HAND-FIRING OF BITUMINOUS COAL
IN THE HOME

BY
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PRICE: TWENTY-FIVE CENTS
PUBLISHED BY THE UNIVERSITY OF ILLINOIS
URBANA
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UNIVERSITY OF ILLINOIS,
URBANA, ILLINOIS

UNIVERSITY OF ILLINOIS
ENGINEERING EXPERIMENT STATION
CIRCULAR SERIES No. 46

HAND-FIRING OF BITUMINOUS COAL
IN THE HOME
A Non-Technical Manual for Householders and Operators of Small Hand-Fired Heating Plants

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HAND-FIRING OF BITUMINOUS COAL IN THE HOME
A Non-Technical Manual for Householders and Operators of Small Hand-Fired Heating Plants

1. INTRODUCTION

1. Preliminary Remarks.—The purpose of this circular is to explain in non-technical language the principles involved in the combustion of bituminous coal, commonly known as soft coal, and to discuss the best methods of firing. An improved side-bank method is described, and means are suggested for making it most effective. A new method, designated as the nut-and-slack method, has been developed and is discussed in detail. Methods of burning the cheaper sizes of coal, such as nut and slack, without overheating, of reducing dust when removing ashes and handling coal, and of increasing the efficiency of the heating plant are also discussed.

The improved side-bank and the nut-and-slack methods are recommended as applicable to all types of bituminous coals. No special methods are necessary in order to fire coke or anthracite without producing smoke.

The intent of this circular is to offer helpful suggestions to all householders who are burning bituminous coal in hand-fired furnaces, and particularly to those who from wartime necessity have been forced to change from the use of smokeless fuels to that of bituminous coals in the same equipment. It is not the intention to minimize the desirability either of other fuels, or of any mechanical device to assist in the burning of coal.

The word “furnace” is used broadly throughout the circular to mean any type of equipment in which coal is burned to produce heat. In most cases the conventional warm-air heater, commonly known as the warm-air furnace, has been used for the purpose of illustration. However, any theory developed, any methods discussed, and any suggestions offered apply equally well to hand-fired boilers and heating stoves.

The hand-fired furnace cannot provide the same degree of comfort and convenience as that provided by mechanical stokers and automatic heating systems, particularly when low-priced, high-volatile bituminous coal is used as a fuel. However, many of the disagreeable features can be eliminated, and hand-firing made easier, if the basic principles of combustion are understood and applied so that proper methods of firing may be employed. On the other hand, careless
spreading of bituminous coal over the top of the fuel bed, thus completely blanketing the incandescent surface, inevitably results in the production of unnecessary smoke and a sacrifice in efficiency.

The conventional side-bank method of firing described in Section 7 is recommended by practically every authority on combustion, and is endorsed by the authors. It should be emphasized at this point that there is no known method of hand-firing that will completely and automatically eliminate smoke at all times. That is, with any method, it is possible to have some smoke occasionally. However, both tests and experience have demonstrated that the smoke produced can be reduced to an acceptable minimum, and both better and more uniform heating can be obtained by the application of proper firing methods.

The nut-and-slack method described in Section 8 can be used with good results with nut coal alone, omitting the slack. Under these conditions it has been described in Section 13 and has been designated as the improved side-bank method. The proper use of the nut-and-slack method definitely reduces the amount of smoke produced. In addition it increases the length of time that the fire will hold, and decreases fuel costs. However, in some cases the arrangement of the coal room may make the storing of two separate coal sizes impractical. In any case, in order to avoid dust and dirt, all coal, if it is to be delivered to the basement through a chute, should be thoroughly wetted down before delivery.

2. Acknowledgments.—The improved side-bank and the nut-and-slack methods of firing were developed in the course of an investigation of down-draft smokeless furnaces sponsored by the Engineering Experiment Station of the University of Illinois and conducted in the Department of Mechanical Engineering. The investigation was carried on under the general administrative direction of Dean M. L. Enger, Director of the Engineering Experiment Station and Professor O. A. Leutwiler, Head of the Department of Mechanical Engineering.

II. Requirements for Smokeless Combustion of Bituminous Coal

3. Combustion.—The combustible, or burnable, part of coal consists of various combinations of the chemical elements carbon and hydrogen. Some carbon is present as unattached or free carbon, but the hydrogen is always united with carbon in various combinations called hydrocarbons. In addition, there are impurities in the form of mineral matter which make up the ash, a small amount of sulphur, and some water.

Combustion, or burning, is a process in which the combustible elements in the coal become united with the chemical element oxygen. In all practical burning processes the oxygen is provided by air, approximately 21 per cent of the volume of which consists of oxygen. Oxidation goes on at all temperatures and is accompanied by the evolution of heat, but it is only at high temperatures that the process becomes sufficiently active to be called combustion, and the heat is given up rapidly enough to become useful. It may, therefore, be observed that the two primary requirements for combustion are intimate contact between the air and the combustible elements, and a sufficiently high temperature to support the combustion. The latter temperature is known as the ignition temperature.

The hand-fired furnace offers about the simplest means for burning coal. A typical domestic heating furnace of the warm-air type, with a designation of its different parts, is shown in Fig. 1. Practically all domestic heating furnaces have the same characteristic parts, con-
sisting of a grate designed to support the fuel so that air can be drawn through it, a firepot providing storage space for a reasonable amount of fuel, and a combustion chamber above the fuel bed providing a space for burning any gases that may be given off. A compartment called the ashpit is provided below the grate, and both the ashpit and the combustion chamber are provided with outlets, known as the ash neck and firing neck, for removing ashes and firing coal. The ashpit door is equipped with a damper to admit air to be passed up through the fuel bed, and the firing door has an overdraft damper to admit air into the combustion chamber. Both of these dampers usually consist of an opening covered with a hinged plate, the opening and closing of which permits regulation of the air supply. Sometimes a rotary slide damper is used in the firing door instead of the simple plate damper. A rotary slide damper is circular in form and has a number of radial slots alternating with wide radial bars. A circular plate with similar slots and bars is rotated to open and close the slots. In any case, the amount of opening is adjustable in order to regulate the air supply. This damper should be left open when bituminous coal is being burned.

In operation the air is drawn into the ashpit and up through the grate by the suction, or draft, produced by the chimney. It then passes up through the fuel bed where it comes into intimate contact with the hot coals and maintains the combustion. Any unburned gases coming off the fuel bed are then burned in the combustion chamber by air drawn in through the damper in the fire door. A primary control is always provided in the form of a check draft, or damper, in the smoke pipe, in order to regulate the amount of suction that the chimney can exert above the fuel bed.

So-called smokeless fuels like coke and anthracite, which consist largely of carbon, can be burned in the conventional hand-fired furnace without difficulty. After a fuel bed has been established it is only necessary to add fuel at the top and to shake the grates as the ash accumulates. This is true because these fuels do not have much hydrogen combined in the form of hydrocarbons, and, therefore, they do not produce large amounts of combustible gas when they are heated.

4. Volatile Matter in Bituminous Coal.—Owing to the fact that bituminous coal contains large amounts of hydrocarbons, it must be fired by different methods than those used for the smokeless fuels. These hydrocarbons are technically known as volatiles because they are the gas-forming constituents of the coal.

5. Requirements for Burning Volatile Matter.—Gas escaping into the air from coal heated in an open container will not burn although there is ample opportunity for the surrounding air to mix with the gas. The reason that burning does not occur under these conditions is that the temperature above the coal is not high enough to ignite the mixture of air and gas in this region. Every housewife is familiar with the fact that, although the burners of her gas stove are designed to mix the gas with the correct amount of air, the mixture will not burn until she applies a match or a flame from a pilot light to start the process. In other words, the mixture will not burn until it is brought to the ignition temperature.

The requirements for burning the gases distilled from a bituminous coal bed may now be stated as (1) sufficient air for combustion must be supplied; (2) the air must be thoroughly mixed with the gas; and (3) the mixture must be maintained at the ignition temperature. The last-stated requirement is the one most commonly violated. Even though sufficient air is drawn through the open damper in the firing door and mixed with the gases, the mixture will continue to burn only if exposed to an area of incandescent coals left from the previous firing. These incandescent coals must be at the top of the fuel bed.

III. Methods of Firing

6. Spreading Method.—The spreading method is the one usually adopted by the uninstructed operator. It consists of spreading the coal more or less evenly over the surface of the fuel bed. In the case of power boilers having large grates and requiring constant attention, this method can be applied successfully by firing the fresh coal in small lots on the thin places, thus leaving considerable area of hot coals exposed. In the case of the small firepot furnaces used with domestic heating apparatus, however, this method cannot be correctly applied,
and the result is that, as illustrated in Fig. 2, the coal is carelessly thrown into the firepot in an amount sufficient to last until the next firing period, and the hot coals are completely buried under a layer of fresh coal. Under the action of heat a large amount of gas immediately distills off the fresh coal. No hot coals are exposed at the surface, and even though the damper in the fire door is left open to supply air, the air and gas mixture cannot be ignited. As a result, dense black smoke is formed. This smoke is accompanied by unburned gases and an inevitable sacrifice in efficiency. In addition, the accumulation of unburned gases form an explosive mixture in the combustion chamber, and the result may be a serious explosion when flames from the lower part of the fuel bed finally break through the surface and ignite the mixture. This method of firing is therefore not to be recommended for domestic furnaces.

7. Side-Bank Method.—The side-bank method of firing, as illustrated in Fig. 3a, involves moving all of the live coals to one side of the furnace before placing a fresh charge of coal. If ash has accumulated to any extent between firings, it is usual to shake the grates before any of the hot coals are moved. The grates should be shaken lightly, so that no live coals fall into the ashpit and the grate surface is protected by a thin layer of ash. In moving the live coals, the unburned part of the fuel bed should not be distributed any more than necessary, and ash should not be mixed with it. Mixing ash with live coals usually results in the formation of clinkers. After the fresh charge is placed, the unburned part of the fuel bed is not disturbed until the next firing.

Almost any size of coal can be used with the side-bank method. Large sizes, however, are more expensive and are not to be recommended for domestic use. The draft available from most house chimneys will not permit the use of the very small sizes. On the whole, nut or stove sizes have been found to be best adapted to use in house furnaces. The side-bank method has for many years been advocated by combustion authorities, and when correctly applied has met with considerable success. The advantages of the method are that it prevents the rapid evolution of gases from the fresh coal, and that it provides an exposed surface of live coals to ignite the mixture as the gases are evolved. The evolution of gas is retarded in that the charge is placed beside the hot coals instead of on top, and in this position the heat penetrates the mass of fresh coal more slowly than it would if it were spread in a thinner layer over the top, and burning occurred upward from the bottom.
It is sometimes more convenient, particularly if the furnace is equipped with a water coil at the side, to modify the side-bank method and fire the coal alternately at the front and back, as shown in Fig. 3b. Some operators prefer to push the hot coals to the back of the furnace and always place the fresh coal at the front. In the case of a fairly deep firepot, successful use of the front-and-back method requires a specially built poker, or a hoe with a long plate which permits reaching the front edge of the grate, since it is essential to move all of the live coals so that the fresh coal burns in from the side and not up from the bottom.

Tests have shown that the correct application of the side-bank method eliminates a considerable part of the smoke that would otherwise result from careless or unskilled firing. For best results the fire must not be allowed to burn too low before refiring, and care must be taken that the live coals do not become too cool before the fresh charge is placed. If the remaining coals are black, or not hot enough to ignite the gases, lighted kindling may be necessary to start the initial blaze and keep it going until the coals become hot enough. Otherwise, the fire will smolder and produce a large amount of smoke.

The side-bank method sometimes fails to eliminate smoke owing to stratification of the gases. That is, the air admitted through the damper in the firing door fails to penetrate the column of gas driven off the fresh coal. This is particularly true if the rate of burning is high and the fire is very hot when the fresh charge is added. In this case part of the gas does not mix with air, and, since burning cannot occur under these conditions, considerable smoke is formed. Black smoke thus caused by a high rate of gasification from a hot fire can be materially decreased by controlling the fire as suggested in Appendix A, Section 2.

8. Nut-and-Slack Method. — Tests have been made in the Mechanical Engineering Laboratory at the University of Illinois to determine the best method for hand-firing bituminous coal. These tests have shown that the nut-and-slack method has certain advantages over all others, particularly from the standpoint of smoke prevention. This method is illustrated in Fig. 4, which shows cross sections of two furnaces with fresh fuel charges placed at the side and front, re-
FIG. 6. CONDITION OF FIRE AFTER COVER OF SLACK IS PLACED
Note that the slack on top of the charge of nut coal is deflecting all the gases into the flame at the center of the firepot. Photo courtesy of Life Magazine.

spectively. The conditions represented are for typical cold weather operation.

As shown in Fig. 4, the live coals from the previous firing have been carefully raked to one side, or the back, of the firepot. The ash and small clinkers remaining on the other part of the grate have been thoroughly probed with an oblique-angled poker to provide a loose bed, free of fine ash, to allow a uniform flow of air. A charge of nut coal has been placed, and the top of this charge has been covered with a layer of slack, or fine coal. The purpose of the layer of slack is three-fold: (1) to direct the gases driven off the nut coal into the hot flame in the center of the firepot; (2) to prevent the gases from by-passing around the flame; (3) to intensify the burning at the center of the firepot by confining it to this region. The layer of slack also prevents the fire from spreading too rapidly through the charge of fresh coal, and forms a large compact piece of coke on the top of the charge, thus holding the fire longer and providing a source of live coals available for igniting the gases from the next firing.

Figure 5 is from a photograph taken of the fire after a charge of nut coal has been placed, and Fig. 6 from a similar photograph taken after the slack had been placed on top of the charge. It may be observed that the slack has been placed high against the side of the firepot and away from the center in order to prevent smothering the flame. Figure 6 further shows that the gases arising from the nut coal were deflected into the flame at the center after the slack had been added. Further details for the application of this method are given in Chapter IV.

IV. DETAILS FOR APPLICATION OF THE NUT-AND-SLACK METHOD

9. Preparation of Coal.—The nut-and-slack method of firing was developed in connection with coals mined in the State of Illinois, but there is reason to believe that it should be equally applicable with all types of bituminous coal. For this method two sizes of coal are required, in the proportion of approximately one of slack to five of nut. As an example, the two sizes of Illinois coal used in the laboratory tests are shown in the photograph in Fig. 7. The coarse coal shown was 2-in. by 3-in. nut, and the slack was yard forkings. These sizes proved successful in the tests and are, therefore, recommended. If forkings or mine slack are not available, stoker coal may be substituted. The important requirement is that the fine coal should be much finer than the coarser coal used, so that the covering layer will offer greater resistance to the flow of gases and therefore deflect them from the coarser coal toward the center of the firepot. The nut coal should not be too coarse or the fine coal will sift into it and reduce the effectiveness of the method. Coal designated as egg size may be substituted for the nut coal recommended, but it is more expensive and will not give as satisfactory results. It is not essential that both coals be from the same mine, or even of the same type.

When the coal is delivered it should be placed in the bin in such a way that the two sizes are separate, and that both sizes are available at all times. If the coal has not been oil treated for dust, repeated dampening of the coal in the bin will greatly reduce the coal dust in the house. It is especially desirable that the fine coal be in a dampened condition when fired. The most effective way to dampen slack, or fine coal, is to make a depression in the top of the pile, and then fill the depression with water. Water poured or sprayed on the side of a pile of slack will run off and fail to wet the coal in the inside of the pile.
It is not advisable to wet the coal immediately before firing because some time is required for the water to soak in. This soaking process is known as tempering.

10. Tools Required.—In order to obtain the best results from the nut-and-slack method an oblique-angled poker similar to the one shown in Fig. 8 is essential. This may be made from a \( \frac{1}{8} \)-in. round steel bar. It should be about 58 in. long and have a suitable handle. The lower end should be rounded, and the bar should be bent to an angle of 30 degrees at a distance of 13 in. from the end. This construction makes it possible to probe any portion of the grate. Such a poker can be made at any blacksmith, welding, or machine shop.

It is also desirable to have a conventional right-angled poker, made of \( \frac{1}{2} \)-in. round steel bar and having about 5 inches at the end bent at right angles, to form a hook for lifting out clinkers. In addition, it is often convenient to have a hoe, made by riveting or welding a \( 2 \frac{1}{2} \)-in. by 7-in. steel plate from \( \frac{1}{8} \) to \( \frac{1}{4} \) in. thick at right angles to a bar of \( \frac{1}{2} \)-in. round steel. Both of these tools should have a suitable handle in the form of a loop or a cross bar. The two last-mentioned tools are added conveniences, but if only one tool is available it should preferably be the oblique-angled poker first described.
After the fuel bed has been properly prepared, the empty side of the firepot may be filled to the level of the floor of the firing neck with nut coal free from all fines. One or two shovelfuls of damp slack, or fine coal, should then be placed on top of the charge of nut coal and spread in such a way that it covers the coal next to the wall of the firepot. Too much slack should not be used, and it should not be spread too far toward the center of the firepot. The amount of slack that can be used with good results depends on the fineness and the coking characteristics. A small amount may first be tried and then increased with each successive firing until the maximum amount that will coke completely is found.

The layer of slack which was placed on top of the nut coal will become thoroughly coked, and should not be disturbed until after the next charge of fresh coal has been placed. After this is done, the coke from the previous charge should be broken by probing with the oblique-angled poker. This will provide a coke bed of uniform depth and consistency.

The fire door should not be left open any longer than necessary when preparing the fuel bed and placing the charge, as it is important that the live coals be hot enough to ignite the gases given off the fresh coal. The damper in the firing door should be open and the furnace should not be left until the gases have started to burn. If the flame does not start immediately after firing, the fire door should be closed and the ashpit door opened for a few minutes in order to give the fire a quick start. If this procedure fails to ignite the gases within a few seconds, a few crumpled pieces of paper should be thrown into the center of the firepot, and, if necessary, lighted with a match. A smoldering fire, or one without a flame, should never be left as it may result in an explosion. The ashpit door should never be left open for any great length of time or the fire will burn without control.

If the furnace has been operating at a low rate, and an inspection shows that there is so much hot coke in the firepot that it cannot be moved to one side or the back, the grate should be shaken and one-half of the fuel bed probed to make that half burn faster. The fresh coal should not be fired until the coke in the probed part of the fuel bed has been burned sufficiently to permit the proper cleaning of this part of the fuel bed. If circumstances make it imperative that a charge of fresh coal be fired when there is too much coke remaining, the latter should be piled as high as possible against one side of the firepot. One or two shovelfuls of ashes should then be placed on the opposite side of the grate and the fresh charge laid on these ashes. Fresh coal must not be placed on top of live coals if black smoke and possible explosions are to be avoided.

12. Mild Weather Operation.—In mild weather the entire grate area is not needed, and best results can be obtained by using only the center. This can be done by cleaning only the center of the grate with the oblique-angled poker and allowing the ash to accumulate around the walls of the firepot. Considerable loss from excess air may result if the grate is not completely covered with fuel or ash. Hence, if it is desired to use only part of the grate, the remaining part should be covered with a thick bed of ash. The grate should be shaken very little, if at all. This procedure, illustrated in Fig. 10, has the effect of reducing the effective grate area, and thus controlling the heat output of the furnace without interfering with the responsiveness of the fire. The procedure for preparing the fuel bed for mild weather operation is the same as that for cold weather operation, except that this deep layer of ash is maintained around the walls of the firepot. Furthermore, the procedure for placing the charge is also the same, except that smaller amounts of both nut coal and slack are used at each firing, as shown in Fig. 11.

It may be necessary to use a smaller proportion of slack to nut
coal in mild weather than in cold if the slack does not coke completely, and better results may be obtained by leaving the coke from the previous charge unbroken, especially if a very small amount remains when the new charge is placed. Special care must be taken to be certain that a gas flame has started. Neglect of this detail may result in a flameless, or smoldering fire persisting for hours. As previously mentioned, a flame may be started by using lighted paper. Opening the damper in the ashpit door and closing the check draft for a few minutes before firing may help provide a hot coke bed, and leaving the ashpit door open and the firing door closed while getting coal from the bin will prevent the hot coke bed from cooling. The ashpit damper should not be left open and the check draft closed for too long a time or the coke may burn out completely. Under all circumstances the coke from the last charge should be left undisturbed until after the fresh charge of coal has been properly placed.

The best procedure in mild weather, therefore, is to open the ashpit damper and close the check draft for a few minutes before firing, prepare the fuel bed, and place the charge as directed, making certain that the gas from the fresh coal is properly ignited. The ashpit damper may be left open and the check draft closed for at least half-an-hour after firing, or until the house is comfortably warm. The fire should then be checked by closing the ashpit damper and opening the check draft, and they should be left this way until time for the next firing, unless the house cools too much for comfort in the meantime. Instructions for kindling a fire are given in Appendix A, Section 1.

13. Improved Side-Bank Method.—If for any reason, such as lack of storage facilities, it is not desirable to use slack or fine coal, most of the benefits of the nut-and-slack method can be retained by following the various steps as previously outlined, except that the slack is omitted. This procedure has been designated as the improved side-bank method, and tests have shown that, with proper application, the smoke produced at high burning rates may be reduced 50 per cent as compared with that produced by the conventional side-bank method. Perforation of the bed of ash, placing the charge, and breaking the coke should be carried out exactly as in the nut-and-slack method. As shown in Fig. 12, it may be observed that additional nut coal is added to take the place of the cap of slack that is omitted. With an oversized furnace and ample draft it is possible to burn slack coal alone instead of nut. In this case, the improved side-bank method can be used, substituting slack for the nut coal.

One essential difference between the conventional side-bank method discussed in Section 7, and the improved side-bank method
under consideration is that, in the case of the former, the remaining bed of coke and live coals is usually broken up and disturbed before the charge of fresh coal is placed, and thereafter left alone. In the case of the latter method, however, the major portion of the coke is not disturbed before the charge of fresh coal is placed, and after this it is probed with the oblique-angled poker to provide a uniform and porous bed. A second difference lies in the fact that in the case of the improved side-bank method the grates are rarely shaken, but the part of the ash bed that is to receive the fresh coal is probed with the oblique-angled poker to sift the fine ash through the grates, and to provide a loose, uniform bed before the charge is fired. In this way any mixing of the ash with the mass of hot coke is avoided, and the formation of any large clinkers is practically eliminated.

If a minimum amount of smoke is to be produced, it is especially important in the application of this method that, except in mild weather, the chain operating the ashpit damper be disconnected, and the fire be controlled as suggested in Appendix A, Section 2.

V. Laboratory Tests on Firing Methods

14. Objects.—In order to determine the efficacy of several firing methods, tests were run on a conventional warm-air furnace in the Mechanical Engineering Laboratory at the University of Illinois. The objects of these tests were to determine to what extent smokeless combustion of bituminous coal could be achieved by use of the nut-and-slack method, and to compare the amount of smoke produced by this method with that produced by the use of the commonly-employed spreading method and the conventional side-bank method.

15. Test Conditions.—In running the tests, conditions were reproduced which are met with under ordinary circumstances, and which result in the maximum production of smoke. These conditions were (1) a fire kindled when no live coals were present to ignite the gases; (2) a high burning rate, resulting in too high rate of evolution of gases; (3) a low burning rate with a smoldering fire; and (4) night banking, with a large amount of fresh coal fired into the furnace and the fire checked before the gases had either means or opportunity to burn.

16. Coal Used.—Two Illinois coals differing materially in burning characteristics were used in the tests. A Franklin County coal was selected because it was of the type classified as free burning, or non-coking. With this type the individual pieces do not fuse or melt together when heated in the furnace. A Saline County coal was selected as being representative of the strongly coking or caking coals, in which the individual pieces melt together or fuse when subjected to heat.

Two different sizes of coal were used, namely, yard forkings containing a large proportion of fines, and 2-in. by 3-in. nut. The nut coal was used in all tests, and the yard forkings were used in conjunction with the nut coal in the tests of the nut-and-slack method.

17. Smoke Recorder.—The smoke meter used in the tests made use of a beam of light projected across the chimney and received on
a sensitive thermopile. Since the smoke tended to intercept the beam of light, the amount of light received by the thermopile depended upon the density of the smoke. The voltage generated by the thermopile was dependent on the amount of light received, and hence on the density of the smoke. The voltage generated was recorded on the chart of a recording potentiometer. Since the chart was divided into 100 parts between zero voltage given by complete interception of the light and the voltage given when no smoke was passing up the chimney, the readings of the chart represented an arbitrary percentage in terms of completely black or dense smoke. A sample chart is shown in Fig. 13.

The readings of the chart could be used directly to compare the smoke given by the different methods of firing, but to be used in connection with smoke ordinances they have to be translated into terms of Ringelmann numbers. For the purpose of this discussion it is sufficient to know that a chart reading of 50 per cent corresponded to a Ringelmann number of 3. Since most smoke ordinances* limit the production of smoke to less than Ringelmann No. 3 produced in any six minutes during one hour, it is evident that any chart reading of less than 50 per cent represents tolerable conditions.

18. Results of Smoke Tests.—Figures 14 and 15 show, in graphical form, the smoke records for the different methods of firing. The headings at the top of each figure indicate the burning conditions used and the sub-titles show the method of firing. The figures at the left represent the smoke density in per cent. Figure 14 represents smoke records obtained with Franklin County coal, and Fig. 15 those obtained with Saline County coal.

It may be observed that the worst conditions were obtained with the spreading method. Under all burning conditions this method consistently gave smoke having a density equal to or exceeding the

allowable 50 per cent. Better results were obtained with the conventional side-bank method, although this method at times gave smoke density exceeding 50 per cent, particularly when used in connection with the free-burning Franklin County coal as illustrated in Fig. 14. With only one exception the use of the nut-and-slack method resulted in smoke well under the allowable 50 per cent density. The exception occurred while kindling a fire with Saline County coal, as shown in Fig. 15, and even then smoke having a density exceeding 50 per cent was obtained for only a few minutes.

Figure 16 shows results obtained with the four different firing methods when burning coal at the rate of 15 lb. per hr. on a 21.5-in. grate. This corresponds to a combustion rate of 6 lb. of coal per sq. ft. of grate surface per hr., and represents a fairly high operating rate, although gravity warm-air furnace ratings are based on a 7.5 lb. per sq. ft. per hr. combustion rate. Here again it may be noted that both the spreading and the conventional side-bank methods produced smoke having a density exceeding the allowable 50 per cent, while the smoke resulting from the use of the nut-and-slack and the improved side-bank methods was always well within the allowable limits. In all cases the best results were obtained with the nut-and-slack method.

19. Conclusions.—The following conclusions may be drawn from the results of the tests:

1. Bituminous coal cannot be burned in the conventional hand-fired heating plant without the production of some smoke, but the amount of smoke produced can be decreased and the general performance of the plant can be improved by the use of proper firing methods.

2. The nut-and-slack method gave better results than any of the other methods used.

3. The improved side-bank method gave acceptable results, and was simpler to use than the nut-and-slack method.

4. Successful use of the nut-and-slack and the improved side-bank methods require a poker adapted for the purpose.

5. In order to operate with the minimum of smoke, the air entering the ashpit damper should at all times be limited so as not to exceed the amount required to satisfy the heat demand of the house, with the possible exception of the few minutes after refiring, or in mild weather.

APPENDIX A

SUGGESTIONS FOR OPERATION AND MAINTENANCE OF HOUSE-HEATING FURNACES

1. Kindling the Fire.—When a new fire has to be started, or when it has burned so low that it has to be rekindled, one side of the ash and refuse remaining on the grate should be probed with the oblique-angled poker described in Section 10, in order to sift the fine ash through this side and to leave only a thin layer of small clinkers. A charge of coal should then be placed against this side of the furnace, as shown in Fig. 17. If the nut-and-slack method of firing is to be used, one or two shovelfuls of slack should be placed on top of the nut coal, keeping it close to the wall of the firepot. A liberal amount of dry kindling should then be placed against the coal, with the smaller pieces of wood at the top, followed by a generous quantity of tightly crumbled or twisted papers. When these have been lighted and have started to burn briskly, the fire door should be closed. A fire can sometimes be kindled by omitting the wood and using tightly twisted papers alone. However, this procedure requires a large amount of very tightly twisted paper, and is hardly to be recommended.

In kindling a fire in very mild weather, typical of early fall and late spring, it is best to dig a hole about one foot in diameter into the bed of ash and coke remaining on the grate. This hole should extend down almost to the grate bars, and be filled with nut coal. The coal may then be covered with kindling and twisted papers and the papers lighted at the top. If the chain operating the ashpit damper has been disconnected, as suggested in Appendix A, Section 2, it may be advisable to leave the ashpit door slightly open for fifteen or twenty minutes in order to give the fire a good start.
2. Controlling the Fire.—House-heating furnaces are equipped with a damper in the ashpit door and a check draft in the smoke pipe. Control of the fire is effected by manipulating these dampers. Closing the check draft increases the suction over the fuel bed, thus drawing more air through it, and makes the fire burn faster. Opening the ashpit damper allows more air to enter the ashpit and pass through the fuel bed, and also makes the fire burn faster. Thus, control is accomplished by closing the check and opening the ashpit damper, or vice versa. The opening in the ashpit damper may be large enough to provide air for burning 150 lb. of coal per hr., whereas the maximum burning rate required to heat the average home in the most severe weather does not exceed from 15 to 25 lb. per hr. While the resistance of the grate and fuel bed limits the burning rate to some extent, excessively hot fires are likely to result at times if the ashpit damper is opened the full amount. Fires hotter than necessary to supply the heat required in any given type of weather, instead of either fully opening or shutting the check draft every time it is operated. After some experience the proper opening required in any type of weather may be found, and an almost constant house temperature can be maintained by using this method of control in connection with the nut-and-slack or the improved side-bank methods of firing. In the early fall or late spring it may be desirable to operate both the ashpit damper and the check draft with the chains in the conventional manner, as it is quite impossible to maintain a steady fire when the heat demand is too low.

In order to start the flame, it may be necessary to leave the ashpit door partly open for a few minutes if the coke bed is not hot enough to ignite the gases. However, if all of the fine ash has been worked through the grate previous to placing the charge, it will take but a few minutes for the fire to attain a good start, and the ashpit door may then be closed. At times, when the fire is very low and the house is cold, a quick fire is essential. Under these conditions it is possible to leave the ashpit door open for quite a while, since there is no immediate danger of overheating either the furnace or the house.
3. **Ash Removal.**—The dust arising from removal of ashes can be eliminated by wetting them in the ashpit before they are removed. The proper way to do this is to draw the ashes forward from the rear part of the ashpit with a hoe or a poker. A depression sufficient to hold three or four gallons of water should then be made in the pile, and the depression filled with water from a bucket or a hose. The ashes should then be allowed to remain in the ashpit for several hours, and then they may be removed and placed in a suitable container. With the proper amount of water the ashes should resemble moist soil. They should not be muddy, and no attempt should be made to remove them immediately after wetting. Any ash that has not become moistened may be left in the ashpit and removed with a later accumulation.

If the ashpit is tight another method of wetting which has proved successful consists of filling the bottom of the ashpit with water before the ash is shaken or poked down. After several hours the water penetrates the ashes and they may be removed.

One of the commonest causes for grate bars warping or burning out may be traced to the accumulation of ash in the ashpit to within three or four inches of the bottom sides of the grate bars. If the ash is allowed to accumulate and the grates are shaken until live coals rest on the tops of the bars, some live coals will also drop through the bars. The heat is then concentrated on both sides, resulting in warped or burned bars. In order to avoid this trouble the grates should never be shaken until live coals rest on them, and the ash should never be allowed to accumulate to a depth greater than one-half that of the ashpit. Trouble from hot coals either above or below the grate bars may also be avoided by using the oblique-angled poker as outlined for the nut-and-slack and improved side-bank methods of firing in Sections 11 and 13.

4. **Wetting Coal.**—While a slight loss, arising from the necessity to evaporate the water, results from the practice of firing wetted or tempered coal, most authorities are in agreement that the benefits derived from moderate wetting more than offset the loss. Lump coal and coal in egg and nut sizes can be wetted by spraying or throwing water on the pile. Slack and fine coal, however, must be wetted by making a depression in the top of the pile and filling the depression with water as described in Section 9. Coal should not be wetted immediately before firing, as too much surface water may damage the firepot of the furnace. Coal which tends to disintegrate with wetting should be wetted in small lots at a time, and coal in storage for the summer should not be wetted at all.

5. **Cleaning Heating Surfaces.**—Heat liberated by the burning of coal in a domestic furnace must pass through the metal heating surfaces in order to generate steam for radiators, heat water to be circulated through the radiators, or heat air to be delivered to the rooms. Soot and fly ash may accumulate on any horizontal surfaces, in small tubes, or in pockets. Such accumulations reduce the heat transfer and cause unnecessary waste of heat carried away by hot chimney gases. While it is impractical to brush all of the heating surfaces in a boiler or furnace, it is possible to remove periodically any appreciable accumulations of soot and fly ash from the sides of horizontal surfaces, or tubes in warm-air furnaces and boilers. The latter can be done most conveniently by means of a wire brush made for this purpose and available on the market. Inspection of these surfaces should be made at regular intervals so that they can be kept reasonably free from accumulations of soot and fly ash. Wire brushes are made from tempered steel wires and should not be used when there is a hot fire in the furnace. Soot and ash in the tubes of boilers and in the radiators of warm-air furnaces also reduce the areas of the gas passages and interfere with the draft. This may result in smoking back through the firing door.

Use of proper firing methods will prevent excessive accumulations of soot, but if this does occur, the soot can be burned out by several methods. The U. S. Bureau of Mines* recommends throwing common salt, in the form of rock salt or ice cream salt into the furnace. “This is not only the most available material but also the cheapest. It is not the most effective, and there should be a good bed of hot coke when common salt is used. Two or three teacups are sufficient for a furnace in a six-room house. It is worth while to use common salt, particularly if frequent cleanings are necessary.”

Soot accumulations in the chimney may be burned out by igniting them with burning papers inserted through the clean-out door at the bottom. This process is accompanied by some danger from roof fires, and if the chimney, smoke pipe, and radiator of a warm-air furnace or tubes of a boiler are all to be cleaned out, it is best to do it progressively in order to minimize the danger. The chimney should first be cleaned by burning papers inside the clean-out door at the bottom. The smoke pipe should then be cleaned by burning papers inside of the check-draft opening, and finally the radiator or tubes should be cleaned by burning papers in the furnace.

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6. Correcting Chimney Troubles.—The air is drawn through the fuel bed in a house-heating furnace by the suction, or draft, from the chimney. This draft is produced by the difference in weight between the column of hot gases in the chimney and a similar column of cold air on the outside. Hence, anything which tends either to cool or to dilute the gases in the chimney will interfere with the draft. Poor draft is manifested by the chimney failing to make the fire burn rapidly enough, and, in aggravated cases, by smoke coming out of the fire door.

Poor draft can usually be traced to one or more of the following causes: (1) insufficient chimney height; (2) cooling of the chimney gases; (3) dilution of the chimney gases; (4) excessive resistance or friction; and (5) wind action.

A chimney to be successful must have a height of at least 15 feet measured above the grate. With some coals and some types of heaters a height of at least 20 feet may be required.

Cooling of the gases may be brought about either by air leaks or, in the case of an outside chimney with one or more sides exposed to the weather, by excessive heat loss through the chimney walls. Dilution of the gases always occurs through the action of air inleakage, and a few of the sources may be enumerated as follows:

1. Leakage through cracks in the chimney
2. Leakage through porous or poorly made joints in the brickwork
3. Leakage between the lining and the brickwork, and between joints in the lining
4. Leakage through openings made in the chimney for gas heaters, laundry stoves, etc.
5. Leakage through the clean-out door at the base of the chimney
6. Leakage through cross connections, furnace flues, and fireplace flues
7. Leakage through openings at the bottoms of partitions where several flues are built into one chimney
8. Leakage through poorly-fitting thimbles, which are very common.

Excessive resistance or friction may be brought about by increase in the velocity of the gases caused by reductions in area, or by turbulence caused by obstructions or abrupt bends in the chimney flue.

The most characteristic sources of trouble from this cause are

1. Insufficient chimney flue area
2. Abrupt changes in direction
3. Reductions in area
4. Loose brick or other accumulations at bends
5. Broken flue linings

(6) Soot, and tar from certain coals
(7) Smoke pipe extending partly across the flue where it enters the chimney at the thimble
(8) Restriction caused by a poor chimney cap or extension.

Trouble from wind action will usually occur if the chimney is anywhere near the ridge pole of the house and does not extend at least 2 ft. above it. This trouble is also sometimes caused by nearby trees or buildings.

If a chimney has been working well and suddenly develops trouble it is highly probable that it has developed leaks or that soot and fly ash have accumulated. Leaks can be detected by building a smoky fire and then suddenly placing a board or wet blanket over the top of the chimney and observing where the smoke comes out. This method is rather drastic, but it is effective. Repairs must usually be made by a brick mason. The remedy for accumulations of soot has been discussed in Appendix A, Section 5.

If a chimney has consistently given poor draft from the time the heating plant was installed, then the trouble must be located by a process of elimination among the sources of trouble that have been enumerated in this section. When such trouble is encountered it is usually found that it is not the result of any one defect, but is caused rather by a combination of several, and that repairs had best be undertaken by an expert or a brick mason with experience in this kind of work.

7. Preventing Gas Leakage.—It is possible for furnace gases from neighboring chimneys to enter the house through cracks around windows and doors. However, a persistent odor of gas in a house heated by a warm-air furnace may be an indication of a gas leak in the furnace itself. In the case of a steel furnace it may be the result of a hole being burned or rusted through some part of the shell or radiator. Such trouble may occur if the level of the top of the fuel bed is carried above the top of the firebrick lining. Cast-iron furnaces are cemented together in sections in order to permit expansion and contraction without cracking the castings. In this case the castings may be in perfect condition, and the leak may be at some or all of the joints. The only remedy to be recommended is to have the furnace taken down and the joints recemented by a competent furnace installer. In order to minimize trouble from this source the furnace should be inspected during the summer every two or three years, and any necessary recementing done before the opening of the heating season.
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HAND-FIRING BITUMINOUS COAL

BRIEFS FROM CIRCULAR No. 46
UNIVERSITY OF ILLINOIS ENGINEERING EXPERIMENT STATION
URBANA, ILLINOIS

I-Use Oblique-Angle Poker to Reach Any Portion of Grate

(SEE PAGE 16)

NOTE: MOST CONVENTIONAL POKERS CAN BE CONVERTED TO THIS TYPE.

II-To Kindle Fire  (SEE PAGE 27)

1-PROBE HALF OF GRATE AREA WITH OBLIQUE-ANGLE POKER TO WORK ALL FINE ASH THROUGH GRATE.

2-PLACE COAL ON PREPARED SECTION OF GRATE AREA.

3-IF SLACK IS USED, PLACE IT ON TOP OF COAL NEXT TO WALL OF FIREPOT.

4-PLACE DRY WOOD KINDLING OVER COAL.

5-PLACE TIGHTLY CRUMPLED PAPERS OVER KINDLING. IGNITE PAPERS FROM TOP.

III-For Cold Weather Operation  (SEE PAGES 17 & 21)

NUT-AND-SLACK METHOD

LAYER OF SLACK DEFLECTS GAS INTO FLAME, REDUCES SMOKE, AND HOLDS FIRE LONGER.

NUT COAL

HOT COKE

TO APPLY EITHER METHOD:

1-MOVE ALL HOT COALS FROM ONE SIDE.

2-PROBE EMPTY SIDE TO REMOVE FINE ASH.

3-PLACE CHARGE OF FRESH COAL.

4-BREAK COKE FROM PREVIOUS CHARGE WITH OBLIQUE-ANGLE POKER TO PROVIDE COKE BED OF UNIFORM DEPTH AND CONSISTENCY.

IMPROVED SIDE-BANK METHOD

NUT COAL

HOT COKE

IV-For Mild Weather Operation  (SEE PAGE 19)

APPLY EITHER METHOD AS FOR COLD WEATHER OPERATION, EXCEPT:

1-REDUCE EFFECTIVE GRATE AREA.

2-FIRE SMALLER AMOUNTS OF COAL.

TO REDUCE EFFECTIVE GRATE AREA MAINTAIN A DEEP ASH BED EXCEPT AT CENTER.

USE OBLIQUE-ANGLE POKER TO KEEP CENTER OF GRATE FREE OF FINE ASH.

DO NOT SHAKE GRATES.

NEVER COVER HOT COALS WITH FRESH COAL
Heat With Less Coal

Improve Comfort
Reduce Smoke
and Save Money

When Hand-firing
Bituminous Coal

By Using
NUT-AND-SLACK METHOD

Developed by
UNIVERSITY OF ILLINOIS

By actual test this method was found to produce less smoke and provide better control than any other method of hand firing

See inside for instructions
**HAND-FIRING BITUMINOUS COAL**

1. **BEND YOUR POKER LIKE THIS**
   so you can use it for moving coals, breaking clinkers, and clearing a portion of the grate area.

2. **START FIRE LIKE THIS**
   1. Probe part of grate area to work all fine ash through grate.
   2. Place nut coal on prepared section of grate area as shown.
   3. If slack is used, place it on top of nut coal next to wall.
   4. Place kindling over coal and crumpled paper over kindling.

3. **IN MILD WEATHER OPERATE LIKE THIS**
   1. Use ash bed around edge to reduce effective grate area.
   2. Probe a small area close to hot coals with poker.
   3. Place a small charge of nut coal beside hot coals.
   4. Cover with slack as shown.
   5. Do not disturb hot coals.
   6. Use paper to start flame.

4. **IN COLD WEATHER OPERATE LIKE THIS**
   1. Move all live coals from area to be filled with fresh coal.
   2. Shake grates gently if necessary.
   3. Probe dead area to break clinkers and work all fine ash through grate.
   4. Place charge of nut coal as shown and cover with slack, if available.
   5. Break up previous charge if it is completely coked.
   6. If flame does not start at once, use crumpled paper.
   7. Check fire soon after it has attained a good start.

**NEVER COVER HOT COALS WITH FRESH COAL!**
THE NUT-AND-SLACK METHOD

The instructions in this folder are for firing bituminous (soft) coal in any type of heating plant that is hand fired. These instructions do not apply to anthracite coal or coke.

NUT COAL

Any clean “nut” or “egg” size is satisfactory when this method is used. When lump coal is used the large pieces must be broken up. Nut coal two to three inches in diameter is most desirable.

SLACK

“Slack” as used in this method is simply coal that is much finer than nut coal. Screenings, yard forkings, or stoker coal are all satisfactory for this purpose. If impractical to buy or store slack as a separate fuel, fine coal from the regular coal pile can be used. Slack must be wet when delivered and kept damp in storage.

ADVANTAGES

1. Reduces cost of heating.
2. Soft coal of any grade can be used.
3. Fire is started easier.
4. Fire responds quicker.
5. Fire controls better.
6. Fire requires less attention.
7. Fire holds much longer.
8. Room temperature is steadier.
9. Explosions are eliminated.
10. Smoke is decreased.
11. Soot formation is reduced.
12. Grate requires less shaking.
13. Less dust from tending fire.

Rules for

HAND-FIRING “SOFT” COAL

1. Do not fire fresh coal on top of hot coals. If hot coke remains over all the grate, probe the thinnest section of the coke and, if practicable, wait until this portion has burned out before refiring.
2. Move any remaining hot coals from the area to be filled with fresh coal and clear a small area adjacent to the main body of coke by probing with a suitable poker to break clinkers and work all fine ash through grate, but do not disturb the main body of coke.
3. Place nut coal and slack as shown inside this folder. Always place slack next to furnace wall and use no more than will coke completely.
4. If a flame does not start immediately after firing, use crumpled papers to start blaze. If blaze does not continue freely when blaze door is closed, leave it open about ¼ in. until flame is well established. Failure to establish a flame after firing fresh coal is likely to cause an explosion. Leave slots (or damper) in firing door open just enough to avoid “puffing” when flame has been established and door is closed.
5. Avoid overheating. Do not wait until house is thoroughly warm before checking fire. Allow for heat which will be delivered after fire is checked. If checked fire fails to warm the house in a reasonable time, turn it “on” again for a short period. Never allow fire to become excessively hot.