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BULLETIN No. 28.

The Economic Use of Coal for Steam-Raising and House Heating

BY

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OTTAWA

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LETTER OF TRANSMITTAL.

Dr. EUGENE HAANEL, Ph. D.,
Director Mines Branch,
Department of Mines,
Ottawa.

SIR,—

I beg to submit, herewith, a bulletin on the "Economic Use of Coal for Steam-Raising and House Heating"—which I instructed Mr. Blizard to prepare.

It was considered that a technical publication on this subject would be most opportune at the present time: when the supply of imported coal is precarious, and the price almost prohibitive, and that therefore, the need of economic methods in its use in the homes of the people, in social institutions, in business offices, and in the industries of the country, is of vital importance.

Yours respectfully,

(*Signed*) **B. F. Haanel,**
Chief of Fuels and Fuel Testing Division.

OTTAWA, January 30, 1919.

ECONOMICAL USE OF COAL FOR STEAM-RAISING AND HOUSE HEATING.

INTRODUCTORY.

The aim of this bulletin is, to inform those who are immediately interested in the saving of coal, of the general principles involved in any investigation which is made for the purpose of ascertaining the reasons for, and ways and means of, preventing losses due to incorrect methods of burning it, and the wasteful use of the heat generated by its combustion.

Subdivision of bulletin.—

Part I. deals with the general principles of the combustion of coal, and the generation and use of steam;

Part II is written for the householder, and deals with domestic heating;

Part III deals with the safe storage of coal.

PART I.

GENERAL PRINCIPLES OF THE COMBUSTION OF COAL, AND THE GENERATION AND USES OF STEAM.

Energy contents of coal.—The heat energy content, or calorific value of coal, is commonly given in British Thermal Units (B. Th. U.)* per pound. This energy is liberated by burning the coal, and is used for heating purposes, or for doing work in a heat engine.

It is possible to make use of practically all the energy in coal, for heating purposes, but is impracticable, since it would involve the installation of a bulky and expensive plant. The efficiency of a modern steam boiler plant seldom exceeds 80 per cent; not because it is the absolute limit to the possible efficiency, but because it is not economical to build a more elaborate installation to improve it. For the generation of power, however, it is possible to use only a small fraction of the heat energy of the coal: for example, a modern steam turbine plant seldom attains an efficiency of over 20 per cent.

Composition of coal.—When coal is heated intensely it decomposes, vapours and gases pass off in quantities which vary with the quality of the coal, and a solid non-volatile portion remains. A bituminous coal, for example, gives off more volatile matter than an anthracite coal. The combustible portion of the coal which remains after heating is called the fixed carbon. This is associated with the ash, and may be either in the form of coke or a mass which breaks up into a powder. The composition and heating value of a coal varies very considerably, as the following table shows:—

	Bituminous, from N.S., Sydney Area.	Anthracite, from U.S.A. sold in Ottawa.	Anthracite, from Alberta.	Bituminous, from Alberta.	Lignite, from Saskatchewan.
Moisture	% 2·4	3·1	0·9	1·2	34·6
Ash	% 5·7	14·3	12·1	8·0	8·6
Volatile matter	% 37·7	....	11·7	28·2	24·9
Fixed carbon	% 54·2	....	75·3	62·6	31·9
Calorific value, B. Th. U. per lb.	13,670	12,360	13,190	13,830	6,830

The principal, and almost sole inflammable constituents of coal, consist of carbon and hydrogen: largely in the form of compounds of carbon and hydrogen, known as hydrocarbons.

Combustion.—When coal burns in air, the products of combustion consist of carbon dioxide, carbon monoxide, and steam. These gases are

*The British Thermal unit is 1/180th part of the quantity of heat required to raise 1 pound of water from 32° F. to 212° F.

mixed with the nitrogen of the air, which does not combine with the carbon or hydrogen. When one pound of hydrogen burns to form steam, 52,000 B. Th. U. are evolved; and the heat evolved when one pound of carbon burns completely to carbon dioxide (CO_2), is 14,500 B. Th. U.; but if it burns incompletely to carbon monoxide (CO), it only gives out 4,400 B. Th. U. Actually, both these oxides of carbon are formed simultaneously, and if sufficient air is mixed with the carbon monoxide before it has time to cool below its ignition temperature, it burns to form carbon dioxide.

Recent experiments, conducted by the United States Bureau of Mines, show that practically all the oxygen entering with the air below a bed of fuel is used up before reaching the top of the fuel bed. Therefore, the gases passing off from the fuel consist of steam, carbon dioxide, carbon monoxide, nitrogen, and the tars and gases formed by the distillation of the coal. In order to burn the combustible portion of these gases and the tars it is necessary to supply air above the fuel bed. Usually this air passes through openings in the fire door or bridge, and through cracks in the furnace setting.

The chief loss in boiler and furnace installations is due to a supply of too much rather than too little air for the combustion of these gases. Too much air cools the products of combustion, and this prevents them from giving up as much of their heat to the water in the boiler as they would do if burned completely with less air. It is very important, therefore, to see that there is not an undue excess of air. The quantity of air supplied is demonstrated by analysing the flue gases, and thus finding the percentage of carbon dioxide which they contain. An anthracite coal when completely burned, with no excess of air, will give off a gas containing by volume about 18 per cent of carbon dioxide, 5 per cent of steam, and 77 per cent of nitrogen; while a lignite will give off a gas containing about 16 per cent of carbon dioxide, 16 per cent of steam, and 68 per cent of nitrogen. But the steam condenses before the gas reaches the gas analysis apparatus, and is seldom measured. The percentage of carbon dioxide in the dry flue gas when coal burns completely, without excess air, is about 19. In actual practice, from 10 to 12 per cent carbon dioxide is considered good. This corresponds to a supply of air about seven-tenths to four-tenths in excess of that required.

There are various forms of apparatus on the market for the analysis of flue gas. With such apparatus it is possible to observe the relative proportions of carbon dioxide, carbon monoxide, oxygen, and nitrogen in the gases, and thus determine whether any gases pass off unburnt, or whether the supply of air is excessive.

Prevention of excess air.—The bulk of the excess air enters the furnace through holes in the fuel bed. This is due to bad firing. It is essential, therefore, to employ a good fireman, and to see that he keeps an even bed of fuel on the grate. A draft gauge reading to about 1/100th of an inch of water—which measures the difference in pressure between the ash-pit and the furnace—is of great use in guiding him, since it shows at a glance when the resistance to the flow of air through the fuel bed falls. If this gauge records the pressures on a chart, it gives a means of finding out the air resistance of the fire bed throughout the day. It should be used in conjunction with another gauge which shows the difference in the draft or pressure between the furnace and flue. This difference increases with the load on the boiler. By comparing it with the fuel bed resistance, measured by the other gauge, it is possible to determine whether the drop in the draft through the fuel bed is due to a low rate of steaming or poor firing. The most common instrument used for recording the excess air supply is the "CO_2" recorder. This is a more complicated instrument than the recording draft gauge, but, if properly looked after, indicates the excess air loss more directly.

It is often found that much air leaks through the boiler setting, and this should be thoroughly examined and made tight. Often the bricks which are in the setting are porous, and should be covered with some material which will keep out the air.

Fuel bed and air supply.—The supply of air taken in over the grate will increase with the draft depression or "pull" in the furnace. This draft depression for the same rate of steaming will be greater for an increase in the fuel thickness; for an accumulation of ashes and clinker on the grate; and for a decrease in the air space in the fire bars. Thus the excess air may be reduced by keeping a thin clean fire, and using bars with a larger air space. Thin fires are generally better than thick fires, since the fuel bed is kept cooler and clinkers are not so likely to form.

Complete combustion.—The quantity of unburnt gases which leave the fuel bed will vary considerably from time to time, particularly when high volatile coal is used. Soon after firing, the coal gives off gases and tars, which require considerable quantities of air to burn them. After the gases from the freshly charged coal have been driven off, the requisite amount of air to burn the gases then rising from the fuel bed, will be much less. Since it is usually impracticable for the fireman to continually adjust the air supply, so that it may always suffice to burn the varying quantities of combustible gases leaving the fuel bed, it is advisable to fire small charges of coal frequently, instead of firing larger charges at longer intervals. To burn coals containing much volatile matter successfully, it is necessary to mix it with a supply of air as near to the fuel bed as possible; and to have a large combustion chamber in order that the inflammable gases may have time to burn before they reach the tubes and plates of the boiler, contact with which reduces the temperature of the inflammable gases and retards the combustion. The proportion of the gases rising from the fuel bed, which are subsequently burnt, will increase within reasonable limits with the supply of air over the fire. It does not often pay to entirely consume these gases by admitting large quantities of air, since the loss due to the additional air leaving the boiler at a high temperature offsets the gain due to their combustion. The carbon monoxide content of the flue gas is used as an index to the completeness of combustion. It is not, however, the sole combustible gas present; but it bears a sufficiently constant relation to the other inflammable constituents—which consist principally of hydrogen—to serve as an index.

Combustion and grate area.—If the coal is burned at a low rate per square foot of grate area, the temperature in the furnace becomes so low that the gases do not burn as completely as with higher rates of firing. On the other hand, with very high rates of firing, much solid combustible is carried off by the gases to the stack. When the load on a boiler is considerably reduced for several months during the year, it is advisable to reduce the area of the grate. It is also advisable to use fire bars with as large a percentage of air space as possible; but care should be taken when the coal contains many small pieces to see that the openings are not large enough to permit much unburned coal to pass through to the ash-pit.

Heat Transmission.—In a boiler, heat is transmitted from the incandescent fuel bed, flames and hot particles in the gases, to the boiler heating surfaces, by *radiation*; from the hot gases to the boiler plates and tubes, by *convection;* from the hotter to the cooler metallic walls of the boiler, by *conduction;* and again by *convection* from the metallic walls to the water in the boiler.

Radiation.—The intensity of the heat rays emitted by radiation increases very rapidly with the temperature of the bodies emitting them, and these heat rays will be partially absorbed by those parts of the boiler to which they are exposed. In many boilers, from 30 to 40 per cent of the total heat used for steam-raising is transmitted by radiation. In other boilers which have separate furnaces enclosed by brickwork, the heat transmitted to the water by radiation will be far less. Brick enclosed furnaces are used to ensure more complete combustion, by radiating and reflecting most of the heat received from the burning fuel, and thus maintaining a temperature in the furnace higher than that which would exist in a furnace enclosed or partially enclosed by substances which absorb more heat rays—such as the plates and tubes of the boiler. The heat loss through the walls of a separate furnace; its first cost and cost of maintenance; and the reduced quantity of heat transmitted by radiation, reduces the field for its application to those highly volatile coals, whose volatile portion does not burn completely in the furnace of an ordinary boiler.

Convection.—The rate of transference of heat from the hot gases which leave the combustion chamber, to the walls of the boiler heating surface, increases with the velocity of the gases and the difference between their temperature and that of the heating surface. The principal fall in temperature between the body of the gases and the water in the boiler, takes place across a thin film of gas which adheres to the heating surface. At high speeds of gas flow, the hot gases displace more rapidly than with low speeds the comparatively cool gas in the above-mentioned film. It is important, therefore, to see that suitably high speeds are maintained by baffles, or other restrictions in the path of the gases. The economical limit to the restrictions imposed is reached, when the cost of any increase in the power to drive the fan, or of a larger chimney to exhaust the gases against the greater resistance due to their higher velocity, would not be compensated for by the increased rate of heat transmission.

Heating surface.—The gases of combustion entering the flue from a boiler, are hotter than the steam and water inside the boiler. By increasing the area of the heating surface over which the gases must travel, this temperature difference can be reduced more and more, until the gases leave at practically the temperature of the steam. But the amount of heat which passes through each square foot of heating surface decreases as the gases cool in passing through the boiler; and it is not economical to add heating surface beyond a point where the heat transmitted through it compensates for the initial expenditure. To obtain a good return from the heating surface already installed, it is necessary to keep it free from soot on one side, and scale on the other; to ensure that the hot gases scrub it as thoroughly as possible; to prevent air entering through the setting, mixing with, and cooling these gases; to keep a high temperature in the furnace; and to expose the boiler plate and tubes to as much direct radiation from the flames and fire as possible.

Economizers.—The flue gases after leaving the boiler often pass into an economizer, wherein they give up some of their heat to warm the boiler feed water. It consists of nests of tubes, usually made of cast iron; around which tubes the gases circulate and give up their heat to the water inside. Scrapers, which move continuously over the outside of the tubes, remove the soot deposited by the gases. The use of economizers has been the means of saving considerable quantities of coal in plants where the flue gases left the boiler at a fairly high temperature. The temperature of the gases leaving the economizer must not be below that required for the chimney draft, and the temperature of the feed water entering the economizer should be over 100° F.

Air Preheaters.—With some forced draft installations, the hot waste gases heat the air passing to the furnace. This is another excellent method of economic heat recuperation.

Feed Water Purifiers.—The water fed to boilers often deposits a scale upon the tubes and other parts. This deposit reduces the rate of heat transmission, and is objectionable for other reasons. To prevent this, it is best to first submit samples of the water to an analytical chemist, and then install, under expert direction, a water purifier or other device for the mitigation or removal of the scale forming salts. Many boiler compounds are widely advertised which are supposed to be beneficial when introduced into the boiler. But they generally contain simple chemicals which under some high sounding name are sold at an exorbitant price, and often harm the boilers. They should never be used unless, after analysis, they are approved of by a chemist.

Oil in the feed water will give trouble, lower the boiler efficiency, and should be removed by a suitable oil filter.

Steam auxiliaries.—Steam engines usually drive the feed pumps, and also, where installed, the mechanical stokers and draft fans. The exhaust from these engines should pass to a feed water heater. This saves the greater portion of the heat in the steam which drives the above-mentioned auxiliaries. In electric generating plants, where economizers are installed to heat the feed water—and there is no apparent economic use to which the whole of the exhaust steam from the auxiliaries can be applied—coal will be saved by driving these auxiliaries by electric motors.

Steam Jets.—Steam jets or small turbo-blowers, whose exhaust mixes with the air it blows, are often convenient for forcing air under the grates of boilers. When used during peak loads, they assist in forcing the boiler with a smaller capital outlay than with fans or large chimney stacks. The steam passing in with the air cools the bars, which prevents some coals from forming clinker. But for continuous use they are not recommended, since they use more steam than a good steam driven fan, and none of the waste steam is available for heating the feed water.

Heat loss from steam pipes.—A bare steam pipe of 6 inches diameter, containing steam at 100 pounds per square inch pressure, loses heat equivalent to about three-fourths of a pound of steam per hour, for every square foot of its surface exposed to the air. A covering of good insulating material will reduce this loss to an extent which depends upon its quality and thickness. Usually, it reduces it to about one-sixth to one-tenth of its former value. There are very few installations in which it does not pay to cover the steam pipes. Before the owners of the plant purchase a steam pipe covering they should obtain guarantees from the maker that the material will save a definite quantity of heat, and that it will not deteriorate with usage. The higher the temperature in the pipe, and the smaller the diameter of the pipe, the greater are the heat losses per square foot of exposed area, and, therefore, the greater the amount which may, economically, be expended on a covering.

Boiler blow off valve.—This valve is frequently out of sight and may leak unknown to those responsible for the care of the plant. If possible it should be exposed to view, or if not it should be examined at frequent intervals. When it is necessary to blow off through this valve periodically to remove scale, care should be taken to limit the quantity of hot water leaving the boiler.

Steam for drying.—Whenever steam is used for drying, it frequently happens that it is insufficiently controlled. Thus when used for drying substances it may be wasted by permitting it to flow through steam coils long after the substance has become sufficiently dry. Also the air may not circulate round the substance sufficiently well to remove the vapours; or, it may circulate unevenly, drying one portion of the product more quickly than another. An approximate estimate of the efficiency of the drying process is a great help in making improvements. This may be obtained by dividing the loss in weight of the substance dried by the quantity of steam used to dry it.

Steam for heating buildings.—To keep the interior of a building at a temperature higher than the outside air, it is necessary to supply heat continuously to compensate for the loss of heat through the walls of the building by conduction, and the loss of heat due to the infiltration of cold air which passes out again at the temperature inside. Both these losses increase proportionally with an increase in the difference in temperature inside and outside. It is important therefore to carefully keep down the inside temperature to as low a degree as possible without causing discomfort to the people in the building. This temperature is not easy to define, it is lower when the air is humid or when the occupants are doing physical work. Unless the air which passes into a house is permitted to take up moisture, it will hold only the quantity of moisture it held when outside. And since the air contains more moisture in the early and late heating season than in the much colder midwinter months it follows that buildings will be comfortable at a lower temperature early and late in the season than in midwinter.

The air used to ventilate buildings is sometimes moistened. This is an excellent way of supplying air, and when used, the building is more comfortable at a temperature about 10° F. lower than, when additional steam does not partially saturate the air. But while most desirable from a hygienic viewpoint, it is not economical since more coal is used to evaporate the water into the steam which passes in with the air, than is saved by reducing the inside temperature below that required when the air is not moistened.

It would be well to arrange for standard indoor temperatures at which buildings should be kept according to the temperature which prevails outside. When the air is partially saturated artificially throughout the year, this temperature should remain constant at about 62° F. But where no means are provided for artificial humidification, it should vary with the outside temperature somewhat as follows:—

Temperature outside ° F.	Temperature inside ° F.
60	60 (No heat supply)
40	62
20	66
0	68
—20	70

At the present time 68° F. is recommended as a maximum, and very little or no discomfort need follow from keeping down the maximum temperature to this limit. Once the standard is fixed, it is necessary to maintain it all over the building, and to shut off or cut down the steam supply to radiators in places where the temperature exceeds the standard. Much fuel may be saved also by stopping up all cracks through which air may pass and by keeping all doors closed. It is often possible to reduce the heat lost by conduction through the walls and roof of the building, and care should be taken to see that all new buildings are properly constructed and that good heat insulating materials are used.

Exhaust Steam Heating.—Whenever steam power and steam for heating are required, large quantities of fuel may be saved by using the exhaust steam from the engine for heating instead of live steam from the boiler. The substitution of a simple steam engine with exhaust steam heating for an installation consisting of a compound condensing steam engine and live steam heating, should result in the saving of about one-fourth of the former coal bill.

Measurements and control.—In every plant, as complete records as possible should be kept of the heat used and heat lost—from the coal pile to the finished product. Hot water or steam going to waste represents coal, and if expressed in tons of coal per year, the result is often startling. By weighing all the coal used in the boiler room, and measuring the steam passing from, or the water fed to, the boiler by some meter, or, if no meter is available, roughly by a counter on the feed pump, it is possible to ascertain if a good evaporation per pound of coal is maintained. A low evaporation may be due to cold feed water, poor coal, poor firing, insufficient draft, a dirty boiler, broken baffles in the nests of tubes of water tube boilers, or leaky brickwork. To aid in discovering to which of the above causes the low evaporation is due, it is advisable to install the following instruments, some at least of which should be recording:—

(1) Steam pressure gauge.
(2) Thermometer, to measure the temperature of the feed water.
(3) Thermometer, to measure the flue gas temperature.
(4) CO_2 recorder or flue gas analysis apparatus.
(5) Draft gauges to measure the difference in draft above and below the fire bars, and the difference in draft between the combustion chamber and exit flue.

Summary of Losses, and Precautions to be Taken.

i. Excess Air.—This is determined by flue gas analysis. Take occasional samples from the furnace as well as the flue, and if they differ, air is leaking through the setting. The remedy is to look for cracks and stop them up, or if it be due to porous brickwork, coat the brick with sizing or other non-porous substance. The air leakage into the furnace and through the setting always increases with an increase in the "pull" of the fan or chimney. It is advisable, therefore, to always reduce this by closing the damper in the smokestack at the lower rates of steaming, instead of closing the ash-pit door.

Holes in the fire bed will also cause excess air, hence care should be taken to avoid them. When draft gauges measuring to 1/100 inch of water are used, they will show a marked reduction in the draft, when there are holes in the fire.

ii. Incomplete combustion of gases.—An analysis of the flue gases will indicate, by the percentage of carbon monoxide (CO) present, whether combustion is complete. Carbon monoxide is not the sole combustible gas which leaves the fire, other gases—principally hydrogen (H_2), and methane (CH_4), both formed by the distillation of the coal, accompany it. But it is more easily detected by analysis than the other gases. To burn these gases, it is necessary to mix them at a temperature above their ignition point, with a secondary supply of air, and to provide a furnace large enough to give them time to burn. By firing small quantities of coal frequently, the quantity of combustible gases passing through the furnace will not vary so much between the times of firing as when larger charges of coal are fired at longer intervals. It is necessary to remember that it is not economical to burn these gases by admitting a very large supply of air over the grate, since this would render the increase in loss due to excess air greater than the gain due to the use of the heat generated by the additional gas burnt. The exact quantity to be admitted, must be carefully adjusted by careful experimenting with each particular fuel and boiler.

iii. Incomplete combustion of the solid combustibles.—Some solid combustibles which consist principally of carbon, pass through the air spaces in the grate bars, and are removed from above the grate bars in cleaning the fire. This loss is greater when coals are used which contain a large amount of ash, and when the ash melts at a low temperature permitting the formation of clinkers. To reduce this loss, grate bars must be used which are the most suitable for the size of coal and fusing properties of the ash. In order to decrease the tendency to form clinkers, thin fires should be carried. Steam passed in with the air supply below the bars, also serves to decrease clinkering, and should be resorted to when necessary.

iv. Hot flue gases.—The temperature of the flue gases should be recorded by a pyrometer. If this temperature is found to increase at any time above the average obtained for the same rate of steaming and flue gas analysis, the cause should be investigated. It will probably be due either to improper baffling, or to a deposit of soot or scale on the boiler heating surface.

The practicability of using the heat of these gases for heating the feed water or other purposes, should be carefully examined, and where feasible, the necessary plant should be installed.

v. Radiation Losses.—All boiler settings should contain good insulating material, and all steam and hot water pipes should be covered.

vi. Heat Transmission.—The flue gases should pass over the heating surfaces of the boiler at as high a velocity as the draft available will allow. Baffles must be maintained in good repair to prevent short circuiting of the gases. The tubes and plates through which the heat is conducted must be kept clean on both sides.

vii. Exhaust Steam.—Whenever possible, exhaust steam should take the place of live steam for heating purposes. The exhaust steam from the feed pumps and other auxiliary steam engines should pass to a feed-water heater.

viii. Heating Buildings.—A definite temperature to which it is decided to heat the buildings must be decided upon, and should be maintained throughout the building by regulating the heat supply. As far as possible, all air except that required for ventilation must be excluded from the buildings. When steam is used for heating, return the condensed steam to the boiler.

ix. Drying Products.—When steam is used for drying substances it is necessary to see that the steam formed by the evaporating of their moisture can easily pass off through a vent. The product should be so arranged in the drier, that it may dry evenly; and the steam should be turned off immediately the product is dried to the desired consistency.

x. Measurements.—Account, as far as possible, for every heat unit in the coal. Organize a staff who will see that no heat is wasted unnecessarily.

PART II.

DOMESTIC HEATING.

Temperature.—The heat required to maintain a house at a definite temperature, varies directly as the difference between that temperature and the temperature of the outside air. If, during a heating season, the mean outside temperature is 30° F., and seven tons of coal are used to keep the temperature inside at 70° F., then about one ton more will be used to maintain this temperature than would be required to maintain the house at only 65° F. It is most important, therefore, not to over-heat a house.

Experience shows that the average person feels no discomfort in a house heated only to 60° F., at the beginning of the heating season, and he does not require a temperature greater than 68° F. to 70° F. in the middle of winter.

Humidity in the house.—When the outside temperature falls below 45° F., the house may be rendered more comfortable and healthy to the occupants, by partially saturating the air with steam. This process is known as humidifying or moistening the air, and when used it is possible to keep the house comfortable at a temperature several degrees lower than when it is not used.

While schemes for humidification of the air are undoubtedly desirable, they are not necessarily a means of saving coal. This is because, in the average house, the heat used to evaporate the water to moisten the air, is greater than that gained by maintaining the house at a lower temperature. To save coal it would be necessary for evaporating this water to use the hot flue gases leaving the furnace instead of the heat which would otherwise be used to raise the temperature of the house.

Air leakage into the house.—All air should as far as possible be excluded from entering the house through crevices, by means of weather strips and other devices. In bedrooms and living rooms air may be admitted through the window when required; but when these rooms are not in use they should be closed as tightly as possible.

At night, when the bedroom window is open, cover up the radiators with rugs or close the hot air registers, and so avoid using up heat which would go otherwise to warm the remainder of the house. All rooms not required during the winter should be sealed up, and little or no heat supplied to them.

Regulating the furnace.—The furnace should be so regulated that the temperature in the house remains fairly constant. It may be possible to have the temperature somewhat lower in the morning when the occupants of the house are moving about, than later in the day, but this change should neither be very great nor should it be suddenly raised by burning coal in the furnace rapidly for short periods.

Burning the coal.—The rate at which the coal is used up in the furnace depends entirely upon the rate at which the air passes up through the fuel bed. This supply of air converts the coal substance into a gas. It oxidizes the lower layers of the coal the heat from which distils the gases from the upper fresh charge. But it is impossible to supply sufficient air beneath the average fire bed to burn the gases completely. To complete the combustion, a second current of air must be supplied above the bed of coal. This second current of air should be regulated by opening or closing the damper in the fire door to suit the quantity of combustible gases rising from the fuel bed. The flow of these gases will depend upon the quantity of air passing through the fuel bed, the condition of the fuel bed, and the presence of freshly fired coal. After the coal has been charged and the coal gas from it evolved, the damper in the fire door may be almost or even completely closed, since with the ordinary fire door sufficient air leaks through its crevices to supply sufficient air to burn the combustible portion of the gases then leaving the fuel. Experience alone will show the best method of operating a particular furnace, but the following is a rational scheme of working:—

Immediately after firing a new charge of coal on to a hot bed of coals, close the ash-pit door and admit a good supply of air through the fire door to burn the gases distilled from the coal. After these gases have passed off, less air over the fire is required, and it is then possible to adjust the furnace so that it may heat the house for some hours without attention. The amount of coal burned during this time will depend on the quantity of air which passes through the grate and up through the fire. This flow of air varies with the thickness of the fire, the size of the fuel, the quantity of ashes on the bars, and the "pull" or draft on the top of the fire which tends to draw the air through it. The "pull" or draft is caused partly by the furnace, and principally by the chimney, which contain gases at a higher temperature and lighter than the outside air. These light gases tend to rise in the furnace and chimney, and pull behind them air through and over the fire bed. Their effect in drawing the air through the fire bed may be reduced, by turning the damper in the flue, by admitting air into the flue or through the fire door, and by closing the damper in the ash-pit door. The damper in the flue throttles the flow of gases. Care must be taken not to close it to a point where the chimney draft is so slight that poisonous gases from the furnace pass to the house. Nor should it be closed soon after firing, unless the gases over the fire are burning freely, since by doing so the rising column of unburnt gases and air may explode. The air admitted into the flue acts as a damper, because it cools the gases passing to the chimney, and takes the place of air which would otherwise pass through and over the fire bed.

The first draft to be closed should be the turn damper in the flue; if this does not throttle down the air sufficiently, close the draft in the ash-pit door and also the draft in the fire door in order to maintain the correct proportions of air above and below the fire. If the draft is still too strong, open the damper which admits air to the flue pipe, and finally, if required, open again the damper in the fire door. There are two good reasons for using as little as possible those dampers which reduce the draft by allowing air to pass in and cool the gases. In the first place it is clear that the air must all come originally from outside and so cool the house, and secondly that it will cool the hot gases and so prevent them from giving up as much heat to the house in passing through the flue or furnace as they would do when not mixed and cooled by the air. When, in spite of reducing the draft by the turn-damper and ash-pit door damper, the coal still burns too quickly a better plan than using the other dampers is to either burn a smaller size coal or to supplement that already in use with buck-wheat or other very small size coal.

For the same draft a thin fire will burn more rapidly than a thick fire, since it offers less resistance to the flow of air through it. In mild weather it is wrong, therefore, to try to burn the coal less rapidly by decreasing the thickness of the fire below that prescribed by the makers of the furnace. On the other hand in cold weather if there is too poor a draft to burn the necessary amount of fuel in a deep fire bed, a shallower fire may be used, but it will require more frequent attention. The fire must never be allowed to become dead or burn through in patches, since large quantities of air flow through them and cool the furnace.

Sifting Ashes.—The direct return to be gained by sifting the ashes from a furnace, will depend largely on whether the grates are in good repair and whether the air spaces in them are so large that a portion of the coal may pass through with the ash. After sifting, the pieces of ash and clinker left above the screen or sieve must be separated from the fuel, and only the latter returned to the fire. This residue is in smaller pieces than the original coal, and is an ideal fuel for placing over the fire at night or at other times when it is desired to reduce the rate of combustion of the coal.

Chemicals to improve combustion.—Compounds appear on the market from time to time, under various names, which are supposed to cause the coal to give out more heat. The sellers of some of these articles recommend that they be sprinkled in small quantities, about one pound to a ton, on the coal before firing, or on the ashes after their removal and before returning them to the furnace. Since coal burnt completely in air gives out all the heat it contains, and since it is impossible to burn the ash in the coal, these articles can neither increase the heat energy in the coal nor endow ash with heat energy. If these compounds contained a large percentage of oxygen, the amount would not be sufficient for the combustion of half their weight of good coal. Would-be purchasers are strongly advised not to listen to the extravagant claims made by agents for their sale, and to devote their attention to the scientific combustion of their coal with the oxygen of the air, which may be easily obtained free of cost.

Air leakage into the furnace.—Dampers in the furnace and flue are provided for the purpose of supplying the air necessary for burning and regulating the rate of combustion of the coal. Any other supply of air is wasteful. Care should be taken to see that the cleaning door closes tightly and that crevices through which air is drawn are filled with cement or putty.

Soot removal.—All soot must be removed at frequent intervals from the interior of the furnace and gas passages. A very thin deposit of soot retards the transmission of heat to the water or air.

Covering the furnace and water pipes.—If the basement in which the furnace is placed is warmer than is necessary then all pipes and the furnace should be covered with insulating material.

Summary of Methods for Saving Fuel.

1. Do not overheat your house.
2. Prevent air entering through cracks by means of weather stripping or other device. Use storm doors and double windows and do not open them unnecessarily.
3. Use as few rooms as possible, seal up and cut off the heat from those not in use.
4. Cover up hot water radiators, or shut off hot air supply to bedrooms at night when the windows are open.
5. Keep the furnace working as evenly as possible; do not let the fire burn too low and then burn coal rapidly to warm the house again.
6. Regulate the air supply over the fire to suit the air supply through the fire, except just after charging fresh coal, when a larger supply must be provided to burn the coal gas.
7. Control the rate of combustion in the furnace by the turn damper in the flue pipe as much as possible. Care must be taken, however, in using this damper, to see that it does not unduly cut off the draft which would cause the gases, some of which are poisonous, to pass up into the house.
8. Use those dampers as sparingly as possible which operate by admitting air into the flue or above the fire. It will, however, be dangerous to substitute the turn damper for the air damper, where the flue passes close to unprotected wood or other combustible material.
9. When it is impossible to reduce the rate of combustion in the furnace by the damper, use smaller coal, or cover the top of the fire bed with small size coal.
10. Prevent air from leaking into the gas passages of the furnace.
11. Remember that any device introduced into the space above the fire bed of the furnace for evaporating water for humidifying the air, or for heating water for general purposes, uses heat which would otherwise be used for heating the house. Use water heated by this means therefore, as sparingly as possible.
12. Keep the gas passages in the furnace clean.
13. Where a hot air furnace is installed, take no air into the system from outside.
14. When the basement is warmer than is necessary, cover the furnace and pipes with asbestos, magnesia, or other insulating material.

PART III.

ON THE SAFE STORAGE OF COAL.

When coal is stored in large piles, there is always a danger that its temperature will rise to a point where it begins to burn rapidly. This is due to combustion which takes place on the surface of each piece of freshly mined coal when exposed to the air. Unless the temperature of the body of the coal is allowed to rise unduly, this combustion soon ceases, and the surface only is oxidized. If each particle of coal in the pile is easily reached by a good flow of air the heat generated by this initial combustion is carried off by the air and the coal will not reach a dangerous temperature. If, on the other hand, no air is allowed to reach the coal, no combustion at all can take place, and there will be no possible danger of the coal pile burning.

To prevent the firing of coal piles, it is necessary, therefore, either to keep air away from the coal altogether, or to ventilate the coal pile thoroughly. The only absolutely safe way to exclude all the air from coal is to store it under water—usually an impracticable method in Canada. Fine coal or slack is sometimes stored so as to prevent air reaching the interior, by either building a closely sealed wall round the pile, or packing the fine coal very closely. But a pile of slack coal is always very liable to catch on fire, therefore, it should always be watched, and stored in such a way that it may be moved easily if it gets very hot. Another method of preventing the initial combustion of the surface of the coal is to see that the initial combustion of the surface of the coal takes place before the coal pile is completed. This method, which is often effective, is accomplished by piling the coal in, say, layers of 2 feet, and waiting for two or more days between the piling of each layer. Each layer then becomes oxidized on the surface of the lumps, which are thus less easy to ignite by further combustion in the pile.

The most successful method of storing coal is by placing it in a pile which is well ventilated by currents of air which keep down the temperature. Lump coal is thus more easily stored than fine coal, for two reasons: (1) because there are more voids in the pile for the passage of air; and (2) because the surface of a large lump of coal is smaller in proportion to its weight than with a small lump. Coal, therefore, should be handled so as to reduce the breakage as much as possible. Friable coal should not be stored if one less liable to break-up is available. When it is found necessary to store a coal which contains both lump and fines, precautions should be taken to see that the fine and lump coal are evenly distributed through the pile. Coal should be stored, if possible, in cold weather; or if in warm weather, preferably on a cloudy day. The coal piles should be as shallow as space will permit, and formed in such a manner that the coal may be easily moved if it gets too hot. It is well, for the same reason, to subdivide the pile so that, if necessary, any part may be moved, instead of shovelling away large masses to reach the part which is on fire. The greatest depth to which coal may be piled safely depends (1) upon the kind of coal; (2) its temperature when stored; and (3) the weather. Some coals cannot be piled safely to a depth of more than 4 feet, while, ordinarily, a depth of 8 to 10 feet is safe; many coals, however, may be stored to a much greater depth. If the sulphur content of the coal is high it is probably better that the coal should not be exposed to rain, hence these coals are sometimes piled under sheds for this reason.

It is often found practicable to ventilate "run-of-mine" coal piles, also those containing fines, by forming a system of small air-shafts throughout the pile. This should be carried out as soon as the pile has reached its full height, either by placing numerous perforated pipes vertically throughout the pile, or by driving rods about 2 inches diameter throughout the whole area of the pile, from top to bottom, at intervals of about 16 inches; and then removing the rods. Precautions should be taken to see that fines do not enter and choke the air-shafts.

All coal piles should be carefully watched. The temperature may be observed either by lowering a thermometer into a hole in the pile or by feeling a rod which has been driven into the pile. Special care should be taken when the temperature reaches 150 degrees F., and if a temperature of 175 degrees F. is reached the coal must be removed and thoroughly cooled before restoring it to the pile. If water is available in large quantities the pile may be flooded. Small quantities of water do more harm than good.

Two coals from different localities should not be mixed in a pile, and greasy waste or other combustible foreign matter should be carefully excluded from the pile.

Coal should never be stored near to steam pipes, flues, or other sources of heat.

SUMMARY.

1. If possible, choose for storage a coal free from fines and which is known to have been stored successfully elsewhere.
2. Store in a shallow, well ventilated, subdivided pile, sections of which may easily be removed in the event of fire.
3. Build the pile in cold weather.
4. Watch the temperature of the pile, shovel the coal out, or flood it with water when it reaches 175° F.

OTHER AVAILABLE DATA.

Additional information of considerable value on the *spontaneous combustion of coal,* may be found in vol. VI (No. 83) and in the extra volume on "Weathering of Coal" (vol. VII, No. 388) of the series entitled "Coals of Canada," published by the Department of Mines, Ottawa. These two volumes may be had upon application to the Director, Mines Branch, Sussex Street, Ottawa.