# STEAM LOCOMOTIVE DEVELOPMENT IN ARGENTINA—ITS CONTRIBUTION TO THE FUTURE OF RAILWAY TECHNOLOGY IN THE UNDER-DEVELOPED COUNTRIES



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*Paper presented before the Manchester Centre of the Institution on 7th March,* 1969

**PAPER No. 721**

## 1. INTRODUCTION

The purpose of this Paper is to suggest that in under-developed countries of the 'Third World', which lack finance for heavy capital investment but have adequate supplies of indigenous fuel such as coal or wood, there is scope for the continued development of steam traction. Substantial improvements in performance, efficiency and availability can be achieved with steam traction by application of modern techniques[1].

The Author supports this premise by giving details of improvements to various types of existing locomotives in Argentina, where capital available for railway development has been severely restricted, of a prototype 4-8-0 locomotive which developed probably the highest power output in relation to weight of any metre-gauge steam locomotive and of the 2-10-2 type locomotives of the Rio Turbio mineral railway in Patagonia. The last mentioned machines, incorporating gas-producer firebox and other features designed by the Author, regularly haul 1,700-ton mineral trains over this 2 ft. 5½ in. gauge line, 160 miles in length, despite an axle loading restricted to 7½ tons, and on test have hauled a train 3,100 tons (127 vehicles) on level track sustaining 1,200 drawbar h.p.

From experience gained with the Rio Turbio 2-10-2 type locomotives the Author has prepared designs for a 2-8-0 type general purpose locomotive, adaptable to track gauges from 3 ft. 0 in. to 5 ft. 6 in.; combining high performance capacity with an axle loading of 13 tons. He has also prepared designs for a high-powered 2-10-0 and for a Mallet type locomotive of adequate power to haul 10,000-ton trains.

The writer would stress that his Paper is directed to the traction requirements of under-developed countries, where the application of a new steam technology in conjunction with the use of local fuels, often of poor quality, could be highly relevant. Furthermore, in the Author's view, the possibility of global scarcity of petroleum products, making desirable the use of alternative fuels where practicable, provides additional justification for this Paper.

The writer gladly acknowledges that the inspiration and starting point for his work was an exhaustive study of the work of M. André Chapelon in France. The application of M. Chapelon's researches into improved exhaust systems and flow through the steam circuit resulted in the rebuilding, from 1929 onwards, of the compound

Pacific-type locomotives of the Paris-Orleans Railway, with an increase of maximum power from 2,200 to 3,700 i.h.p.; and gave a new life to the steam locomotive[2, 3].

## 2. IMPROVEMENTS TO EXISTING LOCOMOTIVES

### 2.1. Metre-Gauge 4-8-0 Four-Cylinder Compound Locomotive

The rebuilding by the Author, of an existing 4-6-2 type locomotive as a 4-8-0 followed closely the principles applied by M. Chapelon to the rebuilt 4-8-0 locomotives of the P.O. Railway, where maximum power output was raised from 2,200 to 4,000 i.h.p.; with adhesive weight increased by 33%, compared with the Pacific type locomotives from which they were rebuilt[4].

The rebuilt locomotive has a working pressure of 285 p.s.i. and a total engine weight of 68 tons in working order, of which 54 tons are adhesive. To ensure maximum freedom of steam flow and to reduce pressure drops to a minimum the cross section of steam ports was increased to 25% of the piston area. The boiler was fully welded except for the main barrel seam and built entirely by hand without flanging.

It may be mentioned that practically the whole of the new components in the rebuilt engine were of welded mild steel plate construction; pistons, cylinders, streamlined casing, tender tank extension, axleboxes, etc., being built by this means.

Other features of the locomotive were a supplementary superheater between H.P. exhaust and L.P. admission, as used on M. Chapelon's rebuilt 2-12-0 of the SNCF, and a fully balanced built-up crank axle with 135° crank setting.

Despite numerous initial teething troubles, until steam leakage problems had been overcome, this locomotive has given extremely good results and the maximum power output attained, 2,120 db. h.p.; was almost exactly in proportion of locomotive weights (68: 108) to that of the P.O. Railway 4-8-0 rebuilds.

*Fig. 1.—Prototype metre-gauge 4-cylinder compound 4-8-0 locomotive.*

Track conditions in 1947-1949 made it impossible to reach the designed maximum speed of 75 m.p.h., but riding was very good at 65 m.p.h. when hauling 1,200-ton freight trains, although the coupled wheel diameter is only 4 ft. 2 in., 200-ton trains were hauled at 50 m.p.h.

This locomotive showed remarkable accelerative capacity, due no doubt to large steam passage areas and high steam temperatures, which reached 842° F. in the H.P. cylinders and 602° F. in the L.P. Minimum specific fuel consumption was 1.78 lb./db. h.p./hour at 1,000 db h.p. and 31 m./hr., an extremely low figure (Calorific value of fuel was 12,000 B.Th. U/lb.)

Despite the intense draught produced by the Kylchap exhaust, the combustion system used, in which the bulk of the air for combustion was admitted as secondary air above the fire, enabled high power outputs to be obtained without 'lifting' the fire. Wear in engine components was very low, due no doubt to the even turning moment prevalent with compound working.

## 2.2. Light Rebuilding of 2–6–2 and 2–6–4 Suburban Tank Locomotives, Roca Railway

These locomotives, of which thirty 2-6-2 tanks were built in 1916 and sixty 2-6-4 tanks were built in 1927, work suburban services from Buenos Aires. Some of those working from Tolosa shed have been diagrammed to rosters involving a mileage of about 7,000 per month.

In the extremely difficult labour situation existing around 1950, operating and maintenance conditions were extremely hard, resulting in a reduction in maximum power output for the three-cylinder 2-6-4 tanks from about 900 drawbar horsepower after works overhaul to about 600 db. h.p. after a few months service in these conditions.

The modifications made to these locomotives involved basically the substitution of a multiple-jet exhaust based on the Lemaitre and improvements to the valve setting. At a cost of about £200 per locomotive, at prices then current, the maximum power of the 2-6-4 tank engines was increased to 1,200 db. h.p. with a much smaller falling off than previously when in run-down condition[5].

Whilst it was impossible to design an optimum blast pipe to meet the prevailing conditions, entailing widely varying degrees of steam pipe joint leakage in the smokebox or through piston packings, the Lemaitre type blast pipe gave good results, provided carbon deposits in the nozzles were removed at regular intervals.

The operation of the rebuilt locomotives has been extremely successful and on more than one occasion the whole of the suburban service for the day has been worked without a single train arriving even one minute late, a clear indication of the ability of the locomotives to make up time lost by signal and permanent way checks and overtime at stations.

The performance of the rebuilt 2-6-2 tank engines being superior to that of unrebuilt 2-6-4 tanks, the smaller machines could be substituted for the larger when necessary, giving greater flexibility in diagramming.

The improvement in performance of the rebuilt locomotives

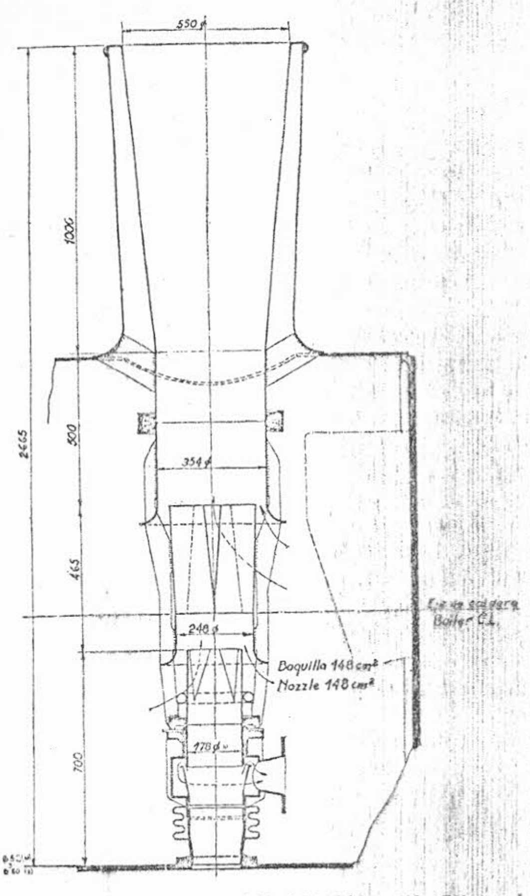


*Fig. 2.—Kylpor exhaust system of 2-6-2 Class "8 C" tank locomotive No. 3477, Roca Railway.*

could be seen frequently in the 'neck and neck' starts of suburban trains from Plaza Constitution station on parallel tracks.

### 2.3. Semi-heavy Rebuilding of 2-6-2 Suburban Tank Locomotive, Roca Railway

Following the successful results of light rebuilding of the 2-6-2 tank engines mentioned above, it was felt desirable to make further substantial improvements by a more extensive rebuilding, but without altering the basic structural design.

The basic defects of the original design included small firebox volume, restricted steam space, low superheat and long steam passages with small cross section. Mechanical defects included weak frames, cab structure working loose, poor sanding and lubrication and heavy axlebox wear—a fairly formidable list.

After a detailed investigation of those defects locomotive No. 3477 was rebuilt incorporating the following major improvements[6].

(*a*) Boiler pressure was raised from 160 to 192 p.s.i. the maximum permissible for this boiler under the A.S.M.E. Code.

(*b*) Superheat was increased from 620° F. to 752° F. at full load by fitting a new superheater with larger elements, having 15% greater heating surface, and by blanking off about one third of the small tubes to increase the gas flow through the flue tubes carrying the superheater elements.

(*c*) To augment the inadequate steam chest volume—which M. Chapelon's work has shown should be equal to that of the cylinder to minimise pressure drop, a supplementary vessel of 6 cu. ft. capacity was connected to the existing steam chest through the hole formerly provided for the snifting valve. Thus the ratio between cross sections of steam chest and cylinder was increased from 43% in the original design to 95%—a most important improvement when one recalls that pressure drop is inversely proportional to cross-sectional area.

(*d*) Substitution of the Kylpor exhaust, derived from the Kylchap, for the conventional circular type provided a substantial improvement in smokebox vacuum for a given back pressure. An evaporation rate of 11 tons of water per hour was sustained with this small boiler, back pressure being only 5.7 p.s.i. and smokebox vacuum 15.8 in. water gauge. The use of an exhaust diffuser, which enables the maximum draught energy to be obtained during the exhaust advance stage, results in back pressure being reduced to about one third of nominal during the exhaust phase[7].

(*e*) The reciprocating parts were redesigned and renewed. The weight of reciprocating masses, which gave rise to perceptible 'fore and aft' motion with the original engines was reduced by 355 lb. This, combined with partial balancing of the reciprocating masses, has eliminated the oscillations experienced previously.

(*f*) To improve steam flow and to enable higher steam temperatures to be used with existing lubricants, new piston valves with narrow rings and admission and exhaust diffusers were fitted. These diffusers are located at the extremities of the valve heads. The advantage of the admission diffuser is that it improves the steam flow through the exposed area of the port, assisted by rounding the edge of the ports to a radius of 4 mm., thereby increasing the flow coefficient of the $10\frac{3}{8}$ in. diameter piston valves to be equivalent to that for 15 in. diameter valves of normal type. The exhaust diffuser deflects the steam at the beginning of release, cooling the valve crown, reducing the exhaust pressure peak and acting as a venturi at port closure to lessen the losses associated with closing at the end of the exhaust stroke. Perlitic materials, used normally in diesel work, were applied for the valve sleeves and rings; effective life being about 60,000 miles with steam tightness equal to new. Whilst retaining the existing Walschaerts valve gear, it was found possible to shorten the combination lever to increase valve lap by 0.2 in. These features, combined with high steam temperature, low exhaust back pressure and increased steam chest volume have produced a very free-running and lively engine.

(g) The frames of the original locomotives were unsatisfactory and the effects of flexing and torsion in service were seen in the fracture of steam pipes, leakage at joints, looseness of cab and water tanks and loss of general alignment. The Author has followed the principles cogently stated by E. S. Cox to this Institution in reinforcing the frames to give maximum rigidity, with the aid of the boiler, in providing maximum resistance to flexure and torsion. This was achieved by fitting transverse reinforcing plate members combined with transverse reinforcing tubes 12 in. diameter and $\frac{5}{8}$ in. thick to the main frame longitudinals, reinforcements to horn gaps and stays and reinforced and redesigned smokebox saddle and dragbox. The boiler is used to resist torsional, vertical and lateral stresses by means of pendulum plates strongly braced to the firebox, whilst still permitting longitudinal movement by the boiler. The resulting extremely rigid frame structure has overcome the defects of the original design and enables high power outputs to be developed with minimal maintenance[8].

(h) Lubrication of cylinders and running gear has been improved. A Friedmann mechanical lubricator supplies 28 oiling points, including the steam brake cylinder. The mechanical lubricator supplies cylinder lubricant also, combined with saturated steam at point of entry to the valves. Despite steam temperatures of 752° F.; with maxima rising to 824° F. in maximum power conditions, cylinder lubrication has been entirely satisfactory using local cylinder oils with an open vessel flash point of 536-554° F. Large capacity oil-boxes are provided on the connecting rods and the locomotive can travel over 600 miles in suburban service without oiling.

(i) The oil-burning equipment of combined type, was redesigned and the burner placed at the back of the firebox with the flame path lengthened by a refractory wall. Despite the limited firebox volume the requisite quantity of oil can be burned to produce a maximum sustained evaporation of 26,000 lb. of cold water per hour from this small boiler, a major factor being the high pumping efficiency of the Kylpor exhaust.

(j) Special attention was paid to providing maximum accessibility of controls and comfort of the crew, the boiler backplate being lagged with glass wool 2 in. thick and the side tanks moved forward 16 in. to give more space in the cab.

The results obtained with the rebuilt locomotive have shown a remarkable improvement on the original. Maximum power output at the drawbar was virtually doubled, reaching about 1,400 h.p. in the speed range 37-62 m.p.h. This power output is virtually equal to the maximum obtainable with the PS 11 class three-cylinder 4-6-2 express locomotives with boiler and firebox evaporative surface areas double those of the rebuilt 2-6-2 tank engine, whose machine capacity enabled it to work services normally handled by the PS 11 engines but with a fuel consumption 30-40% lower. When hauling fast trains on the

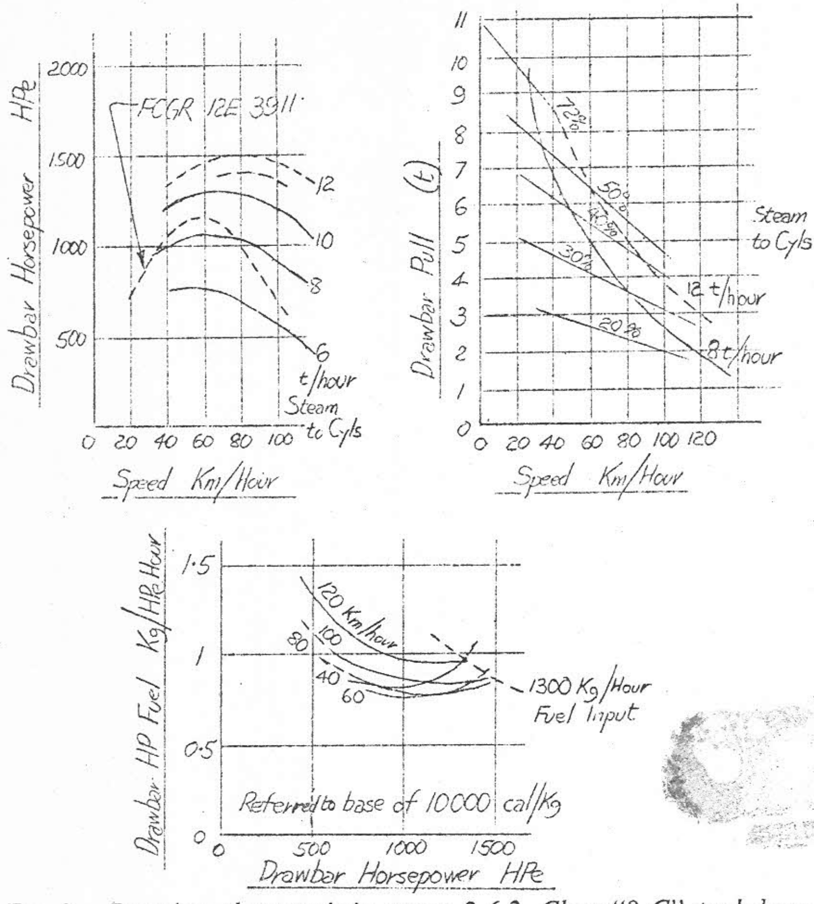


*Fig. 3.—Drawbar characteristic curves* 2-6-2, *Class* "8 C" *tank locomotive No.* 3477, *Roca Railway.*

Mar del Plata line the fuel oil consumption of No. 3477 is only 23-25 lb./mile compared with 43-50 lb./mile with the 12E type Pacific locomotives of the Roca Railway.

### 2.4. Light 4–6–2 type Locomotives—Belgrano Railway (former Province of Buenos Aires Railway).

This metre-gauge railway has a main line 341 miles in length and carries predominantly agricultural traffic to the coast. Of its steam locomotives thirty nine are of the Pacific type having a standard boiler and the last batch of twelve, built by Henschel in 1929 are a beautiful example of classic German design. These 'H' class locomotives, which have large diameter driving wheels and slightly larger cylinders than the earlier Swedish built engines, were rated to haul 1,200-ton trains at 15 m.p.h. average speed in the prairie zone with a mean power output of 500 h.p. at the drawbar.

Investigations carried out by Senor Vittone, then chief technical

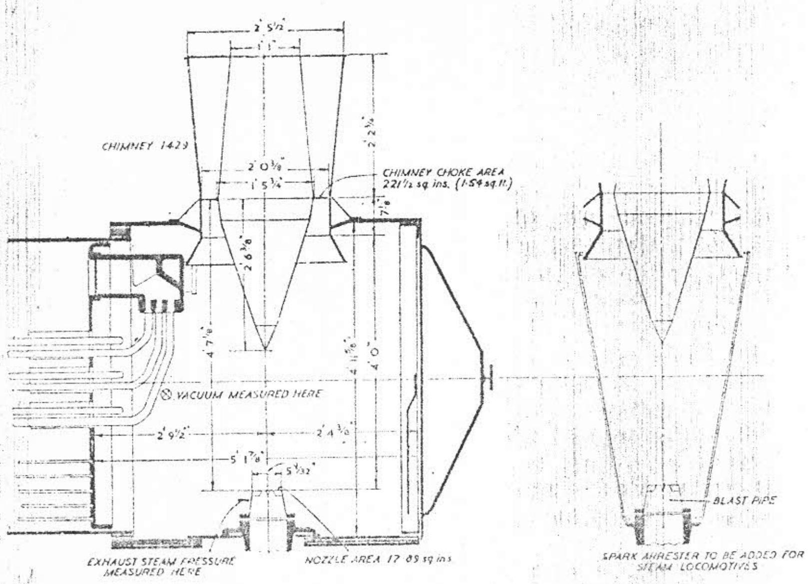


*Fig. 4.—Vittone exhaust system, 4-6-2 Class "H" metre-gauge locomotive, Belgrano Railway.*

adviser to the P.B.A. railway, showed that combustion and steaming of these oil-fired locomotives could be improved substantially. The fitting of refractory arches in the fireboxes gave an appreciable fuel economy and some increase in steaming capacity, which enabled the maximum permissible load to be increased from 1,200 to 1,500 tons, with an economy of 27% in specific fuel consumption per 1,000 ton-miles[9].

Following a profound analysis of the draughting of these locomotives, Senor Vittone carried out experiments to give the greatest possible contact surface between the entraining jet of exhaust steam and entrained combustion gases in the smokebox. The arrangement finally adopted comprised a circular blast pipe cap with projections similar to Goodfellow tips and a large diameter chimney with a body formed of two truncated cones inside it, to obtain an annular exit passage for the mixture of gas and steam.

Locomotive No. 356, incorporating the improvements mentioned above and with the firebox modified to increase its effective volume by 18.5%, proved its ability to haul 3,000-ton test trains in the normal journey time for 1,200-ton trains with the unmodified locomotives. With a laden train of 3017 tons the modified locomotive averaged 21.6 m.p.h. over 122½ miles. Maximum drawbar horsepower was 1,050 at 31 m.p.h.

In terms of practical service operation, the load limit in ordinary service could be increased from 1,200 to 2,000 tons with 50% economy in specific fuel consumption per 1,000 ton-miles.

**2.5. Modified 11C Class three-cylinder 4–8–0 type, Roca Railway**

Seventy five of these broad gauge (5 ft. 6 in.) locomotives were built in England between 1924 and 1929. They have been modernised at relatively small cost—about one seventh of the cost of general overhaul in workshops. Maximum drawbar horsepower at 37 m.p.h. was increased from 1,000 to 1,400. The rebuilding was carried out to the directions of M. Chapelon, following within the limitations imposed by existing layout the principles applied in improving the performance and efficiency of simple expansion locomotives of the S.N.C.F.; and included the following modifications[10,11].

*Boiler*: An RS type burner was substituted for the American type to give finer pulverisation and to achieve complete combustion in the firebox, thereby reducing the damage to and leakage of superheater elements. To compensate for the loss of 'post combustion' which previously took place in the large tubes, the superheater elements were lengthened and carried to within 18 in. of firebox tube plate, whilst the use of restrictors reduced the diameter at entry of the small tubes from 1.9 in. to 1.5 in. The ratio of equivalent gas areas between large and small tubes thus was raised from 0.86 to 1.12. Working pressure was raised from 199 p.s.i. to 213 p.s.i.

*Engine*: Modifications made to valves and to valve gear permitted an increase in port width from 1.5 in. to 1.85 in.; in steam lap from 0.88 in. to 1.07 in. and in maximum travel from 4.15 in. to 4.5 in. enabling the area of steam passage at admission to be increased by from 41.5% to 51% for cut-offs between 20% and 40%. On the exhaust side the application of ports of trapezoidal section reduced the violence of exhaust beats resulting from too sharp a peak flow at release. Greater steam tightness was obtained by substituting narrow rings, five for the valves and four for the pistons, for the two wide rings previously used.

*Exhaust*: The original exhaust with rectangular nozzle was replaced by the single Kylchap and the steam circuit improved between cylinders and blast pipe to obtain maximum possible homogeneity of exhaust jet and exact centring on the vertical axis of the chimney, which is not easy to obtain with three-cylinder simple locomotives.

*Chassis*: The cross-bracing of the frames adjacent to the driving axles has been increased by reinforcing bars of the maximum practic-

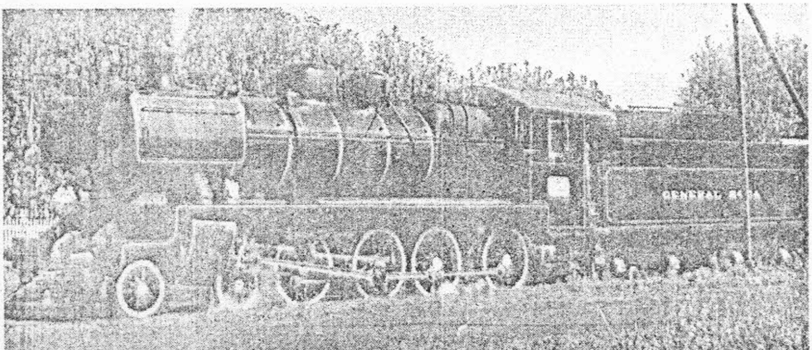

*Fig. 5.—Modified 3-cylinder 4-8-0 5 ft. 6 in. gauge Class "11 C" locomotive, Roca Railway.*

able diameter. To avoid cracks at the corners of the horn gaps steel reinforcing plates have been riveted to the frames at these points. Franklin automatically-adjusted wedges have been provided to eliminate the violent axlebox knock previously experienced with these engines when working hard.

*Results*: Comparative trials carried out between one of the rebuilt locomotives and one of the original type showed that for a given fuel oil consumption the power output at the drawbar of the rebuilt locomotive was 26 to 41% greater. An analysis of the test results showed that roughly one half of the improvement was due to better steam distribution, one third to the improved exhaust system and one sixth to improved combustion.

These locomotives handle freight trains of 1,500 to 2,000 tons in ordinary service with a fuel oil consumption about 30% lower than with the original engines on similar duties. In addition, these locomotives work important fast fruit trains weighing 1,000 tons from the Rio Negro valley to Buenos Aires over a distance of 740 miles, on which they have replaced the more modern and nominally more powerful 15A and B class 4-8-0 locomotives.

The S.N.C.F. preventive maintenance system, evolved by Messrs. Poissonier and Leroy, with inspection of wearing parts at stipulated intervals, dictated by rate of wear of individual components, and systematic replacement of worn parts, determined by gauges set to limits of wear has been applied successfully on these locomotives. The application of this system on the S.N.C.F. enabled its steam locomotive fleet to maintain an average mileage of 156,000 between on-line failures[12].

### 2.6. Rebuilt Metre-Gauge Light 4-6-2 Locomotives, former Santa Fé Railway

One of the ALCO light Pacifics built in 1919 was adapted for the burning of Rio Turbio coal and equipped with gas producer combustion system. Kylpor exhaust and other improvements already applied to Rio Turbio 2-10-2 locomotives. It was especially difficult to obtain the grate level and ashpan capacity desired in the rebuilt engine, the grate being depressed below the foundation ring with adequate refractory protection, although ashes tended to adhere to the refractory surfaces in heavy continuous operation.

Despite the limitations imposed by the original design, the rebuilt locomotive weighing 48 tons, of which only 27 tons is adhesive, showed remarkable tractive capacity and can haul 1,500-ton trains on level road developing 1,000 drawbar horsepower for lengthy periods, with fuel having a calorific value of 9,000-1,000 B.Th.U. per lb. and an ash content of 18%. The locomotive made many remarkable performances including a round trip from Santa Fé to Resistencia and back, 704 miles, with a 1,000-ton fast freight train without refuelling the tender. It is proposed to rebuild similarly all other locomotives of this class.

### 2.7. Rebuilt 4–8–2 type Metre-Gauge Locomotives, Belgrano Railway

Some ten years ago this railway commenced improving its best

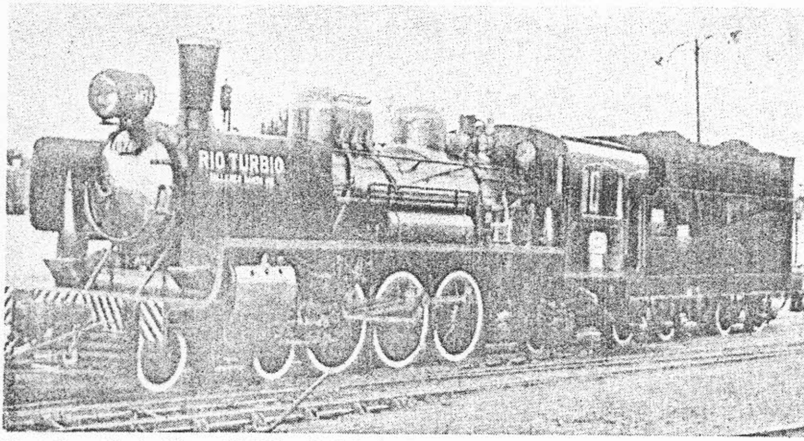


*Fig. 6.—Rebuilt ALCO 4-6-2 metre-gauge locomotive, Santa Fé Railway.*

steam locomotive types to the directions of Eng. J. M. Martinez. Improvements included the fitting of Kylchap blast pipes, multiple narrow rings for pistons and valves and the RS type oil-burning equipment already applied successfully on the Roca Railway 11C type 4-8-0 locomotives previously described. Preliminary tests showed substantial improvements in performance, economy and boiler maintenance. Teething troubles with the RS type oil burning equipment due mainly to inexperience of personnel, although not fundamental, were sufficiently serious to result in this being temporarily replaced by the standard American type until a detailed investigation by the Author's team enabled all the troubles to be overcome successfully.

The performance of these locomotives in original condition and prevailing standards of maintenance limited power output to about 900 h.p. at the drawbar although most trains can keep time, even making up lost time, with drawbar outputs of 600-700 h.p. Tested under the control of the Author the rebuilt locomotives developed 1,300 h.p. at the drawbar with perfect combustion and a slight smoke haze only at the chimney, fuel oil consumption being reduced by 30% for equivalent work done. Most recent tuning-up has enabled maximum power to be increased to 1,500 db. h.p.

### 2.8. Rio Turbio Railway 2-10-2 type Locomotives

The Rio Turbio line, 160 miles in length, conveys coal from the Rio Turbio Mines inland to Gallegos on the coast of Patagonia. The line is of 750 m.m. gauge (2 ft. 5½ in.) and is laid with rails weighing 35 lb./yard, which restrict axle loading to 7½ tons. Gradients against coast-bound loaded trains are 0.3% (1 in. 333) and 0.7% (1 in. 143) against trains of empties. Operating problems are accentuated by the very strong winds prevailing in Spring and Autumn in this extreme southern tip of South America, these winds gusting to 100 m.p.h.

To handle mineral trains weighing up to 1,700 tons laden two

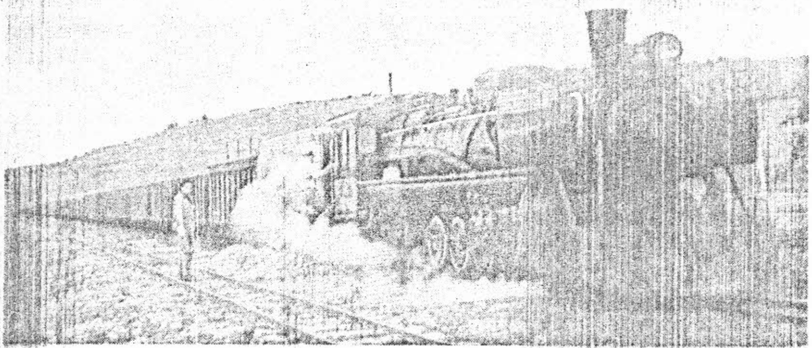

*Fig. 7.—Rio Turbio 2-10-2 locomotive (second series) with coal train of 75 bogie wagons.*

batches of ten 2-10-2 type locomotives have been built by Mitsubishi in 1956 and 1964 respectively, the design being developed from one by the Baldwin Locomotive Company. Total locomotive weight is 48 tons, of which 38 tons is adhesive. Three of the first batch were modified to incorporate the gas-producer combustion system, already applied by the Author to the prototype 4-8-0 locomotive described previously, and the Kylpor exhaust system in place of the conventional circular blast-pipe. These modifications enabled the maximum sustained power at the drawbar to be increased from 700 to 1,200 h.p. and the second batch of locomotives included these and other improvements. The following comments deal with the principal features of the later design.

*Boiler*: Of mixed riveted and welded construction with working pressure of 228 p.s.i., compared with 199 p.s.i. for the first batch. The number of small tubes is reduced from 108 for the first batch to 88 for the second, to increase the proportion of gases passing through the large tubes carrying the superheater elements, which are of standard A type and eighteen in number. Maximum steam temperature is 770-788° F. when working hard.

Boiler tubes are welded to the tube plate and there is no record of tube leakage or replacement of fractured boiler stays, despite wide variation in steam demand and winter temperatures as low as −4° F.

The boiler is secured to the frame by expansion plates with lubricated bronze slides, on which wear has been negligible after twelve years operation. Condition of boilers of the first batch of 2-10-2's after twelve years running suggests that neither boilers nor fireboxes will have to be renewed during the working life of the locomotives.

*Gas Producer Combustion System*: Some 70% of the total air required for combustion is admitted as secondary air above the fire-bed through intake ducts to the sides of the firebox and through the firedoor, which is kept open continuously. Some 3-4% of exhaust steam from the cylinders is introduced into the ashpan for mixing with the primary air, amounting to about 30% of the total. The endothermic action of the exhaust steam cools the firebed to a dull red appearance and enables clinkering to be controlled, such that some forty to fifty hours running can be made without fire cleaning with Rio Turbio sub-bituminous coal. This has an ash content of about 15% and is very friable so that at least 50% is of less than ¼ in. size after one month's exposure to atmospheric conditions[13].

The dull appearance of the firebed with the gas producer combustion system contrasts with the dazzling whiteness of the flames from the firebed, indicating that most of the heat liberation is taking place in the combustion space and not on the grate itself.

An important advantage of the gas producer combustion system is the much reduced unburned fuel loss when working hard, due to the substantially reduced volume of air drawn through the firebed.

Boiler efficiency as recorded on official tests reaches 78-80%, assisted by the use of a long brick arch arranged to prevent carry-over of coal particles entrained by the draught. Combustion is virtually complete and tube cleaning is almost eliminated. The grate is of the Hulson type and the ashpan is self emptying.

With the mechanical stoker used on these locomotives it is not necessary to use the steam jets to distribute the fuel from the delivery table at the back of the firebox. When the engine is working hard the action of the draught is sufficiently vigorous to spread the Rio Turbio slack coal. Under easy steaming conditions occasional shovel firing

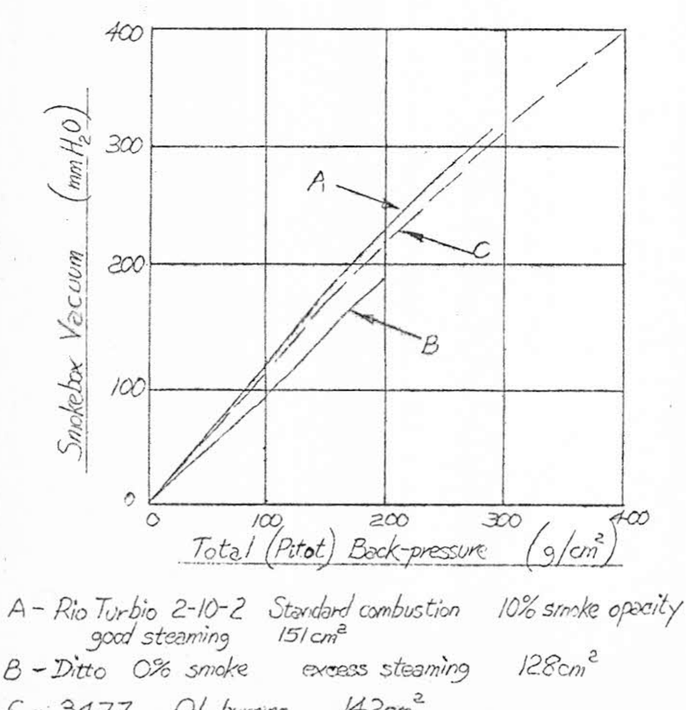


*Fig. 8.—Smokebox vacuum/back pressure characteristics, Kylpor exhaust system.*

to the front of the grate is needed. The avoidance of use of steam delivery jets reduces the tendency to increased unburned fuel loss frequently experienced with stoker-fired engines due to entrainment of coal particles by the steam jets. The steam consumption of the stoker motor amounts to 1-2% only of total steam production.

*Kylpor Exhaust System*: Whilst this is derived from the Kylchap it differs in that the diffuser is of shorter length with wider angle and in the reduced length, with angling of the Kylala exhaust splitter to give some swirling action to the exhaust stream, to obtain maximum performance from the diffuser without losing contact between the boundary layer of the exhaust stream and the diffuser walls. The swirling motion imparted to the exhaust stream also provides a self-cleaning action and obviates the need for self-cleaning plates in the smokebox. In maximum steaming conditions the Kylpor exhaust system of the Rio Turbio 2-10-2's gives a smokebox vacuum of 12.5 in. water gauge with an exhaust back pressure of 4.3 p.s.i. Sustained evaporation rates of about 22,000 lb./hour have been maintained for several hours with this small boiler having an evaporative heating surface of only 950 ft.$^2$ and effective grate area of 22.5 ft$^2$, burning slack coal with a calorific value of 9,000 - 10,000 B.Th.U/lb.

*Engine*: Steel pistons are provided with six narrow piston rings, to standard diesel quality and workmanship. The Fukao gland packings used have given extremely good results and enable steam tightness to be maintained over nearly 200,000 miles running.

Axleboxes are provided with side bearings to deal with piston thrust, wear of about 0.007 in. per 1,000 miles running being taken up by placing shims between bearing and box at periodic inspections every 12,500 miles. Life of bearings is anticipated at over 300,000 miles—an appreciable figure when one recalls the low average running speed of about 15 m.p.h., maximum speed being limited by track condition to 25-28 m.p.h. Axleboxes are spring-pad lubricated.

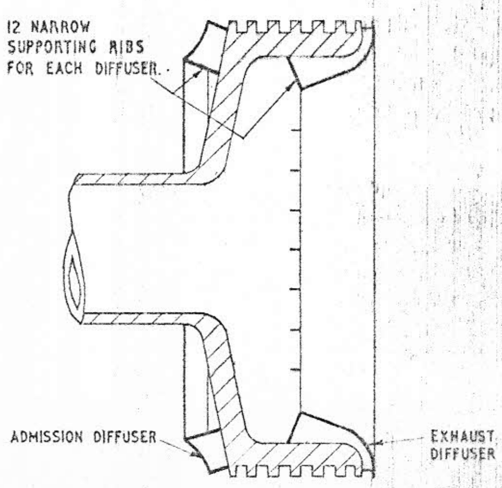


*Fig. 9.—Piston valve with admission and exhaust diffusers for 2-10-2 locomotive, Rio Turbio Railway.*

Lubrication is supplemented by gravity trimming feeds to the lubricating pads. Bronze wedges and horn cheeks are provided which it is anticipated will not require renewal during the working life of the locomotives.

All motion pins are oil tight. Crankpins are provided with hardened steel bushings which wear very little between workshop overhauls. Side rod bearing wear is about 0.02 in. in over 12,500 miles running.

Steam tightness of the whole engine, assisted by a rigid bar frame chassis, is extremely good and after running 25,000 miles in low speed, heavy-duty operation over unballasted track, total steam leakage is not more than 2% of the maximum capacity of the boiler, this figure covering pistons, valves, packings and all steam joints.

*Cyclonic Gas Producer Combustion*: One locomotive of the second batch has been equipped with cyclonic combustion system, the secondary air being directed to give a cyclonic swirling action around the centre of the firebox. The cyclonic swirling action separates and precipitates char otherwise ejected from the chimney and results obtained have been sufficiently encouraging to suggest further development, with the object of maintaining boiler efficiency against the unburned fuel loss which normally increases with firing rate.

*Performance and Service Running*: As mentioned in the Author's introductory remarks these locomotives regularly haul 1,700-ton mineral trains over this 160-mile line with remarkable economy. Specific fuel consumption for the second series is abo..t 2.2 lb./db. h.p./hour, about 20% lower than for the original engines, for mean outputs of about 500 h.p. at the drawbar. With current plans for doubling the output of the mines, it is proposed to improve the track and general alignment and to introduce high-capacity coal wagons to enable 2,500-ton trains to be worked in ordinary service—by one locomotive.

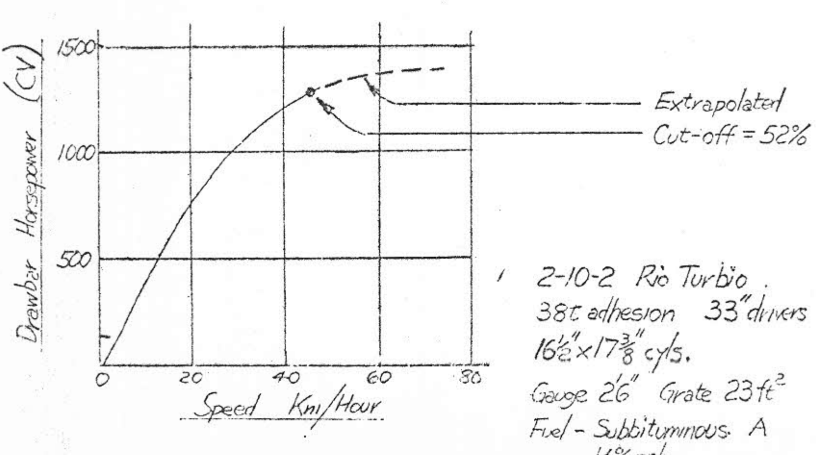


*Fig. 10.—Drawbar horsepower/speed characteristic,* 2-10-2 *locomotive (second series), Rio Turbio Railway.*

## PRINCIPAL DIMENSIONS OF MODIFIED ARGENTINE RAILWAYS LOCOMOTIVES

| Type, Railway and Gauge | Cyls. No. | Cylinders Diameter Stroke in. | Cpld. Wheel. Dia. in. | Work'g Press. p.s.i. | Grate Area ft.² | Effec. F'box Vol. ft.³ | Adh've. Wght. tons | Loco. Wght. tons | Max. Db.h.p. | Db.h.p. /ton |
|---|---|---|---|---|---|---|---|---|---|---|
| 4-8-0 Prototype<br>Metre gauge | (2HP)<br>(2LP) | 14.2 × 26<br>23 × 22 | 50 | 285 | 42 | 200 | 54 | 68 | 2120 | 31 |
| 2-6-4 Tank Roca Railway<br>Light Rebuilding<br>5 ft. 6 in. gauge | (3) | 19 × 26 | 68 | 199 | 29 | 176 | 60 | 95<br>*70 | 1200 | ×17 |
| 2-6-2 Tank Roca Railway<br>Light Rebuilding<br>5 ft. 6 in. gauge | (2) | 19 × 26 | 68 | 175 | 22 | 134 | 50 | 79<br>*58 | 900 | ×15 |
| 2-6-2 Tank Roca Railway<br>Semi-heavy Rebuilding<br>5 ft. 6 in. gauge | (2) | 19 × 26 | 68 | 192 | 22 | 134 | 50 | 80<br>*58 | 1400 | ×24 |
| 4-6-2 Belgrano Railway (ex P.B.A.)<br>Light Rebuilding<br>Metre gauge | (2) | 18 × 26 | 54 | 185 | 26 | 124 | 41 | 56 | 1050 | 19 |
| 4-8-0 Roca Railway Type 11C<br>Light Rebuilding<br>5 ft. 6 in. gauge | (3) | 19 × 22 | 54 | 213 | 29 | 176 | 64 | 84 | 1400 | 17 |
| 4-6-2 ex Santa Fé Railway<br>Semi-heavy Rebuilding<br>Metre gauge | (2) | 18¼ × 20 | 50 | 199 | 24 | 100 | 27 | 48 | 1000 | 21 |
| 4-8-2 Belgrano Railway<br>Light Rebuilding<br>Metre gauge | (2) | 19⅜ × 24 | 50 | 199 | 44 | 210 | 56 | 82 | 1300 | 16 |
| 2-10-2 Rio Turbio Railway<br>Second improved series<br>2 ft. 5½ in. gauge | (2) | 16½ × 17⅜ | 34 | 228 | 23 | 125 | 38 | 48 | 1200 | 25 |

NOTE: *For comparability of power/weight figures, an equivalent weight is given for tank engines, with weight of side tanks, etc., deducted.

## 3. POSITIVE EXPERIENCE AND LESSONS LEARNED FROM ARGENTINE LOCOMOTIVE REBUILDING

Whilst substantial improvements have been made in the performance and efficiency of the various locomotive types referred to in Section 2, the Author would stress that the results were obtained after much hard work in overcoming defective design details and in the face of a difficult labour situation, with a general shortage of skilled fitters and enginemen. The Author feels that the following conclusions may be drawn.

(*a*) Whilst a profound knowledge of the theory of thermodynamics and of mechanics and their application to steam locomotive design is essential for progress to be made, equally one must have respect for existing design practice which is an amalgam of more than a century of experience. Modifications to existing designs, therefore, must be limited to essentials with the minimum number of detail changes to achieve these.

(*b*) High thermodynamic performance can be combined with good, robust and trouble-free mechanical design.

(*c*) Accessibility of mechanism and ample bearing surfaces are essential.

(*d*) Engineering must take into account the operating and maintenance personnel who will handle the machine. Nowadays, alas, there are few highly skilled drivers (such as the workshop-trained French main line drivers whose theoretical knowledge and practical skill enabled them to get maximum performance from their locomotives with minimum fuel consumption) and few skilled fitters, especially in the under-developed countries. Any new or modified equipment must, therefore, be simple, robust and fool-proof.

(*e*) In any rebuilding or modification to existing locomotives it is essential for a careful review to be made of the detail design to ensure that existing mechanical defects are dealt with. This must be done, by, or in conjunction with experienced engineers with practical knowledge of service and maintenance performance of the locomotives to be modified.

(*f*) Design work should take into account the prevalent state of maintenance, personnel and training.

(*g*) Performance should be calculated with allowance for run-down condition.

(*h*) Materials used should be those normally obtainable and in common use.

(*i*) In meeting the requirements of the customer, i.e. the operating department, for improved performance one must bear in mind the local conditions which may preclude adoption of the most refined design solutions.

## 4. PROPOSED LOCOMOTIVE DESIGNS

From the results of the Author's work in Argentina, in particular with the Rio Turbio 2-10-2 locomotives, which have combined simplicity in design with exceptional tractive performance, high Rankine cycle efficiency and minimal maintenance, basic designs have been prepared for a general-purpose 2-8-0 type locomotive taking into account the points already mentioned in Section 3.

In the Author's view there are many countries where there is still extensive use of steam power based on local availability of cheap lower grade fuels and scope for the introduction of modern steam locomotives combining a high level of thermodynamic performance and tractive capacity with strength and simplicity in design and construction. Furthermore, one must consider the rapid growth in consumption of petroleum products which many experts predict will result in scarcity within twenty or thirty years and which may make desirable the use of alternative fuels where available for applications such as rail traction.

In preparing this project which, in the Author's view, represents a new approach to steam locomotive design, the Author again acknowledges his indebtedness to M. Chapelon through whose exhaustive research work and analysis sufficient data is now available to enable close predictions to be made of the behaviour of theoretically designed mechanisms based on exact knowledge of every function of their operation. Steam locomotive design need no longer be based solely on practical experience and often vague empiricism[14].

**Objectives of New Design**

(*a*) Highest possible power/weight ratio.

(*b*) Minimum fuel consumption on an annual basis in service conditions.

(*c*) Maximum "spread of performance" over the operating speed range.

(*d*) Maximum service speed compatible with two-cylinder construction and 2-8-0 wheel arrangement.

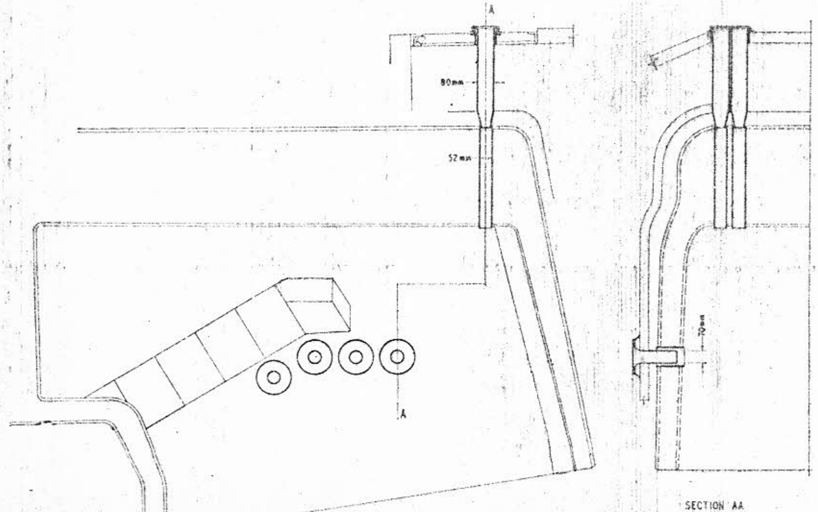


*Fig. 11.—Secondary air admission to firebox for gas producer combustion system, 2-10-2 locomotive, Rio Turbio Railway. There are four intakes in firebox crown and four in each side.*

(*e*) Maximum simplicity of driving and maintenance.
(*f*) Mechanical firing to deal with very low grade coal or wood fuel.
(*g*) Continuous running without servicing for at least 1,200 miles.
(*h*) Maximum use of internationally available components and accessories.
(*i*) Basic design to suit the widest possible range of loading and track gauges—the latter from 3 ft. to 5 ft. 6 ins.
(*j*) Axle loading for 2-8-0 design not to exceed 13 tons for gauges between 3 ft. 0 in. and 3 ft. 6 in. and those lines having severely restricted axle loads. For standard and 5 ft. 6. in. gauge lines with 17/18 tons axle loading the 2-6-0 wheel arrangement could be used.

**Brief Description of Proposed New Design**

The basic design of 2-8-0 type locomotive is a two-cylinder compound with inside cylinders and piston valves actuated by rockers from external Walschaerts gear, following the practice of the "624" Class locomotive of the Italian Railways. The boiler, working at 285 p.s.i., incorporates a gas producer firebox and is stoker fired. The boiler unit incorporates, on the same horizontal axis, high and low pressure superheater units and an economiser. An exhaust steam feedwater heater is fitted. Using fuel with a calorific value of about 9,000 B.Th.U. per lb. the Author calculates, on the basis of previous experience, an evaporation rate of 11 tons of cold water per hour at 75% of full load. This would enable the locomotive to sustain a power output at the drawbar of about 1,800 h.p. in the speed range from 30 to 70 m.p.h. at 75% full load. This level of power output could be relied upon in service, therefore, taking into account the substantial margin to cover all reasonable variations in mechanical condition, maintenance and handling.

Locomotive weight would be 59 tons in working order. The bogie tender would carry sufficient water for two and a half hours operation at full power and would weigh about 18 tons empty and 52 tons fully laden.

Various alternatives are possible within the general framework of the proposed design.

An outside-cylinder locomotive could be produced but inevitably would be slightly heavier and would be subject to greater inertia forces. Furthermore, radiation losses are higher with two outside cylinders compared with two cylinders mounted between the frames.

If simple expansion drive is adopted in place of compound drive fuel consumption is likely to increase by 10%-15% due to the effects of increased clearance volume with the large steam passages essential if high power outputs are to be obtained without throttling, also due to increased condensation losses.

*Boiler*: The cyclonic gas producer combustion system would be used, as described already in connection with the Rio Turbio 2-10-2 locomotives.

The secondary air for combustion, in quantity up to 60% for low volatile coal and up to 80% for wood, would be sucked into the firebox through ducts to give a horizontal cyclonic swirling action around the centre of the firebox. Whilst this swirling action could be

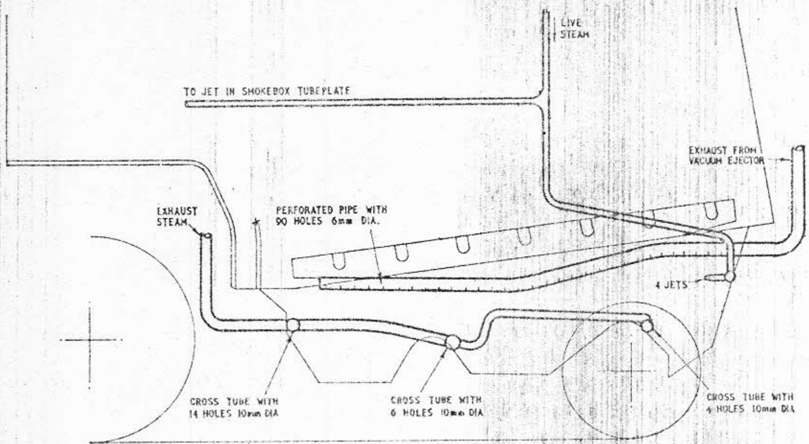


*Fig. 12.—Arrangement of jets supplying exhaust and live steam below firegrate to prevent clinkering, 2-10-2 locomotive, Rio Turbio Railway.*

established in a rectangular or square firebox of normal type, a circular form would be preferable to minimise gas stream losses in the rectangular corners of the conventional design. The best type of construction, to give maximum length of cyclonic path for a given pressure drop, would be a truncated cone.

The boiler would be of welded construction throughout and no special flanging arrangements would be necessary at the junction with the firebox. Use of the Belpaire construction of firebox permits a close estimate of metal stresses likely to be developed in service, particularly on boiler stays.

The boiler would be attached to the chassis by four vertical expansion plates and front-end connections. This system leaves the main body of the boiler free to expand whilst still acting as an integral stress bearing member of the complete structure, giving adequate rigidity against flexure and torsion.

The maximum designed steam temperature is 770° F. and the anticipated exhaust temperature from the h.p. cylinder is 520° F. The low pressure superheater, through which steam would pass after leaving the h.p. cylinder is calculated to raise this temperature to 630° F. before admission to the l.p. cylinder. Both h.p. and l.p. superheater units consist of cylindrical drums with tubes welded to two tubeplates and bolted to each other and to the main boiler body. The tubes could be of ordinary, Serve or Ess type. The chamber between the boiler and the h.p. superheater is provided with aerodynamically shaped deflecting screens to equalise flow and to lessen pressure drop.

*Boiler Feed Equipment*: Normally the boiler feed water would be delivered by a mechanically-driven pump, driven either from the crosshead or from a plunger connected to the piston tail rod, to an exhaust steam surface type feed heater and economiser giving a final

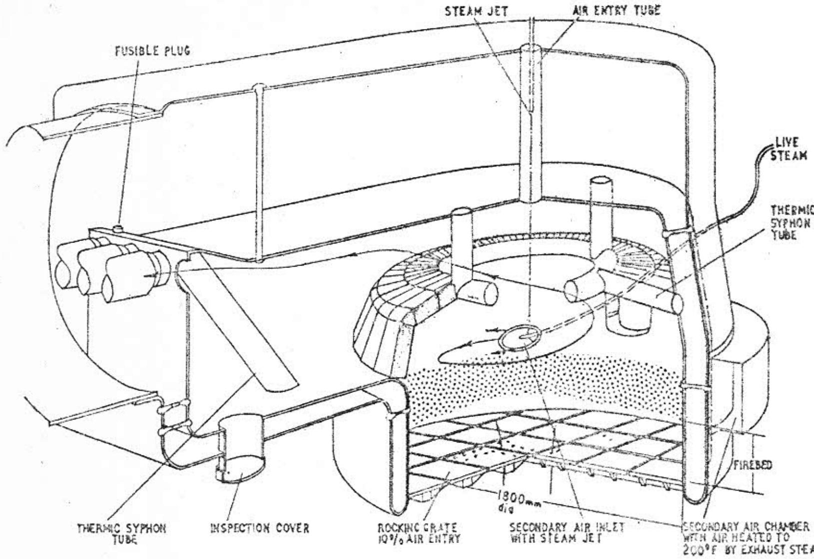


*Fig. 13.—Circular form cyclonic gas producer firebox.*

feed water temperature in the region of 264° F. under full power conditions. A live steam injector would be provided also, which would deliver feed water to the surface heater.

Regulation of the feed pump would be by cavitation, controlled by the admission of exhaust steam on the intake side. This would provide some initial heating of the feed water.

The economiser would be of similar general design to the superheaters, the hind tube plate being bolted to the front tube plate of the l.p. superheater whilst its front tube plate is welded to the smokebox as in an ordinary boiler. The feed water path in the economiser would give maximum counterflow with the gas path, with the aid of internal baffling.

From the thermodynamic viewpoint the proposed economiser would have the same function as the Franco-Crosti feed-water heater but with gas pressure drop reduced to a minimum. Scaling and corrosion on the water side can be controlled with adequate water treatment. Gas side corrosion could be dealt with by using stainless steel, copper or enamelled tubes in the economiser. Gas temperatures at the front end of the economiser will be around 392° F. in service[15].

By comparison with the single-body Franco feed heater, the economiser does not inhibit the use of the boiler as an integral stress bearing member of the chassis structure, the lack of which resulted in frame fractures when the former device was used in Germany. Troubles experienced from sulphuric acid formation in the smokebox, due to low exit gas temperatures, are also avoided and boiler layout is simplified.

A further advantage of the economiser mounted axially with the boiler, in comparison with the Franco heater, is that the layout of the steam and exhaust piping is not inhibited and one can observe the golden rule cited by M. Chapelon 'the design of the front end of a locomotive should start with the layout of its exhaust system'.

*Exhaust system*: The Author proposes the use of the Kylpor exhaust system derived from the Kylchap and already described, which has a pumping efficiency up to five times higher than many conventional circular blast pipes. A further development in the Kylpor exhaust is the use of twin concentric exhaust connections to the exhaust nozzle, the inner being connected in the usual manner to give a strong draught during release whilst the outer pipe offers a larger section for an easy exhaust during the return stroke of the piston to utilise the otherwise lost energy available in the incomplete expansion toe of the indicator diagram.

The Author would stress the importance of improvement in exhaust systems and the need for the highest possible pumping efficiency on which the maximum steaming capacity of boilers depends. He does not wish to dogmatise on the merits of the Kylpor system to the exclusion of others and is well aware of the notable results achieved also, and on a widespread scale, with the Giesl oblong ejector designed by Dr. Giesl-Gieslingen[16].

*Connections from Smokebox to Cylinder Block*: The use of modern systems of controlled water treatment should make removal of the boiler a very rare occurrence. In France experience with the T.I.A. system, which has reduced boiler maintenance costs by up to 90% in bad water districts, has shown that where boilers have been on controlled treatment from the outset this operation may not be necessary throughout the economic life of the locomotive. It is thus possible to use an entirely welded construction for the connections from the smokebox to the cylinder block with a single steel fabrication performing this function[17,18].

*Cylinder Block Insulation*: Special attention has been paid to combating the high radiation losses occurring during intermittent and low speeds operation—M. Chapelon has cited the case of a two-

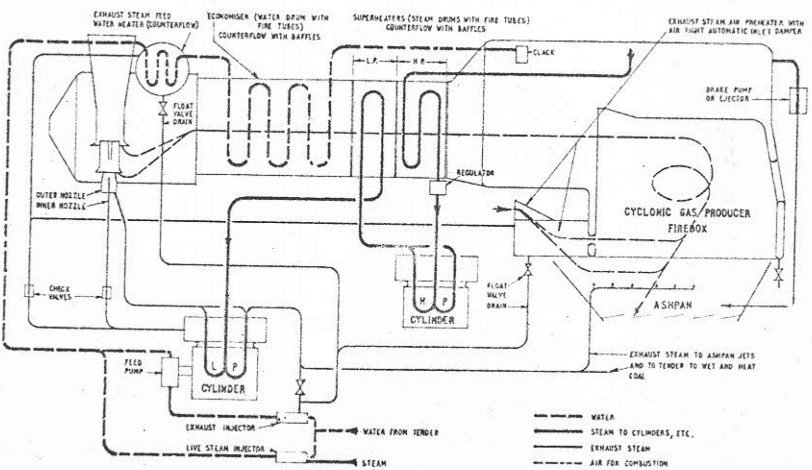


*Fig. 14.—Thermodynamic flow diagram, proposed 2-8-0 locomotive.*

cylinder locomotive in which heat energy equal to one half of that converted into useful work in the cylinder was dissipated in heat transfer to the wall at a running speed of 12 m.p.h.[10].

*Engine Unit*: To secure maximum efficiency in working it is proposed to use two-cylinder compound drive, which has been successfully applied to many locomotives operating in Argentina and elsewhere. At starting a jockey valve on the regulator would admit live steam at reduced pressure to the receiver supplying the low pressure cylinder. The ratio between high and low pressure cut-offs would be fixed, as in recent French compounds of high Rankine cycle efficiency, and driving method would be similar to that for simple expansion machines.

The piston valve chests would be of ample volume, following the recommendations of M. Chapelon, to ensure the maximum degree of pressure equalisation in the steam feed, thus taking full advantage of steady steam chest pressure at the end of the admission period. This important feature of design permits the use of a fairly high piston speed.

The proposed piston valve unit follows the design applied successfully on the Rio Turbio 2-10-2 locomotives. The valve bodies would be lightweight fabrications connected to the valve rods by articulated joints. Valve travel and lap would be the maximum practicable to give the best possible steam flow in maximum working conditions. Piston valves and rings would be of the same materials and accuracy of finish as those used in diesel engines to reduce steam leakage to a minimum, i.e. about 2% of maximum boiler evaporation even in run-down condition. The use of ring materials of the Koppers type, following American practice with some rings of bronze with steel expansion pieces, would maintain near perfect steam tightness over a long period.

The same basic valve would be suitable for both high and low pressure cylinders, with necessary variation in machining of port openings.

Special attention would be paid to the design of all valve gear

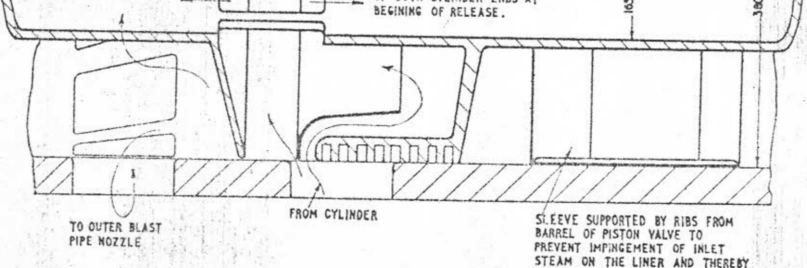


*Fig. 15.—Piston valve for L.P. cylinder with divided exhaust and diffuser, proposed 2-8-0 locomotive.*

components to reduce the weight of reciprocating masses to a minimum. The same considerations would apply to pistons, piston rods and connecting rods. The piston unit would be of low-alloy steel with hollow piston and tail rods screwed together, following French practice. The pistons, also of 'Diesel Quality' would carry ten narrow rings of 8 mm. axial thickness for the high pressure and seven of 10 mm. for the low pressure.

The crank axle would be of the built-up and fully balanced type of generous design with web thickness about 70% of pin diameter.

The distance between axes of cylinders would be kept as low as possible to increase the space available for main axlebox bearings. Thus, if plain bearings were used the pressure could be kept to a minimum, with figures of the order recommended by E. S. Cox[20].

The crank axle would be located close to the centre of oscillation of the locomotive, which should ensure that it would be virtually free from lateral forces due to track irregularities.

The axleboxes would be suitable for roller bearings, those for the crank axle being of the self-aligning type to accommodate flexure under load. The working faces of axleboxes would be fitted with manganese steel liners and automatic wedge adjustment of the Franklin type could be provided if desired. An alternative to roller bearings would be the plain type bearing developed in Rio Turbio from the German Mangold type, where the mileage between overhauls is about 120,000.

*Frame Structure*: Bar type frames would be used to give the greatest accessibility and rigidity, the latter assisted by participation of the boiler in resisting torsion and flexure. The frame would be of mild steel, machined all over and strengthened by diagonal fabricated members. Corners would be of ample radius to keep down stress concentration and horn stays would have large bearing surfaces against the frame legs to counteract wear at these points. Loose alloy steel bolted connections would be used with a minimum of at least 40% margin above minimum requirements, with possible loading by Belleville spring washers. Experience with the Rio Turbio 2-10-2's shows that loose bolts are completely unknown with this arrangement.

The alternative frame arrangements for inside and outside wheels are shown, inside wheels being required for narrow gauges of from 36 in. to 42 in.; whilst wheels would be outside the frames for track gauges between 4 ft. 8½ in. to 5 ft. 6 in. The distance between main frame longitudinal members would differ slightly for the two alternatives but substantial standardisation would be possible for axleboxes, spring gear, ash pan, etc.

*Cab and Running Platform*: The cab would be mounted on the boiler giving easy accessibility to dragbox and drawgear below and greater comfort to the crew due to reduced transmission of vibration. The ample thickness of boiler insulation provided would also protect the crew from discomfort in tropical conditions. As much of the pipework as possible including steam manifold and ejector, would be mounted outside the cab with the same object in view.

Weight-saving would be assisted by the use of aluminium alloy for the cab structure and running platform and of light alloys wherever possible for components which are not designed to high strength limits.

*Lubrication*: Whilst it is proposed that the maximum number of main working points should be fitted with roller bearings (i.e. axle-boxes and running gear), it is not possible completely to eliminate points needing regular lubrication. The Author suggests that such lubrication should be from trimming boxes of ample capacity and simple flat design in preference to mechanical lubrication, which is more costly and requires additional maintenance. If plain bearings are used on the running gear oil needle trimmings with large capacity reservoirs could be fitted on the rods whilst stationary trimmings would be used for the crosshead slippers, following the principle of reducing to a minimum the number of oil reservoirs located on moving parts. The trimming boxes would be grouped together, thereby simplifying routine preparation of the locomotive.

Cylinder and valve lubrication would be from a force feed pump with ratchet and pawl drive, which could be adjusted as necessary from the cab. This system used in conjunction with the type of piston valve used at Rio Turbio enables steam temperatures up to 842°F. to be dealt with. This is assisted by the use of exhaust steam to cool the valve body, of saturated steam to cool the valve liners

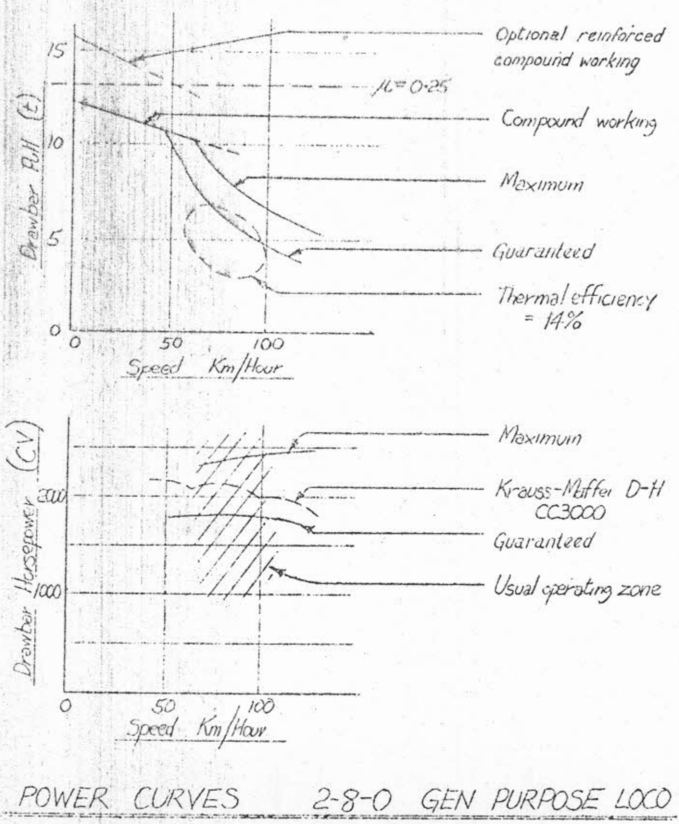


*Fig. 16.—Power curves, proposed 2-8-0 locomotive.*

and the complete exclusion of any oxygen or smoke box gases from the valve chest when operating with closed regulator.

*Performance*: As mentioned previously the locomotive should be able to sustain a power output of 1800 h.p. at the drawbar from 30 to 70 m.p.h. at 75% load using fuel with a calorific value of about 9000 B.Th.U./lb. Optimum thermal efficiency at the drawbar would be about 15% in these conditions and an average figure of 13% would seem reasonable to cover normal variations in operating conditions and maintenance. This latter figure differs somewhat from the thermal efficiency of 5% or so normally conceded to the steam locomotive by its critics!

Special measures are taken in this design to reduce standby losses to a minimum—an aspect of locomotive design which has received far too little attention hitherto—to raise the all day overall efficiency and to reduce fuel costs. The bottom of the ashpan would consist of overlapping elements giving virtually complete closure when required, in which condition standby losses would be limited to those of boiler radiation only, which, with improved boiler insulation would amount to about 2% of maximum heat consumption. Self-emptying facilities would enable the ashpan to be cleared in 30 seconds.

The use of a modern system of controlled internal water treatment reducing boiler washouts to from six to 12 only per year, in place of one every three to seven days previously in bad water areas, will materially reduce the losses involved by this operation.

*Annual Fuel Consumption and Thermal Efficiency*: The Author has carried out calculations on the assumption of 2500 hours annual operation under power at an average output of 1400 h.p. at the drawbar with an average thermal efficiency of 13%. With fuel of 9,000 B.Th.U./lb. this would involve an annual fuel consumption of 3400 tons. A careful calculation based on practical experience, of fuel consumed when standing in steam, light engine running, lighting up after washout and uphill working loss (i.e. tractive power absorbed in moving the locomotive against gravity) and kinetic energy losses in braking gives a total of 1000 tons of fuel for these purposes. The overall thermal efficiency at the drawbar utilised for traffic purposes therefore would be $\frac{13 \times 3400}{4400} = 10\%$.

## CONCLUSIONS

It is extremely difficult to assess the general validity of economic studies between different forms of motive power based on fuel, labour and maintenance costs and conditions, also capital charges, in any one country. Furthermore, the governing factors in choice of type of motive power in under-developed countries may be quite different from those applicable to highly industrialised countries where adequate finance at reasonable rates of interest and highly-skilled maintenance staff are available. Even in the United States, the overall economies anticipated with dieselisation have been virtually counterbalanced by excessively high depreciation charges due to the short economic life, and frequent replacements, of major component units.

In under-developed countries which lack finance for heavy capital investment but which have adequate indigenous fuel supplies, often of low quality, and where skilled maintenance staff are at a premium, steam is often the most suitable and economic form of traction. A further important factor in these countries is the social necessity of providing adequate employment, rather than the economic necessity in industrialised countries to reduce staff to a minimum. These points were brought out clearly in a paper to the Conference on Industrial Development in Athens in 1967.

A survey taken at the end of 1965 quoted a world total of about 75,000 steam locomotives which may surprise many members in Great Britain where steam traction has been abolished on British Railways. The existence of this very substantial number of steam locomotives, which still form the bulk of motive power on many railways, with new locomotives still being built in China, India and South Africa, gives relevance to this Paper in which the Author has briefly given an account of steam locomotive modernisation in Argentina and of a locomotive project representing a new conception of steam locomotive technology applicable to under-developed countries.

**Acknowledgments**

Finally, the Author is happy to acknowledge the suggestions made and help given in preparation of the Paper by his friends, Messrs. Chapelon, Poissonnier, Vuillet, Cantlie, Carling and Carpenter, also by Mrs. Tabern and Mr. Bacon of the Manchester Centre.

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Broken stays: Nil in 400000 km.
Tube repairs: 10% in 400000 km. longitudinal cracks attributable to too strong expanding. Tubeplate leaks: Nil in 400000 km.
Grate elements: Replacement 10% in 400000 km.
Stoker: Nil maintenance in 400000 km.
Ashpan: Nil repair in 400000 km.
Springs: Change one every 30000 km.
Coupling gear: No repairs in 400000 km.

**Comments**

Water quality is medium, about 15° F. hardness. Dearborn water treatment is used. Boiler washout is every 5000 km.

Locomotive lubrication is standard by trimmings; motion is oil lubricated; boxes by underkeep packing. Cylinder lubrication is by condensing lubricator (Detroit model).

Boilers should never be detached or separated from frames, therefore no general repairs are programmed.

Locomotives operate on pooled rosters. Track condition is poor. Repairs are carried out on preventive maintenance shedules similar to those of the SNCF.

Locomotive details are of standard design and usual materials are embodied.

## DISCUSSION

**Col. K. Cantlie** (M.) said that the members had listened to a remarkable Paper which showed what one man could do to develop and improve the steam locomotive.

The Paper fell into three sections; first, the thesis that steam was the most suitable form of motive power in much of The Third World; second, the improvements that Senor Porta had made to existing steam locomotives; and third, the Author's plans for new steam power.

It was nowadays often said that a gap was widening between the advanced countries and the rest of the world. This was true, and in the technological sphere much modern equipment was too complex and expensive to suit The Third World. Diesel locomotives were an example of this. They were being forced on The Third World by propaganda and financial incentives, yet in many countries there was a chronic shortage of skilled diesel and electric fitters because they could always get better-paid jobs in garages and power houses once the railways had trained them. As a result the maintenance standards of diesel locomotives fell, failures increased and there was a fall in availability. Then there was the vexed question of spare parts. Overseas railways with well-equipped workshops could make nearly all the spares for their steam locomotives, but they could not make the numerous and sophisticated spare parts for diesel engines, for even British Railways jibbed at making such spares. The largest manufacturer of diesel locos. had given out the slogan to The Third World "The steam locomotive is a relic of colonialism—abolish it and you are free". The very contrary was the truth. Once an Overseas railway had obtained diesel locomotives, it was shackled to the manufacturer for the life of the locomotives. This was not only very irksome to nationalistic sentiment in the emergent countries, but most of them had great difficulty in getting allotments from their Governments of scarce foreign exchange to pay for such spares. Previously it was believed that these difficulties were temporary, but they were, if anything, growing worse.

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23. "Rationalisation of Railway Operation by Improving Efficiency of Steam Locomotives", Paper No. E.19 to International Symposium on Industrial Development. Athens, 1967.
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## APPENDIX

**Rio Turbio (Argentina) 2-10-2 Locomotives**

**Typical Wear figures**

Due note should be taken that these engines have 2 ft. 10 in. wheel diameter and run over a rail with 1¾ in. head, 34 lb./yard. Train weight is usually up to 1,700 tons.

| Item | Km. $10^3$ | Wear mm. | Repair |
|---|---|---|---|
| Tyres | 80 | 10 | Turning |
| Driving crankpin ovality | 40 | 0.4 | Filing |
| Main coupled crankpin ovality | 40 | 0.15 | Filing |
| Valve gear pins, play | 80 | 0.3 | Change |
| Little-end pins | 10 | 0.2 | Grinding |
| Little-end brasses | 10 | 0.4 | Take up |
| Big-end brasses | 10 | 1.0 | Take up |
| Main coupling rod bush | 20 | 0.8/1.2 | Change |
| Coupling rod bushing | 20 | 0.8/1.2 | Metalling |
| Spring pins, play | 80 | 2/3 | Change |
| Driving journals | 80 | 0.3 | Grinding |
| Axlebox lateral play | 80 | 3 | Remetalling |
| Axlebox radial play, total (new series have take up facilities, making remetalling necessary every 400000 km) | 80 | 0.3 | Remetalling |
| Link block play | 80 | 0.2 | Change |
| Crosshead slippers | 40 | 6 | Remetalling |
| Slidebars | 200 | 0.3 | |
| Piston rod ovality or "coning" | 80 | 0.5 | Grinding |
| Piston rod packing: Change every 400000 km, file every 40000 | | | |
| Piston ring openings | 80 | 6 | Change |
| Piston valve ring openings (Measured piston leakage shows no change over period) | 80 | 3 | Revision |
| Valve liners | 40 | 0.3 | Turning |
| Cylinder linings | 200 | 1.8 | Turning |
| Superheater elements (No replacement in 500000 km) | 80 | | Revision |
| Steam pipe joints: No leaks in 400000 km | | | |
| Regulator valve | 80 | | Grinding |
| Safety valve | 80 | | Grinding |

Another point the Paper mentioned was that many emergent countries had cheap, indigenous coal and wood supplies usable on steam locomotives. They required more labour to handle them, but, unlike many sophisticated countries, this was a positive advantage for many emergent countries which had acute employment problems.

Now that the tumult of propaganda was dying away and comparative statistics over 15 or 20 years were becoming available, it was becoming clear that there was scope for all forms of traction—steam, electric, diesel and gas turbine. Railways should be objective and be guided by facts and not by propaganda or prejudice. India and China were still building steam locomotives in large numbers because they found them better suited to certain conditions in those countries, and many other countries would do well to note this.

Col. Cantlie congratulated the Author on his successes, especially on the gas producer firebox. He himself had been dubious about this, but there was now no doubt of its success, with Rio Turbio coal at least. It should be tested with other coals to see if they were equally successful. As to the principle of admitting a high percentage of air above the fire, he was glad to see Mr. Roscoe and Mr. Cunliffe present because they and he had co-operated on N.C.B. locomotives at Walkden (near Manchester) in doing this very thing in order to abolish smoke and thus render steam locomotives suitable for smokeless zones. Giesl ejectors had provided enough draught to permit the use of six 3½ in. dia. hollow stays to admit air above the fire which eliminated smoke when working, even on 1 in 38 grades. Mr. Roscoe and Mr. Cunliffe had evolved a secondary air system by which steam jets blew air into the firebox and thus eliminated smoke while standing or moving slowly. He recommended to the meeting an examination of these locomotives.

His only comment on the Author's new design was a doubt as to the advisability of making the boiler immovable as he thought this might increase the time necessary for general repairs. He himself had evolved what he called 'The Zip-on boiler', which could be removed or applied to the loco. chassis in about 15 minutes. The main steam pipes, for example, would be fitted with sectioned screw joints, while the controls from the cab would be either chassis-mounted, partly on a false face to the boiler face-plate, or be easily detachable. He would be glad to give Mr. Porta more information about this at any time. There were numerous advantages in an easily detachable boiler.

**Mr. W. G. F. Thorley** (*Member of Council*) said that he was intrigued by the reference which the Author had made to the locomotive which could only be driven as the designer intended and he wondered if the Author would expand his remarks on that theme.

Mr. Thorley asked what arrangements were fitted in the 2-cylinder compound locomotive to enable it to start if the high pressure crank stopped on or near a dead centre.

**Mr. D. A. Hawkins** (A.M.) noted that the locomotive had a stream-lined casing and yet the speeds concerned were not high. Was the casing added to reduce the heat losses?

He noted that all the locomotives had long chimneys and petticoats with the blast pipes set in the bottom of the smokebox and all the locomotives had small-diameter boilers. Did the Author believe that his system could be accommodated within the B.R. loading gauge or that European boilers were of too great a diameter?

**Mr. N. Dudley** (V.) said he wished to confirm the statements which the Author had made about the Rio Turbio Railway. He had been engaged on a study of the railway three years earlier, and had actually driven one of the locomotives (very badly) with the Author as a very good fireman.

On a more general aspect he wished to enlarge on the points made in the Paper concerning fuel supplies in under-developed countries. The rate of growth of world oil usage was now so fast that the rate of discovery of new oil-fields was having difficulty in keeping pace and there could well be the signs of shortage within our life-time. In any case the new oil-fields were becoming more remote, more difficult to work and hence more expensive, so that the time might come when the large reserves of coal, known to exist in various parts of the world, would again become competitive. Many of these coal-fields were not developed because of transport difficulties, and new railways would be required in some cases.

The United Kingdom has much to offer in such development, in both the techniques of mining and transport, but often political difficulties prevented this British expertise from being effectively used. Such a case had recently occurred in Central Africa, where work had been given to French consultants.

The need for efficient transport to complement the mining development was apparently not appreciated in the early days of the Rio Turbio coalfield. This is located about 150 miles from the port used for ship-loading, and originally there was no railway and a poor road. Coal was transported by a fleet of Sentinel coal-burning, steam-driven road vehicles; but their effectiveness was severely limited by the amount of coal they consumed on the downward full and return empty journeys, leaving very little to be loaded on ship. Two of these interesting vehicles were still serviceable about a year ago, while the railway is described in the Paper.

Political considerations have also hampered the effective expansion of the Rio Turbio coalfield, while there are stated to be other sizeable coal reserves in the southern part of South America. However, the position of the frontiers in this part of the Continent seems to prevent their fully integrated development. At present a team of United Kingdom mining and transport engineers is advising on more effective production of the coal, so that there will be an assured supply for the railways in northern Argentina, where Mr. Porta will, no doubt, do his best to see that it is used as efficiently as on any railway in the world.

Finally, it is worth remarking that this very important Paper is being read on the day that the Queen is opening the first new major railway to be built in Britain for some sixty years. (The Victoria Line, London Transport Board—Ed.)

**Dr. Hedley** (V.) said that he was a lecturer in Fuel Technology and Chemical Engineering at Sheffield University and was not a particularly keen railway enthusiast nor was he a member of this Institution. However, from July to December, 1967, he had the pleasure of working with the Author in Argentina as a United Nations technical expert advising on fuel research policy. The combustion of Argentine coal was one of the problems discussed and it was through this that he had been able to see at first hand the cyclonic combustion system and locomotive operation at Rio Turbio in Patagonia. Although he was not a "railway man" he had been very impressed by the Author's work and indeed by the enthusiasm that the Author was able to generate and sustain in all the men who worked with him on the locomotives. Dr. Hedley showed several colour slides of the 3000-ton train on the 75 cm. track in Patagonia burning the very friable Argentine coal without smoke formation. These photographs of the ¾ mile long train were impressive evidence of the work reported by the Author in his Paper.

Dr. Hedley concluded by saying that he was convinced that steam traction still had a part to play, especially in the developing countries where indigenous fuels could be used and where capital investment was expensive. Current research interest in the steam-powered automobile could well further interest in steam locomotives of advanced design for railway operation in countries where legislation against atmospheric pollution (especially from internal combustion engines) is imminent.

**Mr. D. W. Harvey** (A.M.) asked what method the Author adopted to prevent the gases of combustion being drawn down the blast pipe and damaging the very highly finished valves that he uses. He also asked if drivers have any difficulty in shunting one of these suburban tank engines which has the enlarged steam chest.

**Mr. G .C. Marsh** (M.) said that he was particularly interested in the boiler feed proposals described in the Paper in which the Author advocated crosshead-driven feed pumps in conjunction with high feed-water temperatures, which would preclude the use of injectors. Such pumps were used in the early days of railways but were abandoned in this country and elsewhere 60 or 70 years ago because they were troublesome. They were replaced by injectors or, on locomotives fitted with feed water heating equipment, by independent steam-driven "Weir"-type feed pumps which, of course, were only operated when actually required.

He asked if the Author had any special reasons for reviving the long-stroke crosshead-driven pump and pointed out that, when a locomotive was coasting at speed, no feed might be required for a considerable time during which there was surely a danger of the pump thrashing about, causing rapid wear and high maintenance charges.

**Mr. H. B. Marshall** (M.) said he had had the privilege and pleasure of having worked for some 30 years on railways serving some of the developing countries. During this time he had had experience of locomotives fired by wood fuel, coal and oil fuels. All of these could give good results, with differing convenience in use. When he left about a year ago, approximately 75% of the mileage was still being run by oil-fired locos, a high proportion of which were less than 16 years old and most of which were fitted with the Giesl ejector and other modern improvements. There is little doubt they could continue to give good service for many years yet, possibly with improved performance—given the will to keep them running. This is not always an easy matter, in fact it proves increasingly difficult. Despite local workshop and manufacturing facilities, invariably some items have to be imported. In his own experience, for instance, boiler and superheater tubes, some steel castings and certain proprietary articles were cases in point. Cost of some imported items had risen by as much as 400% and for deliveries to be in excess of 12 months was not uncommon. Again, it is often difficult to find a manufacturer really willing to produce the relatively small quantities of each item required. In addition, much expertise was being lost as local Governments understandably put on the pressure to localise staffs.

Col. Cantlie's remarks regarding sales talk had caused some amusement, but there was a deal of truth in what he had said. Visiting representatives and 'experts' from overseas invariably concentrated on the virtues of other forms of traction, often understandably. If steam is mentioned at all, the impression usually given is that it is outmoded. This impression (he thought) is heightened when local officers of such Railways visit the 'Developed' countries by invitation, when excellent itineraries and courses of instruction are laid on for them, again invariably with a diesel or straight-electric bias. No such officer visiting UK for instance could have formed a good impression of the steam loco. in its last years as he travelled around the country. In his experience the 'developing' countries earnestly desire to be as up to date as possible in their equipment; the image of the steam locomotive does not fulfil this desire, it is a relic of the past which should be replaced as soon as possible. Additionally, after-sales and spares services offered by the diesel manufacturers are usually good (in his experience anyway), finance on advantageous terms can be made available, and maintenance staff can be recruited to fill the gap whilst local men are being trained, or there can be a maintenance contract. Against this background he felt, rather sadly, it would be extremely difficult to change the steam image at this stage despite any technical improvements possible.

He had three questions to ask: —

i) Was the load hauled by the metre-gauge 4-8-0 four-cyl-compound a test load or was it being achieved in normal service?

ii) Arising from this, is the load related to level track?

iii) The Author has not mentioned shunting locomotives, but he has said that to justify diesels they would have to work 24 hours per day. Does this mean he would advocate the use of diesel locos. only in yards working round the clock?

**Mr. A. N. Marshall** (Assoc.) thought that this was a fascinating Paper and reflected the fresh thinking that the Author and his colleagues had brought to the subject of steam locomotives. Moreover, the Author had had the courage and the opportunity to carry through these ideas into practice. He asked what was the policy of the Argentine Railway administration regarding the continued use of steam locomotives. Did it provide scope for the development of the Author's ideas on the scale they deserved? It would be interesting to be given information as to the numbers of locomotives involved and the type of services on which they are employed.

**Mr. R. M. Tufnell** (M.) said that the final analysis is the operating cost of the locomotive. Could the Author give some idea of the relative operating costs of the converted and the unconverted locomotives?

**Mr. A. F. Cook** (Assoc.) said that it was an honour for him as a steam enthusiast to be called upon to propose a vote of thanks to the Author and to speak at the end of a paper which was sufficiently important for M. Chapelon to have sent his apologies for non-attendance. He was sure that none of the audience would be going away from the meeting in any way disappointed with the paper. From the 'steamless wastes' of the North West of England it was good to know that steam was still being pushed forward somewhere in the world.

There was still one firm in this country which was capable of building steam locomotives; its name had been mentioned that evening—The Hunslet Engine Company. The speaker expressed the hope that Hunslet might still have the honour of building a batch of Mr. Porta's two-cylinder compounds. Listening to the paper and reflecting upon it, it was remarkable to think of locomotives operating on a gauge little more than 6 in. greater than that of the Festiniog and Tal-y-Llyn Railways in North Wales actually hauling test trains of some 3000 tons. It had been gratifying to hear the independent support given by Dr. Hedley to the Author and his locomotives, and to know that they were not just some species of Argentine magic.

The Author was to be congratulated on presenting his Paper in a language foreign to himself, particularly as he had not just followed the set paper, but had spoken directly, and had followed this by facing a long discussion in English. The speaker hoped that when the Paper was published, the ability of the Author to present it and discuss it in a foreign language would be recorded. He had the greatest pleasure in proposing a vote of thanks to Mr. Porta for his Paper, and for the way in which it had been presented.

In a written communication subsequently received, Mr. Cook wrote that it was worth commenting that at this meeting, almost certainly the last at which the Institution will discuss the steam locomotive, the last class of locomotive to be mentioned by name (in the discussion) was the Midland Compound, a type which was already established as a notable design when the Institution was founded in 1911. Mr. Porta mentioned this type in connection with his proposed two-cylinder compound, suggesting that the Deeley type of regulator might be best to use in his design. A detail of this famous

Derby design has thus seen this Institution through its independent existence, and may live on in an advanced locomotive yet to be built.

## COMMUNICATIONS

**Mr. D. R. Carling** (M.) wrote that the Author was to be congratulated on the very good work that he and some of his colleagues in Argentina have accomplished as well as on the presentation of the Paper itself. The 4-8-0 metre-gauge locomotive was indeed a remarkable machine and the performance represented by a figure of 1.78 lb/db.h.p./hr. of coal of 13500 BThU/lb. is outstanding. Could the Author state the working conditions for this minimum fuel consumption, i.e. speed or r.p.m. and steaming rate or power output?

His own experience confirmed that it was often possible to blank off or remove a number of boiler tubes without detriment to the evaporative capacity of the boiler, provided the draught was adequate.

How was the supplementary vessel (Section 2.3, item c) connected to the steam chest? To be effective it must be by a connection of ample size.

He wished to state that it was difficult to make a clear comparison between the performances of different blastpipes and chimneys from figures of exhaust pressure and draught alone; it was necessary to know either the resistance to flow through the boiler, ashpan, grate firebed, brick arch and tubes, or to have figures of gas and steam flow. If the ashpan dampers and the firehole door were tight shut the draught would be high but the flow almost nil and, conversely, if the smokebox door were open the flow through the chimney would be high but the draught almost nil and in both cases the locomotive would soon be short of steam. As the locomotive in this case was an oil burner it probably had a very high resistance to flow into the firepan in order to obtain the necessary turbulence for mixing the air with the oil jet, but for any reasonable value of resistance to flow the figures quoted were very good.

Could the Author say a little more about the diffuser mentioned in this Section as it is neither the chimney diffuser nor that mentioned under item (f) on the valve? Many years ago an exhaust system was used in Russia in which the exhaust from one cylinder created a suction in the other cylinder, but its use was never widespread. The great height of the Russian loading gauge gave sufficient room for the length required.

The strengthening of the frames described was a good job, but what was the additional weight? It was often possible to make locomotives heavier than they originally were after weight limitations had been relaxed by the civil engineer.

Section 2.4 described excellent work by Mr. J. Vittone (*Member*). The great benefit is brought out clearly of lowering the cost of operation of traffic per ton/mile, in given conditions over a given route. In this case costs were halved and the operating conditions were improved by higher speed even with the greatly increased load. Incidentally, Mr. Vittone had explained to him that although the

Pampa is generally nearly flat, quite severe grades do occur at crossings of river valleys and over other railways.

Could the Author give some details of the R.S. oil burner as not many locomotive engineers were familiar with it? Restriction of area of the boiler tubes to improve gas flow through the superheater flues was effective, but it did not affect the flow in proportion to the areas of the restriction as that was for only a very short length of the tubes.

He could certainly confirm the difficulty of getting a well-aligned exhaust jet with a 3-cylinder locomotive; it was even more difficult within the British loading gauge and with larger driving wheels so that the cylinders and valve chests were higher above rail and an inclined inside cylinder made things still more difficult. For these Roca (former BAGS) locomotives also the question of weight limitation was relevant.

As regards Section 2.6, for what quality of coal were these locomotives originally designed? He could remember the catastrophic effect on locomotive performance when some small metre-gauge 4-6-2 locomotives, built at Gorton in this city (Manchester), and designed to burn "Best Welsh Steam Coal" had had to burn local Brazilian coal of a quality very much poorer than Rio Turbio. They had even at one time to burn unsaleable coffee beans, just as Argentine locomotives had to burn maize!

He would like to know where and when the Belgrano Railway 4-8-2 locomotives were built.

The 2-10-2 locomotives of the Rio Turbio Railway were indeed remarkable engines and it was good to have the data about them. It was unusual for a locomotive of this size to have a mechanical stoker, which would normally be regarded as too costly. He had always disliked the steam distributing jets of mechanical stokers and thought it was good to be able to dispense with them as the Author was able to do with Rio Turbio coal. With the gas producer system would it be possible to use an under-feed stoker? The introduction of the fuel from below might still further reduce the loss of fuel unburned due to particles being carried away by the draught, but might increase the loss to the ashpan and hinder the ash from shaking into the ashpan.

The swirling action of the Kilpor exhaust system is interesting as it enables a more divergent chimney diffuser to be used than is otherwise possible without risk of loss of contact between the jet of mixed gas and steam and the surface of the chimney, with disastrous effect on the draught if air could flow down the annular space into the smokebox.

Section 3 of the Paper should be learned by heart by all locomotive designers, be the locomotive steam, diesel or electric. The proposed locomotive design spoke for itself and did not need discussion as a whole, though there might well be argument about details. Could the Author explain how the pipes of the double exhaust system were connected at the steam-chest end so as to get the initial flow at release through the central orifice and then the rest of the flow through the anulus as well?

In supporting the whole proposition one need only think of the large number of unserviceable "Sophisticated" locomotives littering the railways of many of the less developed countries (and of some not so "Under-developed"!) in a way that was rarely, if ever, the case with the steam locomotives that preceded them. The glib talk of salesmen should not persuade the authorities in such countries to expect their railwaymen to run before they could walk.

**Mr. E. S. Cox** (*Past-President*) wrote that one of the main reasons for the demise of the steam locomotive can be stated in a single sentence. Whatever heights the cylinder efficiency may be developed to attain, it is always nullified at full power operation by low boiler efficiency which can fall to 50% and below due to loss of unburned fuel.

Of all the improvements described in the Paper the gas producer combustion system is the most striking in that for the first time a real attack is made on the problem of the large amount of unburned fuel carried away by the blast when high rates of combustion are required. The second advantage, hardly less important, is the delay to the onset of clinkering which reduces effective passage for air through the grate and which again leads to loss. It is unfortunate that this development has reached practical shape so late in the day, and that the nearest point at which it can be seen in full power operation is Patagonia—the southernmost part of South America.

Accepting that the system works as intended, it would be most valuable if the Author could supply a diagram showing the fall in boiler efficiency with increasing firing rate, first for the Rio Turbio locomotives in normal condition and then as converted to the gas producer system. That this system brings an advantage is obvious, but the Paper is not too clear as to how great this advantage is as regards efficiency.

It appears that the fuel remains relatively quiescent on the grate during combustion, and that the major heat release comes from the burning gases in suspension. Firebox volume must thus be of first importance as in oil firing. Not, unfortunately, having access to a stationary test plant, how can the Author determine the optimum volume for a given output, and indeed how can any fixed volume be exactly right for all rates of heat release? How is the best compromise to be arrived at? The idea set out in the latter part of the Paper for using a circular firebox shape in the form of a truncated cone in order to promote turbulence is very interesting. Just however as the round fireboxes of the old Bury locomotive at the dawn of railway history limited firebox volume too much and had to be abandoned, so in this case it is not easy to see how enough volume can be obtained within the loading gauge.

The writer strongly agrees with the Author as to the scope there still should be for steam in under-developed countries having cheap local supplies of solid fuel. However unfashionable it is today to say a good word for steam, it is incontrovertible that it can be composed of very simple robust components, most of which can be easily and cheaply made and replaced locally. Moreover, the whole machine is capable of being understood and maintained by indigenous staff without much mechanical background.

It is very valuable therefore that someone as experienced as the Author should assemble all the available improvements and know-how after so many years of steam development, should add his own original thinking, and should outline a practical way in which they might be combined to prolong the life of steam in favourable areas.

The new design proposals in the Paper are very well thought out, but since the mainstream of steam development has been killed before all of its problems have been solved, it is possible to question in a friendly manner some of the proposals now made. For instance, European, rather than British or American outlook is followed in favouring maximum power to weight ratio at the expense of adhesion. If the writer found himself in charge of a railway in the outback, he would value reliable adhesion above all else, and would prefer a high ratio of weight on coupled wheels to starting tractive effort, which in the example in question would favour a 2-10-0 instead of a 2-8-0, assuming a given maximum allowable axle load. This would also assure even more reliable operation under high power at the permitted running speeds.

Then again the writer would not have inside cylinders at any price. A small advantage in reduction of heat loss there may be, but this is as nothing weighed against the problems and cost of the crank axle. This is the locomotive component which one could well hope to see lost for ever. In addition, why load the axleboxes more severely than need be the case, for simple mechanics indicates how, in the case of a given piston thrust, inside cylinders impose greater loads in this respect than do cylinders placed outside the frame?

There is much to be said for a permanent connection between boiler and chassis, and modern conditions can avoid the need to lift the boiler during the life of the locomotive. On the other hand, if the firebox is disposed above coupled wheels as in the present proposal, sufficient freedom and space is not left for cutting out and removing defective portions of the inner firebox and for inserting and welding in replacements. The Author is surely not so bold as to think his inner fireboxes will be everlasting, and American experience has shown that best accessibility for firebox repairs, if the boiler is not to be lifted from the frame, comes when removal of ashpan and trailing truck leaves only two slender rear frame extensions to obstruct free access. In other words a 2-8-2 or 2-10-2 instead of 2-8-0 or 2-10-0.

Finally, the proposal to use compounding is a very dubious one. It is impossible to ignore world experience which has never shown the two-cylinder compound arrangement to be very sprightly, while the advantages of compounding as such have usually been severely curtailed where provisions of independent cut-offs and use of intercepting valves have been absent. The full application of Chapelon principles to simple expansion has been shown capable of striking results and it is possible to feel that the small percentage further efficiency that the proposed simplified form of compounding might bring could be dearly bought, especially in conjunction with such complexity as an additional L.P. superheater.

The foregoing are only opinions based upon one man's experience, and do not detract from the enterprise and original thinking which the Author has displayed. Technically there seems to be no answer to the fact that steam should be capable of further exploitation on the general lines of this Paper.

One can only hope that fashion and high-powered salesmanship, coupled with the shrinking almost to vanishing point of manufacturers throughout the world prepared to build for steam, will not strangle at birth such interesting possibilities.

**Monsieur Andre Chapelon** (*Hon. Chief Engineer, S.N.C.F.*) wrote that Mr. Porta's Paper was of particular importance as the Author had been in the forefront of those advocating the improvement of the steam locomotive and had devoted his maximum efforts to this end.

It was nearly twenty years since he had occasion to admire the remarkable metre-gauge four-cylinder compound 4-8-0 locomotive, with resuperheater between HP and LP cylinders, which was due entirely to the efforts of the Author. Having travelled on the footplate he could testify to its excellent riding qualities and exceptionally economical working.

During the same visit he had been able to see also the good results obtained with the 2-6-2 tank locomotives of the Roca Railway, which had been improved to the Author's directions, and which maintained an intensive and heavily loaded service in the Buenos Aires suburban area.

A little later he was able to verify how much the work of Mr. Porta was appreciated when the Minister of Public Works spoke to him, at a reception given for members of the French Mission then in South America, of the astonishing improvement in the work of the 2-6-2 tank locomotives.

There was some surprise that economies in fuel consumption were not obtained also, but it is often overlooked that an improved locomotive developing higher power outputs with higher overall efficiency can burn more fuel per ton-mile or per mile if one does not take into account the work actually done. The engine crews use to advantage the improved performance capacity of improved locomotives, which develop more power for a given cut-off, thus giving a better service demanding more horsepower-hours.

Following the visit by the French mission it was decided to 'remodel' the 75 4-8-0 locomotives, class 11C, of the Roca Railway. This work was carried out in the Astarsa shops in collaboration with staff loaned by the S.N.C.F. who were responsible also for running-in the locomotives and for instructing the drivers.

In regular service the fuel oil consumption of these locomotives was reduced from 68 lb. to 50 lb per mile, with excellent and quiet riding at all power outputs to which the Franklin automatically adjusting axlebox wedges applied to the driving and coupled axles, contribute materially. The tendency of these locomotives to slipping disappeared after modifications to sanding gear and increase in capacity of sandboxes. The excellent results obtained with the RS type burner, designed by Robert Segaud, once correctly adjusted raised some doubts as to the good layout and maintenance of these burners when applied to the 4-8-2 type locomotives of the Belgrano Railway

With regard to the extremely successful rebuilding by Mr. Porta of 2-6-2 tank locomotive No. 3477, one may mention the torsional movements of the frames which occurred previously with these engines when developing high tractive efforts; the rear end of the frame structure turning anti-clockwise about its longitudinal axis with the right crank leading and conversely. These movements, which resulted in the rupture of pipework under the cab and of that linking boiler and frame, had their cause in a difference in moments of inertia of the chassis between those parts located above and those below the axis of the driving axles, as is common with plate frames. Therefore, it is only by equalising these moments that one can completely eliminate the troubles due to these phenomena as was achieved here and explained in a paper to the Pan-American Railway Congress in 1957.

Mr. Porta succeeded in applying improvements in design to the maximum extent to the 2ft. 6in. gauge 2-10-2 locomotives at Rio Turbio, particularly with the second series working at 228 p.s.i. These latter locomotives, together with three of the first series, incorporate Mr. Porta's gas producer combustion system already developed, in difficult conditions due to lack of space, on a metre-gauge Pacific of the Belgrano Railway. The results obtained have been extremely satisfactory with Rio Turbio coal.

Special attention is directed, therefore, to this innovation, which introduces a new technique in steam locomotive development.

Primary combustion in CO requires, theoretically, only about one third of the total air necessary for complete combustion. The aerodynamic effect of the air on the firebed spread over the grate is therefore reduced considerably, the weight of unburned fuel entrained is reduced and as a result the ratio between the weight of fuel actually burned out and that fired is increased, as is the overall efficiency of the boiler, especially at high rates of working which is a most desirable feature.

But the primary combustion takes place in extremely reductive atmospheric conditions, lowering the fusion point of the ash, increasing the risk of clinkering—the great enemy of combustion, which can rapidly inhibit performance even to the point of making locomotive operation almost impossible.

Therefore we shall wish to know whether this problem, which does not occur with Rio Turbio coal, arises with other fuels, such as, for example, Brazilian coal having a lower calorific value of 8,000 B.Th.U/lb with 40% ash content heavily charged with iron pyrites, the burning of which requires frequent and laborious grate shaking operations. Certainly the Rio Turbio coal is not comparable with this, having an ash content of 18% with a probably small content of fusible matter.

In one of the Rio Turbio 2-10-2 locomotives Mr. Porta has taken a further step forward in using a gas producer firebox with 'cyclonic' secondary combustion, which appears to be the final form of his invention.

Mr. Porta also has striven to perfect draughting systems including the Lemaitre and the Kylchap.

Nevertheless, one must recall that the Kylala exhaust spreader used now for over fifty years, to the great relief from anxiety of firemen to whose locomotives it has been fitted, and retained in the recent 'Kylpor' exhaust system, represents one of the greatest advances in locomotive draughting. It is a mixing device of remarkable efficiency, easily doubling the smokebox vacuum for a given back pressure when interposed between blast pipe and chimney of the same locomotive.

Its progressively decreasing cross section cannot, according to Prandtl, cause any appreciable energy loss, which would not be the case with a device of diverging section. Similar comments apply to interior frictional losses due to the relatively large diameter of the four nozzles, given as denominator in the expression for energy loss with the Reynolds number to the power of 1/4. The theorem of quantities of movement projected also shows that, theoretically, the proportion of gas aspired is governed only by the ratio between the cross section of the exhaust nozzle and the terminal cross section of the mixing device, it being clearly understood that the latter, as in the present case, is not restricted at entry.

But that which gives the Kylala spreader its greatest advantage is the aid given to the penetration of the aspired gas to the core of the entraining gases leaving the four nozzles, their lines of flow being almost parallel at all points, the mixing process being carried out, following Bellanger's theorem with the minimum of energy loss.

The example of the rebuilt 4-8-0 of the Roca Railway shows that although used with a short chimney, due to loading gauge restrictions, its Kylchap exhaust gives a ratio for smokebox vacuum back pressure approximating to and even better than that for the Rio Turbio 2-10-2, i.e. 13.6 in. vacuum for 4.3 p.s.i. back pressure.

The length of the chimney in fact plays an important role in the efficiency of the draughting system. Nozo settled the useful length of chimney at up to seven times its diameter. Certainly one is far from attaining this today which explains why, for example, the German railways have standardised the use of chimney extensions, which, despite a relatively short length of 10⅝ in. have improved steaming considerably. Removal of these chimney extensions, necessary when operating within the European passe partout loading gauge, was critical to the steaming of these locomotives and it was necessary to fit cross spreaders in the blast pipes, with substantial increases in back pressure. The Kylchap exhaust then provided a solution, the slanting of the four jets of the Kylala spreader permitting a reduction in the distance necessary between the blast pipe and the chimney top.

The table of ratios between locomotive weights and power outputs at the drawbar given by Mr. Porta was interesting, although one may regret that no reference was made to the periods during which these outputs were sustained, nor to the relevant speeds, nor to the corresponding specific consumptions.

In this connection it may be mentiond that the improved 11C class 4-8-0 locomotive of the Roca Railway was tested at constant speed and cut-off, with regulating counterpressure locomotive, and the power quoted was a continuous output at 37 mile/h., i.e. 3.73 r.p.s. with a fuel oil consumption of 2.2 lb/db.h.p./hour. The unrebuilt locomotive of the same type tested comparatively could develop only 1000 db.h.p. for a given hourly fuel oil consumption of 1.4 tons compared with 1400 db.h.p. for the rebuilt locomotive, its specific fuel oil consumption of 3.1 lb/db.h.p./hour thus being 40% higher.

But probably the most interesting part of Mr. Porta's Paper is that in which he outlines his 2-8-0 locomotive project, which seems to incorporate all developments now available due to progress in steam locomotive technology.

Thus, the locomotive has a working pressure of 285 p.s.i., uses compound drive with high superheat and resuperheater, has a steam circuit of large cross section with improved exhaust system and reheating of feed water by combustion gas and by exhaust steam. The boiler is of a new type with circular cyclonic gas producer firebox with conventional full length boiler barrel replaced, within the same external form, by three barrel sections all of fire tube type, the two sections nearest the firebox—being respectively devoted to superheating and resuperheating; the third economiser section at the smokebox end being a reheater for feedwater using flue gas, which resembles that tried previously on Mallet locomotives in the United States.

Certainly, it seems that a careful choice has been made in the elements of the proposed locomotive, although these will give the results anticipated only when each new component has been proven by experience.

Whilst two-cylinder compound drive is certainly the best solution from the viewpoint of thermal efficiency, one may question whether the diameter of L.P. cylinder necessary for the locomotive to attain a power of about 2000 h.p. even with a working pressure of 285 p.s.i.; and improved steam distribution will not be too large to be accommodated between the frames.

Furthermore, this cylinder arrangement does not seem advisable because at the power output envisaged the crank will be at the limit of forces which it can withstand without risks of fissuration, displacement and heating of axleboxes.

It was exactly these problems experienced with crank axles of the largest four-cylinder compound locomotives required to sustain power outputs of this outlet which induced us to adopt, with complete success, three-cylinder compound drive, with inside H.P. cylinder, the single-throw crank axle being much more robust and giving all required latitude for axlebox installation.

The cyclonic firebox may require development and subsequent service testing on account of its new shape.

The efficiency of the H.P. superheater perhaps may be questioned because it will probably be very difficult to ensure an adequate speed of steam circulation when in contact with the tubes. The life of this part of the boiler unit could be affected also by the high steam temperature required, the static resistance of metal to rupture diminishing considerably at temperatures approaching 840°F, therefore demanding increased thickness for bracing stays as well as for fire tubes. To a lesser degree these problems will be met also for the L.P. superheater.

The location of the reheater at a considerable distance from the actual boiler section will probably complicate the boiler feed circuit.

Finally, despite the use of the economiser, the resiting of the conventional tube plate can produce variations in the weight of water evaporated per unit of fuel burned as a function of firing rate and affect the automaticity of draughting, at present obtained very easily with a fixed blast pipe.

Without going further into details, it seems clear that the satisfactory development of such a prototype locomotive requires a tuning-up period on the test bed and running-in on line before being submitted to the final test of full service running.

From the results already obtained from improvements to steam locomotives, as shown once again in Mr. Porta's Paper, and with the new perspectives now offered, it would be incomprehensible if the numerous railways for whom dieselisation and electrification would be costly and debatable should not be encouraged, first to improve their existing fleet of steam locomotives, at a cost which is often minimal, and subsequently to order new locomotives embodying all the improvements in steam locomotive technology.

## AUTHOR'S REPLY

1. **Types of Traction Systems and their Applications.** (*Messrs. Cantlie, H. B. Marshall*)

The Author did not intend to make the Paper controversial on this issue. He appreciates the case for diesels when they can be used very intensively in appropriate economic, operating and maintenance conditions justifying financially their use. However, the Author fully endorses Col. Cantlie's comments on the motive power situation in countries of the 'Third World', of which Argentina is probably a typical example. Diesel designers should offer locomotives suitable for the state of technology in the countries concerned.

2. **Locomotive Spare Parts.** (*Mr. H. B. Marshall*)

This question is of great importance as the economic life of diesel locomotives is governed largely by the cost of replacement components at general overhauls, the quantity and value of which tend to increase rapidly with age.

Experience in Argentina is that whilst most diesel spares must be imported, involving foreign currency, most steam locomotive spares can be made without difficulty locally.

3. **Methods of Locomotive Handling.** (*Messrs. Harvey, Thorley*)

Steam locomotive design is an application of the science of thermodynamics, but the results obtained in service depend largely on the skill of the engine crew. In the past this resulted in varied methods of driving and firing, especially with locomotives with poor draughting arrangements. Following the development work done by Chapelon in France, Ell in England and Giesl in Austria the widespread use of improved draughting systems has led to greater uniformity in driving methods, generally with greater use of shorter cut-offs and thus to increased efficiency.

The next step is to produce a mechanism allowing only the best method of driving, with regard to point of cut-off and regulator opening, for given conditions. This can be done using cut-off control indicator gauges as applied successfully for over thirty years to the Vulcan Foundry-built 4-8-4 locomotives of the Chinese Railways and described in *Journal* No. 133.

To secure the best methods of firing requires an adequate period of education and training whether mechanical stokers are used or not.

During coasting periods the Rio Turbio 2-10-2's are operated with valves in mid-gear and regulator closed with a small quantity of saturated steam fed from the sight-feed lubricator. This drifting feature results in extremely low carbon formation and sticking of piston rings is a very rare occurrence, despite high steam temperatures and low flash point of the lubricating oil used. Indicator diagrams show that resistant pumping work done on the cylinders is nil, compression and expansion lines being coincident.

4. **Shunting Service.** (*Mr. Harvey*)

Difficulties have never been experienced when shunting with locomotives having large steam chest volumes.

5. **Boiler Heat Losses.** (*Messrs. Cox, Hawkins*)

The Author would suggest that the following be added to the first paragraph of Mr. E. S. Cox's contribution;—"and by the neglected question of stand-by losses".

When the locomotive is running boiler heat losses, expressed as a percentage of the fuel consumed, are far less than is generally assumed. The point is that they exist whether the locomotive is working or standing. In the Author's view it can easily be proved that efficient boiler lagging combined with tight ashpan dampers, or a chimney cover plate which will convert the boiler into a virtual steam accumulator, is a paying proposition. Actual tests at Rio Turbio have shown that only three shovels of coal per hour are necessary to maintain steam in a locomotive with a power rating of 1,200 db. h.p.

It is of paramount importance to avoid losses through leakage in piping, valves and glands. The use of stainless steel valve seats deals with alkaline water conditions prevalent where modern methods of water treatment are used.

6. **Oil Burning/Mechanical Stokers/Firebox Design.** (*Messrs. Carling, Chapelon, Cox*)

The "RS" type oil burner was developed by the S.N.C.F. and the work of the Author's team was in connection with tuning-up to improve performance. It consists of a four- or six-jet burner located in the centre of a single air intake giving a swirling action by using directional vanes. Atomisation is good and complies with the rules derived from recent technology in dual fluid atomisers, whilst the swirling action gives a flame which opens wide shortly after leaving the burner, as required with a firebox which is square in plan.

Experience with locomotives using this burner has shown markedly reduced firebox maintenance costs due to the avoidance of high localised heat transfer. Draught energy in the firebox is used effectively to produce turbulence, and consequently low excess air conditions, instead of being consumed uselessly in coping with the tortuous air passages often associated with standard designs of oil-burning equipment.

The application of the "RS" type burner on the Belgrano Railway was handicapped initially by teething troubles associated with the difficult operating and maintenance problems on this railway.

The mechanical stoker of the Rio Turbio 2-10-2 locomotives is a very small one but its capacity exceeds maximum demand. After twelve years in operation maintenance has been limited to a change of piston rings in the stoker engine. The steam jets can be used or not, at will, the thick fire associated with the gas producer combustion system being less sensitive than conventional primary air systems to even distribution of fuel over the grate area.

For various reasons the Author does not favour underfeed stoking, amongst them are the reduction in grate area and the limitation of combustion rate due to the low speed of downward burning of the fuel, dictated by the constantly rising firebed due to the underfeed action.

With the gas producer combustion system clinkering is avoided because the firebed temperature is reduced below the lowest fusion point of the main constituents for the ash. The ash of Rio Turbio coal has a low fusion point but nevertheless it has been found possible to obtain running conditions approaching those of a power station. Many experiments have been carried out with mixtures of fines and lump coal, with final ash content as high as 35%, and with fairly satisfactory results. To deal with clinkering, should this arise with other coals, a different type of grate has been designed, to operate on the principle of the stone crusher, which would break it up. This new grate has not yet been thoroughly tested.

The gas producer combustion system has shown itself able to burn effectively a large variety of fuels including wood, charcoal fines mixed with 10% oil, clinkering Polish coal and sawmill waste.

Mr. Cox has correctly understood the working of the gas producer system, despite never having seen it in locomotive operation. The Author can quote the results of many boiler efficiency tests, obtained under service conditions with the Rio Turbio locomotives, which were always in the region of 80% referred to the lower calorific value of the coal. On one test of 6½ hours duration boiler efficiency averaged 80.5% with fuel having a lower calorific value of 10,300 B.Th.U./lb. and an ash content of 18%. There is much practical evidence to prove that the gas producer system works as intended, especially in the minute size of particles ejected from the self-cleaning smokebox.

The relation between firebox volume, rate of heat release, efficiency of combustion and draught required to produce turbulence, has been the subject of a special study which still awaits publication. Helped by an efficient draughting system it is possible with the Rio Turbio locomotives to get down to 0.1% $CO$ and 4% $O_2$, reduced further to 2% $O_2$ with cyclonic combustion, at very high rates of heat liberation.

7. **Firebox Repairs.** *(Mr. Cox)*

These are a common occurrence in Argentina, due to indifferent water treatment to date, and patch welding is widely used. This is done simply by welding the patch on the "Tross system" without removing the existing stays.

8. **Draught Arrangements.** (*Messrs. Carling, Chapelon, Hawkins*)

The Author would stress the fact that the exhaust system is the very heart of the steam locomotive and every effort should be made to perfect it. The Kylchap exhaust, single, double or triple (the last mentioned used on the prototype 4-8-4 compound of the S.N.C.F.) is one system of high pumping efficiency enabling one to deal with difficult conditions, whilst the Giesl ejector is another. The pumping efficiency of any draughting system being influenced by the height available, the Author is now actively considering the following possible means of improvement to the Kylpor exhaust, which is derived from the Kylchap:-

(*a*) Angling the lobes of the Kyläla exhaust splitter to give a swirling motion to the exhaust stream, thus making possible a reduction in its length.

(*b*) Control by suction of the boundary layer of the chimney.

(*c*) Increasing the efficiency of the diffusing cone of the chimney by provision of additional contact surface area, i.e. using concentric diffusers as an alternative to increasing the total length of the mixing cone.

(*d*) Reducing the length of the mixing cone of the chimney by taking advantage of the swirling action of the whole exhaust stream. See (*a*) above.

(*e*) Lowering the position of the blast pipe nozzle as much as possible, if necessary by dishing the bottom of the smokebox.

The spreading out of the lobes of the Kyläla exhaust splitter is intended to give more energy to the periphery of the steam-gas mixture entering the mixing cone. The frictional losses occurring inside the Kyläla exhaust splitter, shown to be of the order of 6% of the actual draught, are now being considered. The swirling action imparted to the exhaust stream is intended to be moderate, the whole subject being a question of advanced gas dynamics.

In the Kylpor exhaust the legs of the breeches pipe leading to the exhaust nozzle are so shaped at their junction point as to make the steam at release from one cylinder assist in drawing the exhaust steam from the other. The attempt of the Russian Kordina to achieve this failed because of the low pumping efficiency of the whole exhaust system used, with its small round nozzle and high terminal pressure.

9. **Detachable Boiler.** (*Col. Cantlie*)

With regard to rapidly detaching the boiler from the locomotive chassis, on a unit replacement basis using suitable easy locking devices, this should be considered in the light of the very substantial reduction in boiler repairs following the application of modern methods of controlled water treatment which can, as French experience in bad water districts has shown, reduce boiler maintenance costs by 90%. In 1961 the Author recalls seeing boiler repair shops which had been closed down for this reason, despite the corrosive qualities of French water supplies in many areas.

The Author wonders whether it is better to flame-cut and reweld on the occasions when it is necessary to disconnect steam pipes for boiler removal, in preference to using bolted connections requiring hand fitting. However, the 'zip on' design proposed by Col. Cantlie deserves further study and the sectional boiler design proposed in the Paper embodies this principle in some measure.

10. **Fuel Resources and Fuel Costs.** (*Messrs. Carling, Chapelon, Dudley, Tufnell*)

Mr. Dudley, who like Dr. Hedley has witnessed the locomotive developments at Rio Turbio, quotes the fact that in this area are some of the largest unexploited coal reserves in the world. Mr. Dudley also mentioned the excellent coal-fired steam lorries used at Rio Turbio which, in the Author's experience, gave far better reliability and length of working life than their diesel counterparts and were a good example of the value of steam propulsion equipment in difficult conditions when fuel is cheap. It is not without interest to mention that in the U.S.A. experimental steam-driven automobiles are being developed by Ford, General Motors and Lear.

The light Pacific type locomotives of the Santa Fé Railway were designed to burn the best Welsh steam coal, imported into Argentina in pre-war days, and were equipped with Kylchap exhaust. After modification and fitting with gas producer combustion system the performance in terms of power output, economy, availability and length of run was improved, despite the use of lower grade locally produced coal.

Monsieur Chapelon clearly appreciated that the remarkable tanks on the Buenos Aires suburban services, where previously much improvement in performance of the remodelled 2-6-2 and 2-6-4 time was being lost and the public's patience exhausted, involved an actual increase in fuel consumed per mile; but the remodelled locomotives were able to keep time despite traffic delays and very difficult operating and maintenance conditions.

11. **Total Annual Operating Costs.** (*Mr. Tufnell*)

As stated in the Paper, it is difficult to evaluate, on a truly comparable basis, economic studies between different forms of motive power. However, annual overall operating costs have been worked out for Argentine conditions of main line service on the basis of average mileages of 62,000 and 125,000 per annum, the latter figure being entirely practicable with the proposed steam design. Fuel costs have been taken as \$40 (U.S.A.)/ton for gas oil and \$20/10 M.Cal. (i.e. 18 million B.Th.U. or one ton with heat content of 8,000 B.Th.U./lb) for coal. Fixed financial charges have been calculated on the basis of the 20% interest rate prevalent in Argentina, which is more than double the interest rates in Europe. Diesel costs include charges for necessary workshop modernisation and training.

| Annual locomotive mileage | 62,000 | 125,000 |
|---|---|---|
| Total annual costs, \$ U.S./mile | | |
| Diesel Traction | 3.40 | 2.38 |
| Improved steam locomotives | 2.05 | 1.97 |
| New steam locomotives | 1.65 | 1.46 |

Taking the relevant figures for the New York Central "Niagara" Class 4-8-4's and comparable diesel power cited in the late P. W. Kiefer's book "A Practical Evaluation of Railroad Motive Power" and adapting them to 1965 price levels, one obtains the following for a different type of service and higher power output; at an average annual mileage of 125,000: - Diesel $2.59/mile, steam ("Niagara" Class) $2.40/mile[22].

12. **Performance and Testing Data.** (*Messrs. Chapelon, H. B. Marshall*)

Whilst the Author and his colleagues in Argentina have lacked the full testing facilities available to British Railways and the S.N.C.F., the following comments are made on the performance data given:

(*a*) All power outputs quoted may be regarded as continuous with water level in the boiler maintained constant, including blow-down where required for water treatment. The Rio Turbio 2-10-2 locomotives were able to raise the water level even after operation at full power for eight hours, hauling 75 coal wagons against a 60 m.p.h. wind.

(*b*) The trailing loads hauled by the prototype 4-8-0 locomotive involved the operation of lengthy trains over indifferent earth-ballasted track in ordinary running conditions. However, with drawgear in the poor condition then prevalent, train parting was a frequent occurrence. Owing to these operating limitations it was never possible to work this locomotive at its maximum power, which consequently remains unknown.

(*c*) Trailing loads stated are those which can be hauled on level track and drawbar horsepower outputs are calculated from drawbar pulls measured by dynamometer.

(*d*) The light Pacific type locomotive No. 4674 of the former Santa Fé Railway was tested for one week on a shunting roster of 16 hours daily at the request of the Mitre Railway. This involved 16 hours shunting duty without refuelling, fire cleaning, smoke-box cleaning, tube cleaning, oiling or other attention. The remaining eight hours per day were spent on shed with but little servicing attention, despite the fact this type of locomotive was not intended for shunting duty. Consumption of Polish coal was about six tons per week which could be reduced if the vacuum brake were replaced by a steam brake.

The Author realises belatedly that he has given insufficient attention to the problems of shunting operation, which are an important aspect of traffic operation. One may mention that one-man operation of steam shunting locomotives, coal- or oil-fired, has been a long and illegal tradition in Argentina, even in the intensive operating conditions at Plaza Constitution main station. He understands that this type of one-man operation is not unknown with steam locomotives of the N.C.B.

13. **Modified or Rebuilt Locomotives Types.** (*Mr. A. N. Marshall*)

The Argentine locomotives improved may be summarised as follows:

(*a*) One prototype four-cylinder compound 4-8-0, completely rebuilt from an earlier Pacific type locomotive in 1947/50.

(*b*) Seventy-five 2-6-2 and 2-6-4 suburban tank locomotives of the Roca Railway.

(*c*) 2-6-2 tank locomotive No. 3477 of the Roca Railway, which was the prototype for a more extensive remodelling of the whole class and included certain new and experimental features.
(*d*) Four metre-gauge 4-6-4 suburban tank locomotives.
(*e*) Two 0-6-0 shunters for the Port Authority.
(*f*) One light Pacific locomotive No. 4674 of the former Santa Fé Railway. This metre-gauge locomotive was converted to the gas producer combustion system and was the prototype for the improvement of the class.
(*g*) Sixty metre-gauge 4-8-2 locomotives of the Belgrano Railway improved to the directions of Ing. Martinez, which are now being fitted with RS type oil-burning equipment.
(*h*) About one hundred metre-gauge Pacific and 4-8-2 locomotives of the Belgrano Railway improved by Ing. Martinez, including fitting of multiple narrow rings to pistons and valves, Kylchap exhaust system and, more recently, Franklin wedges with automatic adjustment, also RS burners.
(*i*) Thirteen 2-10-2 locomotives of 2 ft. $5\frac{1}{2}$ in. gauge, Rio Turbio Railway.
(*j*) Seventy-five three-cylinder 4-8-0 locomotives, Roca Railway, type 11C, remodelled to the directions of M. Chapelon.
(*k*) Ninety-nine 2-8-0 locomotives, Roca Railway, type 11B, with mechanical improvements to M. Chapelon's directions.
(*l*) Ten metre-gauge Pacific type locomotives of the Province of Buenos Aires Railway improved to the directions of Ing. Vittone.
(*m*) Five metre-gauge Pacific locomotives of the Belgrano Railway modified by the late Ing. La Padula.

With regard to general support received by the Author for his work, this has been variable as has been the case in many fields of activity in Argentina during the past twenty years.

14. **Feed Pumps.** (*Mr. Marsh*)

Whilst the Author has no personal experience with crosshead-driven pumps they were used in Argentina many years ago and information from retired drivers and firemen infers that their performance was excellent. They were abandoned because they fed cold water to the boiler without preheating, which latter is obviously desirable.

However, the Author has read that the main defect of these pumps was valve breakage, which was overcome by fitting four or eight valves, instead of two, of considerably reduced size, weight, instantaneous velocity and acceleration. The work of Schweter in Germany in connection with high-speed reciprocating pumps should be mentioned here.

The amount of water admitted to the boiler by feed pump on the Author's proposed locomotive would be controlled by regulation of the steam admitted to the feed pipe. Thus, when running with a full boiler only steam would be pumped, and no water.

The reasons for adopting this type of pump are its simplicity and low energy consumption. If required the tail rod could function as its plunger.

15. **Crank Axles.** (*Messrs. Chapelon, Cox*)

The location of large low-pressure cylinders in the proposed design has been studied carefully. In this case it is possible to make the crank web thickness 70% of the crankpin diameter. The use of roller bearings of the self-aligning type would take up any flexure in the crank axle and obviate any risk of overheated driving axleboxes.

16. **Streamlining.** (*Mr. Hawkins*)

The streamlined casing applied to the prototype 4-8-0 locomotive was in conformity with the principle of using every reasonable means to achieve increased power. This locomotive was designed for a maximum speed of 75 m.p.h. at which the gain in power from streamlining would be far from negligible. In practice, indifferent track conditions allowed a maximum of 65 m.p.h. only.

It is true that the streamlined casing restricted accessibility and this was later modified to reduce this hindrance as much as possible.

17. **Adhesion.** (*Mr. Cox*)

Effective adhesion is not only a question of the ratio between tractive effort and adhesive weight and today there are available many means to improve this by both locomotive design and rail conditioning. In the Author's' view it is often cheaper to reduce rail contamination in bad conditions by conditioning rather than by introducing additional locomotive weight. In this connection he would refer to the Paper on this subject read before the X11 Pan-American Railway Congress at Buenos Aires in November 1968. However, the Author agrees with Mr. Cox that ample adhesion weight is necessary but feels that, in Argentine conditions, adequate adhesion is provided in the proposed design.

18. **Compounding.** (*Messrs. Chapelon, Cox*)

Two-cylinder compound locomotives have been extremely successful in Argentina, especially for freight and suburban services. Their driving and maintenance has never presented major problems. In the Author's opinion, present-day knowledge of the science of locomotive design makes it no more difficult to design a satisfactory compound locomotive than one using simple expansion. In the past, however, there was not available the thermodynamic performance data since produced, following extended research at Vitry, Rugby and other testing stations. Important advantages of compound locomotives, with resuperheating of steam between H.P. and L.P. cylinders, are that the temperature and fluidity of the steam is essentially maintained throughout the steam cycle, with economy in steam consumption assisted by reduced clearance volume (equivalent to as little as 4% in a simple expansion locomotive) and reduced radiation and condensation losses. Thus the Author feels that the two alternatives of compound and simple expansion should be considered carefully on their merits before reaching a decision.

19. **New Designs.** (*Messrs. Carling, Chapelon, A. F. Cook*)

It is very comforting to the Author to know that, in the main, M. Chapelon endorses the principles of his new design. As the "proof of the pudding is in the eating" it seems reasonable to suggest that any proposed design based on sound principles should be regarded with quiet optimism as to the results to be obtained. In this connection he would stress that forecasting of locomotive performance is probably more accurate than ever before with present-day knowledge of fluid dynamics, heat transfer, etc.

It is intended that the proposed locomotive should always work full compound, except at starting for which several simple and reliable devices are available such as the Von Borries valve and the auxiliary regulator as used on the Midland compound locomotives. If desired a reinforcing valve could also be provided to augment pressure in the L.P. cylinder at low speeds for use in exceptional circumstances, such as working heavy trains of vehicles with plain bearings in low temperatures, as on the former Santa Fé Railway, Argentina, in winter.

The temperature of metal in the H.P. superheater can be predicted very accurately by heat transfer calculations, whilst at the hottest part, where the hot gases impinge, a molybdenum steel portion could be welded to each element. The barrel incorporates a simple internal insulation to keep its temperature well below the creep limit. To design this component of the boiler the designer has at his disposal all the science and technology used in heat exchanger development.

Whilst it is true that many experimental locomotives of sophisticated design were failures, to a greater or lesser extent, it does not necessarily mean that the basic design concepts were faulty. The Author admits that the proposed design is intellectually complex but feels that this aspect can be tackled by intelligent design and adequate tuning-up of the prototype on the road. Being a practical locomotive man as well as a designer, the Author would hardly propose a design unlikely to work! Furthermore, it should be noted that most of the improvements in design apply to fixed components of the locomotive.

The Author is especially grateful to Mr. A. F. Cook for his comments, which encourage him to proceed further with design matters which he feels are far from having reached the ultimate.

## 20. CONCLUSIONS

The Author would stress that it has been extremely dffiicult for him to convey his philosophy of locomotive design in a short paper and to describe adequately what has been achieved in Argentina by Messrs. Chapelon, La Padula, Martinez, Vittone, himself and others.

With virtually no tube cleaning, no black smoke from the chimney, no dirty repair work to carry out on the boiler and no axlebox failures, steam locomotive driving and maintenance should become a fairly clean job—with drivers working in white collar and tie! This dress actually was common in the "golden days of steam traction" in Argentina thirty years ago, even before the improvements since evolved had been applied.

A computer-optimised design is of course essential for future steam locomotives and it is to this approach that developing countries should look, bearing in mind that not all that is old in concept should be rejected, but rather adapted to the needs of the modern world taking advantage of developments in technology.

The Author is particularly indebted to his diesel and electrical colleagues for having pointed so clearly to future requirements for railway motive power, giving an incentive to progress and development which was sometimes lacking in the past 'golden days of steam', also because he has taken many ideas from them and from aeronautical, marine and stationary boiler engineers.

Still more important is the philosophy of design and operation learned from technologies far removed from the railway world. For example, it left a vivid impression on his mind when his career brought him into contact with factory steam-producing equipment demanding continuous twenty-four hour service and many months of continuous and reliable steam production without any possibility of 'changing the engine' or taking advantage of 'recovery margins in the timetable' to cope with unfavourable working conditions, as can be done in locomotive operation.

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# "WHITHER MOTIVE POWER?"

By Capt. W. A. Stewart, C.B.E., R.N.(Retd.)

(*Published in Journal Inst. Locomotive Engineers, Vol.* 59 (1969-70) *No.* 327)

## WRITTEN COMMUNICATION

**Dipl.-Ing. Onno Syassen** wrote that the Author gave a very detailed survey of the demands that will be made on prime movers for rail traction purposes and the likely technical solution in order to meet these requirements. Hence the writer would like to discuss only two points:

*First*—The proposed standardisation of Diesel prime movers in two ranges of size, e.g. Range I and Range II rather than one.

*Second*—The possibility of developing higher ratings for all purpose diesel engines.

The writer is in agreement with the Author that the demands for prime movers for locomotives, marine, and other duties are extraordinarily similar, but does not think it is necessary to continue the development of two different principal sizes, namely the so-called medium-speed (750-1000 r.p.m.) Range I as well as the light and compact, but high volume, 1350-1800 r.p.m. high-speed, Range II. In fact, no less than nine firms in Europe are developing such an engine with horsepowers up to 3000 C.V. (metric horsepower) or more.

It is being claimed that such engines will obtain 20,000 hour T.B.Os. (time between overhauls) *and if properly rated for the service.*

The only exception is in the U.S.A. where the large 800 r.p.m. G.M. engine still predominates the locomotive field but these have an axle loading of up to 35 tons, since speeds above 70 m.p.h. are rarely achieved by their predominantly freight trains.