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Engine Cooling

10.1. Introduction

Although most text books on thermodynamics contain sufficient information for the determination of thermal efficiency of various types of heat engines in everyday use, the true state of affairs is seldom appreciated. Thermal efficiency η, which is defined as the ratio of $\frac{\text{Heat supplied} - \text{heat rejected}}{\text{heat supplied}}$ amounts to barely 28% for average gasoline engines and notable improvements of this figure are not easily attainable. An approximate heat balance chart is shown in Table 10.1.

Table 10.1

Heat converted into useful work	28%
Heat rejected with exhaust gases	43%
Heat dissipated by coolant	20%
Heat lost to lubricants by radiator etc.	9%
*HEAT SUPPLIED	100%

**Note* HEAT SUPPLIED
The specific gravity of petrol varies between ·70 and ·77, and the gross calorific value amounts to about 18,700 Btu/lb. If the thermal efficiencies of various engines are to be compared it is suggested that gasoline from the same barrel is used or, if this is impossible, determine the specific gravity and calorific value of the petrol used to permit calculation of the exact amount of heat supplied to the engine on test and thus make an equitable comparison. The reasons for the apparent wide variation of specific gravity are rather complex and have to do with the refining process of the respective gasoline. It should be noted that the calorific value of a fuel is not related to its octane rating, nor does it vary significantly with octane number; consequently nothing is to be gained by using a fuel with a higher octane number than that required by the particular engine.

Very large marine and stationary type Diesel engines may, by comparison, have thermal efficiencies of up to 42%.

Strictly speaking, the expression 'thermal efficiency' describes a rather complex relationship which takes into account the proportion of potential heat converted and the dynamics of combustion, which depends upon the fuel/air ratio, the proportion and constitution of the vaporised fuel, the composition of the fuel itself, ignition effectiveness, mixture turbulence, mixture temperature and chamber wall temperature.

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Various factors have determining effects on thermal efficiency, as for instance the compression ratio. The empirical relationship between thermal efficiency and compression ratio is shown in Fig. 10.1. Similarly the higher the permissible engine running temperature, the higher the thermal efficiency – axioms which apply to reciprocating and to RC engines alike. Extreme caution would appear appropriate in the case of Wankel RC engines, as results achieved so far suggest that at best the relationship between compression ratio and thermal efficiency is only approximately within the limits shown for compression ratios of 6 to 1 up to 10 to 1.

The highest permissible compression ratio of an engine is affected by the anti-knock quality of the fuel, usually expressed by the Octane number or rating of the respective gasoline. Detonation or knock can, of course, also be promoted by excessive engine temperature or local hot spots, nevertheless it seems that the highest permissible temperatures of the pistons, the cylinders, the cylinder head and valves etc., is still of overriding

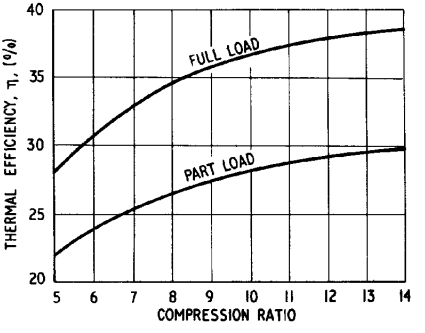


Fig. 10.1. The greatest care is necessary with regard to the relationship of thermal efficiency and compression ratio because actual values for specific engines depend on many virtually imponderable factors. This figure illustrates therefore, only a general trend

importance, bearing in mind that combustion temperatures in excess of 2,000°C are high enough to melt aluminium, cast iron and even steel. Fortunately, there is a difference between maximum momentary combustion gas temperature and piston or cylinder wall temperatures; it is one of the tasks of the cooling system to prevent or even out any tendency towards local hot spots. As present day automotive engines run at average coolant temperatures of 70°–90°C, higher temperatures seem desirable because they raise thermal efficiency and can bring about cleaner exhaust emission. However, this must not be achieved at a sacrifice of volumetric efficiency and subsequent power loss, or lead to excessive vaporisation or involuntary ignition. Surface temperatures of components in direct contact with the combustion process or the exhaust gases are, of course, greatly in excess of the above quoted figure. Nevertheless, these parts must retain sufficient strength to withstand the pressures and strains to which they are subjected without significant distortion. Running the engine at too low a temperature not only reduces thermal efficiency, but may prevent satisfactory vaporisation of the fuel with detrimental effects upon ignition and combustion, not to mention undesirable dilution of the lubricating oil. In the Wankel RC engine conditions are not entirely the same; for instance, only the rotor casing and rotor must retain sufficient strength at the running temperature to contain the high pressure and high temperature mixture. There is no possibility of lubricant dilution by unburned petrol since sealing grid lubrication relies entirely upon the total loss

lubrication. Moreover. the rotor casing and the rotor of the NSU/KKM 502 and of Toyo Kogyo twin rotor RC engines are made from conventional engineering materials – aluminium and/or cast iron – whilst the apex seals are made from a special type of carbon which is inherently capable of operating satisfactorily at much higher temperatures.

The real problem of ensuring optimum engine temperature over a wide load and speed range is complicated by the fact that car engines run characteristically mostly under part load conditions. For instance, it has been found that according to the U.S.A. driving pattern an automobile engine spends

15% of its life idling
16% of its life at constant speed
32% of its life under overrun conditions – engines pushed by inertia.
37% of its life accelerating.

The percentage of its life where an engine runs under full load and particularly at maximum power and speed must, therefore, be very small indeed, and depends very largely upon road conditions and driver temperament.

Since conventional gasoline fuel is required by the Wankel RC engine and its specific fuel consumption in lb/b.h.p./hr, is, for practical purposes, the same as that of equivalent power reciprocating piston engines, it follows that gas temperatures will also be very similar to those of conventional piston engines, though in the absence of potential hot spots, of valves, valve springs and valve operating devices, higher engine running temperatures seem feasible in future. Meanwhile it may safely be assumed that the heat dissipation capacity of the Wankel engine's cooling system as a whole will differ very little from that of the reciprocating piston engine. It is the local conditions over the combustion and expansion arc of the rotor housing, as well as in the region of the exhaust port, which are different because of uninterrupted contact with the hot gases. In other words, a far greater thermal demand is made upon the particular portion of the rotor casing – conditions for the rotor are less critical because every rotor flank comes in contact with the cold induction charges – and a far more sophisticated coolant flow pattern is required if the rotor casing temperature is to be kept within permissible limits. Cooling systems ranging from complete liquid cooling to complete air cooling have been developed for a wide variety of engine sizes and applications. According to accumulated experience NSU rate the capabilities of their RC engines relative to the cooling system as in Table 10.2.

Table 10.2

Cooling Medium		*Maximum b.m.e.p. %*
Rotor Housing	*Rotor*	
Water	Oil—Peripheral inlet ports	100
Water	Oil—Side inlet ports	85
Air	Oil—Peripheral inlet ports	90
Water	Mixture Side inlet ports	75
Air	Mixture Side inlet ports	60

N.B. Mixture = Combustible Mixture.

The few parts of a single rotor Wankel RC engine which require cooling are:

1. The rotor housing containing the epitrochoidal bore.
2. The two end covers or housings.
3. The rotor.
4. The sealing elements, especially the apex seals.

As may be partly deduced from Figs. 7.9 and 8.3, the rotor housing presents the most formidable cooling problem on account of the high local gas velocities (transfer velocities plus turbulence) during the combustion phase, which contribute to the high heat transfer rates, especially in the region of the spark plug and at the exhaust port. The comparatively high exhaust gas temperature at full throttle and high b.m.e.p. figures is at least partly due to the extended combustion, which, under certain circumstances, extends right up to the moment when the exhaust port opens. Admittedly research into means and methods of speeding combustion has barely begun, but the portents are certainly promising. Meanwhile improved and temperature responsive local cooling round the critical sections of the epitrochoidal bore seem to give satisfactory results.

10.2. Air Cooling

The problem of the greater thermal demands on sections of the rotor housing was thought to restrict air cooling to the smaller and lower powered RC engines unless above-average power requirements of the cooling system are acceptable. Although NSU and other licensees have devoted considerable effort to the development of various smaller single and twin rotor air cooled engines, Curtiss-Wright have shown that 310 b.h.p. air cooled aircraft type Wankel RC engines with a bare dry weight of 285 lb are entirely practical. To achieve this the Curtiss-Wright 'design study took a different approach and held that the engine could be cooled effectively provided a break with the traditional high volume low pressure system was made in favour of a high pressure low flow system, tailored closely to the heat input variation of this particular engine type. Since the cooling power is directly proportional to flow quantity and pressure drop, the total cooling power could be comparable even if the relative balance shifted.' The analysis of various cooling arrangements yielded fundamental conclusions which seemed practical from the design and manufacturing point of view. The following commended itself to the Curtiss-Wright research team:

1. Closely crowded cooling fins, machined round the periphery of the rotor housing.
2. Air circulation to be accelerated over the hot arc of the engine.
3. Air circulation to be retarded over the cooler part of the rotor housing by widening the effective passages in diffuser fashion in the axial and radial direction.
4. By trimming back the fins, which reduced the effective cooling area and increased the air passage still further. Fig. 10.2.
5. Excess air not required for cooling the rotor housing to be diverted for cooling the area of the exhaust port.