

pressure is 46 H. U. per pound, each degree of superheat adding to the available energy a considerable percentage, which percentage is greater than that due to an increase of one pound in pressure, but both require the expenditure of energy either by the consumption of coal or otherwise, and must be accounted for in stating the economy of the engine. Something too must be allowed for the fact that the engine tested was new, and probably a great deal of pains taken to eliminate all waste. In conclusion it would seem desirable to obtain much more data in regard to the engine and its operation before we flatter ourselves that any material advance has been made in steam engineering by either Professor Thomson or M. Serpollet.

New York, March 28th, 1899.

[A REPLY BY PROF. ELIHU THOMSON to Mr. Hill's comments on his discussion of Mr. S. D. Greene's paper on "Electricity on Board Ship."]

I am too busy to enter into a lengthy discussion with Mr. Hill on the points raised by him, but will venture, for the present, the following remarks :

My comments following Mr. Greene's paper were made off-hand, and were not prepared in advance. They had necessarily to be brief, and nearly as possible to the point. I certainly did not intend to indicate that the best results of triple-expansion engine practice were likely to be excelled by the simple form of engine which I described. But that the effects of simple engines could be made to approach more nearly the highly economical results of more complex types is evident when it is borne in mind that our simple engine of only five and a fraction horse-power, in reality composed of four simple engines of little over one H.P. each, when tested, gave results in water consumption not greatly differing from those of tests of engines of hundreds of horse-power in compound condensing types. A factor in the cost of power is interest, wear and tear and depreciation, which are manifestly the less, the simpler and cheaper the engine, other things being equal. Mr. Hill finds fault with my comparison of the cycle of the small engine with that of a gas engine, seemingly ignoring those types of single cylinder gas engine which make one explosion every revolution. He must admit, however, that in the simple engine, an action is produced every revolution which in the type of gas engine he selects for comparison is only produced for every other revolution, and that in consequence the simple steam engine described has the advantage of less friction and negative work. Besides, I was speaking only in general terms when I referred to the gas engine

cycle, and merely as an assistance to the understanding of the actions in the simpler engine itself.

We have indeed to be thankful that:—"Nothing in the engine described by Prof. Thomson approaches" the *idle* revolution of the four stroke cycle of the gas engine. I am surprised at Mr. Hill's not understanding what was meant by the statement I made in the words; "throwing it back to the heated surfaces in exhausting," etc. He has totally missed the significance of the words "*in exhausting*." Does he find that the steam goes back to the hot end and out of that end *in exhausting*? It does go back (what amount is left of it) *in compressing*. This is so plainly evident as to need no discussion, and it is certainly not a bad feature. It is not a wasteful process, surely.

Does Mr. Hill really think, and can he truthfully maintain that "it makes no difference at which end of the cylinder the steam is withdrawn? If one end is hot, as heated by the incoming steam at high pressure, is it economical to discharge steam, *cooled* by expansion and delivery of energy to the moving piston, at the hot end, and so allow the steam in exhausting to run away with useful heat? What a beautifully wasteful process is that which involves the admission of steam between or over surfaces which have just been bathed in cool steam (and perhaps condensed water) leaving the cylinder. I freely admit that the fact of the use of superheated steam, has perhaps something to do with the low water consumption shown by repeated tests, and preparations are being made to test a much larger engine of the same type, with steam in all degrees of humidity, dryness and superheat.

As I was testing *an engine* and not a *boiler*, I rather preferred to exclude the boiler from the tests, particularly as no means were at hand to do differently. Just why this was the case I cannot stop to explain now. It is true that to obtain hot, dry steam, may mean the communication of more heat units per pound of steam than in the case of wet steam or saturated vapor, but the difference is comparatively slight. The change of state involved in boiling the water is, as Mr. Hill must know, the chief factor in the case, whether the steam be produced in one condition or another.

I cannot admit that: "A great deal of pains was taken to eliminate all waste." The engine was in good condition, of course, but not exceptionally so. Its simple construction permits of relatively easy maintenance. When I made the engine I expected to realize a result of about 30 pounds of dry steam per brake horse-power hour, which in itself would have been roughly about twice as economical a result as is shown in the best tests of such very small engines, of which I was able to obtain any data. I was skeptical of the result of the first tests, and freely expressed my doubts, but by going over the work and watching it personally, while insisting that everything be done to have the

errors count against the engine rather than in favor of it, I became convinced that my expectations had been greatly exceeded, and that a result of 20 pounds per horse-power hour, or slightly better than that, had been in fact, obtained, as I have indicated.

It remains to finish and test an engine of larger capacity and to do it under such varied conditions as will be likely to point out the relative values of those features which undoubtedly contribute to the still lower consumption which will probably be obtained.

The small engine tested was designed for automobile work, it being regarded as extremely desirable that but little water and fuel be carried, and but little steam escape during work. The clearance is great and the manner of exhaust and admission such that no trouble is ever experienced with condensed water in starting.

The engine is now in use upon a steam automobile, having a coil-pipe boiler heated by ordinary kerosene. It runs satisfactorily even under the very extreme condition adopted in some experiments with it, of a steam supply-pipe at a bright red heat. But this is, of course, abnormal and only indicates the wide range in character of steam which is permissible. That it is not injured by excessive heat in the steam supplied, is due, doubtless, to the poppet valve admission and the extremely early cut-off which permits the entrance of only a momentary puff of hot steam when the piston is full in.

As a matter of interest in this connection I would conclude by calling attention to the fact that Ewing in his work on "The Steam Engine, and other Heat Engines," on pages 160 and 161 gives some results of tests by Willans on a small, simple, non-condensing single-cylinder engine, in which, with 172 pounds of steam, an indicated horse-power hour was obtainable with $18\frac{1}{2}$ lbs. of steam. This represents, as Ewing points out, an efficiency of 75 per cent. of the theoretical efficiency of an engine working under the conditions. Ewing also refers in this connection to "*Min. Pro. Inst. C. E.*, vol. xiii., part 3, and vol. xcvi., part 2," in a foot note.

Lynn, Mass., April 5th, 1899.