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RESULTS OF EXPERIMENTS WITH A FIFTY HORSE-POWER SINGLE NON-CONDENSING BALL AND WOOD ENGINE TO DETERMINE THE INFLUENCE OF COMPRESSION ON THE WATER CONSUMPTION.

BY D. S. JACOBUS, HOBOKEN, N. J.

(Member of the Society.)

IN a paper presented to this Society at the recent Chicago meeting by Mr. F. H. Ball,† a theory was advanced in regard to the probable effect of compression on the economy of the steam engine, and a law was suggested for determining the most economical compression curve. Since that meeting, an opportunity has been afforded, at the Stevens Institute of Technology, for investigating this subject by experiment, and the following pages are a record of the facts thus obtained.

The engine used for this purpose, which will be more fully described further on, was provided with two valves for alternate use, one of them being a special valve arranged for obtaining full compression to initial pressure, as shown in Fig. 1. Owing to the rather large clearance of this engine, it was found impracticable to obtain the compression curve sought, if any later cut-off was used than the one shown, giving only about 20 lbs. M.E.P., and thus limiting the M.E.P. of Fig. 3 to about 30 lbs., which is considerably below the rated capacity of the engine at which it is supposed to give its highest economy. It was also found necessary to reduce the pressure to about 71 lbs. to obtain the desired compression, and the temporary foundation made it

* Presented at the Montreal meeting (June, 1894) of the American Society of Mechanical Engineers, and forming part of Volume XV. of the *Transactions*.

† *Transactions American Society of Mechanical Engineers*, Volume XIV., p. 1007, No. 545.

necessary to run the engine about 50 revolutions per minute below its normal speed; so that, because of this reduced speed, the low boiler pressure, and the small load, the consumption of steam per indicated horse-power per hour was considerably above what might have been expected from an engine of this class under more favorable conditions. These unfavorable conditions, however, did not present any obstacles to the investigation that was sought regarding the relative economy of varying amounts of compression.

The experiments prove that for either equal amounts of work produced, or for equal points of cut off, the cushion steam in an engine should not be compressed as high as the initial pressure but to some lower pressure in order to obtain the best economy, thus verifying conclusions arrived at by theory in the paper referred to.

The results obtained are as follows:

With a special valve in the engine, so arranged as to compress the cushion steam to the initial pressure, and cut-off at one-quarter stroke, the steam consumption was 37.9 lbs. per hour per horse-power.

For the same work as with the special valve, and compression to two-thirds the initial pressure, the steam consumption was 36.8 lbs. per hour horse-power.

For the same cut-off as the special valve, and compression to about five-eights the initial pressure, the steam consumption was 34.8 lbs. per hour per horse-power.

The cylinder dimensions were: bore, 10 inches; stroke, 11 inches. The steam pressure averaged about 72 lbs. above the atmosphere, and the revolutions 250 per minute.

The average indicator cards for the three sets of conditions are given in Figs. 1, 2, and 3.

The special valve released the steam at a later point in the stroke than the regular valve, so that small corrections have been made in the above figures to eliminate variations from this cause, by extending the expansion line in each case to the end of the card, as represented in Figs. 1, 2, and 3. A Barrus calorimeter was employed to determine the amount of moisture present in the steam, and the moisture was deducted to obtain the steam used. In making the tests, the work developed by the engine was absorbed by means of a Prony brake. The exhaust steam was condensed in a surface condenser, and

weighed. Indicator cards were taken every five minutes, the indicator being cleaned and oiled between each three cards. Readings of the revolutions, temperatures, pressure, etc., were also made every five minutes. The water was collected in barrels, and weighed each fifteen or twenty minutes. The weighings agreed very well among themselves. All tests were

Fig. 1

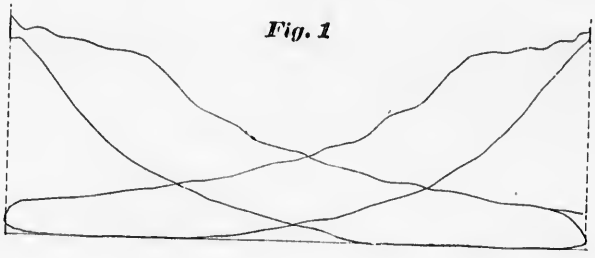


Fig. 2

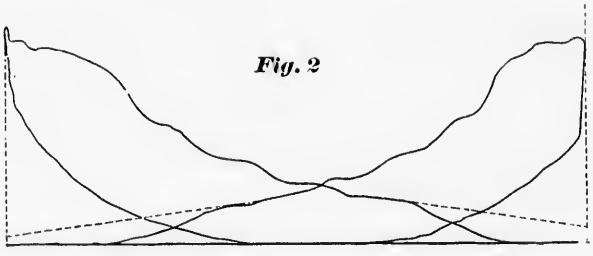
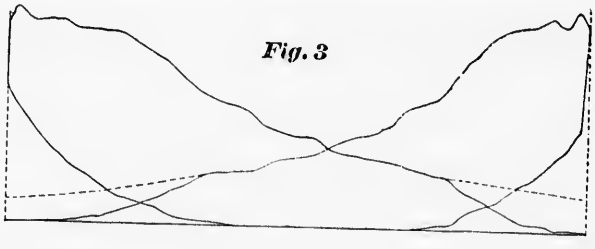


Fig. 3



an hour or longer in duration. In order to make certain that the tests were long enough to insure the proper accuracy, the steam per hour per horse-power was calculated for the first half of five of the runs, and the maximum discrepancy between the results for the first half of the runs and the entire runs was found to be one-tenth of a pound of steam per hour per horse-power, or about one-fourth of one per cent.· this is less than the

possible error, and thus proves that the tests were of ample length.

The results of the separate tests are given in Tables I. and II. The tests made under similar conditions are seen to agree very well among themselves, the greatest discrepancy being one per cent.

TABLE I.

FINAL RESULTS OF TESTS, CORRECTED FOR DIFFERENCES IN POINTS OF RELEASE BY EXTENDING THE EXPANSION LINES TO THE ENDS OF INDICATOR CARDS, AS IS INDICATED IN FIGURES 1, 2, AND 3.

Steam pressure at engine = 72 lbs. above atmosphere. Revolutions per minute, about 250.

Conditions.	No. of Test.	Duration of test in minutes.	Average mean effective pressure in lbs. per sq. inch.	Indicated horse-power.	Steam per hour per horse-power.
Special valve so arranged as to compress the cushion steam to the initial pressure.	4	60	20.81	22.76	37.8
	5	100	20.90	22.80	38.1
	6	120	20.90	22.79	37.9
Average			20.87	22.78	37.9
Ordinary valve. Nearly the same mean effective pressure as for the special valve. Cushion steam compressed to about two-thirds the initial pressure.	2	80	20.37	22.65	36.8
	7	60	20.20	22.00	36.8
	8	60	20.02	21.62	36.6
Average			20.20	22.09	36.8
Ordinary valve. Same point of cut-off as for the special valve. Cushion steam compressed to five-eighths the initial pressure.	1	105	28.14	30.29	35.0
	3	75	27.30	30.46	34.7
Average			27.72	30.33	34.8

For results in detail see Tables III., IV., and V.

TABLE II.

FINAL RESULTS NOT CORRECTED FOR DIFFERENCES IN THE POINTS OF RELEASE SO THAT THE STEAM USED PER HOUR PER HORSE-POWER GIVEN IN THIS TABLE IS THAT ACTUALLY CONSUMED BY THE ENGINE.

Conditions.	No. of Test.	Duration of test in mins.	Average mean effective pressure in lbs., per square inch.	Indicated horse-power.	Steam per hour per horse-power.
Special valve so arranged as to compress the cushion steam to the initial pressure.	4	60	20 69	22.63	38.1
	5	100	20.78	22.68	38.3
	5*a*	40	20.89	22.78	38.2
	6	120	20.78	22.71	38.1
	6*a*	60	20.72	22.62	38.2
Average, not including partial runs marked *a*.....			20.75	22.67	38.2
Ordinary valve. Nearly the same mean effective pressure as for the special valve when allowance is made for differences in the points of release. Cushion steam compressed to about two-thirds the initial pressure.	2	80	18.66	20.75	40.2
	2*a*	40	18.71	20.89	40.2
	7	60	18.48	20.18	40.2
	8	60	18.31	19.77	40.0
Average, not including partial runs marked *a*.....			18.48	20.22	40.1
Ordinary valve. Same point of cut-off as for the special valve. Cushion steam compressed to five-eighths the initial pressure.	1	105	25.89	27.98	37.9
	1*a*	60	25.99	28.01	37.9
	3	75	25.23	28.15	37.5
	3*a*	45	25.08	27.99	37.6
Average, not including partial runs marked *a*.....			25.61	28.06	37.7

The averages marked *a* are for the first portions of the corresponding tests. These averages are used in calculating the performances for the first portions of the runs, which are shown not to vary over one-fourth of one per cent. from the results deduced for the entire runs. This indicates that the runs were of sufficient length. For comparative figures see Table V.

The Barrus calorimeter was attached in the main steam pipe about three feet from the steam chest. The waste steam was carried off a short distance through a three-quarter-inch pipe, which produced a slight back-pressure, so that the lower thermometer read 213° when the exit steam was saturated. The various percents of priming are given along with the average data for the tests in Table III.

Table IV. gives the average heights of the indicator cards, and Table V. the mean effective pressures and calculations of horse-power. Table VI. gives the data observed, and Table VII. the measurements of the indicator cards for one of the tests.

The indicator spring was tested over the entire range of the indicator cards, and all variations in the scale were corrected for

by employing the scale corresponding to each ordinate of the forward and back pressure lines, as explained at the last meeting of this Society in a paper on the Comparison of Indicators. Cards for each set of conditions were taken, and it was found that the differences in the equivalent scales corrected for all variation between the cards under the several sets of conditions, and between the largest and smallest cards of a set, were within the limits of practical errors. The average of the scales, or 58.2 lbs. per inch, was, therefore, used in computing the horse-power. The calculation of the equivalent scales for one of the cards is given in Table VIII.

TABLE III.

AVERAGE DATA OF TESTS AND WEIGHT OF STEAM LESS ENTRAINED WATER.

Number of Test.	Date.	Conditions.	Duration of test in mins.	Total number of revolutions by counter.	Average pressure of steam at engine in pounds per square inch above atmosphere.	Total weight of steam and entrained water in pounds.	Average temperature of exit steam at calorimeter.	Percentage of moisture in steam.	Steam per hour less entrained moisture.
1	March 10	Equal cut-off	105	26,186	70.8	1,881¼	253	1.4	1,060.2
1*a*	" 10	" "	60	14,976	70.8	1,076	253	1.4	1,060.9
2	" 12	Equal M.E.P.	80	20,608	72.1	1,116	227	2.9	831.6
2*a*	" 12	" "	40	10,342	72.1	556¼	224	3.0	838.8
3	" 15	Equal cut-off	75	19,377	71.2	1,322½	256	0.1	1,056.7
3*a*	" 15	" "	45	11,629	71.0	793½	271	0.4	1,053.8
4	" 15	Special valve	60	15,205	71.8	870	259	1.0	861.3
5	April 3	" "	100	25,280	71.7	1,475¼	244	1.8	869.4
5*a*	" 3	" "	60	15,148	71.8	888¼	242	2.0	870.5
6	" 4	" "	120	30,383	72.2	1,741¼	268	0.6	865.5
6*a*	" 4	" "	60	15,175	71.7	868¼	268	0.6	863.0
7	" 4	Equal M.E.P.	60	15,136	72.1	824¼	248	1.7	810.2
8	" 4	" "	60	15,015	71.5	796¼	265	0.7	790.7

A small variation in the amount of work done will cause a greater discrepancy in the results than the difference between the economy at full and for partial compression ; so that unless the greatest care be exercised in performing the experiments, the comparative results may be misleading.

TABLE IV.

INDICATOR CARD MEASUREMENTS.

Number of Test.	Mean Height of Indicator Cards in Inches.				Mean Effective Pressures in Lbs. per Square Inch. Scale = 58.2.			
	Head End.		Crank End.		Head End.		Crank End.	
	Actual.	Corrected for release.	Actual.	Corrected for release.	Actual.	Corrected for release.	Actual.	Corrected for release.
1.....	0.468	0.505	0.425	0.462	27.24	29.39	24.74	26.89
1*a*	0.468	.....	0.425	.....	27.24	.....	24.74	.....
2.....	0.330	0.369	0.302	0.331	19.73	21.48	17.58	19.26
2*a*	0.340	.....	0.303	.....	19.79	.....	17.63	.....
3.....	0.466	0.501	0.401	0.437	27.12	29.16	23.34	25.43
3*a*	0.464	.....	0.398	.....	27.00	.....	23.16	.....
4.....	0.370	0.373	0.341	0.342	21.53	21.71	19.85	19.90
5.....	0.369	0.372	0.345	0.346	21.48	21.65	20.08	20.14
5*a*	0.371	.....	0.347	.....	21.59	.....	20.20	.....
6.....	0.368	0.371	0.346	0.347	21.42	21.59	20.14	20.20
6*a*	0.367	.....	0.345	.....	21.36	.....	20.08	.....
7.....	0.332	0.362	0.303	0.332	19.32	21.07	17.63	19.32
8.....	0.329	0.359	0.300	0.329	19.15	20.89	17.46	19.15

TABLE V.

CALCULATIONS OF INDICATED HORSE-POWER AND STEAM PER HOUR PER HORSE-POWER.

Number of Test.	Duration in Minutes.	Revs. per Minute.	Indicated Horse-power						Steam per hour less entrained moisture.	Steam per Hour per Horse-power.	
			Actual.							Actual.	Corrected for release.
			Head end.	Crank end.	Total.						
1.....	105	249.4	14.82	13.16	27.98	15.99	14.30	30.29	1,060.2	37.9	35.0
1*a*....	60	249.6	14.84	13.17	28.01	.....	.....	.....	1,060.9	37.9	....
2.....	80	257.6	11.09	9.66	20.75	12.07	10.58	22.65	834.6	40.2	36.8
2*a*....	40	258.6	11.17	9.72	20.89	.....	.....	.....	838.8	40.2	....
3.....	75	258.4	15.29	12.86	28.15	16.44	14.02	30.46	1,056.7	37.5	34.7
3*a*....	45	258.4	15.22	12.77	27.99	.....	.....	.....	1,053.7	37.6	....
4.....	60	253.4	11.90	10.73	22.63	12.00	10.76	22.76	861.3	38.1	37.8
5.....	100	252.8	11.85	10.83	22.68	11.94	10.86	22.80	869.4	38.3	38.1
5*a*....	40	252.5	11.90	10.88	22.78	.....	.....	.....	870.5	38.2	....
6.....	120	253.2	11.83	10.88	22.71	11.93	10.91	22.84	865.5	38.1	37.9
6*a*....	60	253.9	11.79	10.83	22.62	.....	.....	.....	863.0	38.2	....
7.....	60	252.3	10.64	9.49	20.13	11.60	10.40	22.00	810.2	40.2	36.8
8.....	60	250.2	10.45	9.32	19.77	11.40	10.22	21.62	790.7	40.0	36.6

TABLE VI.

DATA OBSERVED IN TEST NO. 2.

Time. P. M.	Steam pressure at engine in lbs. per sq. inch above atmos.	Revolution Counter.		Weight of Water Barrels in Lbs.			Prony Brake Scales.	Tacho-meter.	Thermometer in Barrus calorimeter. Degrees Fahr.
		Total reading.	Difference.	Initial.	Final.	Net weight.			
8:35	72	48,428	....	....	....	....	190	158	221
8:40	68	49,723	1,295	....	....	....	190	158	222
8:45	75	51,020	1,297	....	....	....	190	158	226
8:50	73	52,320	1,300	....	....	....	190	158	224
8:55	75	53,610	1,290	79½	369½	289½	190	157	221
9:00	70	54,899	1,289	....	....	....	190	157	220
9:05	72	56,187	1,288	....	....	....	190	157	224
9:10	71	57,471	1,284	....	....	....	190	157	223
9:15	75	58,770	1,299	94½	381½	286½	190	157	222
9:20	70	60,056	1,286	....	....	....	190	157	222
9:25	73	61,336	1,280	....	....	....	190	157	225
9:30	70	62,609	1,273	....	....	....	190	157	238
9:35	73	63,902	1,293	80	365	285	190	157	224
9:40	75	65,190	1,288	....	....	....	190	156	232
9:45	73	66,476	1,286	....	....	....	190	157	222
9:50	72	67,752	1,276	....	....	....	190	157	239
9:55	71	69,034	1,282	95	379½	284½	190	157	237
Averages and Totals.	72.1	257.6*	1,288			1,146	190	157	227

* Revolutions per minute.

TABLE VII.

DETAILS OF MEASUREMENTS OF MEAN HEIGHTS OF INDICATOR CARDS FOR TEST NO. 2.

Time Card was taken. P.M.	Mean Heights in Inches. Head end. Actual.	Head end. Corrected for release.	Crank end. Actual.	Crank end. Corrected for release.	Time Card was taken. P.M.	Mean Heights in Inches. Head end. Actual.	Head end. Corrected for release.	Crank end. Actual.	Crank end. Corrected for release.
8:35	0.344	0.372	0.293	0.322	9:20	0.335	0.366	0.295	0.325
8:40	0.349	0.374	0.303	0.335	9:25	0.335	0.366	0.294	0.323
8:45	0.348	0.376	0.313	0.341	9:30	0.341	0.369	0.303	0.331
8:50	0.335	0.366	0.300	0.329	9:35	0.341	0.369	0.303	0.334
8:55	0.333	0.364	0.300	0.334	9:40	0.333	0.367	0.301	0.323
9:00	0.343	0.375	0.304	0.332	9:45	0.347	0.375	0.304	0.333
9:05	0.344	0.375	0.307	0.335	9:50	0.341	0.369	0.305	0.356
9:10	0.333	0.365	0.297	0.334	9:55	0.337	0.368	0.306	0.338
9:15	0.331	0.362	0.299	0.326					
Average						0.339	0.369	0.302	0.331

TABLE VIII.

CALCULATION OF EQUIVALENT SCALE OF INDICATOR SPRING CORRECTED FOR ALL VARIATIONS IN THE LOT SCALE OF THE SPRING. ORDINARY VALVE. SAME WORK AS FOR SPECIAL VALVE.

Division of card.	Area.	Mean Height.	Corre-spond'g scale.	Area × scale.	Division of card.	Area.	Mean Height.	Corre-spond'g scale.	Area × scale.
A1	0.35	1.10	58.6	20.51	B1	0.20	0.62	58.3	11.66
A2	0.31	0.97	58.7	18.20	B2	0.10	0.31	56.8	5.68
A3	0.21	0.65	58.8	12.35	B3	0.05	0.16	56.8	2.84
A4	0.16	0.50	57.3	9.17	B4	0.005	0.02	56.8	0.28
A5	0.12	0.37	56.8	6.82	B5	0.00	0.00	56.8	0.00
A6	0.09	0.28	56.8	5.11	B6	0.00	0.00	56.8	0.00
A7	0.07	0.21	56.8	3.98	B7	0.00	0.00	56.8	0.00
A8	0.04	0.12	56.8	2.27	B8	0.00	0.00	56.8	0.00
A9	0.004	0.01	56.8	0.23	B9	0.00	0.00	56.8	0.00
A10	0.00	0.00	00.0	0.00	B10	0.00	0.00	56.8	0.00
Totals...	1.354	....	.....	78.64	Totals...	0.355	.....	.....	20.46

Equivalent scale = (78.64 − 20.46) ÷ (1.354 − 0.355) = 58.2