have not been set up by an abuse of the material during the process of construction. It is seen, therefore, that factors of safety are really made up of two parts—one part a true factor of safety, the other a pure factor of ignorance.

Boiler explosions may be attributed to improper installation, or incompetent or careless operation.

Improper construction may consist: of unsuitable or inferior material; poor workmanship; abuse of material, as when unmatched rivet holes are drift-pinned to place, or uncylindrical shells are sledged to form; of employing the more dangerous lap joint for the side seams instead of the more safe and more sensible butt joint, etc.

The lap joint is dangerous because this form of construction promotes the formation of incipient cracks in the upper surface of the lower lap where they may be impossible of detection. These cracks extend from rivet hole to rivet hole and gradually deepen with the continued raising and lowering of the steam pressure until the metal, no longer capable of resistance, gives way and causes a violent explosion.

The lap joint is given the preference over the butt joint solely, because, it appears at first thought to be cheaper. But there is no excuse for its existence, and its employment in the construction of new boilers should be prohibited by law in all states, as it now is in some.

Improper installation may consist of so supporting the boiler and its piping as to allow temperature changes to set up dangerous stresses in the material, of improperly attaching the usual appurtenances such as safety valves, steam and water gauges, check, blowoff, stop valves, etc.

Incompetent or careless operation may consist in allowing the steam gauge to get out of order, in allowing the water-gauge connections to become so clogged as to indicate ample water when there is none in the boiler, in allowing the safety valve to become so stuck to its seat as to fail to blow at the pressure for which it was set, in allowing grease to enter or scale to accumulate in the boiler, in allowing large quantities of cold water to be impinged against hot plates, in allowing the water to be driven from the heated surfaces by forced firing, in allowing a large valve to be opened too suddenly, in allowing two boilers to be cut in on the same steam main when their pressures are unequal, and in allowing minor repairs to be neglected until they endanger the whole structure.

It is significant that many violent boiler explosions occur either just prior to the starting of the engines in the morning or while they are idle at the noon hour, or shortly after they have been shut down for the day. One reason is that when steam is not being drawn from the boiler it accumulates rapidly; and if the safety valve fails to relieve the pressure, explosion soon follows.

The rapidity with which the bursting pressure is reached may be shown as follows:

Let

T = Time in minutes required to reach the bursting pressure;

W = Weight of water in the boiler;

t = Temperature of the steam at bursting pressure;

t' = Temperature of the steam at normal working pressure;

U = Number of heat units per minute supplied by the furnace and absorbed by the water.

The heat balance is then represented by the equation:

$$UT = W\,(t - t')$$

$$T = \frac{W}{U}\,(t - t')$$

which means that if we multiply the difference between the temperature of the steam at bursting pressure and at normal pressure by the weight of the water in the boiler, and then divide the product by the number of heat units supplied per minute by the furnace, the result will be the number of minutes that will elapse from the time the openings are all closed until explosion follows.

Take, for example, a 100-h.p. boiler containing at normal level 5,000 lb. of water and suppose it uses 50,000 heat units per minute when evaporating 50 lb. of water per minute. Then if the normal gauge pressure be 85 lb., the corresponding temperature of the steam is 327 deg., and if the bursting gauge pressure be 485 lb., the corresponding temperature of the steam is 467 deg.; and the time required to reach the bursting pressure with all steam openings closed and the safety valve stuck is:

$$T = \frac{5{,}000}{50{,}000}\,(467 - 327) = 14 \text{ min.}$$

That is, with a stuck safety valve, only 14 minutes would elapse from the time the engines were shut down until the explosion followed.

The temperature of the water in a boiler is approximately the same as the temperature of the steam with which it is in contact. If the fire be drawn when the openings are closed, ebullition ceases. If a valve be opened, ebullition starts again, even though there still be no fire under the boiler.

It is plain, therefore, that with the openings closed it is the pressure on the surface of the water that prevents further generation of steam. It is also plain that if a small rupture below the water line a violent explosion may not ensue. But it ought to be evident that if a large outlet above the water line be suddenly opened, as, for example, when a steam pipe fails, then the sudden liberation of the pressure on the surface of the high-temperature water will allow it to flash suddenly into steam and cause a violent explosion and water-hammer that will disrupt the strongest possible construction.

Grease does not dissolve or decompose in water, nor does it remain on the surface. Heat in the water and its violent ebullition causes the grease to form in sticky drops which adhere to and varnish the metal surfaces of the boiler. This varnish by preventing the water from coming into intimate contact with the metal, prevents the water from absorbing the heat, and this causes a blistering or burning of the plate that often results in a serious rupture, or a violent explosion.

If scale is allowed to accumulate to any considerable thickness in a boiler, a bag or rupture of the shell is inevitable, unless the scale happens to be of a spongy formation, which is not often the case. Just why this is so, is shown by the following simple experiment.

Take an ordinary granite iron or tinned iron stewpan and firmly glue to its underside a postage stamp. Pour water into the pan and place it on a gas stove so that the postage stamp will be in direct contact with the flame. Leave the pan on the stove until the water has boiled violently and then examine the stamp. The stamp will not even be charred, much less burned, notwithstanding that it was on the underside of the pan and in direct contact with the hottest part of the flame.

Now put into the pan a mixture of water and Portland cement half an inch thick. This, when set, will be the equivalent of half an inch of scale. Repeat the experiment made before and it will be found that the stamp will burn up very quickly.

The reason that the postage stamp is not charred by the flame when no scale is present is that the water, being in immediate contact with the thin bottom of the vessel, absorbs the heat as fast as it is put into the vessel by the flame. The result is that, no matter how hot the flame may be, the bottom of the vessel remains at practically the same tem-