coking tendencies may be blended with non-coking types or chemically treated to inhibit the swelling and carbonizing action but in lieu of such treatment mechanical leveling of the fuel bed is needed from time to time to keep it in proper condition. At any rate the problem is vastly more acute with the producers of stoker fuels in Ohio, Pennsylvania and West Virginia and other regions whose coals normally yield a hard dense coke.

A continuous flue gas analysis gives the best index to the condition of the fuel bed. Although the percentage of CO_2 decreased slightly from a maximum immediately after cleaning when the bed was most compact it remained fairly constant under favorable conditions for a considerable period, after which it slowly declined, while on the other hand a sudden and rapid decrease followed the formation of an air channel. Figure 21 is a plot of average CO_2 against time for the Iowa coals studied in this series of tests; indicating as it does the condition of the fuel bed it may serve as a guide to the operator to warn him when attention is needed either in the form of clinker removal or leveling of the bed.

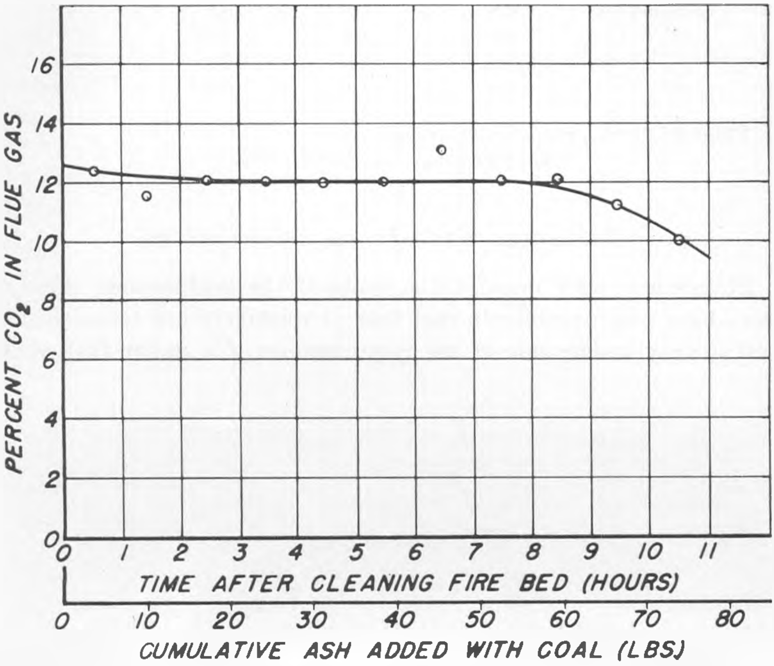


Fig. 21. Plot of average CO_2 in flue gas, domestic stoker burning tests.

In a third series of combustion tests made by a research fellow Mr. Donald Douslin in the winter of 1940-41 with the equipment previously used, effort was centered mainly on the study of clinker formation and some of the problems it prevented.

Table XIV gives data on the sources and properties of the coals used in the burning tests; in each case it was one of the products of the washing laboratory, representative of the quality that could be attained in normal operations.

TABLE XXV.

Composition of Domestic Stoker Test Coals

Test No.	Source	Dry wt. lbs.	Per cent ash	Per cent S	Thermal values B.t.u.
1	Monroe Co.	3,510	7.6	3.5	13,045
2	Mahaska Co.	2,400	7.3	5.6	13,401
3	,, ,,	3,560	9.0	4.6	12,912
4	,, ,,	3,635	7.1	6.0	12,990
5*	,, ,,	3,850	10.9	3.5	12,600

*Prepared from picking table refuse.

(All percentages on the dry basis).

Characteristics of Ash and Clinkers

In common with most of the coals of the middle-west those of Iowa have ash components that fuse at relatively low temperatures and so they satisfy one of the requirements of a stoker fuel whose burning involves the slagging of the ash and its removal in the form of a hard clinker. The average fusion point of the coal ashes used in the five burning tests run in this series was 2,022°F.; similar

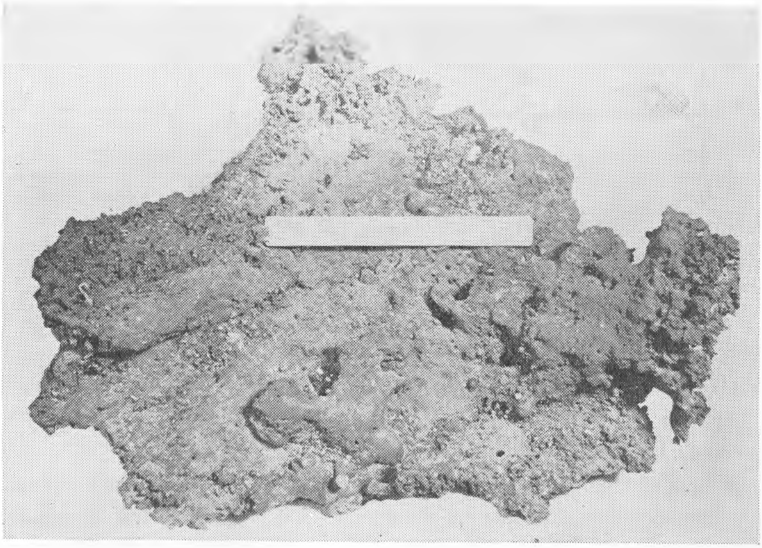


Fig. 22. Typical clinker from Iowa coal burning test.

measurements made on the fused material showed a reduction to 1,951°F.

The size and general appearance of the clinkers obtained under the conditions maintained may be judged by reference to Figure 22. Despite their size and weight they were not particularly objectionable except for the sulfurous fumes they gave off and they presented no difficulty to removal with the fire tongs. In structure they were dense because of their high state of fusion and they would of course have blocked the air flow had they formed near the tuyeres in the retort. Instead they were invariably found on the dead plate well out of the combustion zone. Analytical tests showed them to be almost entirely free from combustible material.

SUMMARY AND CONCLUSIONS

Results of laboratory and pilot-plant studies on the use of the Deister-Overstrom table in the washing of Iowa coal screenings are reported with tabulations of separations and yields given in detail.

In general, commercial fines produced in the preparation of the large graded sizes and carrying from 15 to 20 per cent of mineral impurities may be readily cleaned with a recovery of from 75 to 80 per cent of the gross tonnage to yield a desirable domestic stoker fuel with less than 10 per cent ash. High recoveries obtained also from crushed picking table rejects indicate the possibility of effecting significant economies through the salvaging of coal values otherwise lost.

For the Iowa operator with limited capital and relatively small output the use of the Super Duty No. 7 Deister-Overstrom table with a 15 ton per hour capacity, rather than the jig is recommended because of its comparatively moderate cost and its low power, water and labor requirements. Numerous cases are cited where small operators in other states in circumstances similar to those that prevail in Iowa have established modest but profitable stoker-coal industries.

Results of burning tests of washed screenings run under controlled conditions indicate that they possess satisfactory qualities in both thermal content and ash-fusion points for use in domestic heating with the small stoker.

APPENDIX I.

A Short List of Books on the Production, Preparation and Use of Coal.
(Listings are in the order of publication dates).

1. The Origin of Coal. David White and Reinhardt Thiessen. Bulletin 38, U.S. Bureau of Mines, 1913.

   A classic work by an eminent coal geologist and a famous coal microscopist.

2. Coal Washing. Ernst Prochaska. McGraw-Hill Book Company, Inc. New York, 1921. An old but good elementary book on coal cleaning.

3. American Fuels. R. F. Bacon and W. A. Hamor. McGraw-Hill Book Company, Inc., 1922. A two volume work which, in its day, was recognized as the standard book on fuel technology.

4. Fuels and Their Combustion. R. T. Haslam and R. P. Russell. McGraw-Hill Book Company, Inc. New York, 1926.
   An important and authoritative book on the combustion of all classes of fuels.

5. The Cleaning of Coal. W. R. Chapman and R. A. Mott. Chapman and Hall, Ltd. London, 1928. An authoritative work on coal cleaning, not entirely up-to-date nor adequately reflective of American practice but perhaps the best work on the subject available. Some general references were made to this book in the preceding Monograph.

6. The Competitive Position of Coal in the United States. National Industrial Conference Board, Inc. New York, 1931. The report of an exhaustive study of the economic relations between the coal industry and the consumer.

7. Coal, Its Constitution and Uses. W. A. Bone and G. W. Himus. Longmans, Green and Co. New York, 1936. A scholarly treatise by an eminent English coal technologist.

8. Coal. E. S. Moore. John Wiley and Sons, Inc. New York, 2d Ed., 1940. An extremely readable book on the origin and production of coal.

9. Geology of Coal. Otto Stutzer. Translated and revised by Adolph C. Noe. The University of Chicago Press, Chicago, 1940. A scholarly work with the European background.

10. Minerals Year Book. U.S. Bureau of Mines, Washington. An annual publication giving statistical data on mineral production in the United States with especially complete information on coal.

11. Keystone Coal Buyers Manual. Sydney A. Hale. McGraw-Hill Publishing Co., Inc. New York. An annual publication containing sections on coal preparation and use and a catalog describing the principal coal seams and producing mines of the country classified by states. An invaluable handbook for purchasers of coal.

STUDIES IN ENGINEERING

Bulletin 1. The Flow of Water Through Culverts, by D. L. Yarnell, F. A. Nagler, and S. M. Woodward, 1926. 128 pages, 26 figures, 23 plates. Out of print.

Bulletin 2. Laboratory Tests on Hydraulic Models of the Hastings Dam, by Martin E. Nelson, 1932. 72 pages, 40 figures. Out of print.

Bulletin 3. Tests of Anchorages for Reinforcing Bars, by Chesley J. Posey, 1933. 32 pages, 18 figures, price $0.50.

Bulletin 4. The Physical and Anti-Knock Properties of Gasoline Alcohol Blends, by Theodore R. Thoren, 1934. 32 pages, 13 figures, price $0.35.

Bulletin 5. The Transportation of Detritus by Flowing Water—I, by F. T. Mavis, Chitty Ho, and Yun-Cheng Tu, 1935. 56 pages, 15 figures, price $0.50.

Bulletin 6. An Investigation of Some Hand Motions Used in Factory Work, by Ralph M. Barnes, 1936. 60 pages, 22 figures, price $0.60.

Bulletin 7. A Study of the Permeability of Sand, by F. T. Mavis and Edward F. Wilsey, 1936. 32 pages, 12 figures, price $0.35.

Bulletin 8. Radiation Intensities and Heat-Transfer in Boiler Furnaces, by Huber O. Croft and C. F. Schmarje, 1936. 32 pages, 17 figures, price $0.35.

Bulletin 9. A Summary of Hydrologic Data, Ralston Creek Watershed, 1924-35, by F. T. Mavis and Edward Soucek, 1936. 72 pages, 25 figures, price $0.50.

Bulletin 10. Report on Hydraulics and Pneumatics of Plumbing Drainage Systems—I, by F. M. Dawson and A. A. Kalinske, 1937. 32 pages, 5 figures, price $0.35.

Bulletin 11. The Transportation of Detritus by Flowing Water—II, by F. T. Mavis, Te-Yun Liu, and Edward Soucek, 1937. 32 pages, 8 figures, price $0.35.

Bulletin 12. Studies of Hand Motions and Rhythm Appearing in Factory Work, by Ralph M. Barnes and Marvin E. Mundel, 1938. 64 pages, 24 figures. Out of print.

Bulletin 13. Hydraulic Tests of Small Diffusers, by F. T. Mavis, Andreas Luksch, and Hsi-Hou Chang, 1938. 32 pages, 16 figures, price $0.25.

Bulletin 14. A Study in Flood Waves, by Elmer E. Moots, 1938. 32 pages, 7 figures, price $0.25.

Bulletin 15. The Road Map of Hydraulic Engineering in Iowa, by E. W. Lane and Edward Soucek, 1938. 16 pages, 4 figures, price $0.25.

Bulletin 16. A Study of Hand Motions Used in Small Assembly Work, by Ralph M. Barnes and Marvin E. Mundel, 1939. 68 pages, 33 figures, price $0.50.

Bulletin 17. A Study of Simultaneous Symmetrical Hand Motions, by Ralph M. Barnes and Marvin E. Mundel, 1939. 40 pages, 15 figures, price $0.40.

Bulletin 18. Percolation and Capillary Movements of Water Through Sand Prisms, by F. T. Mavis and Tsung-Pei Tsui, 1939. 32 pages, 13 figures, price $0.25.

Bulletin 19. Two Decades of Hydraulics at the University of Iowa, Abstracts of Theses, Publications, and Research Reports, 1919-1938, edited by F. T. Mavis, 1939. 84 pages, price $0.50.

Bulletin 20. Proceedings of Hydraulics Conference, edited by J. W. Howe, 1940. 260 pages, 84 figures, price $1.00.

Bulletin 21. Studies of One and Two-Handed Work, by Ralph M. Barnes, Marvin E. Mundel, and John M. MacKenzie, 1940. 68 pages, 31 figures, price $0.50.

Bulletin 22. A Study of the Effect of Practice on the Elements of a Factory Operation, by Ralph M. Barnes and James S. Perkins with the assistance and collaboration of J. M. Juran, 1940. 96 pages, 34 figures, price $0.75.

Bulletin 23. An Annotated Bibliography of Fishways, by Paul Nemenyi, 1941. 72 pages, 12 figures, price $0.50.

Bulletin 24. An Investigation of Fishways, by A. M. McLeod and Paul Nemenyi, 1941. 64 pages, 15 figures, 6 plates, price $0.50.

Bulletin 25. The Electrostatic Effect and the Heat Transmission of a Tube, by Melvin R. Wahlert and Huber O. Croft, 1941. 40 pages, 10 figures, price $0.40.

Bulletin 26. Investigations of the Iowa Institute of Hydraulic Research 1939-1940, edited by J. W. Howe, 1941. 64 pages, 15 figures, price $0.40.

REPRINTS

(Reprints No. 1 to No. 10 not included in this list.)

Reprint No. 11. Methods of Calculating Water-Hammer Pressures, by F. M. Dawson and A. A. Kalinske. Reprinted from Journal of American Water Works Association, v. 31, no. 11, November, 1939. Price $0.10.

Reprint No. 12. Application of Statistical Theory of Turbulence to Hydraulic Problems, by A. A. Kalinske and E. R. VanDriest. Reprinted from the Proceedings of the Fifth International Congress of Applied Mechanics, 1938. Price $0.05.

Reprint No. 13. *Studies in Sediment Transportation and Deposition.* Price $0.35.

Stable Channels in Erodible Material, by E. W. Lane. Discussions by R. C. Johnson, E. S. Lindley, J. C. Stevens, C. R. Pettis, Harry F. Blaney, Sigurd Eliassen, R. E. Ballester, Gerald Lacey, V. V. Tchikoff, W. M. Griffith, and E. W. Lane. Reprinted from Trans. American Society of Civil Engineers, v. 102, p. 123, 1937.

Engineering Aspects of Sediment Transportation and Deposition, by E. W. Lane. Reprinted from Bulletin of Associated State Engineering Societies, Oct., 1939.

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