of dependent valve compound condensing engines is well known to be 16 to 24 pounds per one horse-power hour, with the first-mentioned figure rarely reached. Tests on compound condensing engines with independent valves give 14 to 20 pounds of steam per one horse-power hour, while some tests have run as low as 12 pounds. We may notice from these results that the difference between dependent and independent valve gear is less in compound engines than with simple engines. Compound and triple-expansion engines permit greater expansion of the steam without loss of economy; hence, they allow higher steam pressure and a greater temperature range, thus giving higher thermal efficiency. Good practice indicates that for simple engines the boiler pressure should not be less than 90 to 100 pounds per square inch, for compound engines not less than 120 to 150 pounds, and for triple expansion not less than 140 to 150 pounds, and hence up to 200 pounds.

| Kind of Engine. | Steam per 1 h.p. General Range. | Steam per 1 h.p. Working Range. |
|---|---|---|
| Simple, non-condensing, dependent valve | 30 to 40 | 33 |
| Simple, non-condensing, independent valve | 25 to 30 | 28 |
| Simple, condensing, dependent valve | 20 to 30 | 25 |
| Simple, condensing, independent valve | 18 to 25 | 21 |
| Compound, non-condensing, dependent valve | 20 to 28 | 24 |
| Compound, non-condensing, independent valve | 18 to 25 | 22 |
| (1) Compound, condensing, dependent valve | 10 to 24 | 20 |
| Compound, condensing, independent valve | 14 to 20 | 17 |
| Triple, condensing, dependent valve | 14 to 20 | 17 |
| Triple, condensing, independent valve | 12 to 18 | 14 |
| Triple, large, condensing, independent valve | 12 to 14 | 13 |

Unfortunately, engines employed for electrical work are comparatively seldom kept at uniform full load. On railway service there are sudden changes from light loads to very heavy loads, while in lighting service the change in load is usually graduated. These variations affect the economy of the engines unfavorably—at certain loads there is not enough expansion, while at others there is decidedly too much. The variations in economy are largely controlled by the suitability of the engine to its work. For uniformity it is better to rate an engine at the horse-power of maximum economy, whatever the real load may be.

In Fig. 1 curves 1, 2, 4 and 5 are of engines so rated as to have their maximum economy near full load, while the curve 3 is from an engine intended to give highest economy at about three-quarter load. This is generally preferable for variable loads, but for large central station work, where the number of units is large enough to permit loading fully all that are running it is better to have each unit give its best economy near full load, and to vary the number of units instead of the load on each.

For electric railway service under ordinary conditions, it is best to employ an engine which at full load is worked to a high capacity, and hence somewhat uneconomically while at lesser loads, which more nearly correspond to average conditions, its economy will be a maximum. For electric lighting service it is preferable to have the point of maximum economy of all more nearly at full load. For power service, which is on the one hand more uniform than railway service, and on the other hand less uniform than electric lighting work, it is probably best to employ an engine having characteristics between the two mentioned. In cases where variations in the load are very sudden, great mechanical strength of all moving points is necessary, and an attempt should be made in planning the power station to arrange for its best economy at average load.

(1) "Electric Power Transmission." Bell. Page 310.

The curves on Fig. 2 show plainly the advantages to be gained by using compound and triple expansion condensing engines, and disabuse the common fallacy that simple engines are more efficient for varying loads. Their advantage is so great that under any ordinary condition the use of the simple engine is a wilful waste of money. If the saving in first cost was great, their use might be excused, but the extra steam required means addition of outlay in boiler capacity. The curves show that twice the B.h.p. is required for non-condensing engines as is required for triple expansion engines. This same ratio of original cost holds true of the capacity of stack feed pumps, steam piping, water piping, and in the building, so it is poor economy to buy a cheap type of engine.

The greatest economy in recent years has been in superheating introduction, whereby steam on its way to the engine is often raised to 600 to 700° F. This largely increases the working ranges of the engine, and hence the efficiency at a small extra expense of fuel. This high range of temperature has somewhat complicated matters of lubrication, but has been satisfactorily solved, more particularly abroad, where the very efficient result of ten pounds of steam per one horse-power hour has been obtained. Superheaters have been introduced in this country chiefly as auxiliaries to steam turbines, with very good effect, but we do not appear to be getting the very best out of them.

For large railway or power service it is best to direct connect the units for the sake of compactness and economy, and if the station is of the magnitude of 4,000 or 5,000 horse-power, engines direct connecting are advisable in nearly every case. In cases of this kind it is best to work the units at a fairly high speed. It is better to have small units and less weight running at 900 to 1,200 r.p.m. than to exaggerate to size of both engine and generator and run it from 50 to 70 r.p.m. Direct connected units of moderate size give much better efficiency than do the enormously large ones with a heavy piston and enormous flywheel.

We can now refer to engine performances in regard to coal consumption per horse-power hour. The table given below shows the consumption for various engines based on the burning of one pound of coal for every nine pounds of feed-water used, and which may be considered slightly better than is found in practical experience:—

| (14) Kind of Engine. | Coal per 1 h.p. hour. Condensing. | Non-condensing. |
|---|---|---|
| Simple, dependent valve | 2.77 | 3.66 |
| Simple, independent valve | 2.33 | 3.11 |
| Compound, dependent valve | 2.22 | 2.66 |
| Compound, independent valve | 2.00 | 2.44 |
| Triple, dependent valve | 1.88 | .... |
| Triple, independent valve | 1.66 | .... |
| Triple, independent valve (large) | 1.44 | .... |

These figures only apply to engines of several hundred horse-power. From this we see that a combination of great efficiency at the boilers and a small steam consumption in the engines gives remarkable results. The best triple expansion engines can be counted upon to do a little better than one and a half pounds of coal per one horse-power hour, but this is under very favorable conditions.

**Steam Turbines.**

A strong factor in the raising efficiencies of power plants has been the introduction of the steam turbine. Primarily, its first cost is, perhaps, thirty per cent. less than for a steam motor and generator, and it is more economical than the reciprocating engine. With it superheat to the extent of 200° F. reduces the steam consumption about 15 per cent., and its economy is about 20 per cent. better than that of reciprocating engines. It has also been

(14) "Power Plant Economics." Stott, A.I.E.E., January, 1906.