GENERAL REPORT

ON THE

EXPLOSIONS OF STEAM-BOILERS,

BY A COMMITTEE OF THE

FRANKLIN INSTITUTE OF THE STATE OF PENNSYLVANIA

FOR THE PROMOTION OF THE MECHANIC ARTS.

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Report of the Committee of the Franklin Institute, &c., on the Explosions of Steam-Boilers. PART II. *Containing the* GENERAL REPORT *of the Committee.*

THE Committee appointed "to examine into the causes of the explosions of the boilers used on board of steamboats, and to devise the most effectual means of preventing the accidents, or of diminishing the extent of their injurious effects," respectfully submit to the Board of Managers of the Franklin Institute the following report:

The Committee undertook the task imposed upon them by the Franklin Institute, with a deep sense of the responsibility which it involved. On the one hand, a series of disasters by which human life was sacrificed, called loudly for an investigation of the causes which produced them; on the other, an untimely or ill-directed interference with a branch of industry, which has been a source of unparalleled advantage to our country, was truly to be deprecated.

Emanating from an Institute "for the promotion of the Mechanic Arts," the Committee felt advantageously situated. They could not justly be suspected of a desire to trammel the progress of any art; and yet the public confidence, which had always been accorded to the institution, would naturally attach to a committee selected by it.

The Committee further believed that the apprehensions of the public, aroused by the frequent recurrence of accidents, could only be satisfactorily allayed by an investigation, which would show that such accidents were not unavoidably incident to the useful agent which they distrusted, but resulted from a want of due regulation of its power, or from circumstances incidental to its use which could be foreseen, and therefore guarded against. If disappointed in this anticipated result of investigation, the Committee hoped to satisfy those who are public carriers, that it was their duty to provide protection for those who trust life in their hands, against an agent thus found to be uncontrollable.

With these views the Committee commenced, actively, the collection of information upon the subject intrusted to them. The replies to their circular were canvassed in their meetings, and finally laid before the public.*

* As these replies will be frequently referred to in what follows, it is proper to state here, that the references are made to the pamphlet distributed by the Committee to their correspondents and others, and that Nos. I. to XIII., both inclusive, were pub-

It occurred most opportunely for the ultimate success, though not for the rapid completion of their labours, that an opportunity was afforded them for experiment, by which to test many of the suggested causes of, and preventives to, the explosions of steam-boilers.

These experiments, originally proposed by our public-spirited fellow-citizen, S. D. Ingham, Esq., then Secretary of the Treasury of the United States, have been brought to completion and presented to the public under the auspices of the present Secretary.*

The Committee trust that they have, by the experiments just referred to, shown not only what are some of the causes of explosion, but, which is quite as important, what are certainly not causes. In this way they hope to have turned away the attention of ingenious men from false hypotheses which cannot furnish the remedies they are in quest of, and to have pointed out some directions in which their labours may be profitably bestowed.

A desire to complete the reports upon their experiments, has induced a delay in the present report, which, thus far, however, the Committee are satisfied will be found to have been judicious. This conclusion they rest upon the many references, which will appear in the following pages, to those experiments, which have given an authority to recommendations and suggestions, that could not have been claimed for them unless thus strongly supported by facts.

They regret much that the part of their report referring to the strength of materials will, from circumstances, be unavoidably incomplete. This deficiency they hope will hereafter be made up, the experiments on the subject having been some time since concluded; and they do not feel warranted, by this cause, in any longer delaying their general report.

In this report the Committee have endeavoured, by examining the different accounts of explosions on record, and the writings on collateral subjects, to ascertain what causes have been operative in producing these disasters. The difficulty of procuring satisfactory testimony in regard to them, has been often pointed out. Most frequently those from whose mismanagement or want of vigilance they have immediately resulted, have been victims to them, and when they have survived, the precise state of things before the occurrence was imperfectly known to them; and, however honest, their minds have received a bias towards the non-existence of certain circumstances judged likely to have produced the results.

It hence follows that in regard to many explosions, either none of the circumstances which immediately preceded them, and bearing upon them, are known, or by inaccurate statements of them, an appearance of mystery is thrown around the whole matter, calculated to baffle research, and to alarm the community, who are exposed to a recurrence of the same dangers. Thus it happens that of the numerous explosions on record, few are made to subserve the cause of humanity, by a knowledge of their proximate causes. The details of the number of killed and wounded, and of the more or less entire destruction of the boilers and of the boats, are given in the daily prints, and public curiosity is satisfied.

In making their examination, then, of the cases of explosion, the Committee have selected such as they have found most directly to the points

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in support of which they are cited; omitting others in which the facts are less clearly made out, or in which the causes assigned may be resolved into matters of opinion. Having themselves no theory, or theories, to support, they have of course not been biassed, by such views, in the selections made.

This mode of proceeding is, obviously, not calculated, by one effort, to exhaust a subject. But the Committee believe that they are able to make a decided step forward in the knowledge at present existing, in a connected form, on this subject. That to the causes pointed out by a Committee of the British House of Commons,* in 1817, namely, improper construction or material of a boiler and undue but gradual increase of pressure, they will be able to add others as important, and as fully proved as the former. Nor will any cause for alarm result from this extension, since it will be found that it is only ignorance of these circumstances which constitutes their danger, and that they may be prevented from occurring and remedied when they occur. It will be full time after the well-ascertained causes of explosion have been duly guarded against, to look for others more occult in their nature, if indeed there are such.

In the following Report, the Committee propose to examine separately the circumstances which they consider as the proximate causes of explosions in steam-boilers, and the preventives or remedies which have been proposed to meet them. Under each division of the subject they will make the suggestions or recommendations to constructors and others, which they base upon the previous discussion; and at the close of the Report, will present a project of a law for carrying into effect, in regard to steamboat boilers, those recommendations which are of primary importance.

It will be observed thus that while they do their duty to the arts by pointing out as far as their knowledge extends what they consider improvements or valuable alterations, they do not propose to render imperative any measures but such as are required for public safety.†

In submitting this project the Committee obviously do not entertain a doubt of the competency of Congress to legislate on the matters embraced in it. The several discussions in that body on the subject,‡ the recommendation of the President of the United States,§ and especially the very detailed provisions of the bill recently proposed in the Senate, fully sustain them in this opinion. They consider the question now to be, not whether any regulations may be made, but how those to be made may be rendered most efficient and complete. For this completeness the very respectable Committee‖ who reported the bill referred to, in the Senate of the United States, have expressed themselves anxious; and the labours of this Committee, so far from being an interference, will, no doubt, as far as they may be approved, be looked upon as forwarding the views thus expressed.

* Charles Harvey, Esq. Chairman.

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§ In the annual message for 1833.

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The good effects which have attended the adoption of partial preventives in England, and the excellent effects from the more complete ones in France, should urge us, as Americans, to do our part in preventing further destruction of life and property by these disastrous explosions. And while we apply means for this purpose, experience and reason both teach us that they will produce no undue or severe restraints upon mechanical skill or commercial enterprise, but rather that they will aid both, by increased confidence on the part of the public.*

The Committee propose to investigate the different causes of the explosions in steam-boilers under the following general divisions.

I. Explosions from undue pressure within a boiler, the pressure being gradually increased.

II. Explosions produced by the presence of unduly heated metal within a steam-boiler.

III. Explosions arising from defects in the construction of a boiler or its appendages.

IV. Explosions resulting from the carelessness or ignorance of those intrusted with the management of the steam-engine.

V. An examination of the particular cases of collapse of a boiler, or its flues, by rarefaction within.

I. Explosion from undue pressure within a boiler, the pressure being more or less gradually increased.

1. This is one of the most natural causes to look to as producing the bursting of steam-boilers, and one which, probably, is as frequently operative as any other. It might be supposed that with a safety-valve always applied and a mercury gauge so easily applicable, the low pressure boiler should have been exempted from explosion. But such has never been the case, and we find a select committee of the British House of Commons, in 1817, specially directing their inquiries to the cause above-stated, as producing the disastrous explosions which, even at that day, called for legislative interference.

2. That a gradual increase of pressure can produce all the effects of the most violent explosions, may be inferred from many cases on record, attributed with probability to this cause; and was proved conclusively by the direct experiments of this committee. In these latter, cylinders of copper and iron were violently torn asunder, the parts thrown from their places, scattering the materials of the temporary furnaces over which they had been heated, and of the fire, to considerable distances.† There are

* Professor Silliman, in an article on the safety of steamboats, has the following strong expression of opinion: "The boat which is first ascertained to afford absolute security will be a fortune to its proprietors."—Silliman's Journal, vol. xix. p. 146.

† This effect is well illustrated by the rending of a copper cylinder just referred to. The subjoined figure and extract are from the first part of the Report of the Committee on Explosions, &c. p. 68. (Journ. Franklin Institute, vol. xvii. pp. 224, 225.)

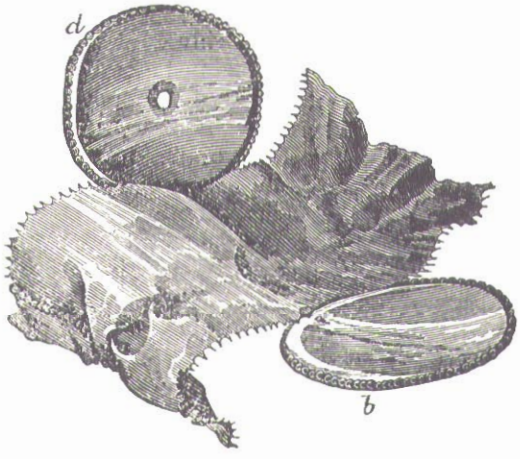
"As before, nothing remarkable occurred previous to the instant of explosion, and the members of the committee, employed in the experiments, were engaged in observing the boiler at the instant it exploded. A dense cloud of smoke and flame, capped by steam, rose from the pit; the stones and combustibles were widely scattered, and the boiler was thrown, in a single mass, about fifteen feet from the furnace. The noise attending this explosion was like that from the firing of an eight inch mortar.

"The boiler was rent as shown in the accompanying figure, giving way in an irregular line, just above the probable water line on one side of the boiler, but not conforming to it. *d* and *b* were the lowest points in the two heads before the explosion.

also cases well made out in which a weak place in a boiler has acted as a safety valve, but such fortunate circumstances are not always to be looked for, and better methods have been devised of effecting the same object, than to imitate them by the use of thin plates. The idea stated to be current,* namely, that a boiler does not explode if duly supplied with water, is wholly untenable and highly mischievous in its tendency.

3. We are warranted, then, in looking to the failure of the apparatus designed to prevent undue pressure, or to the misuse of it, as the cause of explosions of the most violent kind. The current of testimony is too strong to permit the former view to the exclusion of the latter. It has been too clearly shown that those who have charge of the steam engine sometimes not only neglect the means of safety provided, but actually render them inoperative. Not to multiply instances, the Committee refer to the following as entirely well made out, and in which the connexion between the misuse of the means of safety and the explosion is fairly to be inferred. First; That of a cast-iron boiler used in a sugar-house in Wellclose-square,† London, the mercury-gauge attached to which was plugged up and the safety-valve purposely overloaded at the time of explosion. Second; The case of a steam tow-boat on the Rhone,‡ in France, when

The sheet of copper was torn from the heads, unrolled and irregularly bent, adhering to the heads for only a short distance near the top of each; and the heads were



bent outwards. The thickness of the copper along the line of rupture varies from 0.25 to 0.35 of an inch, and the metal appears to have been highly heated at one end of the torn portion."

* Replies to Circular of Com. on Explosions, &c. No. XII. Report of Thos. Bakewell, Esq.—"at a subsequent period and after the captain had conversed with some of those who contend that a boiler cannot burst with 'fair play,' as it is termed."—To meet this prejudice, the Committee have chiefly selected their proofs from accidents which have occurred abroad.

† Minutes of evidence before a Select Committee of the House of Commons, &c. &c. by Geo. Dodd, Civ. Eng. Evidence of Mr. Braithwaite, Mr. Richter, &c. Also, Partington on the Steam Engine.

‡ Annuaire du Bureau des Long., 1830. p. 141. Journ. Frank. Inst. vol. v. p. 401. It is stated in the London Journ. of Arts, that the pistons of the engine had become fixed in the cylinders, by being expanded more rapidly than these latter, and that Mr. Steele the manufacturer of the engine supposed the steam to be insufficient, and was induced by the desire to have his engine succeed, to adopt a device which resulted so fatally. Lond. Journ. Arts, vol. xiii. p. 346.

the safety-valves of the four boilers were fastened down, so as to be immoveable. Third; The explosion in one of Trevithick's locomotives,* when the safety-valve was kept down to raise steam at starting. Fourth; The explosion in the steam carriage of Messrs. Burstall and Hill,† when in going over a soft piece of road, in which the coach laboured, the engineer kept down the safety-valve, by pressing upon the lever. And fifth; The explosion of the boiler of the steamboat New England from a "pressure of steam, produced in the ordinary way, but accumulated to a degree of tension which the boilers were unable to sustain."‡

4. If the apparatus devised for the low-pressure boiler has been rendered inoperative, the high-pressure boiler has had to contend with peculiar difficulties. No gauge applicable to it has yet been brought into use. The open gauge must be of undue height, or cumbrous in its serpentine form; and the closed gauge requires great nicety in construction, and a correction for the temperature of the air inclosed in it. A graduated safety-valve would give the engineer desirable information, and has been to a certain extent used. The engineer of a locomotive engine, where the spring weighing machines are used with the safety-valves, has it in his power to ascertain at any moment, the pressure within the boiler.

He has it is true besides, the power of keeping the valve down even when the pressure within may be unsafe, but then he and his assistants would probably be the only victims of its abuse.

5. The extraordinary and fatal increase of pressure which the Committee have above shown to be produced designedly at times, has at others been attributed to the adhesion of the safety-valve. A practical engineer, Mr. John B. Calhoun, has given a remarkable instance of this kind§ as occurring to a safety-valve on the boiler of the steamboat Legislator, then navigating the Hudson. The mercury-gauge indicating an undue pressure within the boiler without the rising of the valve, the engineer endeavoured first to raise it by a cord which passed into the fire-room: failing in this he went to the top of the boiler where the valve was, and moved the weight upon it towards the fulcrum, but without effect. He then applied his force at the end of the lever to raise it, when suddenly the valve opened with a loud report, and the flow of steam commencing lasted some time before the elasticity had diminished to its usual degree.

6. In this case, there can be but little doubt that the valve had corroded upon its seat or was fastened by the drying of oil, or other matter, to it. The carelessness of the fire-man who had charge of the boiler, and whose duty it was probably to raise the valve from time to time, is fully proved by his allowing the steam to get so high, that the rod of the mercury-gauge

* Minutes of Evidence, &c. Evidence of Mr. Chapman.

† Reply to Circular of Com. on Explosions by L. Hebert, Esq. of London, No. II. See also the bursting of one of Hancock's boilers, from the fastening down of a safety-valve. Lond. Mech. Mag. vol. xviii. and Journ. Frank. Inst., vol. xi. p. 277.

‡ The part marked with inverted commas is the conclusion drawn by an able committee who investigated the cause of this explosion. It is unpleasant to see in this case, how those concerned in the press of steam, were biassed in their views given to the committee and communicated, as the committee testify, as honest convictions, and without intention to deceive. The engine-men were not injured by the explosion. The form of these boilers was no doubt defective, and one part of them will be commented on hereafter. The two boilers exploded almost simultaneously.—Journ. Frank. Inst. vol. xiii. pp. 55 and 126.

§ Account of an extraordinary adhesion of the safety-valve of the boiler on board the steamboat Legislator, on the Hudson. By the Engineer. Journ. Frank. Inst., vol. v. p. 355.

was against the boiler-deck, without giving notice to the engineer. Had not the latter observed, from the rapid working of the engine, that the steam was high, and investigated the matter, the lives of many would no doubt have been sacrificed.

7. The experiments made by M. Clement Desormes* on the tendency of disks, when placed in front of an aperture, through which air is forcibly issuing, to approach it, led him to condemn the safety valve entirely, and especially the disk form. This sentence does not seem to the Committee to be just,† since the tendency upward, under the most favourable circumstances to its action, is very limited in amount, and may easily be counteracted by a device, which will lessen the acting weight, when a safety valve is raised. Besides, the proportion which the area of the disk bears to that of the aperture materially affects the amount of this tendency, and is, in practice, very much less than was used in the experiments of M. Clement. The ingenious experiments of M. Hachette and of Messrs. Hopkins and Roberts of Manchester, have shown the truth of these remarks.‡ If, however, this action were allowed to have full effect, by dimensions in the valve expressly intended to produce it, an increased area of valve would entirely obviate the objection. Different effective means of lessening the acting weight, on the rise of a safety valve have been used or proposed, such as that employed by MM. Arago and Dulong§ in their experiments, on the elastic force of steam at different temperatures, or the very similar one, described by Mr. L. Hebert in his interesting communication to this Committee.‖ In them the weight rolls towards the fulcrum when the valve opens.¶ The Committee apprehend that this form although very effective while in order, would tend by disuse to lose its power of action. They would prefer, in practice, a construction similar to the second form proposed by Mr. Hebert in which the lever being curved effects the same object, while the weight is not required to be moveable. They intend to recommend a suitable form of lever of this kind.

* Notice in Franklin Journal vol. iv. p. 97. See also explanations of the phenomenon offered by Jacob Perkins, Esq. in the same volume p. 252, and in Lond. Jour. Arts, vol. xiii. p. 275. By Doct. Hare in Jour. Frank. Inst. vol. ii. p. 58. By James P. Espy, Esq. in the same vol. p. 59, and by Asa Spencer, Esq. in the same vol. p. 61. also remarks on p. 203.

† In this view the Committee coincide entirely with M. Arago. See Annuaire du Bureau des Long. 1830, p. 157, and Jour. Frank. Inst. vol. v. p. 408. *In fact the committee* named in the next note did not sustain the deduction, above referred to in the text, remarking, in very guarded terms, that the limits within which the phenomenon occurs were not then sufficiently known, to decide upon the possibility of an accident from it.

‡ M. Hachette who investigated this subject shows in a strong point of view the effect of the relative proportions of the disks. When one is not many times the other in size it is impossible to satisfy the conditions of the problem. Annales de Chim. et de Phys. vol. xxxv. p. 44, &c. The Committee who examined this subject in its relation to the Steam Engine, consisting of MM. Biot, Poisson and Navier, made an experiment in which with a disk, nearly six times the diameter of the opening, and a pressure of steam of about 2.8 atmospheres, the tendency to adhesion when the disk was .01 of an inch from the opening, was but half a pound. Annales de Chim. et de Phys. vol. xxxvi. p. 70. In the experiments of Messrs. Hopkins and Roberts, with an excess of pressure in the effluent air of .05 of an atmosphere, over atmospheric pressure; the total tendency to adhesion at its maximum, was but .005 of an atmosphere, with an opening of 2⅜ inches, and a disk of six inches in diameter. With a disk of eight inches in diameter the total tendency was increased from 32 oz. avoirdupois, to 48 oz: and with disks of 4¼ in. diameter and under, no such tendency was manifested, the aperture of efflux remaining the same. Manchester Trans. vol. v. N. S. and Jour. Frank. Inst. vol. x. p. 188.

§ Annales de Chimie et de Phys. vol. xliii.

‖ See replies to circular of Com. on Explosions, No. XI.

¶ In that of MM. Arago and Dulong there was also an arm projecting on the opposite side of the fulcrum from that on which the weight keeping down the valve was placed; upon this a weight rolled from the fulcrum on opening the valve.

The practice of passing the stem of a safety valve through a stuffing box, as it is calculated entirely to defeat the object of the valve, should never be allowed. In fact the more open to inspection all the parts of the apparatus are the better. If it is necessary to carry off the steam from that which the engine-man has the control of, it can be accomplished without resort to packing.

9. There can be no doubt that the form of the safety-valve materially influences the certainty of its action. Although the disk-valve was early recommended, the nicety of workmanship required to make it tight has limited its use, and perhaps the experiments of M. Clement have produced a prejudice against it. The cone, which is in common use, may be more easily tightened when imperfectly fitting the seat; but this very fact is an objection to it. No pressure can cause the disk valve to prevent the escape of steam, if the valve and seat be clean, unless they have been ground to fit. The committee adopted this form of valve in their experiments,* and in no instance was undue adhesion observed. Throughout their experiments, the pressure of the steam corresponding to the opening of the valve with its different weights, was noted by the steam-gauge, or by the temperature of the water within the boiler. No means were used to keep the valve in other than what might be considered fair working order, but when, from the action of dirt, it had become leaky, the grinding upon the seat was very easily performed, and restored its efficiency. Two valves of the same form were used, and the comparison of the calculated pressures due to the weight upon the valve, with the observed pressures at which the valve rose entirely, or leaked so badly as to require additional weight, uniformly gave the former in excess. The average ratio in the experiments was 1 to 1.035, the former number representing the observed, and the latter the calculated, pressure.

10. These conclusions are sustained, in a general way, by the success which has attended the recommendations of the select committee of the British House of Commons. The law, based upon their investigations, requires that there should be two safety-valves upon every boiler, one of which is out of the control of the engineer,—and further provides a penalty for the overloading of either valve, by any person whatever.†

11. In addition to two safety valves, the regulations for the safety of the steam engine in France, require two fusible plates or plugs, of suitable diameter, to be attached to every boiler. These plugs are intended to act by the heat of the inclosed steam, and to give way when it has reached a certain point. In the application of them which we are now considering, they are exposed to a pressure corresponding to the temperature, and in order to prevent them from giving way, as they verge towards the fusing

* Report of Com. on Explosions, part I. pp. 71, &c. Jour. Frank. Inst. vol. xvii. p. 228.

† The regulations relating to the safety-valves of steamboat boilers are as follows:

That every such boiler shall be provided with two sufficient safety-valves, one of which should be inaccessible to the engine-man, and the other accessible to him and to the persons on board the packet.

That the inspector shall examine such safety-valves, and shall certify what is the pressure at which such safety-valves shall open, which pressure shall not exceed one-third of that by which the boiler has been proved, nor one-sixth of that which by calculation it shall be reckoned to sustain.

That a penalty shall be inflicted on any person placing additional weight on either of the safety-valves.

Of twenty-three witnesses, practical engineers and others, examined by the Parliamentary Committee, seventeen recommended explicitly the additional safety-valve, out of the control of the engine-man.

point, they are covered with wire, or with perforated disks or gratings of metal.

12. This mean of safety was made the subject of elaborate experiments by this committee.* The result was, that when alloys of tin, lead, and bismuth, such as are used for fusible plates, are exposed to heat and pressure, parts of them soften at temperatures below that at which the entire plate would become liquid. Being exposed to pressure, these fluid parts are forced out,† leaving a less fusible mass. In one case described by the committee, this operation was carried so far before the plate gave way, that, from a plate melting at 254° to 275° Fahr., was produced a mass fusible only at 312° to 345°. One part of the alloy which oozed out was found to melt at 223° and another at 233°.‡ To this action a fusible plug would be also exposed, and the committee are of opinion that no method of application in which pressure acts upon these compounds, can be efficient in practice.

In the experiments referred to, the plates being thin, were generally burst by pressure; not, however, acting precisely as thin plates of copper or iron would have done, but being partially softened by heat.

13. While the committee deem it very desirable that a convenient steam gauge applicable to high pressure boilers should be devised,§ they

* Report of the Com. on Explosions, of the Franklin Institute, Part I. p. 23. "V. Inquiry in relation to plates of fusible alloys." Jour. Frank. Inst. vol. xvii. p. 74.

† This fact, but to a limited extent, seems to have been noticed by M. Gualtier de Claubry, who did not, however, follow out the suggestion. Receuil Industriel, 1829.

‡ The entire series of conclusions from these experiments, which formed one of the most interesting branches of the committee's investigations, are as follows:

"The conclusions deduced from the foregoing experiments, on metallic alloys, may be thus stated.

"1st. The impurities of common lead, tin, and bismuth, are usually not such as to affect materially the fusing points of their alloys.

"2d. When mixed in equivalent proportions, tin and lead formed alloys, not presenting the characters of distinct chemical compounds, in definite proportions. The alloys between the range of one equivalent of tin, to one of lead, and one equivalent of tin to six of lead, varied considerably in the interval between the temperature of commencing to lose fluidity, and that at which a thermometer, immersed in the solidifying metal became stationary. These different alloys produced nearly the same stationary temperature in a thermometer plunged into the solidifying metal.

"3d. Fusible metal plates covered by a perforated metallic disk, and placed upon a steam-boiler, show signs of fluidity at the disk, before the steam has attained the temperature of fusion of the alloy of which the plate is composed. This fluid metal oozes through the perforations in the disk, and the plate thus loses much of its substance before finally giving vent to the steam.

"4th. The under parts of the plate are not kept from fusion by a protecting film of oxide there formed.

"5th. The thickness of the plate is not important, provided only that it is sufficiently strong to resist the pressure of the steam at temperatures below its point of fusion.

"6th. The temperature at which the plates are cast, and the rate of cooling of the cast metal, do not affect the temperature at which the plates give vent to steam.

"7th. The effect stated in conclusion third, is explained by the nature of the alloys used, which are formed of portions of different fluidities; the more fluid parts, are forced out by the pressure of the steam, leaving the less fusible. These latter in general are burst, not melted.

"8th. By pressure in a receptacle provided with small openings, this effect of separating the differently fluid portions of an alloy, may be imitated.

"9th. Fusible alloys, used to indicate the temperature of any part of a steam-boiler, should not be exposed to the pressure of the steam; at least not in such a way that the separation of the differently fusible constituents of the alloys may be effected."—Report of Com. on Expl. Part I. p. 34, and Jour. of Frank. Inst. vol. xvii. p. 84.

§ The Committee regret that the hydrostatic safety-valve of Mr. Ewbank has not

consider that until this is done, a substitute should be furnished in a graduated safety-valve, marked with numbers expressing directly in pounds to the square inch the bursting* pressure of the steam, and within the control of the engine-man. This would act as a convenient, and, for practice, a sufficiently exact method of knowing what he ought always to be informed of, the bursting pressure in the ordinary working of the boiler. Besides this, however, there should be a lock-up valve, for the original weighting of which there should be a proper responsible agent, and which should be capable of being raised by the engine-man, but not of being kept down. With a valve of this kind of sufficient dimensions, of proper form, and duly weighted, the Committee believe that danger from gradually increasing pressure might be entirely avoided.

A thermometer suitably graduated and passing into the steam or water of the boiler, would prove, under ordinary circumstances, a useful gauge, and may be conveniently applied as described in a subsequent part of this report.

14. With a view to meet the dangers which have been discussed in this section, the Committee would make the following recommendations, the means of carrying out the principal of which, by law, will be found suggested at the close of the report:—

First. That every boiler be provided with two safety-valves, each of which shall be competent to discharge the steam, made in the ordinary working of the engine. The first of these valves should be graduated by the maker of the engine, and have stamped upon the lever by which it is weighted, the bursting pressure at which it will open, by calculation, when the moveable weight is placed at the several notches. The pressure corresponding to the last notch to be equal to the bursting pressure, under which the engine is to work. The second valve to have a weight fixed immoveably upon it, the pressure of which upon the seat, together with that of the atmosphere upon the valve, is equal to the working pressure of the engine. This valve should be so arranged as to admit of raising, but not of placing additional weight upon it. To this end it should be inclosed. The rise allowed by the inclosure should rather exceed half the radius of the valve seat.

Second. The Committee recommend to constructors the disk valve. The diameter of the disk should not exceed once and a half that of the valve seat, as a less ratio than this will leave sufficient margin, and any sensible tendency to close from the effect of the issuing current will certainly be avoided.

Third. That a cord be attached to the lock-up valve, by which it may be raised at the same time with the free valve. And that the working of each be ascertained at least every two hours.

Fourth. That an open mercury-gauge be provided for each boiler of every engine not carrying more than two atmospheres of working pressure. The height of the mercury to be indicated by a float which shall truly mark upon a graduated scale the bursting pressure in inches.

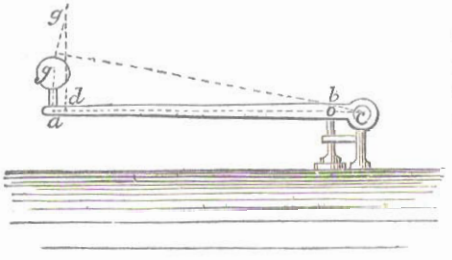
For high-pressure boilers they recommend the thermometer, graduated

been brought into use. It would answer, by a slight modification, as a gauge, and no doubt can exist of its being applicable to the stationary engine. The oscillations of the liquid may interfere with its operation on board of steamboats, but to what extent the Committee are not prepared to say. See description and figures Jour. Frank. Inst., vol. ix. p. 64, and vol. x. p. 2.

* This term is used to signify the excess of pressure of the steam within, over atmospheric pressure, in contradistinction to the *working* pressure, which is used to express the total elastic force of the steam.

to show the pressures corresponding to the temperatures of saturated steam, as a convenient gauge.

Fifth. That the lever of the lock-up valve be bent upwards at the end, so that in rising it shall relieve the valve of part of the weight. A suitable proportion for such relief would be about one-tenth of the pressure derived from the weight, and the height of the bend above the lever should be regulated to meet this.



The lever would have a form similar to the annexed. The part *a g*, which is turned up, may be straight or otherwise. The adjustment should be made so that *d c* is nearly nine-tenths of *a c*. *g* being the centre of gravity of the ball, lever, &c. will lie a little out of the centre of the weight, towards the fulcrum.

Sixth. As there can be no doubt that the competition in regard to speed is, or has been, a strong temptation to an undue increase of pressure by engineers or firemen, it should be expressly prohibited by law.

II. *Explosions produced by the presence of unduly heated metal within a steam-boiler.*

15. In a properly constructed steam-boiler no part of the metal is exposed to the direct action of the fire without being immediately in contact with water: the temperature of the metal cannot be raised above that of the water, and is thus determined by the weight upon the safety-valve. When, from any cause, the metal is not so circumstanced, it becomes unduly heated, and danger may arise from two sources; first, the metal is weakened and rendered less capable of resisting even ordinary pressure; second, it serves as a reservoir of heat ready to bring into existence highly elastic steam, whenever water shall obtain access to it.

16. The first of these positions rests upon the basis of direct experiment, and is, the Committee believe, generally admitted.* Their experiments on the strength of materials have, however, developed a curious fact in regard to the strength of malleable iron, namely, that it slowly increases at first with an increase of temperature, and attains its maximum at a temperature above that at which any of the steam-engines used in practice, are worked. Above this maximum, the decrease of strength is very rapid; so as to be, at a red heat, but about one-sixth of that at ordinary temperatures. Copper, on the contrary, is weakened by any increase of temperature above the lowest, which was tried, namely, 32° Fah. The fact just stated in regard to iron, is interesting in its application to the proof of iron boilers, by the water-press, and as showing the great, and rapidly increasing, danger from diminished strength, as the metal is raised above the temperature of maximum strength.

17. Secondly, the heated metal serves as a reservoir of heat to furnish highly elastic steam, when water is in any way brought in contact with it. That highly heated metal can produce steam, rapidly, has hitherto been a controverted position. In the experiments of Klaproth, successive drops of water thrown into an iron spoon, originally heated to redness, vaporized the more rapidly as the metal lost heat. In the experiments of Perkins and others, larger quantities of water in highly heated metallic

* In the minutes of the Select Committee of the House of Commons there is a statement by Mr. John Steel that cast iron is strongest at the temperature of 300°, but it is not supported by reference to experiment.

vessels, vaporized very slowly. It is true that by injecting water into an iron cylinder, heated to redness, Mr. Perkins found a sudden increase of elasticity; but he attributed the effect to the hot and unsaturated steam which the cylinder contained, and through which the injected water passed.* The Committee found that the temperature of clean iron at which it vaporized drops of water most rapidly was 334° Fah.† The developement of a repulsive force is so rapid above this temperature that drops which required but one second to disappear, at the temperature of maximum vaporization, required 152 seconds when the metal was heated to 395°. One-eighth of an ounce of water introduced into an iron bowl, three-sixteenths of an inch thick, and supplied with heat by an oil bath, at the temperature of 546° Fah., was vaporized in fifteen seconds, while at the initial temperature of 507° Fah., that of most rapid vaporization under these circumstances, it disappeared in thirteen seconds. The cooling effect of the water upon the metal is here strikingly shown, by the increased temperature to which the latter has to be raised at the beginning of the experiment, in order to give the most rapid vaporization. A further illustration of the same kind is afforded by comparing the temperature giving most rapid vaporization, when the metal of the bowl is supplied with heat by a good and a bad conductor, or imperfect circulator, as by a bath of tin and one of oil. With a rough surface, an iron bowl one-quarter of an inch thick, vaporized one-eighth of an ounce of water most rapidly by introducing it when the metal was at 555° Fah., the bowl being in an oil bath; while in a tin bath the corresponding temperature was 508° Fah.

18. By carrying out this idea we have the clue to the action of water thrown, in considerable quantities, upon heated metal; and find, accordingly, that when the water was increased sixteen times, or from one-eighth of an ounce to two ounces, the temperature of most rapid vaporization was raised from 460° to 600° Fah.; the surface of the metal being smooth, and the heat supplied through tin. Now although differences in the mode of applying heat will alter these temperatures, it is clear that they rise, rapidly, with the quantity of water thrown upon the metal. In the case where as much water was thrown into an iron bowl as it could contain without loss by ebullition, the temperature of greatest vaporization, upon a clean surface, was 600° Fah. or about 200 degrees below a red heat, and would, according to analogy, have been higher if on a rough, or oxidated surface.‡

19. These observations explain the direct experiments made by the Committee, in which highly elastic steam was always rapidly produced by injecting water into a boiler heated to bright redness.§ In one case, by the injection of ten ounces of water the elasticity of the steam was raised, in less than two minutes, to upwards of twelve atmospheres, and a miniature explosion produced. The remarks made in this experiment show, that wherever the water slid along the bottom of the boiler the spot of contact was for the instant blackened, by the sudden reduction of temperature, and this under the unfavourable circumstance of the introduction of a limited quantity of water. The bottom of the boiler in these experiments was clean, but not bright. The time required for the generation of

* Franklin Journal, vol. iii. p. 418. Lond. Mechs. Mag. or Journ. Frank. Inst. vol. ix. p. 348.

† Report of Com. on Explosions. Part I. "Vaporization of drops." Reply to Query VI. Journ. Frank. Inst. vol. xvii. p. 90.

‡ Report of Com. on Expl. &c. Reply to Query VI. "Vaporization of increased quantities of water." Journ. Frank. Inst. vol. xvii. p. 160.

§ Ibid. Reply to Query II.

explosive steam under these circumstances does not yet admit of calculation, but this may be affirmed with certainty, that a safety-valve which, under ordinary circumstances, may be adequate to carry off the excess of steam produced in a boiler, will prove wholly insufficient for its escape, in the supposed case.

20. These experiments are entirely supported by well authenticated cases of explosions in steamboat boilers. Mr. Bakewell* gives an instance in the case of the steamboat Grampus, where six cylindrical boilers, each thirty-eight inches in diameter, exploded simultaneously. The engineer had discovered that they contained very little water, and had suddenly thrown in a plentiful supply. When one of the boilers of the steamboat Car of Commerce† exploded, it was well known that the pumps had not furnished the requisite supply of water; and just after an attempt to remedy this difficulty, the head of one of the boilers was thrown off. This boiler was, it seems, differently constructed from the others, with which it was connected, and which did not give way.

The first of these cases is distinctly made out and the second cannot be resolved into a matter of opinion, as may perhaps be done with other accidents, which, though there is a strong probability that they are to be traced to this cause, the Committee refrain from quoting.

21. It is, of course, not assumed that an explosion must necessarily follow the presence of heated metal; for other circumstances must conspire to produce such a result. Facts indeed may be brought to show that, in certain cases, these attendant circumstances have been accidentally wanting, or have been judiciously avoided.

As examples of this, may be taken instances mentioned by Col. Long‡ in which timber on the top of cylindrical boilers has been known to take fire, though considerably remote from any fire-flue. Those to which Mr. Bakewell§ has been an eye witness, when the steam has been so highly heated after leaving the boiler, as still to burn the hempen packing of the steam cylinder, and where wood contiguous to the boiler has been fired. Similar incidents not followed by explosions have occurred in the mines of Cornwall,‖ in one of the Liverpool and Dublin packets.¶ Examples of the second kind will be referred to subsequently.

22. With such a powerful agent present, as the highly elastic steam *which it has been proved may be rapidly generated by the heated metal*, it might have been supposed that no other cause for explosion would have been looked for, than the action of this steam. The case is, however, otherwise, and the Committee must turn aside from their direct course to examine briefly the theory which assigns the production, and subsequent destruction of hydrogen gas, as the cause of the explosion. According to this view, the water thrown upon the heated metal is decomposed, and hydrogen gas evolved; or a similar decomposition of the steam, by the hot metal, takes place. This hydrogen, becoming mixed with oxygen, is ignited by the red hot metal, and an explosion ensues. The diffi-

* Letter to Sec'y. of Treasury, communicated to Com. on Expl. Reply to Circular of Com. No. XII. Also Letter of Thos. J. Haldermann, No. XXI. of Replies.

† Letter of Thos. J. Haldermann, No. XXI. of Replies to Circular, &c.

‡ Replies to Circular, &c. No. II.

§ Replies, &c. No. XII.

‖ Mr. Perkins states on the authority of Mr. Moyle that a ladder accidently resting upon the top of a boiler, was set on fire by heat communicated from thence. Frank. Jour., vol. iii., p. 417, or Lond. Jour. Arts. vol. xiii. p. 95.

¶ Evidence before Com. of House of Commons, 1817. Hazard on Explosions. Frank. Jour. vol. iii. Ewbank on Explosions. Jour. Frank. Inst. vol. x.

culty of furnishing oxygen for the hydrogen to combine with, has lately been met more satisfactorily by Mr. Perkins, than it had been by any preceding theorists. He asserts that air is frequently drawn in by the operation of the forcing pump, and is thus accumulated in the boiler. The primary hypothesis, in regard to the production of hydrogen, having been fully disproved by the experiments of this Committee, there is no necessity for examining the minor ones; it may be well, however, to observe, that if air were introduced into a highly heated boiler, containing hydrogen in too large a quantity either to combine explosively, or silently, with the oxygen of the air, that element would be taken up by the heated metal; and that gases cannot enter, and remain without mixing with the steam, and being carried out with it. In the experiments of the Committee which have been referred to,* water was thrown upon the bottom of a boiler, heated to orange redness, without being decomposed. In fact the scale of oxide existing upon the bottom prevented the decomposition of water, by enfeebling the affinity which would produce it. This boiler was carefully cleaned, and in good working condition; a condition in which no one need be told, a boiler has not a bright metallic surface.

23. Carburetted hydrogen does no doubt exist at times in a boiler, in greater or less quantities, from the decomposition of oil, or of vegetable substances introduced to stop leaks, or to prevent deposites, but nothing warrants the idea that it can accumulate and mix with air, so as to be dangerous.

In furnaces where coal is used as a fuel, it will be seen in the sequel that gas, if prevented from escaping by the closing of a damper, may collect, and may possibly be a source of danger.† The ignition of a mixture of coal gas and air in a furnace has been known to destroy it,‡ as also of a mixture of gas from resinous wood and air; but these are cases altogether foreign from the subject under discussion.§

24. The explosion of the steamboat Enterprise, on the Savannah river, is said to have occurred at the instant the boat was struck by lightning. This has been advanced as confirming the hydrogen hypothesis; but no inference can fairly be drawn from an accident, in regard to which the circumstances are so little known. If there was hydrogen present, there must have been unduly heated metal, and the direct action of electricity on the nonconductors around the boiler, may have so displaced it as to bring water upon the heated metal, and thus to effect an explosion. This, like the other supposition, is mere hypothesis. It is certainly, however, quite as contrary to analogy, that an electric spark should pass through any part of a space, like the interior of a boiler surrounded by a con-

* The reader should refer to these, that he may see the care which was taken in them. A negative result requires so much more caution than a positive one, that more time was devoted to those experiments in order to make them satisfactory than the Committee deemed warranted by the importance of the subject. Report of Com. Explosions, Part I. p. 61, &c. Jour. Frank. Inst. vol. xvii. p. 217.

† Explosion in the Mold mines as given by John Taylor, Esq. Philos. Mag. vol. i.

‡ M. Arago states this to be the fact on the authority of M. Gay Lussac. A furnace was thus destroyed at the Paris arsenal. Annuaire du Bureau des Long. 1830, p. 197, and Jour. Frank. Inst. vol. vi. p. 54.

§ See the case of an explosion of a sheet-iron drum attached to an anthracite stove, with its explanation by Prof. Hare. Jour. Frank. Inst. vol. vi. p. 337. Pine shavings, were used to kindle the fire, the gas, from which mixing with the air in the pipes and drum produced an explosion, when the flame from the kindled shavings rose into it. Refer also to the explosion of the bellows of a smith's forge. Silliman's Jour. vol. xxiv. p. 182.

ductor, and thus explode a mixture of hydrogen and oxygen within it, as that it should shatter this extensive conductor by its direct action. The Committee consider the circumstances of this case as too illy defined to draw any inference from it, certainly not one which is contrary to sound theory, by which they mean general induction from numerous well observed facts.

25. Another case has been urged with much more appearance of directness in the testimony. A boiler in the Union rolling mills at Pittsburgh burst with a tremendous explosion; a cylinder with one of the heads attached, was thrown out of the works, and rising to a considerable height in the air, fell nearly two hundred yards from its former bed. A passenger in a boat which was near at the time, describes a stream of fire, as issuing from behind the boiler, which, according to the hypothesis under discussion, was a stream of burning hydrogen. It is almost needless to remark that if hydrogen had been the cause of the explosion it would not have burned in a stream behind the empty boiler as it rose; the observation is, however, perfectly well explained by Doct. Jones,* by the stream of light which appears to attend every luminous substance moving rapidly, on account of the duration of the impression upon the eye. That the boiler was red hot there appears no doubt.

26. From this digression the Committee return to the pursuit of their subject. They conceive that it has been fully established, that the presence of unduly heated metal is dangerous, both from the weakness of the material, and the possibility of its producing highly elastic steam. They therefore proceed to examine the probable causes leading to this result, and which have been suggested either in the communications made to them or in other documents, and the proposed remedies for, or precautions against, the danger.

27. *First. Unduly heated metal may result from a deficiency of water within a boiler.* This seems to be a frequent and generally acknowledged source of explosion. The forcing-pump, by which a boiler is supplied with water, if at first well regulated, so as to furnish an adequate supply, and if kept constantly in action by the machinery, is subsequently liable to derangement of various kinds. The valves may be put out of order, the passages to or from the pump may be choked by sedimentary, or saline, matter. The pump may in some cases be heated so as to inject steam and not water. Any accident of this sort will cut off the due supply of water, and the level of that within the boiler will be lowered more or less rapidly. This will be true of self-acting as well as of ordinary means of supplying boilers. No one we believe has yet been applied, the working of which can, at all times, be relied on. There are, besides, cases in which the forcing-pump is not in action, when the production and use, or waste, of steam is going forward. In some stationary engines the feeding of the boiler only goes on at intervals, and the due supply is therefore dependant on the attention of the fire-man. The same is true of steamboat boilers when the boat stops at a landing, and indeed the mischief is frequently increased by opening the safety-valve by hand, and allowing the steam, and of course the water, to waste freely. By an approximate calculation† it may be seen that to lower

* Jour. Frank. Inst. vol. iii. pp. 70, 71. "Editor on explosions in Steam Boilers."

† In the case of a cylindrical boiler with an interior furnace and flue, calling l the length of the fire-surface, d the diameter of the furnace, and π the ratio of the circumference of a circle to its diameter, $\pi\, l\, d$ = the extent of fire-surface. Then since in a boiler of this kind 1 sq. foot (144 sq. inches) of fire-surface can convert into steam .356 cub. inches of water, per second; $\pi\, l\, d \times \cdot\frac{356}{144}$ = the number of cubic inches of water vaporized,

the water one inch in a cylindrical boiler with an interior furnace, or in a boiler of the same form where the fire is applied directly to the exterior, and with an interior flue, will require but from five to nine minutes. If by this depression an interior flue of eighteen inches should be laid bare for an inch in depth, between 102 and 103 square inches of surface would be subjected to the action of the fire, for every foot in length of the flue, supposed level.

28. It thus appears that by accident, or in the ordinary management of the steam engine, a deficiency of water may occur, and highly heated metal be produced within a boiler. Recorded instances show that such has frequently been the case.*

29. The metal, then, being softened by heat, may give way to the ordinary working pressure of the steam. This will, of course, depend upon the amount of this pressure, and upon the temperature which the metal has reached. The frequent rupture of boilers near the usual water-line, and in a horizontal plane containing very various thicknesses of metal, would lead us to suspect that this is connected with undue heating, which if all circumstances were equal in the parts of a boiler, would take effect equally, at equal distances from the water-line. But the Committee have not before them any well established instance in which a boiler without interior flues, has exploded merely by the ordinary pressure of the steam, when the boiler had been unduly heated. The case of the explosion of a cylindrical boiler, at the foundry of Mr. McQueen, in New York, may have been an exception to this remark, but the fact of the water having been very low, though rendered probable, is not entirely made out.† The copper boiler exploded in the experiments of the Committee, may be considered, however, as illustrating the possibility of such an occurrence.‡ The explosions in boilers with interior flues, arising from these circumstances, have been found to affect those flues; which "collapse," that is, are crushed, and rent, and are frequently separated from the boiler. The case of the accident on board the steamboat Patriot, which occurred near

per second. Again if we denote by x, the depression of the water level in one second, c the breadth of the water-line, and assume the length of the boiler to be equal to that of the interior cylinder, $x\,c\,l$ will be an approximate value for the quantity of water vaporized. Equating the two values found, and cancelling l, we have $\pi\,d \times \cdot\frac{3\,5\,6}{1\,4\,4} = x\,c$. The depth of water may be assumed at two-thirds the diameter of the exterior cylinder, which, calling D that diameter, gives $c = .98$ D, and $\pi\,d \times \cdot\frac{3\,5\,6}{1\,4\,4} = .98\,x$ D. The ratio of d to D in a number of cases in practice varies from .4 to .6 and even .7; taking the lower limit or $d = .4$ D, we have $.4\,\pi$ D $\times \cdot\frac{3\,5\,6}{1\,4\,4} = .98\,x$ D. Whence $x = .003$ inches per second. Or to lower the level one inch would require 5 mins. 16 secs., supposing the water not to reach the interior flue.

For a cylinder with an interior flue, but where the fire is applied externally, supposing the effective fire-surface to be half that of the boiler, the depression per second, will not be less than two-thousandths of an inch.

* As instances, may be taken, the boiler of the steamboat Huntress, No. VII. Replies, &c. of the Western Engineer, No. II. Replies, &c. Legislator, Eagle, and Massachusetts, No. XVII. Replies, &c. Explosions at Pittsburg, No. XII. Replies, &c. and Jour. Frank. Inst. vol. iii. p. 70.

† Thomas Ewbank "On the Explosion of Steam-Boilers," Jour. Frank. Inst. vol x. p. 3. That the pressure was unusually great, is satisfactorily shown; and with or without undue heating, was, no doubt, the cause of the explosion. In the case of the Etna, the boiler was unduly heated, but, whether it gave way to the pressure, ascertained from the working of the engine, to be lower than usual, or whether water had access to the hot metal, is not known.

‡ Report of the Committee on Explosions, Part I. p. 68. Jour. Frank. Inst. vol. xvii. p. 225.

the mouth of the river Ohio, in 1828, distinctly illustrates this point.* It is stated that the engine was kept in motion after it was known that the water was below the flues; an act of temerity which was followed by the collapse of one of the flues.

30. It is highly probable, as will be seen hereafter, that water is thrown upon the hot metal, in cases where the engine has just been set in motion, or when the safety-valve has been opened, just prior to an explosion, and hence we are not warranted in adducing such cases here.

31. The following, is a well authenticated instance in which the pressure was not sufficient to produce explosion, or in which the metal was cooled by its change of figure, but when the danger was obviously imminent. It was that of the boiler of the steamboat Legislator,† of which an oval flue was flattened by exposure to the steam pressure, when known to be unduly heated. An explosion was avoided by the fire being put out, as soon as the deficiency of water was ascertained.

32. The Committee next proceed to consider the means which have been pointed out, by which, in the event of an undue heating of a boiler, water may obtain access to the heated metal.

Various means by which water may be brought into contact with heated metal, have been suggested. This may occur by the intentional or accidental removal of an obstruction, or by some other repair, to a forcing-pump,‡ or by the injection of water by a hand-pump.§ When it is recollected that one cubic inch of water will produce six hundred and twenty-one cubic inches of steam of three atmospheres, or one hundred and eighty-nine inches of steam of eleven atmospheres, and that this steam is produced far more rapidly than in the usual action of the boiler, we are at no loss to understand that an ordinary safety-valve cannot give vent to it. The explosions on board of the steamboats Grampus, Constitution, &c., should serve as warnings against the introduction of water into a boiler under such circumstances, and the course taken by the engineer of the Legislator as an example to be followed. In this latter case there can be no doubt, from the circumstances stated by Mr. Lester,‖ that an explosion was prevented by cooling the boilers previous to the introduction of water, when the deficiency was discovered. No circumstance of mere convenience, should be suffered to interfere with such a course.

33. A second mean assigned for bringing water in contact with unduly heated, metal, in a boiler is by the foaming produced by the opening of a safety-valve, or in the ordinary working of the engine. This foaming has been abundantly demonstrated, and a detailed statement of the direct experiments made on the subject by this Committee, may be seen in their report to the Secretary of the Treasury of the United States.¶ Since the foaming is

* Replies to Circular, &c. No. XXI. Thomas J. Haldermann, Esq. The explosion on board the Tricolour might be cited as another example. The boat was at rest. No. XXI. Replies, &c.

† Replies to Circular, No. XVII. E. A. Lester, Esq. of Boston.

‡ In the case of the boilers of the Car of Commerce, (No. VII. Replies, &c.) of the Grampus, (No. XII. Replies, &c.,) &c.

§ See explosion of a boiler at Aston Forge, (No. XI. of Replies, &c.) Boiler of the steamboat Constitution, (No. VIII. of Replies, &c.,) &c.

‖ See replies to Circular of Com. on Explosions, No. XVII. Letter of E. A. Lester, Esq., to Sec. of Treasury.

¶ Reply to query first. "To ascertain, by direct experiment, whether on relieving water heated to, or above, the boiling point, from pressure, any commotion is produced in the fluid." See also a paper by Mr. F. Peale, whose observations were contemporaneous

caused by making an opening in the boiler, it may be supposed that it cannot be adequate to do more than to produce steam to supply the place of that which escapes. This view of the subject derives some support from the experiments incidentally made by M. Arago,* and directly with this object by the Committee, but is contradicted by those of M. M. Tabareau and Rey.† In the experiments of M. Arago, the boilers were not unduly heated, in those of the Committee, there was present a considerable amount of heated metal, and in those last referred to, and in which an increase in the elasticity of the steam was produced by opening a safety-valve upon a small boiler, the boiler was surrounded by a charcoal fire. There can be little doubt, then, that the result must depend upon the precise circumstances of the case, and that danger *may* result, though it does not *necessarily* follow, from making an opening in a boiler when the water is low. This effect from foaming would be increased, if, in addition to the agitation produced by the first working of the engine, after stopping, the safety-valve should be opened. This was the common practice on the Hudson, a few years since; the safety-valve being opened, by hand, on putting the boat in motion after the landing or taking up of passengers.

34. The successive explosions of connected boilers such as occurred at the Polgooth‡ mines, and on board the steamboat Rhone,§ are easily explained if referred to the effect of foaming, and difficult to understand on any other principle, since just before the explosion of the second boiler a large opening was made for the escape of steam.‖

35. It has been assumed by our countryman Perkins, in his hypothesis on the subject of the explosion of steam-boilers, that the hot steam formed by contact with unduly heated metal is the true source of danger. This opinion has been shown to be inconsistent with the deductions from sound theory.¶ The injection of water into hot and unsaturated steam, should reduce, not increase, its elasticity. With a view to ascertain if any circumstances had been omitted in the application of theory to this problem, the Committee made direct experiments on the subject. The water was introduced both in a full stream, and through small apertures. In no case, an increase, and in all but one a perceptible decrease of elasticity in the hot and unsaturated steam, was observed. Fourteen ounces of water, injected into steam at 533° reduced its pressure .34 of an atmosphere.** The steam had in this experiment a temperature corresponding to the

with the experiments of the Com. Journ. Frank. Inst., vol. viii. p. 145, and Replies, &c. No. XXI. Potts on Explosions, Jour. Frank. Inst. vol. vi. p. 327.

* M. Arago. Sur les explosions, &c. Annuaire du Bureau des Long., 1830, pp. 148, and 180, and Jour. Frank. Inst., vol. v., p. 404, and vol. vi., p. 47.

† Ibid.

‡ J. Taylor, Esq. "On the accidents incident to Steam Boilers." Lond. Philos. Mag. vol. i., 1827.

§ Annuaire du Bureau des Long., 1830., and Jour. Frank. Inst. vol. v. p. 401.

‖ The same opinion is expressed by M. Arago, Annuaire, &c. p. 184. Translated in Jour. Frank. Inst., vol. vi., p. 49. The other cases referred to by him, in which an explosion followed the opening of a stop-cock by hand, as at Lyons, or of a safety-valve by the steam, as at Essone, may be explained by supposing the openings insufficient to give vent to the steam, which was produced by the action of the boiler, in the circumstances then existing.

¶ Dulong. Annales de Chim. et de Phys., vol. xlviii.

** In a certain theoretical case, namely, that in which all the heat to vaporize the injected water, is derived from the hot steam, and the quantity of water which that steam can vaporize, without reduction of temperature below that of saturated vapour of the same elasticity, is injected, the precise reduction of elasticity has been calculated by M. Dulong. See Ann. de Chim. et de Phys., vol. xlviii., p. 378.

pressure of sixty atmospheres,* and an actual elasticity of only 6.82 atmospheres. There was besides a fire which supplied heat, as it was absorbed by the vaporization of the injected water.

36. A correspondent has suggested† that when a steamboat is first set in motion, the inertia of the water may cause it to rise at one end of the boiler and then to oscillate, by which it would be thrown upon parts of the boiler which might be unduly heated. This is no doubt a true cause, but it would be difficult to say to what extent it would be effective. The subsequent suggestion that water can take a charge of heat in a latent state, which may be rendered free by mechanical means, the Committee do not conceive to be valid. Experiments which have been referred to as showing this, are fully explicable upon well established principles.

37. There are two other important circumstances to be examined falling under this division of the subject, namely, the effect of the careening of a boat especially one having connected boilers, and the effects of the sudden cracking of deposits of mud or sediment, beneath which the metal is unduly heated. These will, however, be treated under separate heads.

38. The Committee now proceed to examine *the means proposed for preventing the occurrence of the dangerous circumstances now under discussion.* These of course have reference mainly to the original source of the danger, that is to the deficiency of water within the boiler, though an avoidance of the secondary causes might prove effectual.

39. First.—Various self-regulating apparatus for the supply of boilers have been proposed and partially used. Second.—Methods for ascertaining the level of the water or of giving notice when it falls to a certain level are in use, or have been suggested. Third.—Some methods for ascertaing the temperature of the boiler or of particular parts of it, have been contrived.

40. 1st. One of the most common methods of regulating the supply of water to a boiler is by the use of the float. This is understood to have been entirely successful in the low-pressure boiler, the float being applied to raise a valve connecting a reservoir of water with the boiler to be supplied. A self-feeding apparatus in which a float was used was proposed by Mr. Charles Potts,‡ who exhibited to the Franklin Institute a very neat working model, in which a glass boiler was kept at nearly a constant level, by this method. Its application is most difficult in the case of a small high-pressure boiler with interior flues.

Engineers differ very much in the amount of confidence which is to be placed in the float: those who have seen it in operation in the large boiler of a low-pressure engine give it implicit confidence, others who have tried it in the small high-pressure boiler consider its action too uncertain to answer a good purpose,§ even when in its best form. If the objections to the float are not valid, and we apprehend that they are only partially so, the real difficulty will be found to lie in general objections to all self-regulating apparatus. This obviously is one which is liable to get out of order since it communicates between the exterior and interior of a boiler and hence must have a packed joint, liable when the stem is not in con-

* Calculated from the formula deduced by M. M. Arago and Dulong from their experiments.

† Replies to Circular of Com. on Explosions, No. XX.

‡ Journal of the Franklin Institute, vol. vi. p. 42, and also p. 327, &c., where the apparatus is illustrated by a figure.

§ D. J. Burr on the explosion of steam-boilers. Jour. Frank. Inst., vol. vi. p. 335. Mr. Redfield objects to its use in steam boat boilers, see Report to Secy. Treas. U. S. in Doc. H. R., No. 478. session 1831—2.

stant motion to become tight, and therefore beyond the power of the change of buoyancy in the float to move.

41. A most ingenious method of feeding boilers was patented in 1825 by Mr. Eve.* It consisted of a revolving cock, bored in part through, and playing alternately into the boiler, and into a box of water. It was expected that this cock being placed at the proper level of the water within a boiler, would merely draw out and return water while this was at a due height, but when it sunk too low would draw out steam and return water. The difficulty of condensing the high steam† drawn out; and of making the returned water flow out of the openings, seem to have rendered this as well as other promising schemes of the same sort, abortive.‡ An attempt to obviate these objections which was seen by some of the members of this committee was unsuccessful. Mr. Charles Potts§ has recently proposed a plan which is similar in principle. It will have to encounter the difficulty of the flow of water from moderately large openings when the pressure on the two ends of the column is the same, and the necessity for the alternate heating and cooling of the revolving plug or chamber which acts as a feeder, and of at least a part of its contents. They agree entirely, however, with the Committee of Science and the Arts that this principle merits further trial.‖

42. The Committee are decidedly of opinion that no self-feeding apparatus has been, or is likely to be, invented which can be a substitute for the care of an engineer; and, indeed, they consider the carelessness which is liable to result from their use as a very serious, though not an insuperable objection, to them.

43. 2nd. Methods for ascertaining the level of the water in a boiler, or of giving notice when it falls to a certain level.

The imperfection of the gauge-cocks in ordinary use has been often pointed out, and indeed is generally admitted. Originating in the very infancy of the art in Savery's engine, they remain at this day, a stain upon its more mature age. At best,¶ when the water is tranquil within a boiler they only show, roughly, the position of the water-line; and when it is above the highest cock, or below the lowest, they fail entirely; and cannot be placed far apart without making their indications within these limits, too rude even for practice. When a boiler is in action, particularly if it is small and contains high-pressure steam, the foaming is so considerable as to interfere with their use. In the report of experiments by this Committee abundant evidence is to be found of this imperfection; as an example of which may be taken the case, where by raising the safety-valve, of the small experimental boiler, indications of water appeared at a gauge-cock, below which the hydrostatic level was known to be nearly two inches.**

* Lond. Jour. of Arts. vol. xii. p. 230., Lond. Mechs. Mag. vol. vi. p. 344., Rep. Pat. Invent. vol. iii. p. 70. A revolving wheel for the same purpose has been patented by Mr. Jesse Fox. Jour. Frank. Inst.Vol. x. p. 161.

† See also J. S. Williams' patent for supplying boilers with water. Jour. Frank. Inst. vol. vii. p. 183, which though different in action is liable to this objection, in even greater force.

‡ Walker's feeding plug. Trans. Soc. Arts, &c. vol. l. part i, p. 63. Sliding valve and box. Lond. Mechs. Mag. vol. xxi. p. 376.

§ Journal of the Franklin Institute, May 1836. Vol. xvii. p. 302.

‖ Report on a "Plan of a new pump for feeding Steam boilers." Jour. Frank. Inst. Vol. xviii. p. iii, 1836.

¶ From the remarks which follow, exclusive of the objection on the score of the effect of foaming, we must except the shifting gauge-cock of Mr. Philos. Tyler described in Jour. Frank. Inst. vol. xv. p. 178.

** Report of Com. on Explosions, Part I. pp. 11, 12. &c. Journ. Frank. Inst., vol. xvii. pp. 9, 10. Peale on the height of water in boilers of locomotives, Jour. Frank. Inst., vol. viii. and replies No. XXI. Potts on explosions. Journ. Frank. Inst. vol. vi. p. 329.

44. The method of indicating the level of the water by a float* is liable to all the objections urged against the feeding apparatus, depending for its action upon that instrument. It has not, however, except in very rare cases, been used in this country. An alarm float was tried by the Committee, which is not subject to the objection in regard to the stuffing-box, since it is entirely within the boiler. This is by no means a new device,† though the particular arrangement was made by Mr. D. H. Mason for the Committee; and is figured and described in the first part of their report.‡ This device is intended to allow the escape of a small jet of steam whenever the water rises above, or falls below, a determinate level.§ The alarm by the issue of steam through a trumpet tube, being only applicable to engines working at very low pressures, does not require special notice here.

45. With due care on the part of the Engineer, and the Committee are of opinion that no substitute has yet been found for such care, the glass tube affords the best means known to us, for observing the level of the water within a boiler. It seems strange that this excellent device which has stood the test both of experiment and of practice, has met with so limited a degree of favour. In the great progress made, of late years, in the locomotive engine, it has been so clearly shown, that engineers and their assistants, can be induced to employ any machinery, the use of which is insisted upon, that the excuse of their indisposition to change, should not be urged any longer. In this very case, in which the glass tube, is probably more exposed to fracture, than in any other, it is practically used. The objection on the score of its breaking by unequal expansion and contraction of the glass, and of the metal with which it is connected, has been obviated, by passing the ends of the tube into stuffing-boxes; that on the score of its breaking by shocks, by giving it great thickness; and that of its breaking by sudden variations of temperature by using well annealed glass. The difficulty of the glass clouding when high steam is used, by the action of the steam on the alkali, is got rid of by using green glass. The experiments which the Committee made on this apparatus, were highly satisfactory and they confidently recommend its use to practical men.‖

46. 3rd. The danger resulting from a deficient supply of water, being produced by the undue heating of parts of a boiler, many means have been proposed for showing such an increase of temperature, before it attains a dangerous degree. The fusible plates applied to the top of the boiler may be intended to indicate the general temperature of the steam when saturated with moisture or not, or the local temperature resulting from the rising of hot and unsaturated steam, produced by unduly heated metal.

* The hydrostat described in No. XXX. of replies is inadmissible, from the interior of the boiler being occupied by a second cylinder leaving only an annular space for the production of steam. For the alarm floats of J. L. Sullivan, Esq., see Silliman's Journal, vol. xx. p. 1.

† See the alarm float of Siebe. Lond. Journ. Arts. vol. xiii. p. 273. The first of those known to the Committee.

‡ Report p. p. 14. 15. Plate 4. Fig. A. Journ. Frank. Inst. vol. xvii. pp. 13, 14.

§ It is exposed to a slight objection from steam pressure acting to keep the disks upon the openings, these latter are, however, quite small, and the pressing surfaces of the disks may be regulated accordingly.

The float described by Mr. Ewbank, Jour. Frank. Inst. vol. x. p. 7, is also referred to by the Committee as deserving a full trial.

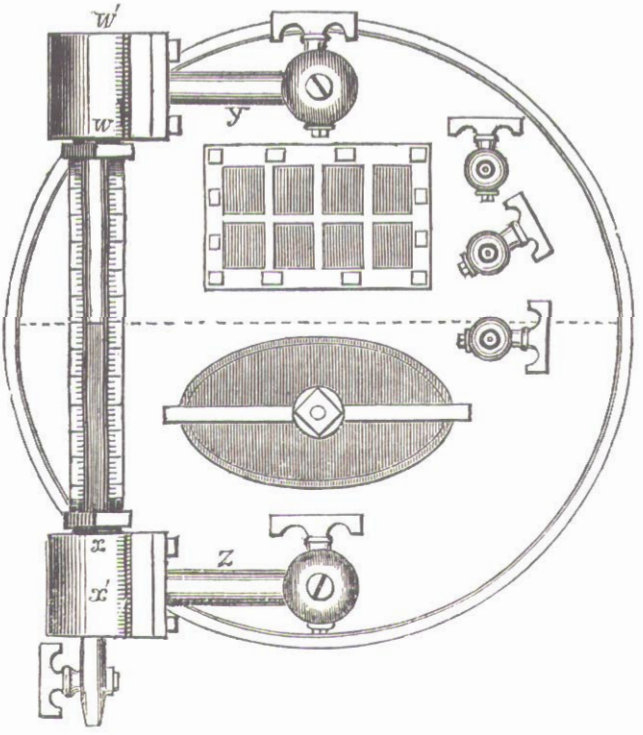
‖ The following description of the tube water gauge used by the Committee is taken from the first part of their report, p. 12, &c. (Jour. Frank. Inst. vol. xvii. p. 10).

"The tube gauge is shown in the annexed figure. *w x* is a tube of green glass

In any case they will be exposed to pressure; though to less in the second case than in the first. The objections already urged, and derived from experiment, will apply to their use, in the ordinary way, in any one of these cases. Indeed without this objection, it appears that as the source of danger is the heated metal, to this the indicator of temperature should be applied.

47. Various methods of indicating the temperature of a part or parts of a boiler have been contrived. One of the most simple is to apply the common thermometer, inserting the bulb and as much of the stem as is necessary, in a tube closed at one end and fastened into the boiler. The tube should contain mercury, through which the heat is conducted to the thermometer. Such a tube may be placed at or near the water line of a boiler, at the fire end of a flue, or in general at the place of greatest exposure to heat from a deficiency of water, of which there will usually be one or more well determined, according to the form of the boiler. A mark upon the scale of the thermometer will show the temperature above which the metal must not be allowed to rise, either from an increased elastic force in the steam, or from a deficient supply of water. The fragility of the

passing into the stuffing boxes, w' x'; the stuffing enables an adjustment to be made for the unequal expansion of the glass and metal by heat, and prevents fracture on the subsequent cooling of the apparatus. y and z, are pipes connecting the tube with the boiler; these have conical terminations, by which the pipes are readily attached to, and detached



from, the tubes connecting them with the boiler, which are provided with stop-cocks: coupling screws might, in practice, be substituted for these conical terminations. To protect the tube, w x, from currents of air, it was surrounded by a second tube, loosely applied. A scale was attached to w x, to indicate the level of the water within the boiler.

instrument, its inconvenient length, or position in certain cases, and its not acting as an alarm, are the principal objections to its use.*

48. The expanding rods proposed by Mr. Cadwallader Evans are ingenious; they give, however, not the local temperature of the boiler, but its general temperature, along the lines to which the rods are applied. A much more appropriate device, is the application of fusible metal proposed by the same gentleman.† This is intended to take the place of the ordinary fusible plate, and to avoid the difficulty, originally existing, but since remedied‡, of replacing the plate when it had fused. In the apparatus submitted to the Committee§ by their chairman, and subsequently made the object of experiment, the fusible metal is applied to the most exposed part of a boiler: it is so small in quantity, that it will serve to indicate a local temperature, while the motion which indicates its fusion is independent of the quantity of the fusible metal. These instruments are intended, respectively, to give notice when the steam or the metal of the boiler is exposed to a temperature, much below that which would produce danger. Both of them, after giving an alarm, can be immediately restored to action if the temperature within has been made to decrease.‖

* For a detailed description of the mode of applying the thermometer see the report of Com. on Expl. Part. I. pages 7 and 8, and Jour. Frank. Inst. vol. xvii. pp. 5, 6.

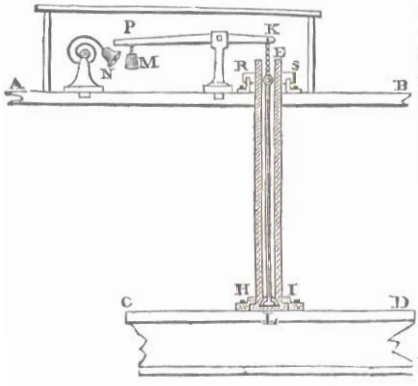
† Communication to Com. on Explosion, No. XXII. of Replies &c. Jour. Frank. Inst. vol. ix. February 1832. Patented in May 1834. See Specification in Jour. Frank. Inst. vol. xiv. p. 391. The Committee prefer this to the apparatus acting by the expansion of mercury.

‡ Hall's method of applying the fusible plate. Bulletin de la Soc. d'Encouragement, &c.

§ Described in Jour. Frank. Inst. vol. x. p. 217.

‖ The apparatus devised by the Chairman of this Committee, was made the subject of experiments, and, with them, is thus described in Part I. of the Report of Com. on Expl. It is obviously as applicable to a common boiler, as to one with interior flues.

"A tube of iron, or copper," according to the material of the boiler, "closed at the lower end, passes through the top of the boiler, its closed end reaching the flue to which it is attached." "This tube, it will be observed, affords a ready access to the flue, to ascertain its temperature, without any restraint from packing." "A mass of fusible metal placed at the bottom of the tube," "will become fluid very nearly as soon as the flue takes the temperature of fusion of the alloy." "To show when the metal at the bottom of the tube becomes fluid, a stem is attached with a cord and weight," "or with a lever and weight." "The weight and longer arm of the lever, descending, may be made to ring a bell, or, by appropriate attachments, to turn a cock, permitting just enough steam to issue to give the alarm, and then to be closed at once. A projection on the lower end of the rod prevents it from being drawn from the metal until this latter is fused, and by widening the lower part of the tube, making it slightly tapering, the metal is kept from being drawn out by the rod."



In the annexed figure "AB is a section through the top of the boiler; CD, a corresponding section of its flue, EH represents a tube closed at the lower end, which is attached to the upper side of the flue. The mode of attachment by a projection on the tube and a ring screwed to the flue, is shown in the figure, as also the stuffing-box, RS, through which the upper end of the tube passes. The lower part HI, of the tube, is made tapering, to retain the fusible metal. KL is the stem, the lower part being inclosed by the fusible metal, the upper part attached by a chain to a lever KP. The weight M, draws the rod KL upwards, and on the fusion of the alloy HI, carries the lever below the bell N, which, being attached to a spring, rings an alarm."

By very simple changes in the apparatus, the fusible metal might be applied to the boilers of locomotive engines.

49. *Second.—The undue heating of parts of a boiler may be produced by deposites.*

No cause of undue heating is better made out, than this one, and the remedy is of the most simple kind.

The water of all rivers contains, in suspension, in greater or less quantities, the muddy particles detached from their banks or beds, and may contain in solution, salts derived from the same sources, or from the springs which supply the stream. The water of springs generally contains so large

The form of this apparatus, which was subjected to trial by the Committee, was essentially the same with that described. One of the tubes in which the thermometers were ordinarily placed, was used to contain the fusible metal, and as giving the more severe test, the short one entering only into the steam, was selected. For the convenience of removing the metal, it was placed in a metallic case, fitting loosely into the iron tube, and having a wire attached, by which it could be drawn out of the tube. This certainly diminished the sensibility of the apparatus, particularly, as the case was quite as thick as the inclosing tube, and as there was a small space between its convex surface and that of the tube; it was required, however, for the convenience of the experiments.

The results of the several trials are contained in the following table. The temperature was registered by the adjoining thermometer dipping into the water of the boiler, and already often referred to; it was raised as rapidly as possible in all the experiments except the first. The first four trials were made on an occasion specially devoted to this purpose, the last two were made incidentally when upon another subject.

Number of trial.	Temperature. Fah°.	Remarks.
1	268	Stem rises. No particular attention paid to raising the temperature rapidly.
2	270	Stem rises. Steam raised rapidly.
3		Metal drawn out and suffered to cool, re-deposited cold in tube. Steam at 258°, and raised to 274° in 2½ minutes.
	274	Stem rises.
4		Metal drawn out and cooled. Steam at 250°, when metal was replaced. Steam raised to 274° in 3 minutes.
	274	Stem rises.
	252	Metal had not become solid again. Steam let off rapidly.
5	270	Melted below this temperature.
6	256	Stem rises. Metal remains a soft solid, so that the stem can be drawn out, until 240°.

A fact noticed during the experiments on fusible alloys was again verified in these; namely, that the mixtures of metals require a considerable time to change their state of solidity or of fluidity, so that in the former case they may be raised, if heated rapidly above the true temperature of fluidity, and in the latter case they may be cooled much below this temperature, without solidifying. The alloy used in these experiments, appears to have put the apparatus very fully upon its trial in his respect, and the experiments were performed so rapidly as to give a further severe test. On the occasion devoted to the trials when the steam was not urged up with its greatest rapidity, the stem was drawn out at 268° when more rapidly at 270°, and with the fire at its maximum intensity, when the water was raised in temperature 24° in three minutes, the stem was drawn out at 274°. In other experiments it gave way at 256°. The range is 18° Fah., corresponding at ten atmospheres, to less than two atmospheres, under the test of very severe comparisons. There appears no reason to doubt, that when tested by no more rigid modes than practice would furnish, this apparatus would not only apply as an alarm to prevent undue heating of the parts of the boiler, but as a manageable, and useful check, in ordinary cases, upon the safety-valve Report &c., Part I. and Jour. Frank. Inst. vol. xvii. p. 85.

an impregnation of saline matter, as to decompose soap. The rivers of our Atlantic States, where perfectly fresh, contain few dissolved impurities, while many of those of the Western States are highly charged with calcareous matter. When waters holding substances in suspension or solution, are evaporated, a sediment is deposited, varying in nature with the water employed. As the quantity of solid matter contained in the water varies, so the time required for such a deposite to take place, from the feeding water of a steam-boiler, must be very variable. If a deposite is allowed to remain in a boiler, it gradually increases in thickness and in density; the heat which before passed rapidly from the metal to the water, is now impeded by a mass of viscid or of solid matter, which is a bad circulator or conductor of heat, and the temperature of the metal rises. The sediment thus heated increases in denseness, and may even form a hard crust upon the bottom of the boiler. A complete non-conducting coat is thus formed, which if from its nature liable to crack or fissure, may allow water to have access to the heated metal below, and produce an explosion. This supposition is, however, as will be seen by no means necessary to such a result. The most usual action of the sediment would seem to be as follows. When it has accumulated in thickness, sufficiently to produce a temperature in the metal, at which its strength is inadequate to bear the pressure without extending, it yields, and becoming more and more attenuated, finally bursts. It seems that the first yielding may bring water in contact with the metal so as to cool it, when the steam produced is not sufficient materially to increase the pressure within the boiler. Thus the attenuation may increase for a considerable time and gradually, and at last the bursting not produce any more injurious effect than to stop the working of the engine.

Accidental circumstances of figure, heat &c., seem frequently to determine the places of deposite of these masses of sediment, but it is principally observed at the fire-end of the boiler, where its presence is most dangerous.

50. The Committee have derived much information of a practical kind on this subject, and coming as it does from entirely different quarters of the country, where the water depositing the sediment was of different qualities, the details agree very remarkably.

Col. S. H. Long* describes a deposite found in one of the boilers of the Western Engineer, a boat used in the exploring expedition of 1818. The sediment had collected in less than two days so as to be two inches thick, and was found in parts of the boiler, where from its construction, the heat was greatest. A difficulty in making steam enough for the supply of the engine, was observed, and induced an examination of the boilers, in one of which, the metal at a particular spot was found to have been made to project an inch and a half. In this case timely precaution prevented further evil consequences.

51. The plan of "blowing off" the lower parts of the fluid in a boiler, which is very generally used in turbid streams to the West, is, no doubt, of considerable service while the boat is running, but should never be used as a substitute for cleaning the boilers, when opportunity is afforded for this complete operation. Indeed it must be carefully executed, since if the flues are bared by it, any deposite upon them may become hardened before the boiler is replenished with water.

52. A practical Engineer of New Albany, Indiana, Mr. Benton,† states

* Replies to Circular of Com. on Expl. No. II.

† Reply to Circular of Com. on. Expl., by Erasmus W. Benton, No. VIII.

that he has found deposites in boilers, used on our Western waters, "almost as hard as the iron itself." These consist of a mixture of calcareous matter with the ordinary mud of the rivers.

The very consistent and satisfactory accounts given of the explosion of a boiler of the steamboat Caledonia, on the Mississippi, show that the disaster had its origin, at least in part, in the deposite within the boiler. The boat had eight connected cylinder boilers of wrought iron, for high steam, thirty inches in diameter and twenty feet long, with interior flues. The engine had been in operation for seven consecutive days, prior to the accident, and had, just before its occurrence, been stopped for about eight hours, to repair the machinery. During the time of stopping, the boilers were not blown out, and two hours after resuming the working of the engine the explosion occurred. On subsequent examination, it was found to have occurred in a patch, which had been put on the year before with *copper* rivets; the sediment on the bottom of the boiler was found to have been heated, so as to render it very hard. The rent began at about one third of the diameter of the boiler from the bottom, that is, at or near the fire line, and passed upwards. The sediment had caused the heating of the copper rivets, and, it is probable, that the working pressure of the steam accomplished the rest.

53. The effect of a deposite of a different kind, in a boiler, near Richmond, Virginia, is well described by Mr. Burr.* The boiler was of wrought iron, five-sixteenths of an inch thick; the water used for its supply was a chalybeate, but not so strong as to prevent its common use, as a beverage, by the workmen. A few weeks after the engine had been put in operation, a crack was observed in the boiler, just over the fire, and on examination, a deposite of oxide of iron was found in this place. The fire-end is stated to have been lowest in the setting of the boiler. A plate of wrought iron was substituted for that which had cracked. In four or five weeks a swelling began to form upon this plate, which continued to increase until it attained a considerable size, and in ten days from the first on which the protuberance had been observed, the boiler burst. No great damage was done. The iron was found to have been diminished in thickness, at the spot where the rent occurred, to one-eighth of an inch.

54. The deposites in boilers using salt water are no less dangerous. Mr. Lester† gives an account of the case of the boilers in the steamboat Eagle, of Boston, which leaked after being in use two or three weeks, and on examination were found to contain a deposite of from two to three inches thick, and which, in some parts, was so hard as to require the use of a hammer and chisel to remove it.‡

55. Various other cases are on record of the effects of deposites in boilers, but the characteristic ones which have been selected convey all the information necessary. They show that no rule as to the time of cleansing a boiler can be general, and fully enforce the necessity for care upon this point. Farinaceous substances introduced into a boiler may tend to ren-

* Jour. Frank. Inst., vol. vi. p. 334.

† Letter to Sec. Treas. U. S. Replies to Com. on Expl., No. XVII. See also Jour. Frank. Inst., vol. vii. p. 289, &c.

‡ In a letter to the editor of the Jour. Frank. Inst., a gentleman of Boston, states that in a boiler using salt water, a deposite of more than two inches in thickness occurred in less than twenty days. Mr. West states that deposites, chiefly of sulphate of lime, occur in from one to six weeks of use, in the boilers at Manchester. See Jour. Royal Institution, vol. i. p. 42. See also F. Naested's letter to Sec. Treas. U. S., Doc. H. Rep. U.S., 1832–3, No. 478, p. 52.

der frequent cleansing less necessary in cases of sedimentary matter, but cannot dispense with it.* Sound economy, as well as safety, require frequent cleansing of a boiler using hard or muddy water. The least that can happen, after the accumulation of sediment, is the injury of the boiler, perhaps its bursting, and a true explosion may result. Two violent explosions, at Bowen's mill,† and at McMickle's mill in Pittsburgh, are fairly attributable to the effect of sediment, and there does not appear in either case to have been a deficiency of water at the time of the explosion.

56. The accidental introduction of materials which are bad conductors of heat within a boiler may produce the same effect as the deposites just described. Mr. Benton‡ suggests that loose packing from the steam cylinder is sometimes passed through the force-pump and collecting under the flues, causes them to be highly heated. M. Arago mentions an instance of a rent made in a boiler, at Paris,§ by the accidental resting of a rag on the bottom of the boiler.

57. Frequent cleansing of the boiler or blowing out the lowest portions by small quantities at a time, are the true preventives to accidents from deposites. Besides them, however, the use of chemical reagents has been proposed for limestone water, and filtering in the case of muddy water. The former of these would prove but a partial remedy, and in unskilful hands would be dangerous, and the latter would probably be objected to on the score of its considerable expense. When the escape steam is allowed to run to waste this would be especially the case.

58. It has been also proposed to use boxes for collecting the sediment, but from them the committee would not anticipate any very good result, though they might in part facilitate the cleansing of a boiler.

59. *Third.—The careening of a steamboat may expose parts of the boiler to heat without their being covered by water, and a subsequent return to its level will bring water in contact with the heated metal.*

There is no evidence known to the Committee that the careening of a boat has ever produced accident in any other than the small connected cylinder boilers, so extensively used in the boats navigating the Western waters. In these, the danger has been forcibly pointed out by several correspondents,‖ and means of remedying it suggested.¶ These boilers communicate by pipes below the ordinary water level, and are supplied by the same forcing-pump. The fire is most generally applied to the exterior of

* It was stated on the authority of Sig. Ferrari, that coarse charcoal prevents or removes deposites in boilers. (Jour. Frank. Inst. vol. ix. p. 420.) The Society of Arts of London awarded in 1833, a premium to Mr. Jas. Bedford for rendering deposites readily removeable by introducing sperm oil into the boiler. We are not aware to what extent this device has been tried. (Trans. Soc. Arts. vol. xlix. Part II. p. 88.) The use of grease for the same purpose is recommended in the Lond. Mechs. Mag. vol. vi. p. 308. and in the same journal (Vol. ii, p. 206.) it is stated that the radicles of barley produced in the process of malting prevent deposites. These act on the same principle as the fecula of potatoes. They merely retard the formation of a deposite, and by rendering the fluid viscid, no donbt ultimately affect the generation of steam.

† Replies to Circular, &c. No. XII. Letter of Thos. W. Bakewell, Esq. to Sec. Treas. U. S,

‡ Replies, &c. No. VIII.

§ Used in producing steam to heat the exchange.

‖ The first communication made to the Committee on this subject was by James J. Rush, Esq. of the firm of Rush and Muhlenberg; by some accident the drawings presented by him were not deposited among the papers of the Committee, and a similar diagram to that of Mr. Rush being afterwards presented by Mr. C. Evans was published among the replies to the Circular of the Com., No. XXII.

¶ Replies to Circular, &c. No. XXII. Earle on Explosions, Journ. Frank. Inst. vol. vii. p. 154.

the boilers, and they have besides interior flues. Being placed side by side, the length of the boiler being parallel to the keel of the boat, they occupy according to their size and number a more or less considerable portion of its breadth. The six contiguous boilers of the steamboat Helen McGregor, and the eight of the Caledonia occupied certainly not less than twenty two feet in breadth of the boat. Calculating upon the dimensions of the boilers in the first named boat, and taking into view the circumstances under which the water has access to the heated metal, we find that a depression of nine inches, at the extreme boiler, taking place about the axis of the set of boilers, would expose a surface of boiler and flue together competent to supply, when the water returned upon them, one-third more steam than the ordinary working of the boiler could furnish: this supply being kept up, at an average, during the cooling of the elevated boilers to their ordinary working temperature. This danger might easily be met by an increased area of safety-valve if indeed those commonly used would be insufficient, for the escape of the extra steam.* But the danger from even the working pressure acting upon the metal of which the tenacity has been much decreased, is the real source of danger, and is not thus to be parried. There are but about 440 degrees of Fahrenheit's scale between the working pressure of eleven atmospheres, and a red heat visible in the dark.

This careening of the boat is liable to occur at every landing-place and to last for a considerable time. Whenever a passing boat, an engaging view, or accident shall call the passengers to one side of the boat, it will be thrown out of trim.

60. In the small boats on our Atlantic rivers there are heavy carriages used to keep the deck level; these are also used in the English steam-packets which carry sails, but the Committee are not aware that they are employed in the boats of our Western waters.

61. *Different modes of remedying the evil under discussion, and to be applied to the boilers themselves have been suggested.*

The first of these which came before the Committee, and which we believe has been applied in practice, was by Mr. James J. Rush. Doors are placed in the flues, at a point furthest from the fire-end, which, when opened, check the draught through the furnace and flues, and consequently prevent their becoming unduly heated. These are to be thrown open at each landing-place. They do not, however, meet the case of accidental careening of the boat, unless made self-acting by expanding rods, as was proposed by Mr. Rush. They expose the flues to the action of air containing its full supply of oxygen, and must tend therefore to oxidize them more rapidly than in the ordinary wear of the engine.

62. The other devices before the Committee are those of Mr. C. Evans,† and of Mr. J. S. Williams.‡ The first places the mouth of the feeding-pipe just below the proper level of the water in the boiler, so that it shall be laid bare by a change of level, and the water be prevented from escaping from the higher boilers. This would remedy the evil except in cases where the careening was sufficiently long continued to exhaust the upper boilers of water by the ordinary working of the engine; those boilers

* We are not able to make the calculation corresponding to this remark, not having the dimensions of the safety-valve, or valves, of the boilers of any one of the Western boats.

† Replies to Circular, &c. No. XXII.

‡ Jour. Frank. Inst. vol. viii. p. 289. The method adopted by Mr. W. C. Redfield places the means of feeding separately, or in the connected way, within the control of the engineer. This was not presented to the Committee, but may be found alluded to in the Documents of the House of Representatives of the United States, 1832-3, No. 478, p. 17.

of which the supply pipes are bare not being likely to receive any supply from the pump. Mr. Williams places the supply pipes below the boilers and feeds through valves opening upwards, which of course prevent any return of water. The valves in this machine and also those proposed by Mr. Evans to prevent any escape of water from the higher boilers, would be objectionable. The method of cleansing the pipes proposed by Mr. Evans is very ingenious.

63. After a careful examination of these devices the Committee are of opinion that they present but partial remedies for the evils which they are intended to meet, and they consider that nothing less than detaching these boilers from each other, and feeding them singly, or at most in pairs, will prove effectual. They would therefore respectfully, but earnestly, urge this upon constructors and owners.

64. *Fourth. Are there cases in which the metal of a boiler may become unduly heated when in contact with water?*

After much reflection and examination the Committee are of opinion that such cases *may* occur. They believe that such have occurred, though not frequently, and that with the common thicknesses of iron and copper boilers, and modes of arranging the furnaces, there is very little liability of their occurrence. Still it is well to recognise that such may be the case, as it may prevent accident by watchfulness in the use of a new construction of boiler, or application of the fire.

65. Mr. F. Graff* mentions specially an instance " in which the heads of the bolts burning off over the fire-place, and the joints parting;" " the boiling water passed into the ash pit." From his known carefulness, there is no reason to suspect that there was sediment in this boiler, which was one of the low-pressure boilers used at the Philadelphia water-works.

66. Mr. Hebert† gives two cases, in the first three different rents of an iron boiler occurred at the same spot, at different times. Previous to the first " disruption, there was observed a bulging, or swelling out, of the metal, which gradually increased until it became nearly of a hemispherical figure, when it burst open and let the water out of the boiler into the fire. The boiler was repaired by putting a thick patch of malleable plate iron over the hole, when after about six weeks wear and exposure to the fire, this metal bulged out again, and burst asunder; *a third* patch was substituted, and in about a similar period of time was destroyed in like manner." " The cause of these ruptures appeared upon investigation to be owing to a partial and very intense heat impinging against that particular spot where they took place." If to this detail had been added proofs that the first rupture was not caused by sediment, nor by a defect in the metal, the evidence would have been complete. It is not however probable that either of these causes were actually operative, since the second and third plates are stated to have bulged out, in the manner of the first, and if sediment had collected at this spot, it could not thrice have escaped notice. The defect in malleable iron, to which the Committee alluded above, is the the want of connection in parts of a plate, resulting from imperfect welding before rolling, and which sometimes separates the plates into distinct layers, for a considerable extent.

In the communication just referred to, Mr. Hebert further states, that the destruction of a boiler, occurring twice in the same place, was traced by Mr. John Martineau, a respectable engineer of London, to the impinging of a current of air upon this spot.

* Letter to Councils. Replies to Circular, &c., 4th of No. I.
† Replies, &c. No. XI.

67. A case apparently of the kind now under discussion, but which was found, subsequently, to be due to the imperfect union of the parts of a sheet of metal of the boiler is as follows. Part of a boiler belonging to Messrs. Merrick and Agnew, of this city, was observed to be protruded, in a similar way to that described by Mr. Hebert. Suspecting the presence of sediment, the boiler was examined and found to be clean. It was a cylindrical boiler, of wrought iron, the fire applied on the exterior and at one end, and without interior flues. The fuel was anthracite coal. The effect was next attributed to the intense local heat produced by this fuel, and the grate bars being lowered the swelling made no further progress. It has been since ascertained that there was a separation into laminæ of the iron, at this place, requiring the removal of part of the sheet.

68. While, then, the evidence in the cases preceding the last is certainly incomplete, the Committee conceive that they are leaning towards the side of safety by admitting the possibility of the occurrence of danger, to the engineer and fireman at least, from peculiarities in the arrangement of a boiler or of the fire which heats it.

69. In these remarks it has been supposed that there is a considerable column of water over the metal; if that should not be the case it may well happen that the steam-bubbles will form so numerously on or near the iron as to allow it, while they rest there, to become heated above what it would be, if the water were in absolute contact with the metal.* This will especially occur with a viscid fluid, such as salt water, or water with much sediment suspended.

70. The views suggested by the several sections of the preceding head are the following:

1. The feeding of a steamboat boiler should not be done at intervals, but go on throughout the working of the engine.

When the engine is stopped, as at a landing, or to take up passengers, &c., the water should still be supplied by the engine itself, or by a subsidiary one, or by hand. In this case the free safety-valve should be raised. The practice of wasting water by opening a valve, when the forcing-pump is not in action, is considered dangerous.

2. If the water should by any accident get down so as to expose a flue or flues, the fire should be in part extinguished, to cool the boiler before adding water. If the engine is at rest, in such a case, it should not be put in motion. If it is in motion it should be slackened, or stopped, the furnace-doors opened, and the heat got down. Then water may be thrown in. The opening of a safety-valve should in such a case be avoided. The engineer should remember that as life is at stake, he cannot be too prudent.

Such a condition of things, however, ought never to be allowed to occur, and the responsibility for the danger which results, must rest upon the master, the engineer, and his assistants.

3. If a self-regulating apparatus for the supply of water is used it should be closely watched, and on no account be implicitly trusted to. It may be a convenience, but can, in no case, be a substitute for human care.

4. For ascertaining the level of the water within a boiler, the Committee recommend the glass tube water-gauge, a form of which is shown in the foregoing pages (p. 24).

5. The Committee recommend for every boiler a fusible metal apparatus,

* Replies, &c., No. II. Communication of "an Engineer." Philos. Mag. vol. i. p. 403.

the metal of which shall be inclosed in a tube, so as not to expose it to pressure.

In boilers without flues it should be attached at the water-line; in those with flues, at the highest part of the flues; or if level, at the part likely to be most rapidly heated, as at the juncture of several flues into one, a sudden change of direction, or the place of most active combustion of the fire.

The form described in the report (p. 25,) is convenient, and the lever should act upon a bell, and upon a small cock. The apparatus should be inclosed, the master of the steamboat having the key of the inclosure, which should further be so arranged as to protect the apparatus from the weather.

The quantity of metal should be no greater than is required to keep the rod in its place. The metal should be regulated so as to melt at a temperature of fifteen degrees* above that corresponding to the working pressure. Tables for this purpose, will be found annexed.

If the metal is melted, the injection of water, or the opening of the furnace-doors, will reduce the temperature of the heated parts; or lower the pressure of the steam if that should have been too high, and the safety-valves be out of order.

By sounding with the rod, it will be ascertained when the metal is about to recongeal, as it becomes a soft solid into which the rod may be forced. If, accidentally, the metal congeals without taking in the rod, the end of the latter being heated, will melt the fusible alloy.

If the safety-valves do their duty, this metal will never be melted by increase of temperature, caused by an increase in the elastic force of the steam.

6. The true remedy for undue heating of boilers by deposites is frequently cleansing them. When this is impracticable, blowing out should be cautiously resorted to, so as not to lay bare the flues of water. The danger from these deposites is especially great in salt water, and muddy water mixed with calcareous matters. It should be guarded against by ascertaining the time required for the water used, to make a sensible deposite. No general rule in regard to this can be given, since boilers in different places and even those fed by springs at short distances apart are liable to deposites in different times.

Negligence on this point will always produce the rapid destruction of a boiler, and may cause it to burst, or even to explode.

No substitute for the care just recommended, has yet been found.

7. The following table of fusible alloys applicable to boilers working at pressures from one to thirteen atmospheres, is deduced from the experiments of the Committee.† The alloys are those, determined approximately, which at temperatures severally 15° Fah. above the working temperatures will allow a metallic stem to be drawn out from the mass. The principles which guided the Committee in their experiments may be seen by referring to Part I. of their Report. (p. 36, &c.) The proportions are given in parts by weight.

* This difference of temperature corresponds at a pressure of two atmospheres, to half an atmosphere or one-half the bursting pressure, and at eleven atmospheres to rather more than two atmospheres, or one-fifth of the bursting pressure. The difference is not, however, too great at low-pressures, because an excess of strength may rather be expected in the low-pressure boilers as now made, and the alloys, containing bismuth, pass through the different states from solidity to liquidity, by slow degrees.

† Report of Com. on Explosions, Part I. p. 36. Journ. Frank. Inst. vol. xvii. p. 86.

TABLE OF ALLOYS FOR USE IN CLOSED TUBES, AND WITH A METALLIC STEM.

Working pressure in atmospheres.	Tin.	Lead.	Bismuth.	Working pressure in atmospheres.	Tin.	Lead.	Bismuth.	Working pressure in atmospheres.	Tin.	Lead.	Working pressure in atmospheres.	Tin.	Lead.
1½	8	8	7.5	4	8	8	3.4	8	8	8	12	8	12.3
2	8	8	6.2	5	8	8	2.2	9	8	9.8	13	8	13.2
2½	8	8	5.3	6	8	8	1.2	10	8	10.6			
3	8	8	4.6	7	8	8	0.5	11	8	11.4			

71.—III. *Explosions may arise from defects in the construction of a boiler, or its appendages.*

This comprehensive division includes the discussion of the form, material and mode of manufacture of the boiler and of its appendages. The Committee have, however, no desire to interfere with the present or future state of the engine in these respects, further than as their duty requires them to give candidly to the public, their opinion of facts which are on record.

72. 1*st.*—*Form.* The influence of the form of a boiler in producing danger is of course very great; but to consider the numerous varieties of form would be impossible, even if their minute differences were known to the Committee. Every boiler should be required to stand frequent proofs as a test of its sufficient strength, but the working properties of each, with originally adequate strength, may be very different.

73. It may, in general, be remarked, that the old wagon-boiler of Watt, should be only used when very low steam is employed. The varieties of the cylinder-boiler, with or without interior flues, are in most common use in the steamboat-engines of this country. Of these, experience, both abroad and at home, has shown those without flues to be the more safe, and those with them the more economical. The heads of these boilers are, in this country, plane surfaces, in England, frequently, hemispherical, and in France, are required by law, to be of the latter named figure. There is no reason, however, to doubt the sufficiency of strength of the thick plane wrought-iron heads. Of the flues used, those in the smaller cylinders, which pass directly through both heads of the boiler are the more safe ;* the flues passing through the convex surface, called L flues, and those which in the larger boilers return without passing through both heads, add nothing to the strength of the cylinders. Observation has shown that boilers with interior furnaces, or flues, commonly give way by the yielding of the flues, or by blowing off the heads. The tubular boilers of Woolf, have, but in one case, as far as the knowledge of the Committee extends,† been used in this country. Other forms of tubular boilers, in which very small tubes contain the water to be vaporized, have, in no case, to their knowledge, on full trial, been found successful. The case is very different

* Experience seems to warrant this conclusion, and it does not appear probable that the difference of temperature between the flue and outer shell, even in boilers with interior furnaces, can be sufficient to injure a wrought-iron head, by the excess of the expansion of the flue. The case is different when cast-iron is used for a boiler-head.

† At Richmond, Virginia. See Burr on Explosions. Journ. Frank. Inst. vol. vi. p. 334.

when, as in the locomotive boilers, the tubes are used as flues: and for obvious reasons. Such boilers have, however, only lately been applied to steamboats.

There does not seem to the Committee, evidence to show that any of these forms are essentially dangerous, though, as before remarked, there are grades among them as to impunity from careless management. From this remark, however, in some degree, should be excepted the L flue-boiler, which is incident always to a source of danger, hereafter to be pointed out. The remarks apply to single, or detached boilers.

74. Connected boilers, on board of steamboats, are incident to a source of danger which has already been pointed out, (art. 59, &c.) and after examining the remedies which have been proposed to meet these circumstances, the Committee are of opinion that they are of so varied a kind that the use of these boilers cannot be continued without certain danger, and therefore ought to be laid aside. Those at present in use could easily be detached, so as to connect only two boilers at most, and have a separate supply-pump for each pair.

75. In a former division of the subject, (II.) the Committee showed the great danger which is produced in a boiler by highly heated metal; any boiler, therefore, which has parts exposed to heat, without being in contact with water, is essentially defective. The L flue-boiler is of this kind, though as it is only used in small cylinders, the exposure is not considerable.* The boiler with a steam-chimney presents an extension of this exposure, the boiler being continued up vertically at one end, so as to inclose the flue.† The idea is to economise the heat found in this flue, by heating the steam which is around it, and thus producing a small surcharge of heat which prevents condensation in the steam-pipe and cylinder. But the flues which the chimneys inclose, are thus exposed to become unduly heated Two explosions which have occurred in boilers with steam-chimneys‡ have torn the same portion of the flue, and were so

* A curious case of the overheating of a flue by the accumulation, and subsequent taking fire of soot, is described by Mr. Hebert in No. XI. of the Replies to the Circular of Committee on Explosions.

† It should be recorded to the credit of the liberal minded patentee of this boiler, that he has afforded every opportunity to investigate its defects, and appears no sooner to have been convinced of the danger to particular parts of it, than he has applied his skill to produce a remedy.

‡ In justice to the force of this conclusion, the Committee feel it necessary to give extracts from the excellent accounts of the explosions on board of the Ohio and of the William Gibbons steamboats, by Thos. Ewbank, Esq., of New York. The first of these explosions, occurred on the Hudson, in 1832, and the second, in New York harbour, in 1836. The annexed figures represent in plan and section the ruptured flue of the Ohio. WW, in the elevation, is the water line, C the flue around which the steam chimney is placed, and S the steam-pipe leading from the steam-chimney. The rent took place from fifteen to twenty inches above the water line. This part of the flue is always exposed to the heated air from the horizontal flues which unite in the flue E, and is never covered by water. The line of fracture does not deviate more than six inches from a horizontal line. It is partly along a line of rivets, but chiefly through the centre of the sheets. In portions of one sheet, the metal is reduced from its original thickness of one-quarter of an inch, to one-eighth, and even to one-sixteenth of an inch. Jour. Frank. Inst., vol. x. p. 226, No. XXIX. Replies to Circular, &c. The

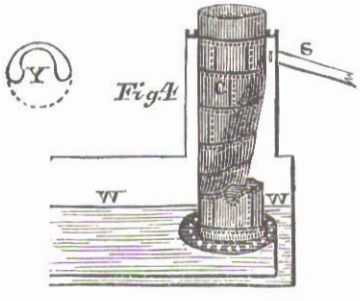


Fig 4

similar, as to show that they are to be attributed to an inherent defect in this construction. Indeed the presence of metal through which a highly heated draught is passing, while it is in contact only with steam, which cannot carry off the heat rapidly, is sufficient to warrant a decision against such a form of boiler, even if facts had not spoken so loudly in regard to it.

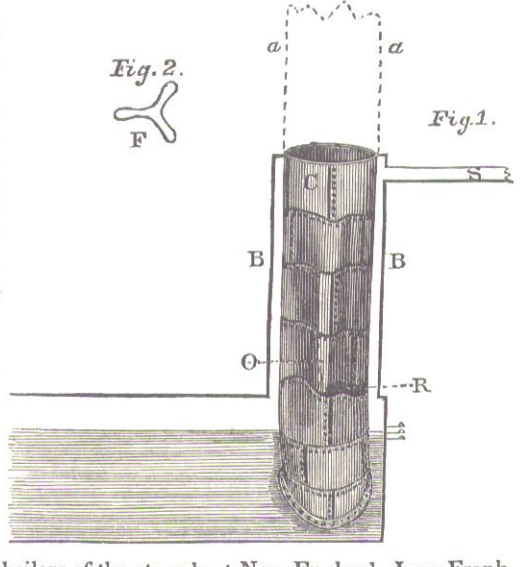
76. The Committee feel constrained to recommend to constructors to discontinue the making of connected boilers, of those with L flues, and with the extension constituting a steam-chimney.

77. It would be improper to leave this part of our subject, without calling attention to another point in the construction of boilers, which is to be avoided. It is the formation of small spaces intended to contain water and surrounded by fire.* All experience has shown that steam cannot be generated in small tubes without driving out the water, and these arrangements are equivalent to tubes; and besides being liable to the accumulation of deposites, they are exposed to have the water carried from them unless when under considerable pressure. The weakness of boilers of these irregular forms should never be lost sight of.

78. *2nd.—Material and manufacture.* As early as 1818 a Committee of the British House of Commons, on the authority of practical and scientific men whom they examined, recommended the disuse of cast-iron as a material for steam-boilers. This material has now so generally been abandoned, for this purpose, that remarks upon its defects are not necessary. Even the cast-iron heads for boilers which were used a few years since on the Mississippi are, the Committee believe, now giving place to wrought-iron ones. The materials in common use for steam boilers are wrought-iron and copper.

79. The committee have made, by the arrangement stated in the preface to the first part of their report, an extensive series of experiments on the strength of the different varieties of wrought-iron and copper, manufactured for steam boilers, in the United States. These experiments they

William Gibbons has one boiler of wrought iron, and similar in construction to those of "The Ohio" and "New England," but having a greater number of horizontal flues. The flue BB within the steam-chimney, was collapsed so as to form a three cusped figure, as shown in fig. 2. The rent R, thus produced, was four inches above the roof of the boiler. It was in one of the horizontal seams, and confined almost wholly to it, extending nearly three feet, or about one-third of the circumference of the flue. The flue was iron, one-fourth of an inch in thickness, and its thickness was not sensibly diminished previous to rupture. Jour. Frank. Inst. vol. xvii. p. 298. The fuel used ordinarily, was a mixture of anthracite coal and wood, but, on this occasion, it appears that the fire had been urged with quantities of wood.



* Ewbank on the explosion of the boilers of the steamboat New England. Jour. Frank. Inst., vol. xiii. pp. 292, 293.

hoped to have presented before making this report, but circumstances not now necessary to be made public have prevented them from doing so, and they deem it inexpedient longer to delay on this account. They must refer, therefore, to a report, specially upon this subject, for a complete development of their views, as well as for information in regard to the proper thicknesses for steam boilers, working under different pressures. They ought, however, to remark here, that the views usually entertained of the importance of working iron, have been entirely confirmed by them. The ultimate strength of a bar, or sheet of iron coinciding more nearly with the strength which the whole bar exerts to prevent a first fracture, or the bar or sheet being rendered more uniformly strong, and therefore better adapted for use in the construction of steam-boilers, the more it is worked. Iron which has been heated nearly to redness has its tenacity permanently injured, being affected, though in a less degree than copper, the weakness of which in such a case has long been well established.*

80. There can be no doubt that the strength of boilers may be diminished by constant and often unequal pressure, by which the material is injured so far as to give way under a less strain, than that which it may once have borne.† By ordinary wear, from oxidation, &c. their strength is necessarily much impaired.

81. When salt water, or spring water highly charged with saline matter, is used to feed boilers, iron is very rapidly acted on, and extreme care should be used in frequently cleansing them.‡ Careful owners would resort to more frequent proof by the forcing pump than in other cases. This would serve to detect corrosion in particular spots, to which the material is so liable. Copper boilers not being similarly acted on, are more safe in such situations, but there seems no reason to suppose that iron may not be safely used, with due precaution.

82. Instances of dangerous defects in construction, or arising from use, in boilers are but too well attested. The awful explosion on board the steamboat Helen Mc Gregor,§ by which more than thirty persons lost their lives, took effect by forcing off the cast iron head of a wrought-iron boiler, throwing the boiler in the opposite direction: the head was known to be cracked, before the explosion occurred. It is not clearly made out whether this result was produced by a gradual increase of pressure,‖ or by the return to its level of the boat, which had been careened by stopping at a landing place. The steam was not let into the cylinder to propel the engine, when the explosion happened. The boiler was one of six connected boilers of three feet diameter. A cast-iron head should never be united to a wrought-iron boiler with flues,¶ since, independently of the defects to which the metal is liable, the inequality of expansion is very likely to crack it.**

* On both these points see also the remarks of Mr. Lester in Replies to Circular, &c. No. XVII. where the fact is stated both in regard to iron and copper, as resulting from his own experience.

† See Replies to Circular, &c. Nos. II. and XII. Col. S. H. Long and T. Bakewell, Esq. also evidence of Mr. Bramah before Com. of House of Commons, 1817, Dodd's collection.

‡ An instructive description of the action of salt water on iron will be found in the evidence of Professor Faraday before the Com. H. Commons of Eng. on steam navigation, 1822.

§ Nos. III., IV., and XXI., of Replies, &c.

‖ Replies to Circular, No IV.

¶ See also explosion of Atlas, Replies, &c. No. VIII., and No. XXI., Car of Commerce, No. XXI.

** Evidence of John Taylor, Esq. before Com. of House of Commons. A cast-iron boiler-

83. A defect in a wrought iron boiler head, was detected, by one of our correspondents, which we are surprised that any boiler maker should have allowed to pass. In turning the flanches by which the head is riveted to the cylinder, the iron was turned so sharply, as to crack it more than half-way through. This was one of four boiler heads belonging to the same set, found by Mr. E. W. Benton to be unsound. They could not have stood proving.*

There can be no doubt but that the repairs to the boiler of the Caledonia were improperly made,† an iron plate having been fastened upon the boiler with copper rivets: this seems, at least in part, to have been the cause of the accident which subsequently occurred.

84. The idea seems formerly‡ to have been entertained that dangerous explosions could not occur in wrought iron boilers, which were merely rent without doing injury. It is almost needless to remark that the whole tenor of the evidence before the Committee contradicts the idea. Wrought iron may even be separated into fragments, but the great source of danger is in the escape of the hot water, which, with the steam generated by it, produces death in one of its most painful forms.

85. Steam-boilers should not only be proved when originally made, but from time to time, to guard against their gradual wear, or accidental injury; and especially after every important repair made to them. In the intervals care must be secured by other means. These proofs have been recommended by most of our valued correspondents.

86. In the attachment of sheets of metal to each other to form boilers, and in the fixing of heads to boilers, constructors appear to have lost sight of the fact that the metal which is taken out for the rivet-holes weakens the sheet, and that materially. In examining cases of explosion from direct pressure, and where no undue heating or special weakness has led to the result, the lines of rivets appear to determine the direction of the first fracture.§ A very neat example of this was given in the bursting of an iron cylinder in the experiments of the Committee.‖ The head of the cylinder was forced off, carrying with it the metal which projected beyond the line of rivets. The rivet-holes had cut out rather more than half of the circumference of the metal forming the convex surface, along the circle passing through the centres of the rivet-holes, and thus had made the strength of the convex surface to resist rupture in a direction perpendicular to the axis of the cylinder, less than its strength to resist a rupture in the direction of the axis.¶

87. The exposure of joints, formed by the junction of boiler plates, to the fire, may be mentioned as liable to produce very rapid wear. The heat is not conducted off as rapidly as by the other parts of the boiler, and the lower sheet is exposed to rapid oxidation.

88. 3*rd.*—*Appendages to the boiler.* Of these the principal ones have already been made the subject of remark, and recommendation by the

head affixed in his shops to a wrought-iron boiler and originally proved with a pressure of 100 lbs. cracked by heat when only exposed to a pressure of steam of 20 lbs.

* No. VIII. Replies, &c. Boilers of Tally-ho Steamboat.

† Replies, &c. Nos. V., VI., VII., VIII., XXI.

‡ Evidence before Committee of House of Commons. Dodd's Collection.

§ Ewbank on the Explosion of the Boilers of the New England Steamboat. Journ. Frank. Inst. vol. xiii. p. 293.

‖ Report of Committee on Explosions. Part I. p. 67. Journ. Frank. Inst. vol. xvii. p. 224.

¶ With an equal thickness of metal the strength in the former case would have been double that in the latter.

Committee. The forcing pump, as one of the most important, deserves further notice in this place. It is not the intention to recommend any particular form of this pump, especially as the Committee believe that most commonly in use to be entirely adequate to all its objects. They may remark, however, that they consider several valves, between the supply reservoir and the pump, and also between the pump and boiler, as of the greatest importance. They would further recommend to be placed on the eduction pipe a cock similar to that used in locomotive engines. A rod and handle connected with this should be placed in a convenient position, for the engine-man to ascertain, by turning the cock, if the pump is in action. Although this apparatus cannot dispense with due attention to the means of ascertaining the level of the water within a boiler, it may give notice of a defective supply, in time to apply a preventive, instead of a remedy.

89. The Committee consider that their remarks already made in relation to the mode of applying heat to a boiler have been sufficient. They do not see that the use of a fusible metal or fluid bath can be applicable, in practice, to the heating of a steam-boiler, or would, if applicable, realize the advantages which have been claimed for them.

The recommendations embodied in the present division of the subject will be found carried out by the suggestion of appropriate enactments in the project of a law which is appended to this Report.

90. IV. *Carelessness or ignorance of those intrusted with the management of the steam-engine.*

It might be supposed that the fact once known that the engineer or fireman, who, from carelessness, or other cause, allows a boiler under his charge to explode, is in almost every case the first victim of the disaster, would produce care in those intrusted with the engine. But experience shows that this is not so; and the Committee, in proposing remedies, do but the duty which has been confided to them, and proved indispensable by examples, not to be mistaken or disregarded.

91. Familiarity with any sort of danger is so sure to produce callousness to it, and due caution is so apt to be considered as timidity, that a tendency to carelessness must be considered as the natural consequence of the situation of an engineer, or fireman. The subject of the causes of explosions in steam-boilers has been so little investigated, that men well versed in general science might be excused for ignorance of it, and steam-engineers should not therefore be too harshly or hastily blamed for what is incident to the nature of the subject, rather than the fault of the profession. The fact of carelessness or ignorance has however been so much insisted upon by our correspondents* that it must be assumed, and endeavours made to apply a remedy.

92. In the present state of general education in our country it would obviously be impracticable to insist that firemen, or even steam-engineers, should be versed in the scientific principles which regulate the use of steam. The public have, however, a right to expect from employers, that their agents, who are intrusted with human life, should have a thorough practical acquaintance with the steam-engine, and to demand that those who have information of the sources of danger, should lay down plain rules for the guidance of those who have been referred to. As a guard against carelessness, the public have further a right to expect from the higher

* Replies to Circular, &c. Nos. III., VIII., IX., XVII., XIX., XX., XXI., XXIII., XXVIII. Also, Remarks by "an Engineer," Philos. Mag. vol. i. &c. &c.

authorities, beginning with the chief engineers, and rising to the captains of steamboats and masters of shops, that they should exert all the moral influence which vigilance can produce. And from the law, that it should constrain all these, by appropriate penalties, to the discharge of their responsible duties.

This view the Committee have carried out in the project of a law which accompanies their report.

93. V. *Cases of collapse from a partial vacuum within a boiler, or its flues.*

These cases are so little applicable in the state of the steam engine in this country, that the Committee have postponed their discussion until the last.

It is certain that the boiler of a high pressure engine of proper strength for ordinary purposes, would also be able to sustain the action resulting from even the sudden formation of a vacuum within it. Low pressure boilers have been crushed by the pressure of the atmosphere when a vacuum has been formed within.* These accidents are effectually guarded against, as far as experience has shown, by a valve opening inwards with which Watt's boilers were provided.

94. A case of explosion at the Mold Mines, in Flintshire, which has been circumstantially detailed by John Taylor, Esq.,† seems to prove that a rarefaction produced in the interior flues of a high pressure engine, may determine an explosion of the most violent description. The boiler which exploded, belonged to a set of three, feeding the same engine. The fuel used was bituminous coal. The furnace doors of all three of the boilers had been opened and the dampers of two had been closed, when a gust of flame was seen to issue from the mouth of the furnace of these latter, and was immediately followed by an explosion. The interior flue of this boiler was flattened from the sides, the flue and shell of the boiler remaining in their places, and the safety valve upon the latter not being injured. Mr. Taylor states it as probable, that the steam pressure at the time of this accident did not exceed thirty pounds, and that the water was at its proper height. He assigns as the probable cause which determined the collapse of the flue, the ignition of a mixture of gas from the coal with atmospheric air, the contents of the furnace not being carried up the chimney on account of the closing of the damper, by which a partial vacuum was produced. If the strength of the flue was but little more than sufficient to resist a steam pressure of thirty pounds, it is plain that the cause assigned is adequate to have produced the effect. It must be admitted, however, that the testimony of the fireman who escaped injury by the explosion, and who would have been subjected to all the blame of the accident, if any attached, his comrades having been killed, is of that kind which induces a doubt, whether the steam pressure and height of water, were exactly as stated.

The accident, however, suggests the precaution as necessary with coal, and with some kinds of wood, not to close a damper soon after fresh fuel has been added; if the furnace is within the boiler, the injurious effects may be very serious, even more so than in the cases already referred to, where the furnace is not so placed.

95. That a vacuum can occur within a steam-boiler which is in action,

* Arago on Explosions. Annuaire du Bureau des Long. 1830. pp. 148, 169, and 170., also Journ. Frank. Inst. vol. v. pp. 404 and 412.

† On the accidents incident to steam boilers. Philos. Mag. vol. i. see also remarks upon the same by "a practical engineer," and by W. J. Henwood, in the same volume.

as has been propounded within a few years past, is a supposition too palpably contradicted by the facts of the case to require any examination here.

96. VI. Having closed the subject of the means of preventing explosions in steam-boilers, the committee have yet to consider *whether it is possible to provide protection against their effects when they occur.*

The very respectable scientific and practical men who have at different times drawn the attention of the public to this matter, give undoubted authority to the suggestion. The means proposed are, by carrying the passengers in a separate boat from the engine, or by placing the boilers on the guards of the boat, and separating them from the parts occupied by the passengers, by a suitable bulwark.

97. In regard to the first of these plans, it has been attempted, and for want of sufficient patronage by the public, has been laid aside. Public opinion seems to set strongly towards precautions which shall render the engine safe, without crippling its power of giving speed.

98. The larger steamboats on our Atlantic waters have generally the boilers upon the guards,* but without any obstruction between them and the inner parts of the boat. This affords but a partial security, diminishing probably the extent, but not preventing, the destruction of human life. That a bulwark of sufficient strength to protect against explosion, without adding too much to the weight of the boat, can be devised, the Committee are not prepared to assert positively, though they believe that it could.

99. Their views incline entirely to the protection of the hands, as well as passengers by rendering the boiler safe, and they fully believe that this may be done without incumbering the boats now in use, or requiring, in a majority of cases, an entire change of structure in the engine.

They have, however, to meet opinions which they hold in so much respect, introduced a clause in the proposed bill, annexed to this report, by which a bounty is, in fact, offered upon a boat constructed with suitable bulwarks between the interior part, and the boilers.

100. The Committee having now completed their examination of the causes of explosion with their preventives, as far as they are informed upon the subject, and made all the recommendations, which this examination has suggested to them, refer to the accompanying project of a law for the regulations of the boilers and engines of steam-vessels, for the means of carrying the more important of these suggestions into effect.

The provisions of this law refer only to the means of preventing the explosions of boilers of steamboats, or of affording protection against their effects. With the regulations in regard to the navigation or police of the boats, however important, this Committee do not feel warranted in interfering. They believe that the experience necessary to frame such regulations will be found in the appropriate committees of Congress, upon whose attention they would respectfully urge the annexed provisions relating to the engine.

That such an enactment will contribute to the safety of the public,

* We are pleased to see that a boat in which the boilers are placed upon the guards has been put in operation upon the Mississippi. This we trust is only the first of many of this kind to be hereafter constructed.

without interfering injuriously with those interested in the navigation by steam or in the manufacture of the steam-engine, is the deliberate opinion of this Committee.

Respectfully submitted,

In behalf and by direction of the Committee, by

ALEX. DALLAS BACHE,

Chairman of the Com. on Explosions, &c.

Presented to the Board of Managers of the Franklin Institute of Pennsylvania for the Promotion of the Mechanic Arts, and approved, September 21st, 1836.

M. W. BALDWIN,

Chairman of the Board of Managers.

WILLIAM HAMILTON,

Actuary.