BRITISH TRANSPORT COMMISSION

BRITISH RAILWAYS

PERFORMANCE AND EFFICIENCY TESTS OF SOUTHERN REGION "MERCHANT NAVY" CLASS 3 CYL. 4-6-2 MIXED TRAFFIC LOCOMOTIVE

January 1954

PRICE 10s - 0d NET

Published by
The British Transport Commission,
222, Marylebone Road, London, N.W.1

Printed in Great Britain

BULLETIN NO. 10

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JANUARY 1954

B.R. 10800

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INTRODUCTION

This class of locomotive was first built by the former Southern Railway in 1941.

It was introduced to meet the need for mixed traffic locomotives of greater power than were then available on the Southern Railway.

This Bulletin is concerned not only with the performance of the locomotive "As designed" but also with additional trials of a modified chimney and blast pipe arrangement and of a boiler without the thermic syphons in the firebox, as normally fitted on this class. The Bulletin also describes a basis for the allocation of locomotives to the duties for which they are best suited and to enable those duties to be performed within the most economical part of the locomotive's working range in so far as the requirements of the Operating Department are satisfied.

The presentation of the data in this bulletin, therefore, differs somewhat from that adopted for earlier bulletins.

The first main part, relating only to the "As designed" condition of the locomotive, defines the relationships between coal, as fired, and water, as drawn from the tender, tractive effort and horsepower, both as available at the tender 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.

Besides covering the use of two different coals this part covers the working of the locomotive in two distinct ways, with relatively short cut-offs and fully, or nearly fully, open regulator on the one hand and at a relatively long cut-off and partially open regulator on the other.

The second main part is concerned mainly with thermal efficiency, giving data on a basis of indicated power, covering boiler and cylinder efficiencies, factors of more importance in locomotive design. This part covers the use of three different coals with the locomotive "As designed".

The third and fourth parts deal with the modifications to the "Front end" and to the firebox respectively.

The tests were carried out at the Locomotive Testing Station, Rugby, and with the London Midland Region No. 1 Dynamometer Car. This Bulletin has been prepared by the Rugby and Derby testing staffs.

The work was under the general supervision of the Locomotive Testing Sub-Committee consisting of :-

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Mr. R.F. Harvey	Chief Operating & Motive Power Officer, B.T.C. B.R. Central Staff.
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FOREWORD

This design of locomotive proved to be difficult to test owing to its inconsistent performance, especially with regard to power output. Not only was it often found impossible to obtain reasonable accuracy of repetition on different occasions but the performance would sometimes change appreciably over quite short periodsof time. The changes were usually not of such magnitude as would have affected the locomotive's ability to carry out its normal duties quite effectively, but were such as to make accurate measurement exceptionally difficult, especially on the stationary test plant.

These phenomena are of a kind known to be characteristic of this class of locomotive and are not peculiar to the one tested though their occurrence may vary from one engine to another and from time to time.

For this reason the test results cannot be regarded in all respects as being as soundly established as is normally the case and must be taken as a general representation of the performance of the class rather than as exact results for any particular engine at any one time.

NATURE OF THE TESTS

The boiler and cylinder performances were first established by tests on the stationary testing plant.

These tests were followed by tests on the road by means of the Controlled Road Testing System. On these the boiler efficiencies which had been established on the stationary plant were reproduced and the coal and steam rates also established on the stationary plant were related to the horsepower at the drawbar.

There is some discrepancy between the results of the plant tests and those on the line, which is attributed to the inconsistent behaviour of the locomotive though the broad picture presented by the results from each is fairly representative.

The main tests were carried out between March and November, 1952, the tests with the modified chimney and blast pipe between March and May, 1953 and those with the modified boiler between December, 1953 and January, 1954.

METHOD OF TESTS

The tests were carried out in the first instance at the Locomotive Testing Station, Rugby, and the subsequent Controlled Road Tests were carried out between Carlisle and Skipton in the London Midland Region.

STATIONARY PLANT TESTS

These were conducted at constant rates of evaporation and combustion and at constant speed.

The coal and water rates were established by the summation of increments method and with the aid of the Swindon steam flow meter.

The range covered by the tests was from 15 to 85 m.p.h., from 10 to 50% nominal cut-off and from 10,000 to 42,000 lb/hr. of feed water. The majority of the tests were carried out with the regulator fully open.

Indicating was carried out, on the test plant only, using a modified "Farnboro'" Indicator as described in Bulletins Nos. 5 and 6.

CONTROLLED ROAD TESTS

These tests were carried out at constant rates of steaming using the Swindon Type Steam Flow Indicator to ensure the necessary constancy and in general the same methods of control were exercised over the conbustion as with the Stationary Plant tests.

The ranges of speed, nominal cut-off and steaming rate were all appreciably less than on the stationary plant, the maximum steaming rate being limited to about 29,000 lb/hr. which sufficed to work a train of 20 bogie coaches, 594 tons, at the scheduled speeds involved, this being the largest number of bogie coaches that have ever been operated over this route and over 40% above the rostered tare load, on limited load schedules, for a Class 7, 4-6-0, this being the most powerful locomotive normally permitted.

TEST ARRANGEMENTS

The test arrangements were appreciably affected by special features of the locomotive, mentioned below.

A number of tests on the plant, including all those involving the measurement of coal rates, were of normal duration, varying from 60 to 150 minutes, but a large number were also carried out with much shorter durations for the determination of power outputs and steaming rates only. On the line most of the tests had durations of 65 to 75 minutes but a few were shorter.

For tests at sustained rates of firing appreciably above 3,000 lb/hr. two firemen were used to avoid undue fatigue. These rates of working are greater than anything normally required for train working by engines of this power classification, except for periods of very limited duration.

THE LOCOMOTIVE

The locomotive selected for the tests was No. 35022, one of a batch built in the Eastleigh Works of the Southern Region of British Railways in 1948. It was prepared for testing during a classified repair and had run 1,115 miles in traffic before its first arrival at Rugby.

In the first series of plant tests 10,300 miles were covered and a further 3,840 miles were run in connection with the dynamometer car tests. The tests with the modified chimney then involved an additional 2,460 miles on the test plant, after which the locomotive returned to traffic.

When the modified boiler was fitted the engine was given a light repair, including attention to valves and valve gear and new tyres were fitted, the old ones having been reduced to the minimum turning size before the first series of tests. It then ran some 1,140 miles in traffic before it again arrived at Rugby and covered another 2,820 miles on the Test Plant.

The locomotive was in good working order for all tests although there was some mechanical trouble, which accounted, in part, for the rather high mileages mentioned above.

SPECIAL FEATURES

. The locomotive has a number of special features, some of which either were the subject of particular aspects of the trials, such as the multiple jet blast pipe and the thermic-syphons fitted in the firebox, or affected the tests in general.

Valve Gear

The valve gear is a special feature of the design which gave rise to some difficulty in testing.

It was found that the actual cut-off bore no definite or consistent relationship to the setting of the reversing gear, not only for the locomotive as a whole but especially for the individual cylinder ends. In the shorter cut-offs particularly, there was a general tendency for the actual mean cut-off to lengthen with increasing speed but not in a smooth or regular manner. The power output in the short nominal cut-offs in the upper part of the speed range was found to be greater than that of other locomotives, size for size, and was in some cases more than would theoretically be possible at an actual cut-off equal to the nominal cut-off, even assuming that the cylinders were completely filled up to the point of cut-off with steam at full steam chest pressure and that no early release occured. The true cut-off must have been longer than the nominal. At times quite random changes occurred that appeared to be caused by minute changes of speed or boiler pressure. Some of these random changes were relatively small, though enough to upset the test conditions, but others were of relatively large amount.

Whilst changes that occurred over a period of weeks or months might be ascribed to wear of the motion, however small, this could hardly be the case with changes from one day to the next or which occurred, sometimes more than once, in a single test period.

As an example of the difficulties the following case may be quoted :-

Some tests had been carried out in 10% cut-off at speeds from 15 m.p.h. upwards and then some in 15% cut-off. It was noted that the recorded pulls in the longer nominal cut-off at 15 and 20 m.p.h. were less than those for the shorter cut-off, but that a reasonable relationship existed between the two at higher speeds. On the following day check tests were made and the recorded pull at 15 m.p.h. was double that of the day before and that at 20 m.p.h. more than half as large again as on the previous day; at 30 m.p.h. and above, however, fair agreement was established.

A further difficulty was that the locomotive at certain speeds and cut-offs was unstable in conjunction with the control system of the Test Plant brakes so that the speed varied uncontrollably over a wide range, e.g. from 21 to 29 m.p.h., with consequent rapid fluctuations in power output and steam consumption. This phenomenon resulted from the abnormal way in which the pull of the locomotive, in certain conditions, increased with rising speed, thus almost matching the rising brake characteristics instead of cutting across them as do the falling characteristics of locomotives with other valve gears: The effect was heightened by the time required by the brake system to adjust itself, with is appreciable.

The irregular nature of the characteristic curves made it unwise to interpolate between normally spaced observations and the number of these had, therefore, to be increased.

STEAM REVERSING GEAR

The locomotive is fitted with a steam reversing gear, which could not be prevented, by adjustment, from creeping very slightly: The amount of creep would not have been perceptible in service but it was enough to prevent testing in uniform conditions on the plant. To overcome this trouble a number of special distance pieces were made, against which the reversing gear could be held in a definitely fixed position: These distance pieces, however, could only be inserted whilst the locomotive was stationary, making it impossible to alter the gear to any other definite position once the locomotive was running.

The reversing gear was modified for use during the tests on the line to make fine adjustment possible, but, due to the need for continual alteration of the cut-off with changing speed, the small creep did not cause any difficulty.

Slipping

The proneness of the locomotive to slipping whilst running (as opposed to slipping at starting), is ascribed to the fact that it cannot be run for an appreciable time without lubricating oil reaching the wheel treads and, on the Test Plant, the rollers. Thorough cleaning before every test and wiping of the Test Plant rollers at frequent intervals were necessary to enable any high powered tests to be completed.

Whereas usually a severe slip can be tolerated on the line and on the plant results only in the need to repeat the test in progress, with this locomotive it was also liable to lead to buckling of coupling rods, which occurred on a number of occasions during the tests on the plant and on the line.

It was the possibility that such slipping might give rise to more serious damage to the locomotive and to the Test Plant that made it inexpedient to attempt to find the true "Front end limit" with either South Kirkby or Bedwas coals or to define it very precisely with Blidworth. As such rates of working, in any case, are beyond the ability of one fireman to maintain in service, no advantage was to be gained from attempts to obtain the utmost possible output from the boiler.

Steps were already being taken to provide redesigned coupling rods for the Merchant Navy locomotives.

MECHANICAL FAILURES

During the trials on the test plant the locomotive demonstrated its ability to work at very high sustained rates of steaming, far higher than those at which it would normally work continuously in service. Under these conditions, however, there was a tendency for mechanical failures to occur, such as heating of coupled axleboxes, inside big ends, coupling rod bushes, etc.

No mechanical trouble, other than the buckled coupling rods, was experienced during the trials on the line.

INJECTORS

Live steam injectors only are fitted to this class of engine and the rates of steaming and of evaporation are therefore identical with the feed water rates on the test plant.

INDICATING

All indicating was carried out with the modified "Farnboro'" Indicator, which has been described in Bulletins 5 and 6. Some representative diagrams have been converted to a stroke base, for ease of comparison: Some of the finer detail of the originals is lost in such conversions. It should be noted that, as a consequence of this conversion, the stroke base scale of the diagrams for the inside cylinder is larger than that for the outside cylinders.

COAL

Three kinds of coal were used for the tests of the locomotive in the "As designed" condition on the test plant :-

South Kirkby, a grade 1A, Hard South Yorkshire.
Blidworth, a grade 2B, Hard East Midlands.
Bedwas, a grade 2A, Soft South Wales.

The South Kirkby and Blidworth coals were also used for the trials on the line.

The tests at Rugby of the single blast pipe and without thermic syphons were all carried out with Blidworth coal only.

The South Kirkby was supplied in very large pieces which were broken down to "Cobbles" for firing. For the sake of uniformity of test results the consequent fines and small coal under 1" size were screened out.

The Blidworth coal was supplied as "Small Cobbles" and although some smaller sizes were present it was very suitable for firing, without screening.

The Bedwas, like all soft coals, is so friable that a considerable amount of small coal and fines are inevitably fired. It is not quite typical of South Wales coals, most of which have an even higher proportion of fixed carbon and lower volatile content, but it is representative of some of the coal that is supplied to a number of the Merchant Navy Class locomotives in service.

For each coal the samples shewed little variation in analysis and calorific value, representative values and analyses being given in table No. 1.

There was, however, a deterioration in the quality of the Blidworth coal between the original tests and those with the boiler without thermic syphons, which took place a year or so after the original tests, and this may have had a small effect on some of the results of those tests.

OBSERVATIONS

Some comment is required on the various graphs shewing the test results.

Graphs 1 and 2 shew the drawbar pulls, for various speeds at various steaming rates for Part Regulator and nominal "Full" Regulator conditions. In the former the cut-off was a nominally constant 30% and all control effected by throttling at the regulator, a method of working akin to that often used in ordinary service with these locomotives.

It was found impossible to work the locomotive at full regulator throughout its whole power and speed range, and after cut-off had been brought back to a nominal 10%, corresponding to a drawbar pull of about 10,000 lb. on the level, further reduction in pull had to be met by partially closing the regulator. This was done to obtain the correct steam flows at any hourly rate used in the tests on the line for either a part or the whole of the speed range. The upper part of the diagram does, therefore, actually refer to working with the regulator fully open but the lower part refers to working with partly open regulator and a nominal cut-off of 10%, the shortest at which the gear was operated.

These curves are for both Blidworth and for South Kirkby coals except that the efficiency contours apply to the former only.

The same operating conditions apply for graphs 3 and 4 as for 1 and 2, respectively.

Comparison of these two pairs of graphs shews that at any speed above 30 to 32 m.p.h. it is uneconomical to work at a comparatively long cut-off with severe throttling of the steam and is so to a very serious extent at normal express speeds, the reduction in power output at the same steaming rate reaching 20%, even at high rates and increasingly more as the rate becomes less.

Graphs 5 and 6 shew the specific water consumption and the corresponding specific consumption of Blidworth coal for the Part Regulator and graphs 7 and 8 for the nominal "Full" regulator working. Although absolute minimum steam rates were not reached the levels of the lowest values attained are comparatively high but they mostly occur at relatively high rates of working, such as are only rarely required continuously in service.

Graphs 9 and 11 shew the inlet and exhaust steam temperatures attained at various rates of steaming when Blidworth, Bedwas and South Kirkby coals were fired. The differences in inlet temperature made no difference to the specific steam consumptions within the limits of measurement for this locomotive. The exhaust steam temperatures are approximate as these depend to some extent on the nature of the engine working as well as on the rate of steaming. Nevertheless they are a good deal higher than might have been expected for the corresponding inlet steam temperatures.

Graphs 10 and 12 shew the smokebox gas temperatures and the firebox gas temperature, about six inches from the centre of the tubeplate, for various rates of firing Blidworth coal.

Graphs 17, 19 and 21 shew the Steam-Air-Combustion relationships and graphs 18, 20 and 22 the Steam-Gas-Draught-Blast Pipe Pressure relationships for Blidworth, Bedwas and South Kirkby coals respectively. The type of firedoor fitted is intended to be kept closed except at the moment of firing but it did not admit enough air to give a smoke free exhaust, especially with the Blidworth coal, and it had to be left open to an increasing degree as the rate of firing was increased. Even so, the amount of smoke produced was more than would normally be expected.

Graphs 27, 28 and 29 relating the feed water rates (which are the same as the steaming rate on the Test Plant) to the coal rates and the corresponding boiler efficiency graphs 30,31 and 32 shew no "Front end limit" for the locomotive in its "As designed" condition. With Blidworth coal an actual rate of 33,300 lb/hr. was sustained but the true limit was not reached and no higher rate was attempted owing to the liability to severe slipping and possible damage to both engine and test plant: It has been judged reasonable to include a rate of 34,000 lb/hr. in some of the later graphs relating to this coal. With Bedwas coal an actual rate, still well below the limit, of 37,000 lb/hr. was sustained and with South Kirkby coal 39,000 lb/hr. was actually sustained for a measured test period of over an hour and a rate of 42,000 lb/hr. was held for over 20 minutes without any indication that the limit had been reached: This last figure is close to the critical "Discharge limit" of the multiple jet blast pipe cap.

The curves of indicated tractive effort and indicated horsepower in graphs 34 and 35 are valid for all three coals except that the upper curves can only be attained with the better quality fuel. Lines of constant cut-off have been omitted as these could not be repeatably defined. As an indication of the unusual nature of these lines, at a particular stage in trials, graph 36 is included but it can only be regarded as applicable to No. 35022 at the time and not to the "Merchant Navy" class generally.

The specific consumptions of steam and Blidworth coal per I.H.P. hour are shewn in graphs 37 and 38. The former of these shews that the lowest specific steam consumption of the "Merchant Navy" is just under 15.9 lb/I.H.P.hr. against figures between 13.2 and 13.8 for a variety of comparable locomotives, i.e. from 15 to 20% higher. The specific coal consumption is increased in a rather greater degree since the minimum specific steam consumption of the "Merchant Navy" occurs at a relatively high steaming rate at which the boiler efficiency is lower.

Graphs 29 and 40 shewing the cylinder thermal efficiency and efficiency ratio are in accord with the specific steam consumption curves and the efficiency contours of graph 41 are consistent with the specific coal consumption curves.

CONCLUSIONS (As Designed)

The essential conclusions to be reached from the first two parts of this bulletin, dealing with the locomotive "As designed" are that it is a most effective and capable engine but one that is relatively uneconomical.

If operated, as they frequently are in service, with the reversing gear in a relatively long cut-off and with the regulator very little open, these locomotives will be still less economical though their performance will then be more reliable from the mechanical point of view and from that of power output. The vibration, associated with full regulator and very short cut-off working, is also avoided.

In spite of the good draught provided by the multiple jet blast pipe the combustion was never very good particularly with the lower grade coal. There was, however, no evidence that the thermic syphons had anything to do with this: On the other hand there was some evidence that wider spacing of the grate bars and the provision of a deflector plate and admission of rather more air through the firehole door, with the doors closed, would effect some improvement.

The actual draughting arrangement could almost certainly be improved by some re-design of the chimney. The actual choke is located about 7 inches above the effective choke where the vacuum is highest.

SINGLE BLAST PIPE

One locomotive of the class has been in service for some time with a special blast pipe with a single circular orifice and with a chimney of reduced diameter.

A similar chimney, adjustable vertically in the smokebox, and two blast pipes, with different orifice diameters, were supplied as a basis for the trials.

The essence of the whole problem, with this class of locomotive, is that the height available between the top of the inside valve chest and the top of the chimney, as limited by the loading gauge, is very restricted for so large a locomotive. It is not possible to obtain good proportions for the parts as the various requirements are conflicting.

A longer blast pipe was desirable to direct the exhaust better, the short sharply tapered pyramidal pipe allowing the exhaust from each cylinder end to escape at an appreciable angle to the centre line of chimney and blast pipe. Adding the extension (originally $5\frac{1}{4}$" diameter and parallel) which was fitted to direct the jet better, reduced the height from the top of the blast pipe cap to the chimney choke, already severely restricted: Raising the chimney to restore its position relative to the blast pipe top involved shortening the chimney itself, which is also detrimental.

For these reasons a redesigned blast pipe was made, but this too was reduced in height during the trials.

The actual blast pipe and chimney arrangement giving the best result is shown in Fig. 2.

In spite of every effort to obtain good combustion none ofthe combinations of blast pipe and chimney gave results that were up to the standard set by the multiple jet arrangement and none of them enabled the boiler to produce an amount of steam comparable with that produced with the multiple jet exhaust or such as ought to be possible from the boiler of a "Class 8" mixed traffic locomotive.

Graph 32 shews a single line for the boiler efficiency for both the single jet and multiple jet conditions as the two could not be distinguished within the limits of experimental error.

The maximum steaming rate was, however, reduced from about 34,000 lb/hr. to about 31,000 lb/hr., which is a serious diminution of the engine's potential capacity.

Graphs 23 and 24, which also refer to the best single blast pipe arrangement, show how the boiler was starved of air at the higher rates of firing and steaming in comparison with the results depicted in graphs 21 and 22 for the "As designed" state.

CONCLUSIONS (Single Blast Pipe)

The trials shewed that a satisfactory compromise between the conflicting requirements is impossible in the reduced height available as a good single blast pipe and chimney would need about a foot more.

The fact that one locomotive so equipped has run "Satisfactorily" for many months must be attributed to the fact that most of the duties performed by "Merchant Navy" class engines can be carried out at continuous steaming rates appreciably below the maximum of which the class is capable or that higher rates are only required as transitory performances.

On these locomotives the use of the multiple jet arrangement is practically unavoidable if anything like full use is to be made of the steaming capacity of the boiler when inferior coal is used.

There was nothing to suggest that the multiple jet blast pipe gives rise to the ejection of abnormally large amounts of unburnt coal from the chimney, as the losses due to unburned coal were not seriously larger than those of other locomotives.

BOILER WITHOUT THERMIC SYPHONS

The removal of the thermic syphons necessitates a completely different type of brick arch and it must be emphasised that such differences as were observed may have been due as much to the different arch as to the absence of the syphons.

In addition a year had elapsed and there was some deterioration of the quality of the coal, although there was nothing of any real note different in the analyses.

Much trouble was experienced from clinkering of the grate and 'Birdsnesting' of the tubeplate, but how much of this should be ascribed to the alterations to the boiler and how much to some change in the coal is doubtful. The locomotive was certainly far more difficult to fire correctly than it had formerly been.

Graph 33 shews the boiler efficiency, this being marginally higher than that for the boiler with the syphons. The difference of about $1\frac{1}{2}\%$ is barely outside the limits of experimental error and but little, if at all, above the order of difference that might be found between two nominally identical boilers.

The highest rate of steaming actually reached was 32,000 lb/hr., no attempt being made to go beyond this. This rate was reached, however, more easily than the 33,300 lb/hr. had been attained with the syphon equipped boiler and it can reasonably be said that there is no significant change in the maximum outputs, which are nearly identical on the basis of equivalent evaporation.

Combustion was not improved nor was smoke emission **reduced**. Compare graphs 25 and 26 with 21 and 22.

The temperatures attained were as shown on graphs 13 to 16, the only outstanding differences being some increase in the temperature near the firebox tube-plate and an appreciable increase in inlet steam temperature, as compared with the curves in graphs 9 to 12.

COMMENTS (Without Syphons)

The removal of the thermic syphons has virtually no effect on the maximum output of the boiler, when using Blidworth coal, because the limit is set by the amount of fuel that the draught can burn and not by the ability of the heating surfaces to transmit the heat of the gases to the water; the boiler tubes can transmit to the water virtually the whole of any additional heat in the gases that has no longer been transmitted by the syphons in the firebox. The maximum actual evaporation may be very slightly lower but, due to the higher superheat, the equivalent evaporation is practically identical with that for the syphon equipped boiler.

The removal of the syphons and the change of brick arch resulted in an increase in the inlet steam temperature of some 40° to 60°F.

The fact that the thermic syphons in this locomotive do not make any improvement in either efficiency or output is contrary to test results obtained in the United States. This is probably due to the larger size of the U.S. locomotive concerned and the fact that, there, it is usually very difficult to obtain sufficient firebox heating surface without syphons or similar devices, whilst the effect of changing the brick arches may have been quite different in the two cases.

CONCLUSIONS (Without Syphons)

Whilst it would not be worthwhile, on boiler performance grounds alone, to remove the syphons it seems equally not worthwhile to fit them in any British coal fired locomotive of similar or smaller size, at least whilst hand firing is in operation.

An appreciable advantage in improved steam consumption would, however, normally be expected from the higher superheat that results from the removal of the syphons.

TABLE NO. 1

	SOUTH KIRKBY		BLIDWORTH		BEDWAS	
	AS RECEIVED	DRY	AS RECEIVED	DRY	AS RECEIVED	DRY
CALORIFIC VALUE						
Calories per gram.	7775	7963	7159	7692	7905	8070
British Thermal Units per lb	13994	14334	12887	13846	14229	14526
Pounds of water at 212^{o}F converted into steam at the same temperature by 1 lb. of coal.	14.43	14.78	13.29	14.27	14.67	14.98
PROXIMATE ANALYSIS						
Moisture %	2.37	-	6.92	-	2.05	-
Volatile Matter, less moisture %	36.63	37.52	32.91	35.36	26.22	26.77
Fixed Carbon %	57.41	58.81	55.71	59.85	66.36	67.75
Ash %	3.59	3.67	4.46	4.79	5.37	5.48
Total Sulphur %	.99	1.02	.84	.91	.61	.63
Coke : Character.	Hard, slightly swollen		Hard. unswollen		Medium Hard. Swollen	
Ratio of Volume to that of coal	1.25 : 1		1 : 1		2.25 : 1	
Ash	Brown		Almost White		Mid Brown	

DIMENSIONAL DETAILS AND RATIOS OF THE LOCOMOTIVE

18" Dia
24" Stroke
(3)

CYLINDERS AND STEAM CHESTS

Piston swept volume.	cu. ins.	6106
Cylinder Clearance Volume as % piston swept volume.		9.8
Steam chest volume as % of piston swept volume		73.53

PISTON VALVE

Nominal diameter	ins.	11
Steam lap	ins.	1.5/8
Lead	ins.	1/8
Maximum cut-off Fore Gear	%	70
" " Back Gear	%	70

BOILER

Barrel diameter outside min.		5' 9¾"
max.		6' 3½"
Small Tubes number		124
outside dia.	ins.	2¼
Thickness		11 SWG
Large tubes number		40
outside dia.	ins.	5¼
Thickness	ins.	5/32
Superheat elements (Schmidt short return loop)		
Outside dia.	ins.	1½
Thickness		10 SWG
Length between tubeplates		17' 0"
Heating Surfaces. Firebox (including syphons)	sq.ft.	275
Tubes	sq.ft	1241.6
Flues	sq.ft.	934.3
Total Evaporative	sq.ft.	2450.9

Superheater (outside)	sq.ft.	662.0
Total combined	sq.ft.	3272.9
Grate Area	sq.ft	48.50
Water Surface at half glass	sq.ft.	130
Firebox Volume/Grate Area		6.19
Firebox volume/ firebox heating surface		1.09
A/S large tubes		1 : 404
A/S Small tubes		1 : 492

STEAM CIRCUIT

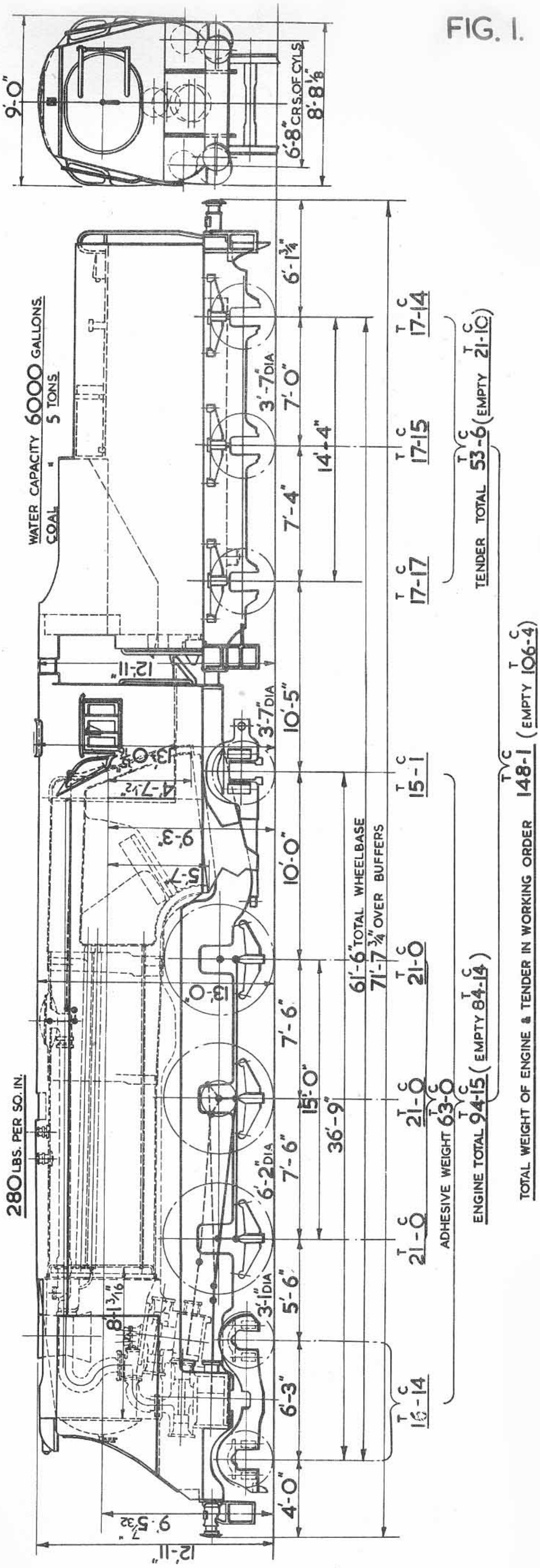
Regulator Area through Main Valve	sq.ins.	26.6
Main Steam pipe through boiler dia.	ins.	7
cross sectional area.	sq.ins.	38.5
Superheater elements area through tubes.	sq.ins.	48.7
Steam pipes to cylinders dia.	ins.	7
cross sectional area.	sq.ins.	38.5
Steam chest cross sectional area through liner	sq.ins.	95.03
Ports. Width	ins.	2
Cross sectional area	sq.ins.	36.8
Exhaust passage		
max. cross sectional area adjacent to steam chest	sq.ins.	60

GAS CIRCUIT

Area through ashpan dampers.	Front	sq.ft..	5.6
	Back	sq.ft..	6.6
Air space through grate as % of grate area			50
Free area through tubes.	large	sq.ft..	3.34
	small	sq.ft..	2.75
	Total	sq.ft.	6.09
Area through large tubes as % of total free area			54.8
Total free tube area as % of grate area			12.6

DRAUGHTING ARRANGEMENTS

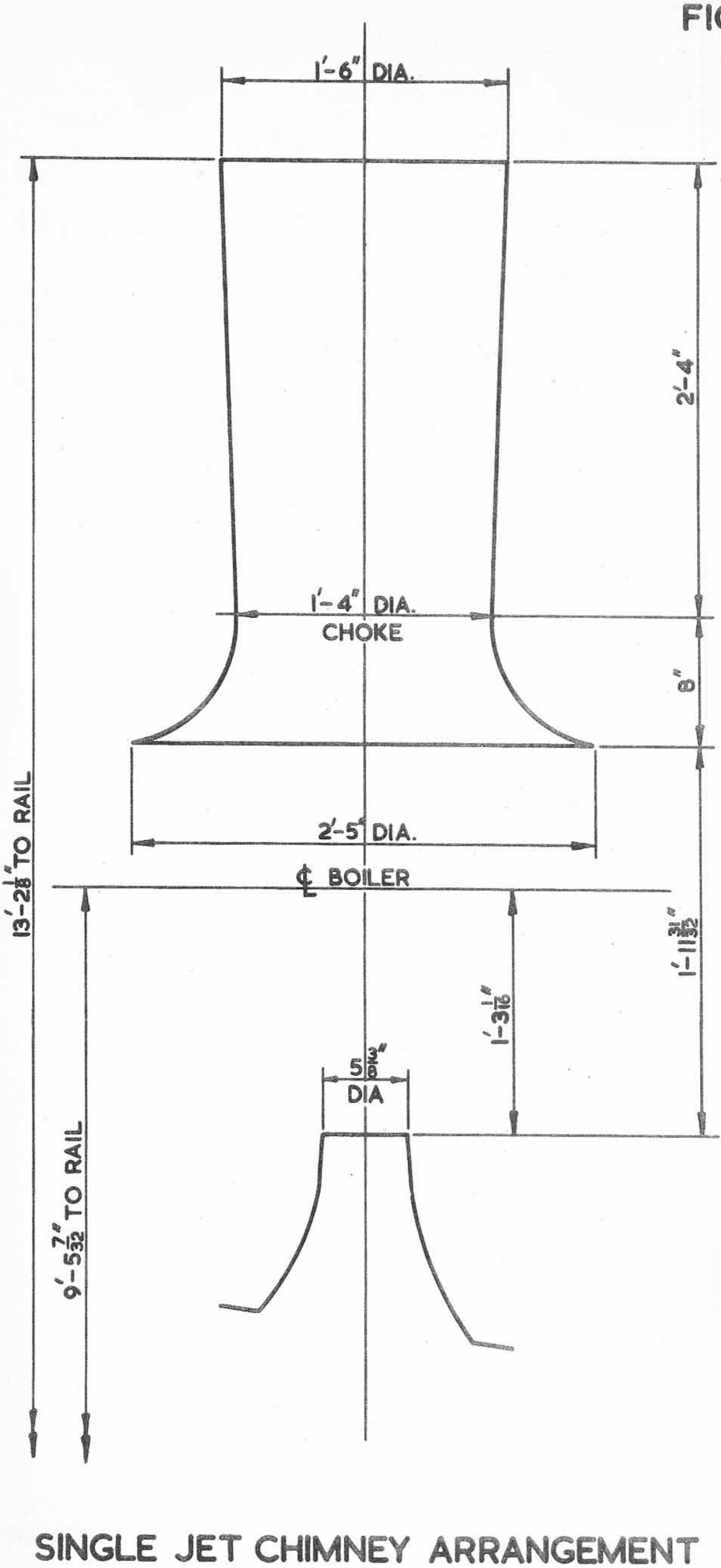
Blast pipe orifices(5) dia.	ins.	2 5/8
Total area	sq. ins.	27.05
Chimney dia. at choke		2' 1"
Area at choke	sq. ft.	3.41
Dia at top.		2' 5"
Blast pipe orifices below smokebox centre line.	ins.	15 5/8"
Chimney choke above blast pipe orifices.		3' 2 3/8"
Height of chimney choke to top	ins.	19 1/32
Chimney sides taper		1 in 4.76
Chimney choke dia. / Total blast pipe orifices dia.		18.15
Height of choke above orifice / Dia. of choke		0.762



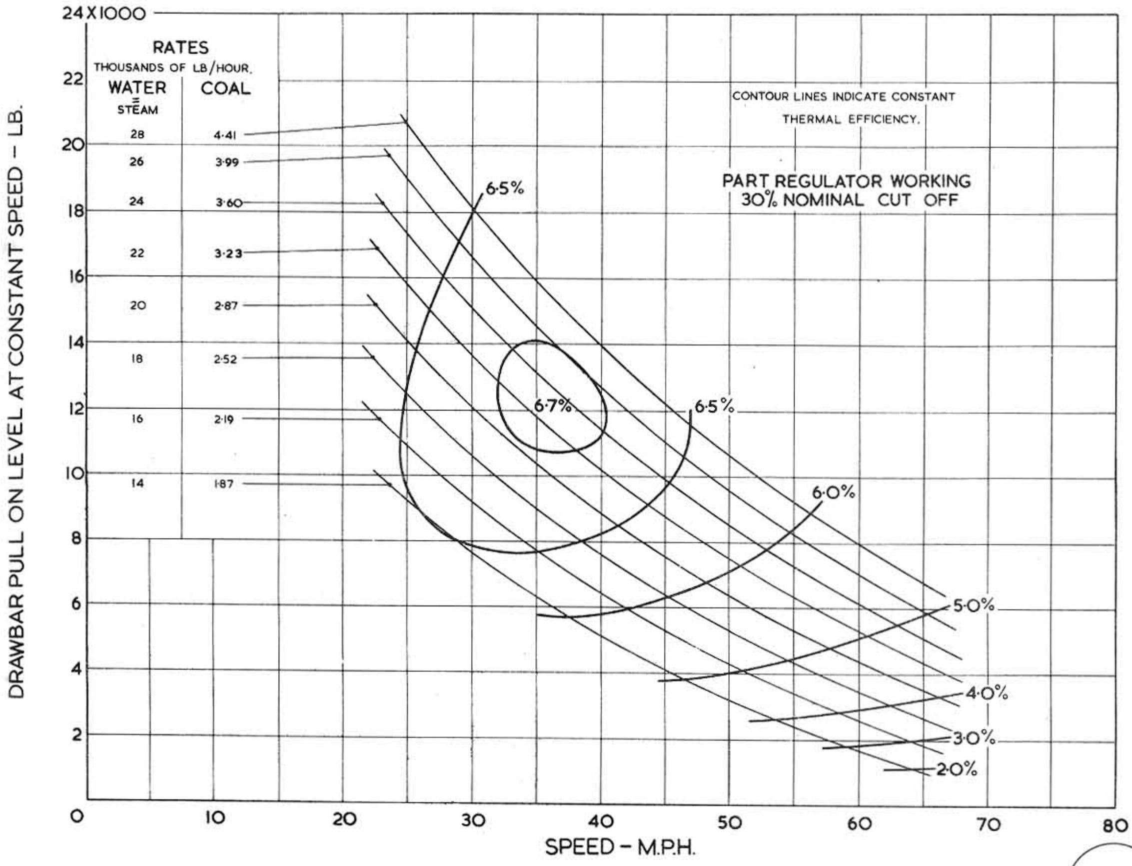
WATER CAPACITY 6000 GALLONS
COAL " 5 TONS
280 LBS. PER SQ. IN.
9'-0"
6'-8" CRS. OF CYLS
8'-8 1/8"
12'-11"
13'-0 1/2"
4'-7 1/2"
9'-3"
5'-7"
13'-0"
8'-13/16"
9'-5 7/32"
12'-11"
3'-7" DIA
3'-7" DIA
6'-2" DIA
3'-1" DIA
6'-1 3/4"
7'-0"
7'-4"
10'-5"
10'-0"
7'-6"
7'-6"
5'-6"
6'-3"
4'-0"
14'-4"
15'-0"
36'-9"
61'-6" TOTAL WHEELBASE
71'-7 3/4" OVER BUFFERS
T C 17-14
T C 17-15
T C 17-17
T C 15-1
T C 21-0
T C 21-0
T C 21-0
T C 16-14
TENDER TOTAL T C 53-6 (EMPTY T C 21-10)
ADHESIVE WEIGHT T C 63-0
ENGINE TOTAL T C 94-15 (EMPTY T C 84-14)
TOTAL WEIGHT OF ENGINE & TENDER IN WORKING ORDER T C 148-1 (EMPTY T C 106-4)

FIG. 1.

FIG. 2.



SINGLE JET CHIMNEY ARRANGEMENT



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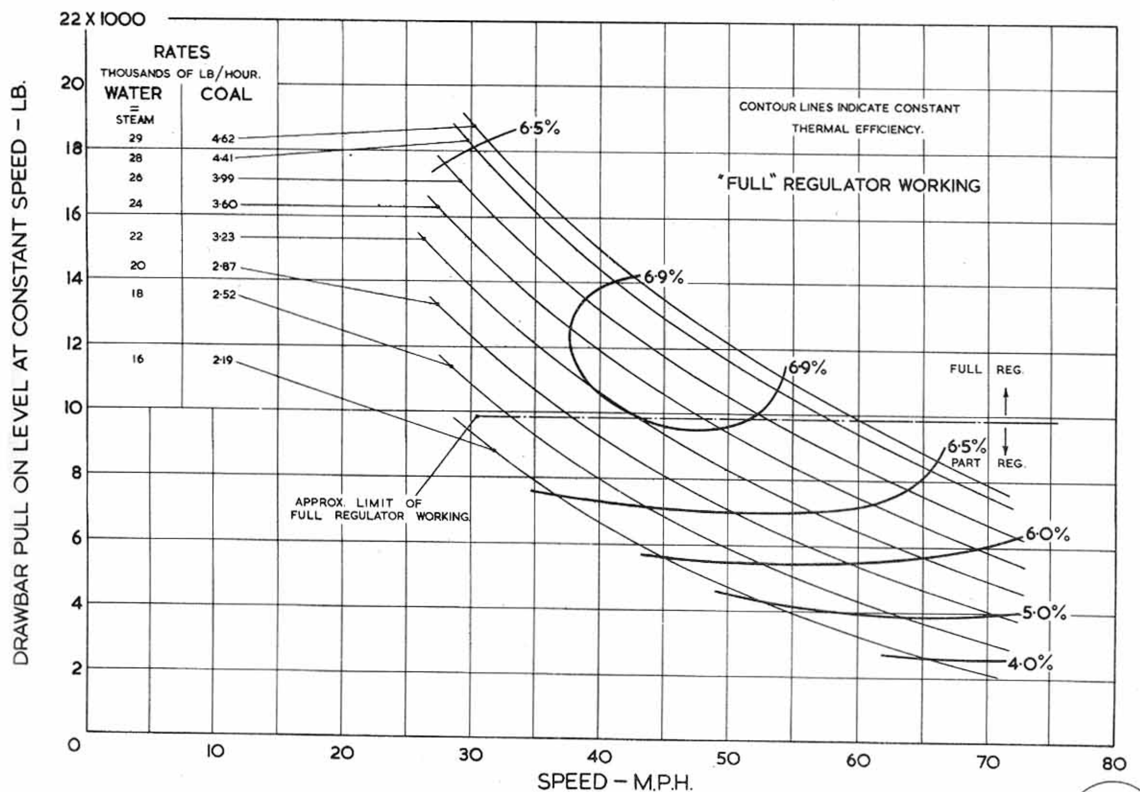
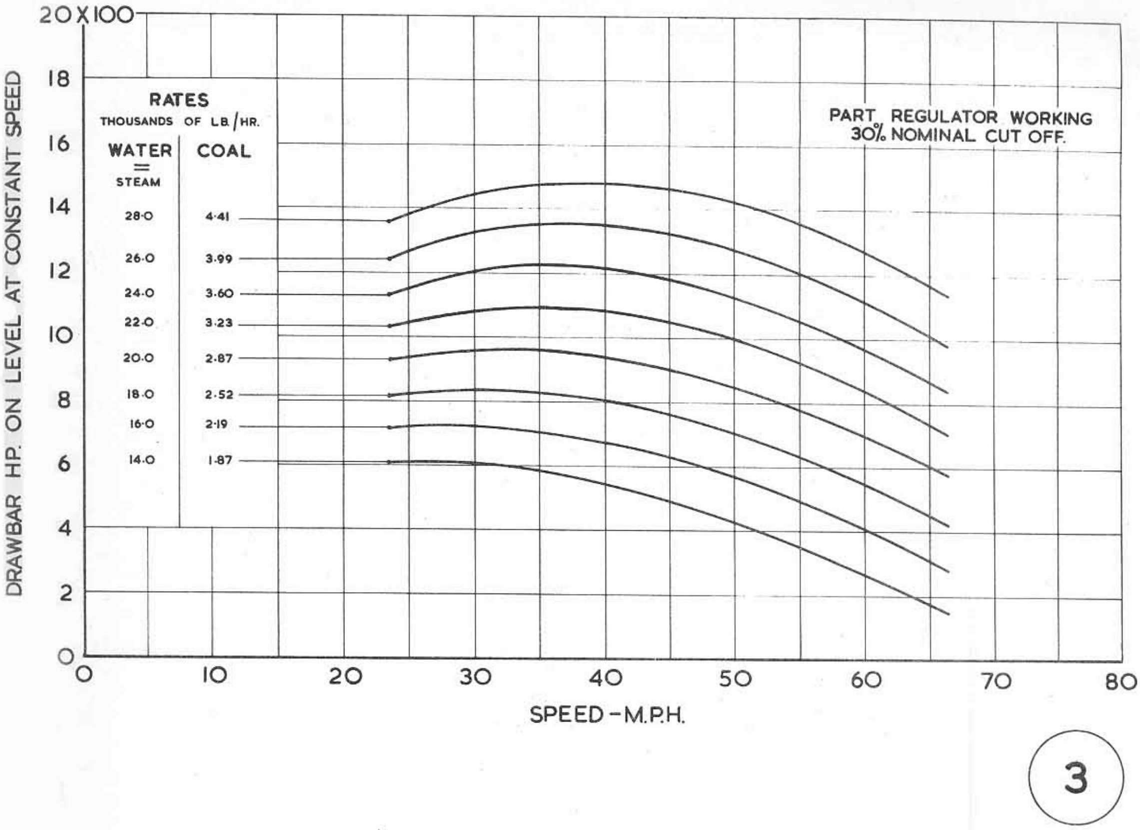


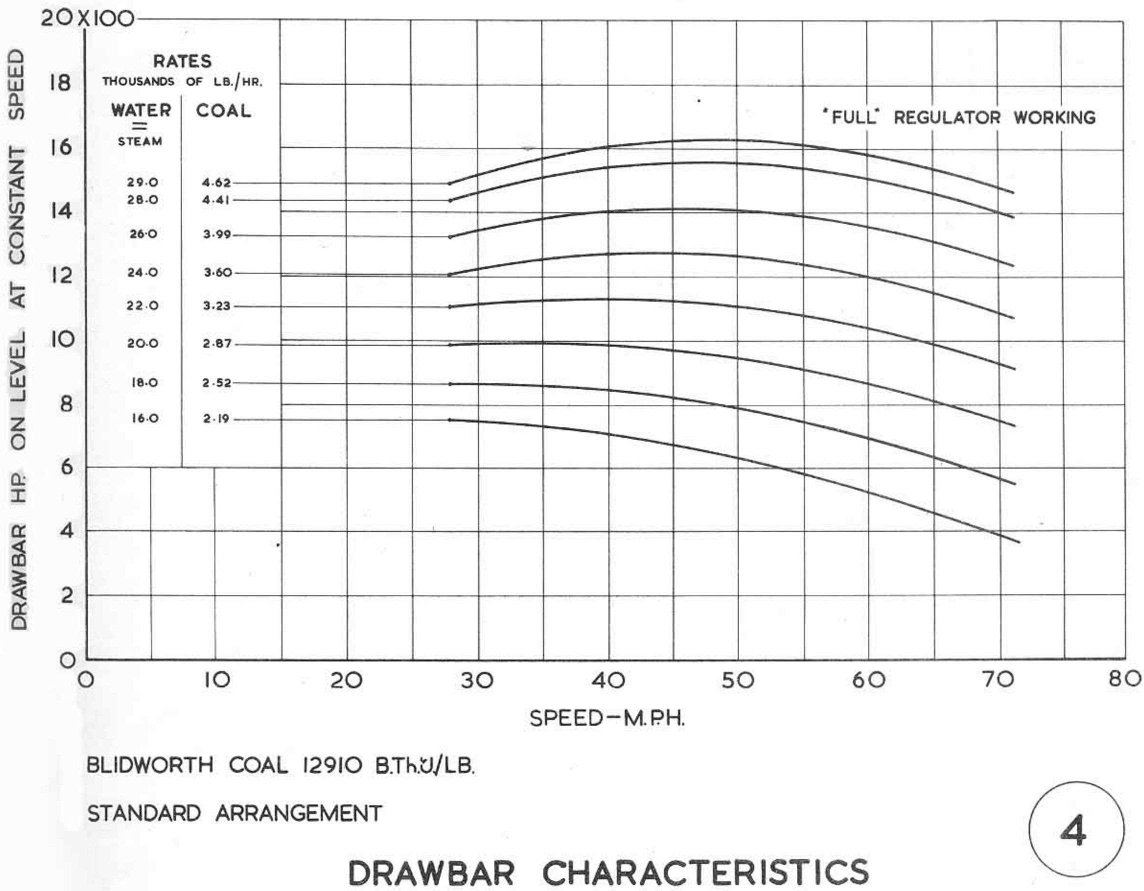
2

BLIDWORTH COAL 12910 B.Th.U./LB.

STANDARD ARRANGEMENT.

DRAWBAR CHARACTERISTICS

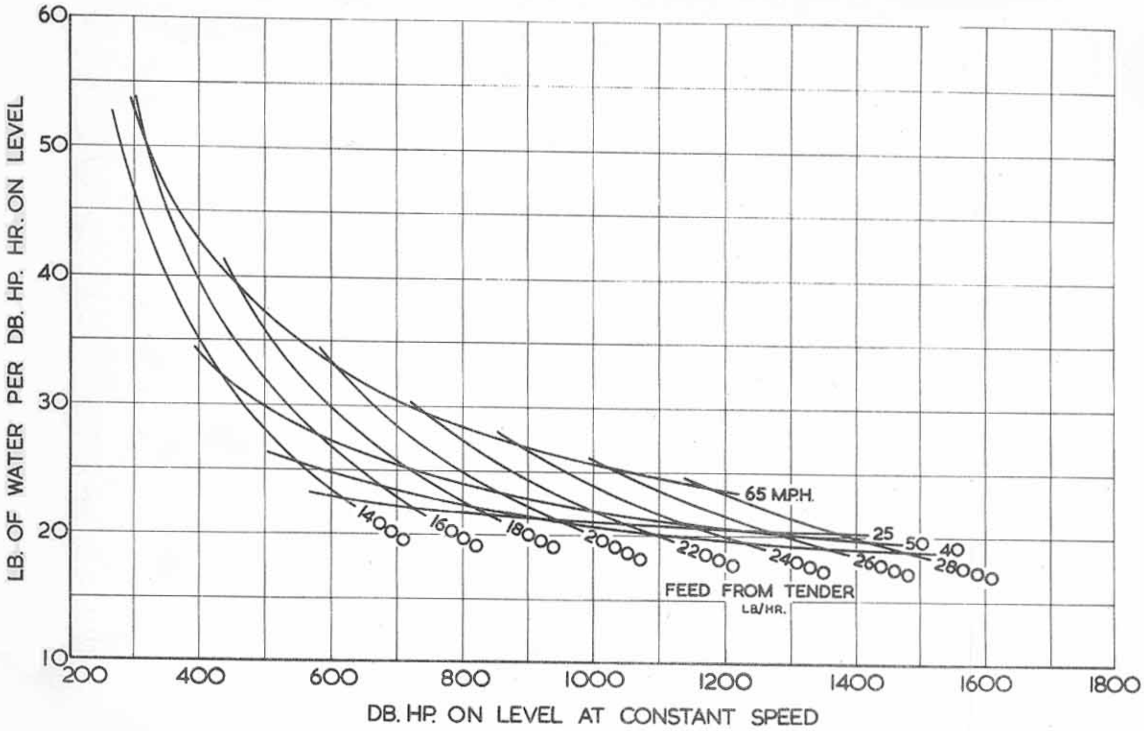




BLIDWORTH COAL 12910 B.Th.U/LB.

STANDARD ARRANGEMENT

DRAWBAR CHARACTERISTICS



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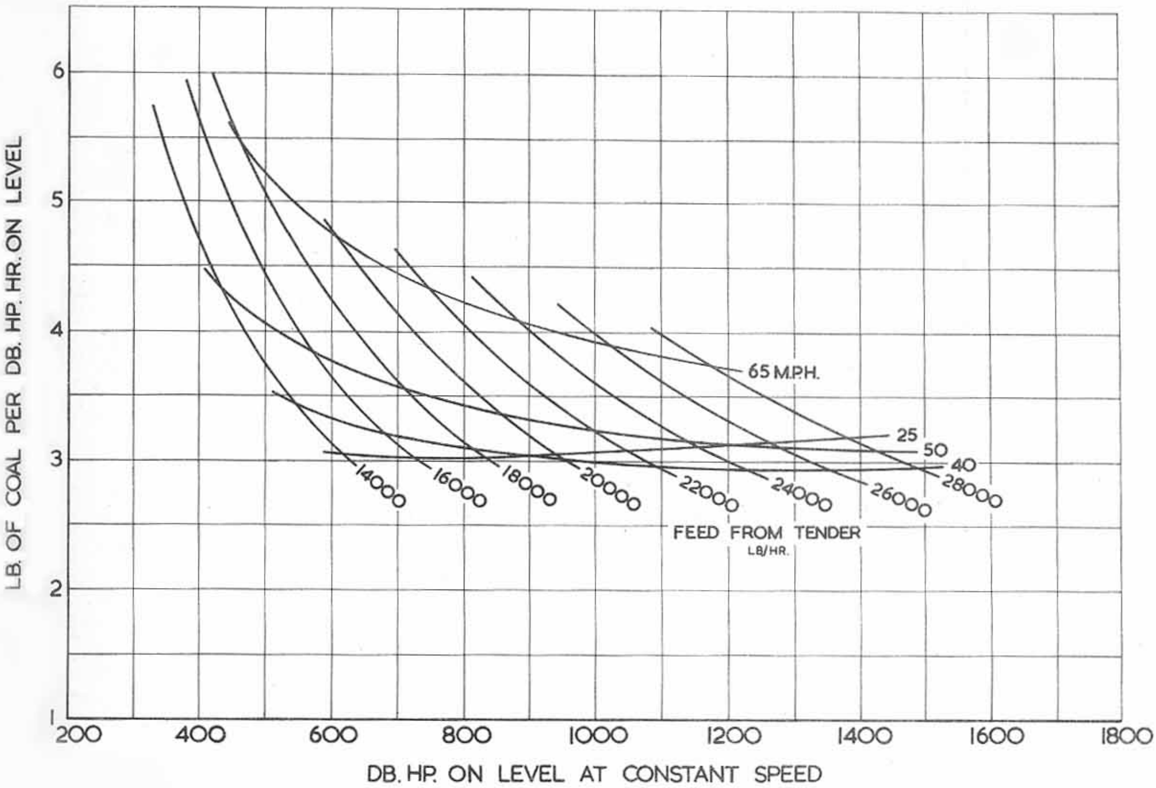


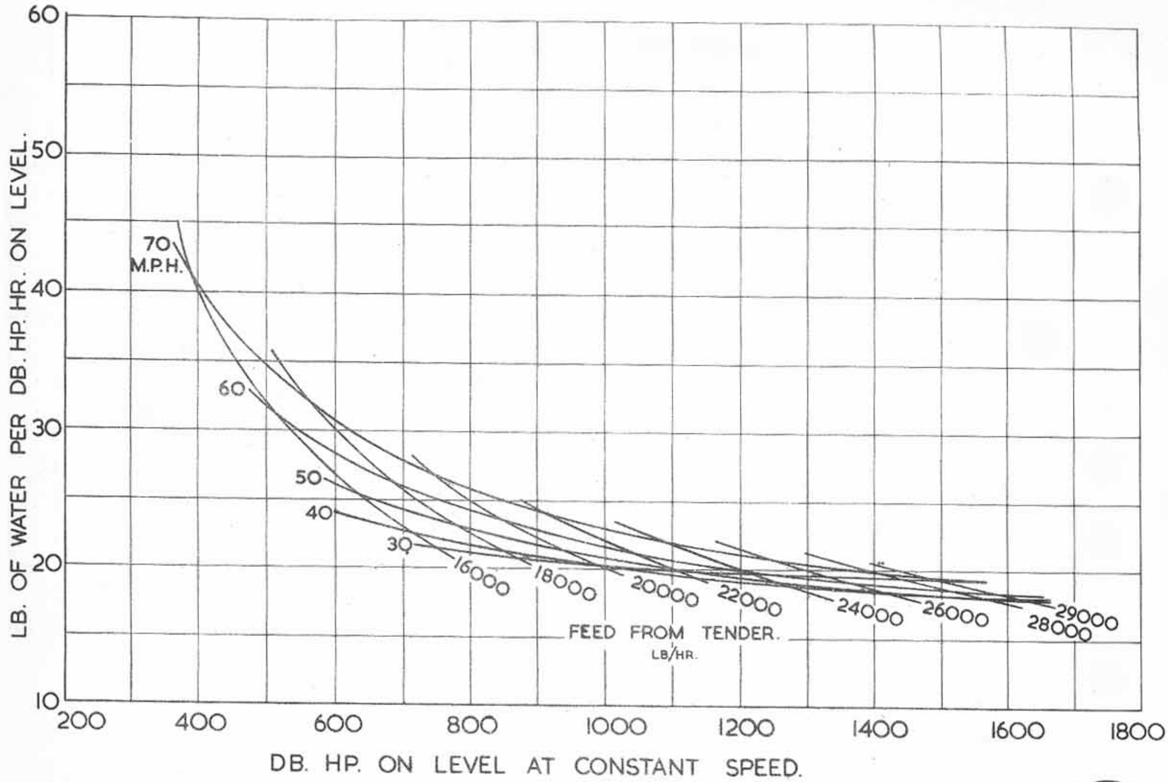
BLIDWORTH COAL 12910 B.Th.U/LB.

PART REGULATOR WORKING

STANDARD ARRANGEMENT

6

WATER & COAL PER DB. HP. HR.



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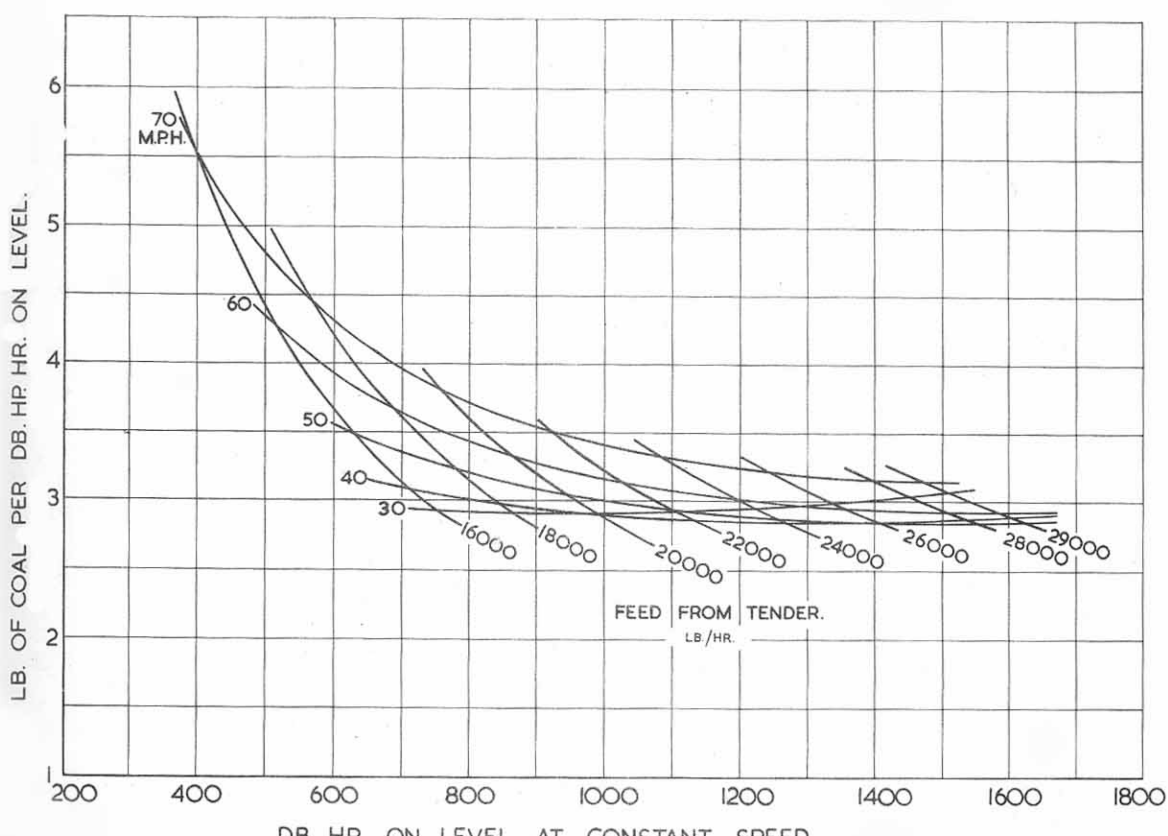
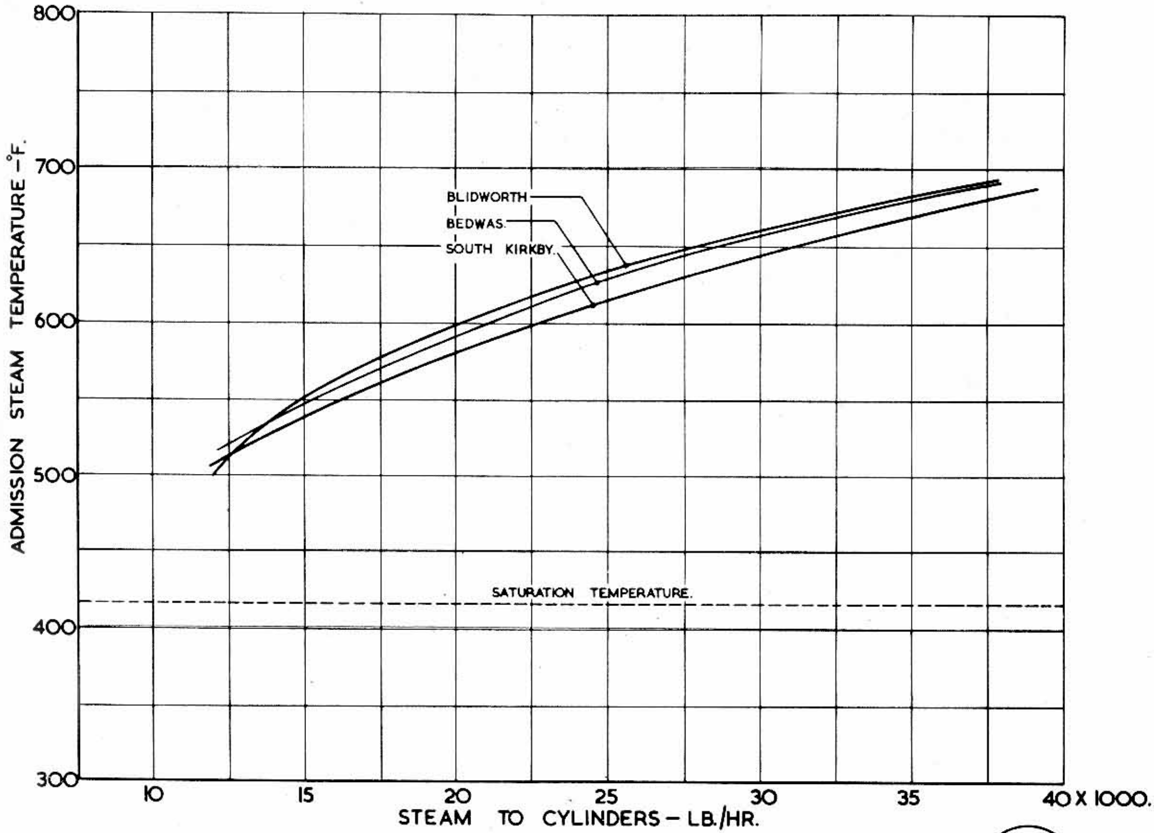


8

BLIDWORTH COAL. 12910 B.Th.U./LB. FULL REGULATOR WORKING.

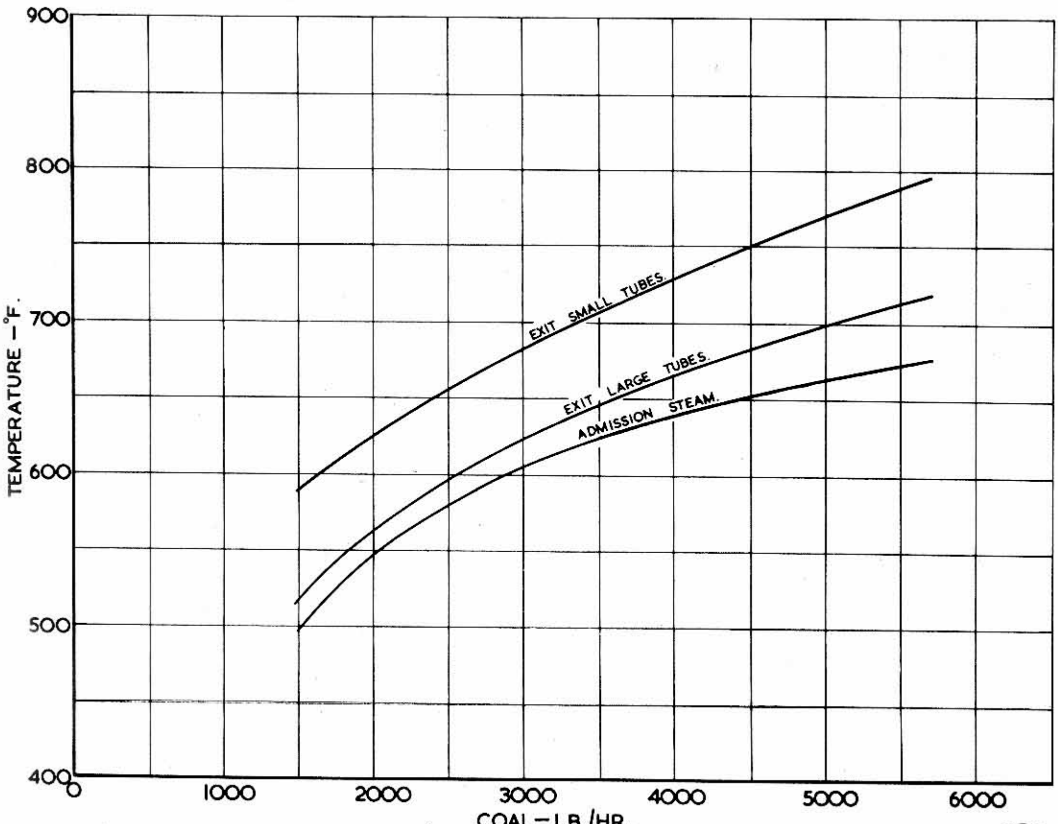
STANDARD ARRANGEMENT.

WATER & COAL PER DB. HP. HR.



STANDARD ARRANGEMENT.

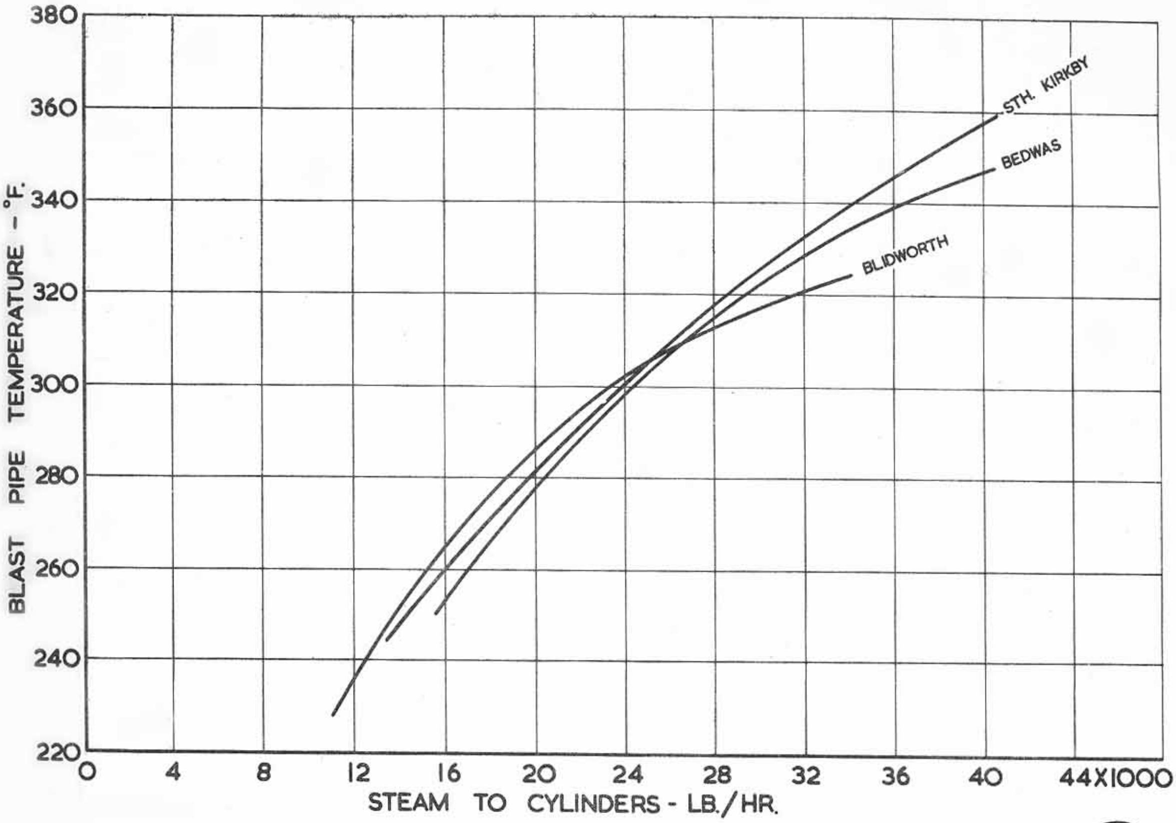
9



BLIDWORTH COAL - 12910 B.Th.U./LB.
STANDARD ARRANGEMENT.

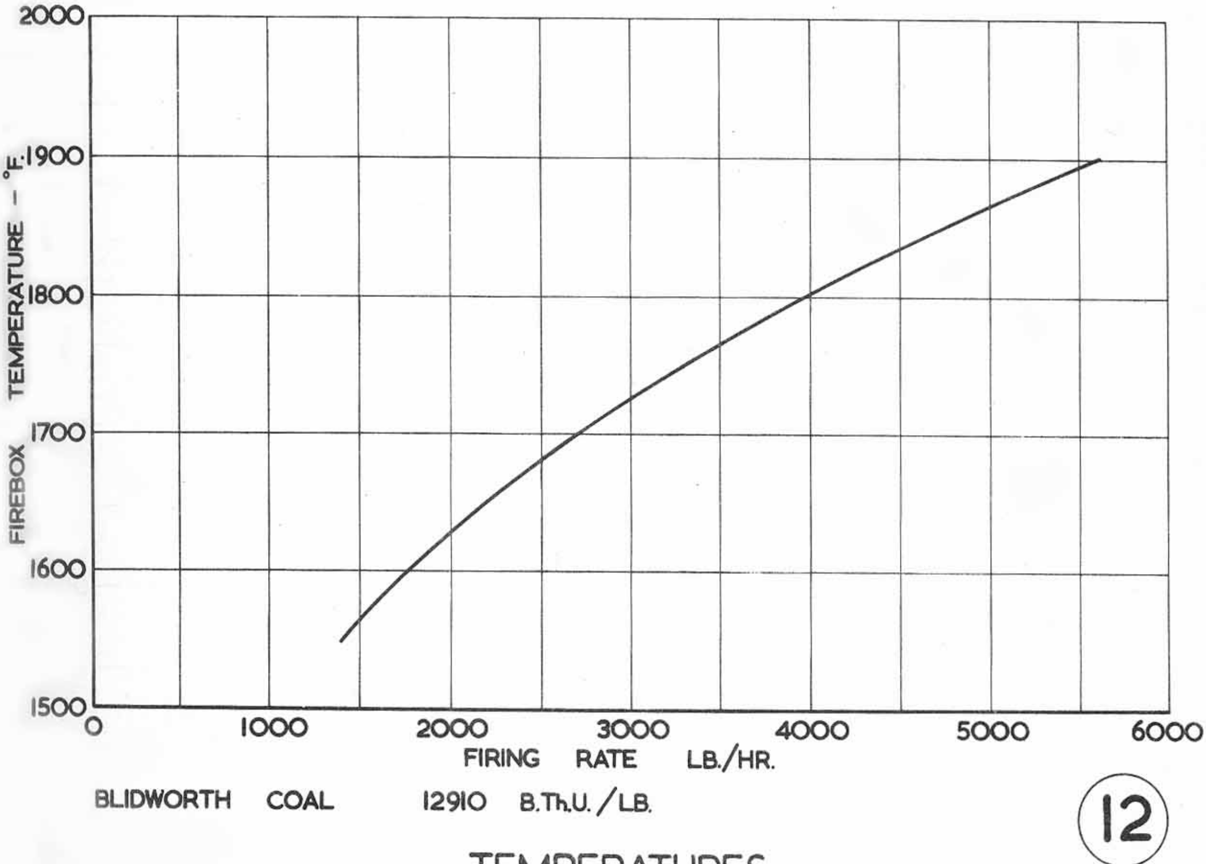
10

TEMPERATURES.



SOUTH KIRKBY COAL 13990 B.Th.U./LB.
BEDWAS COAL 14230 B.Th.U./LB.
BLIDWORTH COAL 12910 B.Th.U./LB.

11

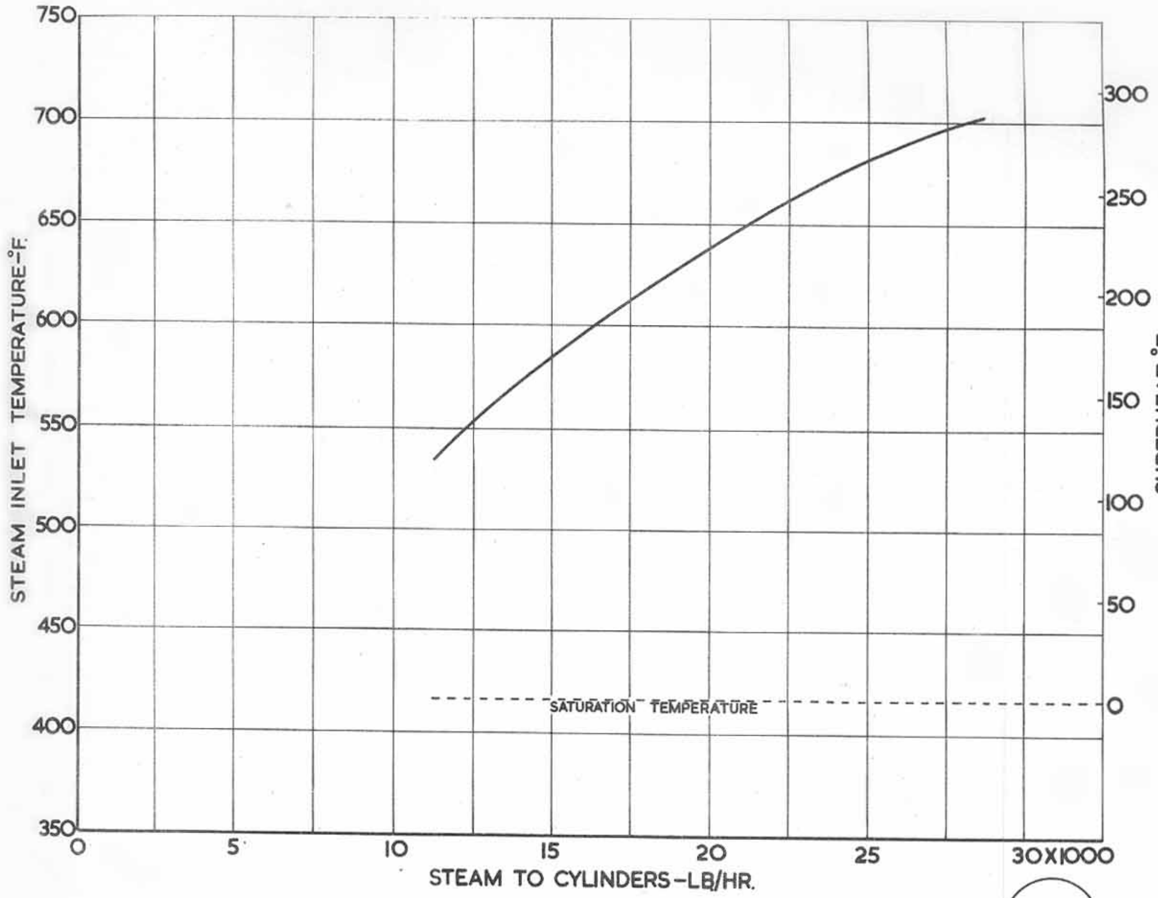


BLIDWORTH COAL 12910 B.Th.U./LB.

12

TEMPERATURES

STANDARD ARRANGEMENT



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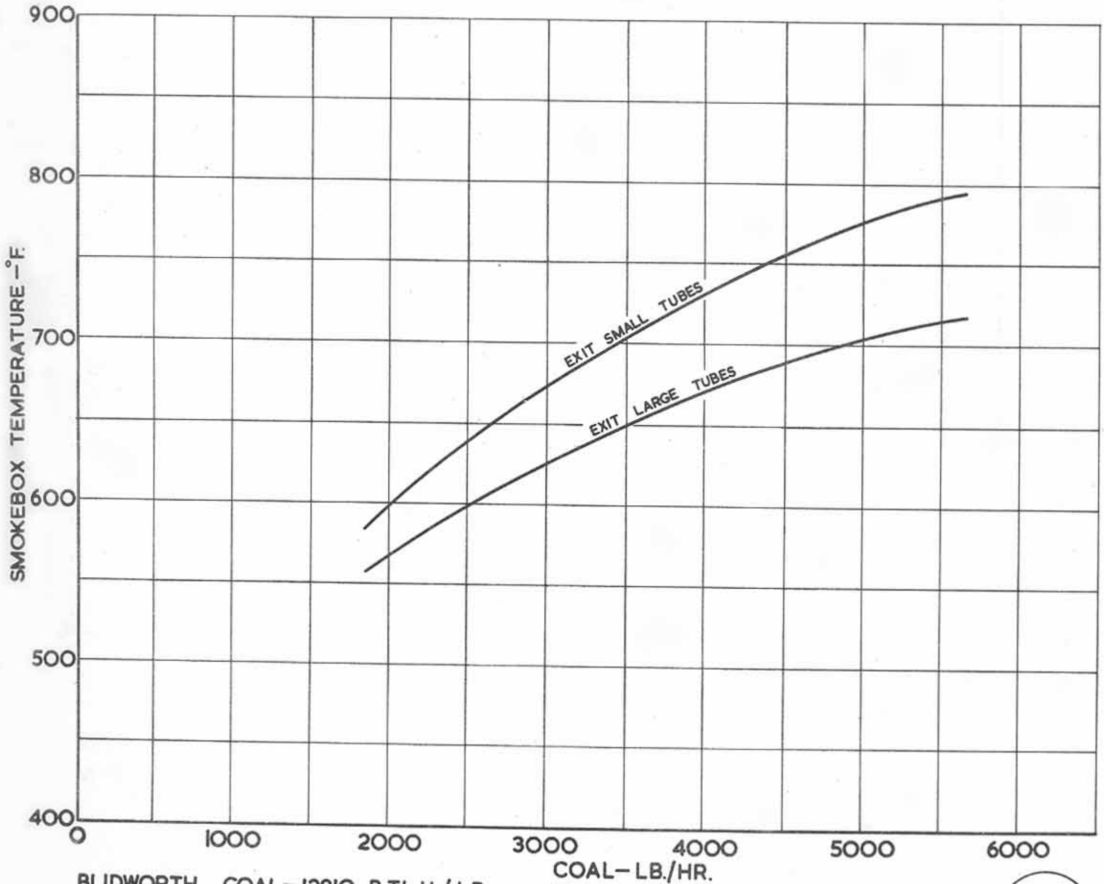
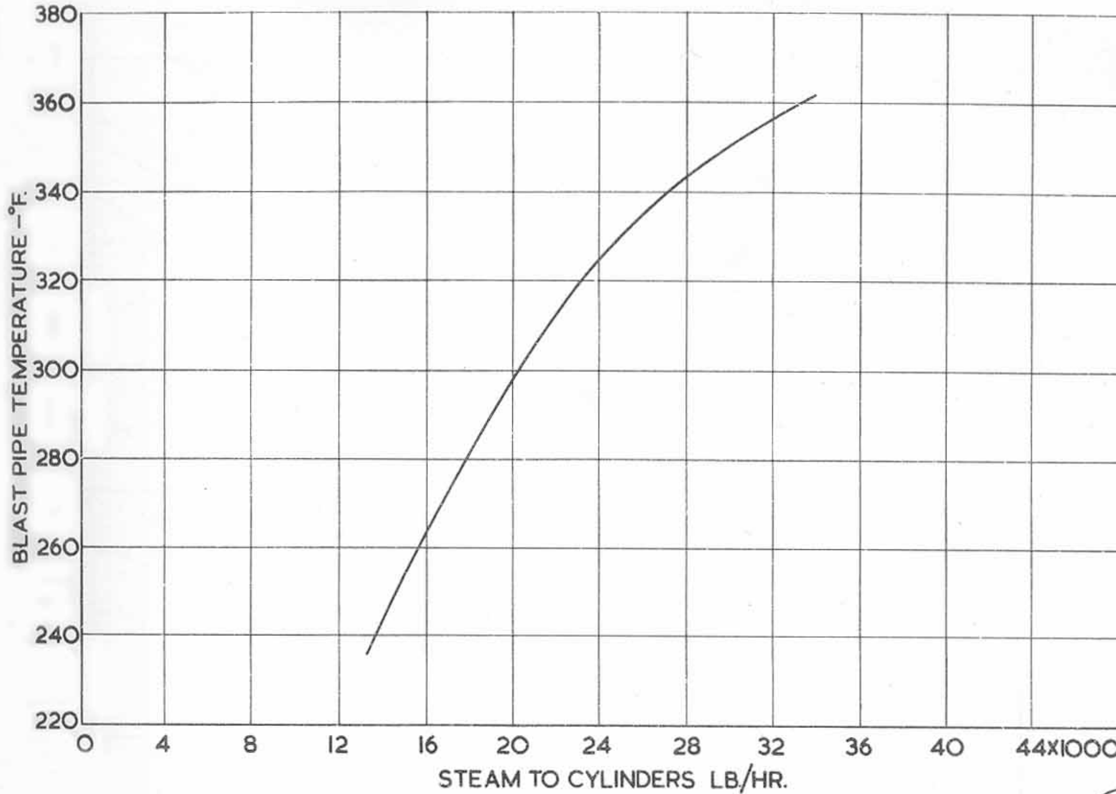


BLIDWORTH COAL-12910 B.Th.U./LB.
WITHOUT THERMIC SYPHONS.

14

TEMPERATURES



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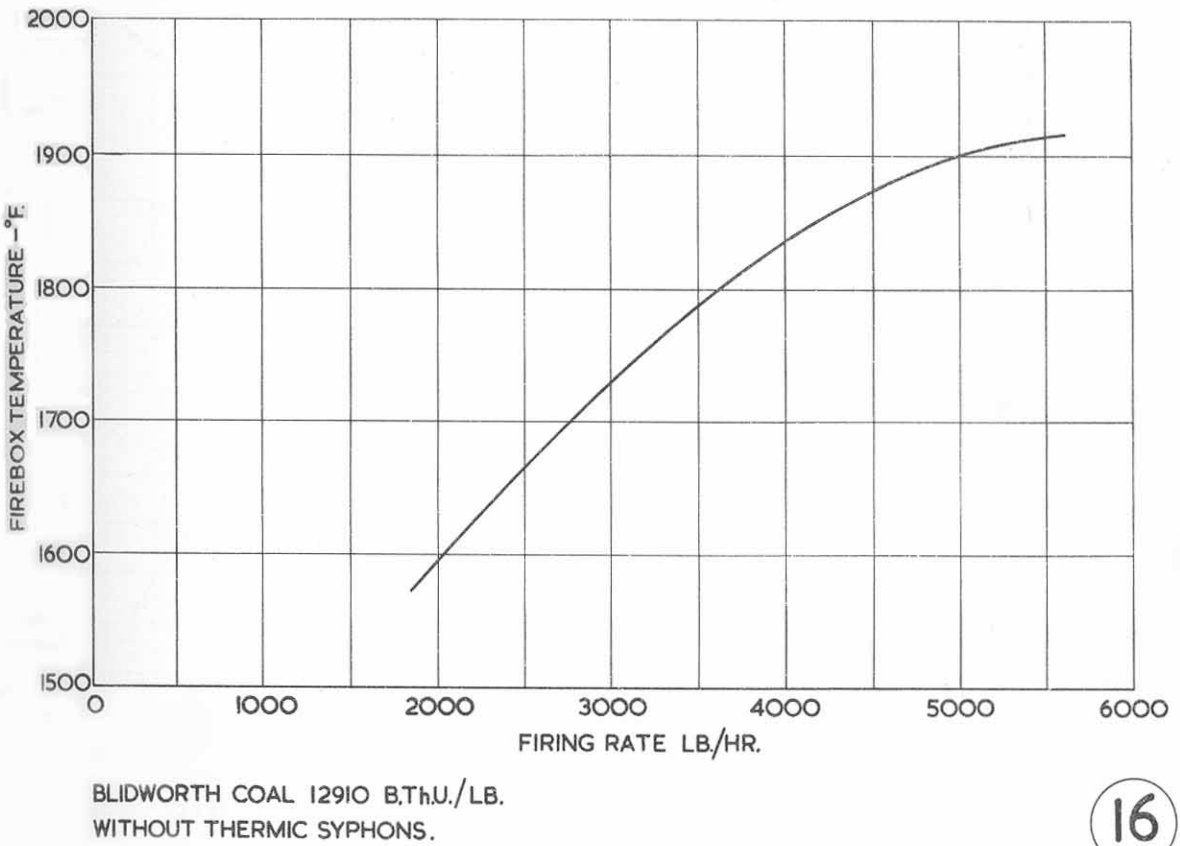
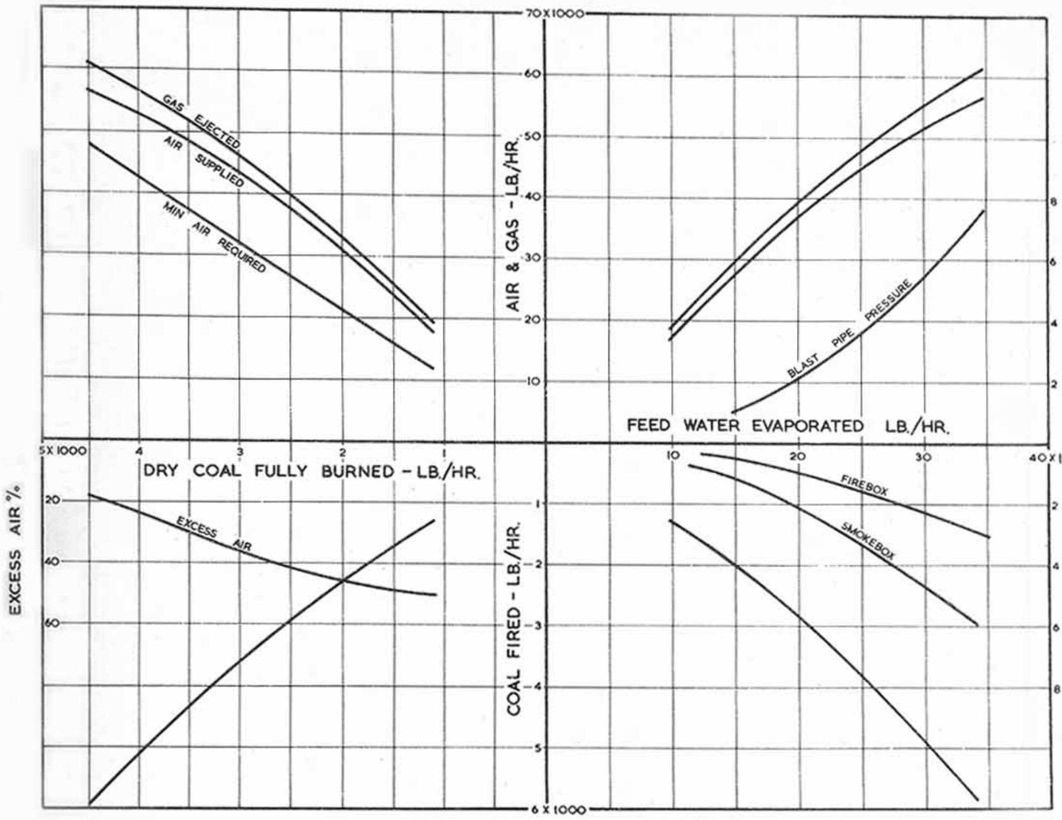


BLIDWORTH COAL 12910 B.Th.U./LB.
WITHOUT THERMIC SYPHONS.

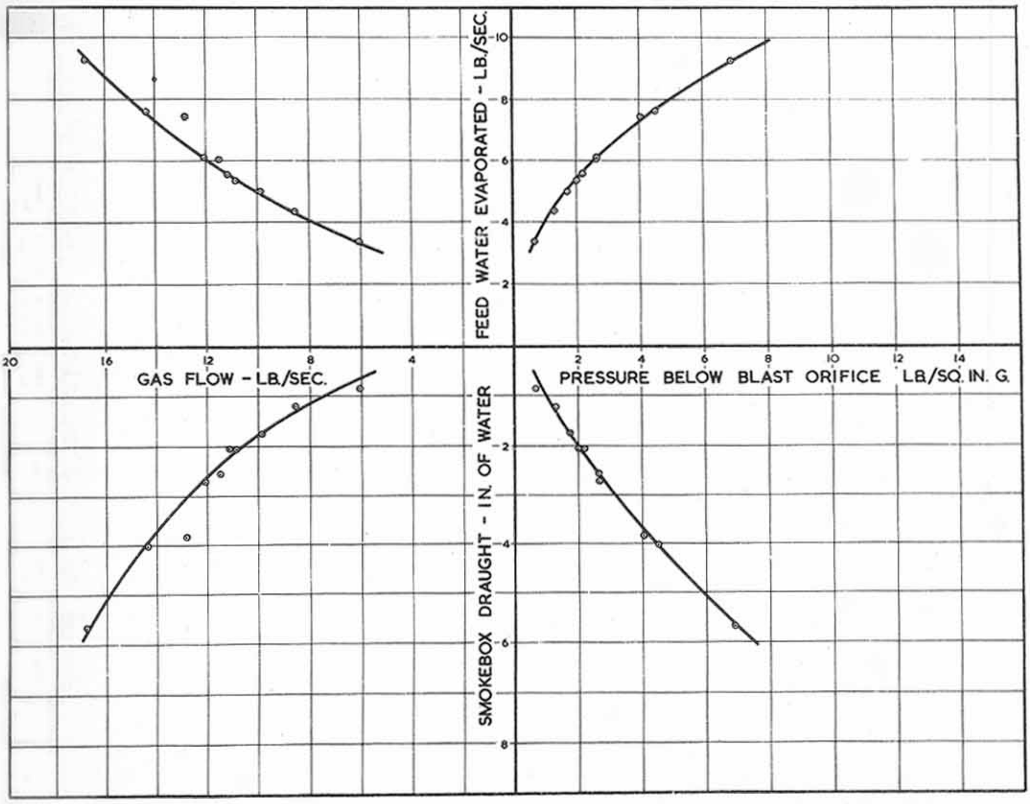
16

TEMPERATURES



STEAM - AIR - COMBUSTION

17

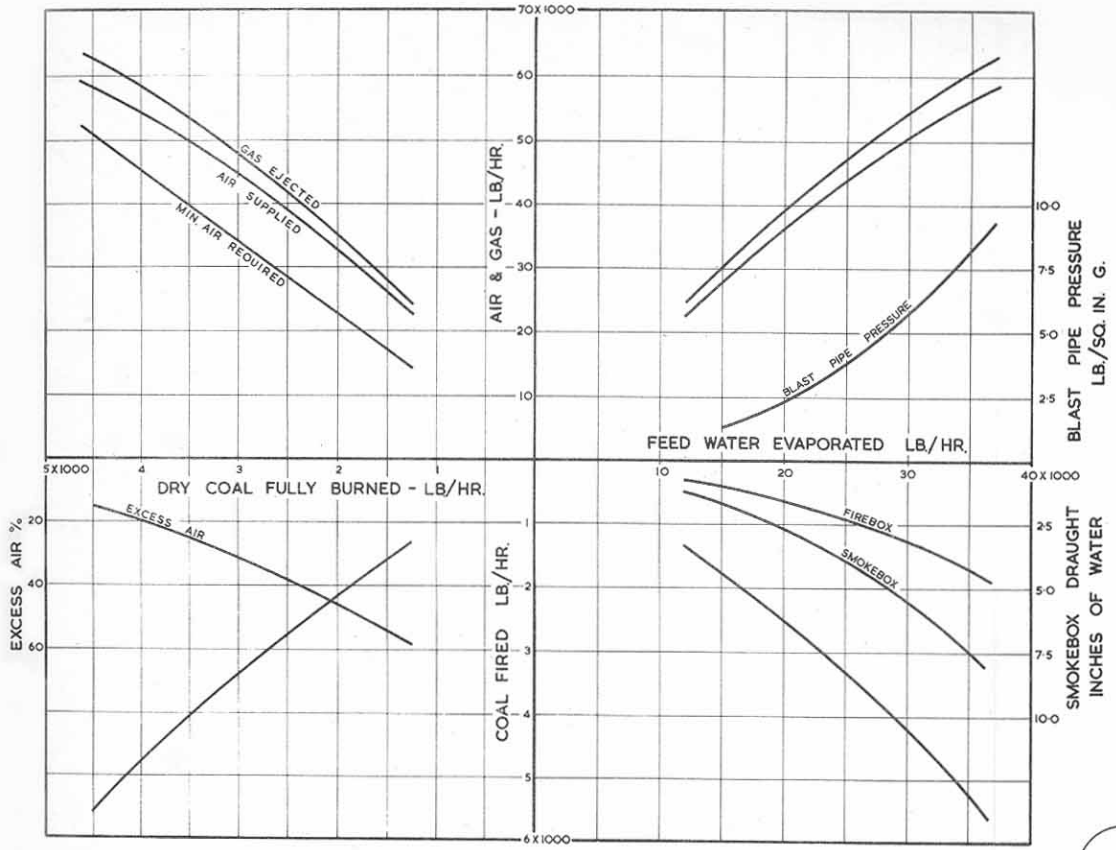


STEAM-GAS-DRAUGHT & BLAST PIPE PRESSURE

18

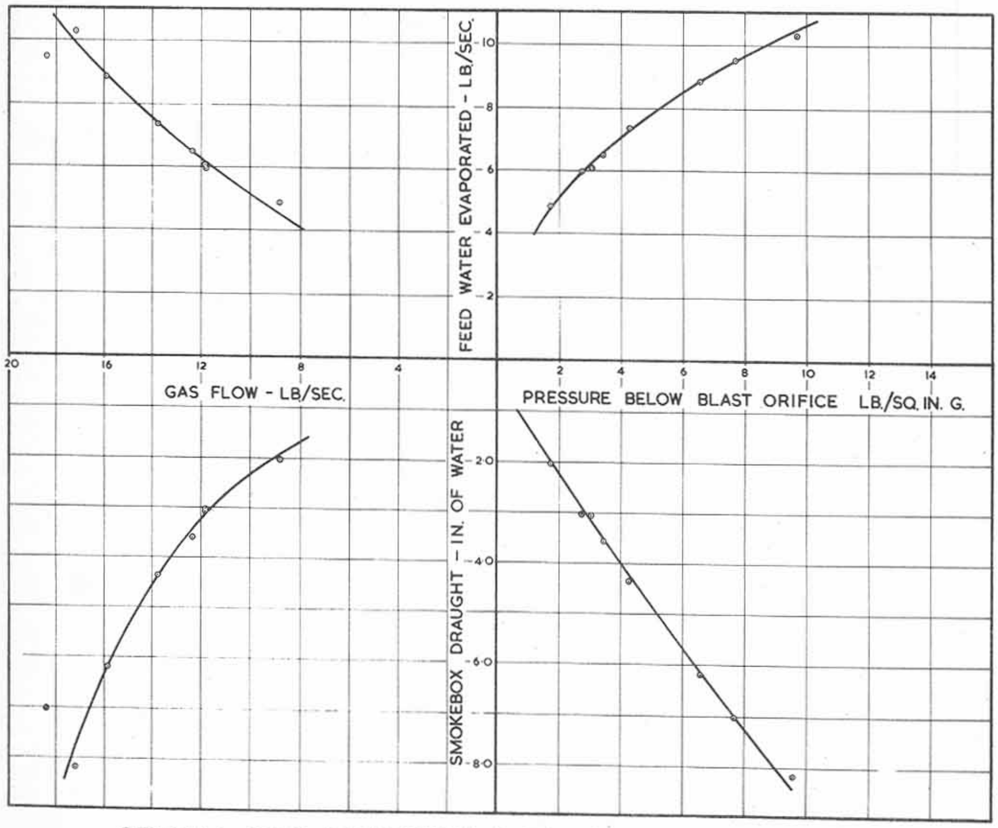
BLIDWORTH COAL - 12,910 B.Th.U./LB.

STANDARD ARRANGEMENT



STEAM - AIR - COMBUSTION

19

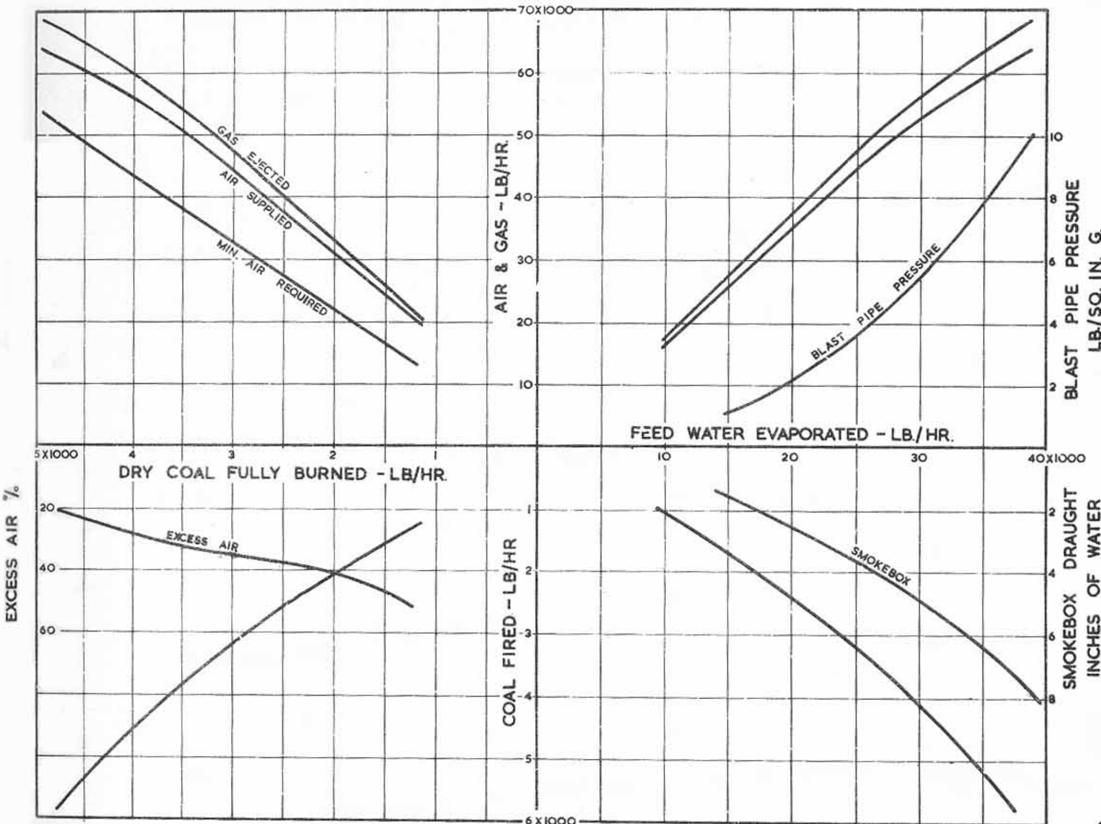


STEAM-GAS-DRAUGHT & BLAST PIPE PRESSURE

20

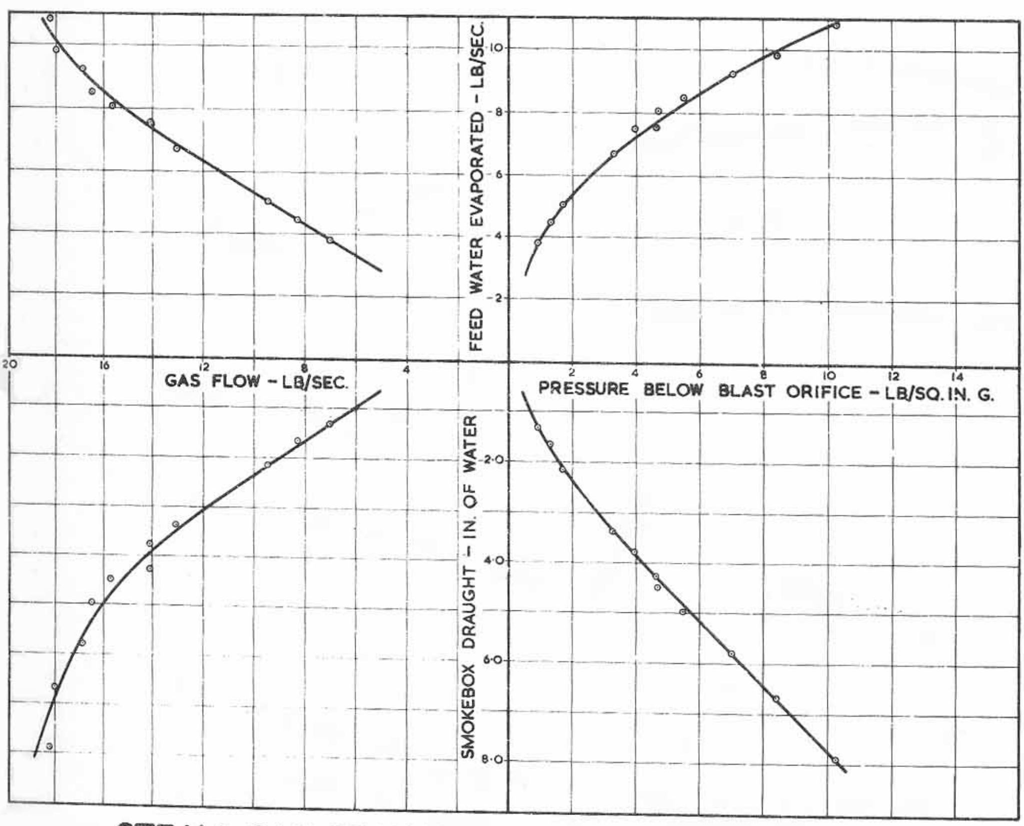
BEDWAS COAL - 14,230 B. Th.U./LB

STANDARD ARRANGEMENT



STEAM - AIR - COMBUSTION

21

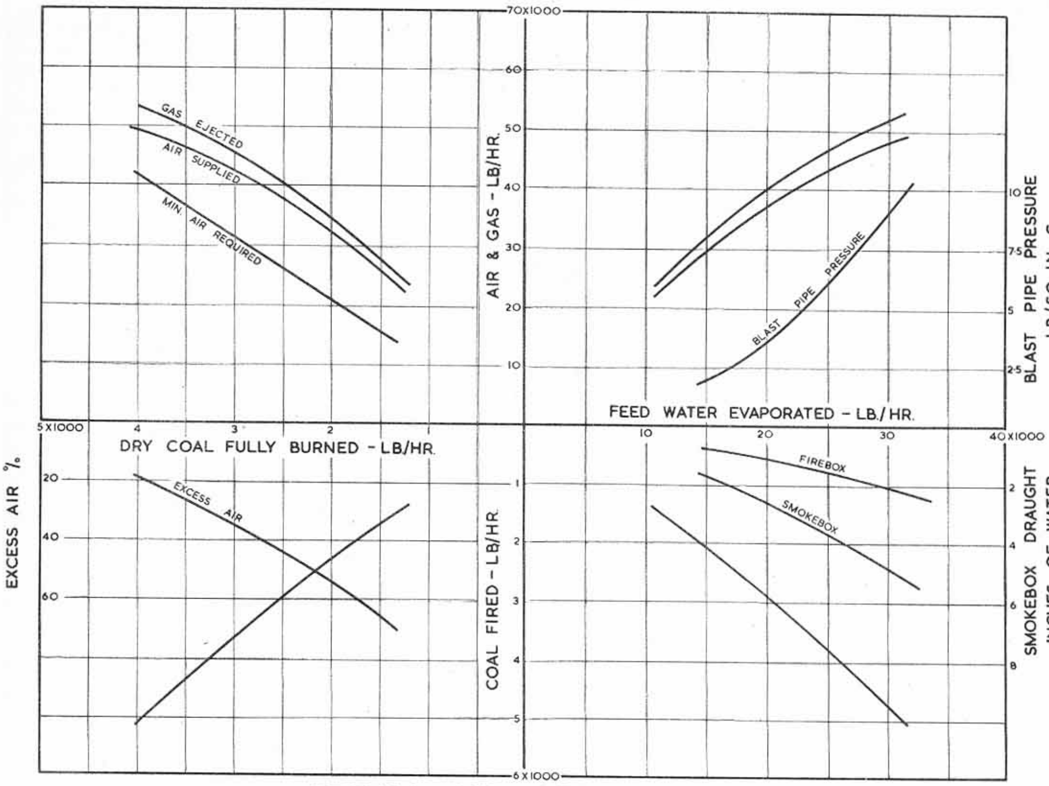


STEAM-GAS-DRAUGHT & BLAST PIPE PRESSURE

22

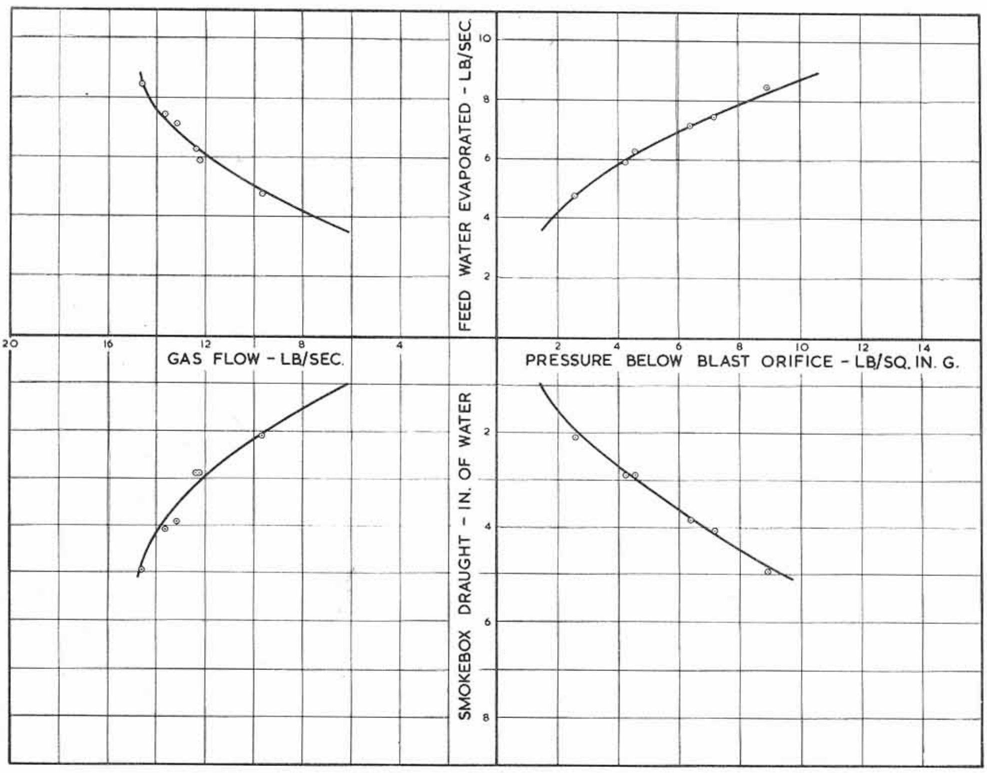
SOUTH KIRKBY COAL 13,990 B.Th.U./LB.

STANDARD ARRANGEMENT



STEAM - AIR - COMBUSTION

23

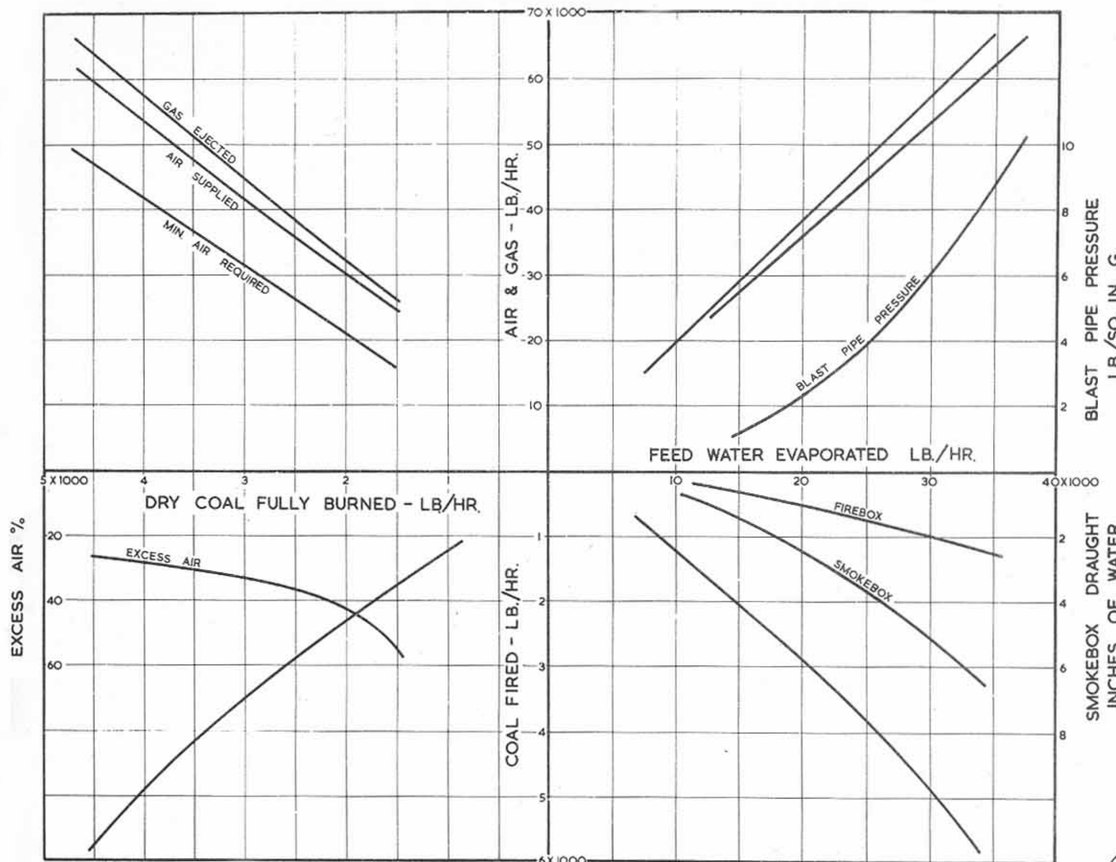


STEAM-GAS-DRAUGHT & BLAST PIPE PRESSURE

24

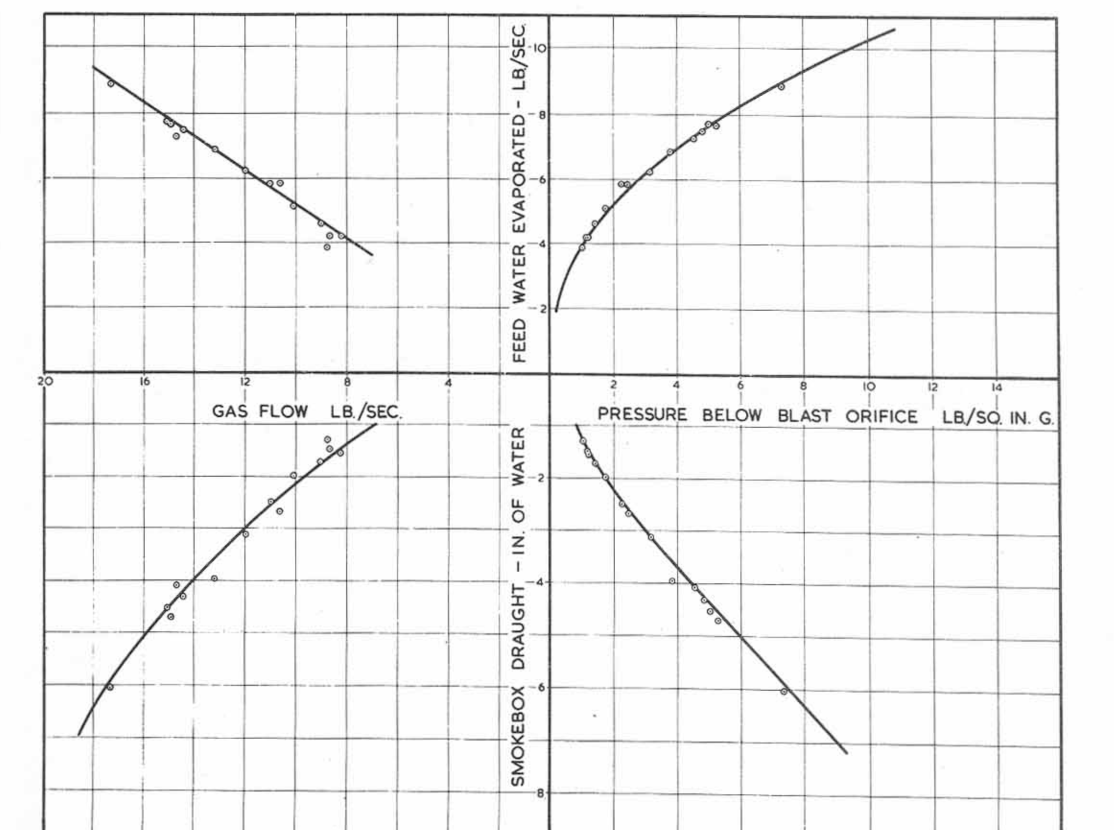
BLIDWORTH COAL 12,910 B.Th.U/LB.

SINGLE JET ARRANGEMENT



STEAM - AIR - COMBUSTION

25

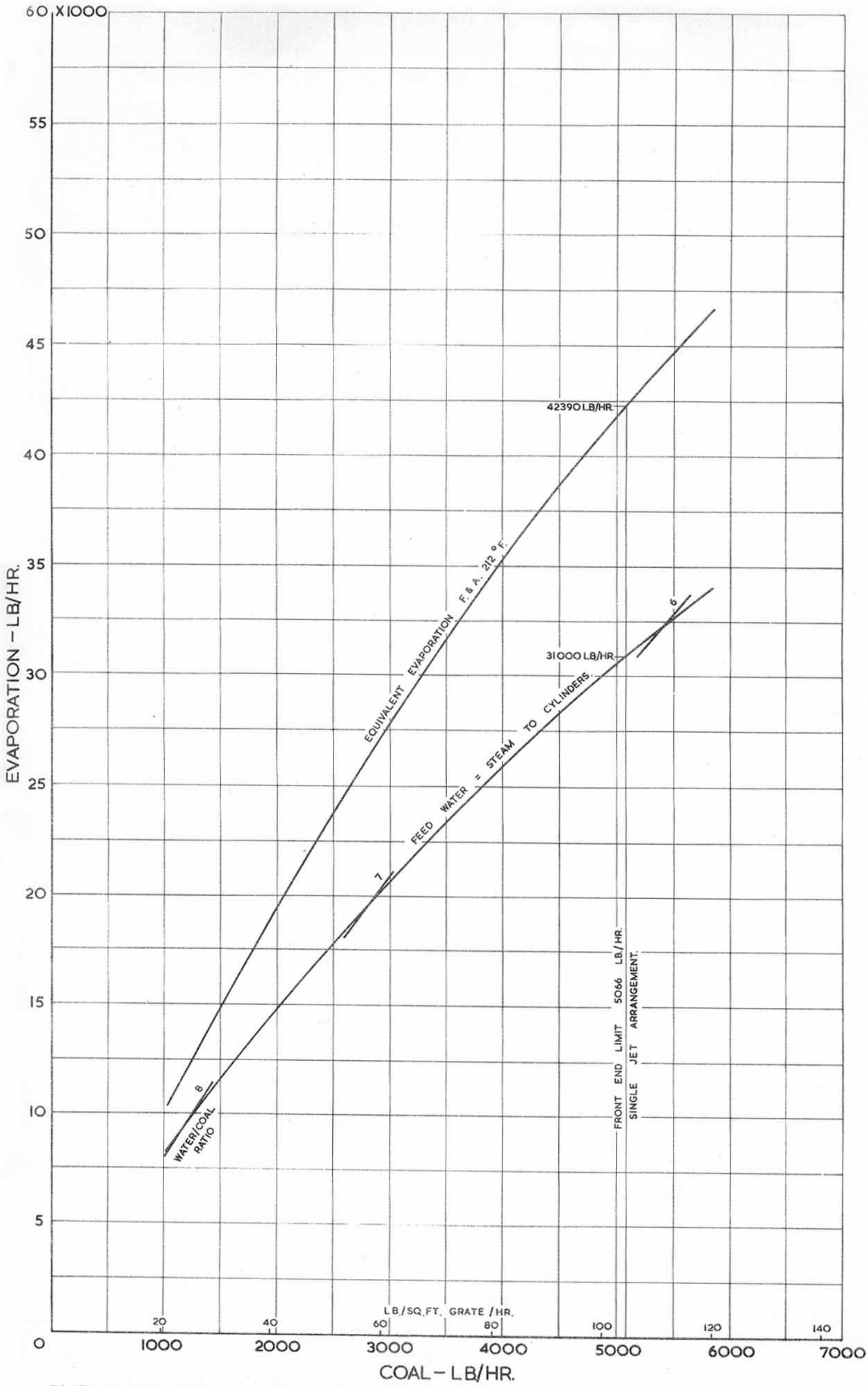


STEAM-GAS-DRAUGHT & BLAST PIPE PRESSURE

26

BLIDWORTH COAL - 12,910 B.Th.U./LB.

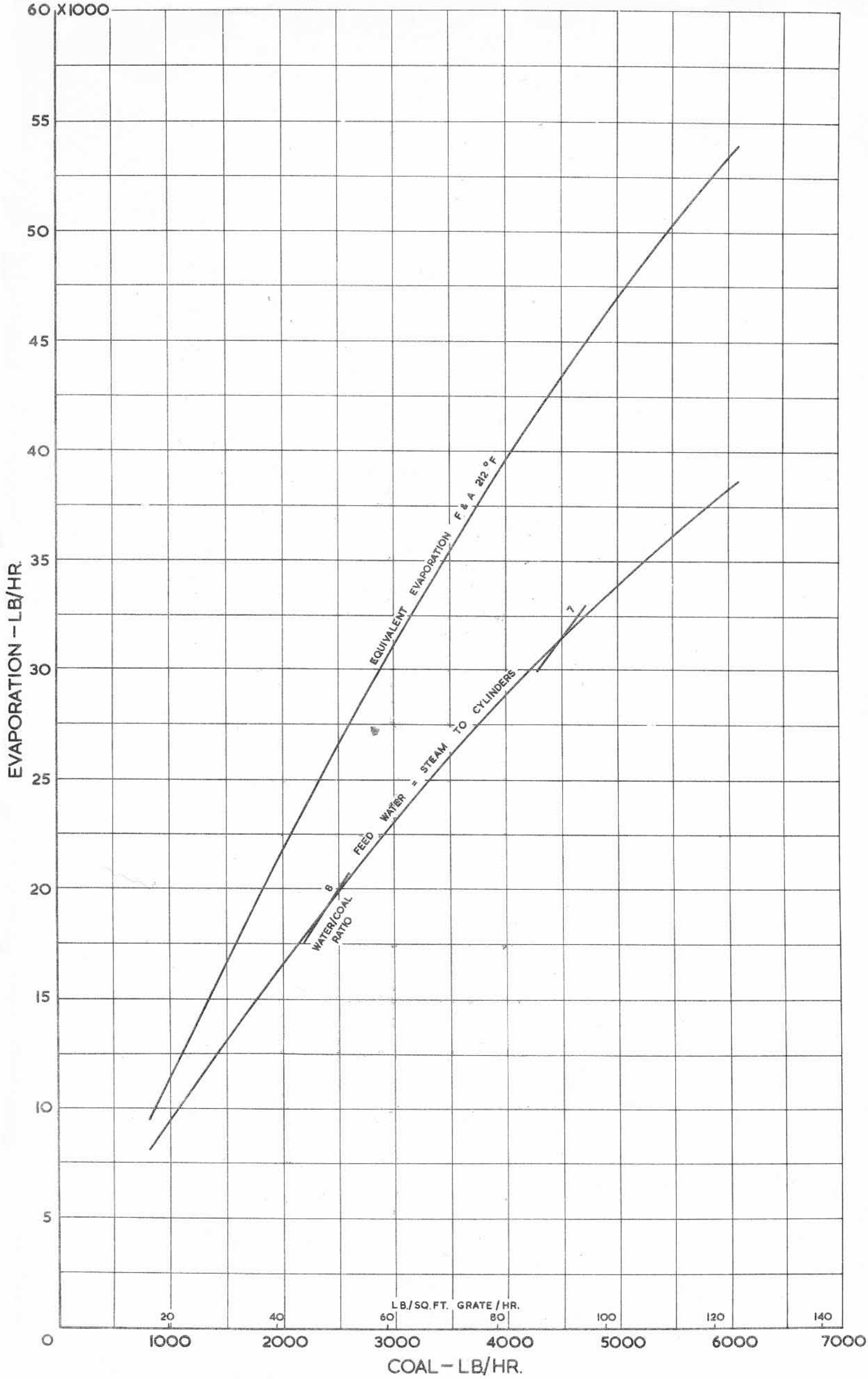
WITHOUT THERMIC SYPHONS



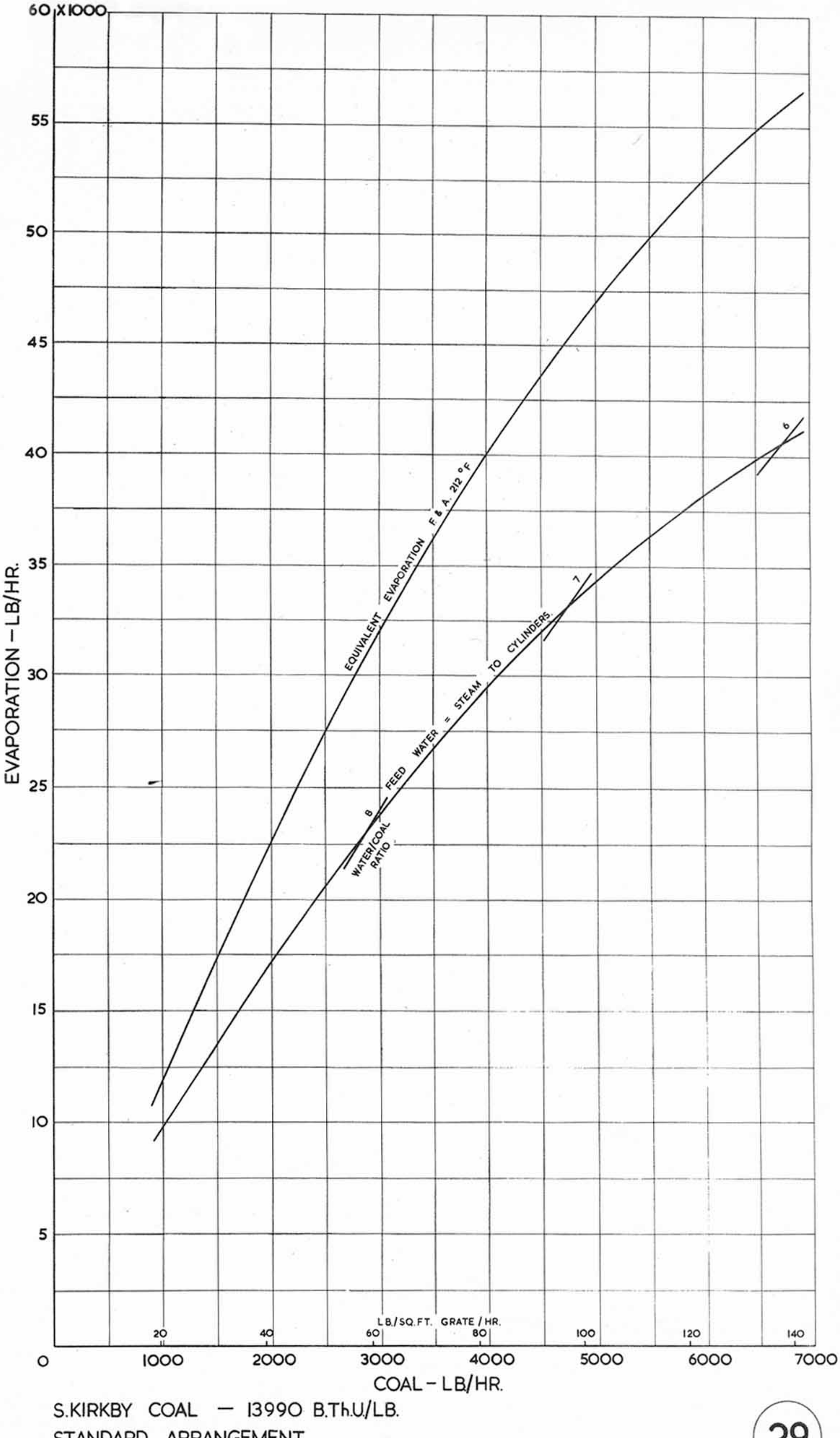
BLIDWORTH COAL 12910 B.Th.U/LB.
STANDARD & SINGLE JET ARRANGEMENT

27

EVAPORATION



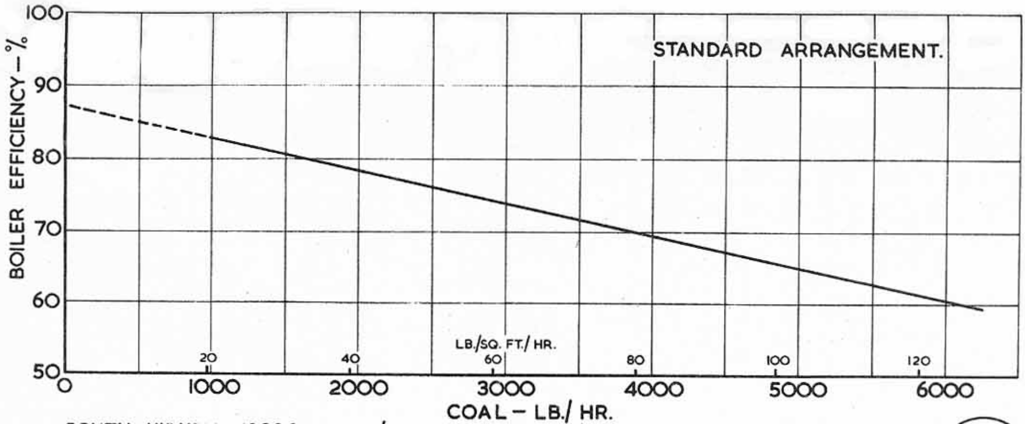
BEDWAS COAL — 14230 B.Th.U/LB.
STANDARD ARRANGEMENT



S.KIRKBY COAL — 13990 B.Th.U/LB.
STANDARD ARRANGEMENT

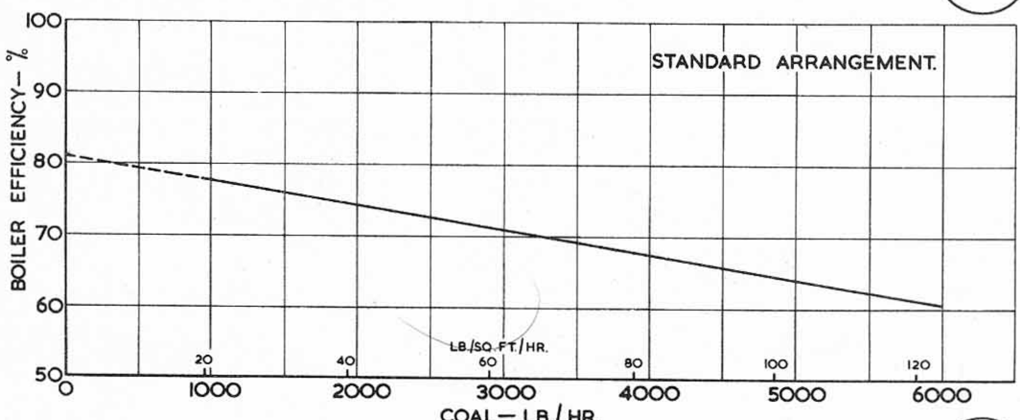
29

EVAPORATION



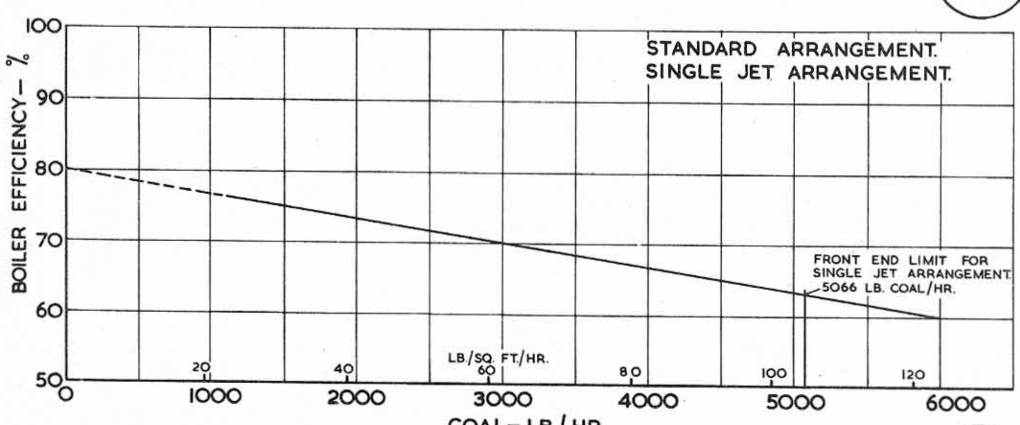
SOUTH KIRKBY. 13990 B.Th.U./LB.

30



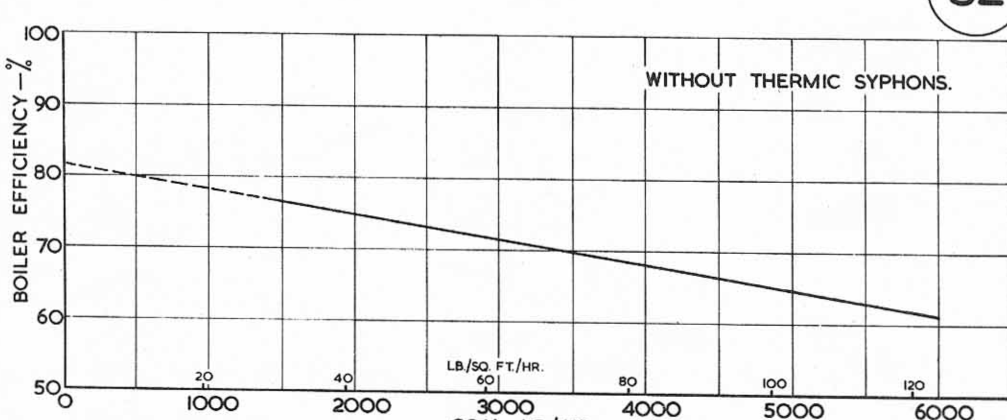
BEDWAS. 14230 B.Th.U./LB.

31



BLIDWORTH. 12910 B.Th.U./LB.

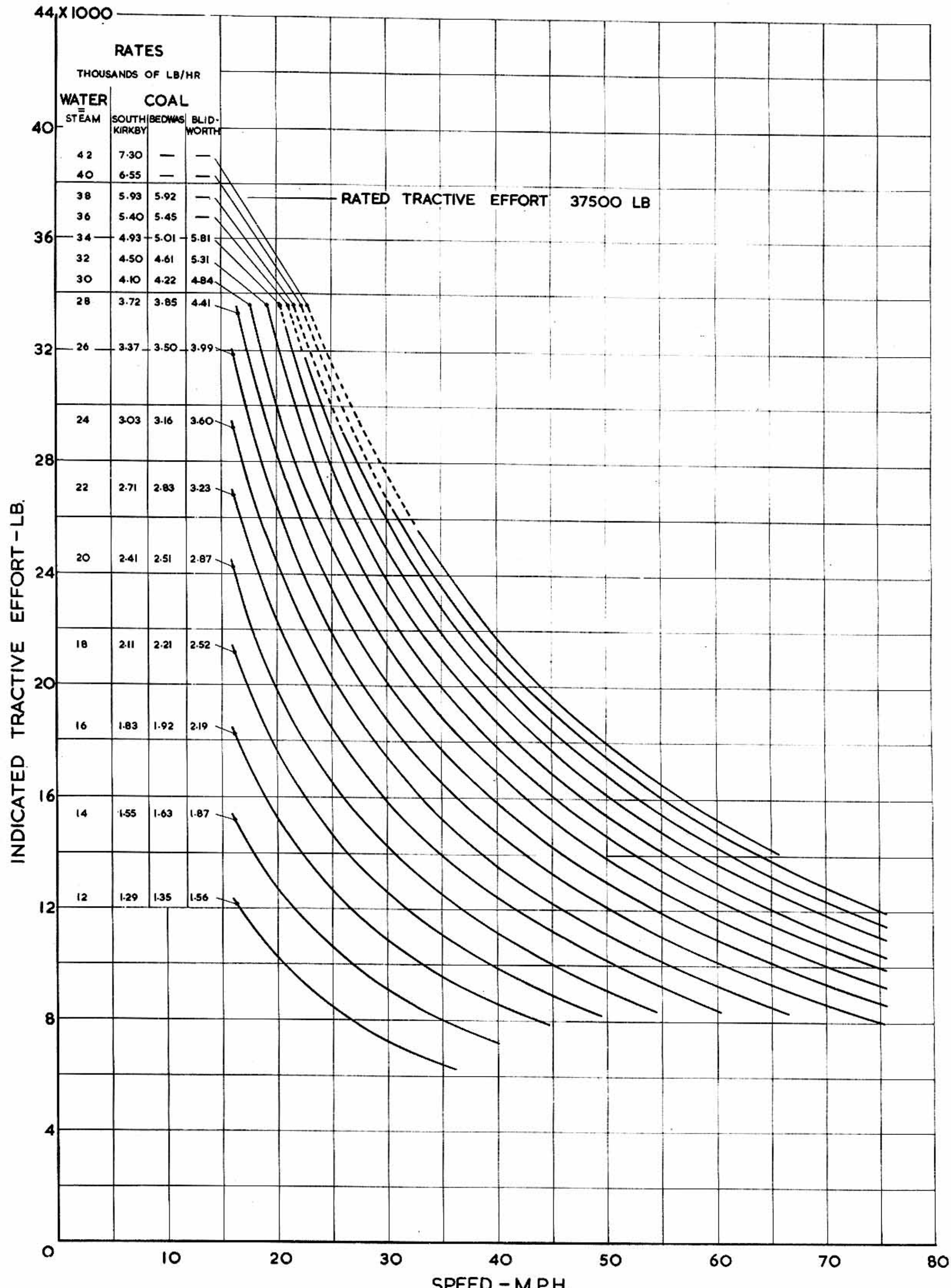
32



BLIDWORTH. 12910 B.Th.U./LB.

33

BOILER EFFICIENCY



WATER = STEAM	COAL SOUTH KIRKBY	COAL BEDWAS	COAL BLIDWORTH
42	7.30	—	—
40	6.55	—	—
38	5.93	5.92	—
36	5.40	5.45	—
34	4.93	5.01	5.81
32	4.50	4.61	5.31
30	4.10	4.22	4.84
28	3.72	3.85	4.41
26	3.37	3.50	3.99
24	3.03	3.16	3.60
22	2.71	2.83	3.23
20	2.41	2.51	2.87
18	2.11	2.21	2.52
16	1.83	1.92	2.19
14	1.55	1.63	1.87
12	1.29	1.35	1.56

SOUTH KIRKBY COAL 13990 B.Th.U./LB.
BEDWAS COAL 14230 B.Th.U./LB.
BLIDWORTH COAL 12910 B.Th.U./LB.
STANDARD ARRANGEMENT

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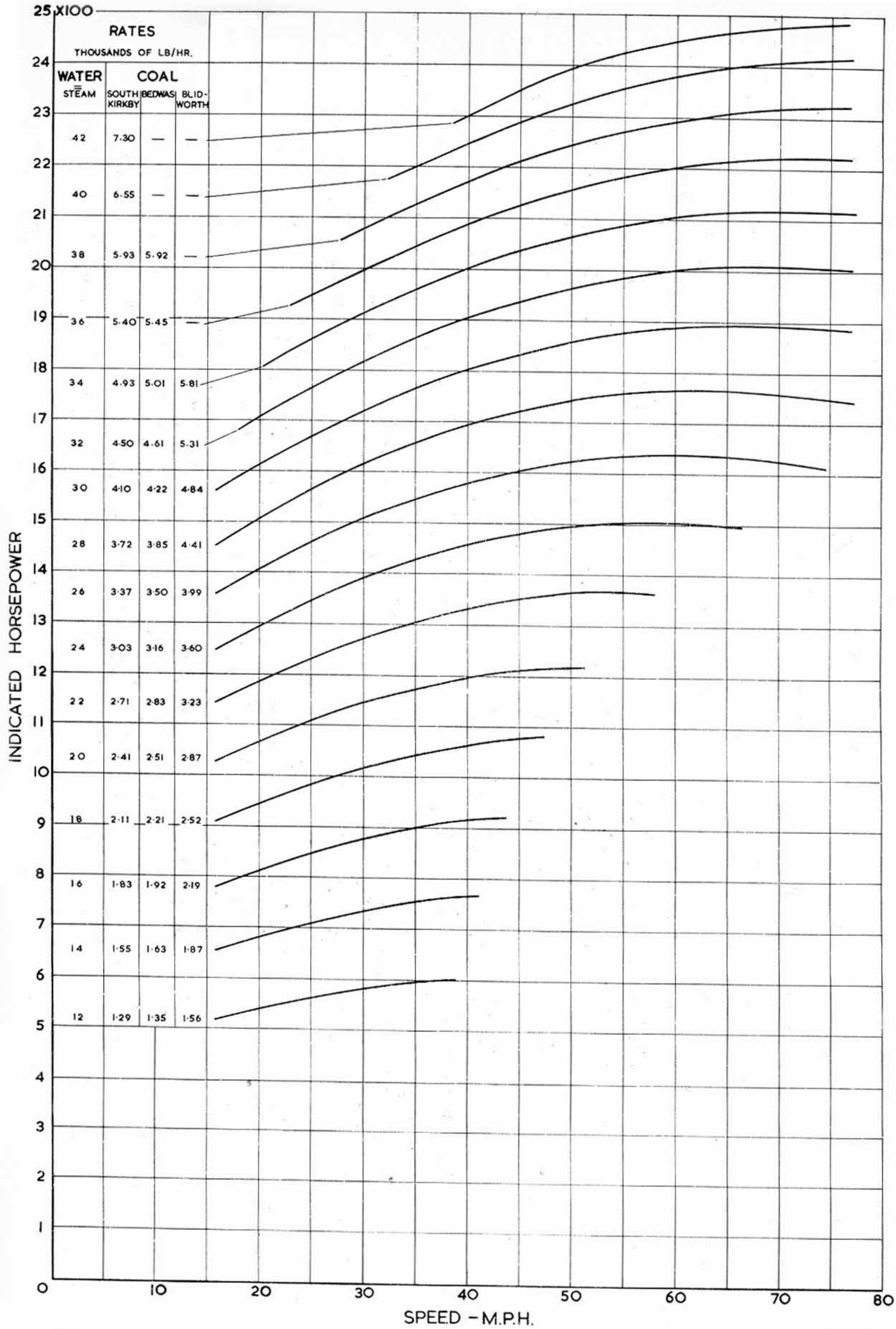
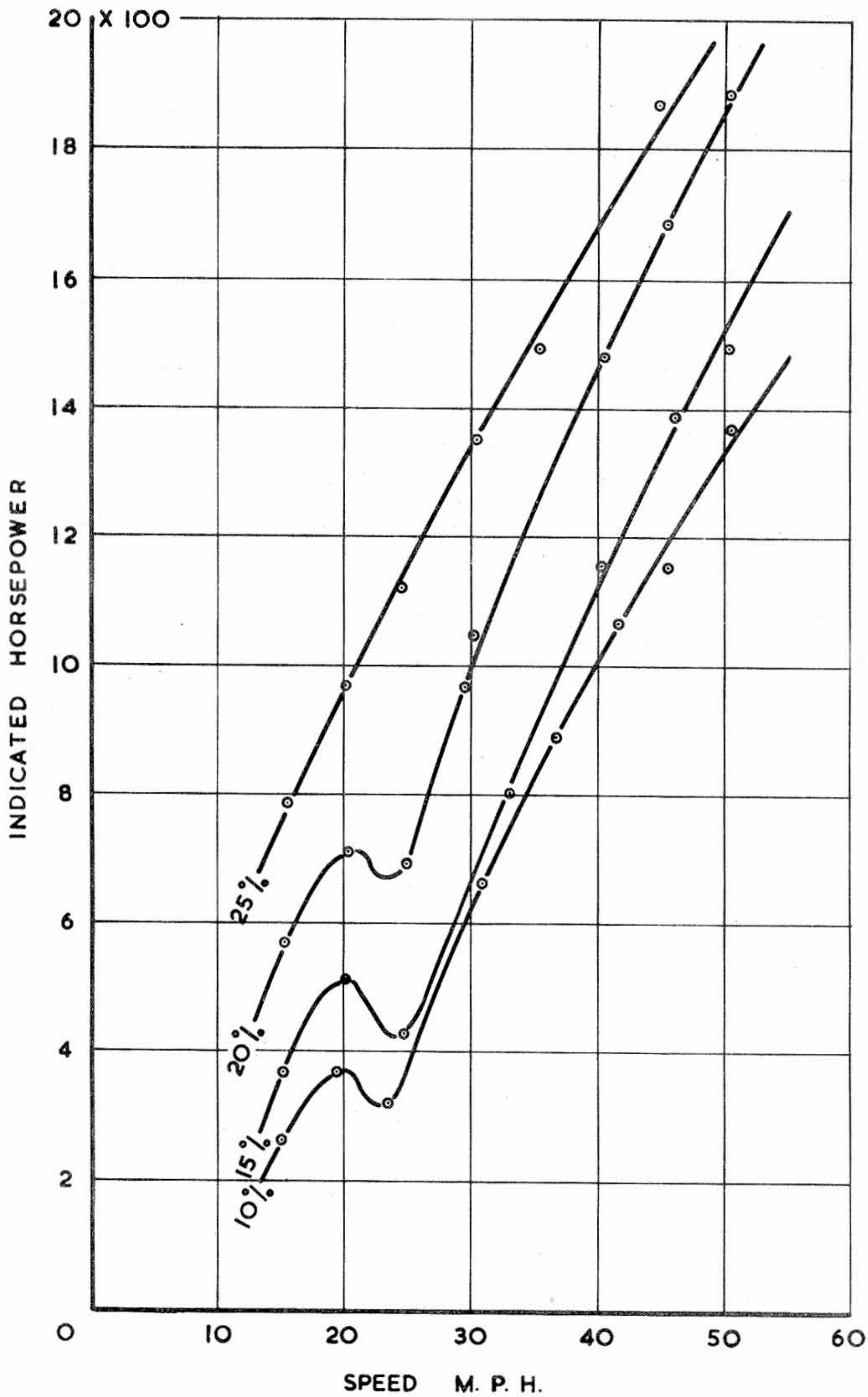
INDICATED TRACTIVE EFFORT CHARACTERISTICS



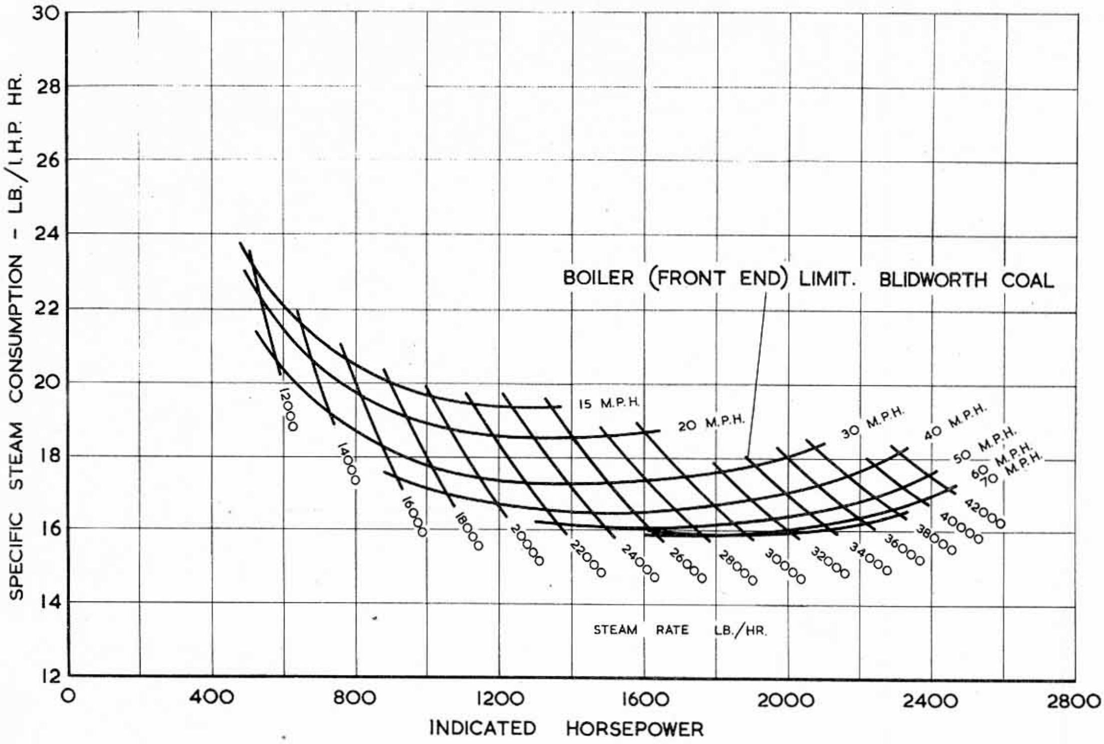
WATER = STEAM	COAL SOUTH KIRKBY	COAL BEDWAS	COAL BLIDWORTH
42	7·30	—	—
40	6·55	—	—
38	5·93	5·92	—
36	5·40	5·45	—
34	4·93	5·01	5·81
32	4·50	4·61	5·31
30	4·10	4·22	4·84
28	3·72	3·85	4·41
26	3·37	3·50	3·99
24	3·03	3·16	3·60
22	2·71	2·83	3·23
20	2·41	2·51	2·87
18	2·11	2·21	2·52
16	1·83	1·92	2·19
14	1·55	1·63	1·87
12	1·29	1·35	1·56

SOUTH KIRKBY COAL 13990 B.Th.U./LB.
BEDWAS 14230 B.Th.U./LB.
BLIDWORTH 12910 B.Th.U./LB.
STANDARD ARRANGEMENT

INDICATED HORSEPOWER CHARACTERISTICS



INDICATED POWER CHARACTERISTICS
AT NOMINALLY CONSTANT CUT OFFS



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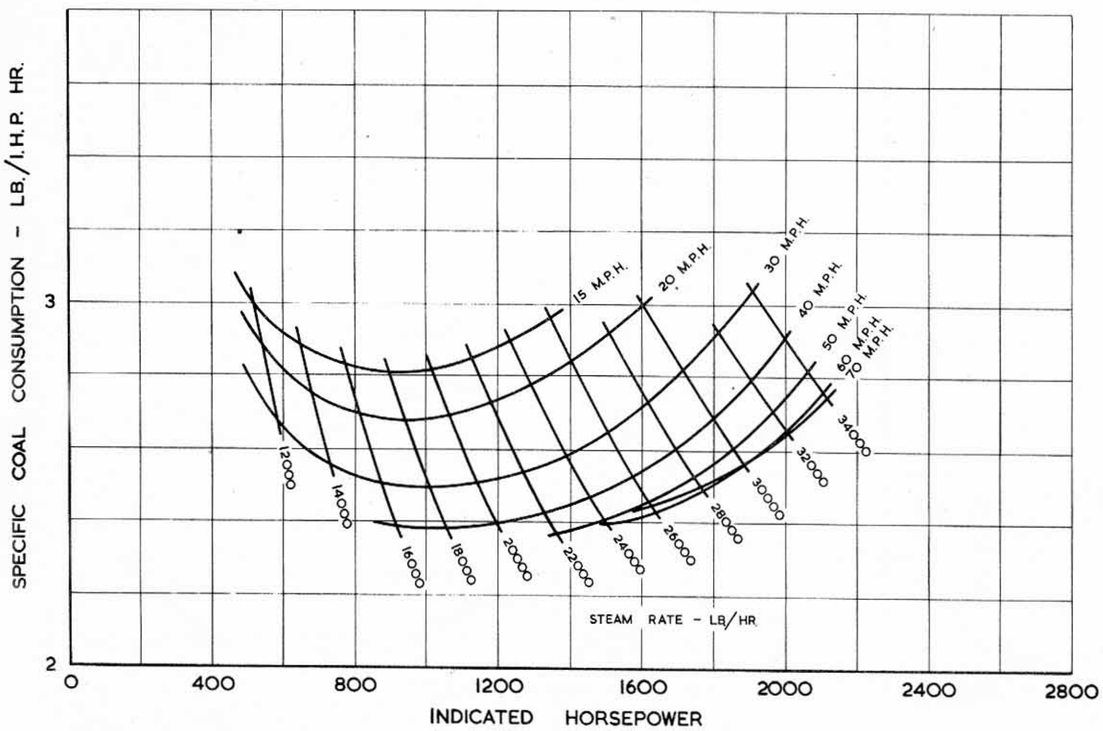

BLIDWORTH COAL – 12,910 B.Th.U./LB.
STANDARD ARRANGEMENT

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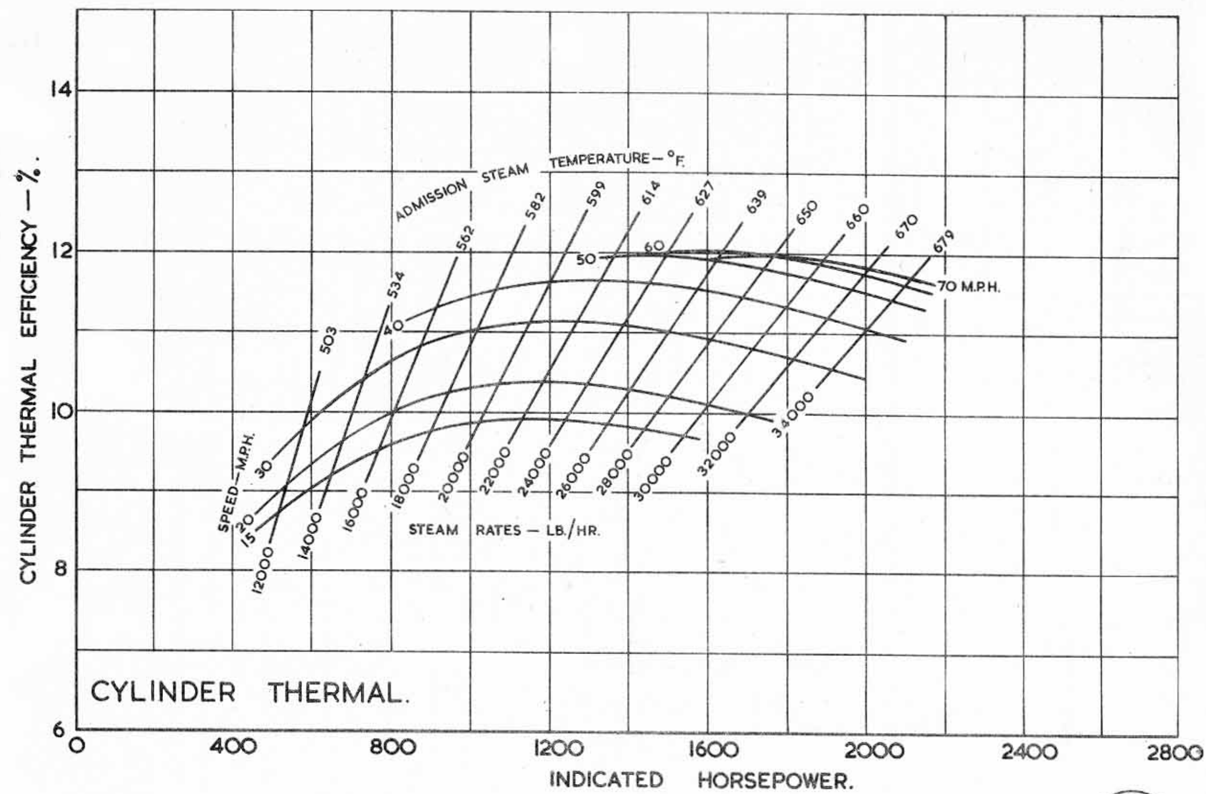
STEAM & COAL PER I.H.P. HR.



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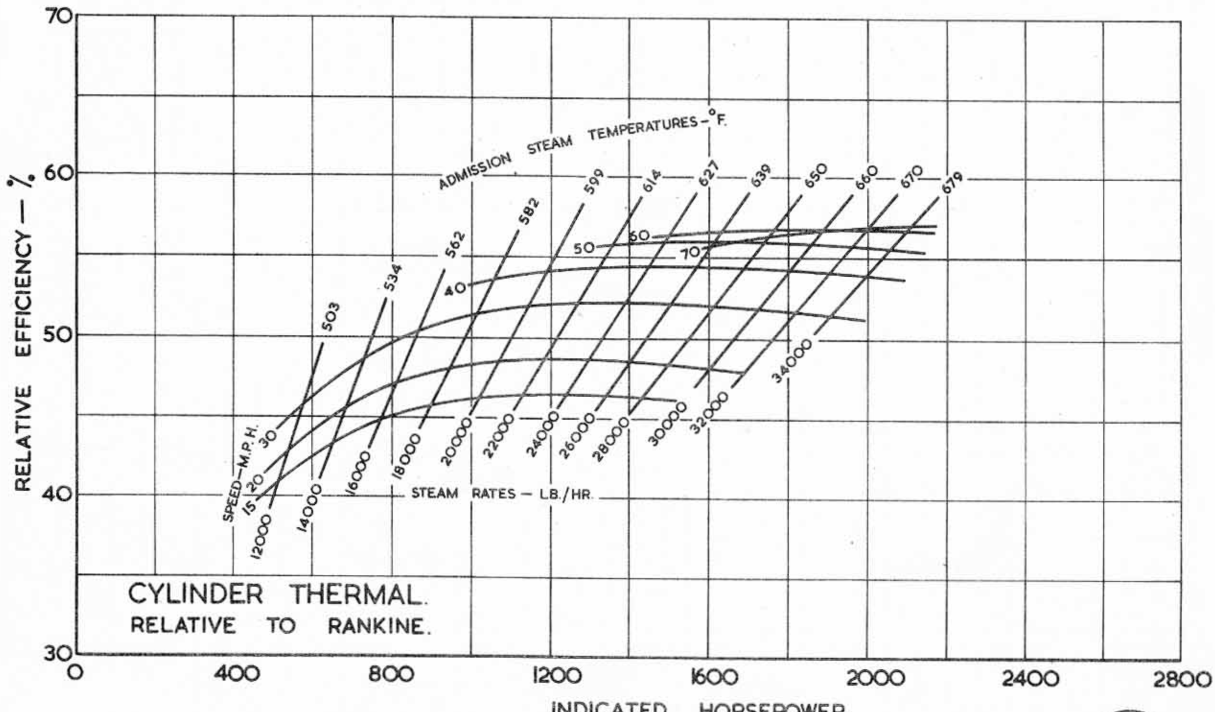
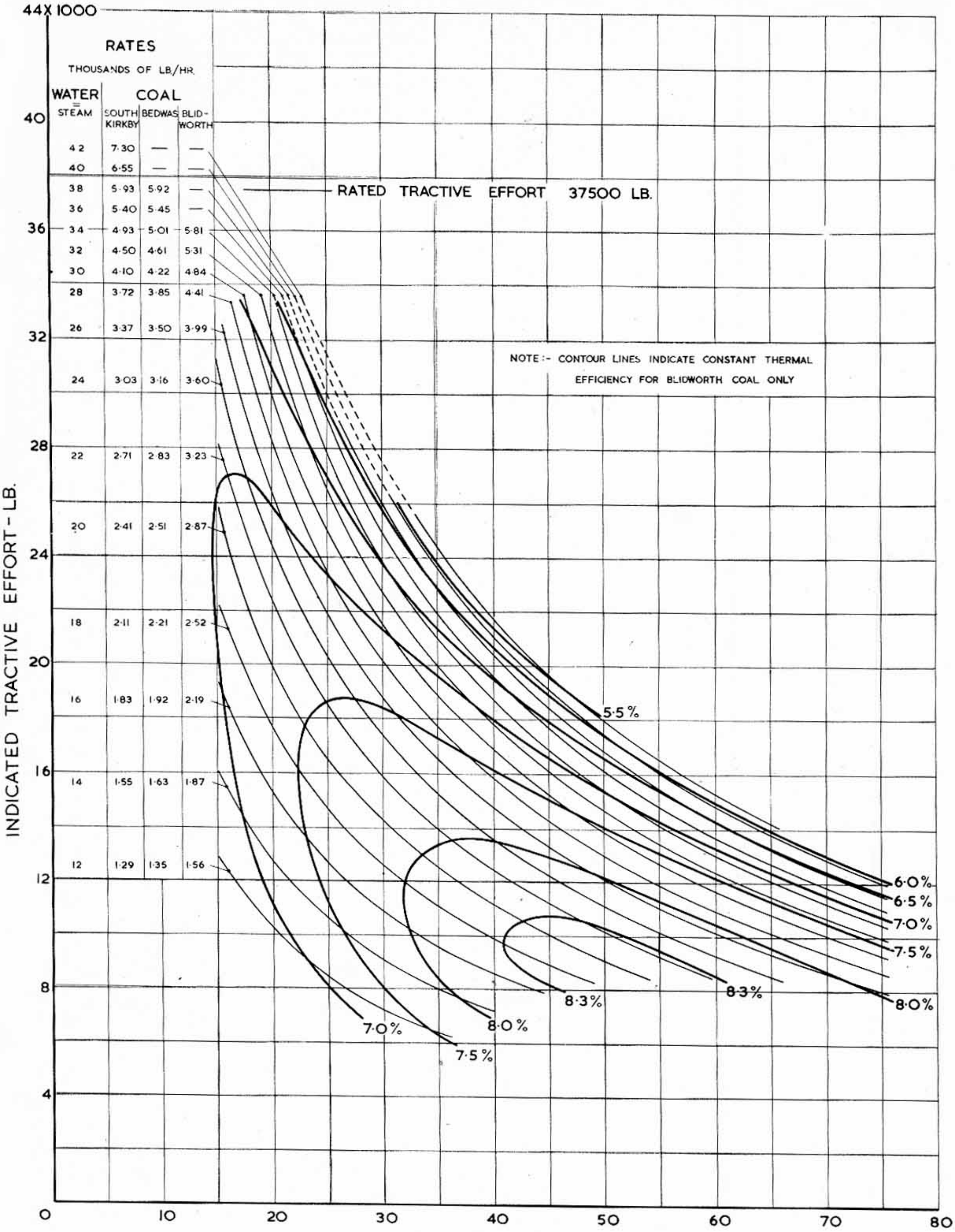


BLIDWORTH COAL — 12910 B.Th.U./LB.
STANDARD ARRANGEMENT.

40

EFFICIENCIES



SOUTH KIRKBY COAL	13990 B.Th.U./LB.
BEDWAS COAL	14230 B.Th.U./LB.
BLIDWORTH COAL	12910 B.Th.U./LB.

STANDARD ARRANGEMENT

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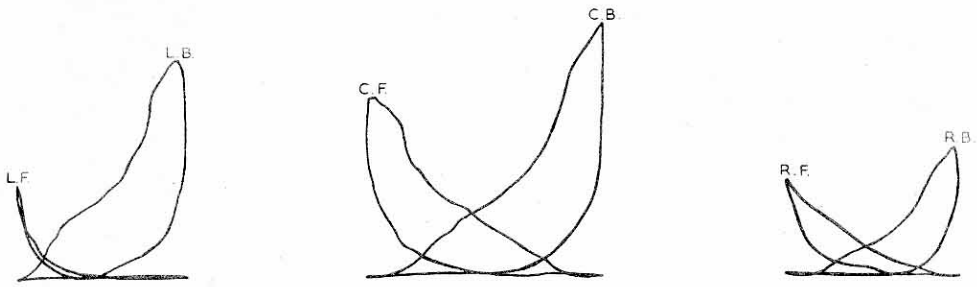
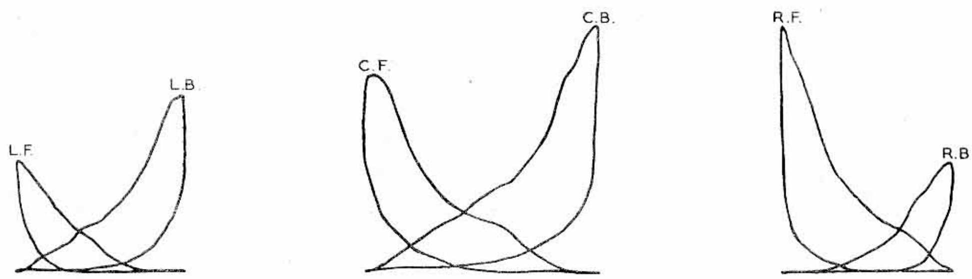
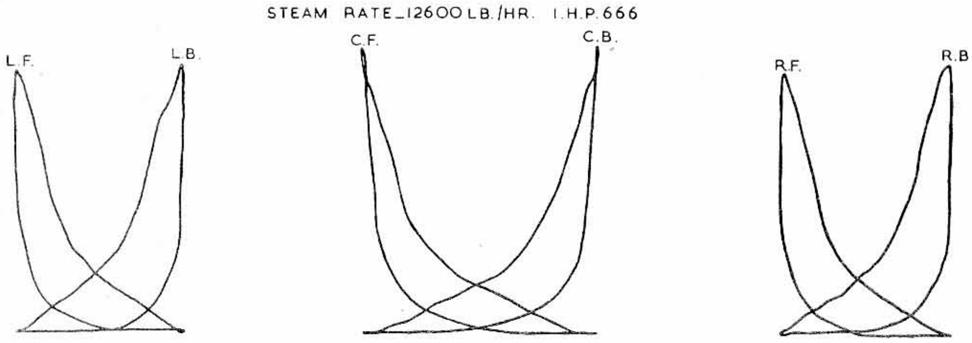
OVERALL EFFICIENCY REFERRED TO CYLINDERS



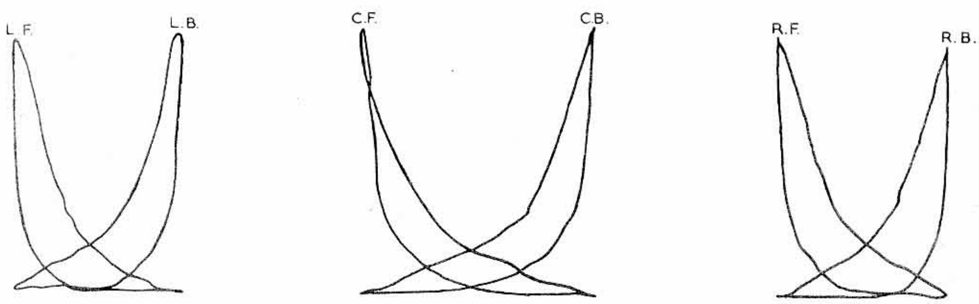
CUT-OFF_10% SPEED_15 M.P.H.
STEAM RATE_8000 LB./HR. I.H.P._262



CUT-OFF_10% SPEED_30 M.P.H.
STEAM RATE_12600 LB./HR. I.H.P. 666



CUT-OFF_10% SPEED_55 M.P.H.
STEAM RATE_23500 LB./HR. I.H.P. 1461

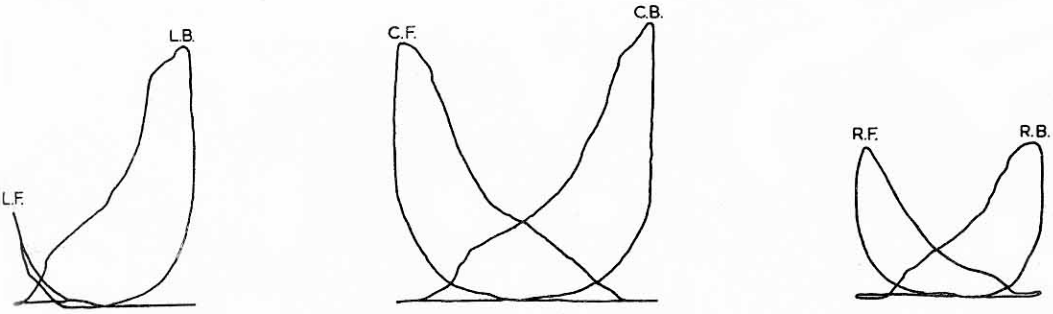


CUT-OFF_10% SPEED_80 M.P.H.
STEAM RATE 29400 LB./HR. I.H.P. 1820

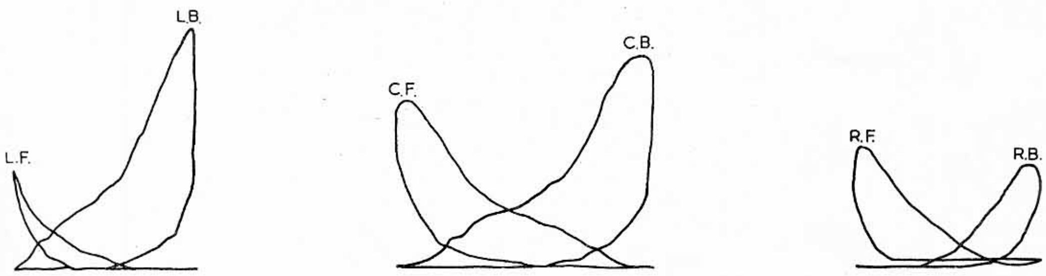
10% CUT-OFF

MAXIMUM STEAM CHEST PRESSURE

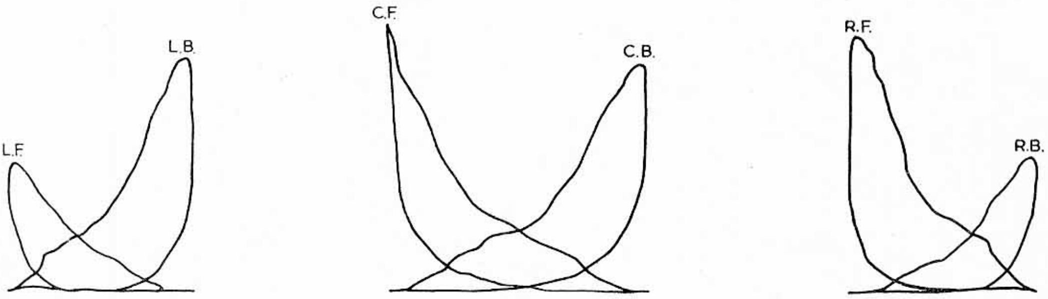
EXAMPLES OF INDICATOR CARDS



CUT-OFF - 15% SPEED - 15 M.P.H.
STEAM RATE - 9700 LB/HR I.H.P. - 372



CUT-OFF - 15% SPEED - 25 M.P.H.
STEAM RATE - 10610 LB/HR. I.H.P. - 427

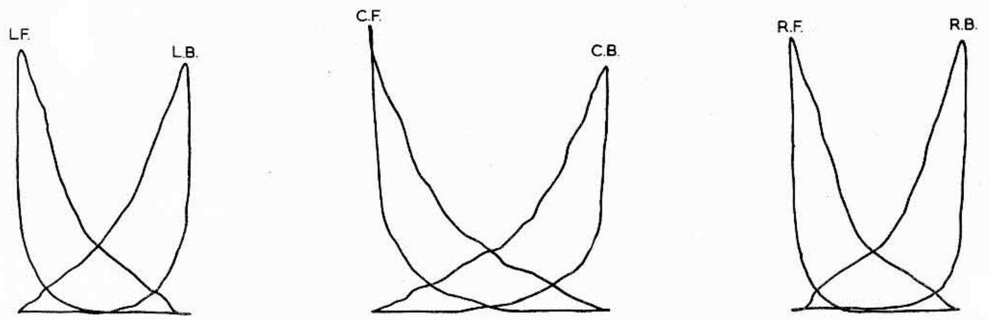


CUT-OFF - 15% SPEED - 35 M.P.H.
STEAM RATE - 14750 LB/HR I.H.P. - 802

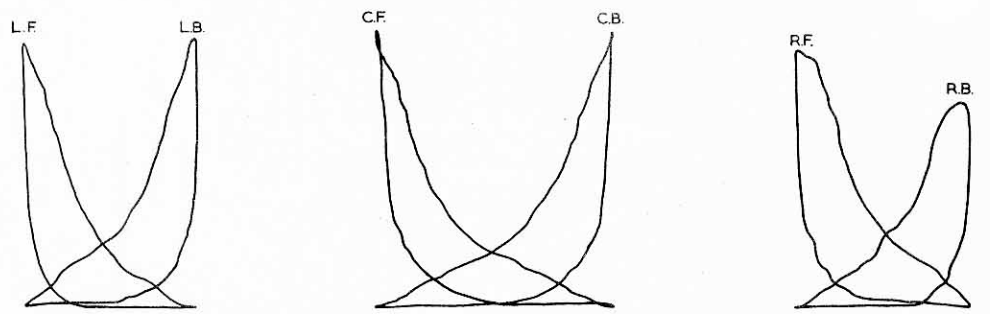
15% CUT-OFF

MAXIMUM STEAM CHEST PRESSURE

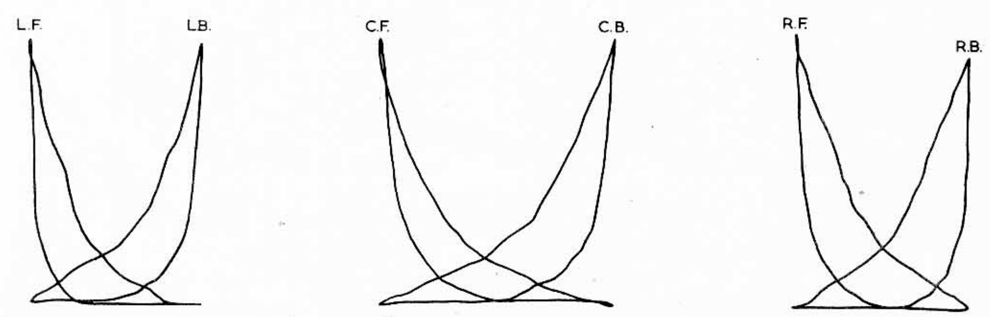
EXAMPLES OF INDICATOR CARDS



CUT-OFF_15% SPEED_45 M.P.H.
STEAM RATE_22050 LB/HR. I.H.P._1389



CUT-OFF_15% SPEED_60 M.P.H.
STEAM RATE_27650 LB/HR. I.H.P._1746

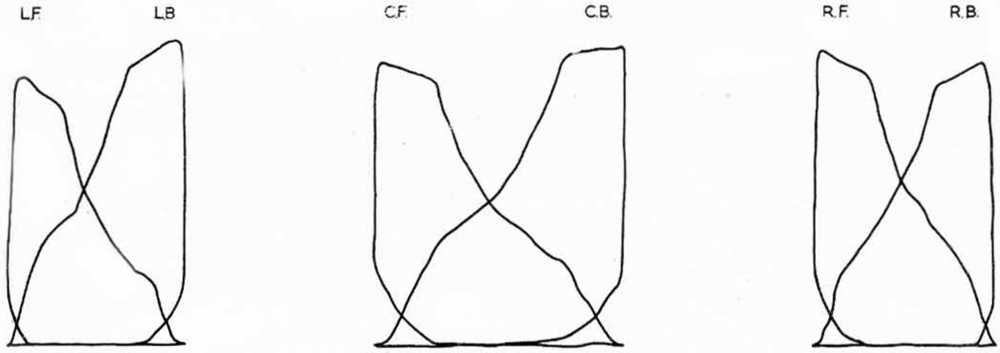


CUT-OFF_15% SPEED_80 M.P.H.
STEAM RATE_31850 LB./HR. I.H.P._1861.

15% CUT-OFF.

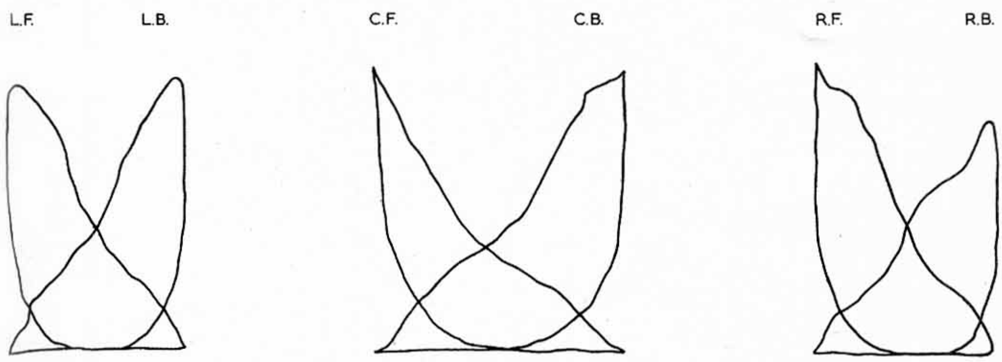
MAXIMUM STEAM CHEST PRESSURE.

EXAMPLES OF INDICATOR CARDS.



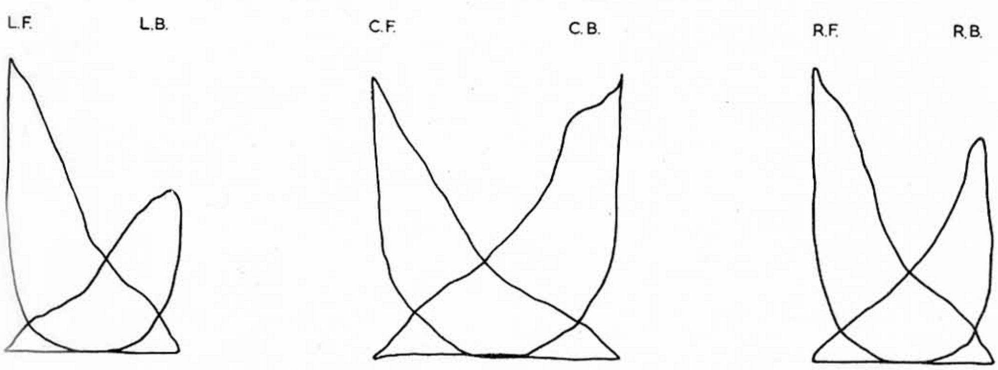
CUT-OFF - 30% SPEED - 15 M.P.H.

STEAM RATE - 18,400 LB./HR. I.H.P. - 897



CUT-OFF - 30% SPEED - 50 M.P.H.

STEAM RATE - 38,950 LB./HR. I.H.P. - 2230



CUT-OFF - 25% SPEED - 50 M.P.H.

STEAM RATE - 32,220 LB./HR. I.H.P. - 1938

25% & 30% CUT-OFF

MAXIMUM STEAM CHEST PRESSURE

EXAMPLES OF INDICATOR CARDS