But, apart from this, an important merit of the compound system is that, while it absolutely prevents the grade of expansion from being reduced below a certain minimum, depending on the ratio of cylinder volumes, it also permits a comparatively high degree of expansion, which in an ordinary locomotive would involve the use of specially large cylinders and a separate cut-off valve. Experiments on the steam-jacketing of locomotive cylinders have not hitherto been attended by success.

237. *Tramway locomotives* for the most part resemble railway locomotives in the general features of their design. The boiler is of the usual locomotive type. A pair of cylinders in front, either inside or outside the frames, are connected directly to the hindmost of two coupled driving axles. Owing to the smallness of the driving-wheels, the axles lie near the road, and the cylinders are set sloping at a considerable angle upwards to keep them clear of dirt. To prevent the discharge of steam into the atmosphere, the exhaust steam is often led into an atmospheric con­denser, consisting of a large number of pipes set on the top of the engine, and exposed to free contact with the air. In some instances the common locomotive type is widely departed from : a mixed vertical and horizontal boiler is used, and the engine is connected to the driving axle by worm-wheel or other gear, or by a rocking lever between the connecting-rod and the crank.@@1

238. In the “ fireless ” tramway locomotive of M. Léon Francq, a reservoir which takes the place of an ordinary boiler is charged at the beginning of the journey with water heated under pressure by injecting steam from stationary boilers at a pressure of 15 atmospheres. The thermal capacity of the water is sufficient—without further addition of heat—to supply steam to the engine during the journey, at a pressure which gradually falls off.@@2 The system has not come into general use.

239. Several forms of tramway engine have been devised in which the motive power is supplied by compressed air.@@3 In the Mekarski system the compressed air, on its way from the reservoir to the cylinders, passes through a vessel containing hot water and steam under pressure (charged, as in Francq’s system, by injecting steam at a station). In this way the air is heated, and may then expand in the cylinder without having its temperature lowered to an objectionable degree.

240. Steam *road-locomotives* or traction-engines have usually a boiler of the locomotive type, with a cylinder or compound pair of cylinders, generally on the top, driving a shaft from which motion is taken by a gearing chain or spur-wheels to a single driving axle at the fire-box end. The engine is steered by means of a leading axle, whose direction is controlled by a hand-wheel and chain-gear. To facilitate rapid turning the driving-wheels are connected to their axle by a differential or compensating gear which allows them to revolve at different speeds. This is a set of four bevel-wheels like White’s dynamometer coupling : the outside bevel-wheels are attached to the driving- wheels ; the intermediate ones, which gear with these, turn in bearings in a revolving wheel driven by the engine. So long as both driving-wheels are equally resisted both are driven at the same speed, but if one is retarded (as the inner wheel is in turning a curve) it acts to some extent as a fulcrum to the bevel gear, and the outer wheel takes a greater share of the motion. An important feature in traction engines is the elasticity of the driving-wheels. Many devices have been employed, partly to give the wheels an extended tread, or arc of contact with the ground, and partly to avoid shocks in passing over rough ground. Both objects are accomplished

by Mr R. W. Thomson’s plan of surrounding each wheel with a thick tyre of india-rubber, protected on the outside by an armour of small plates. In most modern traction- engines the rim is itself rigid, but is connected to the nave through a system of springs which allow it to take up an eccentric position, and the tyres have skew bars on the surface to increase their adhesion to the road.

XIV. Air and Gas Engines.

241. Under this head we may include all heat-engines in which the working substance is air, or the gaseous pro­ducts of the combustion of fuel and air, whether the fuel be itself solid, liquid, or gaseous. When air alone forms the working substance, it receives heat from an external furnace by conduction through the walls of a containing vessel, as the working substance in the steam-engine takes in heat through the shell of the boiler. An engine sup­plied with heat in this way may be called an *external- combustion* engine, to distinguish it from a very important class of engines in which the combustion which supplies heat occurs within a closed chamber containing the work­ing substance. The ordinary coal-gas explosive engine is the most common type of *internal-combustion* engine.

242. Compared with an engine using saturated steam, air and gas engines have the important advantage that the temperature and the pressure of the working substance are independent of one another. Hence it becomes pos­sible to use an upper limit of temperature greatly higher than in the ordinary steam-engine, and if the lower limit is not correspondingly raised an increase of thermodynamic efficiency results. It is true that the same advantage might be obtained in the case of steam, by excessive super­heating; but this would mean substantially the conversion of the engine into the type we are now considering, the working substance being then steam gas.

243. A simple, thermodynamically perfect form of external- combustion air-engine would be one following Carnot’s cycle (§ 40), in which heat is received while the air is at the highest tempera­ture τ1, the air meanwhile expanding isothermally. After this the supply of heat is stopped, and the air is allowed to expand adia­batically until its temperature falls to the lower extreme τ2. At this it is compressed isothermally, giving out heat, and finally the cycle is completed by adiabatic compression, which restores the initial high temperature τ1.

244. In place of adiabatic expansion as a means of changing the temperature from τ1 to τ2 we may follow Stirling’s plan (§ 54) of

storing the heat in a re­generator, from which it will afterwards be taken up and so produce the elevation of temperature from τ2 to τ1 which in the above cycle was per­formed by adiabatic com­pression.

Stirling’s air-engine, in which the action approximated to the perfect cycle described in § 54, is diagramatic- ally shown in fig. 141. A is a closed vessel containing air, externally heated by a furnace beneath it. A pipe from the top of A leads to the working cyl­inder B. At the top of A is a refri­gerator C, consisting of pipes through which cold water circulates. In A there is a displacer plunger D, which is driven by the engine ; when this is raised the air in A is heated, whereas when D is lowered the air in A is brought into contact with the refriger­ator and cooled. On its way from the bottom to the top of A, or *viee versa,* the air must pass through an annular lining of wire-gauze E. This is the regenerator. At the beginning of the cycle D is up. The air is then receiving heat at τ,, and is expanding isothermally ; this is the first stage in § 54. Then the plunger D descends. The air is driven through the regenerator, where it deposits heat, and its temperature on emerging at the top is τ2. Next, the working-

@@@1 See *Min. Proc. Inst. C.E.,* vol. xxix., 1884 ; also *Proc. Inst. Mech. Eng.,* 1880.

@@@2 *Proc. Inst. Mech. Eng.,* 1879.

@@@3 *Proc. Inst. Mech. Eng.,* 1878, 1881.