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Influences of temperature when operating aero-engines by the ring process.

BRIEF OUTLINE: The experiments showed that operation is possible with relatively low cylinder and intake air temperatures. The lowest values are BMW 132 N. 120° cylinder temperature, 20° intake air, Jumo 211: 30° cooling water temperature, 20° intake air, at full load actually without useful output.

Low intake air temperatures give better results down to half load (increase of the maximum load by 10-15%). Low cylinder temperatures too give better results in the region of full load, for part load however an earlier fall in output results. Low temperatures have littleinfluence on consumption in the region of full load, for leaner mixtures cold air and cold cylinders result in high consumption.

Optimum results:

BMW: 80° intake air, 210° cylinder temperature

JUMO: 50° intake air, cooling water temperature 50° to half load, 80° intake air temperature from this point to idling.

The temperature most favourable for the lubricant is 90°C, not 60° and 80° which temperatures have also been experimented with.

PURPOSE OF THE EXPERIMENT: It was to test the performance and consumption of an air cooled and a liquid cooled engine on a single cylinder test-stand by varying the temperatures of the air intake cylinder or of cooling water, and lubricating oil; the optimum combination of these factors was determined.

CARRYING OUT OF THE EXPERIMENT: The experiments were carried out on an I.G. research engine, fitted with a BMW cylinder 132N and a JUMO cylinder 211A. The nozzles used were found in previous experiments to be most suitable for the ring process. The position of the nozzles and the temperature test points of the BMW cylinder can be seen on page 1. The respective arrangement of the B-fuel nozzles, likewise the working conditions are given in Table 1. In Table 2, the experiments are recorded in chronological order. As can be seen from this the experiments were carried out on both cylinders with different R-fuel-consumption; but this is of little importance in the total result, as the corresponding series of tests were carried out with constant R-fuel-quantities per stroke.

TABLE 1: Conditions of Operation for the Engines in Question.

	BMW Cylinder I.G. Test Engine No.1	JUMO Cylinder I.G. Test Engine No. 3	JUMO Cylinder *) I.G. Test Engine No.2
Bore m/m	155	150	
Stroke m/m	162	162	
Capacity litre	3.08	2.86	
Valve timing	Intake opens 20°BTC Intake closes 77°ABC Exhaust opens 76°BBC Exhaust closes 21°ATC	Intake opens 13° BTC Intake closes 45° ABC Exhaust opens 46° BBC Exhaust closes 32°ATC	
Main Fuel	ET 110+0.12% Pb (H_u-10500 kcal/kg)	CV2b+0.12% Pb (H_u-10000 kcal/kg)	50% CV2b+50% ET1 + 0.12% Pb (H_u-10200 kcal/kg)
Main fuel pumps		Bosch PZ 1/100 V 635 a	
Main fuel nozzles	Bosch DB40N6OM6	Bosch DV2313/2 angle of pin 45°	Bosch DB40N6OM6
R-fuel		R 300 (H_u=6880)	
R-fuel pump		Bosch PE 1 B, 6 m.m. - piston	
R-fuel nozzles	Bosch DV 2313/2 angle of pin 20°	Bosch DV 2311 bore diameter 0.4	
Injection Angle: gasoline	30° KW. ATC	35°K ATC	35° ATC
Injection Angle R-fuel (optimum value)	30-70° KW BTC	60-85° KW BTC	75-85°K BTC
Pressure of injection pump for gasoline and R-fuel atü.	1	1	1
Power diameter for gasoline and for R-fuel m/m	1.5	1.5	1.5
R-fuel nozzle position	Plate 1A	Plate 1B	Plate 1C
Pressure of throttle plate mm. of Hg.	760	760	800
Speed revs/min.	2000	2000	2000

*) only used at different oil temperatures (cf. p.7)

RESULT OF THE EXPERIMENTS:

1). B.M.W. Cylinder: Mixture loops at 80°, 50° and 20° air intake temperatures and a constant cylinder temperature of 210° were plotted at first (Plate 2). As can be seen from these curves, working at 50° air intake gives a 5-8% better result over the whole range than working with boost air at 80°, whilst an air temperature of 20° in the rich mixture region up to about 2/3 of the load yields a higher output still; in the weaker region however this results in a steeper fall in output together with a greater increase in consumption. From the point of view of consumption the most favourable performance curve, especially in the weak region, is the one which was obtained under working conditions at 80° intake air. In a second series of experiments the static pressure was adjusted to a constant value. (200 mm. water column) so that with increasing air, excess cooling took place in the cylinder. The results which were now obtained with 3 boost air temperatures, are represented on plate 3. In the rich region the increase in performance is better defined owing to colder intake air. The reason for this can be seen in the somewhat lower cylinder temperature of 175°C (as opposed to 210° previously), which lowers the local heating of the mixture to a certain extent. The increase in performance at full load and 50° air intake is 5 per cent, and at 20° about 8 per cent as compared to what it was at 80°. At λ = 1.4 the performance drops under the 80° curve and at an air excess of 1.6 at 20° and 50° boost air temperature the engine ceases to run and the cylinder temperature has fallen to 120°C. In the rich mixture region consumption has about the same value as in tests with constant cylinder temperatures. Minimum values are however not obtained with uniform cooling. For all experiments the performance and measured combustion air quantities for constant air excess are shown in Table 2. (The values were not taken at full load, but at a value corresponding to λ = 1.1 to eliminate irregularities of the curve through shifting of the maximum position) In the adjacent columns the increase in performance and boost air quantities are tabulated in comparison with the lowest values obtained at 80° On comparing figure 2 and values in table 2 (cf. 1, 2 and 3) there is hardly any difference in performance at the maximum load and similarly at λ =1.1 there is no comparable increase in performance with increase in the quantities of air used, whilst in the following experiments (14,13 and 12) the increase in performance and in combustion air is of the same order so that one can conclude, that the combustion of the mixture is the same in this case for all three air temperatures; whilst previously the cylinder temperature was too high and this resulted in an irregular combustion in the rich mixture region. The better performance at low air temperatures can be explained by a better weight distribution of the load in the cylinders.

On plate 4 for both series of experiments the output is plotted against the consumption. One sees here once more that the influence of the wall temperature in the case of the hotter cylinders has even a greater effect than the intake air temperature, and thus there is a great increase in output with cold intake air.

Exhaust temperatures and injection advance angles in the case of R-fuel behaved very similarly in both series of experiments and showed little variation with change in temperature.

2). JUMO - cylinder: Experiments similar to the first ones on the BMW cylinders with constant cylinder temperatures were carried out in this case at 80°, 50° and 20° respectively. As can be seen from plate 5, intake air at 50° results in a rise in the maximum performance of 12 per cent compare with 80°. This increase in performance remains fairly constant up to an air excess of 1.75. The fall in air temperature to 20° results in an increase in performance in the rich mixture region (in the best case by about

16 per cent at $\lambda = 1$); however in consequence of poorer combustion an earlier fall in performance sets in (at $\lambda = 1.5$) below the performance curve reached at 80° boost air temperature. On comparing the flow of air quantities on Table 2 with the increase in performance, it is seen that the extra output is obtained as in the case of the BMW cylinder by better filling of the cylinder. The following holds good for both engine models: Favourable performance in the rich mixture region at low intake air temperatures. Low consumption and slowly decreasing performance in the weak mixture field (from half load) at high air temperature.

In a second series of experiments the cooling water temperature was altered to 55°C, whilst previous intake air temperatures (80,50 and 20°) were retained. The curves obtained on Plate 6 have a similar shape as at 80° cooling water temperature (Plate 5), the best values of those experiments however cannot be realised.

The results of the conclusive experiments with 30° cooling water temperature are shown on Page 7. Mixture loops were drawn only in the unfavourable range of temperatures of 50° and 20°. The decrease in maximum performance is considerable in the case of cold intake air (10.5 per cent) as a result of incomplete combustion in the cylinder. As can be seen from the exhaust temperature after burning takesplace in the exhaust pipe, the consumption at this point reached the lowest value of 2400 kg. cals/HP/hr. compared to 2000 kg. cals/HP/hr. at 50° air and 80° cooling water temperature. For the last 5 experiments the comparison between performance and combustion air used is interesting (numerical Table 2). Though it was found at 80° cooling water temperature that the increase in performance corresponded very nearly to the extra air used at 55° cooling water temperature the performance increased with colder intake air only by 7.2%,on the other hand the intake air quantity increase as previously by 17 per cent, i.e. the combustion at this stage had already become somewhat worse. This is even more noticeable in the case of the last experiments, where the performance not only does not increase in spite of the increase in the supply of combustion air by 5.3%, but decreases by about approximately 6.5 per cent.

The experiments with a constant intake air temperature are reproduced on pages 8, 9 and 10. The comparison of the two different charts shows that at high air temperature the alteration of cooling water temperature is of little importance, whilst a change in boost air temperature results in a bigger difference in output. If conditions of combustion are influenced by low water and air temperature, all changes whether in cooling water or air are very noticeable (Plate 7 and 10).

The injection advance angles are slightly higher for the JUMO than for the B.M.W. cylinder. But in this case too no definite relationship for the temperature can be ascertained. For large injection advance angles slight knocking occurred between $\lambda = 1.0$ and $\lambda = 1.3$ at high temperatures and retarding the pre-injection was necessary (cf. Plates 5 and 6). For all the experiments performances are plotted against consumption on Plate 11.

Influence of the lubricating oil Temperatures.

These experiments were carried out on a different test bed under different external conditions and thus they are not strictly comparable with the previous experiments (cf. numerical Table 1 and 2) The boost air temperature was delivered here under a pressure of 800 mm. Hg, and higher loads were achieved. Experiments were carried out at the lubricating oil temperatures of 60°, 80° and 90°, whilst the cooling water and boost air temperatureswere kept the same. The results can be found on Plate 12. It is evident from here that with a higher oil temperature a somewhat better performance was obtained. The consumption thus is less in the weaker mixture region. With an air excess of 2.0 the decrease of consumption at 80° oil temperature amounts to about 10% in comparison with 60°, at 90° oil temperature 14.5%; for all three experiments the injection advance angles were kept in the same position.

Plate 1. Nozzle Arrangement.

Plate 2. Tests on the BMW. 132 N with different boost air temperatures at constant cylinder temperatures (210°)

Plate 3. Tests on BMW.132N with different boost air temperatures with constant cooling air static pressure (200 mm. water column)

Plate 4. Tests on BMW 132N Consumption characteristic curves.

Plate 5. Tests on JUMO 211A at 80° cooling water temperature.

Plate 6. Tests on JUMO 211A at 55° cooling water temperature.

Plate 7. Tests on JUMO 211A at 30° cooling water temperature.

Plate 8. Tests on JUMO 211A at 80° boost air temperature. Influence of the cooling water temperature. Test No.134 and 137.

Plate 9. Test on JUMO 211A at 50° boost air temperature. Influence of cooling water temperature. Test No.135, 138 and 139.

Plate 10. Test on JUMO 211A at 20° boost air temperature. Influence of cooling water temperature. Test No.136, 187, and 186.

Plate 11. Tests on JUMO 211A

Plate 12. Tests on JUMO 211A at 80° cooling water temperature. Influence of oil temperature.

TABLE 2. TEST PLAN

Test No.	Engine	TEMPERATURES: Cylinder °C	TEMPERATURES: Cooling Water °C	TEMPERATURES: Intake Air °C	TEMPERATURES: Lubricating oil °C	Cooling Air Static Pressure mm. Water Column.	R-Fuel Quantity cu.mm/stroke	AIR: Air Consumption Kg/hr.	AIR: Increase in air Quantity per cent	PERFORMANCE: MEP λ = 1.1 atm.	PERFORMANCE: Increase by contrasting with 80° intake air temp. %	Result shown on Page.
1	BMW 132 N test engine 1	210	-	80	85	regulated	32	171.5	Ø	8.3	Ø	2 & 4
2		210	-	50	85	"	32	184.1	7.35	8.6	3.6	
3		210	-	20	85	"	32	195.8	14.2	8.8	6	
12		decreasing with air excess.	-	20	85	200	38	173.8	Ø	8.1	Ø	3 & 4
13			-	50	85	200	38	184	5.6	8.8	8.6	
14			-	80	85	200	38	192.8	11	9.1	11.1	
134	Jumo 211A test engine 3	-	80	80	85	-	20	182	Ø	8.5	0	
135		-	80	50	85	-	20	205	12.6	9.6	14.7	5
186		-	80	20	85	-	20	214	17.6	10.1	18.8	
137		-	55	80	85	-	20	183.5	Ø	9	0	
138		-	55	50	85	-	20	199	8.45	9.4	4.5	
187		-	55	20	85	-	20	214.5	17	9.7	7.2	6
139		-	30	50	85	-	20	204.5	0	9.3	Ø	
186		-	30	20	85	-	20	216.5	5.3	8.7	-6.5	7
213	Jumo 211A test engine 2	-	80	80	60	-	22	-	-	-		
213		-	80	80	80	-	22	-	-	-		12
213		-	80	80	90	-	22	-	-	-		