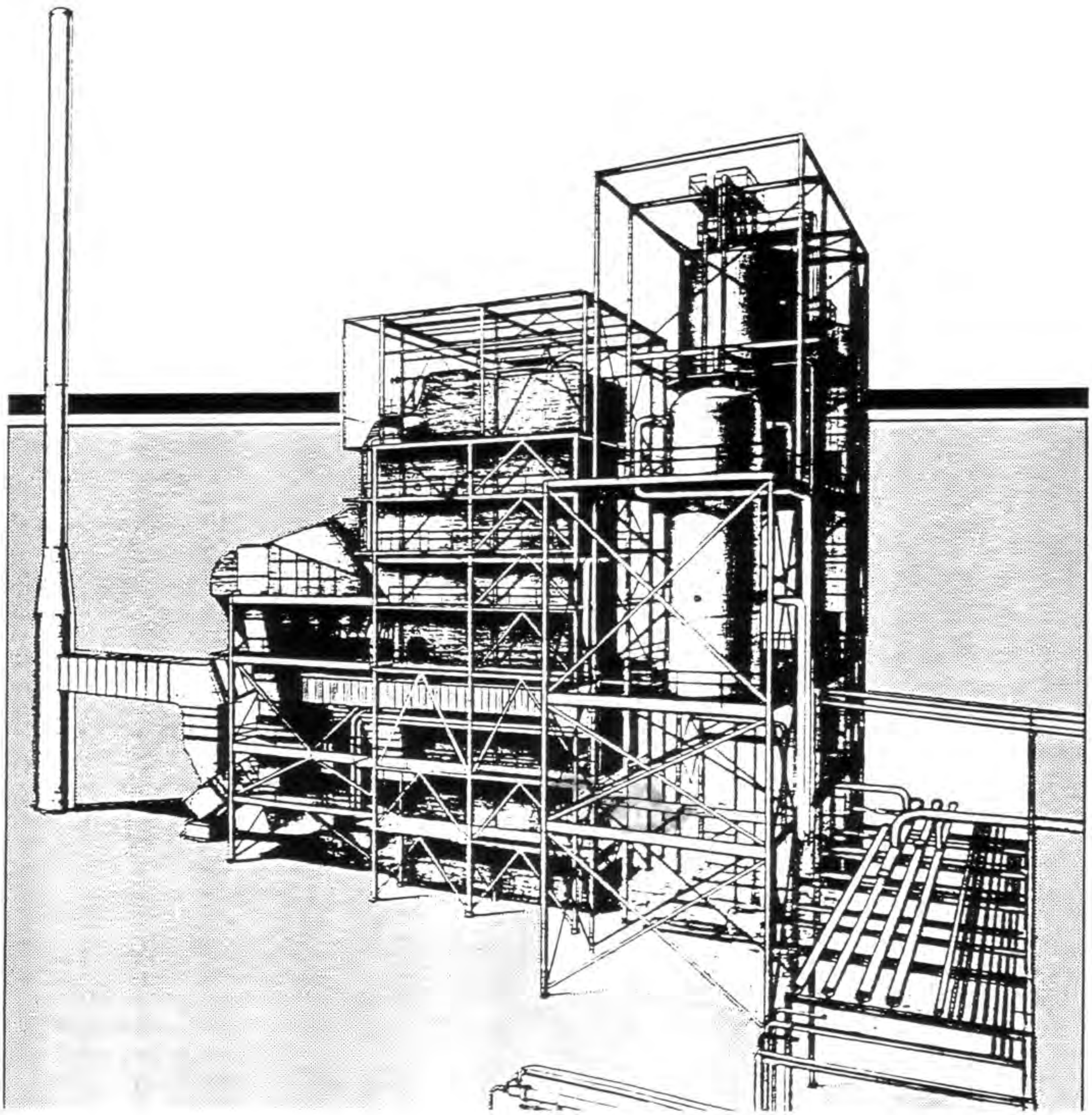
POWER ENGINEERING

POWER PLANT PRIMER



POWER PLANT PRIMER

by

Andrew W. Kramer

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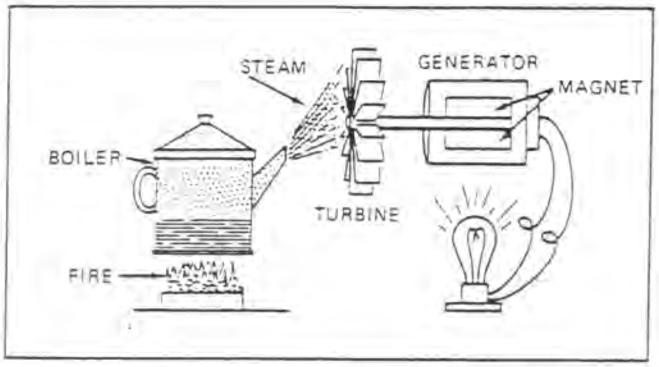
POWER ENGINEERING Magazine

Power Plant Primer

A steam power plant is a means for converting the potential chemical energy of fuel into electrical energy. In its simplest form it consists of a boiler and a turbine driving an electric generator.

The boiler is a device for turning water into steam. The steam jet issuing from the spout spins the fan (turbine) and also the generator. In the sketch the very simplest kind of boiler and turbine are shown. The boiler is a tea kettle, and the turbine is nothing more than a little windmill. Actual turbines are more complicated but the principle is the same.



A word about the generator shown in the sketch. To most people the process of generating electricity is very mysterious, yet the actual process is easy to understand. As shown, the generator consists of a little bar magnet spinning inside a stationary coil of wire. This may seem an absurdly simple affair, yet that is exactly what a real generator consists of—a magnet rotating inside of a coil of wire. As the magnetic field issuing from the ends of the magnet moves across the turns of wire in the stationary coil an electric current is set up in the wire. By winding a large number of turns of wire into a ring or doughnut, the current set up in each turn is added to the current set up in the other turns of wire, and so a much more powerful current is produced.

This is all you need to know about an electric generator now—just think of it as a rapidly rotating magnet inside of a coil of wire; this produces an electric current in the wire. Later we will elaborate on this simple description.

You may wonder, if a power plant is basically as simple as this, why we build the complex plants we see described in POWER ENGINEERING Magazine? The answer is quite simple: the plant shown in the sketch is not very efficient—indeed its efficiency is close to zero—and since we want to get as much power as possible out of a given quantity of fuel it is necessary to make our plants as efficient as possible.

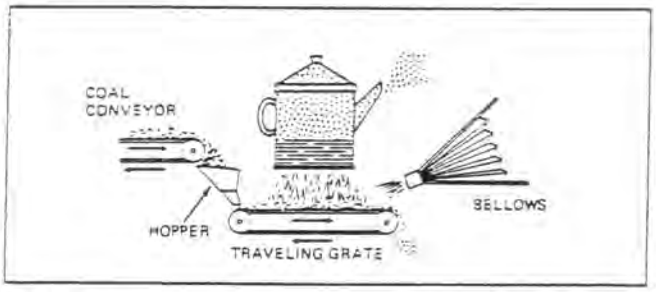
Until the early 1920s, the electric power plants of the nation used over 3 pounds of good coal to produce a kilowatthour of electricity. Today, the national average is less than 1 pound of coal per kilowatthour. In other words, plants built at that time used three times as much coal to produce a kilowatthour as we use today. In 1977, the electric utilities of this country produced over 985 billion kilowatthours by means of coal-fired plants. This required the burning of 447.2 million tons of coal. If, however, we had had to produce this amount of electrical energy by means of the type of plants we had about 60 years ago, we would have needed three times the coal, or over 1.34 billion tons. Coal-fired plants supplied 46.4% of total electricity production by electric utility companies in 1977. Oil-fired plants supplied 16.8%, gas-fired 14.4%, nuclear 11.8%, hydro 10.4%, and all other 0.2%.

The reason for the great decrease in the consumption of coal lies in the gradual improvement of our power systems, both with respect to the individual pieces of equipment and in the system as a whole. Just how do we go about improving the system shown in the sketch?

Boiler components

Looking at it again, it is obvious that it can be broken down into several divisions. First, there is the fire under the boiler. This involves not only the fuel itself but also the method of placing the fuel under the boiler and the arrangement for burning it properly.

So let us extend the diagram to look like this:



Here, we see a belt conveyor transporting coal to the furnace where it is burned on a traveling grate stoker. Air for combustion is supplied by a bellows.

Remember, when you burn coal you are really promoting a chemical reaction—a *chain* reaction. When coal is heated to a high enough temperature in the presence of air, the carbon in the coal combines with the oxygen of the air to form either carbon dioxide (CO_2) or carbon monoxide (CO). These, of course, are both gases. Which gas is formed depends upon the quantity of oxygen present. The CO means that the coal is only partially burned, indeed, the CO can be combined with more oxygen to form CO_2.

In burning coal we do not want CO because that means the coal is only partially burned: there is still energy left in the gas, energy that we can recover if we can burn it to CO_2. It is desirable, in the operation of our boiler furnaces, always to get as much CO_2 as we can because in that way we get all the heat out of the fuel.

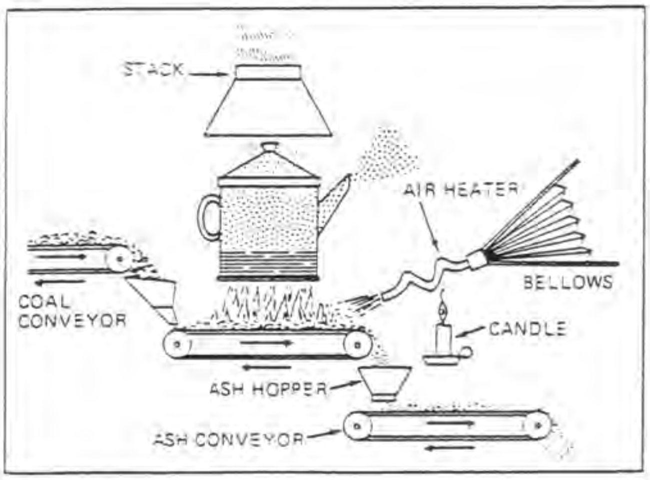
We can obtain the CO_2 by supplying more air to the fuel as it is burning. But we do not want to supply too much air, because if we do we will be supplying more oxygen than is actually needed to combine with the carbon, and this excess oxygen will play no part in the combustion process. Not only will it play no part but it will actually detract from the efficiency by absorbing heat that otherwise could be used to heat the water in the boiler. In actual practice it is not possible to supply exactly the required amount of air, so somewhat more than enough is supplied. This is commonly referred to as *excess air*.

So, in the process of combustion, we are dealing with chemistry. It involves a knowledge of the composition of the coal, its physical condition, its behavior under various conditions of temperature, moisture, etc. Actually, the combustion of coal is a very complex process requiring a good knowledge of both physics and chemistry. In a large plant it involves a major problem in materials handling—fuel, ashes, air and flue gas. Remember, to burn coal, you have to supply about 11 pounds of dry air for each pound of dry coal used. Because of widely varying coal compositions, and allowing for excess air and moisture, the actual amount required is usually somewhat more than this.

So far, we have merely mentioned ashes and flue gas. These have to be removed continuously. In the days of hand firing the removal of ash was simple, though laborious. The fireman merely raked the ash out of the ashpit and carried it away in wheelbarrows. Today, in large plants, the removal of ash is a complicated process requiring rather elaborate equipment. So, we must add ash removal equipment to our diagram; also a chimney for the removal of flue gas.

Furthermore, the process of combustion is stimulated by heat; indeed, the process will not start until the fuel is brought to the kindling temperature. Everything must be done, therefore, to maintain a high temperature in the furnace. This makes it desirable to heat the air for combustion before it is delivered to the furnace. This aids combustion and increases the efficiency.

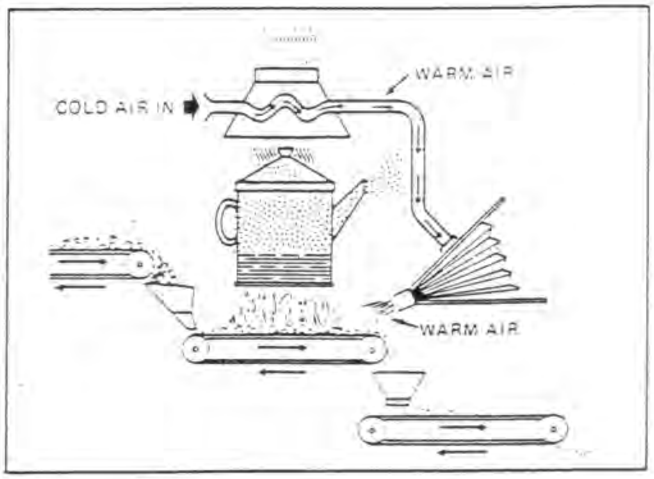
With these facts in mind, let us redraw our diagram to incorporate these improvements. This way:



As you see, it is becoming more complicated. Now, we have a chimney or stack to remove the gas of combustion and a heater to heat the air from the bellows before it is blown into the furnace. Also, we have put in an ash conveyor.

Now, if you are of an analytical mind, you will see that it takes *additional* heat to heat the air. We have shown a candle. Since candles cost money, it is obvious that we are not going to save much money that way. Why can't we use some of the heat from the fire under the boiler itself to heat the air? Maybe that would be cheaper than buying candles?

Well, it is, and moreover, there is heat going to waste up the stack. You know from experience that if you hold your hand above a tea kettle on a stove that there is a lot of heat being wasted. So, let us put a heating coil in the stack so the bellows will be blowing warm air into the fire as shown in the sketch.



All this probably seems absurdly simple, and it is. The reason for explaining it in this way, however, is to show, by means of the simplest kind of equipment, how engineers go about improving the efficiency of any system. Step by step, adding something here, saving something there, establishing closer supervision over everything gradually improves the effectiveness and the efficiency of almost any kind of system. These are the kinds of things engineers are concerned with. Nearly all of them are more or less complex and require a great deal of specific as well as general knowledge. In the example just described, for example, just how much surface should the heater in the stack have to heat the air to a certain temperature? How hot should the air be for best combustion, how much air should be supplied, how much power will it take to run the bellows, what happens to the flue gases if too much heat is extracted from the gases, what happens to the stack? None of these is a foolish question.

Consider the last question, for example, that of cooling the flue gases too much. What happens? Well, there is always a certain amount of water vapor in the flue gases; from the air and from the hydrogen in the fuel. As the temperature of the gases is lowered, there comes a time when the saturation point is reached and the moisture condenses. If, at the same time, there happens to be any sulfur in the gas (and there usually is), sulfuric acid will be formed, resulting in the spread of a thin but extremely corrosive layer of liquid on the inside surfaces of the flues.

This single example, then, shows what the engineer runs into when he begins to *refine* the simple system we began with. He may add something to improve it but he may find that the improvement is not an unmixed blessing; it may also have deleterious effects. These he must guard against.

But let's get on with our power system. The tea kettle representing the boiler is not a very efficient generator of steam. Let's see if we cannot design a better one. Look at the sketch on the next page. Here we have a boiler consisting of two steel drums connected by a number of steel tubes, and arranged in a furnace so that the hot gases have to pass through the bank of tubes on their way to the stack. The total surface of the tubes is large, making it possible to absorb a great deal of heat. The steam bubbles formed in the tubes rise to the upper drum (called the steam drum)