THE BURNING OF IRON IN STEAM

Cases have occurred at sea of an unusual type of fire, following the loss of water in a boiler. The most recent incident of this nature occurred in a destroyer and the result is shown in the accompanying illustrations. At the enquiry which followed, the engineer officer of the ship said that, when he went down to the boiler room, there was no fire in the furnace but the upper rows of tubes were incandescent, and molten metal was dropping down through the tube nest into the furnace (see Figs. 1 and 2). There was fire in the uptakes, and the actual metal of the tubes was burning.

It is well known to chemists that iron is liable to burn in steam, with the production of free hydrogen. Ignition takes place at about 700° C. and the reaction will cease if the substances involved are cooled below this temperature, which is a low red heat. While the burning of iron in steam can continue entirely independently of any supply of oxygen from the air, the hydrogen produced by the reaction will burn on coming in contact with air if the temperature is high enough to cause ignition. This means that there are likely to be two types of fire burning simultaneously, the one in steam and the other in air. Any smothering attempt would probably result in extinguishing the hydrogen-in-air fire while the other continued burning: a hydrogen concentration would build up and an explosion might result.

Amplifying his evidence, the engineer officer of the vessel in question stated that, when he went down below, he saw this intense fire in the upper parts of the boiler, but the lower tubes were still in place. It was impossible at this time to assess exactly what damage had occurred, but it was obvious that the upper casings in the boiler room were red hot. After checking that all the oil fuel valves were shut off, the engineer officer isolated the oil fuel suction lines and then closed down the boiler room entirely to eliminate air. He had hoped this would extinguish the fire, but as a matter of fact it grew worse. At this point, the first lieutenant emptied the pom-pom magazine when he found one or two casings becoming hot. Water sprays were directed through the doors at the bottom of the funnel and actually down the outer casing as well as down the inside of the funnel. The engineer officer visited the boiler room at regular intervals to make sure that there were no fires starting outside the casing.

At this stage, the S.E.O. (D) came on board and remarked that it was inadvisable to put water down the funnel. Foam was introduced through the funnel door, but the fire increased in intensity. An adaptor was then made from an old boiler tube with a bent end, the water was directed on to the fire through the door in the funnel casing. Between 0700 and 1230, when the fire was extinguished, there was not at any time a fire in the furnace; it was among the tubes. In addition to the incandescent tubes a flickering flame was also noted; this must have been due to the liberated hydrogen.

The oxidation of iron in steam with the liberation of hydrogen occurs every time a boiler or a single tube gets overheated and not only if the sprayers are kept on. Indeed, loss of vacuum due to the release of hydrogen passing over to the engines is often the first indication of shortage of water in a boiler. The reaction starts at the bore of the tube *before* the burst occurs. The subsequent outrush of water cools the overheated tube below the ignition temperature and washes away the scale in the vicinity of the burst, but black oxide is always present in the bore a short distance away on either side of the burst. If the source of heat is not removed and the supply of feed water is not maintained, the reaction will start up again.

The possibility of setting up this reaction in other circumstances must not be overlooked, particularly when the necessity arises for blowing out a boiler

FIG. 1.—VIEW OF TUBES SHOWING HOW METAL HAS MELTED AND SOLIDIFIED

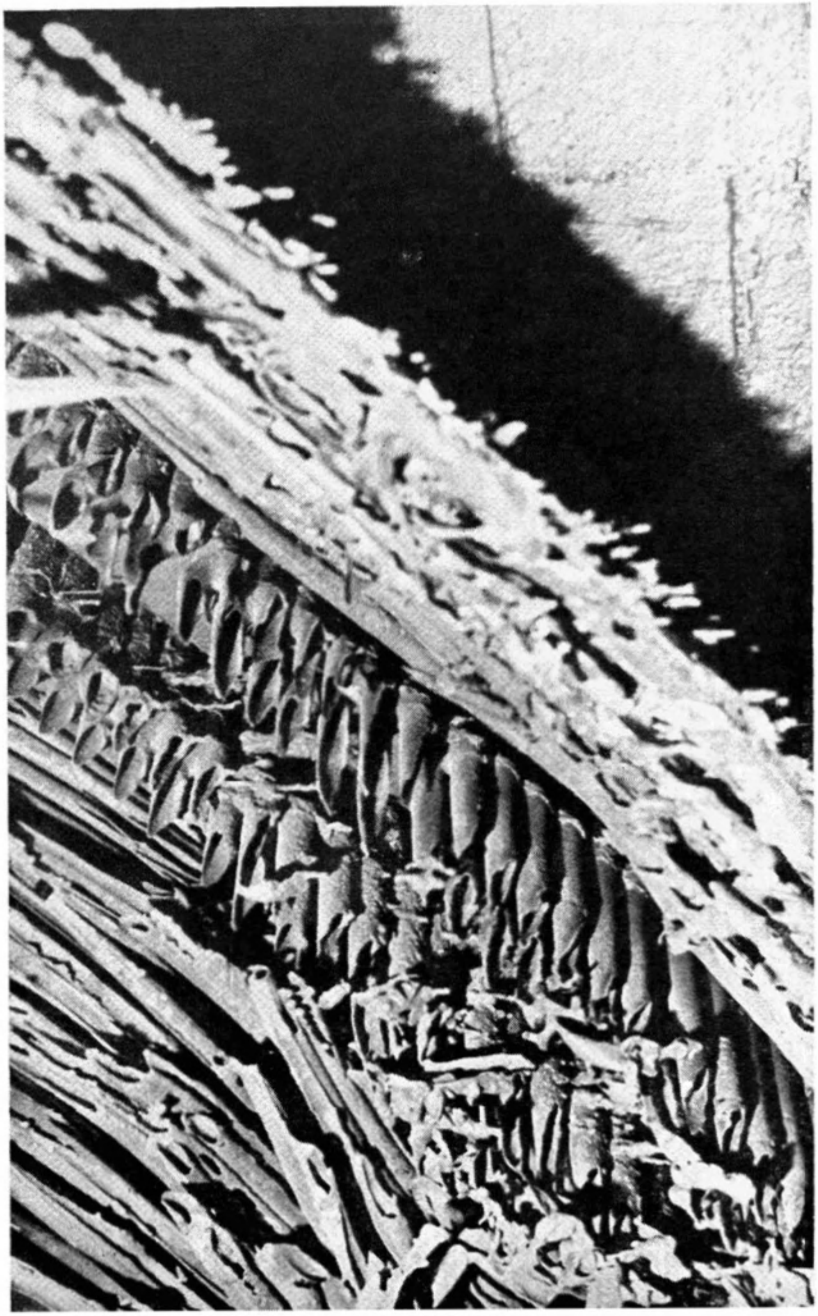

FIG. 2.—GENERATOR AND SUPERHEATER TUBES BURNT THROUGH

while steam remains, preparatory to opening for cleaning. Under these conditions a boiler is likely to be foul externally and there is a possibility of an accumulation of smouldering soot in the tube nests. So long as water remains in the boiler at or near working level such an accumulation of soot does not constitute a danger. If, however, the contents of the boiler are blown out and the air flaps are opened with the object of hastening the cooling of the boiler the increased supply of air may accelerate the combustion of the soot to such an extent as to raise the temperature of the tubes sufficiently to initiate this reaction at the internal surfaces.

Accumulations of soot will smoulder for a considerable time. When blowing out a boiler preparatory to cleaning it is therefore imperative that no attempt should be made to accelerate cooling by opening air and casing doors. After blowing out a boiler it should not be left untended until the pressure is down to zero and the manhole doors have been knocked in.

The reaction, which is the basis of Lane's process of hydrogen production, can be expressed thus :

$$3\ Fe + 4\ H_2O = Fe_3O_4 + 4\ H_2$$

(Fe_3O_4 is the black oxide of iron sometimes known as ferrosic oxide.)

The reaction is exothermic, i.e. it produces heat and is self-sustained until such time as :—

(*a*) the temperature is reduced below 700° C.,
or (*b*) all the iron is oxidised,
or (*c*) the steam supply is reduced.

By this reaction, 168 lbs. of iron, treated with steam produced by 72 lbs. of water, will liberate 8 lbs. of hydrogen. At atmospheric temperature, 8 lbs. of hydrogen would fill a balloon fourteen feet in diameter.

Steam can be dissociated into hydrogen and oxygen by heat alone but only 0.0007 per cent. is dissociated at 1124° C. (2050° F.) and 11 per cent. at 2656° C. (over 4000° F.). Clearly, thermal dissociation was not the cause of this fire.

Both on theoretical grounds and from consideration of the case cited above, it is clear that the best way of fighting such a fire is to get the maximum flow of water to the seat of the fire in the shortest possible time. A jet from a main branch is the best method of achieving this object. The improvization of a directing device may be necessary. A very heavy spray directly applied might have an adequate cooling effect, but a light spray or any application in which water merely drips on to the fire, is undesirable because it would result in the creation of more steam, while the cooling effect is inadequate.

There is a parallel in the war-time developments in dealing with magnesium-cased incendiary bombs. Spray accelerates burning, and, because the magnesium content of the incendiary bomb is limited, the technique was, at first, acceptable. Subsequently, a good water jet was recommended. The cooling effect of a jet of water on iron is more rapid than on magnesium because iron has a lower calorific value and a higher thermal conductivity than magnesium.

For obvious reasons, attempts to smother an iron in steam fire by reducing the air supply are doomed to failure. Moreover, there are dangerous potentialities in such an attempt. The secondary hydrogen-in-air fire may be extinguished and a highly dangerous concentration of hydrogen may build up and eventually lead to explosion. The hydrogen should be allowed to continue flashing as fast as it is produced. The compartment should be ventilated as fully as possible and in such a way as to carry away any unburned hydrogen to the fresh air, and, if possible, to reduce the supply of steam in the neighbourhood of the incandescent iron.

Foam is not an effective extinguishing agent for such a fire, because the cooling effect is less than that of water. Foam application would be justified

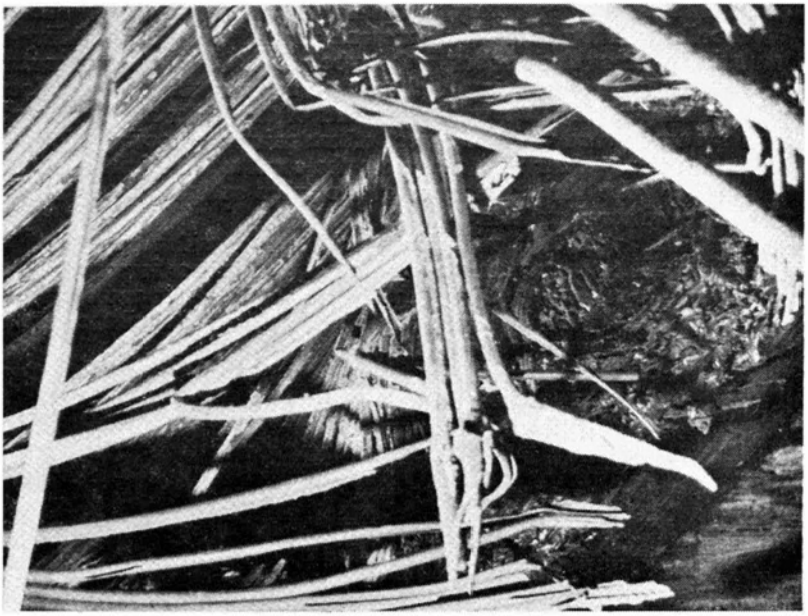

FIG. 3.—GENERAL VIEW INSIDE FURNACE

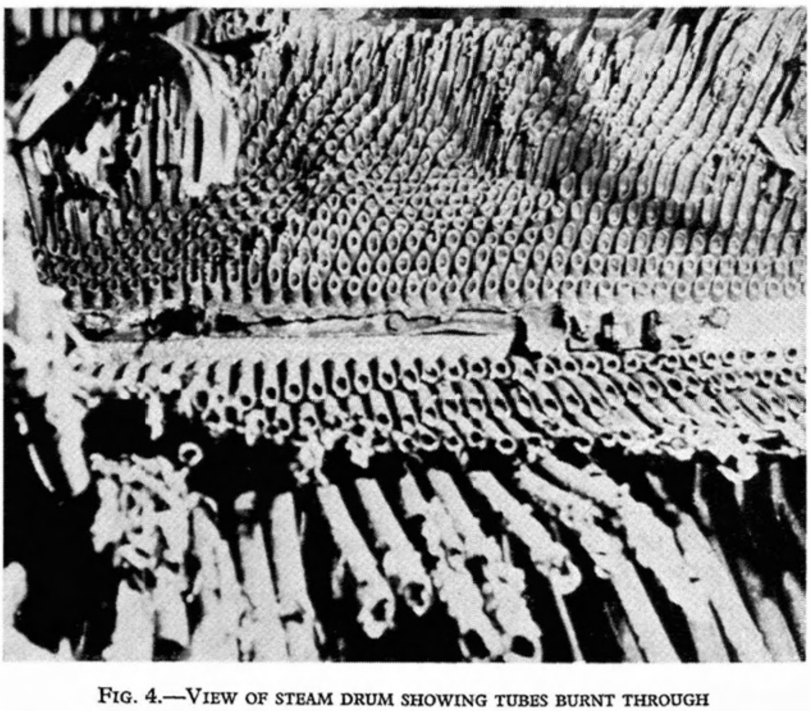

FIG. 4.—VIEW OF STEAM DRUM SHOWING TUBES BURNT THROUGH

only if there were complications such as an ignited oil spill, a condition which did not exist in this case.

It has already been stated that spray is less effective than a jet on such a fire, but spray branches may be used to prevent the spread of fire to other compartments, providing that every effort is made to avoid creating additional steam in the neighbourhood of the iron-in-steam fire.

A similar incident occurred in the German cruiser *Prinz Eugen*. Following a shortage of water, fire occurred in the boiler room. It involved the tubes and spilled oil was ignited. The ship was fitted with a fixed installation for the introduction of an inert gas, known as Ardexin. The compartment was closed down and the fire extinguishing gas was introduced. At the end of one hour the oil fire was extinguished, but when personnel entered the compartment again, the boiler tubes were still burning, and continued to burn for four hours. It was believed the fire finally burned itself out when the supply of steam was exhausted.