6.5. Surface/Volume Ratio

The surface/volume ratio is often quoted as a relationship which allows conclusions about the interplay of the actual heat release during combustion and the proportions of the combustion chamber. Nevertheless it is doubtful whether it has much more than red herring value. Text books preserve a virtually ominous silence on this subject, and there is little controversy about it in professional automobile engineering circles.

By way of definition it may be assumed that by the surface/volume ratio is meant the relationship between the minimum volume within a cylinder when the piston is at the t.d.c. position and the relevant surface is the surface area of the chamber when the volume is at its minimum.

Assuming a fixed displacement volume, a hemispherical cylinder head matching up to a 76 mm diameter bore which contains a flat top piston. Considering compression ratios (ε) of 10 to 1 and 5 to 1, the surface/volume ratio for an ε of 10 to 1 =

$$\frac{136{\cdot}09379}{114{\cdot}92424} = 1{\cdot}1842\ \text{cm}^{-1}$$

and when ε is 5 to 1 the surface/volume ratio =

$$\frac{211{\cdot}70152}{258{\cdot}57965} = 0{\cdot}81870\ \text{cm}^{-1} = 100\%$$

$$\text{and } \frac{1{\cdot}1842}{0{\cdot}8187} = 144{\cdot}64\%$$

This means that high compression ratio engines have necessarily inferior surface/volume ratios which approach infinity towards the absolute limit.

Furthermore, it is imperative to state precisely the units used in calculating a particular surface/volume ratio. For example, the Surface/volume ratio of the above 76 mm diameter chamber for a compression ratio of 10 to 1 is, in metric units,

$$\frac{136{\cdot}09379}{114{\cdot}92424} = 1{\cdot}1842\ \text{cm}^{-1}$$

whilst in Imperial units—square and cubic inches respectively—it amounts to

$$\frac{136{\cdot}09379}{114{\cdot}92424} \times 2{\cdot}54 = 3{\cdot}008\ \text{in}^{-1}$$

Some of the factors which have a determining influence upon the significance of the surface/volume ratio are, for example:

1. The material of the chamber walls—cylinder head and piston.
2. The heat transfer capacity of the respective material.
3. The wall temperatures under operating conditions.
4. Factors 2 and 3 obviously alter as carbon deposits build up on the surface.
5. Chamber shape, turbulence, ignition timing, presence of an oil film etc.

Nor is it yet possible to incorporate the innumerable variables into some formula so that a computer could work out a valid comparative index figure.

Whilst throwing doubt on the significance of the surface/volume ratio, it is not intended to ridicule its consideration, but to suggest that it poses a most complex problem so that perfectly valid conclusions applicable to reciprocating piston engines cannot be applied simply because both types of engines rely upon the same thermodynamic cycle. Due to the different conception of the RC engine mechanism there are unavoidable differences in the internal gas velocities and different heat loss factors are applicable because the whole mass of the mixture is moved round. Recognition of these factors is important and indicates a point where certain research and development may start.

Perhaps it should be frankly admitted that not enough is known to date about the surface/volume relationship, even of the conventional reciprocating piston engine, to allow any conclusions, applicable to the reciprocating piston engine, to be presented as irrevocable criteria permitting a forecast concerning combustion phenomena in the Wankel RC engine. Of course, no engine designer will deliberately include seemingly undesirable features in his design, and this includes an unrealistic surface/volume relationship. In cases of doubt, as in this instance, special care is required in the design stages lest undesirable influences gain determining significance. This seems perfectly feasible in the case of the surface/volume ratio by arranging that neither hot spots nor local overcooling can occur. It should perhaps be emphasised that research into these aspects of performance has already permitted pin-pointing of certain parameters of the surface/volume relationship relative to performance; nevertheless, a great deal more research effort seems necessary before the significance of this relationship can be exhaustively interpreted for all circumstances and applications.

Those who may wish to look deeper into the problems associated with the surface/volume relationship are obliged to calculate the relevant bore areas and that of a rotor flank.

The length of the trochoidal bore when the minimum volume is contained between it and a rotor flank is found as follows, using Fig. 6.14.

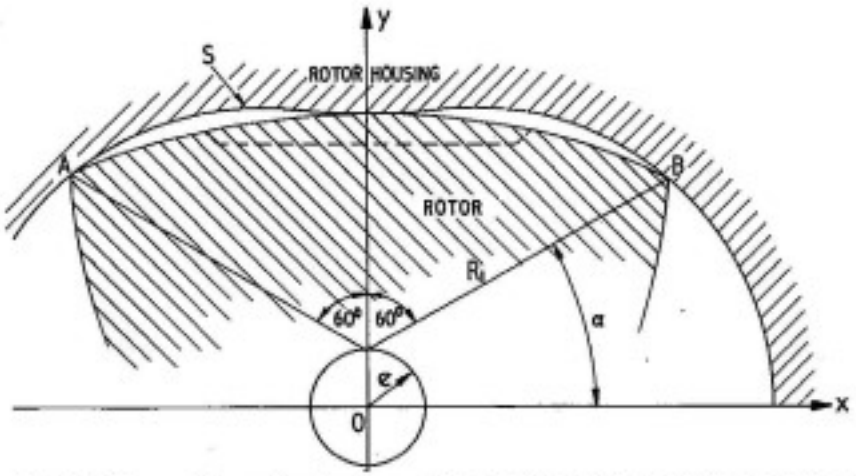


Fig. 6.14. A fractionally less favourable surface/volume ratio is obtained by calculating S according to Equation 6.25 which seems adequate for most practical purposes since the value of the surface/volume ratio for comparative evaluation is suspect. Accurate results are obtainable by using Equations 3.3a and 3.4a. (Fig. 3.5) for the calculation of the rectangular co-ordinates of the requisite points on the curve and by altering Equations 6.24 and 6.25

Length s of locus of point P

$$\begin{aligned} x &= e\cos 3\alpha + R_1\cos\alpha \\ y &= e\sin 3\alpha + R_1\sin\alpha \\ \mathrm{d}x &= (-3e\sin 3\alpha - R_1\sin\alpha)\mathrm{d}\alpha \\ \mathrm{d}y &= (+3e\cos 3\alpha + R_1\cos\alpha)\mathrm{d}\alpha \\ \mathrm{d}x^2 &= (9e^2\sin^2 3\alpha + R^2\sin^2\alpha + 6eR_1\sin\alpha\sin 3\alpha)\mathrm{d}\alpha^2 \\ \mathrm{d}y^2 &= (9e^2\cos^2 3\alpha + R^2\cos^2\alpha + 6eR_1\cos\alpha\cos 3\alpha)\mathrm{d}\alpha^2 \\ \mathrm{d}x^2+\mathrm{d}y^2 &= 9e^2 + R_1^2 + 6eR_1(\sin\alpha\sin 3\alpha + \cos\alpha\cos 3\alpha)\mathrm{d}\alpha^2 \\ &= (9e^2 + R_1^2 + 6eR_1\cos 2\alpha)\mathrm{d}\alpha^2 \end{aligned} \tag{6.24}$$

since $\sin\alpha\sin 3\alpha + \cos\alpha\cos 3\alpha = \cos 2\alpha = 1 - 2\sin^2\alpha$

$\sin A\sin B + \cos A\cos B = \cos(A-B)$

$$\begin{aligned} S &= \int\sqrt{[9e^2 + R_1^2 + 6eR_1\cos 2\alpha]}\,\mathrm{d}\alpha \\ &= \int\sqrt{[9e^2 + R_1^2 + 6eR_1 - 12eR_1\sin^2\alpha]}\,\mathrm{d}\alpha \\ &= \int(3e + R_1)\sqrt{(1 - k^2\sin^2\alpha)}\,\mathrm{d}\alpha \end{aligned} \tag{6.25}$$

where $k^2 = \dfrac{12eR_1}{(3e+R_1)^2}$

The answer is an elliptical integral of the second order. If e and R_1 are known it may be worked out with the assistance of tables of elliptical integrals.

Since the rotor flank contour is derived from the actual bore, that is it is generated by a curve parallel to a true epitrochoid, it seems unjustified to exert considerable mathematical effort in order to find the actual area of a rotor flank, especially if the indispensable depression in every flank is taken into account. Direct measurement of the length of this flank by any convenient means seems adequate, alternatively it is possible to draw a radius which approximately coincides with the rotor contour and calculate the length of the arc.

According to Fig. 6.15 $\sin\theta = \dfrac{R_1\sin\dfrac{\pi}{3}}{R_o}$

where R_o is the radius of the equivalent circular arc and θ is half the subtended angle.

Therefore, the length of arc $= \int = \dfrac{R_o(2\theta)\pi}{180}$

and the approximate flank area (disregarding the depression)

$$= \frac{R_o(2\theta)\pi}{180}B_c \tag{6.26}$$

The shape of the depression will suggest the easiest method by which its surface area/volume may be calculated. Hence the surface volume/ratio =

$$\frac{S\,.\,B_c + 2(A_{\min} - A_r) + \dfrac{R\,.\,(2\theta)\pi}{180}B_c \pm (\text{Area of Depression})^*}{(A_{\min} - A_r)B_c + (\text{Volume of Depression})} \tag{6.27}$$

*When calculating the surface area of the depression it must not be forgotton that the area of the depression, as projected onto the rotor contour, has already been included.

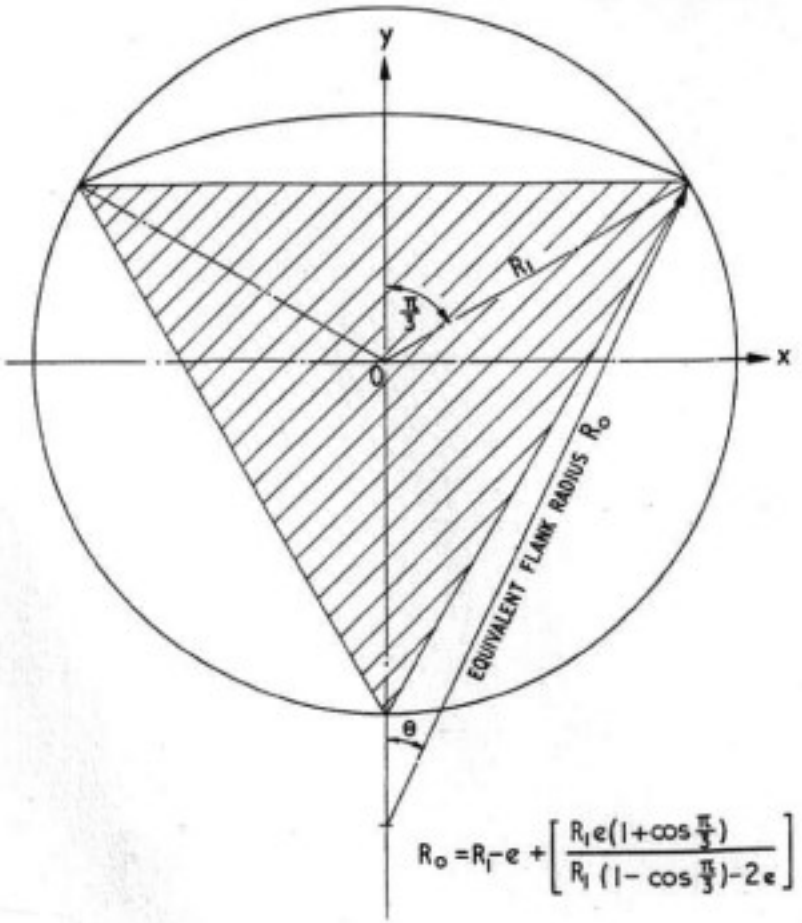


Fig. 6.15.

Charles Jones, in charge of RC engine work at Curtiss Wright, wrote in his S.A.E. paper 886D in 1964:

'The study of RC engine combustion is still in its early stages. Nonetheless, it is apparent that a whole new set of comparative parameters will have to be developed specifically for this engine breed. For example, the over-simplification of the surface/volume ratio falls apart as a valid heat loss index because of the different internal gas velocities, metal temperature distributions, characteristic dimensions for film thickness, and radiation factors. Having mentioned the surface/volume ratio it would be appropriate to add that it is 7·2 for the RC-60, as compared to a range of roughly between 4·5 and 10 for current (American reciprocating piston) engines, with higher compression ratios and increasing bore-stroke ratios tending towards the high end.

Insofar as detonation, pre-ignition, rumble and similar phenomena are concerned, surveys covering a range of compression ratios, rotor combustion chamber configurations and different fuel ratings have indicated the RC engine to be generally similar to automotive engines in these respects'

Considerably more knowledge has accumulated since then but very little is, as yet, available for publication. However, high speed films of the combustion process have revealed that flame propagation is primarily downstream, that is in the direction of rotation. Fig. 6.16 is intended to illustrate this trend. Ionisation detection plugs have confirmed these findings.

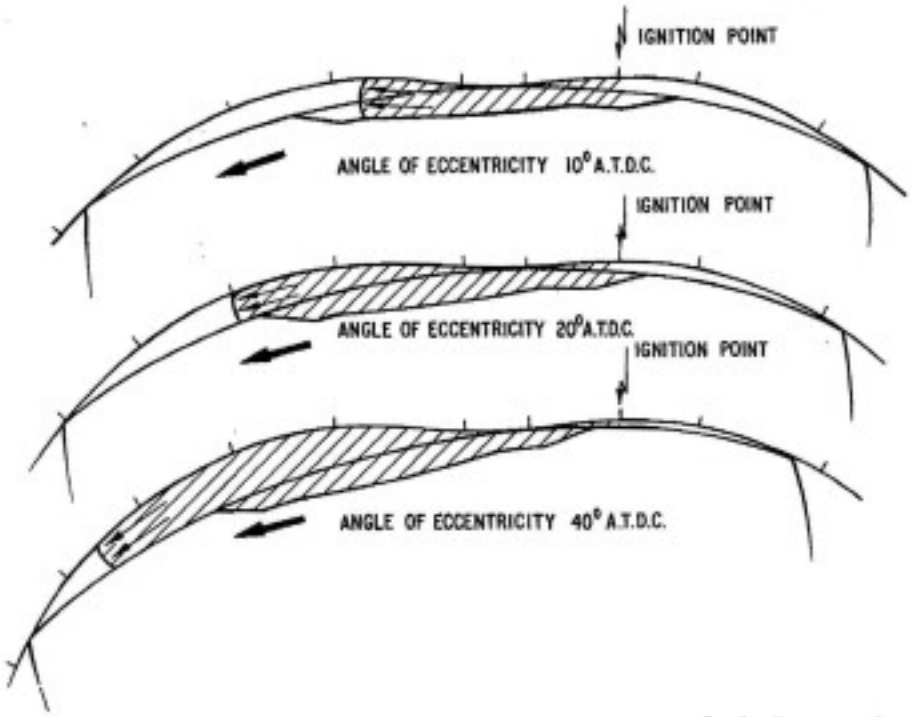


Fig. 6.16. Flame propagation with standard symmetrical depression in rotor flank. Propagation is in direction of rotation only

Dual ignition and reliance upon a plug in either the leading or trailing portion of the chamber can also affect combustion. Fig. 6.17 shows the more sudden rise in pressure and a slimmer expansion curve resulting from reliance upon dual ignition and consequential more rapid heat release. At 4,000 rev/min, combustion is about 3 msec whereas when a single plug is used it takes about 4 msec. The effects of dual ignition and ignition

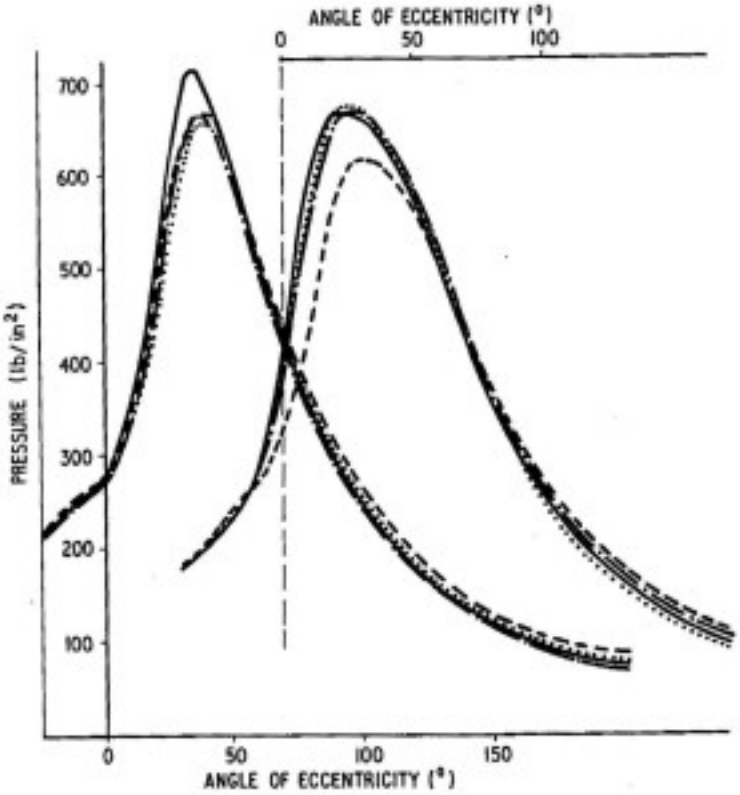


Fig. 6.17. Comparison of the pressure-time variations of an NSU/Wankel RC engine at 5,000 rev/min running with a wide open throttle and firing a single plug and two plugs simultaneously

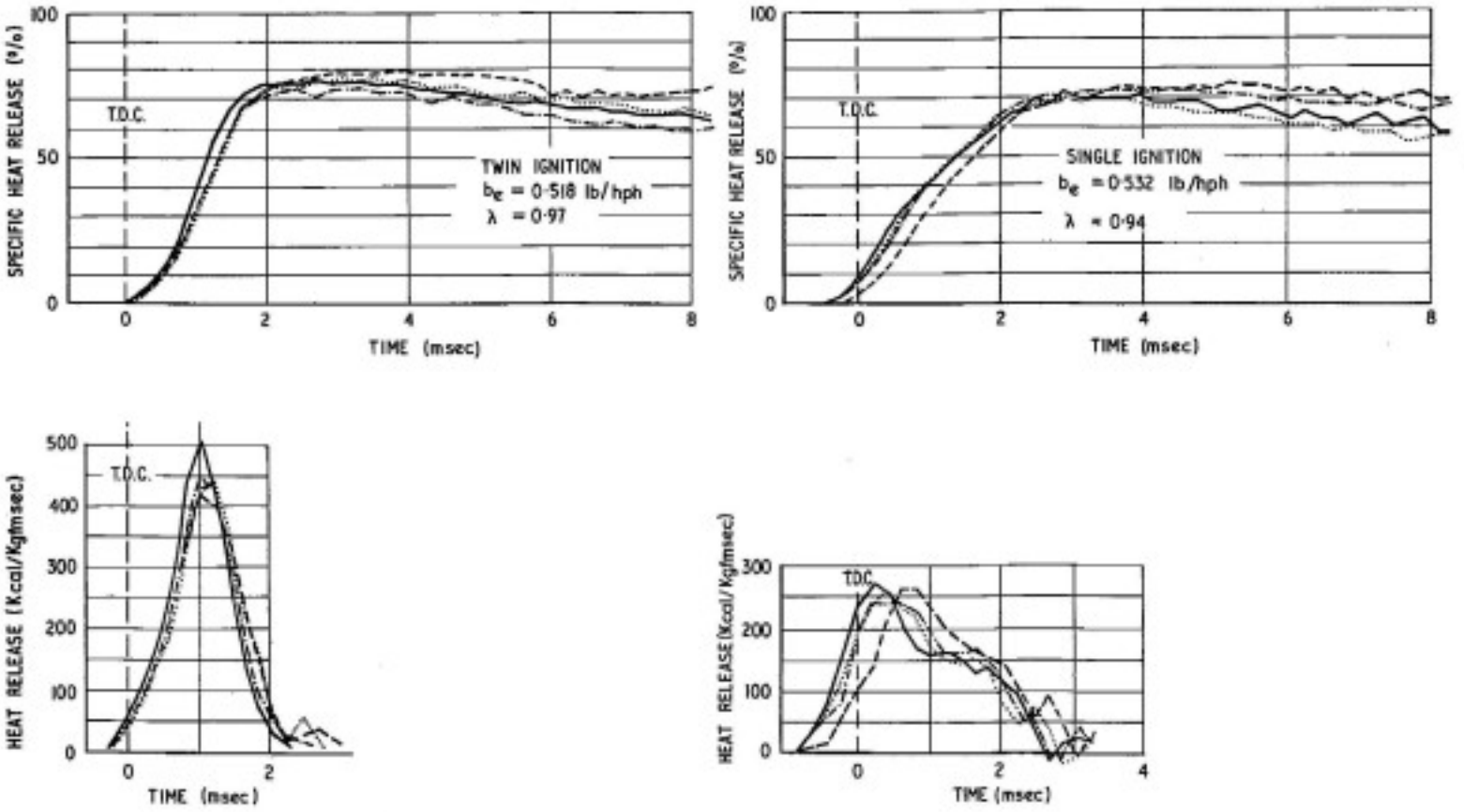


Fig. 6.18. Heat release and specific heat release of NSU/Wankel RC engine at 5,000 rev/min running with a wide-open throttle and firing a single plug and two plugs simultaneously

by a single plug in one of the two alternative positions is shown in Fig. 6.18. Similar results were obtained at 2,000 rev/min, when the heat energy release period was, of course, longer.

Considering the infinite variety of shapes for the depressions in the rotor flanks relative to various spark plug positions, not to mention any possible effects of fuel injection and temperature control of the rotor and the casing, it will be recognised that this may preoccupy research engineers for many years to come. Most important of all, these results suggest that there is greater flexibility in the way combustion may be influenced than there seems to be in reciprocating piston engines.

It would be presumptuous to speculate on the outcome of research into these very complex realms, though there is no reason to believe that the task cannot be accomplished by modern research facilities and techniques.

It is of interest to note the manner in which the surface/volume ratio of the Wankel RC engine varies as the rotor turns. D. J. Lockley, M.Sc., of The B.S.A. Group Research Centre has worked out these variations for the NSU KKM 502 engine, Fig. 6.3, as well as the fundamental relationship between the basic RC engine proportions given by R/e and the surface/volume ratio, Fig. 6.4. These graphs emphasise the importance of extreme caution when comparing instantaneous or maximum surface/volume relationships.

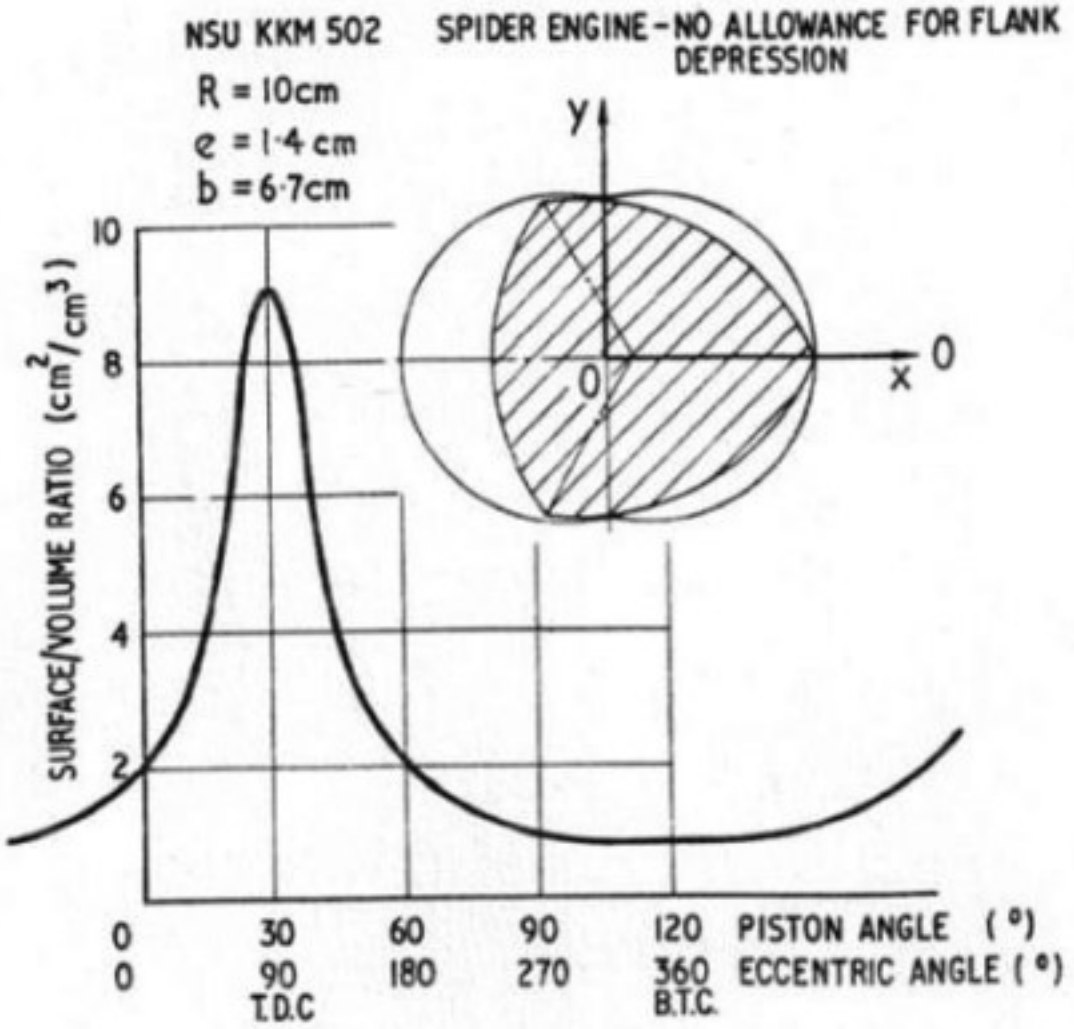


Fig. 6.3. (Taken from Appendix Fig. A.18)

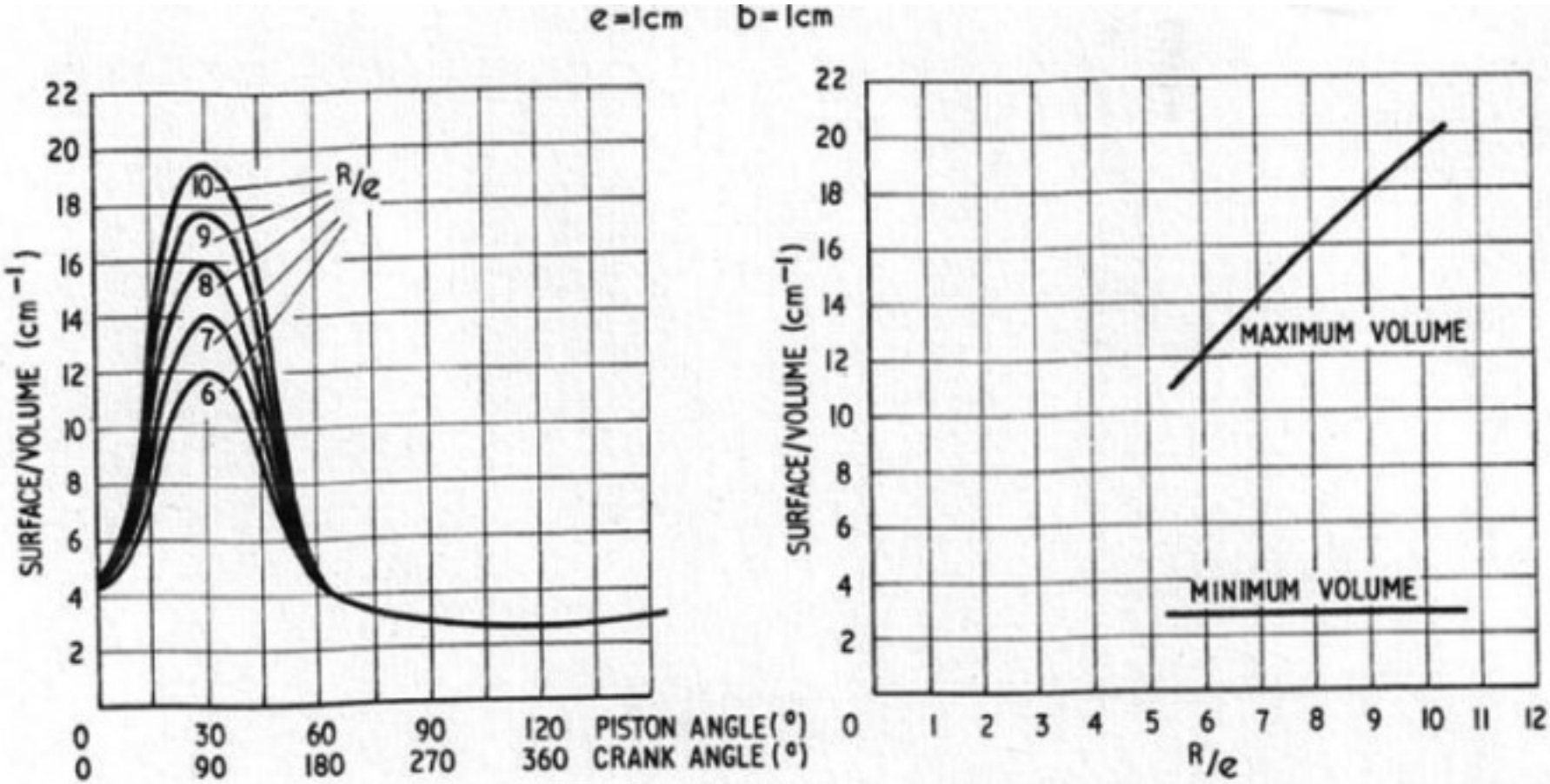


Fig. 6.4. (Taken from Appendix Fig. A.17)

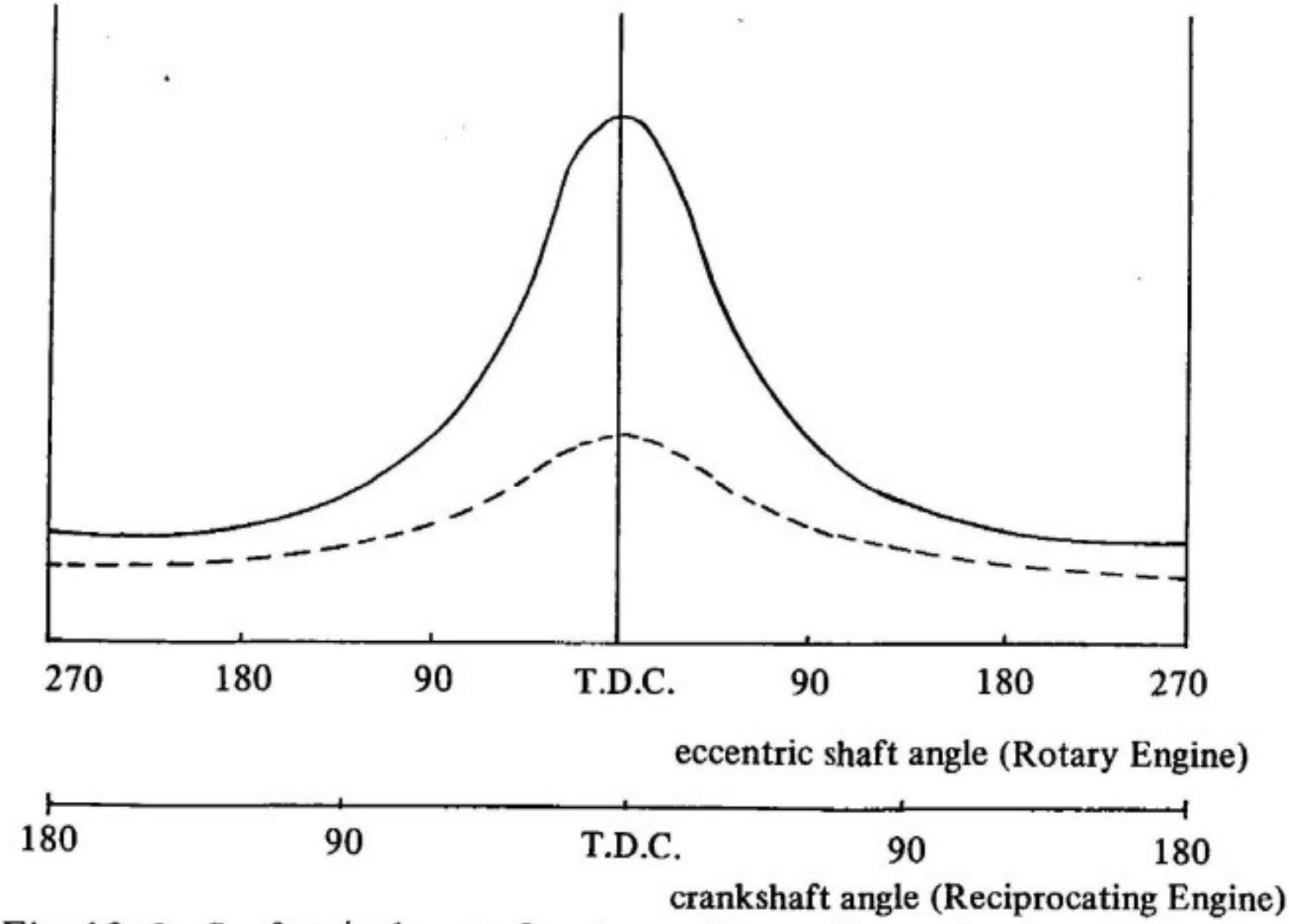


Fig. 13. 2 Surface/volume of reciprocating engine and rotary engine