all. Near the close of its career the atmospheric engine was much improved in its mechanical details by Smeaton, who built many large engines of this type about the year 1770, just after the great step which was to make New­comen’s engine obsolete had been taken by James Watt.

Compared with Savery’s engine, Newcomen’s had (as a pumping-engine) the great advantage that the intensity of pressure in the pumps was not in any way limited by the pressure of the steam. It shared with Savery’s, in a scarcely less degree, the defect already pointed out, that steam was wasted by the alternate heating and cooling of the vessel into which it was led. Though obviously cap­able of more extended uses, it was in fact almost exclu­sively employed to raise water,—in some instances for the purpose of turning water-wheels to drive other machinery. Even contemporary writers complain of its “ vast con­sumption of fuel,” which appears to have been scarcely smaller than that of the engine of Savery.

11. In 1763 James Watt, an instrument maker in Glasgow, while engaged by the university in repairing a model of Newcomen’s engine, was struck with the waste of steam to which the alternate chilling and heating of the cylinder gave rise. He saw that the remedy, in his own words, would lie in keeping the cylinder as hot as the steam that entered it. With this view he added to the engine a new organ—an empty vessel separate from the cylinder, into which the steam should be allowed to escape from the cylinder, to be condensed there by the application of cold water either outside or as a jet. To preserve the vacuum in his condenser he added a pump called the air-pump, whose function was to pump from it the condensed steam and water of condensation, as well as the air which would otherwise accumulate by leakage or by being brought in with the steam or with the injection water. Then as the cylinder was no longer used as a condenser he was able to keep it hot by clothing it with non-con­ducting bodies, and in particular by the use of a *steam- jacket,* or layer of hot steam between the cylinder and an external casing. Further, and still with the same object, he covered in the top of the cylinder, taking the piston-rod out through a steam-tight stuffing-box, and allowed steam instead of air to press upon the piston’s upper surface. The idea of using a separate condenser had no sooner occurred to Watt than he put it to the test by constructing the apparatus shown in fig. 5. There A is the cylinder, B a surface condenser, and C the

air-pump. The cylinder was filled

with steam above the piston, and

a vacuum was formed in the sur­

face condenser B. On opening

the stop-cock D the steam rushed

over from the cylinder and was

condensed, while the piston rose

and lifted a weight. After seve­

ral trials Watt patented his im­

provements in 1769; they are

described in his specification in

the following words, which, apart from their immense historical interest, deserve careful study as a statement of principles which to this day guide the scientific develop­ment of the steam-engine :—

“ My method of lessening the consumption of steam, and conse­quently fuel, in fire-engines, consists of the following principles :—

*“First,* That vessel in which the powers of steam are to be employed to work the engine, which is called the cylinder in common fire-engines, and which I call the steam-vessel, must, during the whole time the engine is at work, be kept as hot as the steam that enters it ; first by enclosing it in a case of wood, or any other materials that transmit heat slowly ; secondly, by surround­ing it with steam or other heated bodies ; and, thirdly, by suffering neither water nor any other substance colder than the steam to enter or touch it during that time.

*“Secondly,* In engines that are to be worked wholly or partially by condensation of steam, the steam is to be condensed in vessels distinct from the steam-vessels or cylinders, although occasionally communicating with them; these vessels I call condensers; and, whilst the engines are working, these condensers ought at least to be kept as cold as the air in the neighbourhood of the engines, by application of water or other cold bodies.

*“Thirdly,* Whatever air or other elastic vapour is not condensed by the cold of the condenser, and may impede the working of the engine, is to be drawn out of the steam-vessels or condensers by means of pumps, wrought by the engines themselves, or otherwise.

*“Fourthly,* I intend in many cases to employ the expansive force of steam to press on the pistons, or whatever may be used instead of them, in the same manner in which the pressure of the atmo­sphere is now employed in common fire-engines. In cases where cold water cannot be had in plenty, the engines may be wrought by this force of steam only, by discharging the steam into the air after it has done its office. . . .

*“Sixthly,* I intend in some cases to apply a degree of cold not capable of reducing the steam to water, but of contracting it con­siderably, so that the engines shall be worked by the alternate expansion and contraction of the steam.

*“ Lastly,* Instead of using water to render the pistons and other parts of the engine air and steam tight, I employ oils, wax, resin­ous bodies, fat of animals, quicksilver and other metals in their fluid state. ”

The fifth claim was for a rotary engine, and need not be quoted here.

The “ common fire-engine ” alluded to was the steam- engine, or, as it was more generally called, the “atmo­spheric” engine of Newcomen. Enormously important as Watt’s first patent was, it resulted for a time in the production of nothing more than a greatly improved engine of the Newcomen type, much less wasteful of fuel, able to make faster strokes, but still only suitable for pumping, still single-acting, with steam admitted during the whole stroke, the piston, as before, pulling the beam by a chain working on a circular arc. The condenser was generally worked by injection, but Watt has left a model of a surface condenser made up of small tubes, in every essential respect like the condensers now used in marine engines.

12. Fig. 6 is an example of the Watt pumping-engine of this period. It should be noticed that, although the top of the cylinder is

closed and steam has ac­

cess to the upper side of

the piston, this is done

only to keep the cylinder

and piston

warm. The

engine is still

single-acting ;

the steam in

the upper side

merely plays

the part which

was played

in Newcom­en’s engine

by the atmo­sphere; and it

is the lower

end of the

cylinder alone

that is ever

put in commu­nication with

the condenser.

There are three

valves, — the

“ steam ” valve *a,* the “ equilibrium ” valve *b,* and the “ ex­haust ” valve *c.* At the beginning of the down-stroke *c* is opened to produce a vacuum below the piston and *a* is