BULLETIN No. 1

BRITISH RAILWAYS

Performance and Efficiency Tests with Exhaust Steam Injector

WESTERN REGION - "HALL" CLASS 2 CYL. 4-6-0 MIXED TRAFFIC LOCOMOTIVE

May 1951

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BR.10800

LIST OF GRAPHS.

BLIDWORTH COAL

Performance Data.

Design Data.

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MARKHAM COAL.

I. INTRODUCTION

This Bulletin contains a series of graphs illustrating inter-dependent relationships in performance and efficiency of the particular locomotive tested, with appropriate notes in explanation.

Whereas there is almost no limit to the range of such interesting relationships which can be worked out, effort has been made to include only those which are necessary to establish in respect of certain engine classes -

(a) The price in terms of coal and water of hauling different train loads at different speeds over given routes.

(b) An indication of the level of efficiency of the locomotive.

(c) Means of comparing one locomotive with another on a common basis.

The presentation of the data in the report is divided, therefore, into two main parts.

The first defines the relationship between coal as fired, water as drawn from the tender, tractive effort and horse-power both as available at the drawbar, data directly applicable to the immediate commercial purpose of examining train loadings and schedules to obtain reduction in fuel consumption by working the locomotives where possible nearest their point of maximum operating efficiency.

The second part concerns itself mainly with thermal efficiency, giving data on a basis of indicated power covering boiler and cylinder efficiencies, factors of more importance in locomotive design.

At a later date it is proposed to issue a bulletin containing a critical comparison of the test results obtained from selected individual locomotive types.

In considering this first series of test bulletins, the following points should be noted :-

(1) In all relationships based on coal, the values shown apply to a particular coal. Variations in quality of coal have a direct bearing on the amount consumed irrespective of locomotive design or condition. As far as possible each locomotive type is tested with at least two qualities of coal, one of which is common to the various engines tested.

(2) By the nature of the testing procedure every value shown on the graphs is obtained under constant conditions maintained for a period of time. Data is not yet available to cover periods of rapidly fluctuating power output, such as occur during acceleration or coasting of stopping trains, and the estimates of coal burned when examining different train speeds and loads are, therefore, in this stage of our knowledge, comparative and not absolute.

(3) The tests described have been made under one or other of two methods of locomotive testing. One of these is generally arranged as a combination of stationary plant test with road Dynamometer Car test at

(3) (Cont'd)

constant rates of steam production, but which may consist of the latter only, a method initiated and developed by Swindon, (Controlled Road Tests). The other is based on the use of the Mobile Testing Plant at constant speeds, a method initiated by the former L.M.S. Railway.

(4) The locomotives tested were in good condition. It is clearly desirable to establish values also for the engine in run down condition but some reflection will indicate the extreme difficulty of defining this in a manner which will be sufficiently representative for a whole locomotive class and this aspect is the subject of further consideration.

(5) Since one of the purposes of these Bulletins is to explain to the Operating Department the manner in which test results can be applied to a consideration of train schedules, a special section is included, setting out this aspect in simple terms.

The tests were carried out under the direction of Mr. R.A. Riddles, Member (Mechanical & Electrical Engineering) Railway Executive, the work being controlled by the Locomotive Testing Committee consisting of :-

	Mr. E.S.	Cox (Chair)	- Executive Officer (Design) R.E.
	Dr. H.I.	Andrews	- Research Dept., Derby.
	Mr. D.R.	Carling	- Superintending Engineer, Locomotive Testing Station, Rugby.
	Mr. C.S.	Cocks	- L.M.R. Derby.
	Mr. S.O.	Ell	- W.R. Swindon.
+	Mr. R.F.	Harvey	- Chief Officer (Motive Power) R.E.
	Mr. T.M.	Herbert	- Director of Research, R.E.
	Mr. R.G.	Jarvis	- S.R. Brighton.
	Mr. B.	Spencer	- E. & N.E.R. Doncaster.

+ Replacing Mr. F.W. Abraham, Superintendent of Motive Power, L.M.Region, as from 14/9/51.

II. NATURE OF THE TESTS.

The boiler and cylinder performances and efficiencies were established in the first instance by tests on the stationary testing plant where also the draughting arrangements were examined, modified and proved. The first series of these tests was made with the live steam injector only in operation because, when this injector is used, the steam produced by the boiler and the steam utilised by the cylinders can be related with greater accuracy to the coal rate and power respectively than is possible when the exhaust steam injector is in use. When these tests were concluded the economy in coal and water effected by the exhaust over the live steam injector was made the subject of special tests. In this Bulletin, results only with the exhaust injector are given.

In the second instance the boiler and cylinder performance were reproduced and their efficiencies confirmed on road tests by the Controlled Road Testing System which also enabled the coal and steam rates to be related to work at the drawbar.

The locomotive allocated to the tests was one of the later engines of its class as distinguished by a larger superheater. When this superheater was introduced no alteration was made in the draught arrangement, which had worked satisfactorily on the earlier engines for many years. The initial tests however indicated that a modification to this arrangement would make available a higher proportion of the potential capacity of the boiler. A modification was therefore carried out, following the proportions recently found at the Swindon Plant to be most efficient for engines with higher superheat. The alterations consisted of reducing the blast pipe orifice diameter by $\frac{1}{8}$" to $5\frac{1}{8}$", in order to maintain the velocity of discharge, and of decreasing the taper of the chimney to 1 in 14 and increasing the length to 2'-4" from choke to top to effect a more efficient ejection. The diameter of the chimney choke was left unaltered at 1'-3".

With these modifications, tests on the stationary plant were possible up to a steam rate to the cylinders of 22,000 lb/hr when Blidworth Hards were fired, this rate corresponding to the maximum grate capacity of the engine on this coal (the "Grate Limit"). With Markham Coal the maximum steam rate to the cylinders on which tests were carried out was 23,000 lb/hr, which is just below the "Draught" or "Front End" Limit for Welsh Coal.

The Grate Limit is reached when no increase in steam production is obtained for an increase in firing rate; an example is given in Graph 12.

Before the "Grate" Limit is reached, steam production may be limited, when some types of coal are burned, by the ability of the draught arrangements to supply the air necessary for combustion, as in the case illustrated by Graph 33. This limit is called the "Front End" Limit; it is obtained by experiment on the Stationary Plant by finding the maximum rate of evaporation at which a balance may be continuously maintained between steam demand and production.

In these results, where a Front End Limit is given, it represents a rate which has actually been fully maintained throughout the stipulated test period; the corresponding Grate Limit has been obtained by extrapolation.

Where a Grate Limit only is given, that also represents a rate which has actually been fully maintained throughout the stipulated test period.

The lowest rate of evaporation on which tests were made was 8000 lb/hr.

The speed range covered was 15 to 70 m.p.h. and the engine was indicated on all but a few tests.

Retaining the modified front end arrangements, the controlled road tests were conducted at rates varying between 20,000 lb/hr and 10,000 lb/hr., with speeds ranging up to just over 70 m.p.h. and loads up to 550 tons behind the tender. On some of the tests the cylinders were indicated and the results showed fairly consistant values of engine resistance over the full speed range and the i.h.p. values agreed closely with those obtained on the stationary tests at the same speeds and steam rates. For the drawbar characteristics, extrapolation was therefore possible to the relatively small extent that was necessary to complete these characteristics beyond and below the rates that were actually obtained.

During the tests observations were made on pressure and metal temperature conditions in the cylinders under power and during drifting with steam shut off. In respect to this investigation and to the economy effected by the exhaust steam injector special Bulletins will be prepared at a later date.

III. METHOD OF TESTS.

As already mentioned the tests were carried out in two parts - as Stationary Tests, on the Swindon Locomotive Testing Plant, and as Controlled Road Tests on the Wantage Road - Filton section of the Western Region, in which tests the Western Region Dynamometer Car was employed as the testing unit.

Stationary Plant Tests.

The basis of all testing was the maintenance of constant rates of combustion and evaporation over relatively long periods. The measurement of the water and coal rates during each test was by the Summation of Increments Method as developed at the Swindon Plant. In this method coal is placed at the disposal of the fireman in equal increments, the weight of the increment being chosen so that it requires 5 to 7 minutes for its consumption whilst the water in the boiler gauge glass is maintained at a constant level. The time is taken at the instant the fireman finishes one increment and is given another. The water injected up to this moment is also measured so that a plot can be made as the test progresses of water injected and coal fired against elapsed time. The validity of the test is shown when it is possible to draw fair straight lines through the points on this graph, covering at least the minimum stipulated test period. The slopes of the lines establish the water and coal rates; as a check the water:coal ratio, reckoned at the end of each increment, is also plotted.

Using this method a few tests were made at constant speed but the majority were made at variable speed and constant rates of evaporation with the help of a special instrument which gives an indication of the rate of steam exhaustion.

The instrument employs the blast pipe orifice as a metering device by measuring the pressure differential across it (actually it is necessary to measure only the pressure below the orifice). This is done by balancing the pressure below the orifice with air pressure, and measuring the air pressure by sensitive manometers, one of which is situated on the Control Table.

The instrument is never used to establish a rate but to show only the variation from the mean, the exact value of which is given by the slope of the water line of the Summations of Increments Graph.

The variable speed tests on the stationary plant are made by running the first part of the test at constant speed until the water and coal rates appear firmly established; the mean value of the flow indication over this period is then ascertained and a movable pointer on the scale of the instrument on the Control Table is set at this value.

Cut-off and speed are then altered together in such a way that the flow indication is kept at the set pointer, and this is arranged to be done in speed "steps" of about 5 m.p.h. The cut-off is noted at each "step" and several indicator cards are taken, great care being observed to take the cards only when the flow indication appears exactly opposite the fixed pointer. In several "steps" a wide range of speed and cut-off can be covered. Meanwhile the summations of increments plots are continued and these must be found to follow linear extensions of the straight lines through the points made during the constant speed portion of the test. The combustion - steam - air cycle of the boiler is found to function irrespective of engine working conditions.

Hence in one variable speed test the dual relationship of coal and steam, steam and power can be established over a wide working range, and by repeating the process at other rates of evaporation the whole of the working range of the locomotive may be covered.

For each variable speed test mean effective pressure-speed - cut-off curves related to a known steam rate are constructed without the necessity of adjustment for boiler pressure variations. The curves corresponding to the various tests are correlated by Willans' lines which are constructed for a number of suitable speeds. These, besides giving data on full and partial regulator working economy, are used as the basis for the construction of the Indicated Characteristics, which show the interrelationship of coal, steam, power and engine working over the whole operating range.

For the purpose of accurately determining the steam rate with respect to power the first series of tests were run with the live steam injector only in use, as already noted.

These were then followed by another series with the exhaust injector in operation, when the economy effected by the use of this injector was measured. The Indicated Characteristics for the live steam injector were subsequently adjusted, having regard to all variations in the principal relationships, to produce the Indicated Characteristics on the exhaust steam injector which are given in this Bulletin.

Controlled Road Tests.

The Controlled Road Testing System consists of running the locomotive with normal loads (of which a Dynamometer Car forms the leading vahicle), at constant rates of evaporation and combustion, for the purpose of relating drawbar effort with steam and coal consumption so that the operating performance and efficiency characteristics may be defined.

The control of the rates of evaporation and combustion is by the adaptation of the flow indicator in conjunction with the summation of increments method of measurement of the coal and water rates, as practised on the variable speed stationary plant tests from which the system was developed.

The fireman takes coal from a partitioned-off part of the shovelling plate of the tender, into which the coal increments are tipped as required from previously weighed bags. An observer in the cab signals this operation to the Dynamometer Car, where the time is noted and where the feed water injected up to that moment is read from a water meter. Overflow from the injectors is lead to a self discharging tank which automatically signals the discharge of a known amount to the Dynamometer Car.

In the steam flow indicator equipment (the air injection apparatus of which is carried in the Dynamometer Car) is included one special manometer in the cab for the driver, one visual and recording manometer in the Car, and one manometer in the indicating shelter on the front of the locomotive when the cylinders are indicated.

Control is entirely in the hands of the driver who, with a full or partial regulator opening as may be previously decided upon, adjusts the cut-off so that, whatever the speed, the flow indication is kept at a pre-set mark. This working is under constant surveillance from the Car, which is in telephonic communication with its observer in the cab.

The slopes of straight lines which must be drawn through the points plotted on the summations of increments graph on all valid tests establish the values of the mean rates by direct measurement, as on the stationary plant tests. The requirements as to maintenance of constant water level are also observed; this is under control from the Dynamometer Car where the relative levels at any instant can be ascertained from comparing the water meter reading with the water line of the summations of increments graph.

The running of one of these tests is shown diagrammatically in Graph 26, although this graph does not show the "warming up" portion of 18 miles which preceded the actual start of the test.

Indicator cards are taken only when the flow indications are level with the pre-set mark and values of drawbar effort which are found when these conditions apply are "weighted".

By running a number of tests at various rates of evaporation, choosing suitable loads for each rate so that the speed range may be covered on each test, the Drawbar Performance and Efficiency Characteristics may be constructed from the results. Train and engine resistance values are produced, of course, in the process.

The Characteristics are checked by calculating speed-distance curves for the test route from data given on these characteristics in respect to loads and steam rates of three of the actual tests at widely differing rates of evaporation; a valuable verification is obtained when these agree with the corresponding test records in respect to speeds, times and coal rates.

Comparing the principal boiler relationships and the steam rate - power relationships resulting from controlled road and stationary plant tests, no significant differences have been found. Results of controlled road tests which were run with the live steam injector have therefore been adjusted for the exhaust steam injector condition in accordance with the findings of the special comparative tests already mentioned. In this connection attention is drawn to the fact that the test illustrated in Graph 26 was run with the live steam injector for special reasons. The relationship between steam and coal consumption for this test may therefore be compared only with the lower curves of each pair of curves in Graph 33, these appertaining to equivalent evaporation from and at 212°F and actual evaporation respectively; the IHP - steam rate relation is not significantly affected in this locomotive.

IV. TEST ARRANGEMENTS.

The steam rates and speeds at which the engine was tested fairly covered the range between the limits given in the preceding subsections. On the stationary plant tests the test period proper was approximately 90 minutes on the average; it was not less than 60 minutes at the highest rates whilst it exceeded 120 minutes on the lowest rate. On the controlled road tests the periods were all approximately 60 minutes of unrestricted steaming on stabilised combustion conditions.

V. LOCOMOTIVE.

The locomotive selected for the test was No.7916 which, since it was built in 1950, had run 22,000 miles; in the interval it had had no piston and valve examination nor had it been in shops for repairs. By the end of the tests the mileage had increased to 26,000.

A diagram giving the leading particulars of the locomotive is given on another page. Additional ratios of interest are :

Free area through grate as a percentage of nominal grate area ...	40
Free area through tube system as a percentage of nominal grate area ...	16
Free area through superheater as a percentage of total free flue area ...	43
Clearance volume of cylinders as a percentage of swept volume	7

The valves are actuated by Stephenson Link Motion; the actual valve setting is shown in a special table on another page.

The superheater is of the "bifurcated" type.

VI. COAL.

The tests were carried out on Markham, a Grade 1 coal from the Tredegar Group Collieries and on Blidworth Hards, a Grade 2 coal.

The Markham in appearance was fairly bright, soft and friable and samples contained a very small amount of shale. In size it varied from pieces of about 2' 0" in greatest dimension to dust, the bulk being 1' 0" in greatest dimension. The Blidworth Hards was generally rather dull and very hard; with a laminated structure. In size it varied from 2' 6" in greatest dimension to dust, the bulk being 2' 0" in greatest dimension. In each coal, the various samples showed little variation in calorific value and proximate analysis; representative values and analyses are given below :-

	MARKHAM		BLIDWORTH	
Calorific Value (Gross)	As received	Dry	As received	Dry
Calories per 1g.	7,960	8,080	6,937	7,685
B.Th.U.per 1 lb.	14,330	14,550	12,490	13,840
Pounds of water at 212°F converted into steam at same temperature by 1 lb. of coal.	14.82	15.05	12.92	14.31
Proximate Analysis	As received	Dry	As received	Dry
Moisture %	1.5	-	9.7	-
Volatile matter, less moisture %	18.5	18.8	32.5	34.9
Fixed carbon %	73.9	75.0	55.1	61.0
Ash %	6.1	6.2	3.7	4.1
Total sulphur %	.82	.83	.50	.55
Coke Character	Fairly hard, Porous		Hard, Porous	
Ratio of volume to that of coal	1.0 : 1.5		1.0 : 1.0	
Ash	Buff, grey tinted		Buff	

Owing to the friable nature of Markham in common with other Welsh coals, and the effect of fine coal on Boiler Efficiency, it was arranged that each increment of coal as bagged and weighed, contained 8% of fines. This was generally less than the proportion of fines in the coal as fired as the coal was subject to further breaking down by the fireman after the increment had been placed at his disposal.

VII. OBSERVATIONS.

The method of testing and frequent sampling and analysis of smokebox gas imposed a rigid control over the frequency of firing and quality of combustion. In general the firing technique was that normally followed in this class of engine.

The firebed for Markham coal was thicker than for the Blidworth at the same firing rate, the depths being roughly in the ratio of the proportions of fixed carbon in the coal fractions. This was reflected in the respective resistances through the firebed. The back damper was used in preference to the front damper as the former effected a more even distribution of air supply over the grate.

Superheat from 10°F. at the lower steaming rates to 30°F at the higher was measured in the exhaust steam. Former tests of engines of this class in new condition gave no significant superheat in the exhaust at any rate. The exhaust steam temperatures observed during the present tests are considered to indicate some leakage past pistons and valves and probably reflect the mileage run by the engine since the last piston and valve examination, although the mechanical condition of the cylinders and associated parts had the appearance of being excellent for that distance.

The engine remained free from mechanical defects for the period of the tests.

APPLICATION OF TEST RESULTS TO OPERATING CONDITIONS.

As indicated in the introduction, the main purpose of these tests was to provide data on which most economical working of the locomotive could be based, consistent with meeting traffic requirements.

There is no reason to think that in general present-day schedule and train loads based upon long standing practice and experience do not allow economical locomotive operation. But since in the testing equipment now available to the Railway Executive there is means of finding accurately the rate of coal consumption of every locomotive at each point in its working range, it will clearly be of some value to examine present schedules and loads to check that they are in fact within the most economical range in their entirety and if not, whether by adjustments over particular sections acceptable to the Operating Department, they could not be so modified as to bring about a reduction in coal consumption. Similarly, proposals for new or accelerated timings can be examined in relation to their cost in coal.

Since the method used, with its possibilities and limitations, will not be familiar to Operating Departments on Regions generally, this section endeavours to explain in simple terms how the data contained in this Bulletin can be applied.

Graphs 1 and 2 indicate the range of power which has been designed into the locomotive in new condition as built. It will perform satisfactorily at any speed, cut-off, drawbar pull or horse-power within the area of these graphs, sufficient test points having been taken to verify this by actual observation. The only variable not connected with the design of the locomotive is the boiler limit which may vary with different qualities of coal.

The cost in coal, the rate of coal consumption per unit of work done, for the various rates of doing work, i.e. different speeds, or different horse-powers, which in turn can be translated directly into actual train loads, is shown in Graph 4. If between two points on the level or on the same gradient on any run, the horse-power required to move the train is calculated based on speed and train resistance, then the rate of coal consumption applicable to those conditions can be derived from Graph 4, and the actual amount of coal used can be calculated. If this is done for each successive change in power demand throughout a whole journey, then the total coal used by that particular engine on that journey can be arrived at, and this can be compared with the amount of coal similarly arrived at which is required to do the same journey with some other load or at different sectional speeds. If the water consumption is required for any reason, this can be similarly arrived at based on Graph 3.

There are different methods by which these calculations can be carried out and after the conditions to be examined have been agreed by the Mechanical Engineering and Operating Departments, the actual working out is better done by the M.E. Department.

In arriving at the final answer, certain commonsense allowances have, of course, to be made, and as more test data and experience accumulates they will be able to be made with increasing exactitude.

For example Graph 4 is based on one particular coal, and adjustments will be necessary if the kind of coal generally available on the particular run to be examined is of different quality. To meet this, the tests which are being carried out with each locomotive class are being made with at least two kinds of coal.

Then Graph 4 is based on an engine in good condition. Separate tests are to be run to ascertain accurately the increase in coal consumption when an engine is 'run down' but in the meantime based on such experience as is already available maximum power output may have to be derated by a certain percentage for engines in such condition, and coal consumption at any rate of working may be increased by a like amount.

Again, all the values obtained in locomotive testing are obtained under constant conditions, and these values may require some adjustment where actual conditions on the road do not allow of stable conditions, as for example when an engine is starting away from a terminal before the fire is thoroughly burned through.

Now there are certain features about the data on Graph 4 which considerably assist in relating test results to practical railway operation. It will be seen that the rates of coal consumption per horse-power at the drawbar for different speeds take the form of rather flat curves. Consumption is higher at low power output, then it continues at a lower rate over a considerable middle range of powers and finally rises again at the highest powers. To make this clearer, Graph 5 extracts a single line from Graph 4 in respect of a particular locomotive, namely that applicable to 40 m.p.h. Instead of showing Drawbar Horse-power as a base, this is translated into actual tons of freight train hauled on the level. The lowest specific rate of coal consumption is seen to result from hauling 640 tons at this speed. If, however, for traffic reasons, the Operating Department does not wish to haul 640 tons, it will be seen that train loads all the way from 480 tons to 900 tons can be hauled without any really appreciable increase in the rate of coal consumption.

This 'flat characteristic' is a most important feature in the economy of the steam locomotive, for it means that although thermal efficiency may not be great in comparison with other forms of motive power, such efficiency as it has is applicable to a wide range of working. This is shown in another way by the thermal efficiency contours indicated on Fig. 1.

Referring again to Fig. 4, lines of constant rate of steam production will be noted, and it will also be observed that the lowest points of coal consumption at each speed fall at a particular constant steam rate. If one of these rates is chosen, say 16,000 lb/hr, then whatever the speed, the engine will be working at or very near its lowest rate of coal consumption all the time it continues to work at that steam rate.

This fact connects with the principle of controlled firing. The greatest economy in the use of fuel is obtained when the engine is worked at this constant rate of steam consumption and coal is fed into the fire at a steady rate of shovelsful every few minutes while steam is on, whatever the gradient or speed conditions may be at the time.

Graph 4 or in a similar manner Graph 1, if the efficiency contours are studied, indicate what steam rate is the most economical. Here again, arising from the 'flat characteristic' feature there is actually a range of steam rates which can be worked to, in this case from 12,000 to 18,000 without appreciable sacrifice of economy.

To sum up, therefore, schedules and loads can be worked out for any route which will give lowest rate of coal consumption, and it will be found that these are related to a certain constant rate of steam production, which in turn relate to a certain rate of controlled firing.

Graph 26 shows part of an actual test run at the most economical steam rate for this particular engine.

To illustrate the trend which this working out of actual schedules and loads may take, four additional graphs, Nos. 6, 7, 8 and 9 are included, which give examples of the cost in coal rate, lbs, per D.B.H.P. and lbs. per trailing ton mile, which results from working different train loads, both passenger and freight, at selected speeds on the level and on 1 in 200.

So far as working of the engine is concerned, certain things must be borne in mind. The data from the actual tests as set out on Figs. 1 and 2 covers working at constant speed and full regulator at different cut-offs down to 10%. While the valve gear will operate over this range, it is not customary for drivers to work engines of this class in service at cut-offs below 20%, lower power requirements being covered by partial regulator working. This is done mainly because a two cylinder engine operates more easily from a mechanical point of view under these conditions, but also from an instinct confirmed by test results, that no sacrifice in economy is being made by so doing. In the graphs showing coal consumption related to train load, therefore, (Figs. 5, 6, 7, 8 and 9) where points of cut-off are shown along the various speed lines, no lower cut-off value than 15% is shown. At any train load lower than that which can be covered by working at 20% cut-off with full regulator, it must be understood that appreciably the same values in coal per D.B.H.P. or per ton mile can be attained by partial regulator working.

Within the above definition a point clearly brought out by graphs 5, 6, 7, 8 and 9, is that the earliest cut-offs are not necessarily the most economical on a Drawbar Power basis. It is true that the earliest cut-off is the most economical from the point of view of the power developed in the cylinders, but a good part of that power is used for moving the engine itself. When the coal used is related not to the total power output in the cylinders but only to that part of it which is available for hauling the train, then the relationship alters and the most economical cut-off from this latter point of view is found usually to be neither very early nor very late but somewhere in between.

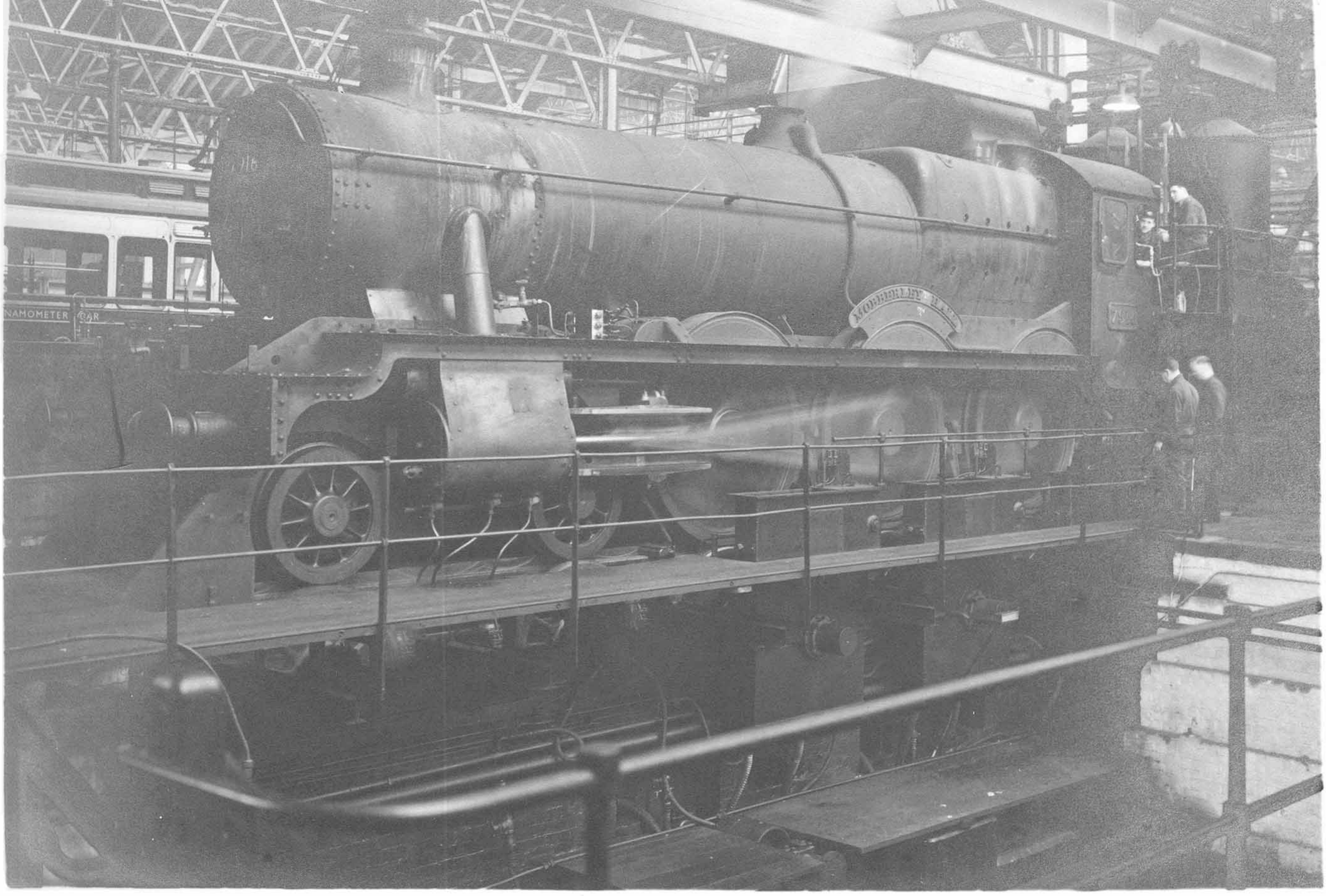
TABLE OF VALVE EVENTS, ENG. NO. 7916.

Piston Stroke 30"; Steam Lap = $1\frac{3}{4}$"; Exhaust Lap = 0.

FORWARD GEAR

Nominal Cut-off %	Travel of Valve	Lead		Opening to steam		Steam Cut-off %		Exhaust Opens %		Exhaust Closes %	
		F.S.	B.S.	F.S.	B.S.	F.S.	B.S.	F.S.	B.S.	F.S.	B.S.
	ins.	ins.	ins.	ins.	ins.						
Full Gear	6.91	-.17	-.19	1.65	1.76	77.2	77.7	94.2	93.7	94.2	93.7
75	6.75	-.14	-.17	1.58	1.68	75.9	76.4	93.5	93.3	93.5	93.3
70	6.29	-.09	-.11	1.36	1.43	72.2	72.8	91.9	91.9	91.9	91.9
60	5.58	-.01	-.03	1.02	1.06	63.4	64.9	88.7	89.0	88.7	89.0
50	4.99	+.06	+.04	.71	.73	51.6	54.4	83.9	84.7	83.9	84.7
40	4.57	+.1	+.09	.53	.54	40.2	43.6	79.3	80.6	79.3	80.6
30	4.28	+.13	+.12	.39	.39	29.4	32.7	73.6	75.6	73.6	75.6
25	4.15	+.14	+.13	.33	.32	24.7	27.9	71.0	72.9	71.0	72.9
20	4.05	+.16	+.14	.28	.27	19.3	21.8	67.5	69.3	67.5	69.3
15	3.97	+.16	+.15	.24	.23	15.5	17.3	64.1	66.1	64.1	66.1
Mid-Gear	3.83	+.18	+.15	.18	.15	6.0	6.1				
				BACKWARD GEAR							
Full Gear	6.62	-.19	-.17	1.62	1.5	78.3	77.8	94.6	94.0	94.6	94.0
75	6.42	-.15	-.15	1.5	1.42	76.4	76.0	94.0	93.8	94.0	93.8
70	5.99	-.08	-.09	1.28	1.21	71.7	71.6	92.5	92.3	92.5	92.3
60	5.3	+.02	0	.92	.88	61.1	61.5	88.9	88.4	88.9	88.4
50	4.81	+.08	+.06	.68	.63	49.5	50.8	84.9	84.4	84.9	84.4
40	4.45	+.13	+.1	.48	.47	36.9	38.6	79.6	79.6	79.6	79.6
30	4.18	+.16	+.14	.35	.33	28.6	28.0	74.1	74.3	74.1	74.3
25	4.08	+.17	+.15	.3	.28	21.0	22.7	70.4	70.6	70.4	70.6
20	4.0	+.17	+.15	.27	.23	17.3	18.5	67.1	67.6	67.1	67.6
15	3.94	+.19	+.15	.24	.2	13.1	14.0	62.9	63.7	62.9	63.7
Mid-Gear	3.86	+.19	+.17	.19	.17	6.1	6.2				

Note:- F.S. = Front Stroke; B.S. = Back Stroke.
Front Stroke is the Piston moving from Front towards Firebox.



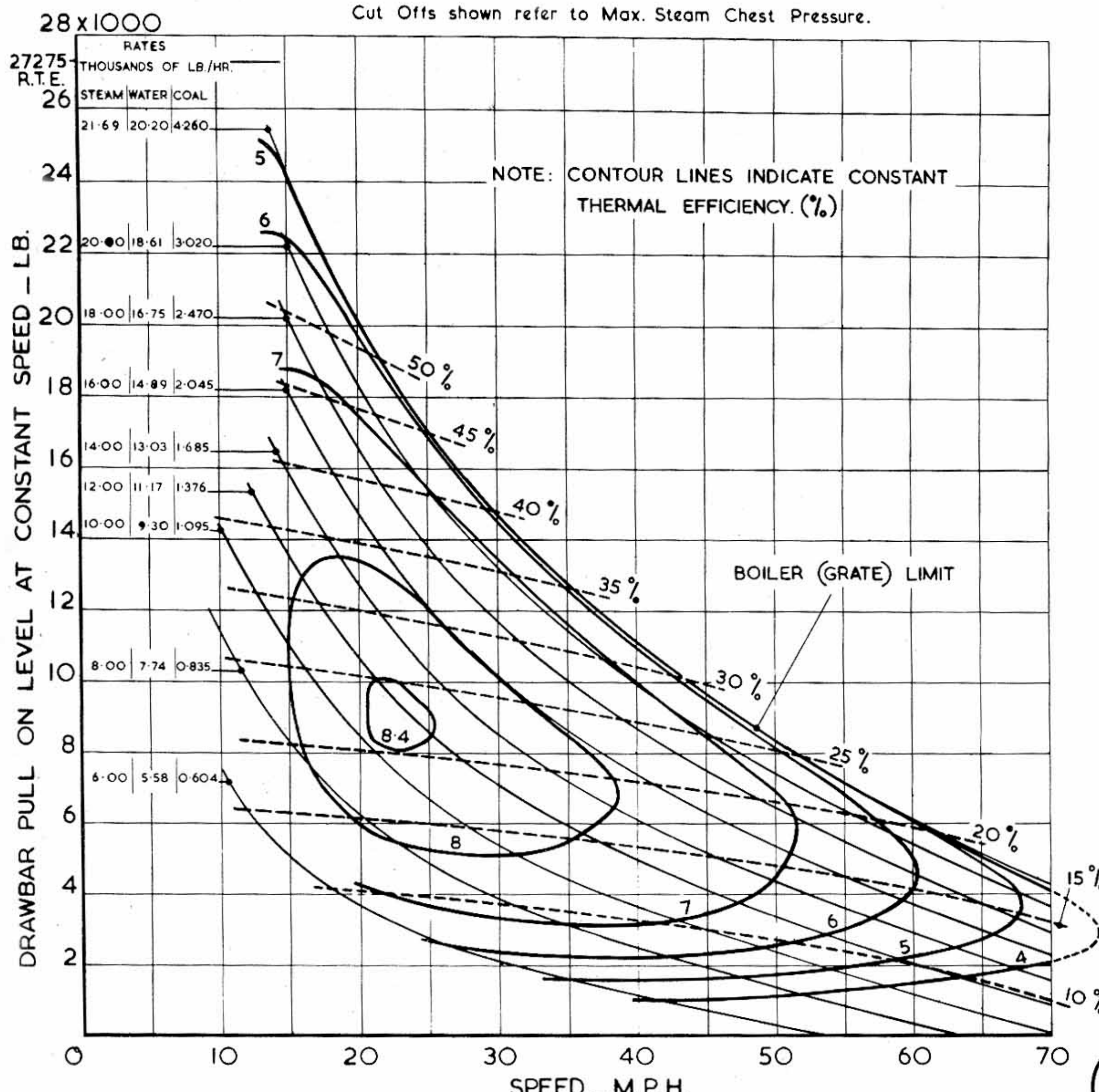
No. 7916 on Test on the Swindon Plant.

No. 7916 with a load of 550 tons about to start from Wantage Road (W.R.) on a Controlled Road Test.
Testing Unit: Western Region Dynamometer Car.

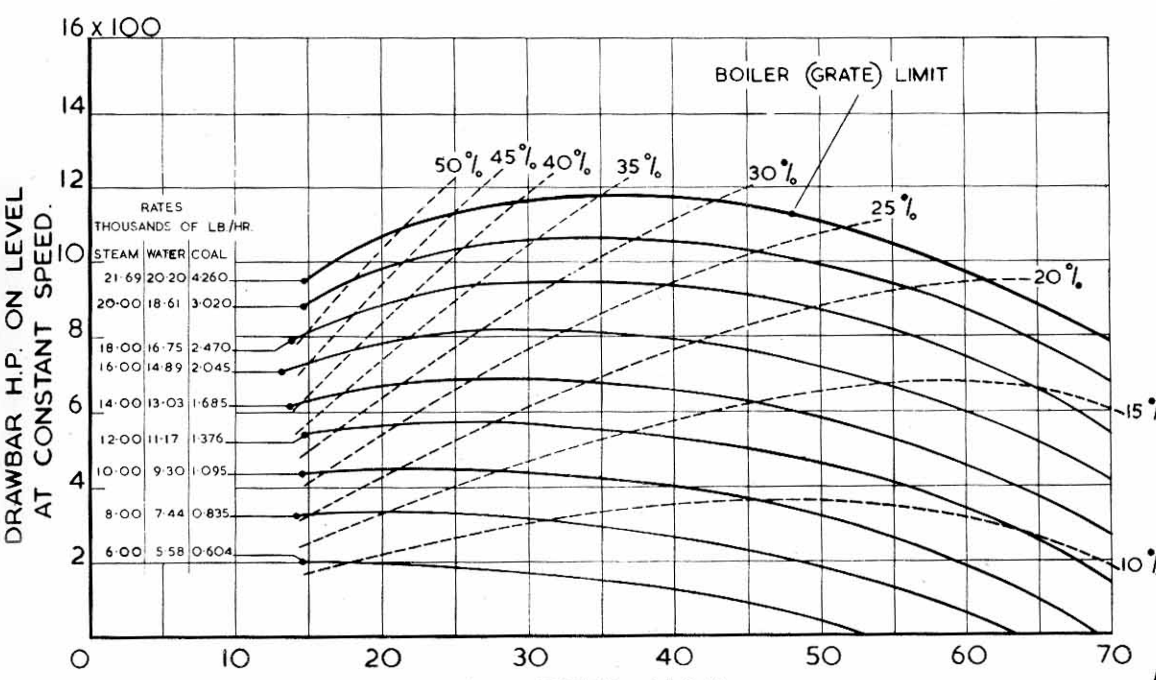
<u>B L I D W O R T H   C O A L.</u>

Performance Data : Graphs 1 to 9.

Design   Data : Graphs 10 to 21.



1



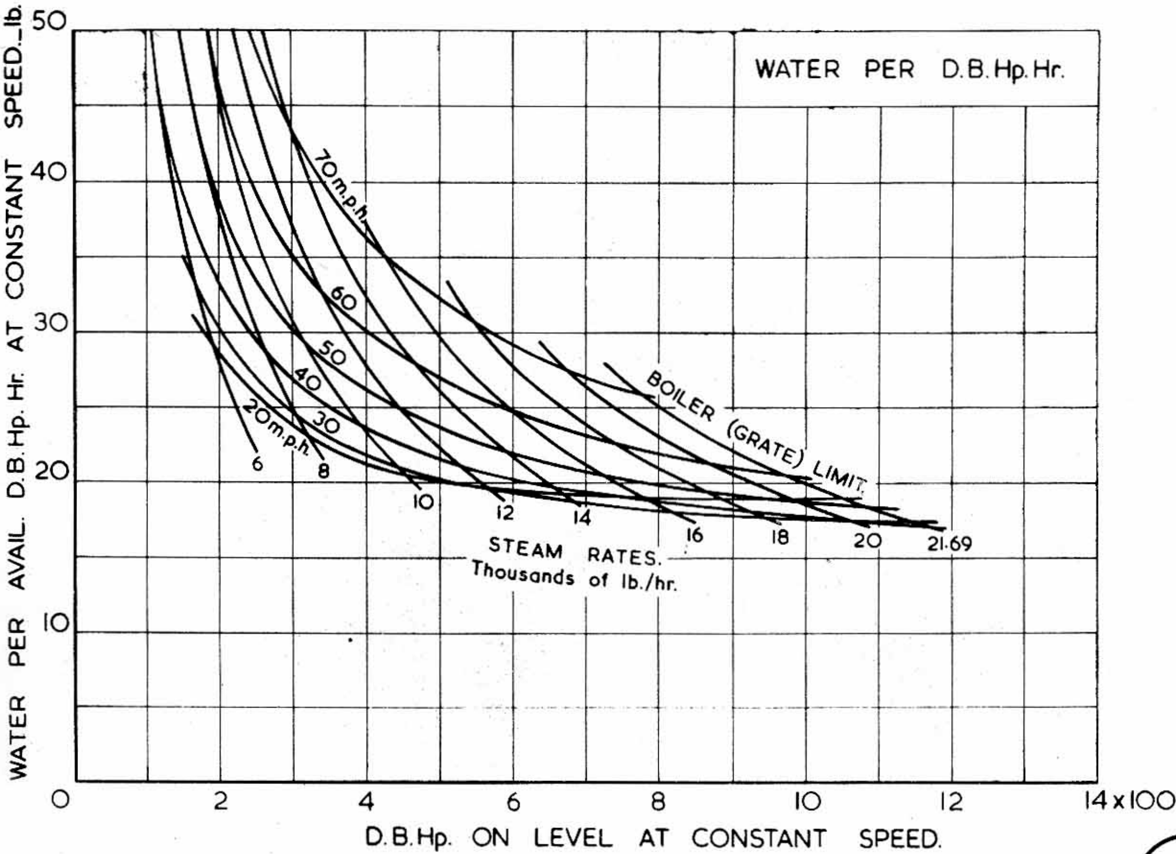
2

BLIDWORTH COAL
12500 B.Th.U./lb.

EXHAUST STEAM INJECTOR.

DRAWBAR CHARACTERISTICS.

LU/7916/51.



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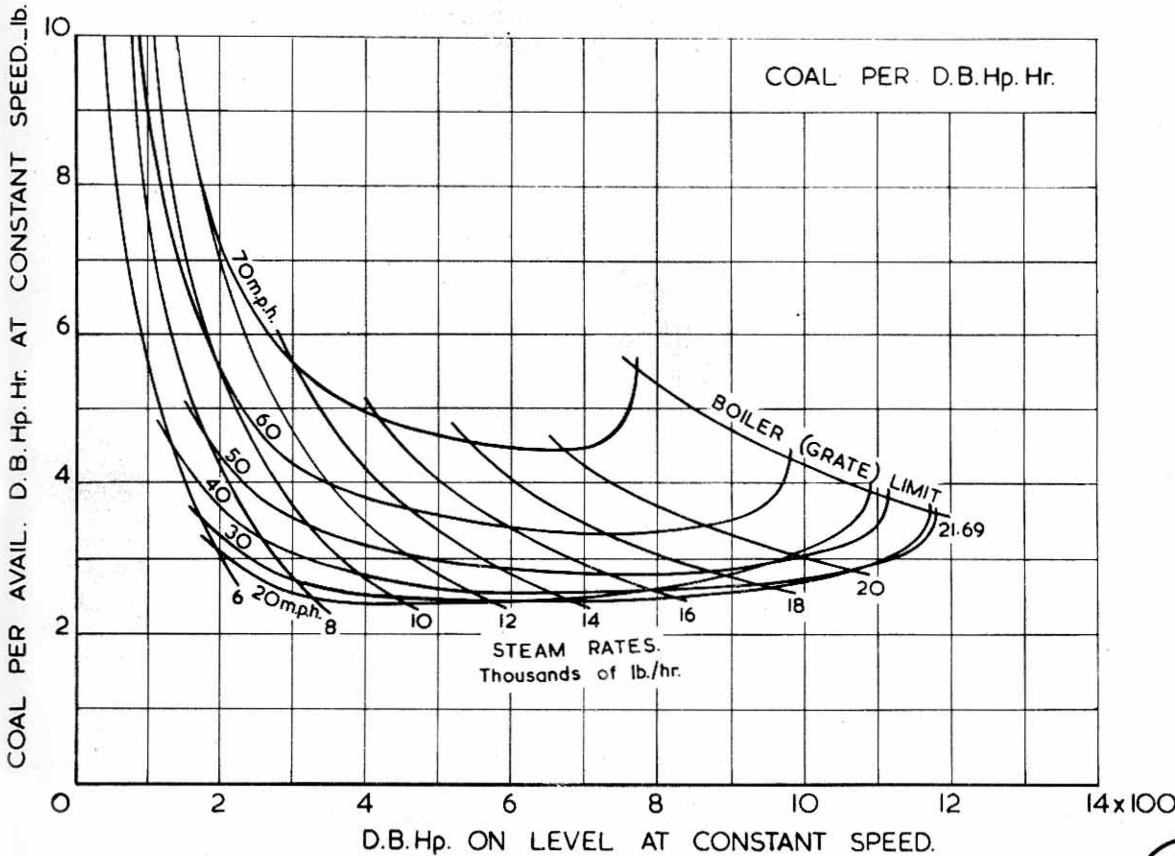


BLIDWORTH COAL
12500 B.Th.U./lb.

EXHAUST STEAM INJECTOR

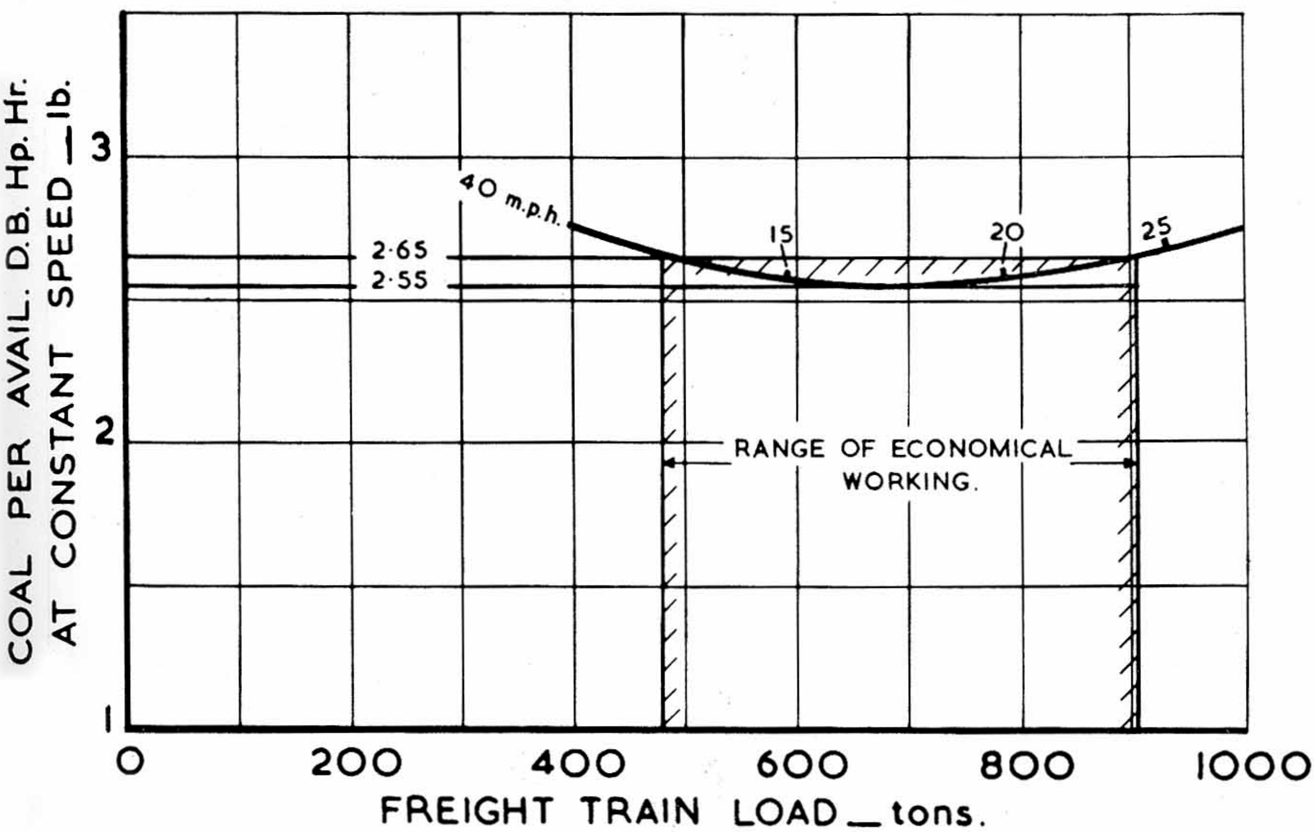
4

WATER & COAL PER D.B.Hp.Hr.

LU/7916/51.

BLIDWORTH COAL.
12500 B. Th. U./lb.

EXHAUST STEAM
INJECTOR.



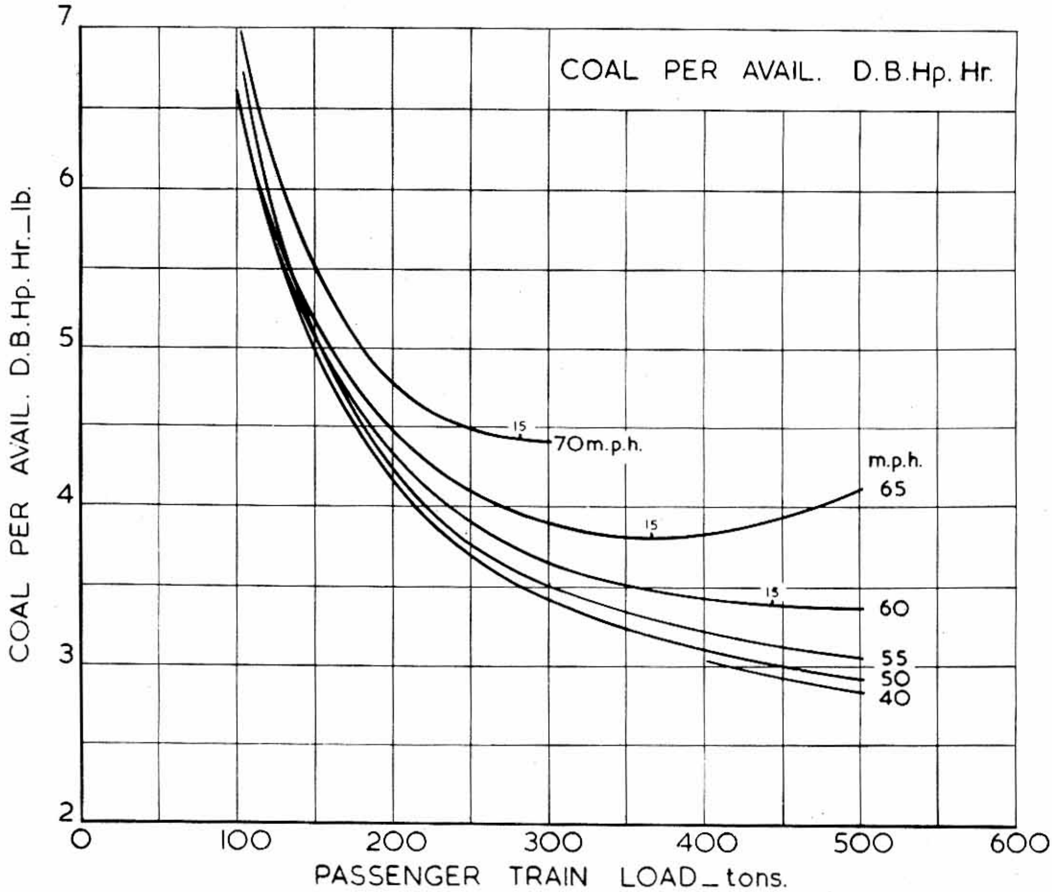
FREIGHT SERVICE _ LEVEL.

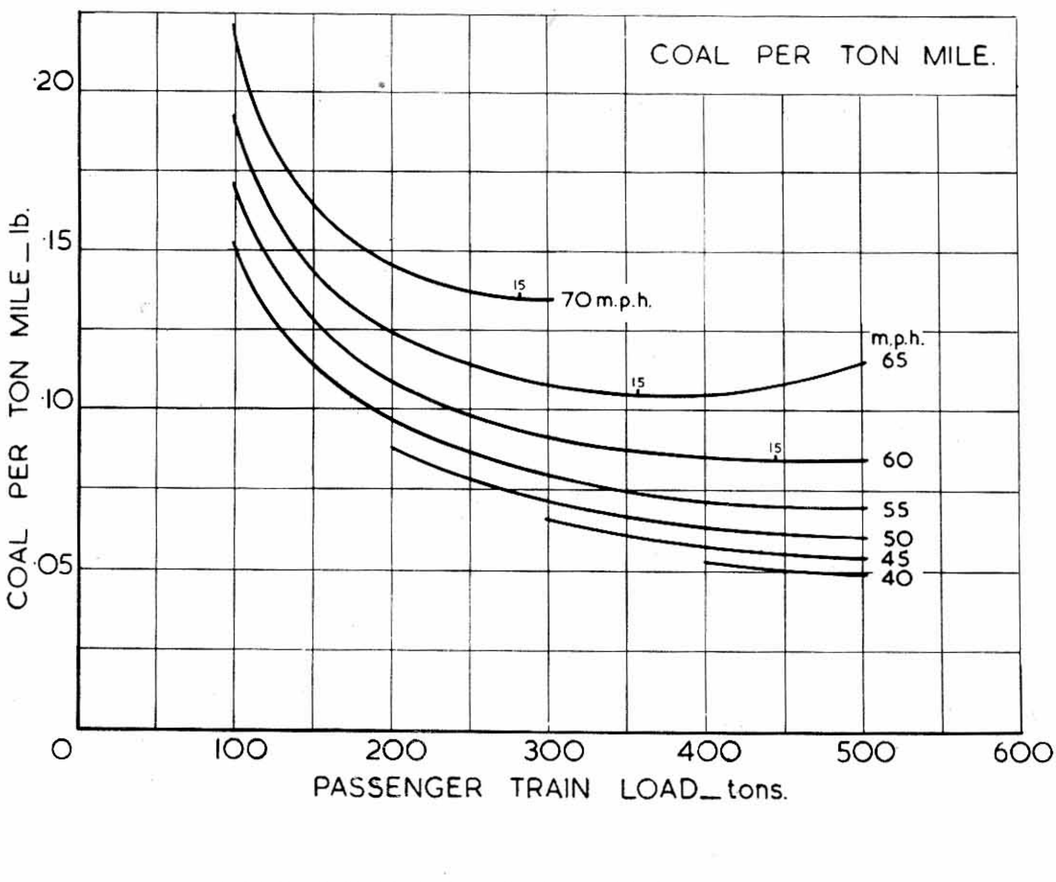
EXAMPLE OF RANGE OF ECONOMICAL
WORKING AT 40 M.P.H.

LU/7916/51.

BLIDWORTH COAL. 12500 B.Th.U./lb. EXHAUST STEAM INJECTOR.

Small Figures on Curves indicate Cut Off, Max. Steam Chest Pressure.





PASSENGER SERVICE _ LEVEL.

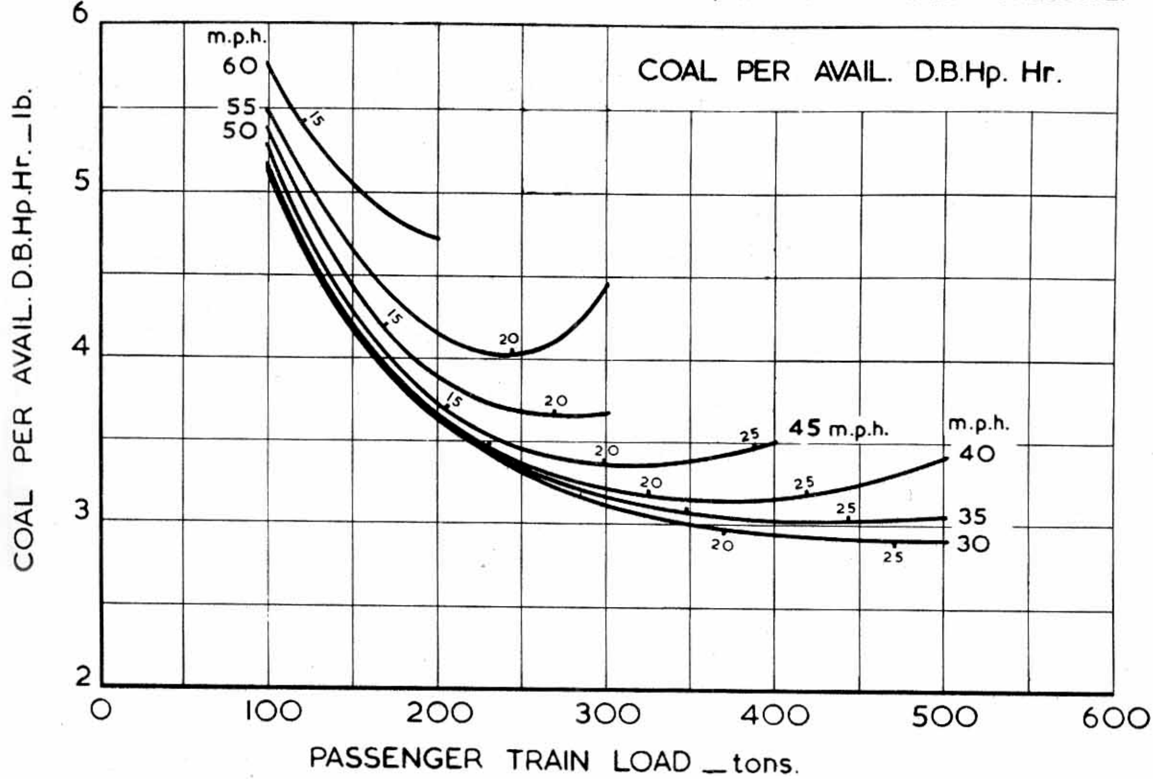
EXAMPLES OF COST IN COAL OF DIFFERENT TRAIN LOADS & SPEEDS.

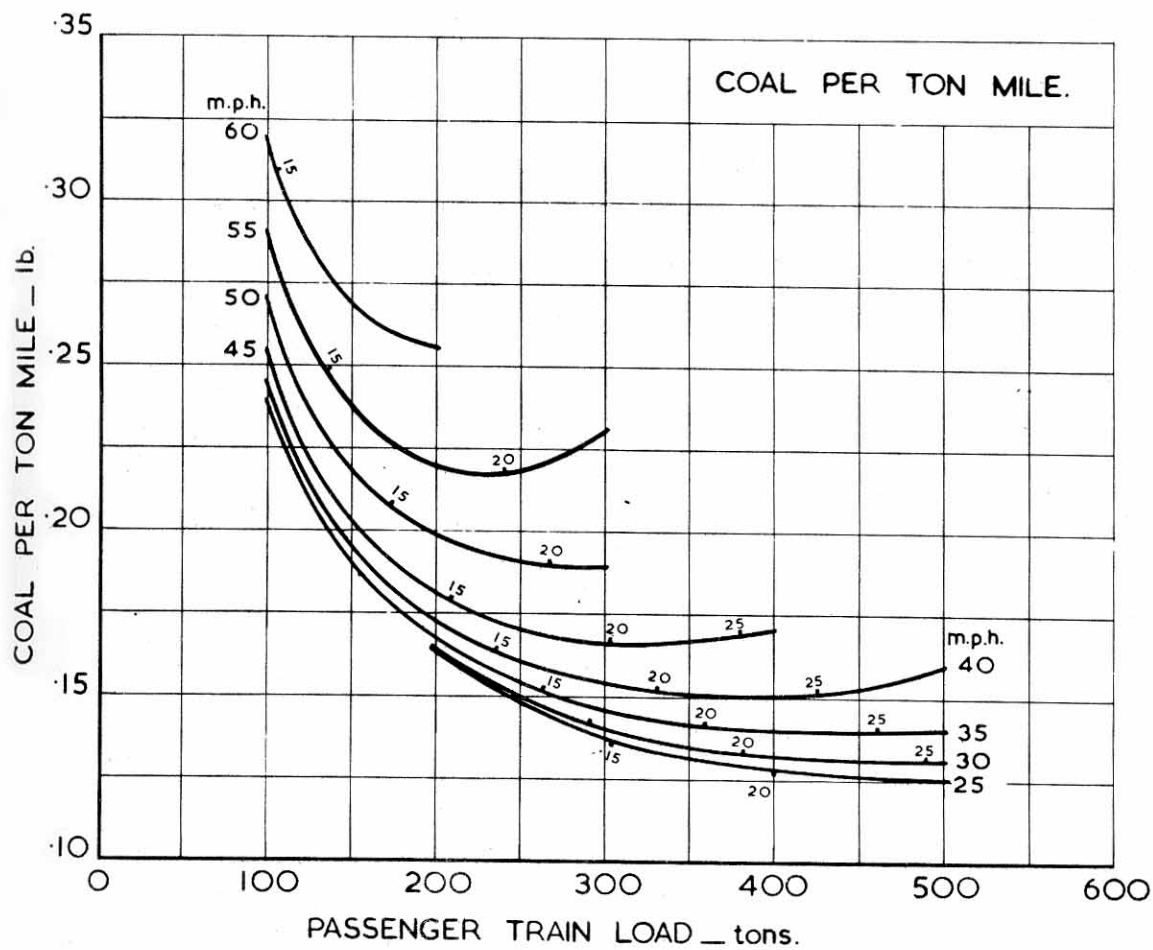
6

LU/7916/51.

BLIDWORTH COAL. 12500 B.Th.U./lb. EXHAUST STEAM INJECTOR.

SMALL FIGURES ON CURVES INDICATE CUT OFF, MAX. STEAM CHEST PRESSURE.





PASSENGER SERVICE _ 1 IN 200 RISING.

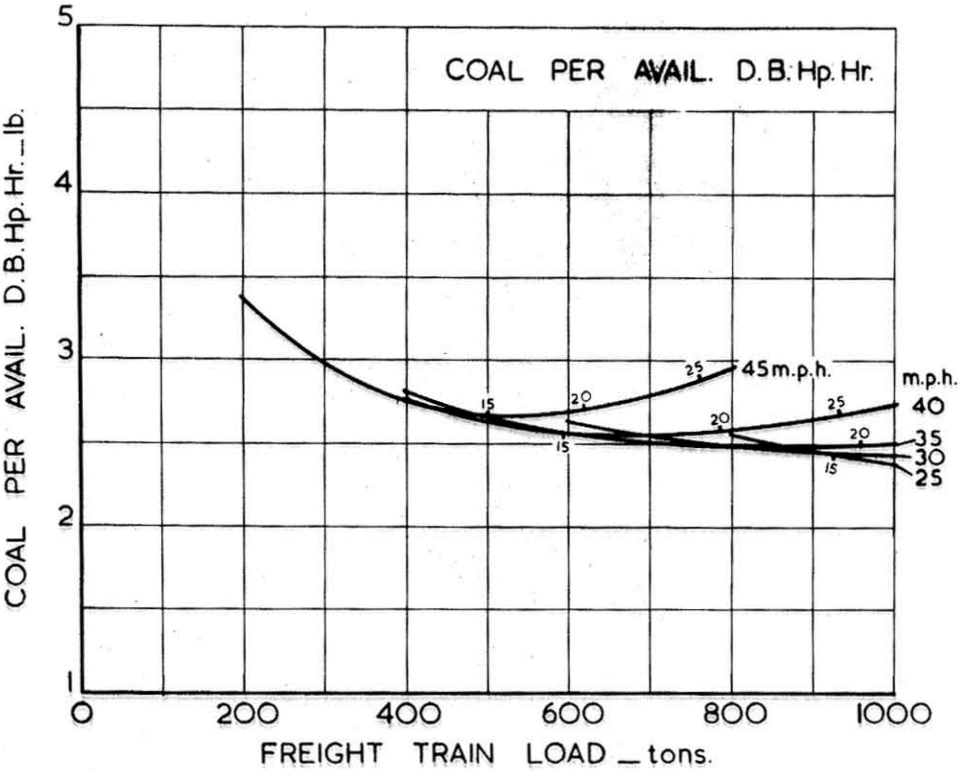
EXAMPLES OF COST IN COAL OF DIFFERENT TRAIN LOADS & SPEEDS.

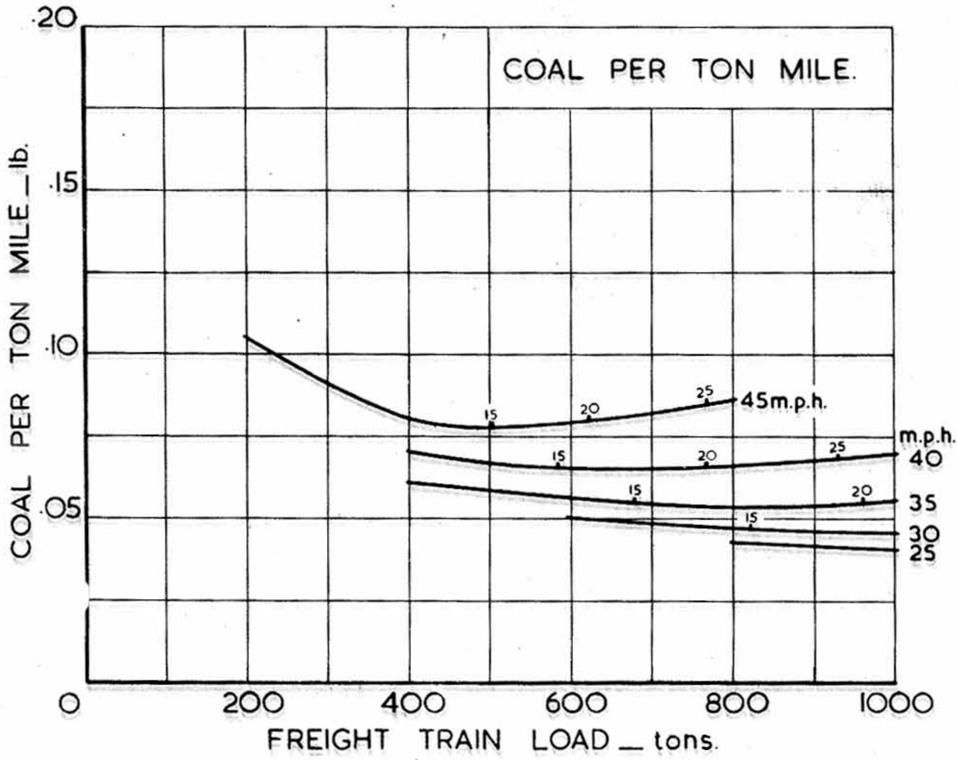
7

LU/7916/51.

BLIDWORTH COAL. EXHAUST STEAM INJECTOR.
12500 B.Th.U./lb.

Small Figures on Curves indicate Cut Off, Max. Steam Chest Pressure.





FREIGHT SERVICE _ LEVEL

EXAMPLES OF COST IN COAL OF DIFFERENT TRAIN LOADS & SPEEDS.

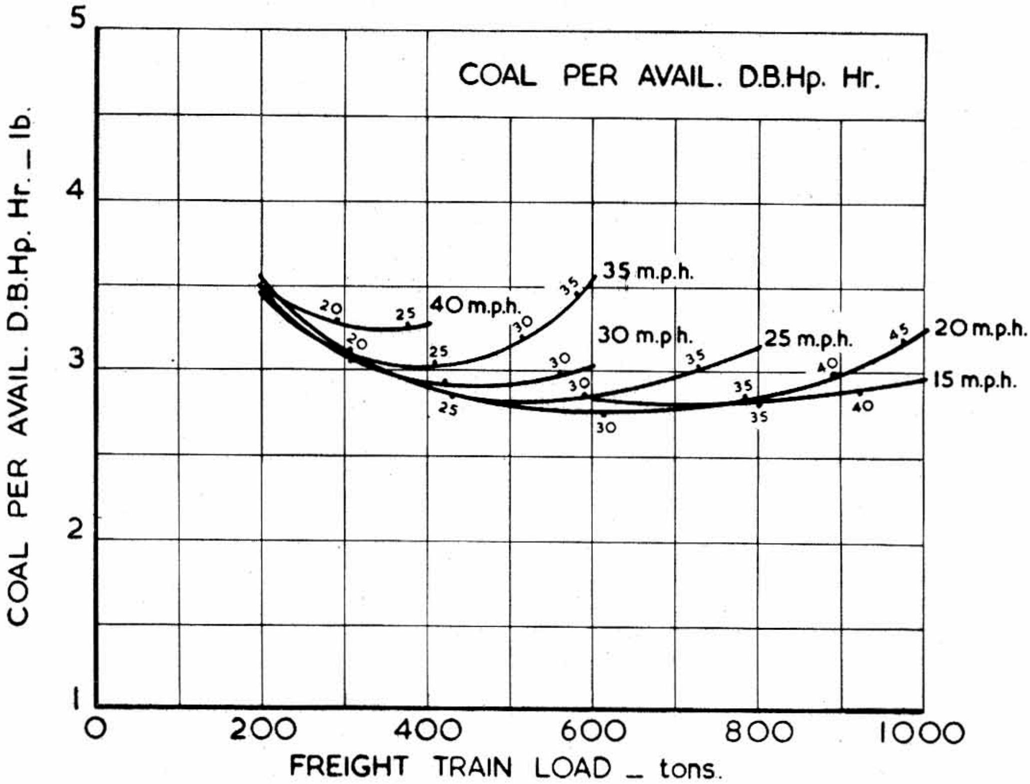
8

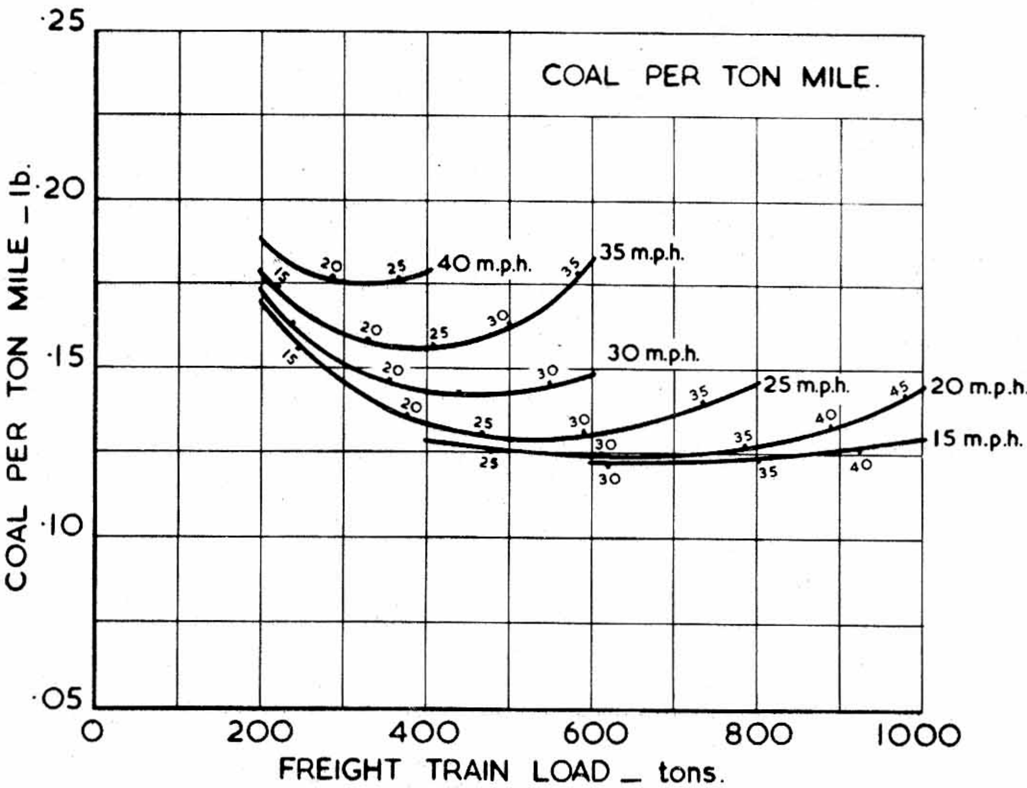
LU/7916/51.

BLIDWORTH COAL. EXHAUST STEAM INJECTOR.

12500 B.Th.U./lb.

Small Figures on Curves indicate Cut Off, Max. Steam Chest Pressure.



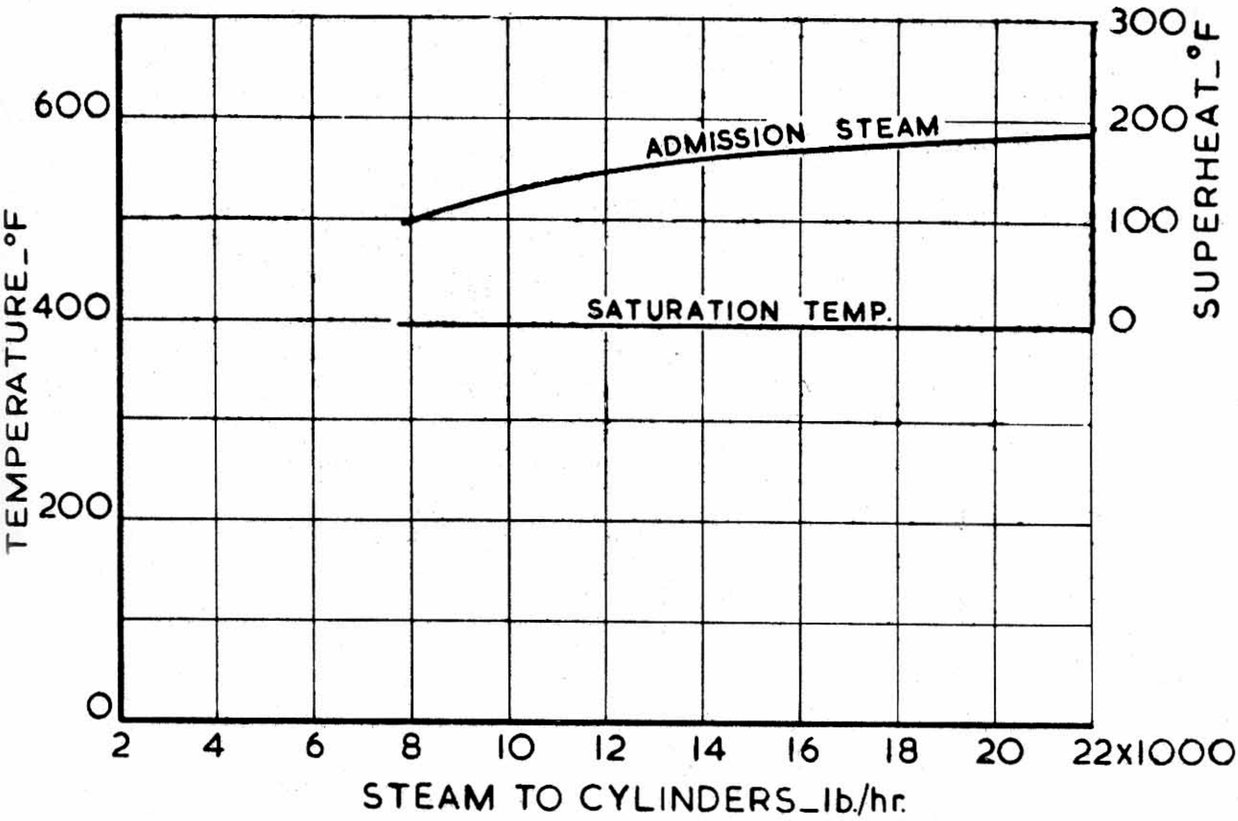


FREIGHT SERVICE _ 1 IN 200 RISING.

EXAMPLES OF COST IN COAL OF DIFFERENT TRAIN LOADS & SPEEDS.

9

LU/7916/51.



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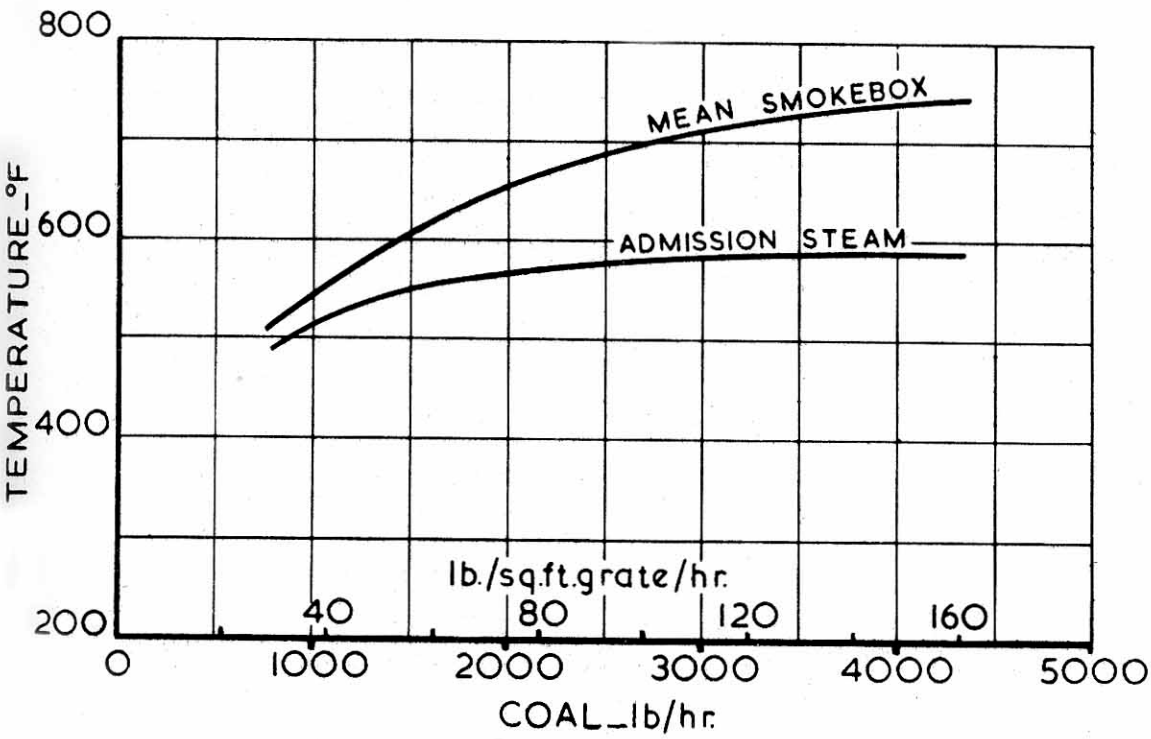


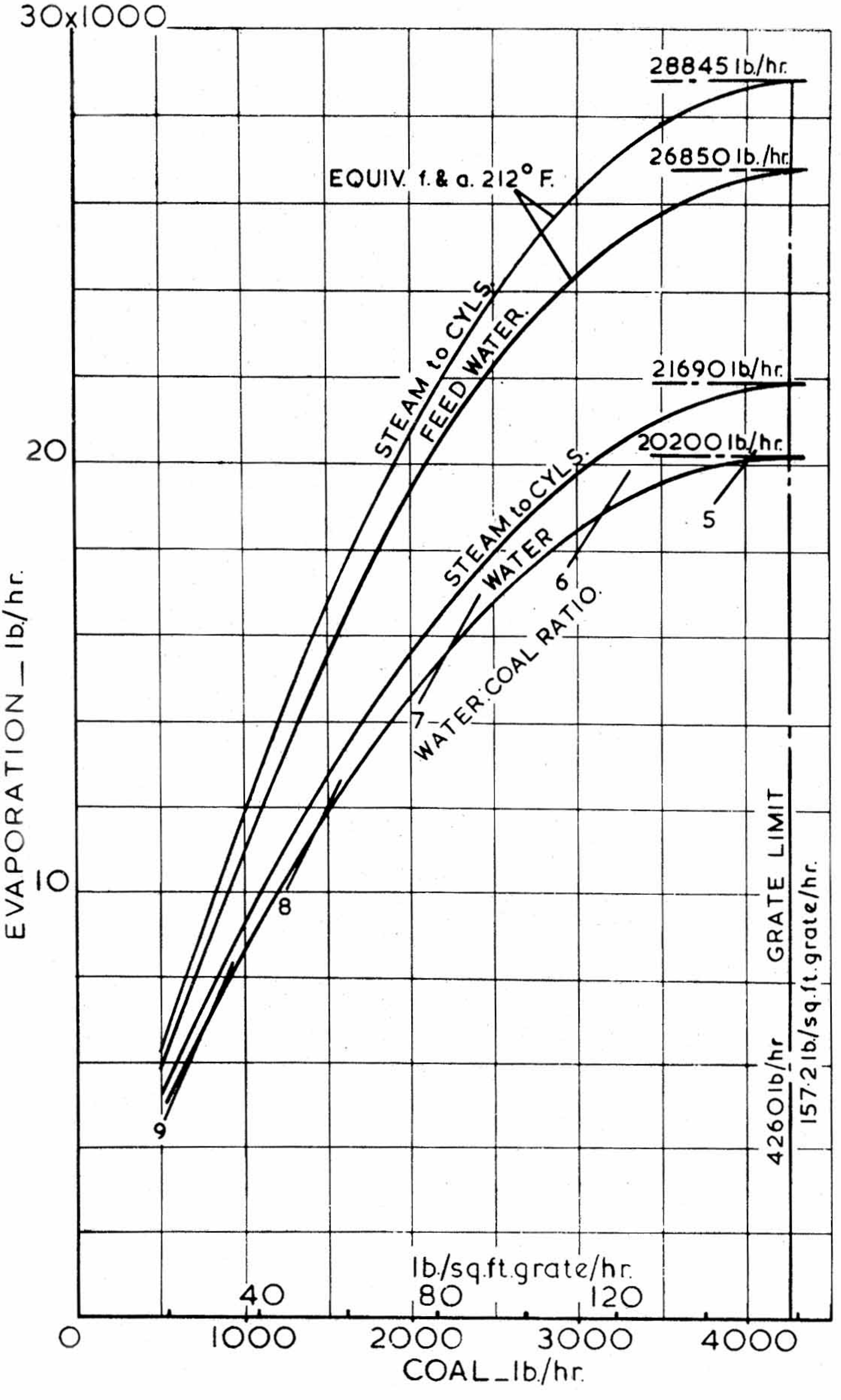
BLIDWORTH COAL
12500 B.Th.U./lb.

EXHAUST STEAM INJECTOR

11

TEMPERATURES

LU/7916/51.

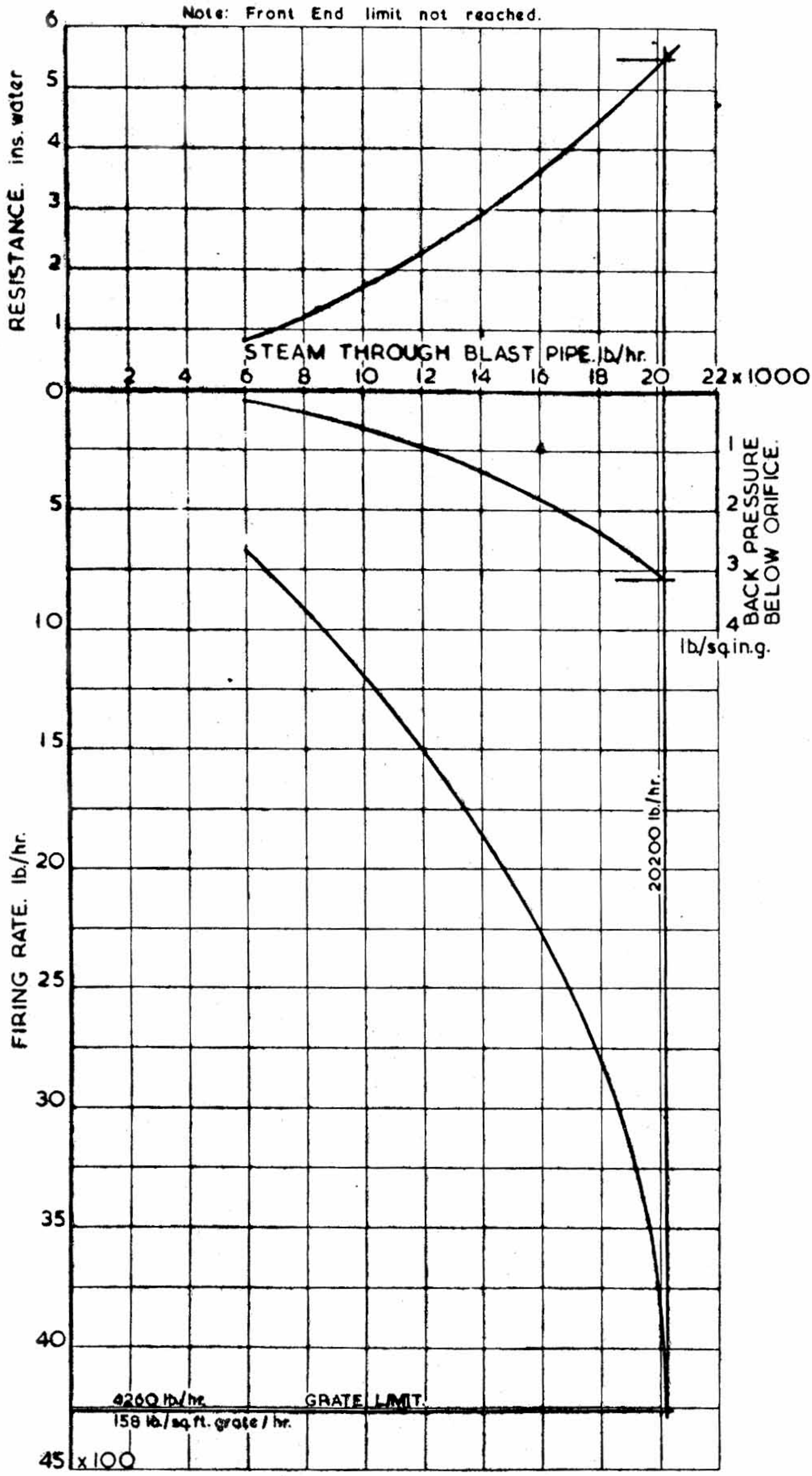


BLIDWORTH COAL. EXHAUST STEAM INJECTOR.
12500 B.Th.U./lb.

EVAPORATION

12

LU/7916/51.



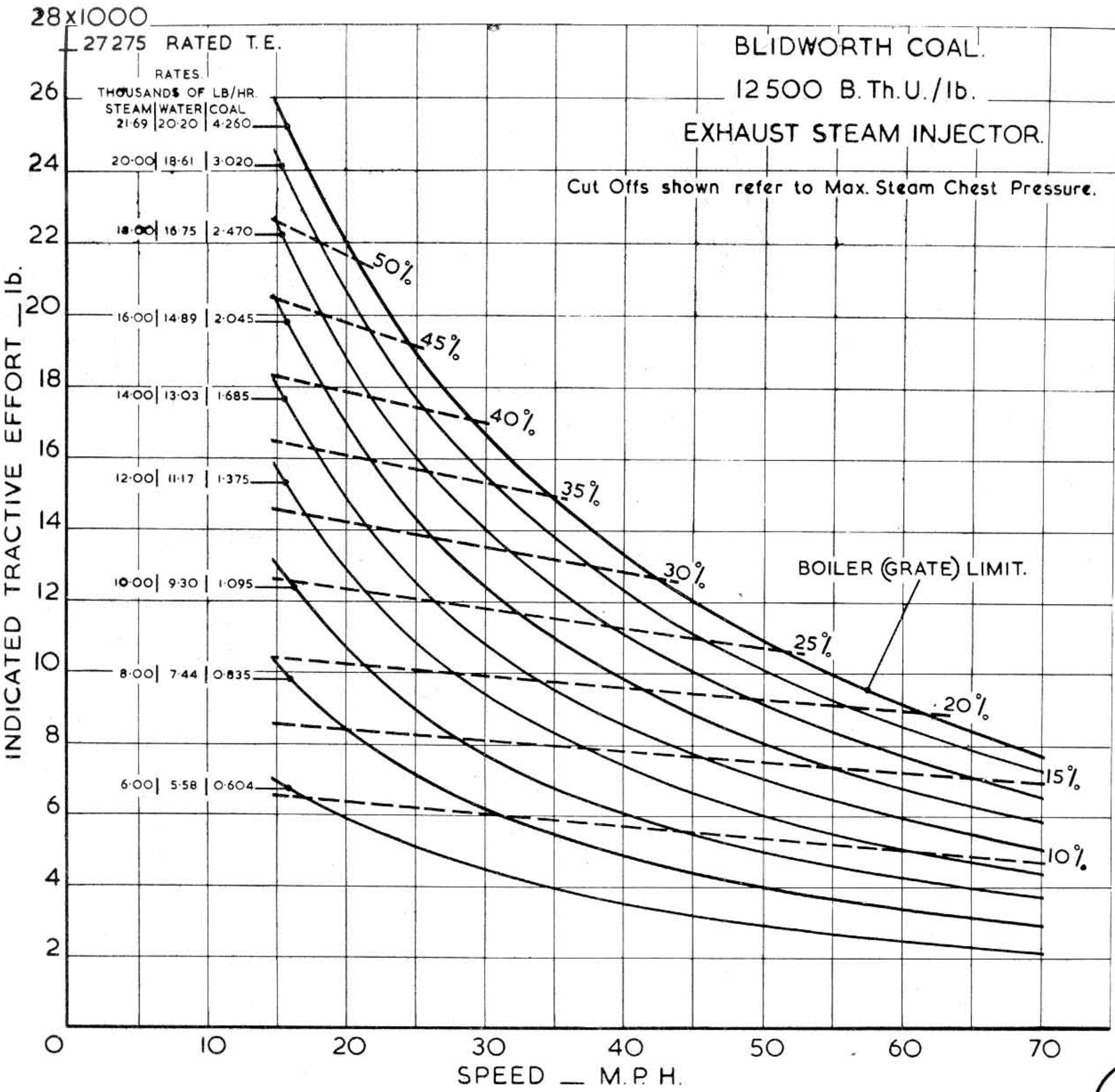
BLIDWORTH COAL
12500 B.Th.U./lb.

EXHAUST STEAM INJECTOR.

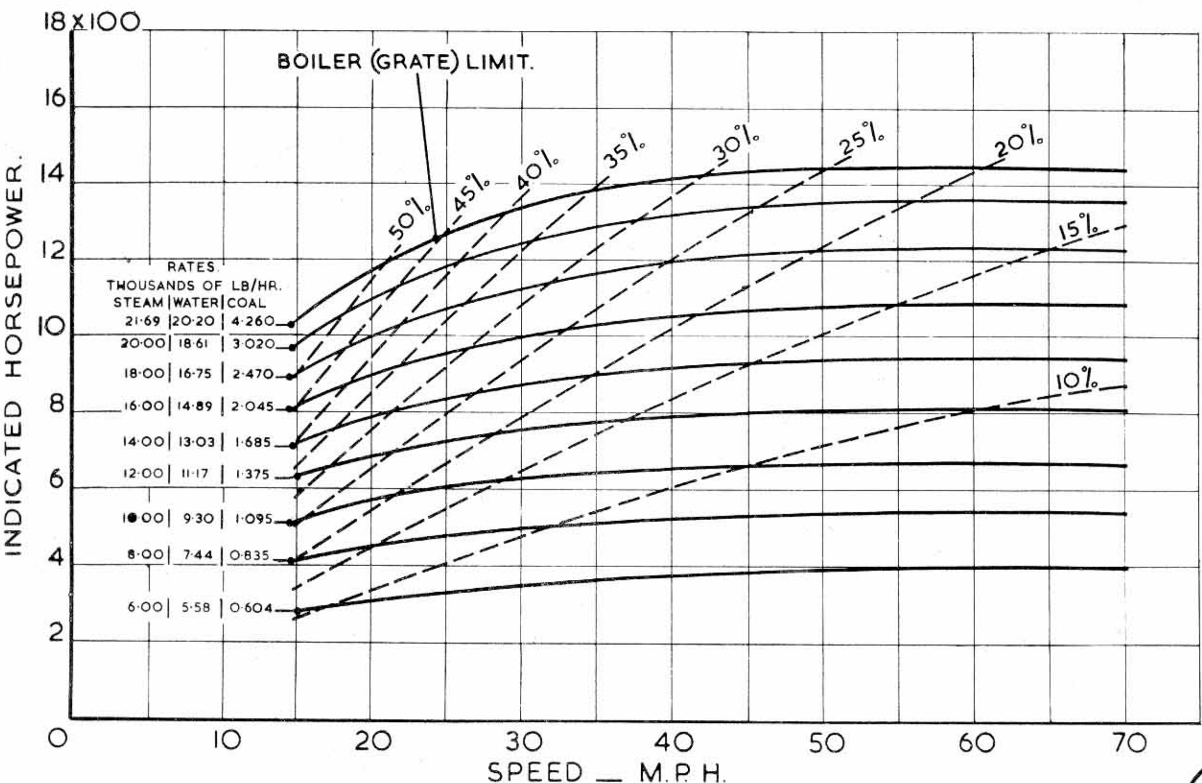
13

DRAUGHT

LU/7916/51



14



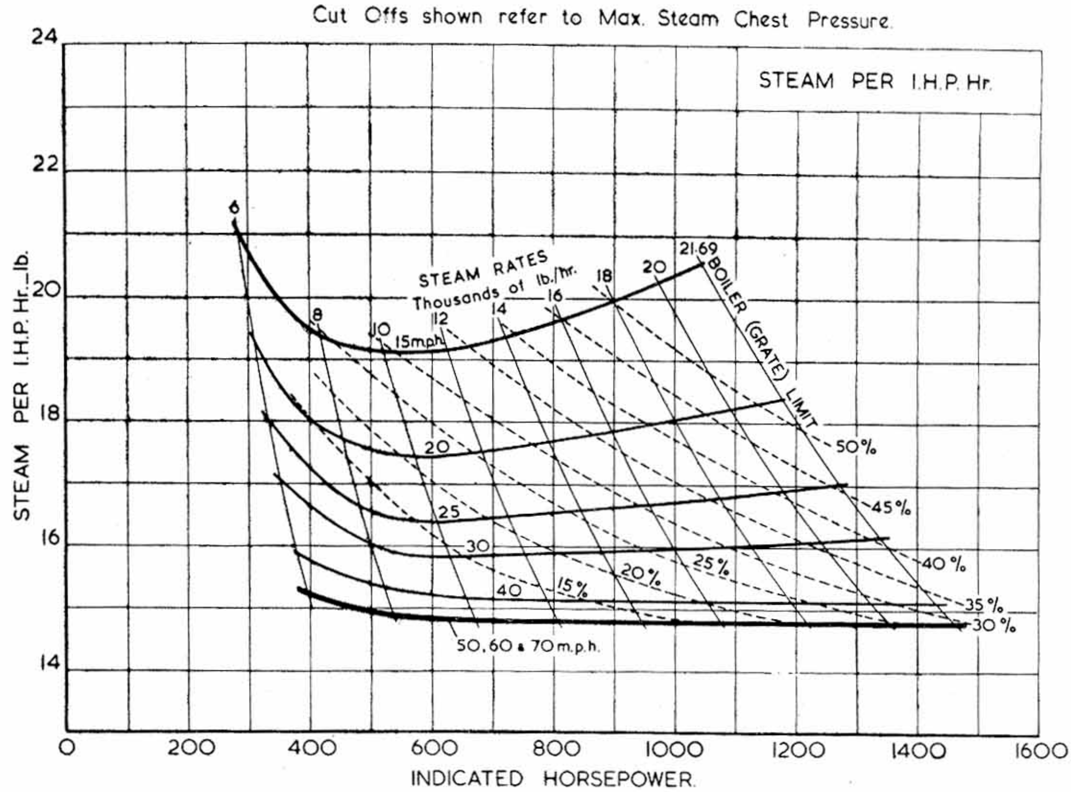
15

INDICATED CHARACTERISTICS.

BLIDWORTH COAL.
12500 B.Th.U./lb.

EXHAUST STEAM INJECTOR

Cut Offs shown refer to Max. Steam Chest Pressure.



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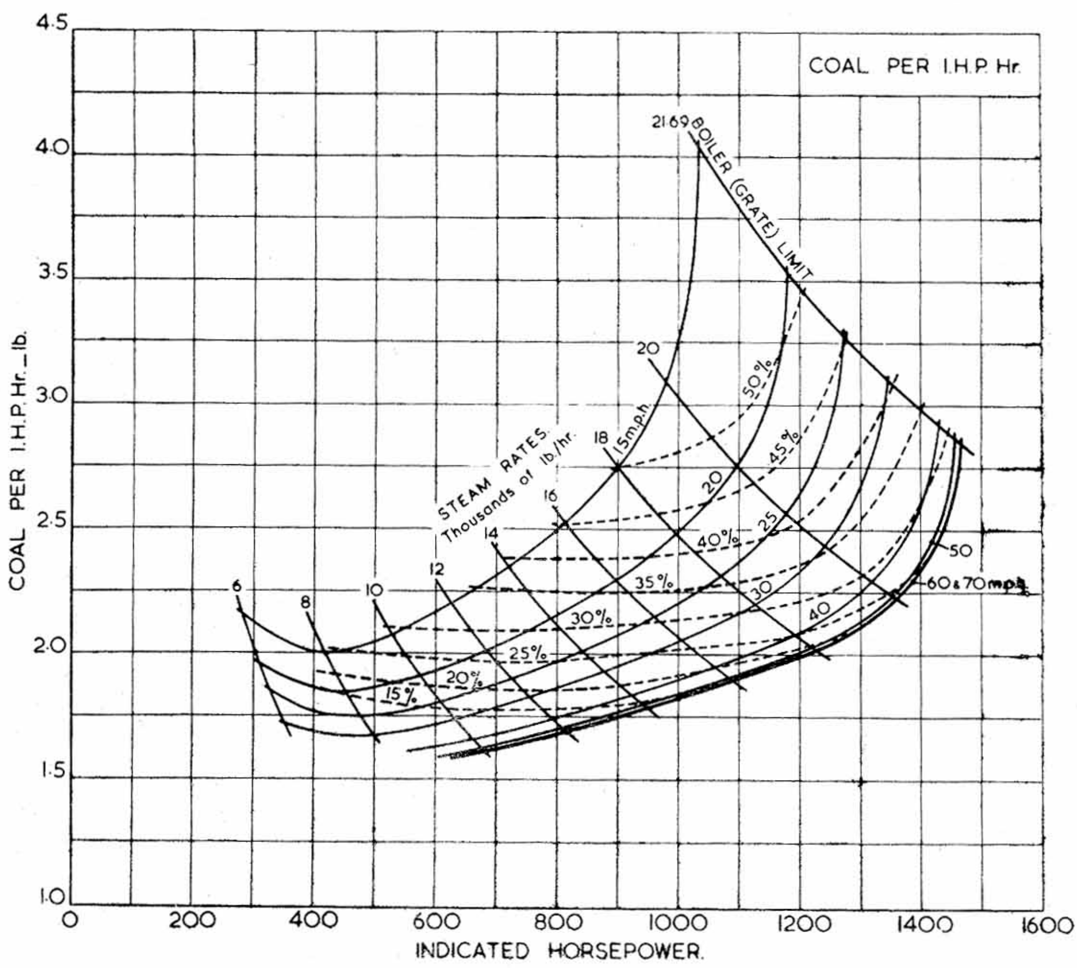
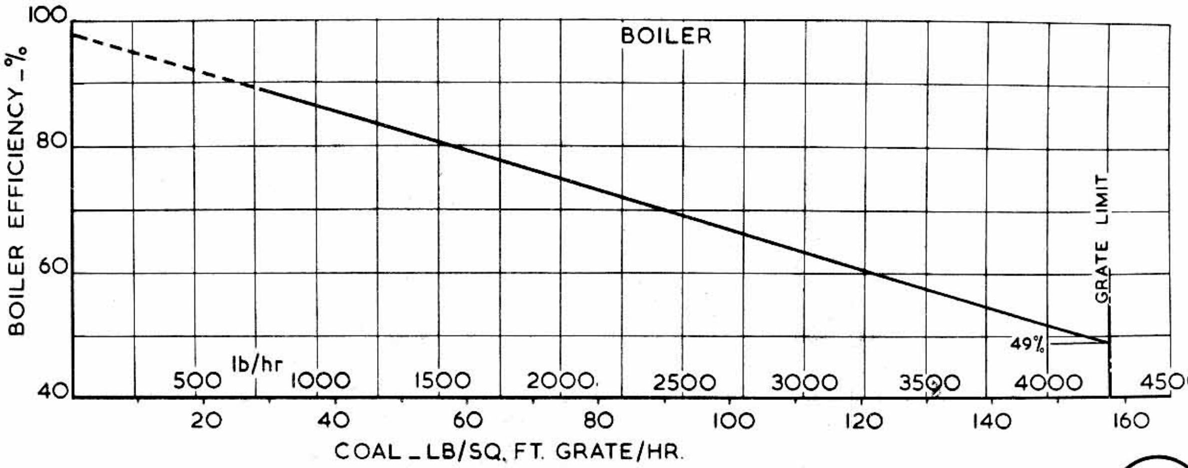


STEAM & COAL PER I.H.P. Hr.

17

LU/7916/51



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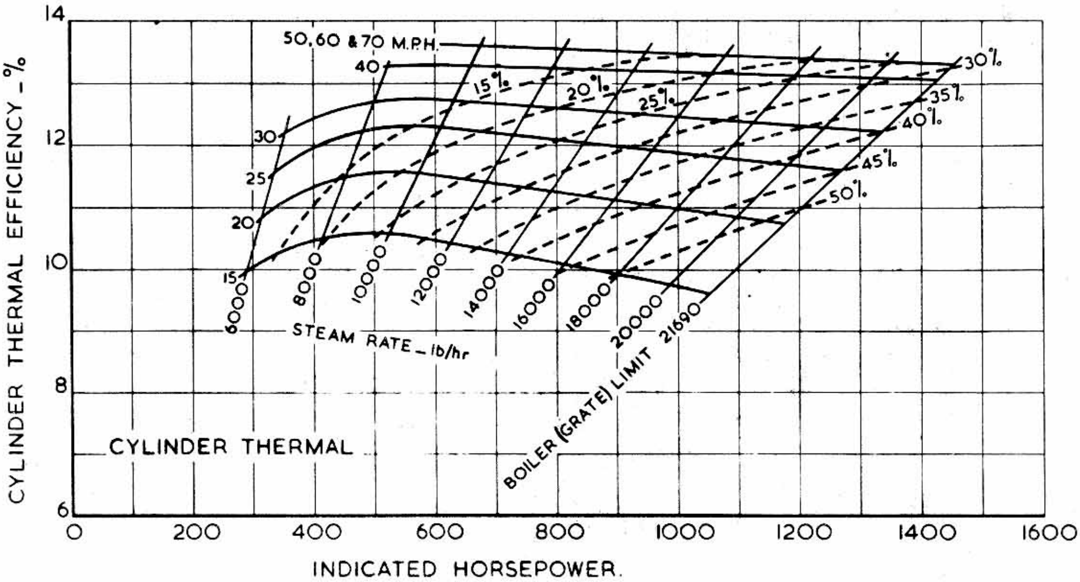
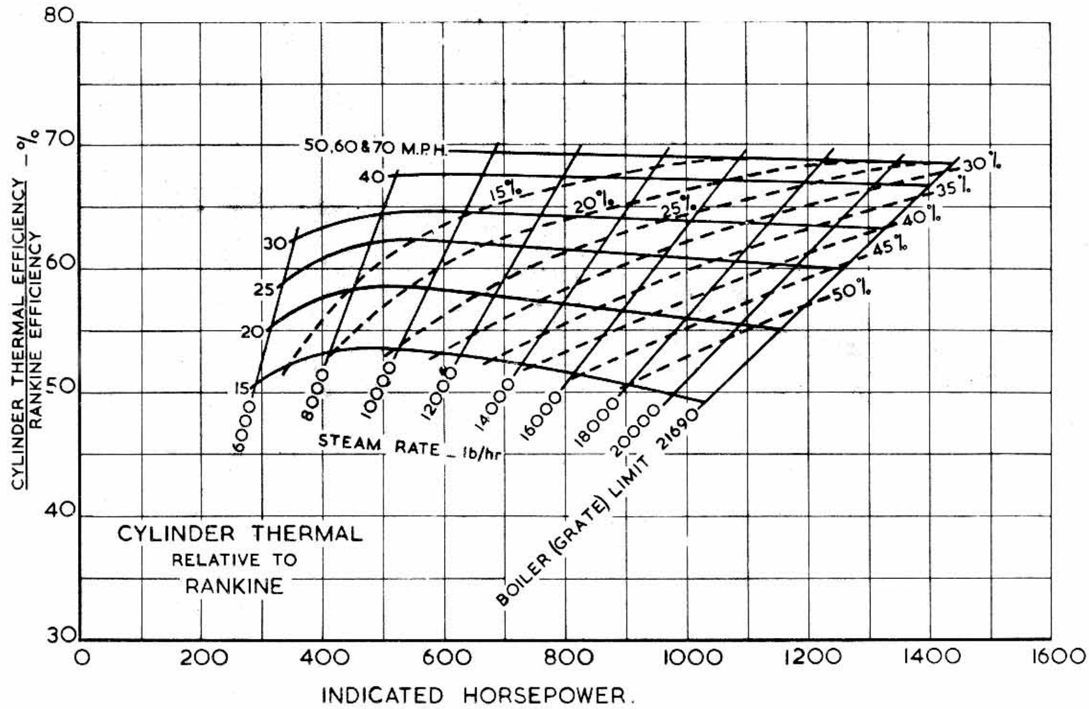


Cut Offs shown refer to Max. Steam Chest Pressure.

19



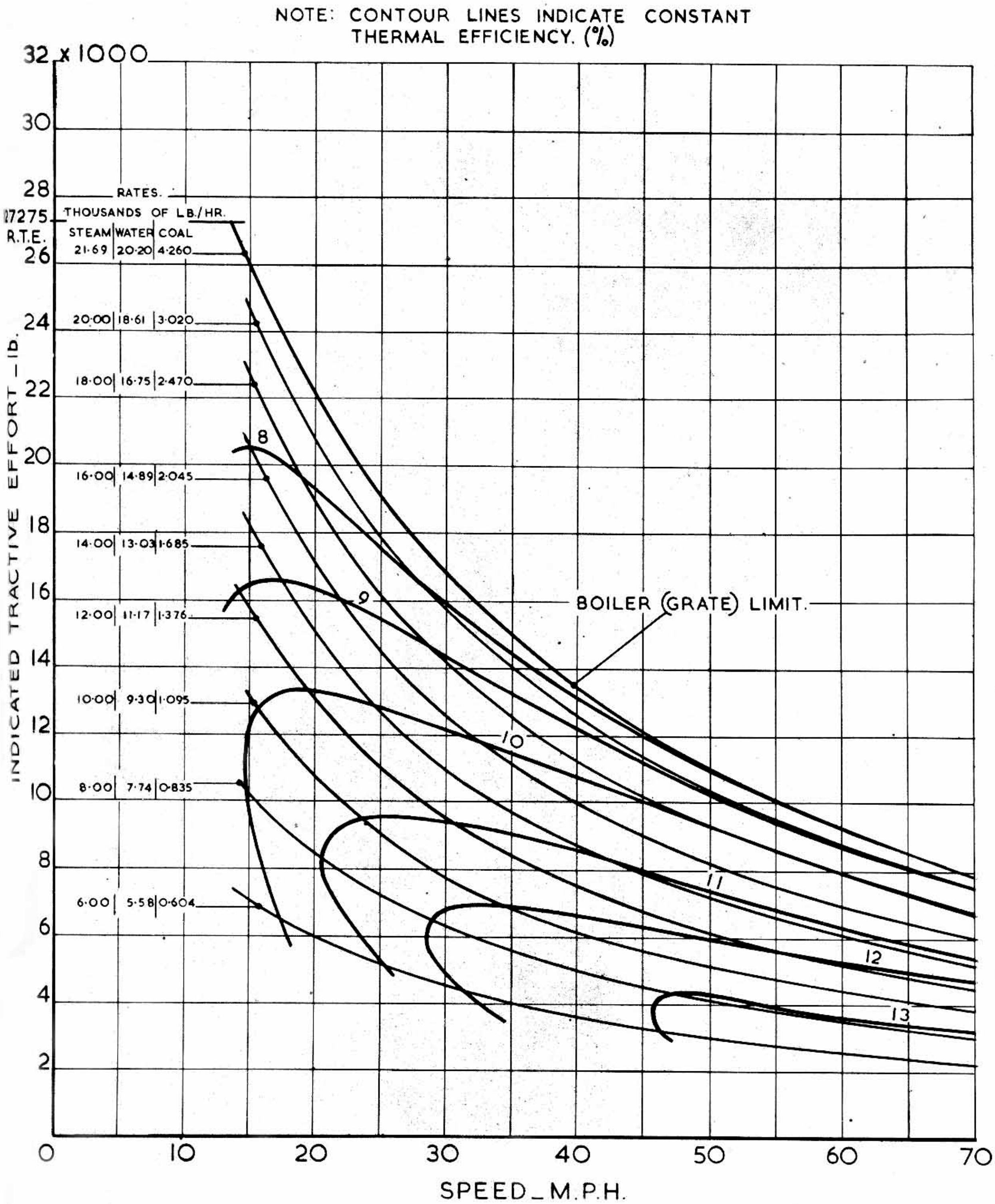
BLIDWORTH COAL.
12 500 B.Th.U. / lb.

EXHAUST STEAM INJECTOR.

20

EFFICIENCIES.

LU/7916/51.



BLIDWORTH COAL
12500 B.Th.U./lb.

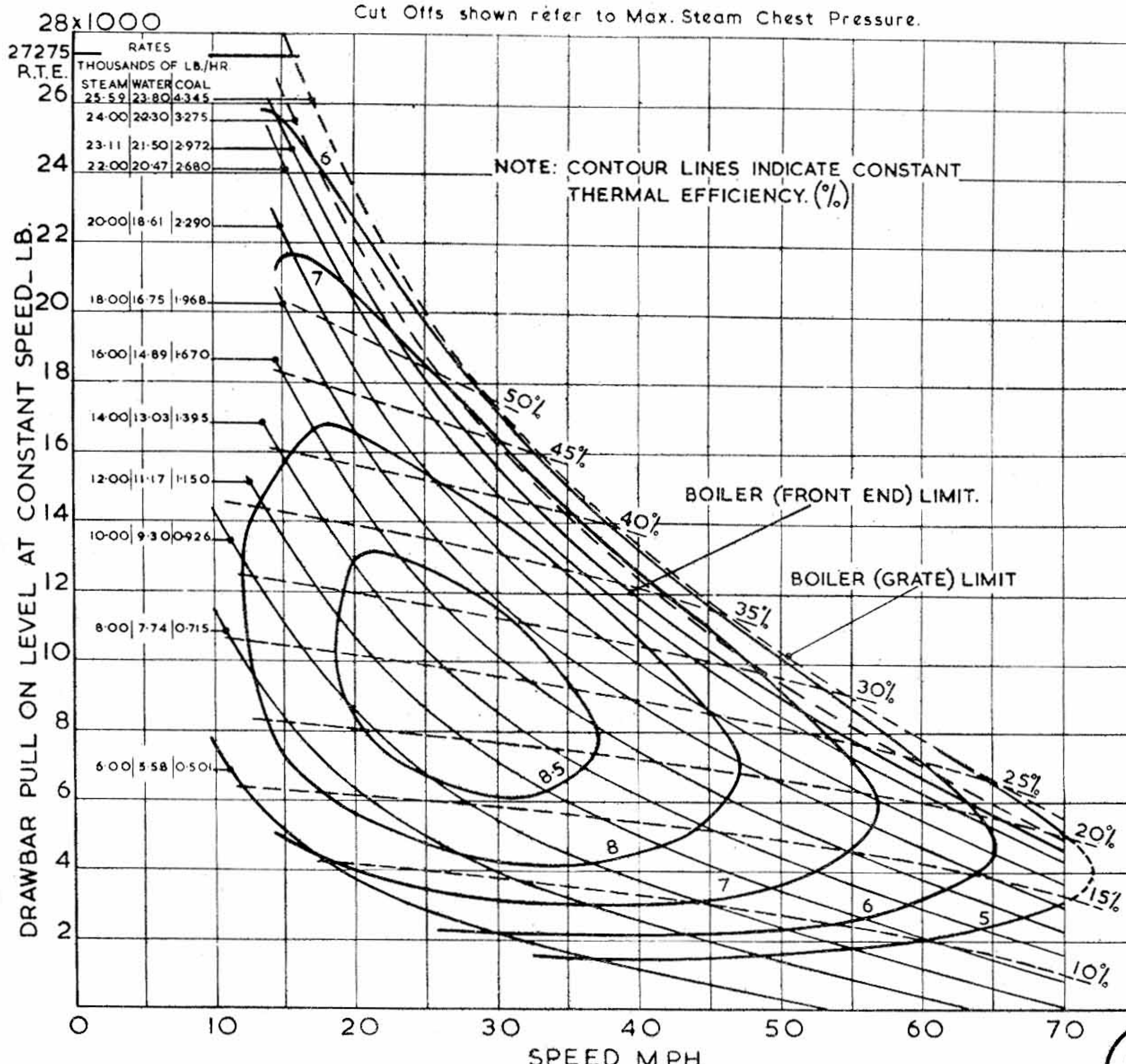
EXHAUST STEAM INJECTOR.

OVERALL EFFICIENCY REFERRED TO CYLINDERS.

LU/7916/51.

MARKHAM COAL.

Performance	Data :	Graphs 22 to 30.
Design	Data :	Graphs 31 to 45.



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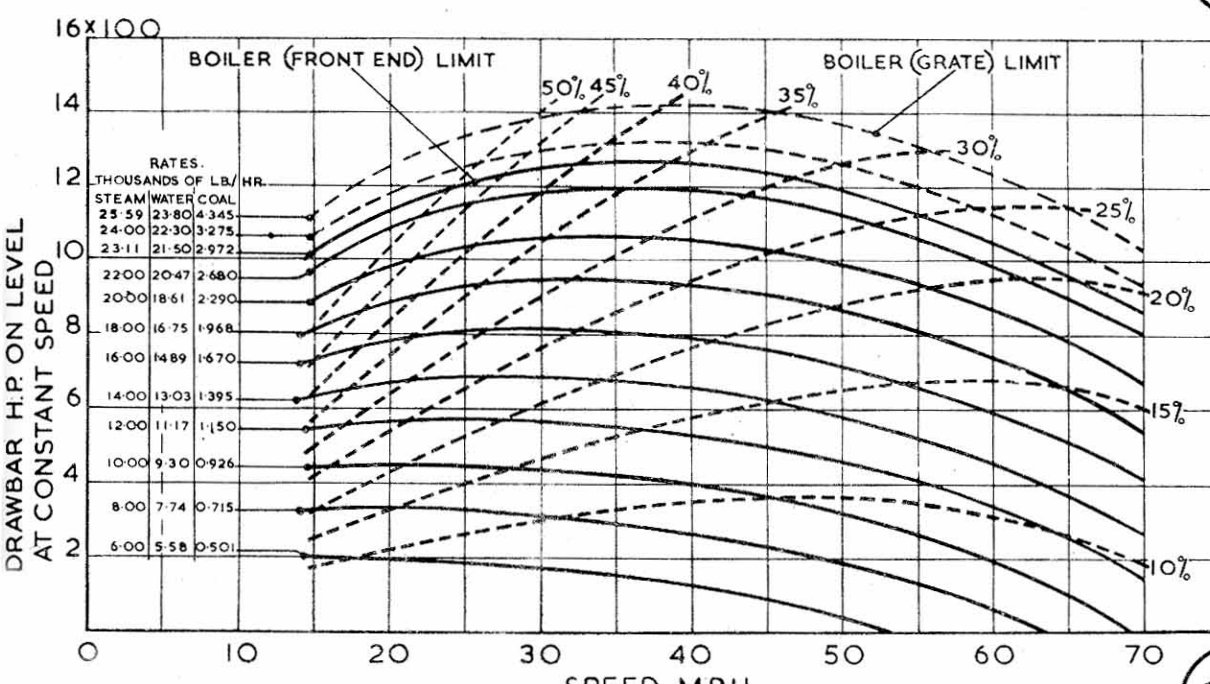


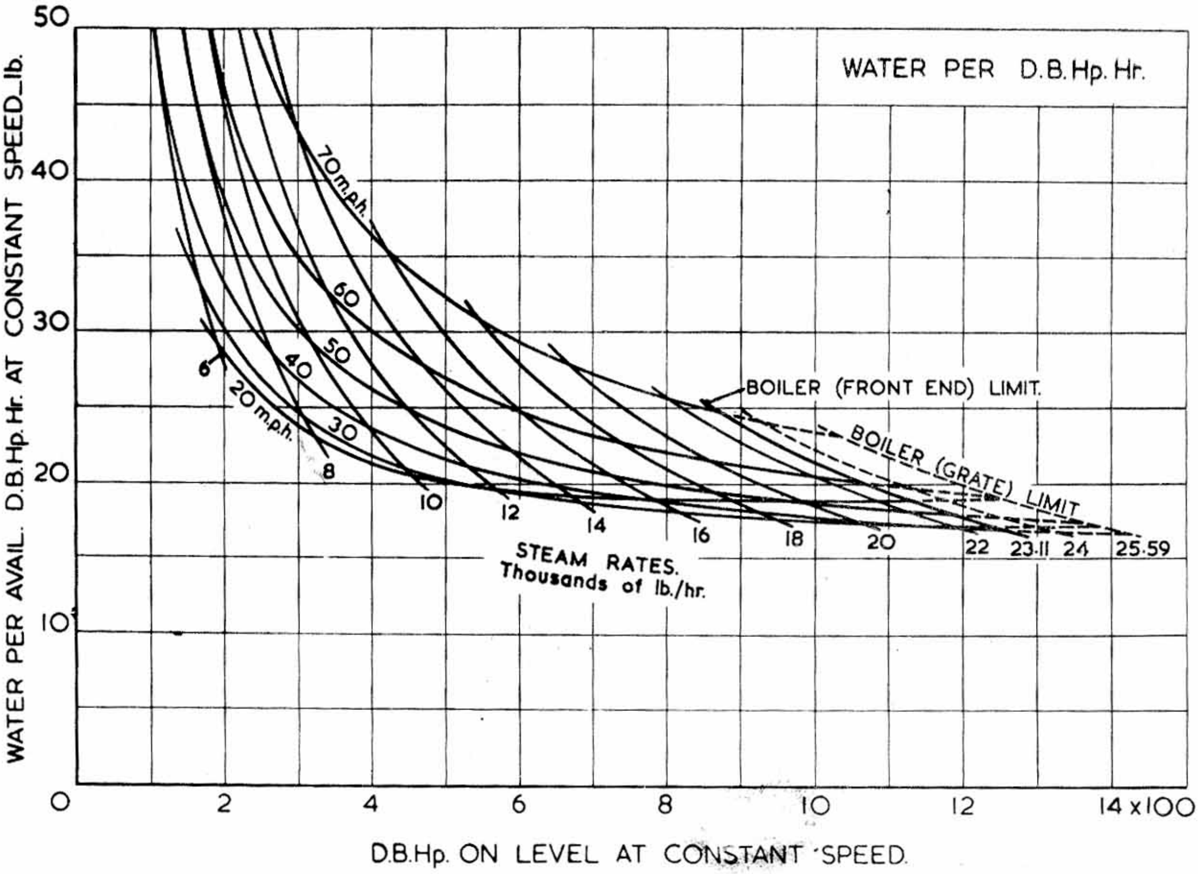
23

MARKHAM COAL
14330 B.Th.U./lb.

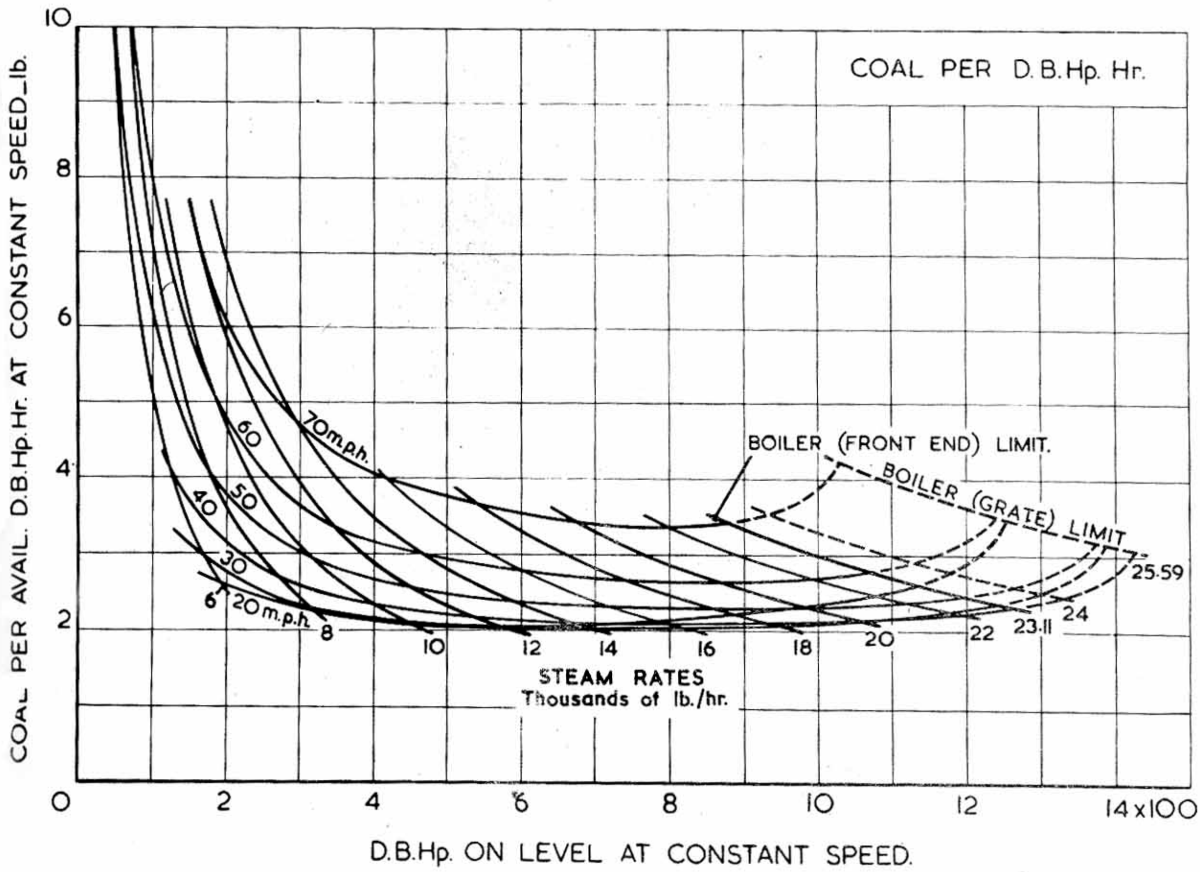
EXHAUST STEAM INJECTOR

DRAWBAR CHARACTERISTICS

LU/7916/51



24



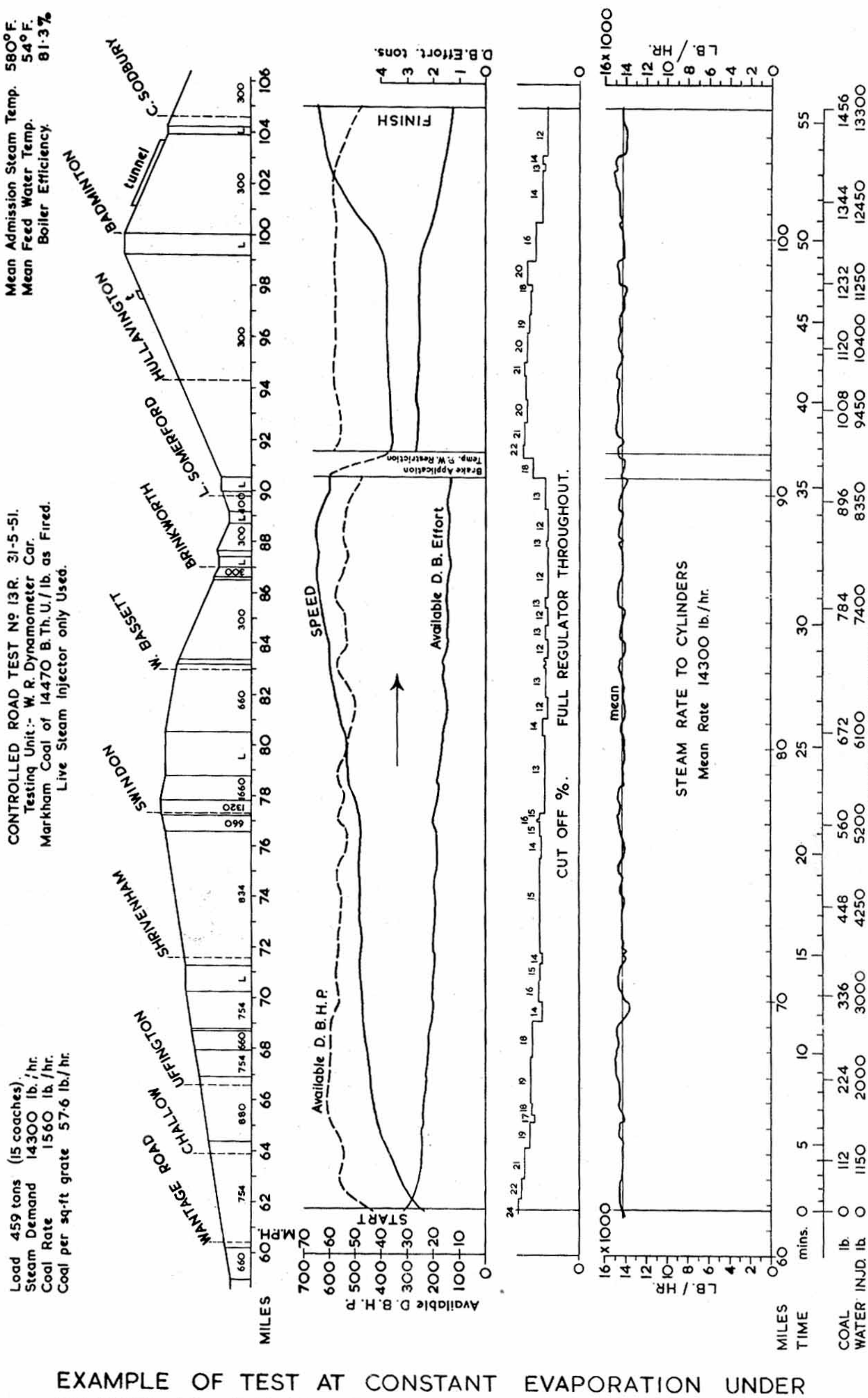
MARKHAM COAL
14330 B.Th.U./lb.

EXHAUST STEAM INJECTOR.

25

WATER & COAL PER D.B.Hp.Hr.

LU/7916/51.



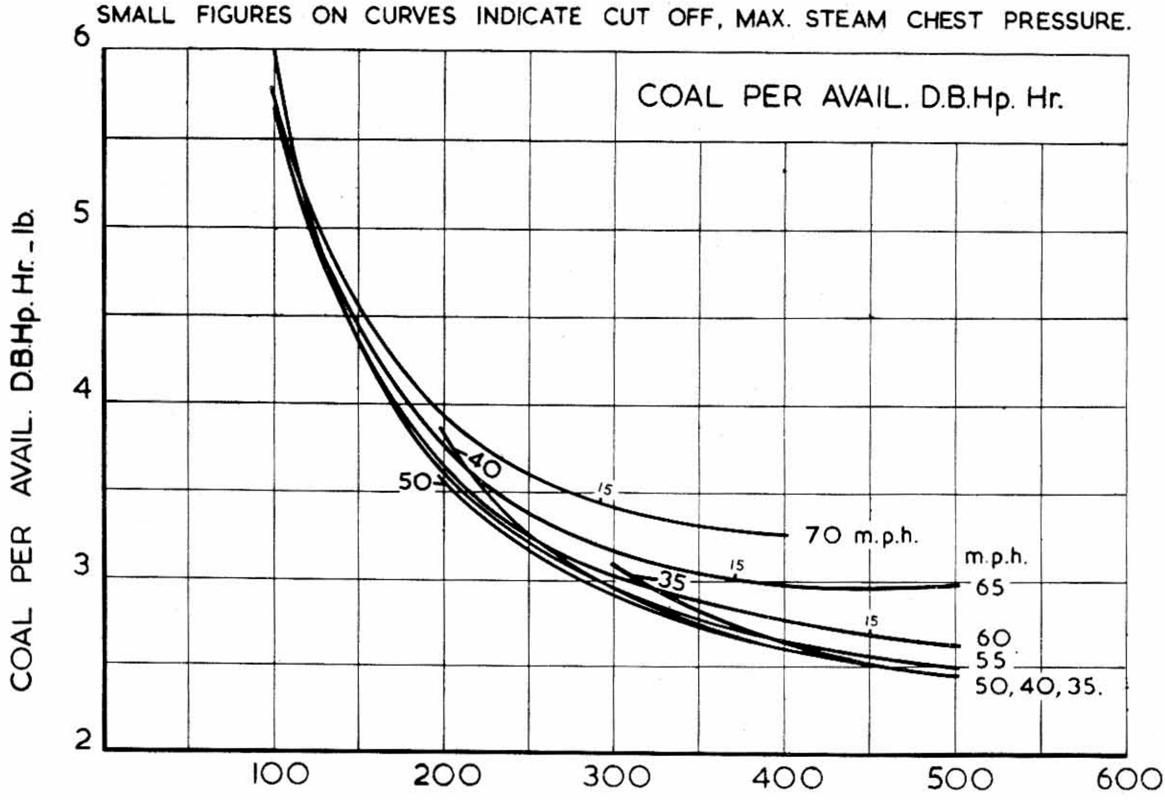
EXAMPLE OF TEST AT CONSTANT EVAPORATION UNDER CONDITIONS GIVING APPROXIMATELY MOST ECONOMICAL COAL CONSUMPTION.

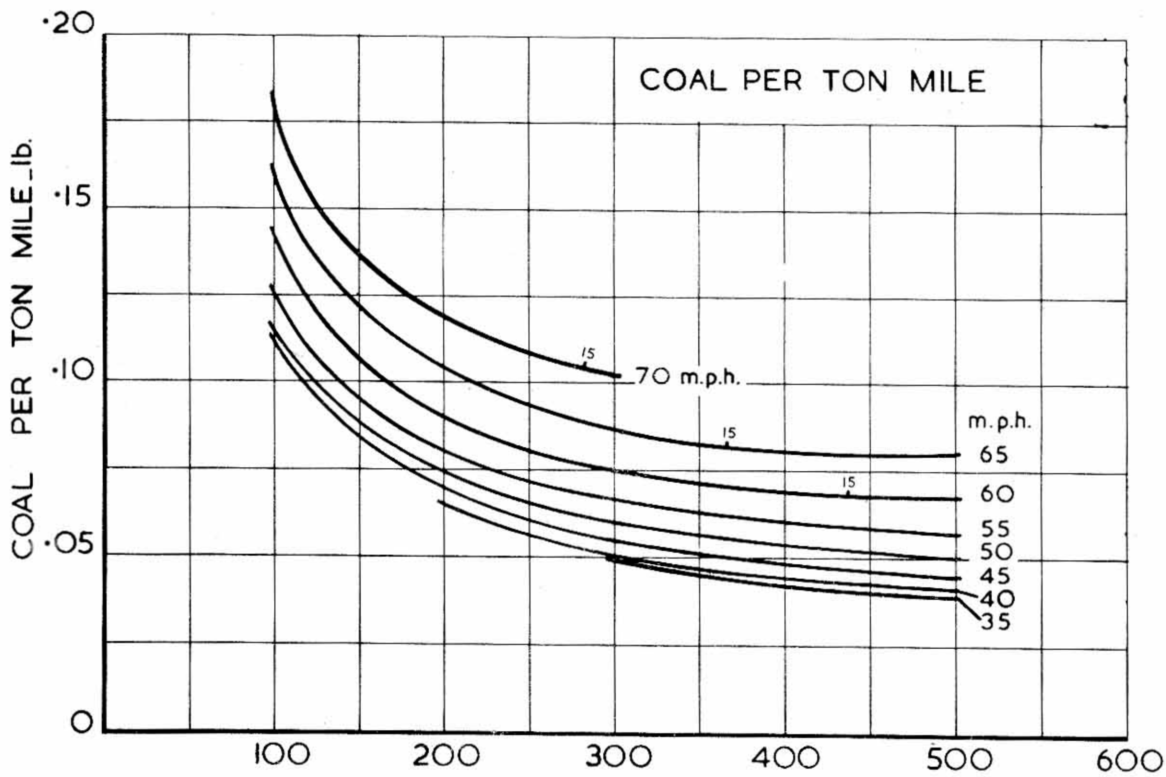
LU/7916/51.

MARKHAM COAL.
14330 B.Th.U./lb.

EXHAUST STEAM INJECTOR.

SMALL FIGURES ON CURVES INDICATE CUT OFF, MAX. STEAM CHEST PRESSURE.





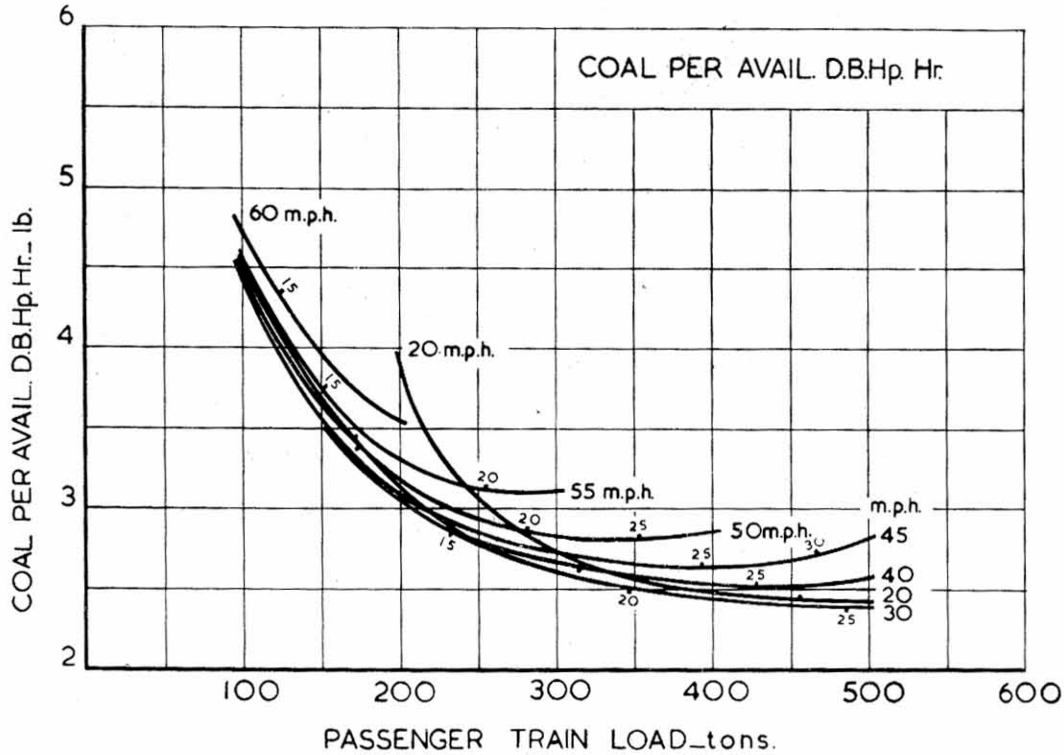
PASSENGER SERVICE_LEVEL.

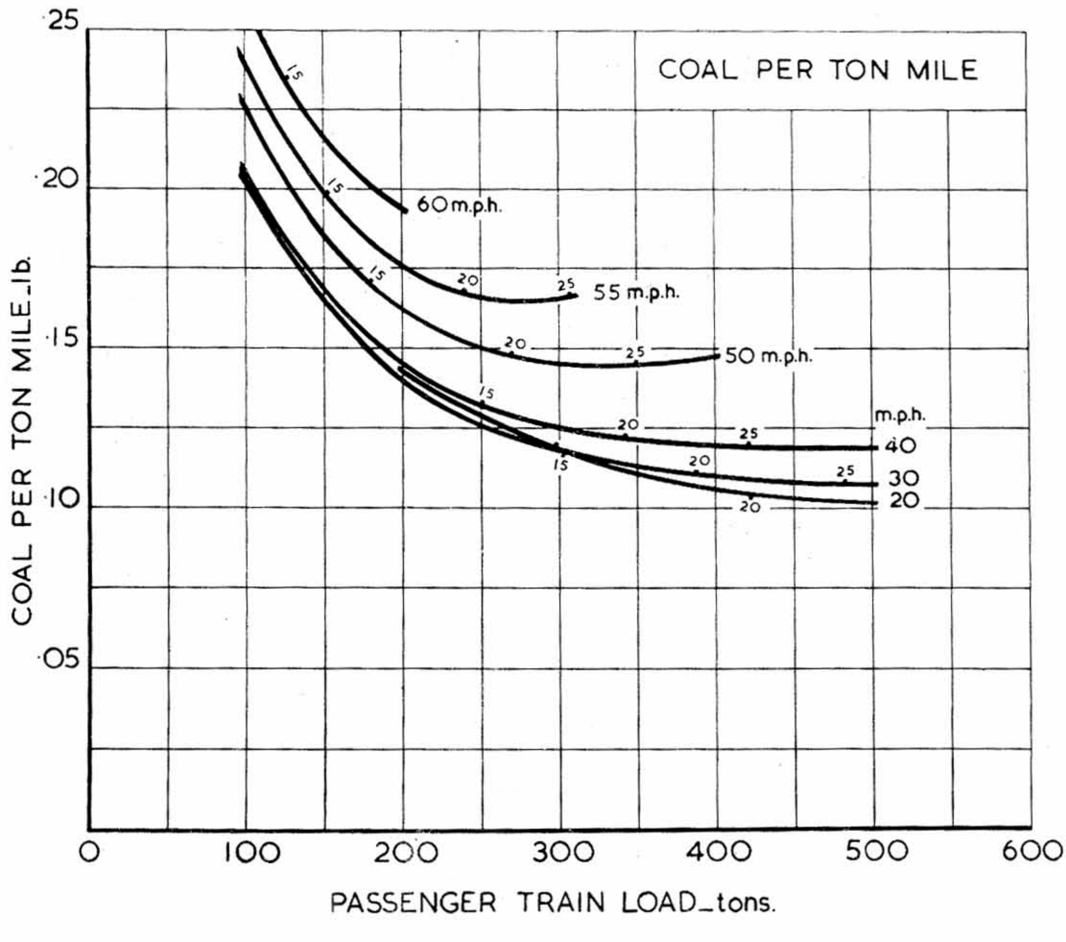
EXAMPLES OF COST IN COAL OF DIFFERENT TRAIN LOADS & SPEEDS.

LU/7916/51

MARKHAM COAL 14330 B.Th.U/lb. EXHAUST STEAM INJECTOR

Small Figures on Curves indicate Cut Off, Maximum Steam Chest Pressure.





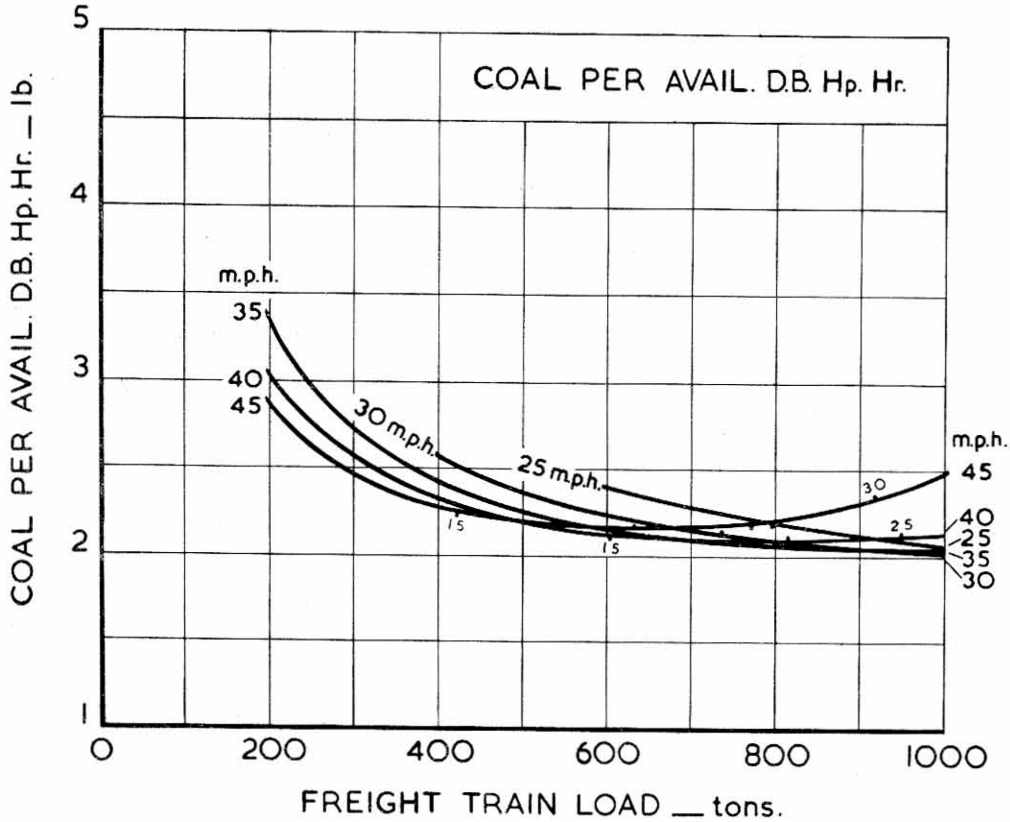
PASSENGER SERVICE_1 IN 200 RISING.
EXAMPLES OF COST IN COAL OF
DIFFERENT TRAIN LOADS & SPEEDS.

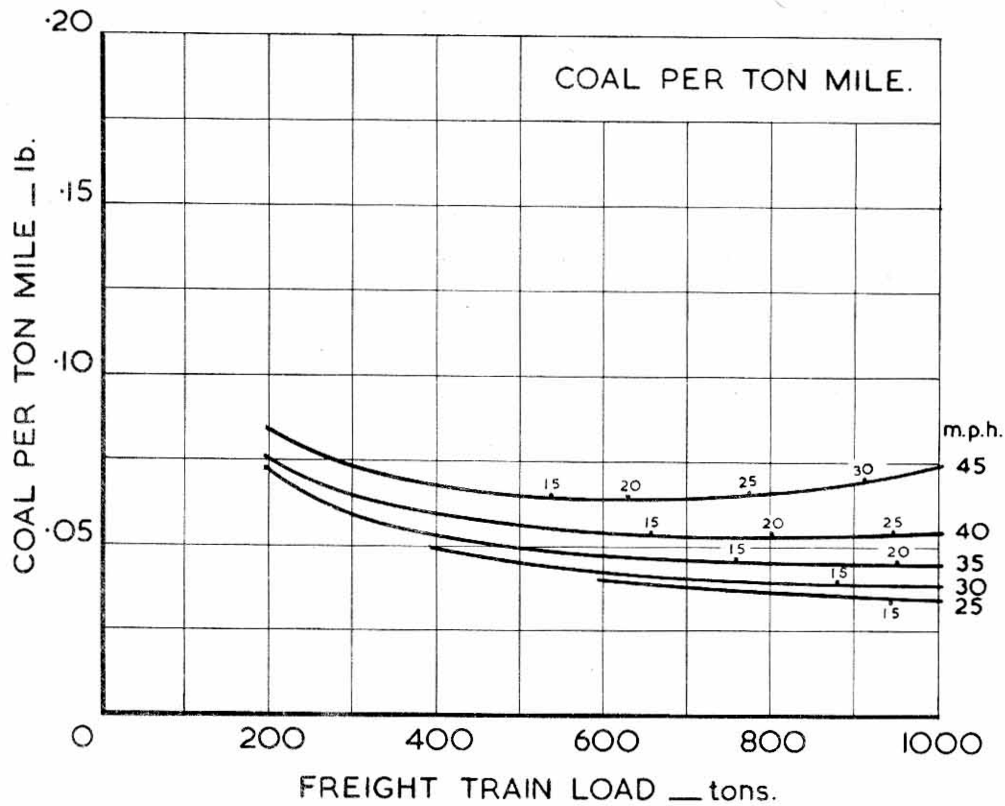
LU/7916/51.

MARKHAM COAL
14330 B.Th.U./lb.

EXHAUST STEAM INJECTOR.

Small Figures on Curves indicate Cut Off, Max. Steam Chest Pressure.





FREIGHT SERVICE – LEVEL.

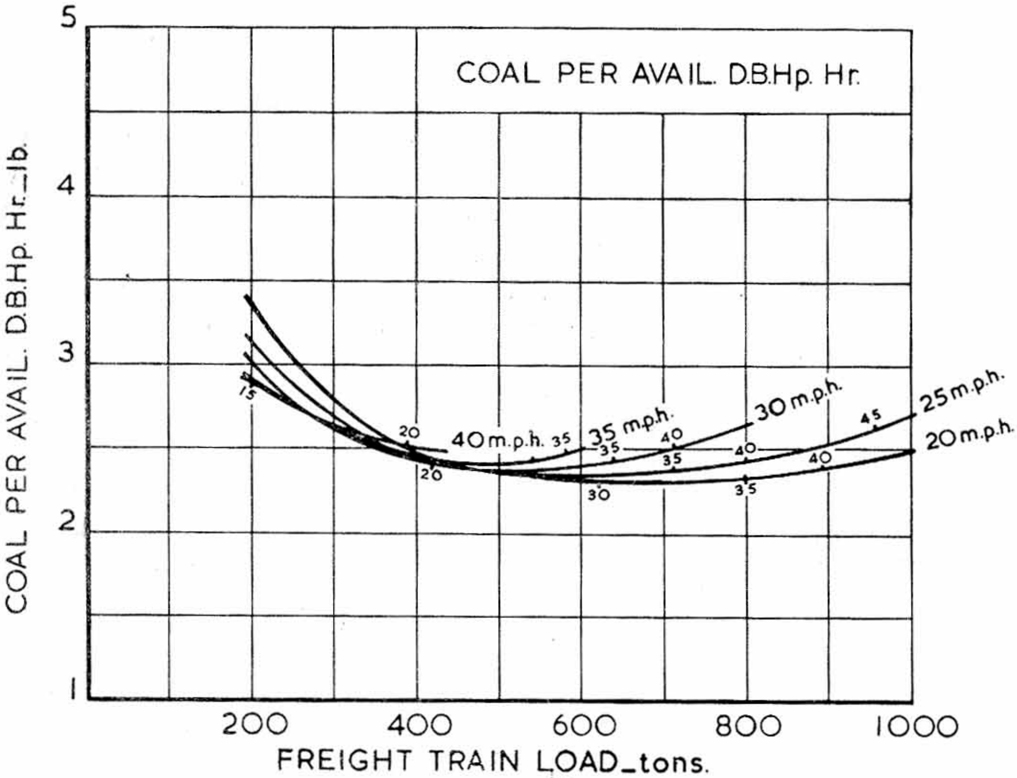
EXAMPLES OF COST IN COAL OF DIFFERENT TRAIN LOADS & SPEEDS.

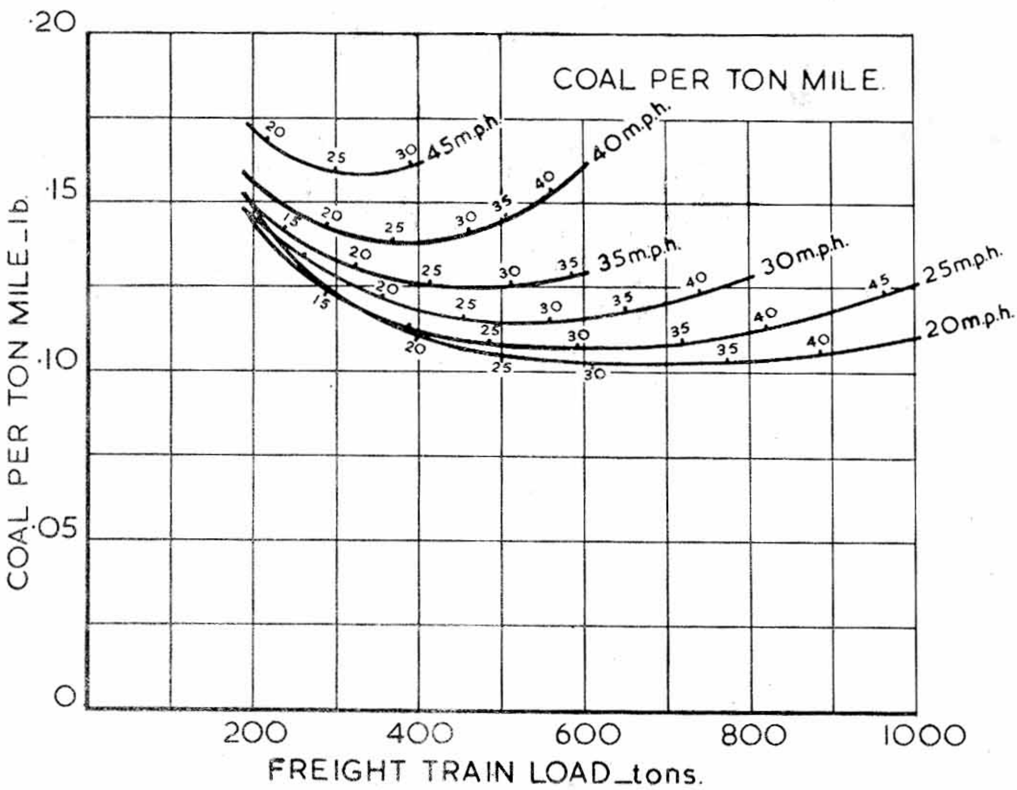
LU/7916/51

MARKHAM COAL
14330 BThU./lb.

EXHAUST STEAM INJECTOR.

Small Figures on Curves indicate Cut Off, Max. Steam Chest Pressure.

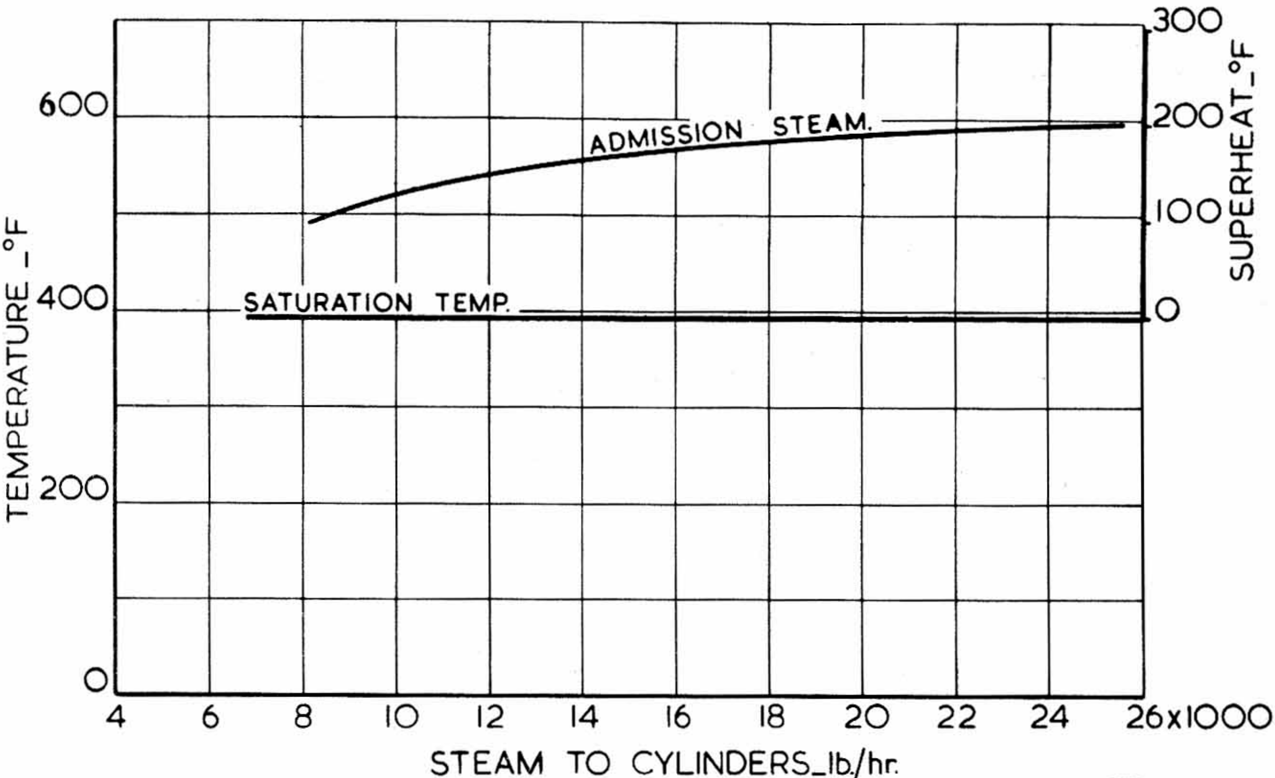




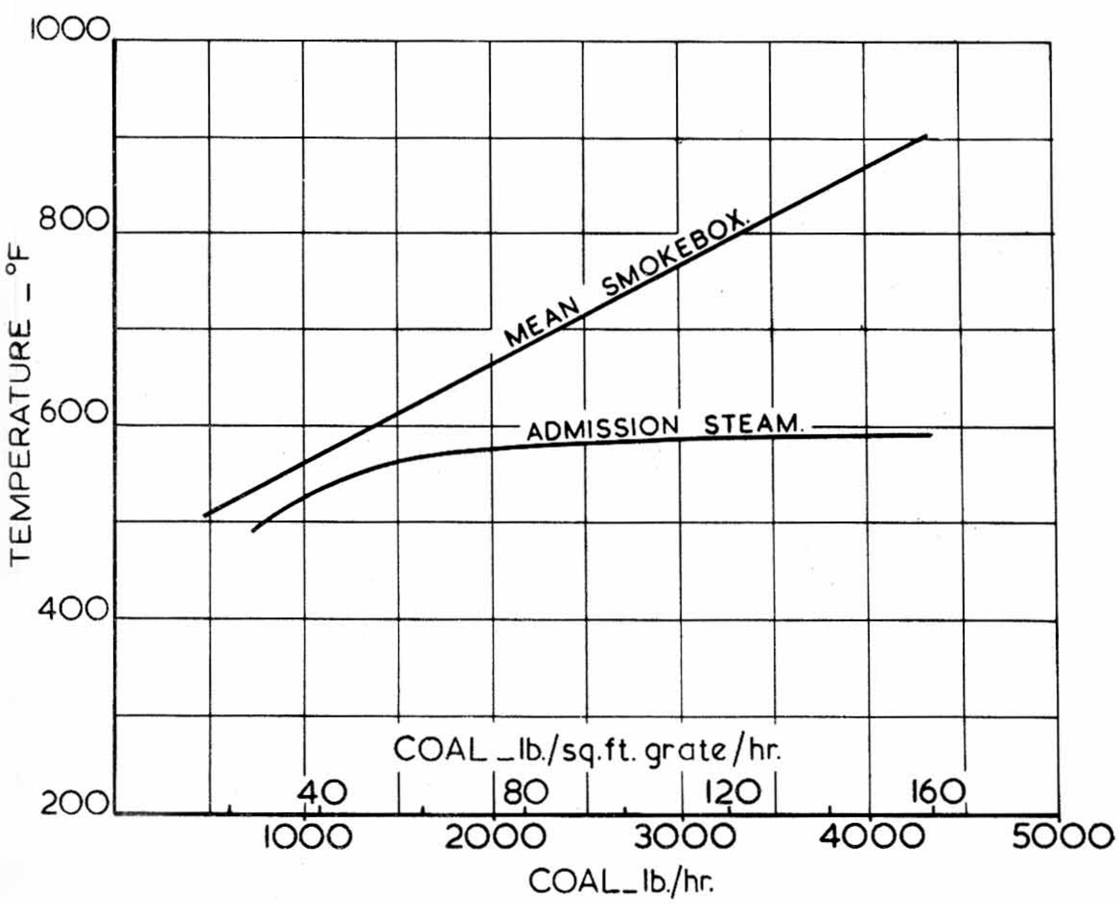
FREIGHT SERVICE_1 IN 200 RISING.

EXAMPLES OF COST IN COAL OF DIFFERENT TRAIN LOADS & SPEEDS.

LU/7916/51



31



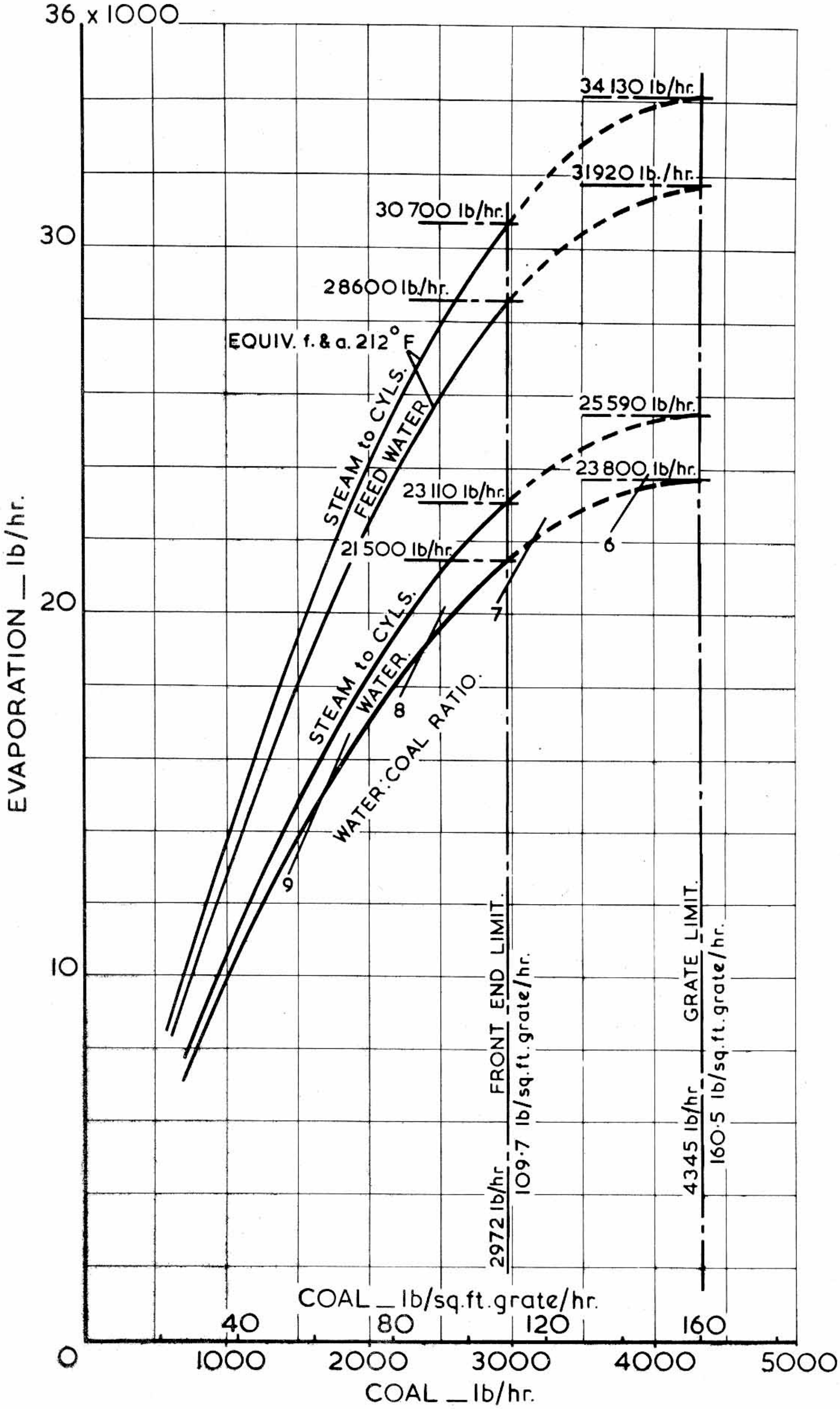
MARKHAM COAL
14330 B.Th.U./lb.

EXHAUST STEAM INJECTOR

32

TEMPERATURES

LU/7916/51.

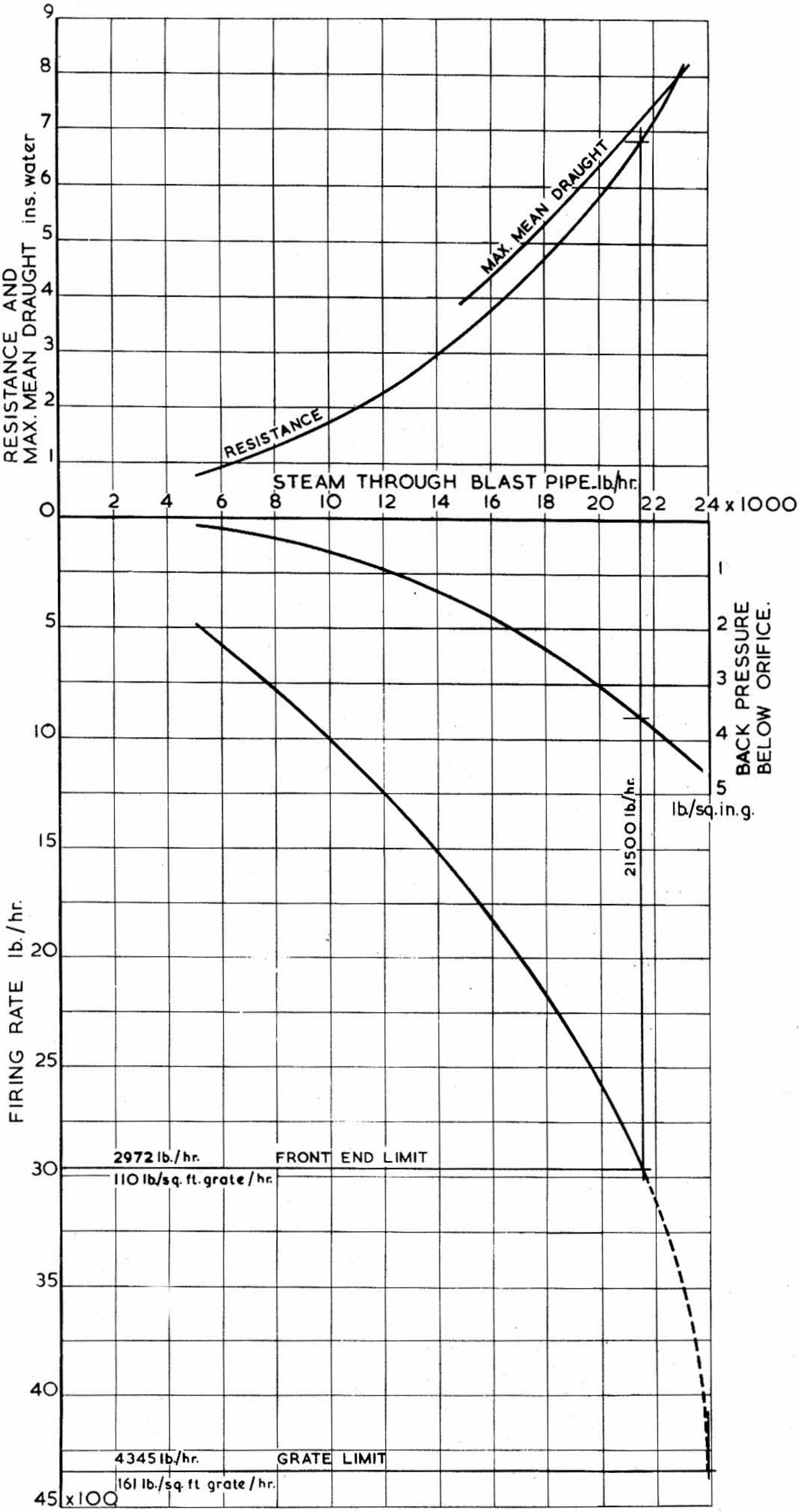


MARKHAM COAL.
14330 B.Th.U./lb.

EXHAUST STEAM INJECTOR.

EVAPORATION.

LU/7916/51



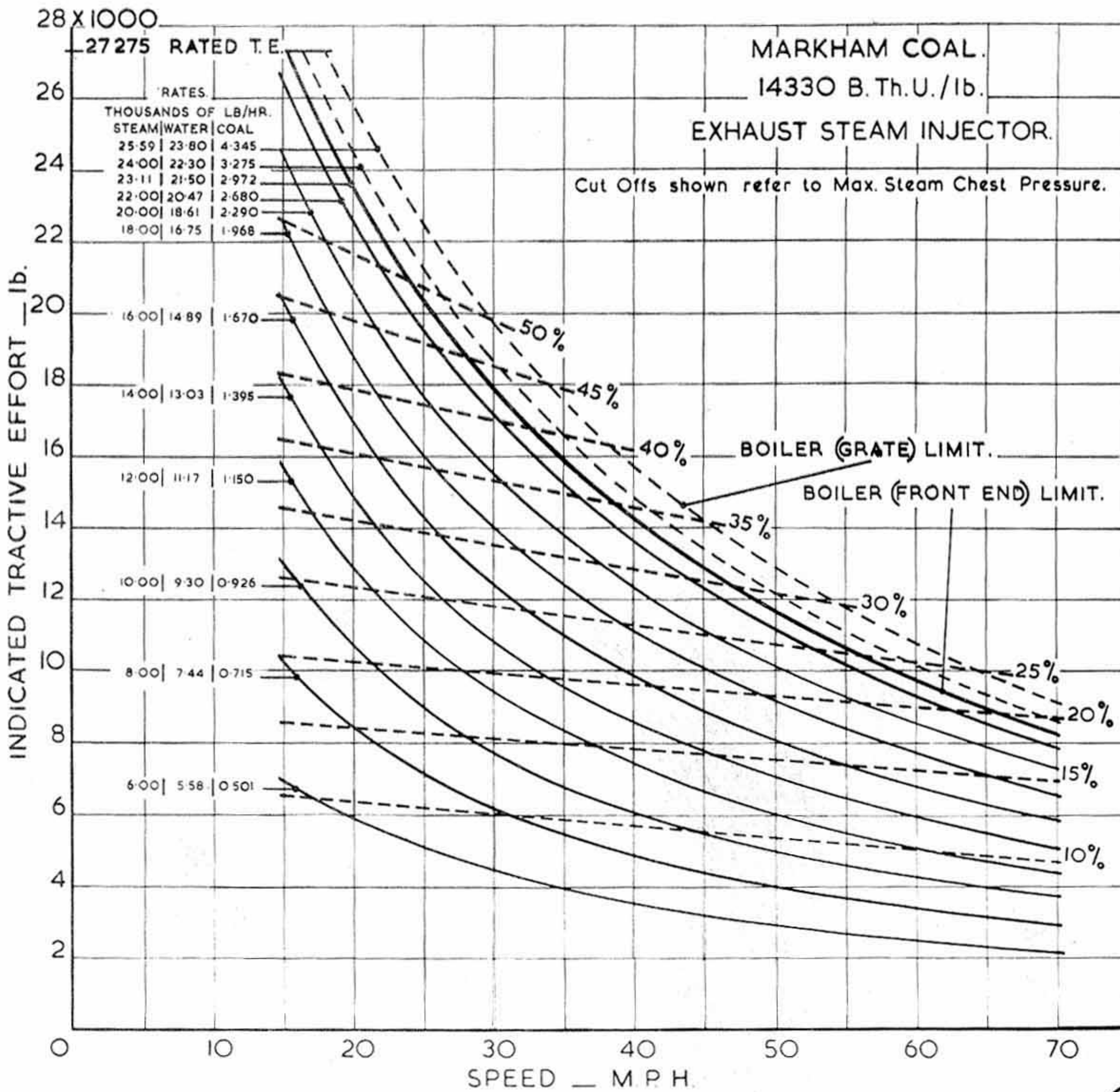
MARKHAM COAL
14330 B.Th.U./lb.

EXHAUST STEAM INJECTOR

DRAUGHT

34

LU/7916/51



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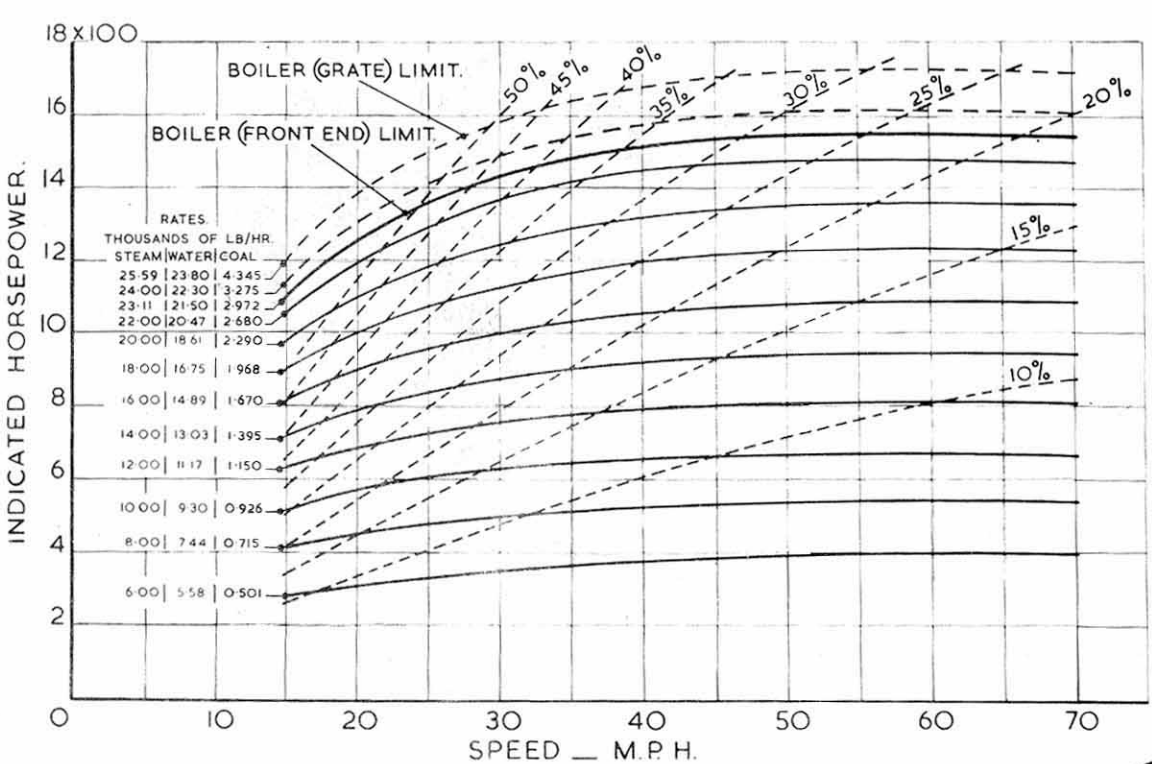
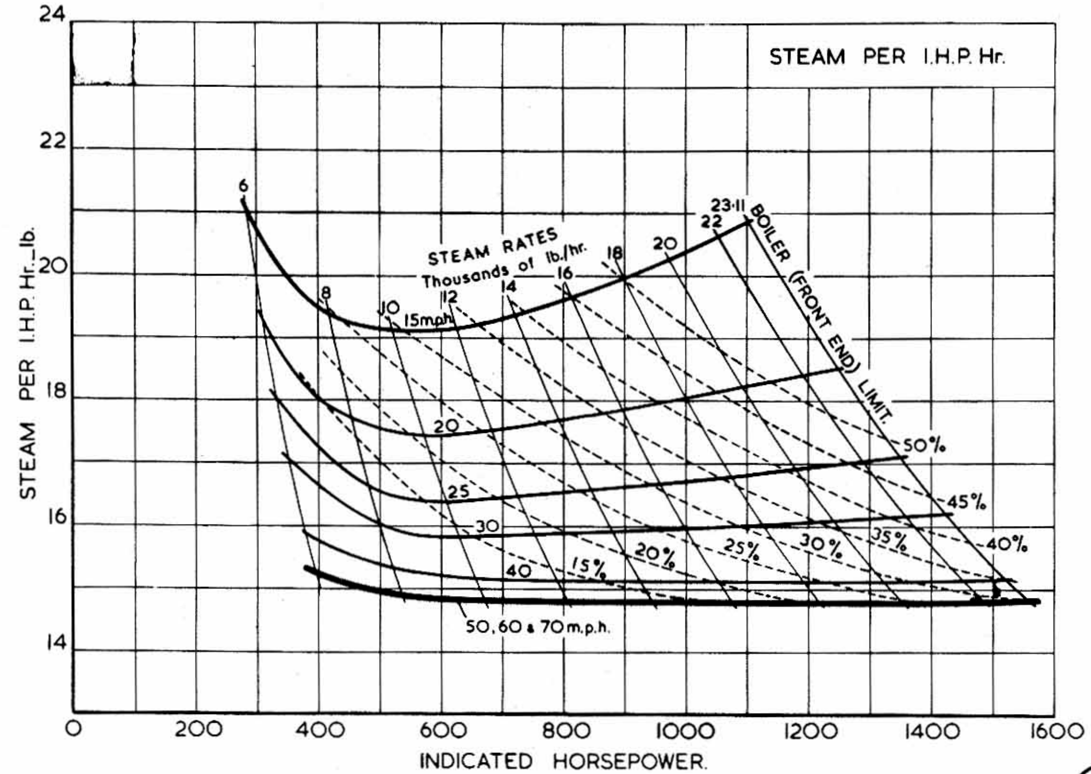


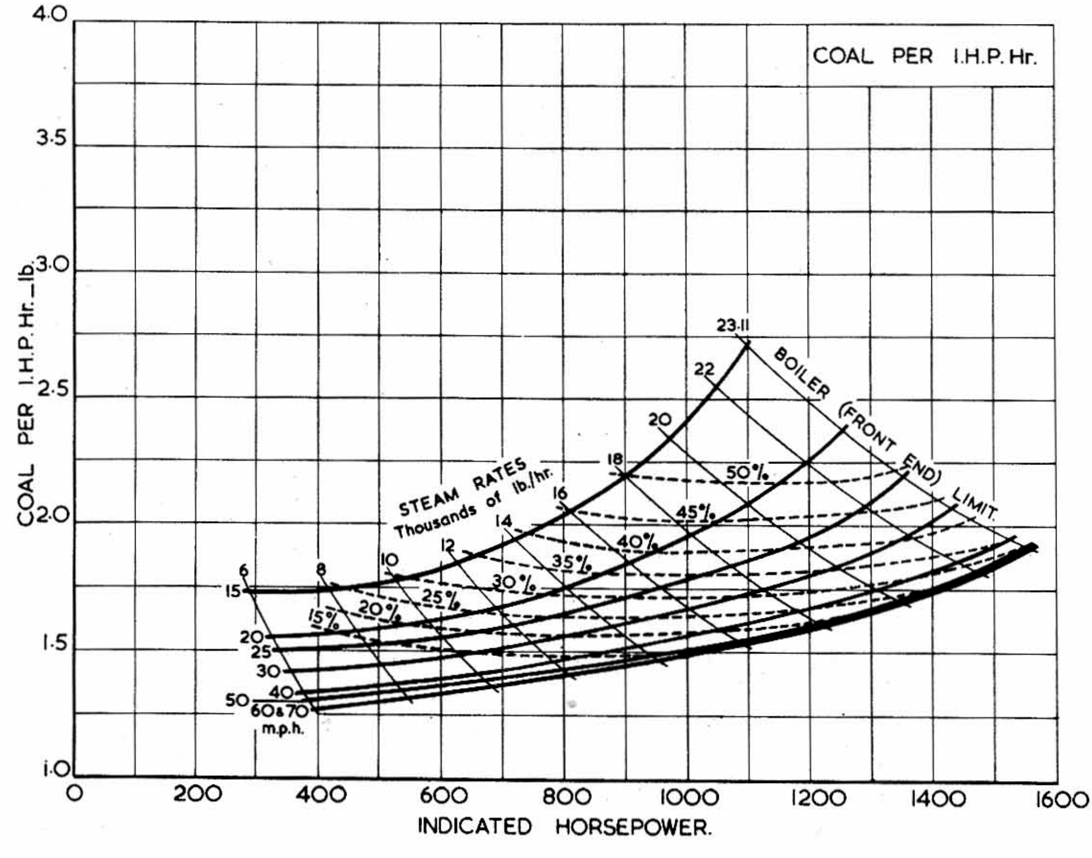
INDICATED CHARACTERISTICS.

36

Cut Offs shown refer to Max. Steam Chest Pressure.

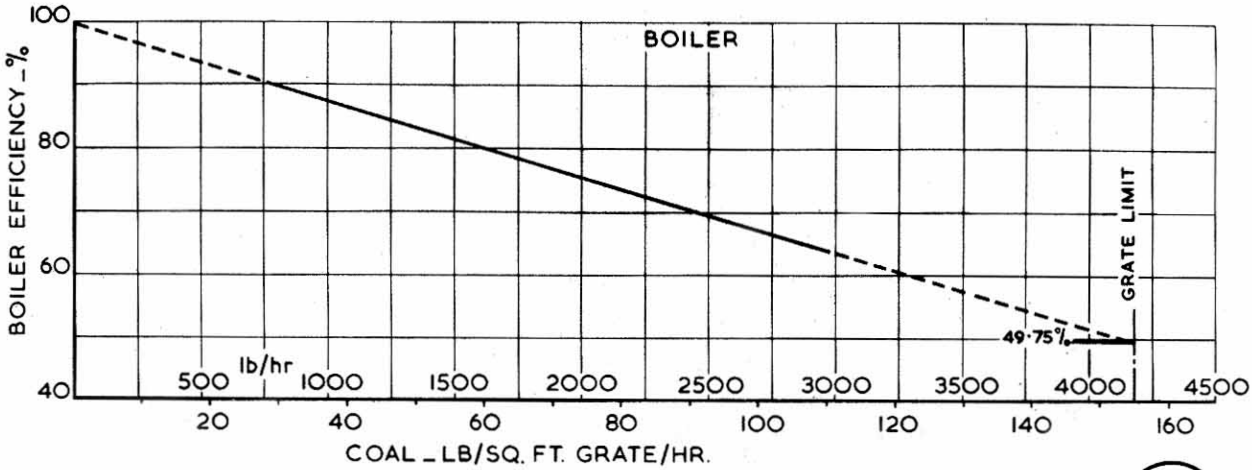


37



STEAM & COAL PER I.H.P. Hr.

38



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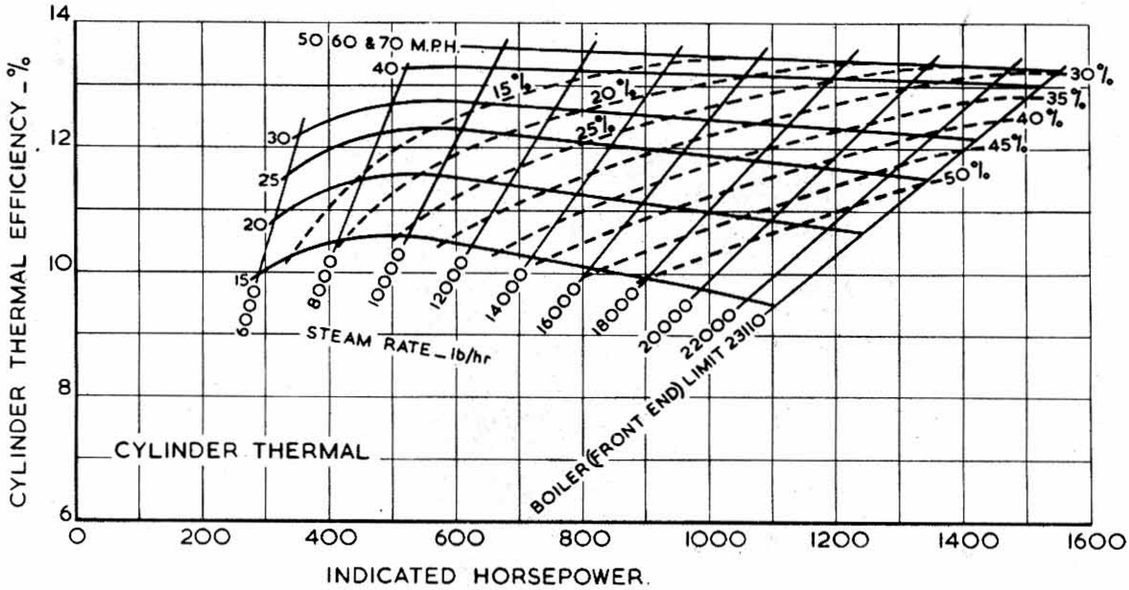
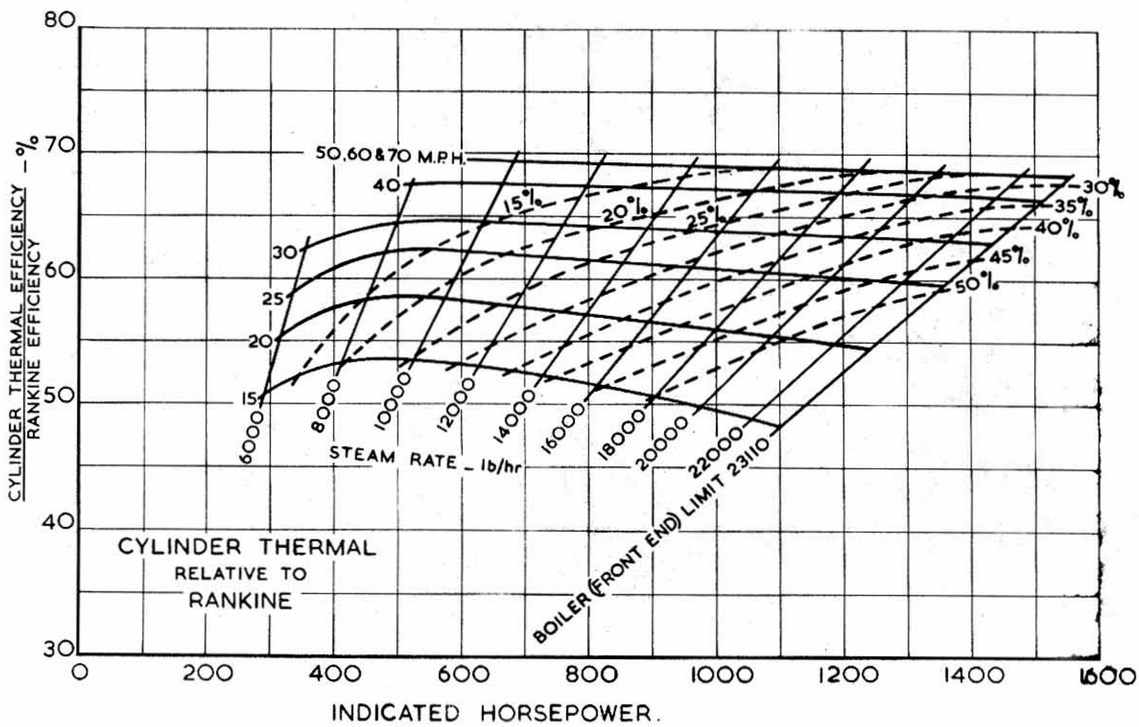


Cut Offs shown refer to Max. Steam Chest Pressure.

40



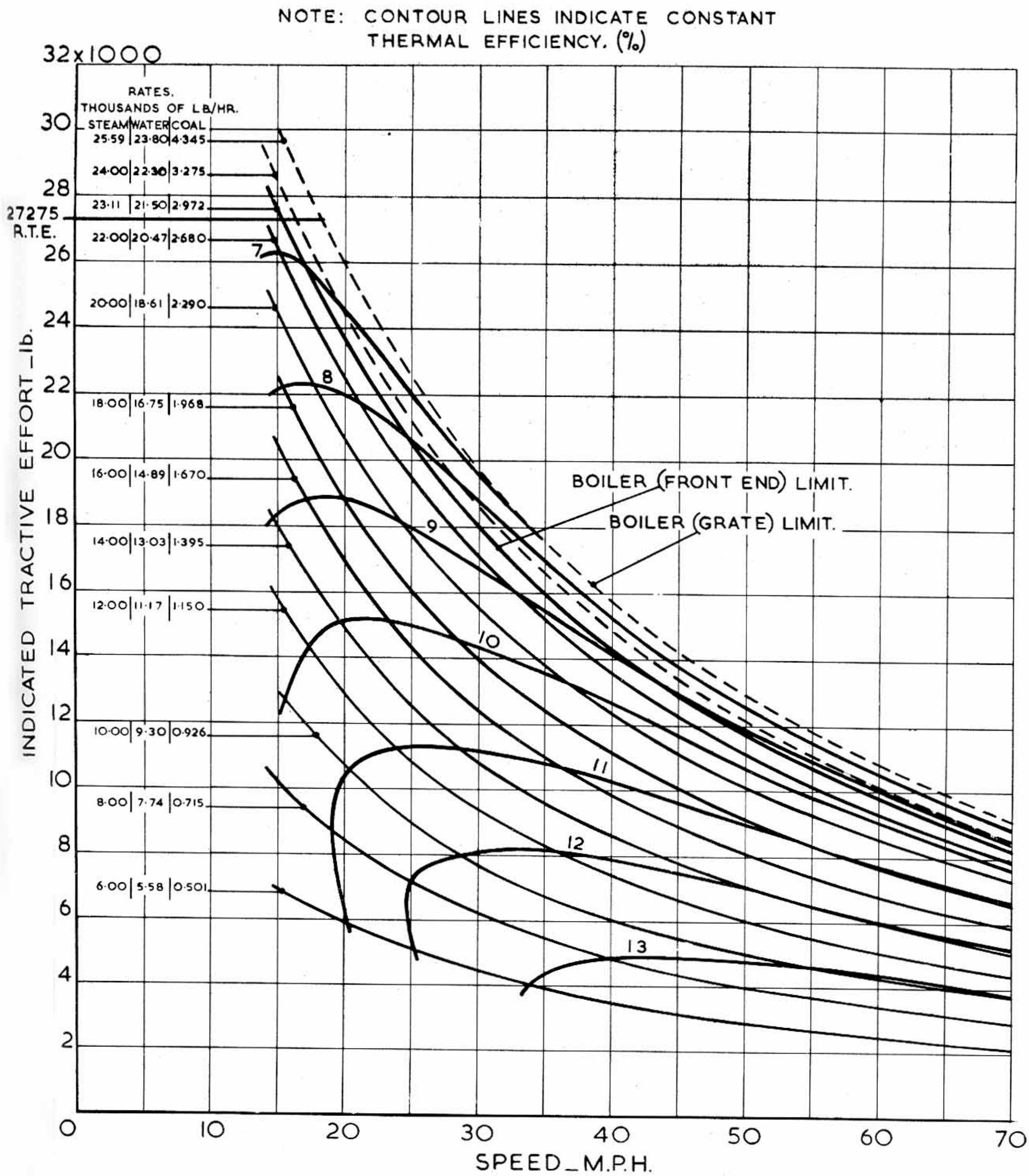
MARKHAM COAL.
14330 B.Th.U. / lb.

EXHAUST STEAM INJECTOR.

EFFICIENCIES.

41

LU/7916/51.



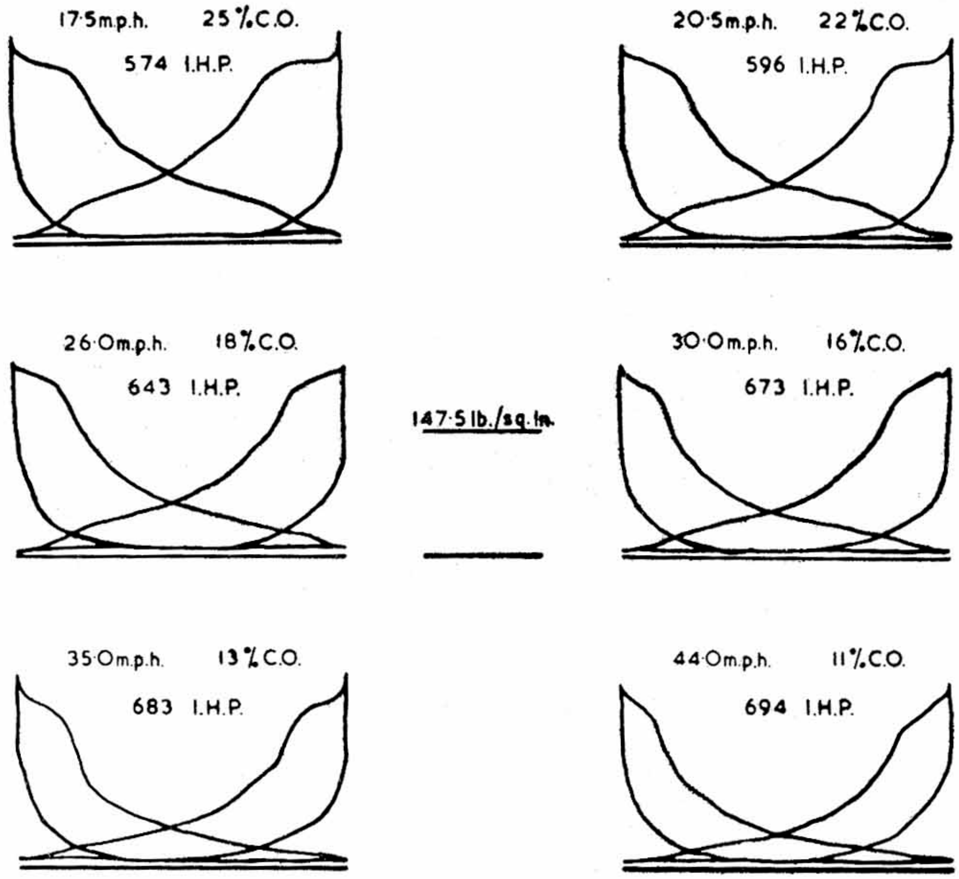
MARKHAM COAL
14330 B.Th.U./lb.

EXHAUST STEAM INJECTOR.

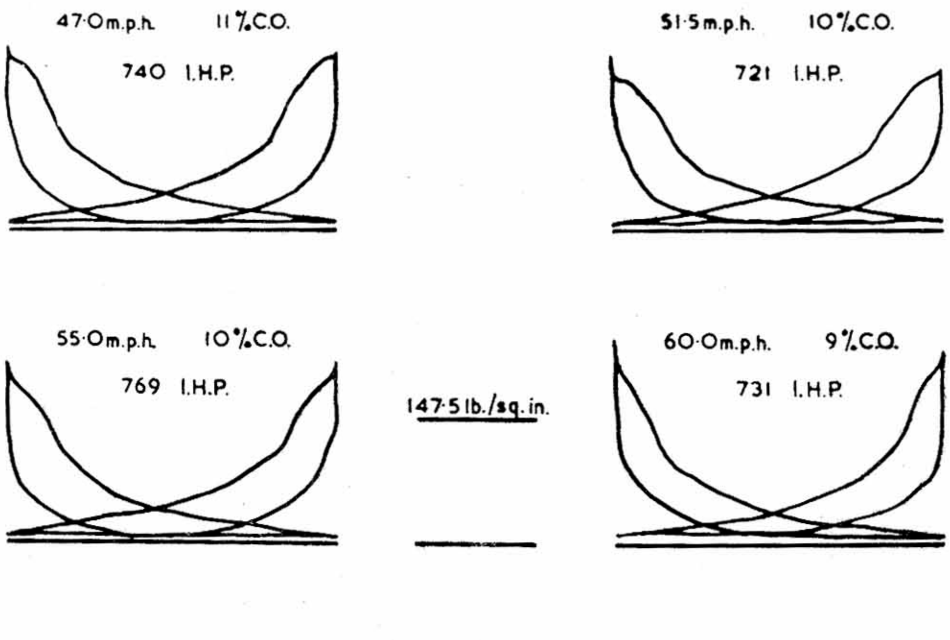
OVERALL EFFICIENCY REFERRED TO CYLINDERS.

LU/7916/51.

MEAN STEAM RATE 10450 lb./hr.. FULL REGULATOR.

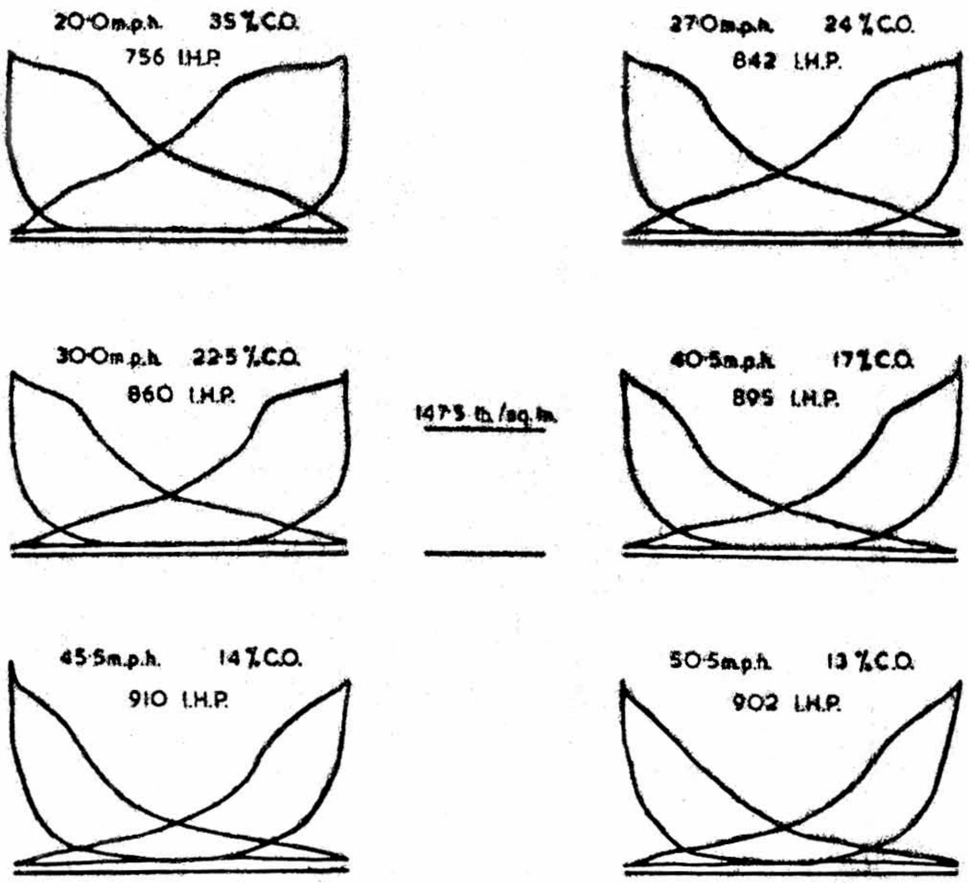


MEAN STEAM RATE 11000 lb./hr.. FULL REGULATOR.

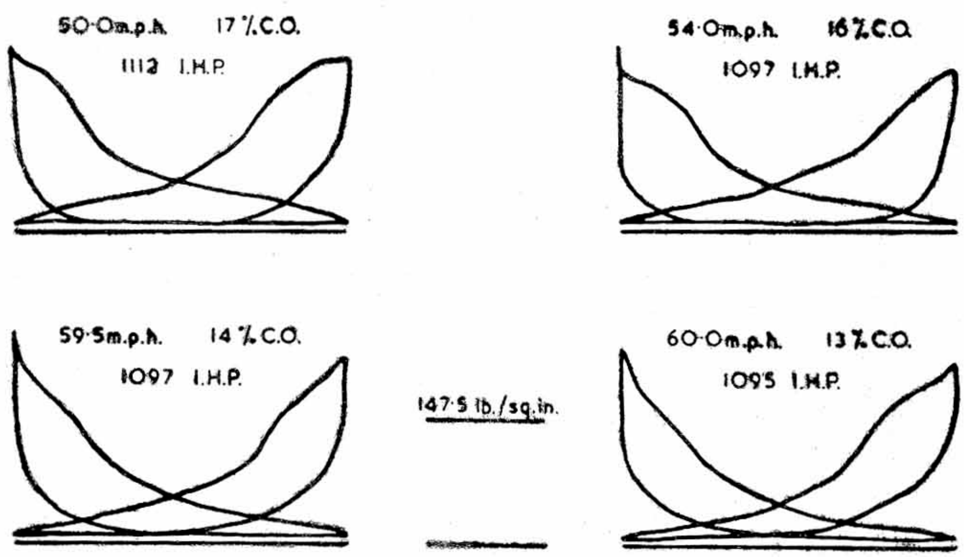


EXAMPLES OF INDICATOR CARDS.

MEAN STEAM RATE 13600 lb./hr.. FULL REGULATOR.



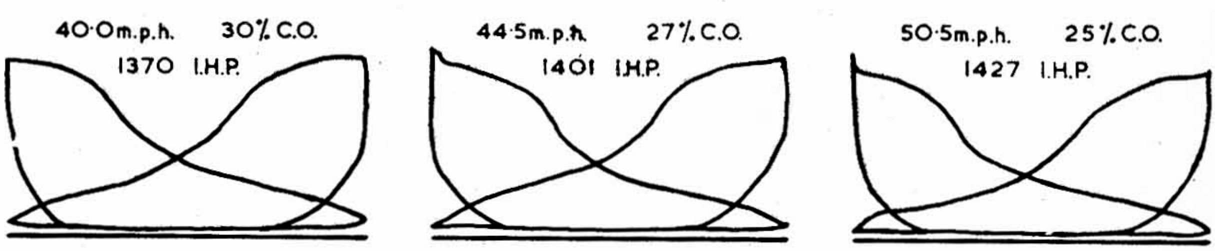
MEAN STEAM RATE 16150 lb./hr.. FULL REGULATOR.



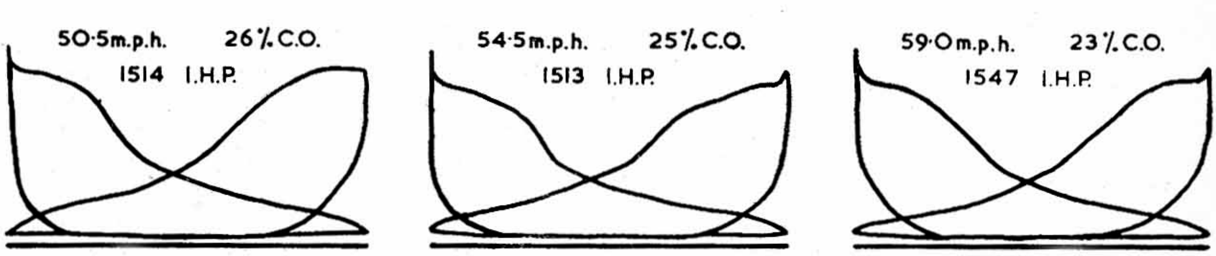
EXAMPLES OF INDICATOR CARDS.

MEAN STEAM RATE 17300 lb./hr.. FULL REGULATOR.

MEAN STEAM RATE 20900 lb./hr.. FULL REGULATOR.



MEAN STEAM RATE 22600 lb./hr.. FULL REGULATOR.



EXAMPLES OF INDICATOR CARDS.

LU/7916/51.