matter given off is such as to make it very difficult to secure complete combustion. Smoke is an indication of incomplete combustion and the problem of reducing the amount of smoke is important, not only from the standpoint of the smoke inspector, but also because of the losses in combustible gases such as carbon monoxide (CO) and hydrogen which escape with the smoke.

Table III.—Showing Relation of Smoke to CO in Flue Cases.*

Average per cent. of black smoke	0	7.1	15.5	24.7	34.7	43.1	52.9
Average per cent CO in flue gases	0.05	0.11	0.11	0.14	0.21	0.33	0.35
Number of Tests averaged	37	18	56	51	36	17	4

Experiments by several investigators have shown that whenever smoke is given off there is also a considerable quantity of carbon monoxide gas, and that as a rule this gas is accompanied by small percentages of hydrogen and hydrocarbon compounds. The losses due to these combustible gases which are found in connection with a smoke stack may vary between one and ten per cent. of the fuel.

Table IV.—Showing Relation Between CO in Flue Cases and Other Combustible Cases.†

	Smoky				Clear.			
Boiler Furnace	CO_2	CO	CH_4	H_2	CO_2	CO	CH_4	H_2
Hand Fired .	10.95	3.00	0.70	3.23	8.15	0.0	0.0	0.0

When burning a bituminous coal, the volatile matter must be raised to a high temperature while mixed with a sufficient quantity of air and burned on its passage from the fuel bed to the surfaces of the boiler. In most boiler settings this distance for combustion is very short and when the gases strike the cold surfaces of the boiler shell or tubes they cool below the temperature at which they will burn rapidly, and as a result some escape unburned and others are only partially burned, as shown by the heavy deposits of soot. In properly designed furnaces the space provided for combustion is large for coals giving off high percentages of volatile combustible. Even in such furnaces the firing must be carefully done or at times enough air cannot be supplied to the gas, and smoke results for short periods. In most plants the time required for the gases to pass from the fuel bed to the top of the stack is between 10 and 15 seconds, assuming the velocity to be reasonably uniform at different sections, then it will be seen that the gases pass from the fuel bed to a distance of say 12 feet in one second. At the end of this period there is but little opportunity for the gases to burn. This will make clear the great importance of a sufficient air supply, properly distributed, and an ample space above or back of the grates in which the gases may thoroughly mix and burn within considerably less than one second of time.

That there is a loss due to the volatile gases escaping unburned from an ordinary furnace is shown very clearly by the results of tests made on house heating boilers. The following table gives figures obtained on two series of tests for the purpose of determining the fuel values of several coals and briquettes,* when burned in a house heating boiler.

Table V.—The Relation of Volatile Matter of Smoke and Unconsumed Cases.

Number of tests Averaged	Volatile matter in the combustible	Ash in dry Coal	Efficiency	Black Smoke	CO in dry Flue Gases
4	18.30	8.00	60.56	18.2	0.44
12	22.71	8.94	56.33	18.0	0.50
7	34.70	11.27	54.11	22.1	0.55
11	38.79	15.02	47.19	30.8	0.62
16	44.46	14.57	47.19	32.9	0.74

The furnace in which the results shown in Table V. were obtained is best suited to coke, anthracite, or low volatile coals, and, as will be seen, is not adapted for burning bituminous coals, with good efficiency, yet many furnaces having practically the same features, such as a grate surrounded by heating surface, and a small combustible chamber, are used in power plants for burning high volatile coals.

Even with furnaces of improved design it is difficult to charge the coal by hand firing and secure smokeless combustion. This is due to the fact that a comparatively large quantity of gas is liberated immediately after firing, at the same time the fuel bed has been thickened and the air enters with more difficulty and without being well distributed with respect to the gases rising from the bed. With such a furnace the loss of combustible gases may be reduced to 5 per cent. or less depending on the coal and the operation.

It is because of the advantage in having the coal gradually heated and the gases distilled from it at a low temperature that a mechanical means of feeding the coal to the furnace is usually more successful in the prevention of smoke.

A good furnace should permit the burning of bituminous coal in sufficient quantities without loss of escaping gases or the formation of smoke when the air supply is about 50 per cent. in excess of the theoretical amount.

It has been found by experience that to approach this performance, the coal must be fed regularly in small quantities, gradually heated if possible, and the air supply admitted in such a way as to thoroughly mix with the distilled gases. Furthermore the space for burning the gases should be large and preferably enclosed in fire bricks.

A furnace suitable for certain coals may be entirely unsuited to other coals and it is only after a careful study of all the factors, such as power to be generated, size and kind of boiler to be used, and the coals available, that an engineer can undertake to design a furnace which will be satisfactory and at the same time give good economy under operating conditions.

Even after the best types of furnaces are installed it is necessary to supervise the operation of the boiler plant closely in order to secure the best results. The proper drafts, the best thickness of fire for any given coal when burned on grates at the rate required for the plant, and the best method for the removal of ash and clinkers to prevent loss of fuel into the ash pit are all factors in securing the highest economy. Failure to attend to these important details may easily cause a loss of as much as 10 per cent. in the fuel fed to the furnaces.

In conclusion:

1. Even well designed furnaces may be expected to give off smoke if improperly operated, or under any of the following conditions:

   (a) When a new fire is built in a cold furnace.

   (b) When an excessive amount of coal is burned on the grate, making it difficult or impossible to properly mix the air with the gases and burn them in the furnace.

   (c) When the rate of combustion is suddenly changed, due to a change in demand for steam, for the same reasons as under (b).

2. Smoke may be reduced and in most cases prevented:

   (d) By burning a fuel having a small amount of volatile matter.

   (e) By burning a bituminous coal in a specially designed furnace with more than ordinary care on the part of the fireman under the supervision of a competent engineer.

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* See United States Geological Survey Bulletin 325, pages 101 and 167.

† See Manchester (England) Smoke Abatement Report.

* See United States Geological Survey Bulletin No. 366.