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THE COAL SUPPLY,

BEING THE

PRESIDENTIAL ADDRESS

OF

SIR W. G. ARMSTRONG, C.B., LL.D., D.C.L., F.R.S., &c.,

TO THE

MEMBERS OF THE NORTH OF ENGLAND INSTITUTE OF MINING AND MECHANICAL ENGINEERS.

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GENTLEMEN,—The North of England Institute of Mining and Mechanical Engineers was, in its origin, a Society limited in its scope to the discussion of subjects belonging to the practice of mining, and, especially, of coal mining. At that period, the working of coal and other minerals was carried on with less aid from machinery than at present, and the district in which the Society is located, was not so distinguished as it now is for the practice of mechanical engineering in all its branches. Hence, the Society, in its growth, has gradually assumed more and more of an engineering character; and my recent election, as your president, indicates that mechanical science is no longer regarded by the members as secondary, or merely subsiduary, to the practice of mining. But we must guard against this tendency of the engineering element to outgrow the mining element of this Institute. We must not forget that we are situated in the very heart of the coal-field which, more than any other, has rendered England pre-eminent as a producing nation, and that, notwithstanding the increasing magnitude and importance of the engineering works of this district, the raising of coal is still foremost amongst the industries of the North, both as regards the extent of the interests involved, and its importance to the general prosperity of the nation. For these reasons, although I come before you as the first president of this Society elected from the ranks of mechanical engineers, I shall, in this address, make coal the principal topic of my remarks, including however, mechanical applications associated with its use, or involved in its production.

As I shall speak of coal in an economic as well as in a technical point of view, I cannot well avoid making some reference to its present excessive cost, because coal, like every thing else, must be governed in the extent of its application by its price in the market. In addressing an Institution, so largely composed, as this is, of colliery proprietors, it is not an agreeable task to dwell on the evil of dear coal; but our Institution is not a commercial one, and I must speak of this subject, not as affecting particular interests, but as bearing upon mechanical art and national prosperity.

For many years past the consumption of coal has been increasing at the rate of about 4 per cent., per annum, computed in the manner of compound interest. We are all familiar with the cumulative effects of compound rates of increase; and it is easy to see that if the consumption of coal continued to advance at this rate, we should speedily arrive at impossible quantities. Thus, in 18 years our present enormous consumption would be doubled; in 36 years it would be quadrupled; and in 54 years it would be eight times greater than at present. It is clear, therefore, that our consumption has been increasing at a rate which could not possibly last. If nothing else was destined to arrest it, a failure of mining labour was inevitably approaching to have that effect; but a few years would probably have yet elapsed before the number of hands became inadequate to meet the required demand, had not the miners precipitated the event by restricting the hours of work.

The hours of mining labour in this district, 25 years ago, were 9 per day. At a subsequent date, they were reduced to 8, then to 7, and, finally, to 6. Hitherto, the men have worked 11 days a fortnight, but it seems doubtful whether more than 10 can now be worked, consistently with the very proper limitations of the recent Coal Mines Act, in regard to the labour of the boys. The full hours per fortnight, will, therefore, at the most, be 66, or 33 hours per week, of labour at the face of the coal; but as it is only the steadiest men that work full time, the average time will, of course, be considerably below that limit. I am not aware to what extent reduction of time has been carried in other parts of England; but we hear of the same policy of restriction, either of time or output, or of both, being put in practice in all the important coal districts. I do not suppose that the average output, per man, has fallen off proportionately to the reduction of hours. The men work hard, even harder than formerly, while at their post; but it is impossible that so great a reduction of working time can have taken place without so lessening the output, per head, as to neutralize, in a great degree, the increase of production due to the numerical growth of the mining population.

Under these two conditions of increasing consumption, and restricted labour, we have reached a point at which the demand has overtaken the supply. As yet, the deficiency cannot be great, for it has only very recently become apparent. Consumption does not advance by jumps; and we may assume that if a progressive increase of 4 or 5 per cent., per annum, could have been maintained in the production of coal, a balance would still have existed between supply and demand. Though production has ceased to keep up with demand, it has not, so far as we can judge, actually receded, and it would, therefore, appear, that a small addition to the present supply would restore the equilibrium. But small as the deficiency must be, it is sufficient to create a sense of scarcity, and, as a consequence, to send up prices to a famine pitch.

The situation is a grave one, and the public has not yet fully realized how very grave it is. Taking the present consumption at 110 millions of tons, (exclusive of exportation) and estimating the extra price to consumers at 8s. a ton over all, the annual loss to the community from the additional cost of fuel, amounts to 44 millions sterling. Had a Government tax of 44 millions been levied upon coal, in addition to existing taxation, the effect would have been regarded as utterly ruinous, not only in regard to its prodigious amount, but on account of its repressive effect upon every kind of production. Yet, it is a fact, that we are now paying the equivalent of such a tax—with this unfavourable difference—that the money does not go into the coffers of the nation. Whether it chiefly goes to coal-owners, or coal-miners, is a question which I need not discuss; but I may observe, that the restrictive action of the men has benefitted their employers as well as themselves, and that the public are the only sufferers. Coal-owners have long been aware that limitation of quantity was the only effectual mode of raising price, but they have never been able, by their own action, to maintain a restricted production. At last their workmen have done it for them, and we see the result.

Whether the trade of the country will bear up against the heavy burden of dear coal, combined as it is with dearness of other products, arising from similar causes in other industries, is a question on which I shall not attempt to prophecy. It will be more to the purpose to consider what can be done to mitigate the evils under which the nation is now labouring in regard to the price of coal. It is vain to appeal for relief either to coal-owners or coal-workers. Self-interest is the ruling principle of trade, and it is visionary to expect that men will sell either labour or the produce of labour for less than the market price. However generous a man may be, he will not exhibit his generosity by selling an article below its value. Speaking then, as one of the public and not as a coal-owner, I say, we must strive to economize the use of coal; speaking as President of an Institution of Mining and Mechanical Engineers, I say, we must endeavour to make up for the deficiency of human labour, by a more extended use of machine labour.

The waste of coal, both in domestic and manufacturing use is a threadbare subject; but there never was a time when its consideration was of so much importance as at present. The small deficiency of supply, which is now so violently stimulating the market, would be just as effectually expunged by economizing consumption, as by increasing production. If, on the one hand, the mining population could easily, by a few hours addition to their weekly labour, restore the equilibrium between supply and demand, so on the other hand, consumers, taken as a body, could do the same thing, by discontinuing in a small degree, those reckless habits of wasting coal to which they obstinately adhere.

The consumption of coal takes place under three great divisions, each absorbing about one-third of the whole produce :—1st, Domestic consumption; 2nd, Steam-engine consumption; and 3rd, Iron-making and other manufacturing processes. In the first two divisions the waste is simply shameful; in the third it is not so great, but still considerable, though in some processes, and especially in the smelting of iron, economy of fuel has been so diligently pursued, that there remains but little apparent scope for further saving.

I shall not dwell on the waste of coal in domestic consumption, as it is scarcely a subject for engineers; but the circumstances of the times are such as to forbid my passing it unnoticed. It is impossible to conceive any system of heating a dwelling more wasteful than that of sinking the fire-place into a wall directly beneath the chimney, which carries off the products of combustion. Nothing can be clearer than the advantage to be gained by merely advancing the fire-place a little into the room, and constructing it with proper heating surfaces, as in the "Gill stove" and in many other stoves acting on the same principle. There is no occasion to shut out the fire from view. Neither is there any difficulty about ventilation, since fresh air can easily be introduced from the exterior by a pipe delivering its supply against the heated plates, so as to temper the air before it enters the room. By this simple and unobjectionable departure from the conventional fire-place, the quantity of coal required to produce a given heating effect might easily be reduced to one-half, and still greater economy would be effected by the use of hot water apparatus, which, however, has the objection of being too costly in first outlay to admit of very general application. For cooking purposes also, the consumption of coal is in most houses equally extravagant, and I may add, equally inexcusable, since the means of prevention are attainable by the adoption of known methods and appliances for concentrating the heat upon the work to be done.

A more appropriate subject for the consideration of this Institution is the wasteful employment of coal for steam power. The steam engine is, at best, a very imperfect machine for utilizing the mechanical power of heat, for in no case do we realize more than about one-tenth of the theoretic effect of the fuel. But the difference in economy between our best steam engines and our worst is enormous, and unfortunately by far the most numerous class belong to the category of the worst. In the best kind of engines, the consumption of coal per horse-power per hour is rather less than 2 lbs., but there are thousands of steam engines in daily use which burn from 12 to 14 lbs. per horse-power. This excessive wastefulness arises from defects, both in the mode of raising the steam, and in the mode of applying it. Theoretically, 1 lb. of coal is capable of evaporating 13 lbs. of water, but the conclusion arrived at on this subject by the late Royal Commission on the duration of coal, was that in practice 1 lb. of ordinary coal did not, on an average, evaporate more than 4 lbs. of water. The causes of this deficient result are perfectly understood, and, therefore, cannot be excused by ignorance. They are, insufficient boiler surface to absorb the heat, insufficient steam space to allow of a complete separation of the steam from the water, unclothed boilers, and imperfect combustion of the fuel, arising from badly constructed furnaces and from bad firing. The defects in the mode of applying the steam, or in other words the defects which belong to the engine, in contra-distinction to the boiler, are equally well known and equally remediable. The steam, to begin with, should be taken from the boiler at a much higher pressure than is usual. It should be admitted upon the piston at the full boiler pressure, and allowed to expand in the cylinder until its power is practically exhausted. The cut-off valves should be close to the ends of the cylinders, as in the Corliss arrangement, so as to leave the smallest possible amount of space between the valve and the piston when commencing its stroke. Finally, the cylinder should be steam jacketed to prevent its cooling during the expansion of the steam, and thereby causing condensation on the next admission of steam. Nobody disputes these requirements of a good engine, and yet how few engines there are in which these conditions are fulfilled. The responsibility, however, for this waste of coal, lies more with the users than with the makers of steam engines. Old fashioned engines are retained in use, partly on account of the outlay involved in replacing them, and partly from a dread of novelties and refinements requiring more care and delicacy of treatment than steam engines commonly receive. Even in replacing old engines the repugnance to any increase of first cost, and the distrust of departures from long tried patterns, powerfully tend to a conservation of antiquated types of steam engines.

As an encouragement to those who comtemplate reforming their engine power, I may state what my own experience has been of the advantage of so doing. The engines and boilers originally applied at the Elswick Works, though representing a fair average of efficiency, were of the simple description then almost invariably used in factories. My firm, like others, was naturally averse to changing them on account of the expense of so doing; but about two years ago they determined to begin the renovation of all their old engines by putting down, as a first instalment, two large engines of the Corliss pattern, to do the work previously performed by ten smaller engines. These two Corliss engines are now both at work. They have boilers of the best construction, and are fitted with various accompaniments favourable to economy of fuel, including Jukes' arrangement of mechanical firing. One of these engines uses 24 tons of coal per week, against 60 tons used by the engines it has superseded. The other appears to be doing equally well, but I have not the necessary data for making a similar comparison. Assuming the economy effected to be the same in both cases, the aggregate saving of coal amounts to 72 tons per week. The number of firemen required is also much diminished, and the general result is, that notwithstanding the enormous rise which has taken place in the price of coal, the required steam power is now obtained at a less cost than before, after allowing for interest on the capital expended.

Thus, then, the consumers of coal, as well for domestic use as for steam engines (under which two heads about two-thirds of our whole comsumption are comprised), have it in their power to economize their use of coal to an enormous extent, without any diminution of effect. In metallurgical and other manufacturing processes there is also room for much saving of coal; but I must not extend my observations into that division of the subject. Speaking generally of coal consumption in all its branches, there can be little doubt that without carrying economy to its extreme limits, all the effects we now realize from coal could be attained with half the quantity we use. If a reduction to that, or any approximate extent, were effected, we should hear nothing more of scarcity or prohibitive prices for many years to come.

And now as to the practicability of economizing human labour in coal mines by the employment of machinery. Much has already been done in applying machinery for the underground traction of coal, and a great reduction has thereby been effected both in men and horses; but the cutting of the coal is still almost exclusively performed by human labour. The service is a hard and dangerous one, and as it requires skill and experience, it is not easily taken up by untrained men. In every point of view, therefore, there is the strongest inducement to substitute mechanical appliances for manual labour in the process of cutting coal. Many attempts have been made to make a machine do the work of a man in this kind of labour, but with only imperfect success; and yet the problem does not appear, upon the face of it, to be one of very difficult solution to persons accustomed to mechanical invention, and thoroughly acquainted with the conditions under which the work has to be performed. What is wanted, is a machine capable of cutting a groove at the base of the coal, so as to allow the superincumbent mass to be easily dislodged. The mode of cutting may be by hewing, by slotting, by sawing, or by scooping. The machine must travel along the face of the coal so as to follow up its cut. It should have a long face to work at, so as to avoid frequent stops and changes, and for this purpose the long-wall system of working must be adopted. The difficulty of supporting the roof may, in some cases, be an impediment to the adoption of the long-wall system, but I believe the cases would be few in which this difficulty would be insuperable. Then, as to the power for driving the machine: that must clearly be compressed air transmitted from a steam-engine at the surface, as is now actually practised for the propulsion of all forms of these machines. Compressed air is not an economical medium for transmission of power, partly, because the power expended in its preliminary condensation is not recovered by corresponding expansion in the exercise of its power; and partly, because much of the force exerted in compression takes the form of heat, which is dissipated during the transmission of the air. In other respects, compressed air is peculiarly adapted for conveying power into a mine, because, unlike water, it requires no provision for its removal, and actually helps to supply the necessary ventilation. This is a fair statement of the nature of the work to be done, and of the conditions under which it must be performed. Whatever difficulties there may be, must be of a nature capable of being surmounted by mechanical skill and careful observation of the impediments to be overcome. Partial success has already been realized, and I confidently look forward to a time, when, to the many services which we exact from coal as a source of motive power, we shall add the cutting of the parent material from the solid beds in which it is deposited.

But it is not alone in coal mines that the extension of machinery is called for. The dearth of labour is being felt in every department of industry, and we have to fear on the one hand a ruinous collapse of trade, or on the other, a continued rise in the price of all productions, threatening to neutralize the advantage of high wages, and impoverish persons dependent on fixed incomes. The only hope that I see of escaping one or other of these alternatives, is by increasing the use of machinery and diminishing the direct employment of men. It is in the interest of working men, as well as of all other classes, that we should throw the burden of our wants as much as possible upon inanimate power, and it is a high function of mechanical science, to relieve man from that description of labour which consists in the exertion of mere animal force, and leave him more free for the exercise of skill, which is beyond the province of machinery.

One of the worst effects of dear coal is that it involves dear iron. Coal may be economized, but iron cannot, without positive loss. Production of every kind, as also steam navigation and railway transport, are essentially dependent upon the use of iron as well as of coal. Hence, dear iron, like dear coal, is a burden, both on manufacture and on commerce, and its dearness diffuses itself over every article which we derive either from foreign trade, or from home manufacture. But although the present high price of iron is chiefly due to the scarcity of coal, it is not wholly so. The dearness of labour employed in its production is also telling seriously upon its cost, and the importance of substituting some system of mechanical puddling for the present laborious process is daily becoming more apparent. Many inventions for attaining this object have been tried, but no substantial success was realized, until Mr. Danks produced his rotating furnace in America. If Mr. Danks' success be confirmed by continued trials, he will have conferred an immense benefit, both upon the makers and the consumers of iron. Unhappily for him, the general ideas embraced in his apparatus appear to have been suggested before, and although he has the great merit of having shown how the previous ideas on the subject can be rendered available, the patent laws do not afford him that protection which they so lavishly bestow upon others who have accomplished no practical result. Under an equitable and discriminative system of patents, Mr. Danks would have obtained a monoply as due to the importance of his invention, notwithstanding the abortive attempts of others to reduce the same ideas to successful practice. It is to be hoped that advantage will not be taken of Mr. Danks' unprotected position to deprive him of an adequate reward.

Having spoken of steam engines in reference to the great defects of those in most general use, it is only fair that I should acknowledge the great improvements which are exhibited by nearly all classes of those engines in their most modern forms. Mr. Bramwell, in his recent presidential address to the mechanical section of the British Association at Brighton, points out with justice how much has recently been done to improve the efficiency of marine, locomotive, and agricultural engines, and urges the importance of carrying out to a still greater extent the application of those principles which have already been productive of so much advantage. To this recommendation I may add that we must not neglect to follow up any new line of improvement which the progress of discovery may present to us. At the present moment attention is being drawn to a new method of increasing the efficiency of the steam engine by pumping heated air into the boiler. It is impossible to conjecture what theoretical considerations could have led Mr. Warsop, the discoverer of the system, to anticipate beneficial results from the adoption of such an expedient, and yet the experiments that have been made in proof of its efficacy are so authoritative that they cannot be repudiated on the ground of their being unsupported by theory. This subject, although much debated of late, is still so ambiguous and obscure that I shall take the present opportunity of stating the difficulties of the case in the hope of eliciting satisfactory explanation.

Mr. Warsop's method consists in attaching to a steam engine a forcing pump, for the purpose of injecting air into the boiler. The pipe from this forcing pump is formed into a coil in the flue so that the air may absorb a portion of the waste heat. After entering the boiler the pipe is laid along the bottom, and being perforated with holes allows the air to bubble up through the water at many different points. The result appears to be that, with a given expenditure of fuel, the available power of the engine is considerably increased by the action of the air-pump, notwithstanding that the power for working it is derived from the engine itself. How, then, is this to be explained? It is clear that air forced into a receiver cannot without the aid of extraneous heat give back all the power expended upon the forcing pump. There must of necessity be loss of power by friction, and also from the impossibility in practice of realizing all the expansive action of the condensed air corresponding to the compressive action of the pump prior to actual injection taking place. It would be a liberal estimate to assume that one-half of the power expended on the pump is recoverable from the air. Hence, to make up the deficiency by the application of heat, we should have to double the volume of the air, which would require it to be heated to upwards of 500° F. above its initial temperature. Now, in the case of the Warsop arrangement, considering the feeble heating power of the escaping gases to which the air-pipe is exposed; considering also the slow absorbing power of air, and the smallness of the surface presented by the coiled pipe, it is hard to believe that the air could enter the boiler at such a temperature as I have named, but even if it did, where is the surplus power to be found that gives the engine a palpable increase of efficiency? The mere reaction of the compressed air, with all the aid it can possibly derive from absorption of waste heat, would barely save a loss, and certainly could never account for an important gain. It seems obvious, therefore, that whatever beneficial action is exercised by the air must be of an indirect nature, and not the immediate effect of its mechanical energy. Three modes of action have been put forward to account for the effects obtained.

Firstly, it is said that the air, in bubbling through the water, facilitates the disengagement of the steam. This may very possibly be the case, for we know that water, entirely deprived of air, may be heated in an open vessel to a temperature geatly exceeding the usual boiling point, before ebullition commences. The reason of this is, that the adhesion between the water and the containing vessel, and also between the particles of water themselves, is sufficient to restrain the formation of steam at the usual boiling heat, unless air be present to afford points of separation. So far the explanation is plausible; for if the abstraction of air from water raises the boiling point, we may infer that the addition of air will lower it. But the reduction of the boiling point, within any supposable limits, would not lessen the quantity of heat required for the production of the steam sufficiently to afford a solution, because the sum of the latent and sensible heat, though not constant, as was formerly supposed, does not vary in relation to the boiling point to such an extent as would account for any important saving in that direction. A tangible advantage might, however, accrue from the accelerated transmission of heat from the fire to the water, caused by the increase of difference which a lowered boiling point would occasion between the temperature of the water and that of the fire and gases acting on the boiler; but in the absence of thermometric experiments to show how much the boiling point is actually reduced, and how much the escaping gases are cooled, it is impossible to form any definite opinion as to the amount of this saving. It is certain, however, that unless the reductions of temperature be greater than can be readily conceded, they will not be sufficient to account for so large an economy as is said to be realised.

Secondly, it is argued that the bubbles of air virtually afford an extension of heating surface. So they do, in relation to the heat carried in by the air; but the air can only part with its heat by lessening its direct contribution to the power of the engine. Moreover, if the heat carried in by the air, be insignificant in quantity, as I believe it to be, the explanation fails in every point of view.

Thirdly, it is stated that the action of the air prevents and even removes incrustation, and thereby keeps the heating surfaces free from all obstruction as regards the transmission of heat. Very careful observation would be required to establish this fact; but, granting the fact, it would follow that the advantage of injecting air would be limited to those cases in which deposit would otherwise be formed. In a boiler perfectly free from incrustation the injection of air ought to be nugatory, but this does not appear to be the case.

Fourthly, it has been ingeniously suggested by Mr. Siemens, that the air passing with the steam into the cylinder may form a film on the interior surface, capable of arresting, in a great measure, that condensation which is known to be so wasteful of power in unjacketed cylinders, where the steam is used expansively. It is highly probable that the air would really accumulate in this manner against the sides of the cylinder, because, while the particles of steam sank down into water, the particles of air would remain. It is also pretty clear that this film of air would intercept the abstraction of heat by the cooled material of the cylinder, but if we admit this mode of action, then it would seem to follow that it is only in the absence of a steam jacket to the cylinder, that the economy of injecting air is realised, and, in fact, that the injection of air is merely a substitute for steam jacketing. Moreover, if such be the action of the air, pumping into the steam should, in this point of view, produce the same effect as pumping into the water.

I have dilated upon this subject more perhaps than necessary, but I have done so with a view to stimulate action in the matter, for it is time that the doubts and obscurities which beset the system should be cleared up, and its adoption or rejection be brought to an issue.

There is no class of steam engines in which economy of fuel is of so much importance as it is in marine engines, for not only is it an object in steam navigation to diminish the cost of the coal, but it is a still greater object to save room, and thereby increase the space available for cargo. The introduction of compound engines has enabled steam to be used of much higher pressure than formerly, and with greatly increased expansive action. The result has been a saving of about 50 per cent. in the consumption of coal, and I believe I am substantially correct in saying that in steam vessels, employed on long voyages, this saving of coal has been attended with a fourfold increase of the previous carrying power. It is highly probable that still further reductions of fuel will be effected by following in the same path, which has already led to such great economy. The pressure of steam in marine engines is still far inferior to that which is used in locomotive engines, and there is no obstacle, of an insurmountable nature, against the expansive action being increased proportionately to any further increase of pressure. But our efforts to increase the efficiency of marine engines must not run too much in one groove. Recent improvements have been almost exclusively directed to the mode of *applying* the steam, and but little attention has been paid to the mode of *producing* it. The engine has advanced enormously in improvement, but the boiler has actually receded; for we now get less evaporative effect from marine boilers than was obtained from those previously in use. This diminution of effect has resulted from changes made in the form of the boiler, to enable it to resist the greater pressure of the steam; but there is no inherent necessity for sacrificing evaporative power to meet this requirement, as is proved by the example of the locomotive boiler, which, while it produces steam of double the pressure of that supplied by marine boilers, stands unrivalled in regard to evaporative effect. The superiority of the locomotive boiler in regard to evaporating power, is chiefly due to the large capacity of its fire-box, which affords ample space above the surface of the fuel for perfecting the combustion of the gases. In the old form of marine boiler, the flame space above and beyond the fire, was also very large, and the evaporation per pound of coal was nearly as great as in the locomotive. But this advantage has been sacrificed in the modern form of boiler, by adopting a cylindrical fire-chamber within the boiler. This form is very favourable to strength, but it affords very little head-room over the fire, and the consequence is, that, although the tubular heating surface is relatively as great as before, the evaporation per pound of coal has fallen considerably. I do not say that the locomotive form of boiler, pure and simple, is that which ought to be adopted for marine engines, but it is well worth consideration, whether by adopting the same principle of construction, a more efficient boiler would not be obtained for marine engines. A more powerful draught would probably be required than is now necessary, but this could be obtained by known mechanical methods, applied either to *draw* air through the furnaces, or to *force* it into a closed stoke-hole. The production of draught by auxiliary power, would have the great advantage of enabling the rate of combustion to be regulated at pleasure, so as to meet the varying demand for steam, and it would also facilitate the application to marine boilers, of mechanical firing, which does not succeed with a slow draught, and requires a variable draught to meet the fluctuating production of steam required at sea. The great number of stokers required in large steamers, the severity of the work, and the inefficiency of the method they pursue, as evidenced by the dense clouds of smoke they produce, render the introduction of mechanical firing in such vessels, a matter of the utmost importance; and, I do not believe, that any of the difficulties which appear to stand in the way are incapable of removal.

I must not dismiss the subject of steam power without some allusion to its application to agriculture. In no description of steam engine has economy of fuel been more perseveringly and successfully followed out as in engines for agricultural use, and Mr. Bramwell, in his late address to the mechanical section of the British Association, does full justice to the mechanical engineers who have been the means of bringing these engines to such a high degree of efficiency. It is satisfactory to see that the application of steam to the cultivation of the land, and to every kind of farming operation, is rapidly extending; for if the food producing power of the land has to be increased, it must be by substituting, as far as possible, the comparatively cheap power of steam, for the labour, both of men and horses. The greatly increased demand for labour in manufacturing occupations, as well as for mining and constructive purposes, will certainly diminish the supply of rural labour and increase its cost. Such a result is not to be regretted, considering how miserably ill requited farm labour in most parts of England has been; but unless the growing cost of agricultural labour and of horse work, can be counterpoised by a more extensive use of steam power, we may expect much of the land in this country to be thrown out of cultivation. Very different are the views of those who maintain that food would be more economically produced, by increasing, instead of diminishing, the labour employed on the land. Such is the doctrine of those who advocate the parcelling out of the land in small plots to peasant holders, and who even contend that waste lands, incapable of profitable return by ordinary treatment, could, by this means, be advantageously cultivated. It would, indeed, be a retrograde step to renounce the aid of capital and mechanical skill in tillage, and fall back upon the primitive system of spade husbandry. If there be a country in the world where such a mode of cultivation is the best, that country is assuredly not England, where all the resources of science and skill are necessary to the maintenance of a large population, under adverse conditions of soil and climate, and where labour is more highly paid in manufacture than in agriculture.

I have had considerable personal experience of steam cultivation, and am a thorough believer in its efficacy; but I may here draw attention to a very general subject of complaint concerning the machinery and implements employed for the purpose. I refer to the frequency of breakages due to insufficient strength in the construction. If makers of the apparatus, used in all the varieties of steam tillage, could only be induced to be more liberal in the use of material, the introduction of their machines would be very greatly accelerated.

I must also touch upon the subject of steam traction on common roads, which has lately received a considerable impulse from the introduction of Mr. Thomson's invention of India-rubber tyres. The number of horses in this country is enormous, and being great consumers of food, their maintenance is a heavy charge on the resources of the nation. Next to human power, horse-power is the most expensive that we can use, and we may welcome the dawn of a period when steam will, to a great extent, supplant animal power in our streets and highways.

But these, and all other extensions of steam power, involve greater consumption of coal, and we may well look with anxiety to our diminishing stock of this precious mineral, which, when once expended, can never be replaced. It will, therefore, be a fitting conclusion to this address, briefly to review the results arrived at by the late Royal Commission, of which I was a member, as to the extent of our available coal and its probable duration.

I will not trouble you with the vast amount of detailed information collected by the Commissioners as to the extent of the British coal-fields, nor with the elaborate calculations of the quantities of coal which those coal-fields contain, but I will chiefly direct my observations to those points of the enquiry which fall within the province of mining and mechanical engineering, and to the broad conclusions at which the Commissioners arrived.

It being well known that a great extent of our coal lies at depths greatly exceeding those of our present deepest mines, it was essential to the enquiry that the limit of possible depth of working, should be approximately defined. One of the Committees, therefore, into which the Commission was divided, was entrusted with this branch of the subject, and having acted in the capacity of chairman to that Committee, I am especially familiar with its proceedings.

It fortunately happens that water is never met with in large quantities at great depths, and it is easy to exclude it from the upper portion of a deep shaft, by the modern process of encasing the shaft with cast iron segments. Nothing, therefore, is to be feared on the score of excessive pumping power being required; neither would there be any practical difficulty in drawing coals from the utmost depth to which we should have to descend. Steel wire ropes tapering in thickness towards the downward end, would not be overstrained by their own weight added to the usual load, and even if the depth were carried to such an extreme as to render the strain on the rope due to its weight a serious difficulty, the alternative of drawing at two stages could be adopted.

With regard to explosive gas it might have been anticipated that the greater superincumbent weight upon deep coal would cause more gas to exude, and thereby render the workings more fiery, but this does not appear to be the case. On the contrary, the evidence given before the Committee on this point was to the effect that the evolution of gas appeared generally to diminish with increase of depth. In short, the only cause which it is necessary to consider as limiting the practicable depth of working, is the increase of temperature which accompanies increase of depth.

The rate of this increase of temperature is about 1° F. for every 60 feet in depth, starting from 50 feet from the surface, where the temperature is in this country 50° at all seasons. The questions involved in this increase of temperature are, at what depth would the air become so heated as to be incompatible with human labour, and what means could be adopted to reduce the temperature of the air in contact with the heated strata. A great deal of interesting evidence was heard by the Commission, as to the limit of human endurance of high temperature. The natural temperature of the human body, or rather of the blood which circulates through it, is 98°. A higher temperature is the condition of fever, and the maximum of fever heat appears to be about 105°. Labour appears to be impossible, except for very short intervals when the external conditions are such as to increase materially the normal temperature of the blood. The temperature of the air may be considerably in excess of 98° without unduly heating the blood, provided the air be very dry, because the rapid evaporation which then takes place from the body keeps down the internal temperature, but if the air be humid, this counter-action does not take place, or not in a sufficient degree, and then the blood absorbs heat from the surrounding medium and the condition of fever sets in. Now, in a coal mine, the air is never very dry, and is often very moist, and we must, therefore, regard a temperature of 98° in a coal mine as the extreme limit that could be endured by men performing the work of miners. For my part, I believe this temperature is beyond the limit of possible continuous labour in a mine, and most persons familiar with the interior of coal mines, will agree with me in thinking that even 90° would prove a very distressing temperature, and one which would render the cost of labour much greater than usual. However, granting the practicability of working in a coal mine in an atmosphere at 98°, the next question is, what depth would involve that temperature of the air?

The depth at which the earth would exhibit a temperature of 98° would be about 3,000 feet, but it is a different question at what depth the air circulating through the mine would acquire that temperature. The air being cold when it enters the workings at the bottom of the shaft, absorbs heat with great avidity from the surfaces of the passages through which it flows. As it travels along it continues to absorb heat, but less rapidly as its own temperature increases. The rate of absorption is complicated by the superficial cooling of the passages by the contact of the air. This cooling action is necessarily greatest near the shaft, where the air is coldest, and diminishes by increase of distance, so that both the air, and the surfaces against which it sweeps, become hotter as the length of the air-course is increased. The progress towards complete assimilation of temperature is much slower in the permanent air-courses, than at the working face of the coal, because the coal, at the face, being newly exposed is hotter, and therefore communicates heat more readily to the air. In any case, however, the air will eventually acquire the full heat due to the depth, if its contact with the strata be sufficiently prolonged. It follows, therefore, that the temperature of the air in a mine, depends on the extent of the workings, as well as on the depth of the pit. But great depth involves extensive workings, because the cost of the sinking could only be repaid by working a large area of coal. Extremely deep mines will consequently possess *both* the conditions tending to produce a high temperature of the air, and unless those conditions can be counteracted by some artificial expedient, the air would acquire the temperature of 98°, assumed to be the limit of practicable labour, at a depth not greatly exceeding 3,000 feet.

It is a common idea that increase of temperature may be kept down to any extent by increase of ventilation, but this opinion will not bear examination. In the first place it requires an extravagant increase of motive power to accelerate the velocity of the current of air in any considerable degree, because the resistance increases in a ratio somewhat exceeding the cube of the velocity. In fact, the only way of materially increasing the volume of air is by enlarging the sectional area of the shafts and air-courses, which would be attended both with difficulty and expense.

Assuming, however, that it would be generally practicable to effect a large increase of ventilation under the conditions incident to extremely deep mining, it is necessary to consider what would be the cooling effect realized by so doing. This is a very complex question, because the reduction of temperature in the air increases the emission of heat from the strata, and because the rate of absorption is affected, not only by difference of temperature, but also by the velocity of the current. The uncertainty on the question of the power of air to absorb heat when flowing at different velocities and in different volumes through heated air-courses, and the difficulty of reasoning out any conclusion upon the subject, led me to make, for the guidance of the Committee, a series of experiments in which air was forced, in varying quantities, through pipes of different lengths and sizes, immersed in hot water; the temperatures being observed at the point of emergence. In these experiments the pipes were regarded as representing, on a small scale, the air-courses of a deep mine; the hot water being the equivalent of the heated strata through which the air would be conveyed. The particulars of these experiments will be found in the Appendix to the evidence taken by the Committee, and the results are embodied in tables, illustrated by diagrams, which show the progressive heating of the air as it travels along the passages, and exhibit the reductions of temperature effected by successive increments of the volume of air. From these tables and diagrams it will be seen that, with short pipes, representing short distances from the shaft, increased circulation has considerable effect in lowering temperature; but with pipes representing long distances from the shaft, the cooling effect of increasing the volume of air becomes insignificant.

The conclusion to which the Committee came, as to the depth at which coal could be worked, is expressed in the following words:—

"The depth at which the temperature of the earth would amount to 98° would "be about 3,000 feet. Under the long-wall system of working a difference of about "7° appears to exist between the temperature of the air and of the strata at the "working faces; and this difference represents a further depth of 420 feet, so that "the depth at which the temperature of the air would, under present conditions, "become equal to the heat of the blood would be about 3,420 feet. Beyond this "point the considerations affecting increase of depth become so speculative, that "the Committee must leave the question in uncertainty; but they consider that it "may be fairly assumed that a depth of at least 4,000 feet could be reached."

The Committee declined to deal with hypothetical expedients for overcoming the difficulties, but they recognized the possibility of future discovery and experience counter-acting, in some unknown degree, the effects of heat and humidity in restricting the depth of working. It will, therefore, be for mining and mechanical engineers to bring all the resources of their science to bear upon this difficult problem of counter-acting terrestrial heat, at depths where it approaches the limit of human endurance.

The Commissioners adopting 4,000 feet as the probable limit of practicable depth, came to the conclusion, that there exists in this kingdom an aggregate quantity of about 146,480 millions of tons of available coal. If we assume that the future population of this country will remain constant, and that the consumption for domestic and manufacturing purposes, including exportation, will continue uniform at the present quantity, or merely vary from year to year without advancing, then, our stock of coal would represent a consumption of 1,273 years. But, if, on the other hand, we assume that population and consumption will go on increasing at the rate exhibited by the statistics of the last 15 years, or, I might probably say, of the last 50 years, had accurate statistics been so long recorded, then the whole quantity of coal would, as shown by Mr. Jevons, be exhausted in the short space of 110 years. It will be generally admitted, that the truth is likely to lie between these two extremes.

The Commissioners refrained from expressing an opinion as to what the period of duration would actually be, but they presented certain alternative views of the question, resulting in periods varying from 276 to 360 years. But, all these estimates of duration have reference to the time required for absolute exhaustion of available coal, and leave untouched the important question of how long we are likely to go on before we become a coal importing instead of a coal exporting country. The computation of quantities made by the Commissioners, includes all coal-seams exceeding one foot in thickness, whatever the quality may be, and it is obvious, that vast quantities of such coal can never be worked, except at a price which would render it more advantageous to purchase coal from abroad, than to work it from such unfavourable beds. If, at the present time, while working our best and most available coal, our markets will barely exclude the coal of Belgium, what will be our position when driven to inferior coal more costly to work? If we look to cheaper labour for enabling us to work less valuable coal, I fear, we shall look in vain; but, there is one hope for a longer endurance of our prosperity, as dependent on our coal, and that hope rests on the skill and perseverance of mining and mechanical engineers, who, even now, are called upon to lessen, by all the resources of mechanical science, the amount of human labour required in coal-mines.

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