April 5, 1853.

ROBERT STEPHENSON, M.P., Vice-President,
in the Chair.

THE following candidates were balloted for and duly elected :—
Terence Flanagan, as a Member ; Joseph Augustus Clarke,
Thomas Minchin Goodeve, Henry Maxwell Lefroy, and Thomas
Wright, as Associates.

No. 891. "On Locomotive Boilers and on Fuels."

By JOHN SEWELL.¹

THE subject of locomotive economy naturally divides itself into three distinct processes :—First, the production of heat ; second, the generation of steam ; and, third, the employment of steam.

These processes may be either wholly, or partially independent of each other. For stationary engines they are all nearly independent, but for locomotives they are only partially so, as in the latter the steam aids in generating heat, and the central position of the cylinders is affected by the boiler.

The two first processes of generating heat and steam, are however, more strictly the duty of the boiler, and may be considered together.

A cubic foot of water requires an equal amount of heat to convert it into steam, of an equal temperature, in any boiler, whatever be its form, or proportion ; and it is somewhat remarkable, that the variations of steaming economy of stationary, marine, and locomotive boilers, only vary within nearly the same range as the different fuels in the same boiler, or to the extent of about twenty per cent. of the theoretical value.

The object of a good boiler is to effect the most complete combustion of the fuel, and to transmit the caloric so evolved sufficiently to the water. To realize these two points, numerous forms have been designed, and various rates of combustion have been tried, both in stationary and locomotive boilers. Space, or weight rarely interferes in designing stationary boilers, but for either marine or locomotive boilers, lightness and economy of space are essential.

¹ The Author has since been elected Assoc. Inst. C. E.

The early marine and common road steam-engineers adopted the principle of dividing the water by small tubes, whereby lightness was obtained; and the strength was such, that pressures of 250 lbs. to 300 lbs. per square inch could be, and were used.

Railway engineers have adopted the principle of dividing the heat by small tubes, which leaves the elastic force of the boiling water and steam in one mass, and requires a strong case to confine it. The safe pressure is, therefore, limited to about 100 lbs. or 150 lbs. in the common locomotive boiler as now made.

Historically this form of boiler embraces the Egyptian cylindrical boiler, with its internal hot-air chamber and hot-air blast on the fire, as illustrated by Hero, of Alexandria, Papin's tubular flue, Allen's fire-box of 1730, and Brindley's copper flues of 1756, as arranged by Stephenson in 1829.

In testing the comparative economy of different boilers, it is desirable to keep in view the different steaming powers of different fuels in the same boiler. For this purpose an example is given of the efficiency of each of the best Welsh, Newcastle, Lancashire, and Scotch coals, with one of Tanfield coke, as carefully tried in a small Cornish boiler, 12 feet long, and 4 feet diameter, with an internal flue of 2 feet 6 inches diameter, split at the back into two side flues, which joined at the front and returned below the boiler to the chimney.¹ Taking the heating value of 1 lb. of hydrogen as 62,470° Fahrenheit, and of 1 lb. of carbon as 13,268° Fahrenheit, the heating value of the above fuels are—

Class of Coal.	Name of Fuel.	Carbon.	Hydrogen.	Heating Value.
		Per Cent.	Per Cent.	Deg. Falt.
Welsh . .	Aberaman . .	90·94	4·28	14662
Newcastle	Tanfield . .	85·58	5·31	14671
Lancashire	Ince-Hall . .	82·61	5·86	14621
Scotch . .	Elgin . . .	76·09	5·22	13356
Carbon or	Pure Coke . .	100·00	..	13268
Scotch . .	Dalkeith . .	74·55	5·14	13102

¹ *Vide* "Third Report on Coals suited to the Steam Navy." By Sir H. De la Beche and Dr. Lyon Playfair. Folio. London, 1851.

The steaming value of fuels is usually taken for the atmospheric pressure of 14·7 lbs., or 1178°; but as locomotive boilers are worked up to 8½ atmospheres, or 1212° of total heat, the economic value must be estimated accordingly. Taking the initial heat of the water in the boiler as 52°, the theoretic value of the before-mentioned fuels contrasted with their practical value is as follows :—

STEAMING VALUE of 1 lb. of various Fuels.

Fuel.	Theoretical Pressures.		Practical Pressure.	Per Cent. of Theoretical Value.
	1 Atmosphere.	8½ Atmospheres.	1 Atmosphere.	
	lbs.	lbs.	lbs.	
Hydrogen . .	55·4	53·8	..	..
Aberaman Coal	13·0	12·6	10·7	82·56
Tanfield „	13·0	12·6	9·8	75·26
Ince-Hall „	12·9	12·6	9·4	72·95
Elgin . „	11·8	11·5	8·4	71·33
Coke, or Carbon	11·7	11·4	7·9	67·14
Dalkeith Coal .	11·6	11·3	7·1	61·20

This table shows, that with the utmost possible care, there is a practical difference in the value of different fuels, in the same boiler, to the extent of 21 per cent; and that the results follow the proportion of carbon generally, although the coke experiment, which was aided by a steam-jet blast in the chimney, clearly shows the beneficial influence of the hydrogen in the coals, for with 20 per cent. less carbon, the Elgin coals evaporated 4 per cent. more water than coke of the best description.

The coke experiment gives very nearly the same result, in this boiler, as is obtained from coke in the great majority of locomotive boilers; and as ordinary coke is not pure carbon, 5 per cent. may be fairly deducted from the carbon value, which leaves 10·8 lbs. of water, as the steaming value of coke.

A few practical results, obtained from very differently-proportioned boilers, are given below. They show a remarkable

coincidence of difference, with those obtained from different fuels in the same boiler.

Class of Boiler.	Area of Grate.	Total Heating Surface.	Ratio of Heating Surface to the Grate = 1.	Ratio of the Heating Surface to the Fire-box = 1.	Fuel consumed per Hour.	Fuel consumed per Foot of Grate per Hour.	Water by 1 lb. of Fuel.	Evaporation per Cent. of Fuel: Value per Cent.
	Sq. ft.	Sq. ft.			lbs.	lbs.	lbs.	
Haystack . .	35	229	6.5	5.4	357	10.2	7.76	61.6
Waggon. . .	21	342	16.3	7.6	217	10.3	7.87	62.4
„ . .	23	148	6.7	3.1	94	4.0	9.17	72.8
Cornish. . .	23	961	41.7	26.2	82	3.5	10.53	81.0
LOCOMOTIVES.								
Loco. A. . .	10	903	90.3	14.5	..	132.0	9.0	83.3
„ 234 . .	14	1,215	87.0	13.4	757	53.0	8.12	75.2
Iron Duke . .	21	1,769	84.0	12.4	1,727	82.0	8.32	76.8
Heron . . .	10	707	70.7	13.2	829	82.9	7.74	71.6
„ . .	..	..	..	..	1,099	109.0	6.72	62.2
„ . .	..	..	..	..	708	70.8	7.66	70.9
Mr. McConnell's . .	23	1,133	49.0	3.7	1,815	79.0	8.5	79.1
„ . .	..	..	..	..	1,041	45.0	8.27	76.5
„ . .	..	..	..	..	1,509	66.0	7.99	74.0

In this table, the standards of comparison adopted are, for the waggon and haystack boilers, 12.9 lbs. of water, being the value of Lancashire, or Ince-Hall coals; for the Cornish boilers, 13 lbs. of water, being the value of Welsh coals; and for the locomotive boilers, 10.8 lbs. of water, being the value of coke.

The difference in the value of fuels, in the trial boiler, varied about 21 per cent.; whilst the practical difference in various boilers, as seen in this table, is not quite 20 per cent. It is satisfactory to find that 9 lbs. of water, evaporated by 1 lb. of coke, in a locomotive boiler, exceeds the Cornish standard of comparative economy, by 2 per cent. of the value of the fuel used.

In daily practice, the locomotive boiler ranges from about 4 to 10 per cent. less than the Cornish boiler, and, apparently, without reference to the form, or proportions of any given type. Mr. McConnell's boiler, with a heating surface of only 3.7 times that of the fire-box, shows an equal evaporative economy to Engine No. 234, and to the "Heron," both having surfaces, 13 times that of the fire-box.

The following table, compiled from various authorities, gives the heating surface, the evaporative power, and the economy of a number of locomotive boilers, and three stationary boilers :—

RELATIVE HEATING SURFACE AND EVAPORATIVE POWER of various
LOCOMOTIVE and other BOILERS.

Boilers.	Ratio of Flues to Fire-box = 1.	Total Heat, say	Evaporation per hour.			Velocity per Hour.	Net Load.	Work- ing of Engine.
			Total.	Per 1 sq. ft. of Heating Surface.	Per 1 lb. of Fuel.			
		Sq. ft.	Cub. ft.	Cub. ft.	lbs.	Miles.	Tons.	
Haystack . . .	5.46	229.5	45.0	.196	7.76	..	..	Ord.
Waggon . . .	7.6	342.8	34.4	.100	7.87	..	..	„
Cornish . . .	26.21	961.6	41.4	.043	10.53	..	..	„
Killingworth . . .	4.50	124.0	47.8	.391	4.25	9	..	„
Rocket . . .	5.89	137.8	18.2	.132	5.30	14	..	Max.
Sanspareil . . .	4.75	90.3	24.0	.265	2.16	14	..	„
Novelty, 2nd . . .	7.48	280.0	40.0	.142	10.4	..	..	Exp.
Lincoln and Manchester . . .	7.01	334.5	55.4	.165	6.2	21	..	Ord.
Patentee . . .	8.64	482.0	76.8	.159	7.8	..	..	Exp.
Harvey Combe . . .	6.69	390.1	106.0	.271	7.8	30	..	Max.
Bury, No. 15 . . .	9.68	417.4	94.0	.225	7.4	30	..	„
North Star . . .	9.35	724.7	201.6	.277	7.57	33	40	„
Premier . . .	6.25	377.0	154.0	.408	7.4	26	..	„
Cyclops . . .	6.20	699.0	120.0	.177	7.69	30	60	Ord.
Hesperus . . .	9.17	803.5	116.0	.158	10.3	28	60	„
Royal Star . . .	8.95	821.5	134.0	.163	7.6	30	60	„
No. A . . .	14.5	903.0	170.0	.188	9.0	48	60	Max.
Ixion . . .	6.2	700.0	210.0	.300	7.4	55	60	„
Iron Duke . . .	12.6	1769.0	230.0	.130	8.32	50	70	Ord.
Courier . . .	11.6	1740.0	203.0	.116	7.19	50	70	„
Sphinx . . .	9.97	951.7	233.0	.244	8.75	12	..	Exp.
Caledonian . . .	13.94	704.6	83.2	.118	8.43	35	..	„
Edinburgh and Glasgow . . .	10.47	718.6	91.0	.126	8.5	25	..	„
London and South-Western . . .	10.97	898.5	152.0	.169	8.9	50	..	„
London and North-Western, 234 . . .	12.43	1125.4	78.0	.069	7.94	32	70	„
„ Heron . . .	13.26	707.0	110.0	.155	7.76	38	85	„
„ Mr. McConnell's . . .	3.84	1133.0	191.0	.168	7.79	36	170	„
„ „ . . .	..	..	137.0	.120	8.29	38	85	„

In Mr. McConnell's engines, the fire-box is carried about 5 feet into the cylindrical part of the boiler; and that extension may be an arch, or other convenient form, as the particular class of engine requires. The tubes are 303 in number, each 7 feet long by $1\frac{3}{4}$ inch in diameter; but it is calculated that by using

$1\frac{3}{8}$ -inch tubes, the surface would be increased 30 per cent. without detriment to the engine. Its heating surface is—

—	Outside.	Inside.	With $1\frac{3}{8}$ in. Tube outside.
	Sq. feet.	Sq. feet.	Sq. feet.
Fire-box . .	260	260	260
Tubes . .	978	873	1,270
Total .	1,238	1,133	1,530

As regards rapidity of evaporation per square foot of the total heating surface, it will be seen, by the table, that it follows closely the ratio of the fire-box area, being greatest in the small boilers, and least in the largest boilers. This is probably due to the tubes being too close together in the latter class. The proper disposition of the tubes, to aid the ascent of the steam, early attracted and still requires notice.

The ordinary practice is to place the tubes alternately, hence the steam generated by the lowest, has to run round each alternate tube to the surface. In boilers having sixteen, or more rows of tubes, thus placed, it is quite possible, that the loss of time, in the ascent of the steam, may occasion a relatively slower evaporation; and that by placing the tubes in vertical rows, this might be remedied. With small tubes, the sacrifice of heating surface might be inconsiderable, since 30 per cent., more heating surface, could be got, in the same space, by using tubes $1\frac{3}{8}$ -inch diameter instead of $1\frac{1}{4}$ -inch diameter.

Mr. Stephenson's early practice was, to use tubes $1\frac{3}{8}$ -inch in diameter, and the 'North Star,' with tubes only $8\frac{1}{2}$ feet long, when tried to its utmost power, and speed, by Dr. Lardner, in 1838, evaporated $7\frac{1}{2}$ lbs of water by 1 lb. of coke. This shows how little advance has been made in boiler economy, as distinct from the economy of using the steam after it is generated. In the 'North Star' there was no 'lap' on the slide valves, and the blast pipe was several inches up the chimney, so that its performance was limited by the back pressure of the escaping steam. The 'lap,' and a shorter blast pipe, were subsequently added by Mr. Andrews.

In ordinary working, the greatest portion of the heat passes

through the lowest tubes of large boilers ; whilst in small boilers, it necessarily passes through tubes nearer the surface of the water, so that the want of a free and large evaporating surface of water, appears to be the greatest defect in large locomotive boilers. For, if the steam has not only to struggle up the winding tubular pathway, but has also to force its way from the widest part of the boiler, to a surface 20, or 30 per cent. less, as is the case in many of the large boilers, their relative slowness of evaporation may be accounted for, by the difficulty with which the steam reaches the surface, both from the side and lower tubes. In this respect, Mr. McConnell's boiler has a decided advantage, from its long unbroken surface, near the top of the water. In all the boilers made for Watt, great attention was paid to keep the evaporating surface rather below the widest part of the boiler, as essential to rapidity of steaming, and economy of fuel.

When a locomotive boiler of 58 inches diameter, has only 10 per cent. of steam space, to 39 per cent. of water space, and 51 per cent. of heating space, it is seen how limited must be the evaporating surface, compared to a Watt boiler, where the steam and water spaces were equal.

Compared with a large boiler, as at present constructed, the small boiler has the following advantages—a shorter ascent for the steam,—the heat passes through the tubes nearer the surface of the water, and there is a much larger ratio of evaporating surface, as compared with the water surface. All these points tend to evaporative rapidity.

It is a question open to discussion whether, on a fair trial, a boiler with its tubes in vertical rows, with free vertical steam channels between them, and an evaporating surface nearly equal to the diameter of the boiler, would not give as good results, as the same boiler fitted with a greater number of alternate tubes, and the water surface about 18 inches above the centre of the boiler.

The tabular summary of the trials of boilers, from the 'Rocket' to the present time, shows that, with the ordinary locomotive boiler, evaporative economy follows the increase of the tubular surface, but that evaporative rapidity follows the ratio of the increase of the fire-box surface. Now since the power of a locomotive depends upon the rapid generation of

steam, and the economy of fuel depends upon the velocity of running, it is evident that economy of fuel may be obtained at too great expense of speed and power.

The gauge trials showed this clearly, for with 200 square feet less heating surface, the 'Ixion' evaporated 40 cubic feet of water per hour more than the 'A' engine, or 24 per cent. difference. The economy of fuel was about 15 per cent. in favour of the 'A' engine; but it was obtained under circumstances protested against at the time, and it will scarcely be doubted but that the extra performance of the 'Ixion' was more than equivalent to the economy of the engine 'A,' since power and speed were the prizes contended for, and not economy of fuel alone.

In practice, rapidity of evaporation is as essential as economy of fuel. The boilers with long tubes are the most economical of their class, and the temperature in the smoke-box, at their running velocity, shows that they are not too long, so far as the fuel is concerned; therefore, if it requires a tube 14 feet long, for a speed of thirty miles an hour, it would require a much longer tube, for a velocity of sixty miles per hour, to maintain an equal economy of fuel, or temperature, in the smoke-box. At a speed of thirty miles, the heat may be fairly transmitted to the water, but it may cease to be so transmitted at forty miles, and become wasteful at fifty miles, or sixty miles per hour, as is daily experienced.

In the tabular comparison of boilers, in Mr. Clark's Paper, the Great Western speed is given as fifty miles, the Caledonian as from thirty miles to forty miles, and the Edinburgh and Glasgow—as under twenty-nine miles. With such discrepancies of speeds, there can be no real comparison; for if the economical small engines can neither maintain the speed, nor exert the power of large engines, then all comparison ceases. Economy of fuel also varies with the load and speed, so that comparing heavy engines, at high speeds, with light engines, at low speeds, is much the same as comparing goods' and passenger engines, without reference to the duties they were designed to perform.

Large boilers, mounted on high wheels, have the advantages of a slower rate of combustion, and of longer time to transmit the heat to the water, than boilers on low wheels; and at equal

velocities these recognised elements of economy should give the greatest evaporation.

The number of draughts of steam from the boiler per hour, depends upon the height of the driving-wheels, and, all other circumstances being alike, there will be the least amount of priming, with boilers on high wheels.

For different sized driving-wheels, and different velocities, the draughts of steam, and the time allowed for the absorption of the heat, in locomotive boilers, are comparatively as follows :—

Diameter of Driving Wheels.	Draught of Steam and Blasts per Second for a speed per hour of			Ratio of Draught and Time to 8-foot Wheel.	Difference in Favour of 8-foot Wheel.
	40 Miles.	50 Miles.	60 Miles.		
Fect.	No.	No.	No.	Per Cent.	Per Cent.
5½	13.58	17.0	20.4	68.6	31.4
6	12.4	15.5	18.7	74.8	25.2
6½	11.5	14.3	17.4	80.4	19.6
7	10.7	13.3	16.0	87.5	12.5
7½	9.95	12.4	14.9	93.8	6.2
8	9.1	11.6	14.0	100.	..

This table shows, that the boiler on 8-foot wheels, has an advantage of 19 per cent. over the 6½-foot wheels, 25 per cent. over the 6-foot wheels, and 31 per cent. over the 5½-foot wheels, in the time given for the absorption of heat, and the escape of steam.

The wear of the tubes also decreases, with the decreasing number of blasts through them. This has been found to be the case with the Great Western locomotives. On that line a set of tubes has run with

5-foot wheels	from	62,018	to	68,728	miles.
6	„	„	71,264	to	83,425 „
7	„	„	74,778	to	94,620 „
8	„	„	116,634	to	140,000 „

The locomotive boiler may be said to have originated, in this country, in 1829, with the 'Rocket,' although it was not the tubes, but the blast-pipe, which decided the issue at that memorable trial; for without the blast-pipe, the 'Rocket' only

realised about 10 miles per hour, whilst with it the speed attained was about 30 miles per hour.

With nearly 60 per cent. less heating surface, and 13 per cent. greater load, the 'Sanspareil' evaporated 24 cubic feet of water per hour, whilst the 'Rocket' only evaporated $18\frac{1}{4}$ cubic feet. Taking their relative surfaces, this gives, in round numbers, double the evaporative rapidity per square foot for the 'Sanspareil,' and rather more than double the economy of fuel for the 'Rocket.'

The table also shows, that, without reference to speed, there are only four boilers which exceed the Great Western, or Mr. McConnell's boilers, in evaporative economy. After conducting a series of eighteen experiments with Mr. McConnell's engine, Mr. Marshall reports, "The amount of this combustible gas appears to be important, as the combustion-chamber in the new engine is maintained full of flame, reaching to the mouth of the tubes." He also states, that the pressure of steam increases rapidly, when standing at the stations; that on one occasion it rose 35 lbs. in $3\frac{1}{2}$ minutes; on another 18 lbs. in 3 minutes, but that the damper prevented any particular waste of steam. These eighteen experiments were extended over a distance of $1,398\frac{3}{4}$ miles. The steam was up 4,860 minutes, and deducting the time lost in ninety-six stoppages = 2,279 minutes, the rate of travelling was $32\frac{1}{2}$ miles per hour, over the rails in a bad state, during the months of December 1852 and January 1853.

Whilst running, the consumption of coke was 52,637 lbs. and the water used was 418,932 lbs.; giving an evaporation of 7.97 lbs. of water by 1 lb. of coke. As experience was gained in managing the fire, the evaporative economy increased up to 9 lbs. of water by 1 lb. of coke. During the last five trials, the mean speed was 35 miles an hour, with 70 tons; there were twenty-nine stoppages in $413\frac{3}{4}$ miles, and an evaporation of $8\frac{1}{2}$ lbs. of water by 1 lb. of coke.

The following table gives the results of some comparative trials, with two ordinary engines, called the 'Heron' and the 'Prince of Wales,' one of Mr. McConnell's engines, (No. 291,) and one of Mr. Stephenson's eight-wheeled engines, (No. 234). The 'Heron' and 'Prince of Wales' had cylinders 15 inches diameter, and stroke of 20 inches, with driving-wheels 6 feet

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diameter. Mr. McConnell's engine had cylinders 18 inches diameter, and stroke of 24 inches, with driving-wheels 8 feet diameter; whilst Mr. Stephenson's engine had cylinders 16 inches diameter, and stroke of 24 inches, with driving-wheels 7 feet 1 inch, diameter.

ENGINES.	Net Load.	Coke.		Water Evaporated by 1 lb. of Coke.	Distance run.	Velocity in Miles per Hour.	Direction of running.	Date.
		Total.	Per Mile.					
		lbs.	lbs.	lbs.	Miles.			1853.
McConnell's (291)	45	2,470	22.25	5.92	111	42.1	Up	Feb. 24
Heron	45	2,192	19.75	7.17	111	42.1	"	"
McConnell's (291)	65	3,310	29.82	6.4	111	36.5	Down	" 25
Heron	65	3,479	31.34	7.32	111	34.5	"	"
McConnell's (291)	85	3,040	27.38	6.59	111	34.2	Up	" 26
Heron	85	2,872	25.88	7.74	111	32.0	"	"
McConnell's (291)	105	3,420	30.81	6.84	111	31.0	Down	" 27
Heron	105	3,374	30.41	7.44	111	30.0	"	"
McConnell's (291)	125	3,347	30.15	8.14	111	25.0	Up	Mar. 1
Heron	125	3,144	28.32	7.66	111	25.0	"	"
McConnell's (291)	85	3,220	29.0	7.03	111	35.8	Down	" 4
Heron	85	3,179	28.64	7.56	111	33.6	"	"
McConnell's (291)	85	3,157	28.44	8.27	111	38.0	Up	" 7
Heron	85	3,210	28.91	6.72	111	38.0	"	"
McConnell's (291)	85	2,942	26.45	8.3	111	38.0	Down	" 5
Heron	85	2,815	25.37	7.97	111	36.9	"	"
McConnell's (291)	170	4,529	40.8	7.99	111	36.4	Up	" 8
Heron and Prince of Wales	170	4,851	43.70	8.33	111	34.5	"	"
Stephenson's (234)	35	1,853	22.39	7.19	82 $\frac{3}{4}$	27.0	Up	Mar. 10
"	60	1,973	23.84	8.09	82 $\frac{3}{4}$	31.5	Down	"
"	50	1,899	22.94	7.94	82 $\frac{3}{4}$	25.7	Up	" 11
"	60	1,996	24.12	7.67	82 $\frac{3}{4}$	"	Down	"
"	60	1,920	23.20	8.0	82 $\frac{3}{4}$	26.0	Up	" 12
"	70	1,959	23.67	8.12	82 $\frac{3}{4}$	32.0	Down	"

With few exceptions, the speed was in favour of Mr. McConnell's engine; and as time is equivalent to coke, at equal speeds, the consumption of coke would have been less per mile. For instance, with the load of 170 tons Mr. McConnell's engine performed the distance in ten minutes less time than the 'Heron' and the 'Prince of Wales,' which is equivalent to 6 miles running. The coke consumed was 4,529 lbs. and taking the distance as 117 miles, it gives 38.7 lbs., and one set of men, against a consumption of 43.7 lbs. of the two engines, and two sets of men. In like manner, in some of the other trials, the time was 13 minutes in favour of the new engine.

If the consumption of coke is given correctly for the two engines, it would appear, that two engines with a load of 170

tons consume about 15 per cent. less coke, than they would do separately, each with 85 tons.

As, however, the ratio of evaporation gives about 2 tons more water used by the two engines for the lesser duty, than was required by Mr. McConnell's engine for the greater duty, it indicates, that either the extra machinery of the second engine required this power, or that priming took place, through the number of draughts from the boiler, in several of the trials.

It is stated, that speeds of nearly 60 miles an hour with the heavy load, and about 70 miles an hour with the light loads, have been attained with Mr. McConnell's engine; whilst the trials of the engines with driving-wheels 8 feet in diameter on the Great Western, which have frequently run 53 miles in 50 minutes, and even in 48 minutes, with express trains, sufficiently demonstrate that a maximum speed, of 70 miles an hour, is attainable by such engines.

Since it is a matter of experience, that no new engine, or boiler, works so well as an older one, which has reduced the substance of its tubes, and polished its own bearings, and that each locomotive has its own constitutional peculiarities, the first performance of the first engine of a class, may, or may not, be the best as regards its power and economy. Taking the experiments as the first performance of a new engine, they are decidedly favourable. The evaporative economy ranges from about 7.6 lbs. to 8.5 lbs. of water per 1 lb. of coke, under ordinary circumstances, and up to 9 lbs. under favourable ones, or the assigned limit of the best boilers with long tubes. These evaporative results are the best proof, that the heat is fairly transmitted to the water, by the new form of boiler.

Mr. McConnell's present boiler may, or may not, be judiciously proportioned in all its parts, but that is not the question, since if it accomplishes this rate of evaporation, it would appear to be proved, that there are other and more convenient forms of boilers, adapted for locomotives, than those in general use.

Locomotives require to be constructed of different power for different duties. Mr. McConnell's boiler seems to admit of considerable variety of form and size, and of inside cylinders, with a low centre of gravity and high driving-wheels, so long felt to be a desideratum on the narrow gauge; although it is held by some engineers, that outside cylinders are not ob-

jectionable, more particularly on Mr. Crampton's plan, with the driving-wheels behind the fire-box.

By arching the combustion-chamber of Mr. McConnell's boiler to any extent desirable, the height of the boiler may be reduced at pleasure, and yet the cylinders may either be close together, or not, as might be preferred for the valve-gear arrangements.

As at present constructed, the position of the cylinders of the three varieties of engines, already referred to, with wheels of 8 feet in diameter, are,

Mr. McConnell's Engine	27 inches	between their centres,	or	100 per cent.	
'Iron Duke' . . .	50	"	"	"	185 "
'Liverpool' . . .	76	"	"	"	281 "

This shows a difference of 85 per cent. over the 'Iron Duke,' and 181 per cent. over the 'Liverpool,' in favour of the central traction of the pistons of Mr. McConnell's engine.

Thus fairly tested by the highest standard, Mr. McConnell's engine takes a high position, alike for its power, economy, and constructive facilities.

In comparing different boilers, or engines, it is necessary to keep in view the pressure of the steam, under which the evaporation takes place. For although a cubic foot of water, as steam of equal temperature, will perform an equal duty in any engine as a whole; yet it gives out an increasing power as the temperature is increased under which it is generated. This difference is shown in the following table.

It may be remarked, that as a more convenient dynamic standard than the ordinary one, has often been suggested, the natural law that a cubic foot of water, as steam of the pressure of the atmosphere, gives out exactly 60,000 lbs. raised one foot in one hour, it readily suggests itself as a convenient unit for two horses' power, and is also in accordance with Watt's practice, of estimating the power of his engines, by a cubic foot evaporated per horse-power per hour. It has also the advantage of being exactly $\frac{1}{10}$ ths of the usual 33,000 lbs. value, so that they are easily convertible into each other. The inconvenience of changing standards is however fully appreciated, but for convenience the 30,000 lbs. value is taken as the horse-power.

POWER of a CUBIC FOOT of WATER, as STEAM of different TEMPERATURES.

Tempera- ture.	Pressure per square Inch.	Total Power.	Atmo- spheric Resistance.	Available Power in 30,000 lbs. H.P.
Fah.	lbs.	lbs.	lbs.	
212	14.7	60,000	60,000	..
295	60.0	67,680	17,254	1.671
306	70.0	68,544	14,400	1.804
315	80.0	69,504	12,776	1.89
324	90.0	70,200	11,470	1.958
332	100.0	70,800	10,411	2.013
339	110.0	71,544	9,563	2.066
345	120.0	72,000	8,823	2.106
352	130.0	72,696	8,223	2.149
357	140.0	73,250	7,694	2.185
363	150.0	73,600	7,235	2.212
368	160.0	73,728	6,776	2.231
378	180.0	74,736	6,106	2.288
387	200.0	75,569	5,541	2.334

In this table, the atmospheric resistance is taken, for the volume due to the pressure, without reference to the expansive action of the steam. For, if that volume is expanded fourfold, the atmospheric resistance has also to be overcome four times; therefore the economical working of steam, expansively, is limited by the aggregate of the atmospheric resistance, and the friction of the mechanism. It will also be noticed, how rapidly the power derivable from a cubic foot of water, as steam, increases with the pressure, irrespective of expansion; and that from being equal to the atmosphere at 14.7 lbs. pressure, it is about fourteen times greater than the atmosphere at 200 lbs. pressure per square inch, or as steam of 75,569 lbs. power, to the atmospheric resistance of 5,541 lbs.

The investigation, by Mr. D. K. Clark, of numerous boilers in daily use, concludes by recommending a proportion of 85 square feet of heating surface to each square foot of fire-grate, as consistent with consuming 112 lbs. of coke per square foot of grate, and an evaporative power of 9 lbs. of water by 1 lb. of coke.

As the formula takes no cognizance of the two important elements of load and speed, its application must be limited to one particular class of engines, under given conditions; but it is not adapted to the fluctuating conditions of ordinary traffic. If the proposed formula can be amended, to embrace this fluctuating condition of railway traffic, it will be a useful effort to apply defined rules, for each class of engines.

The various tables given in this Paper show clearly, that the proportion of tubular and fire-box surface, may be varied for constructive, or other requirements, without any appreciable loss; and that the Great Western, Crampton's, and McConnell's boilers, on 8-foot wheels, combine the acknowledged elements of evaporative economy.

By way of contrast, with the latest designed locomotive,—that by Mr. McConnell,—allusion may be made to the first locomotive constructed at Paris, from the designs of M. Cugnot, in 1769-70, or eighty-three years previously. Cugnot's boiler was of a flattened spheroidal form, with two separate fire-places inclosed in an outer case. The mechanism and boiler were mounted on a bogie frame, with a single leading wheel in front, 50 inches in diameter, having a tire 7 inches broad, with a fluted surface to bite the road. It had two vertical single-acting cylinders, each 13 inches in diameter, arranged on Papin's plan—usually known as Leupold's—with a four-way cock, which admitted steam alternately from the boiler to one cylinder, and from the other cylinder to the atmosphere. The piston rods worked downwards, as afterwards adopted by Bull, in Cornwall, to avoid Watt's patent, and now common in pendulous and other engines. Locomotion was obtained by the piston rods working a double-ended ratchet-wheel catch on each side of the driving-wheel, and their alternate action maintained rotation. The motion was reversed by changing the acting end of the catch, and was stopped by throwing both ends out of gear.

It may be remarked, that it is a question open to discussion, whether, as traction is preferable to propulsion, it would not be preferable to place the driving-wheels of all locomotives in front, like Cugnot's, than as they are usually placed.

The safe strength of boilers is another and most important part of locomotive economy. As at present constructed, a locomotive boiler is far from being a homogeneous structure, and as it becomes old, the parts which have to sustain the alternating force of expansion and contraction, lose their original cohesive force, and an explosion occurs. If the structure were homogeneous, and of equal elasticity, or nearly so, it would tend to greater safety in all boilers; and since Mr. McConnell's boiler shows, that the ordinary form may be departed from, as regards the tubes, it suggests that the rectangular fire-box might

be changed into the stronger cylindrical form, and thus the real strength of the boiler would be increased.

Experience leads to the opinion, that the safety-valves and the steam-pipe orifices are the two most dangerous parts of any boiler; and that explosions are much more likely to occur at these parts, or directly opposite to them, than at any other part.

This opinion is based upon the fact, that several locomotive boilers have burst at those parts, arising, it is believed, from the concentrated rush of steam to the steam-pipe, or to the safety-valve, as either might be opened, and to the internal equilibrium in a weak boiler, becoming thus destroyed.

This would produce a local pressure, for an instant, far greater than the ordinary pressure, and if the point of collision, or its opposite point of reaction, failed to resist that pressure, rupture would ensue, even though the safety-valve should be in perfect order, and should not be overloaded. The vast elastic force, of the expanding water and steam, thus suddenly released, would, like any other spring, exert a force far beyond the limit due to the quiescent pressure, and after investigation might show, that the explosions had frequently resulted from tampering with the safety-valves. It may also be noticed, that the ordinary safety-valve does not open its entire area to any boiler, but only a concentric ring of about one-eighth, or one-fourth of an inch wide, which is too little for such expansive force, even when directed against the valve itself. Suppose, for example, that the pressure in a boiler is 100 lbs. per square inch, in a quiescent state, but that the sudden opening of the regulator, or safety-valve destroys that equilibrium; there is then an instantaneous rush of steam towards that opening, and a simultaneous formation of steam by the disturbed water; therefore, it is not the 100 lbs. pressure which the boiler has to sustain, but it is the collision of various forces of 100 lbs. each, sustained by the rapid formation of more steam, which the boiler has to resist, and which leaves their destructive energies only too apparent, when rupture ensues.

This view of the explosive force of steam and heated water, does not involve any supposed tampering with, or neglect of valves, so often mooted, and it is believed to be more in accordance with the known powers of elastic force and boiler resistance.

Before closing these remarks, it is desirable also to call atten-

tion to the numerous cases of passenger-engines, or trains running off the rails, without apparent cause, although goods', or slow trains seldom meet with the same casualty.

This points directly to velocity as the ruling cause, and to deeper wheel-flanges as a simple and good remedy. It is quite probable, that many of these accidents might have been prevented, by a flange only one-half inch deeper than the present one; for, at the high velocities now run, a flange of one inch deep, is but a narrow limit between safety and danger. An extension to $1\frac{1}{2}$ inch, or even 2 inches, where the rails would admit of it, would greatly increase the safety, without, in the slightest degree, increasing the friction in running.

When the late Mr. Stephenson designed the Liverpool and Manchester Railway, and speeds of only fifteen miles, or twenty miles an hour were contemplated, flanges about one inch deep were sufficient, as is still proved by goods' and other slow trains. But now that heavy engines and high speeds of fifty miles and sixty miles an hour, over indifferent roads, are in the ascendant, a greater depth of flange is required, alike for public safety and railway economy.

From what has been stated, it may be concluded—

That different boilers at different speeds, or the same boiler at different velocities, are not economically comparable.

That fuels differ nearly as much in their steaming powers as boilers.

That a cubic foot of water, as steam, gives out a power varying with the temperature of that steam.

That boilers, with pressures varying from 90, 100, 110, to 150 lbs. per square-inch, are not tractively comparable.

That evaporative economy is not confined to any one form of boiler, and is influenced by the fuel used.

That economy of evaporation may be purchased at the cost of speed and power.

That the economic length of tubes, in ordinary boilers, depends upon the velocity of running and the temperature of the steam.

That Mr. McConnell's boiler gives great constructive facilities, for further improvements in locomotive boilers.

That the Great Western, and other boilers on high wheels, combine the elements of evaporating power and economy.

That boiler explosions are frequently due to internal commotion acting against some local point.

That deeper wheel-flanges would increase the public safety.

The discussion upon the Paper, No. 887, "Experimental Investigation of the Principles of the Boilers of Locomotive Engines," by Mr. D. K. CLARK, being resumed, was continued throughout the evening.