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SURFACE TEMPERATURES OF A DIESEL ENGINE AND IT'S EXHAUST SYSTEM

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SUMMARY

Diesel engines of powered lifting and transporting appliances are often considered sufficiently protected to be safe for use in industrial areas where flammable concentrations of gases and vapours may occur.

The work described in this Note was carried out to obtain quantitative information about the surface temperatures of an air cooled engine and qualitative information regarding emission of sparks and the ability of an air intake filter to function as a flame arrester preventing flashback of flame from the engine to the atmosphere.

The results obtained have shown that dangerously high surface temperature values can be attained on the surfaces of the components of exhaust systems under various working conditions. Sparks and flames were observed in the exhaust system of the engine and it was shown that an oil bath type air cleaner cannot be regarded as a flame arrester.

Suggestions are made as to the modifications and additional appliances necessary to flameproof an engine for safe working in industrial areas in which flammable gas and vapour concentrations may occur.

KEY WORDS: Hot surfaces, Diesel engine.

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JOINT FIRE RESEARCH ORGANIZATION

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INTRODUCTION

Many industrial processes require the use and storage of flammable gases and liquids with relatively low ignition temperatures. In areas classed in Division 1 or Division 2 of the British Standard Code of Practice[1] for the use of electric appliances in flammable atmospheres it may be necessary to use powered lifting and handling equipment. To eliminate the risk of ignition from equipment powered by petrol engines and unprotected electric motors, diesel engines, with starting mechanisms other than electrical, are often used.

With diesel engines some of the possible hazards are - high surface temperatures, emission of sparks from the exhaust system and flashback of flame propagating through the flammable mixtures being drawn into the engine through the air intake system, ignition having been effected by the engine itself. For example, the circumstances of a serious accident involving fire and explosion in a chemical plant[2], which occurred since this work began, have shown that the use of diesel engines in Division 1 areas can provide a source of ignition for flammable atmospheres.

With the co-operation of an engine manufacturer work was carried out with an air cooled diesel engine to measure the temperatures of hot surfaces, to observe for emission of any sparks during normal working of the engine and to test one type of air intake filter for its ability to stop flames propagating in flammable gas mixtures.

In the case of hot surfaces, it was considered necessary to investigate the possibility of simple modification to the air cooling system of the engine as an indication of a method for reducing hot surface temperatures. To achieve the same result the effect on surface temperatures of reducing the power of the engine was also investigated.

The main purpose of the work was to provide information to enable an assessment to be made of the hazard of hot engine surfaces in flammable atmospheres. It was considered that if surface temperatures reached unacceptable values then detailed investigation of the other hazards would not be necessary at this time.

EXPERIMENTAL

Apparatus

A normal commercially available $7\frac{3}{4}$ B.H.P. single cylinder, air cooled diesel engine (Fig 1) with a manual starting mechanism and a fan incorporated in its fly-wheel, was loaned by a manufacturer. The engine exhaust manifold and silencer system were outside the engine cowling inside which air from the fan circulated to cool other parts of the engine. The engine was connected to a single stage centrifugal water pump with a pulley and 'Vee' belt drive system. The pulley ratios could be varied as necessary to constitute part of the load on the engine.

The pump was operated with a flooded intake through a short length of 2 in B.S. pipe from a tank of nominally 230 litres (50 gallons) capacity. The pump delivered back into the tank through $1\frac{1}{2}$ in B.S. piping. The delivery from the pump and thus the load on the engine could be controlled with a hand operated valve, and the pressure in the delivery line from the pump was indicated by a dial pressure gauge.

The whole apparatus was mounted on a steel base 1.52 m x 1.52 m x 6.4 mm thick (5 ft x 5 ft x $\frac{1}{4}$ in thick) supported by four 1.52 m (5 ft) lengths of 152 mm (6 in) I beams.

28 SWG chromel/alumel thermocouples were peened to the silencer, the air inlet and the exhaust outlet and manifold to measure the surface temperatures of those parts of the engine and exhaust system under various working conditions. For some experiments an additional thermocouple was fixed to the rear of the engine block near the cooling air exit. The thermocouple leads were connected to a chart recorder with which their outputs were automatically recorded.

Engine speeds were obtained by measuring the speed of the camshaft with a hand tachometer applied to the end of the camshaft extension, the speed of which was one half that of the crankshaft.

Two spark and flame arrester type silencers were used. Both were of the centrifugal action type in which the exhaust gases and any solid particles are thrown to the interior wall of the appliances in a spiral path before the gases are discharged to atmosphere. One of these appliances with a cast aluminium alloy body was 279 mm (11 in) long and 127 mm (5 in) in diameter at its widest part. Its weight was approximately 1.8 kg (4 lb). The other silencer was 0.44 m (17.5 in) in length and 95 mm (3.75 in) in diameter with its body of 16 gauge metal and its weight was 1.6 kg (3.5 lb).

For one series of tests the power rating of the engine was reduced in accordance with the usual method advocated by the manufacturers and carried out by one of their staff. The engine was regulated to develop approximately 4 brake horse power at 1800 r.p.m. by modification to the fuel injection system.

In the tests in which the air cooling system on the engine was modified in order to indicate a possible method for reducing the surface temperatures of the components of the exhaust system, an aperture 140 mm (5.5 in) x 89 mm (3.5 in) was cut in the engine cowling and a duct 0.64 m long (2 ft) and of 16 gauge steel, which encased the exhaust manifold and the silencer, was fitted to the cowling over the aperture (Fig 2). This arrangement permitted some of the cooling air from the fan to flow over the exhaust system to atmosphere.

During the experiments it was thought convenient to ascertain whether or not temperature indicating stickers could be a practical and reliable method of indicating when parts of an engine were attaining temperatures which would be considered dangerous in the environment in which the engine was being used. Temperature indicating stickers were fixed to the exhaust manifold, the silencer and other parts of the engine.

Observations for sparks were made in a lightproof hood erected over the engine and the exhaust system so that the engine exhaust could be observed against a dark background.

The engine could be fitted with either a paper type intake air cleaner or an oil bath type. For all the experiments with the engine the paper type air cleaner was fitted.

It was considered that the steel wire element of the oil bath air cleaner might possibly act as a flame arrester in the event of flashback of flame from the engine into the air intake system. To test the ability of such an appliance to arrest flames one was subjected to flames propagating in a propane/air gas mixture. The cleaner was mounted at one end of a $2\frac{1}{2}$ in B.S. pipeline and inserted into one end of a 0.3 m x 0.3 m x 1.83 m long (1 ft x 1 ft x 6 ft long) steel explosion duct as shown in Fig 3. The other end of the pipeline was connected to the gas supply. The air filter and pipe was sealed into the end of the duct with polyethylene film. There was also a polyethylene vent cover closing the vent on the side of the duct and adjacent to the air cleaner.

A 'Tee' piece was fitted 178 mm (7 in) from the sparking electrode and between the electrode and the gas cut off valve, so that its side branch could be opened and ignition of the gas mixture could be near an open end with which arrangement low flame speeds would result. The distance between the point of ignition and the air cleaner element could be varied between 100 mm (4 in) and 500 mm (20 in) if necessary. The filter element was tested both dry and wetted with oil of the type recommended for the oil bath by the manufacturers.

Procedure

In order to measure surface temperatures with the engine off load (i.e. the engine disconnected from the pump) and on load with full brake horsepower and the pump delivering 270-680 l/min (60 - 150 gal/min) and with the engine power reduced and the pump delivering 230 - 550 l/min (50 - 120 gal/min) the procedure was to set the variable speed control lever in the idling position and allow the engine to run until the maximum surface temperatures had been attained at that lever setting and as indicated by the temperature recorder. This procedure was repeated for each control lever position up to the highest engine speed that was commensurate with increase in surface temperatures. For the final temperature measurement with the variable speed control lever at its maximum setting, the pumping control valve in the pump delivery line was partially closed to decrease the load on the engine and increase its speed to an optimum value to give a temperature rise. As in all the other experiments the engine was then allowed to run until steady surface temperatures were obtained.

The procedure for the experiments in which air was diverted to flow through the aperture in the engine cowling and over the manifold and silencer was the same as above.

In measuring surface temperatures with the engine working with reduced brake horsepower, the pulley on the crankshaft and the one on the pump were of equal diameters and the pumping load was adjusted such that the engine did not stall and constituted a normal working load just below that which would stall a similar engine installed in a truck. In all other respects the temperature measuring procedure was the same as described above.

When surface temperatures were measured with the engine reduced in power and alternately idling for a timed period, and then working at full speed for a timed period, the temperatures were measured on the surfaces of the exhaust manifold and the silencer. The periods of working at the two speeds were timed with a stop watch and the temperatures were automatically recorded throughout the tests.

The procedure for working the engine to observe sparks and flame in the exhaust was to allow the engine to idle for periods up to 10 min and then quickly accelerate to maximum speed. Observation of the exhaust was made against a dark background. The two centrifugal action, spark and flame arrester type silencers and the standard 'pepperpot' type silencer were used in turn and observations made. Tests were also carried out in which the exhaust manifold was removed so that observation down the 'throat' of the exhaust outlet could be made.

The procedure for testing the element of the oil bath air cleaner for its ability to arrest flames was to fill the apparatus with a 4 per cent by volume propane/air mixture by the method of displacement, the gas being passed through the apparatus for sufficiently long periods to effect ten changes of the atmosphere in the apparatus. The flow of gas mixture was then stopped and the quiescent gas was ignited by an induction spark. Observation was made as to whether or not flame propagated through the element of the air cleaner and ignited the gas in the duct.

RESULTS

Figure 4 shows the effect on engine speed of loading the engine when the latter was used with its designed power of 7.75 brake horsepower.

Figures 5 and 6 show surface temperatures of parts of the engine and both silencers with the unmodified engine running off load.

Figures 7 and 8 show surface temperatures obtained with the unmodified engine working on load.

Figure 9 shows the surface temperatures of the unmodified engine fitted with the cast aluminium alloy silencer and with some of the cooling air from the fan diverted through the cowling, around the exhaust manifold and silencer.

In figures 7 - 9 inclusive the dotted portions of the curves show when the engine speed was increased by decreasing the load as described above.

Figure 10 shows the effect on engine speed of loading the engine when the latter was modified to develop four brake horsepower, and Fig 11 shows the surface temperatures obtained with the modified engine fitted with the 16 gauge metal silencer.

Figure 12 shows the variation of surface temperature of the exhaust manifold and 16 gauge metal silencer fitted to the loaded modified engine under conditions of alternately idling and running at full speed.

The temperatures at which the indicating stickers changed colour were in good agreement with the stated values and those temperatures indicated by the appropriate thermocouples at the time of the change.

No sparks were emitted from either of the centrifugal type silencers when fitted to the engine but sparks were observed in the 'pepperpot' type through its discharge apertures. With no silencer fitted to the engine, alternating idling and sudden full speed running produced sparks from the engine either singly or in groups at random time intervals with a maximum 15 sparks in one minute full speed running. The sparks, while incandescent, travelled for distances up to 0.35 m (1.2 ft).

With the silencer and the exhaust manifold removed from the modified engine, sparks and flame were observed issuing from the exhaust outlet on the engine block when the 'start' and 'stop' engine control lever was in use.

In all the experiments carried out with the oil bath type air filter flames, propagating at low speeds in a 4 per cent by volume propane/air mixture, passed through the filter.

DISCUSSION

In considering acceptable surface temperatures for an engine in a hazardous atmosphere, the present state of knowledge requires an arbitrary maximum temperature to be selected. The present work did not advance sufficiently for a final decision to be required, but tentatively an acceptable maximum surface temperature of 200°C was aimed at. This value is below the Auto-ignition Temperature of most common solvents, and the geometry and conditions of use of the engine surfaces provide additional safety factors.

With the engine working with full power, namely 7.75 brake horsepower, the only condition under which all the surface temperatures of the engine and exhaust system remained at temperatures acceptable in practice was when the engine was run with no load applied to it.

Figures 7 and 8 show that on load, with two different exhaust systems, the surface temperatures obtained were much higher for all parts of the engine than when there was no load. Temperature increases were greater for those parts of the exhaust system outside the cooling effect of the circulating air supplied by the fan in the flywheel of the engine. The surface temperature of one of the silencers used reached 468°C.

Diversion of some of the cooling air through the engine cowling into the experimental ducting which encased the exhaust manifold and silencer showed that the temperature of the exhaust manifold could be reduced to an acceptable value and the temperature of the silencer was considerably reduced (Fig 9). The cooling effect of the air on other parts of the engine appeared to be unimpaired. The results indicate that this method, carried out to heat transfer design incorporating cooling aids in the surface of the silencer could probably meet the requirements for safe temperatures.

The method of "derating" an engine has the effect of lowering its work capacity and ensuring that heat generated will be less and more easily dissipated than with normal loading. The engine was worked for sustained periods with loading just below that at which stalling would occur. Figure 11 shows that all the surface temperatures were reduced as compared with those shown in Fig 7. Those of the exhaust manifold and the silencer were drastically reduced but not sufficiently to ensure safe working in areas where flammable concentrations of gases and vapours could occur.

Alternating periods of idling and running the engine at full speed, which simulated the use of such engines for certain types of duty in industry, showed that for surfaces merely cooling to atmosphere relatively high temperatures resulted.

The conventional method of protecting the exhaust systems of such engines is costly, cumbersome and requires much maintenance. The present work has indicated that ideally the engine and exhaust system should be fully water cooled, or, if fully air cooled, the silencer surface should be designed to facilitate efficient heat transfer to the circulating air. Such a designed exhaust system, incorporating effective flame and spark arresters would satisfactorily 'flameproof' engines.

The performance of the oil bath type air filter as a flame arrester showed that the appliance had poor flame arresting properties and flames, propagating at speeds much lower than those at which flames would issue from the engine cylinder, passed through the element of the filter in all experiments. The addition of commercially available crimped ribbon type flame arresters and cut off valves, preferably automatic, to air intake systems is necessary to eliminate the hazard of flashback through such systems.

CONCLUSIONS

1. With an air cooled diesel engine, working on load, surface temperatures of components of the exhaust system reached values above those at which some flammable gases and vapours may ignite.
2. High surface temperatures were measured on the exhaust manifold and silencer.
3. Surface temperatures of air cooled diesel engines and exhaust systems can be lowered by including all components in the circulating air system.
4. Surface temperatures of air cooled diesel engines can be lowered by the method of power 'derating' but this method alone does not ensure safety.
5. Alternating short periods of full speed running with equal periods at idling speed resulted in silencer and exhaust manifold surface temperatures above those at which some vapours will ignite.
6. It has been shown that centrifugal type silencers are suitable for use as spark arresters.
7. An air intake oil bath filter allowed flames, propagating at low speeds in a propane/air gas mixture, to pass through it.
8. Temperature indicating stickers were found to be reliable for indicating surface temperatures of the engine and components of the exhaust system.

ACKNOWLEDGMENTS

Thanks are due to the engine manufacturers for the loan of the engine and for their continued co-operation throughout the programme. Thanks are also due to silencer manufacturers for the loan of equipment.

REFERENCES

1. British Standards Institution "Electrical apparatus and associated equipment for use in explosive atmospheres of gas or vapour other than mining applications" British Standard Code of Practice CP 1003 : Part 1 : 1964.

2. Quarterly Safety Summary of the British Chemical Industry Safety Council Vol. 41, No 161, Section III pp 3 - 4 1970.

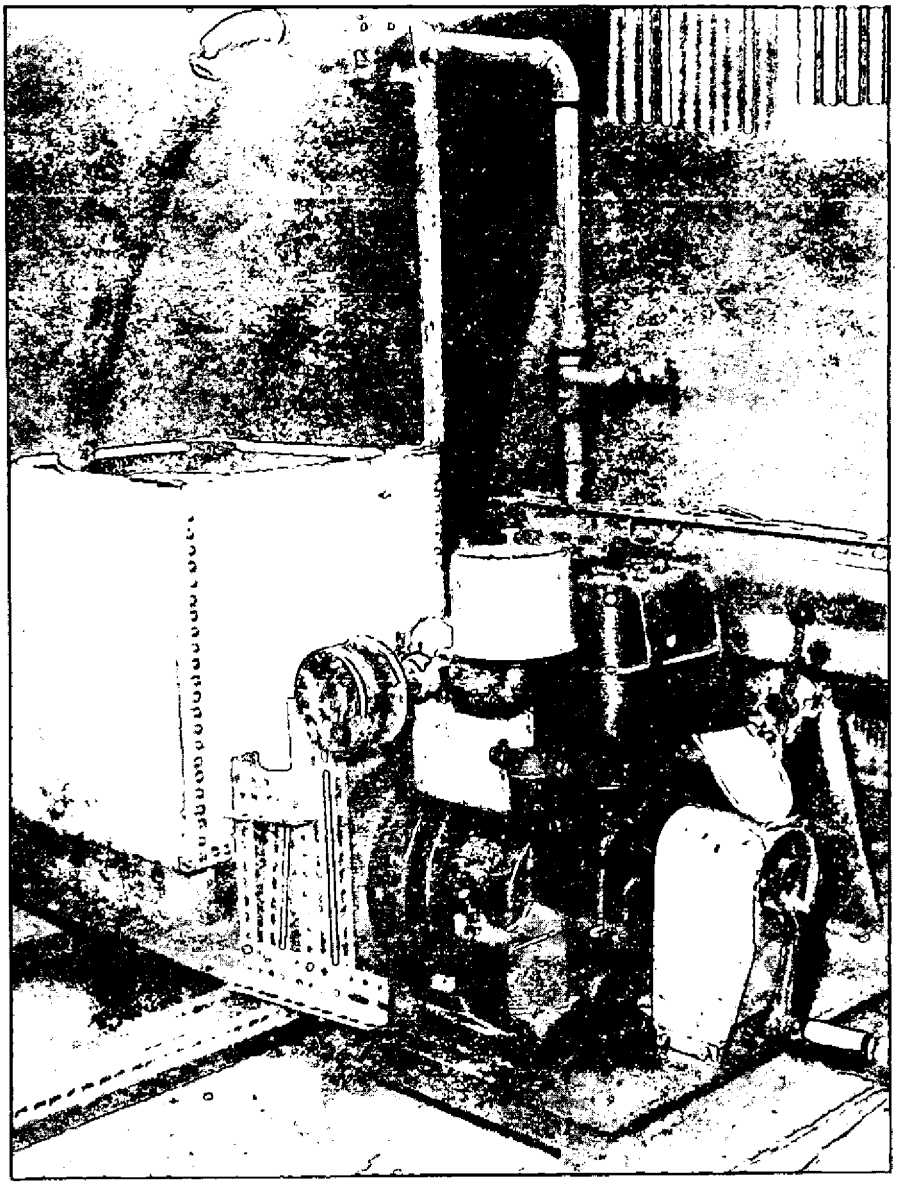

FIG. 1. GENERAL VIEW OF THE DIESEL ENGINE

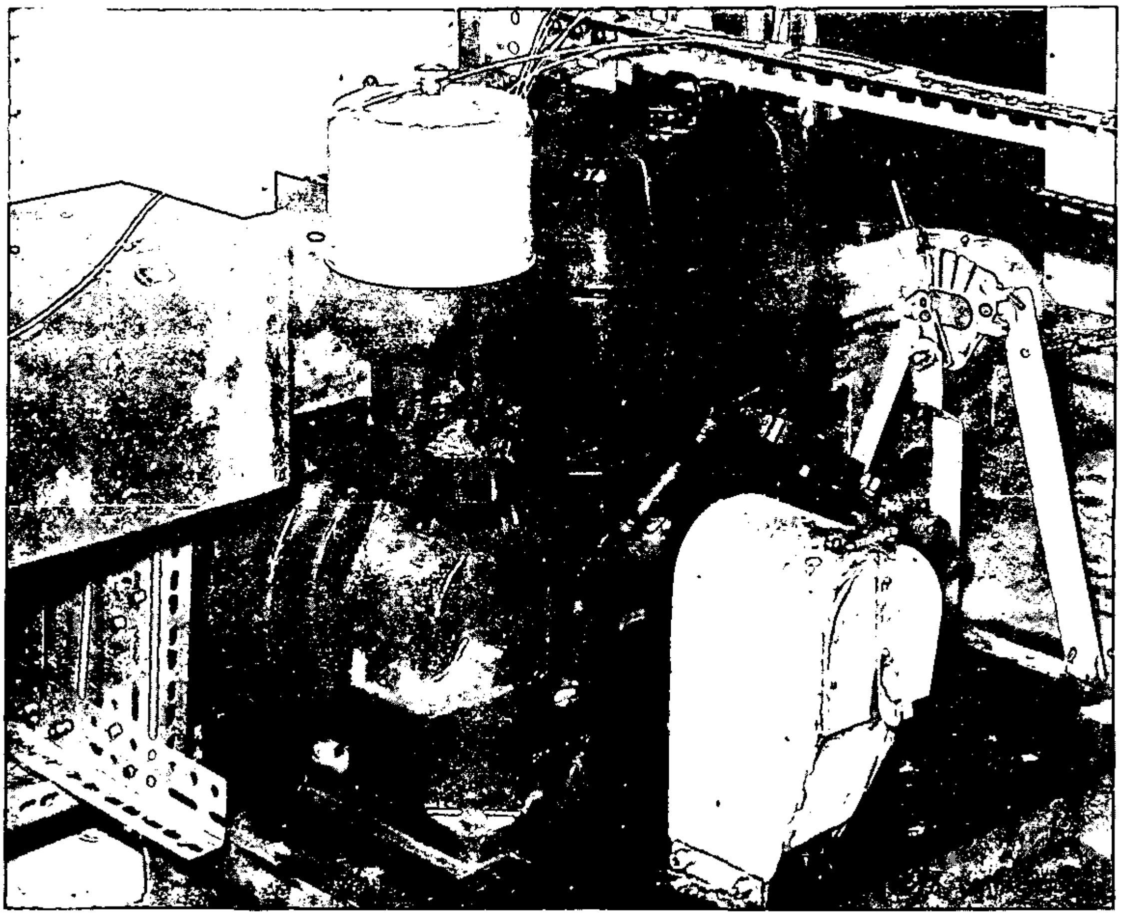

FIG. 2. THE DIESEL ENGINE WITH ALL COMPONENTS OF THE EXHAUST SYSTEM IN THE MODIFIED AIR COOLING ARRANGEMENT

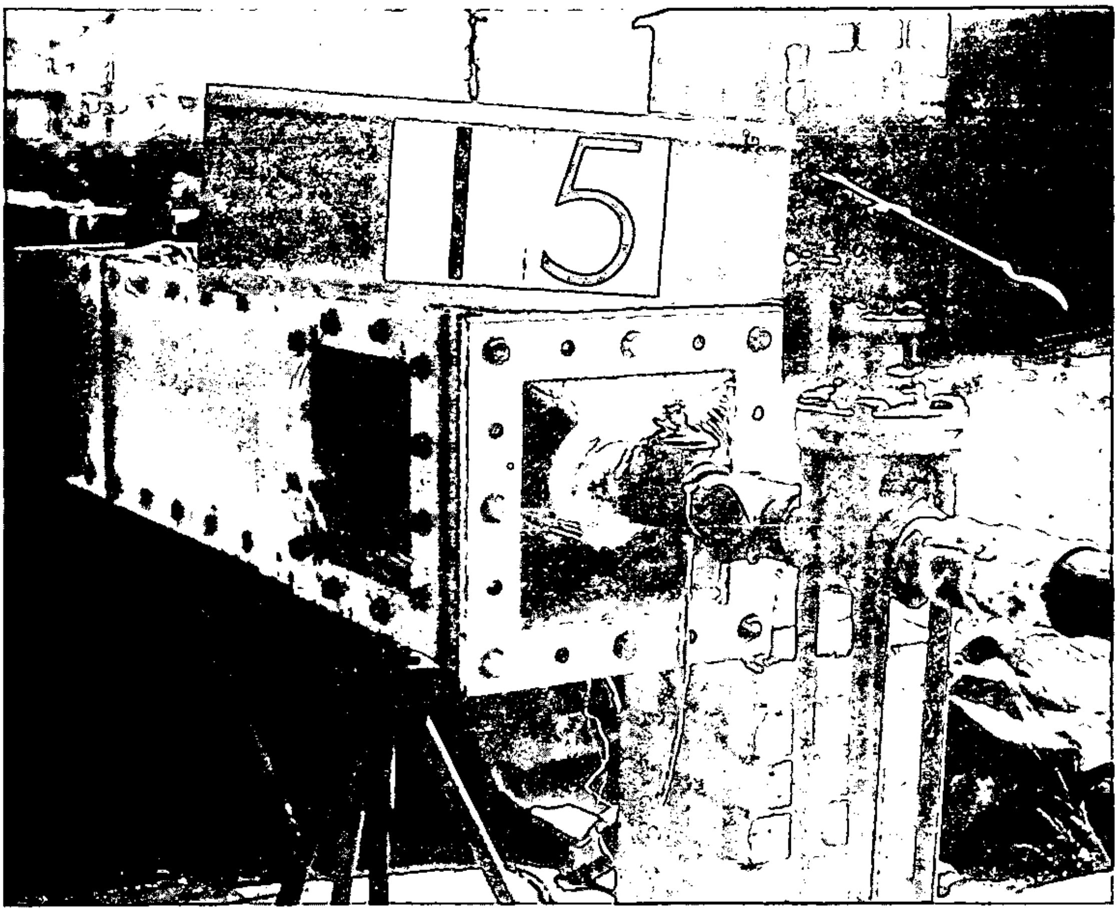

FIG. 3. AN OIL BATH TYPE AIR FILTER UNDERGOING FLAME ARRESTING TEST

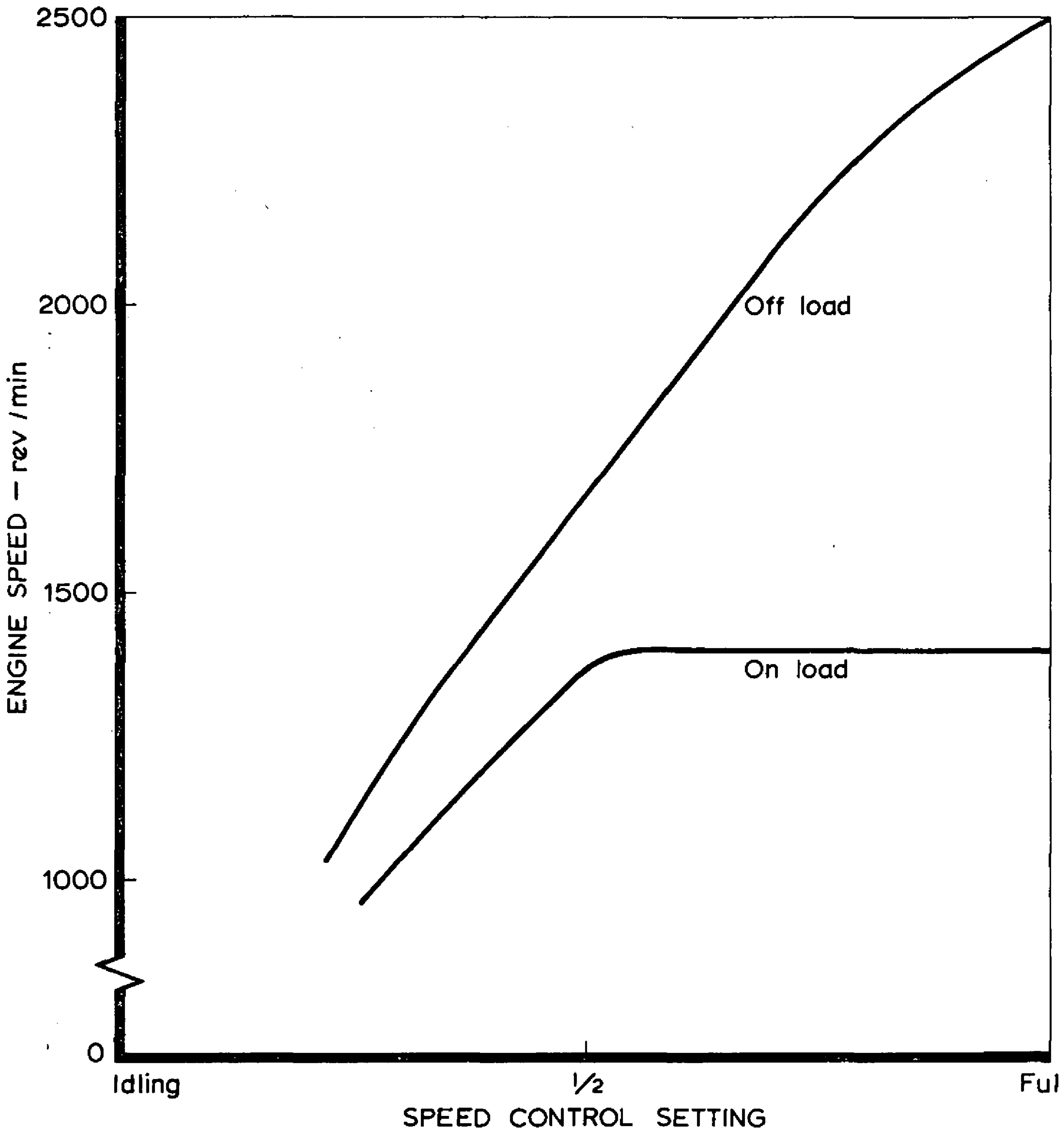

FIG. 4 THE EFFECT OF LOADING ON THE SPEED OF A 7·75 B.H.P. DIESEL ENGINE

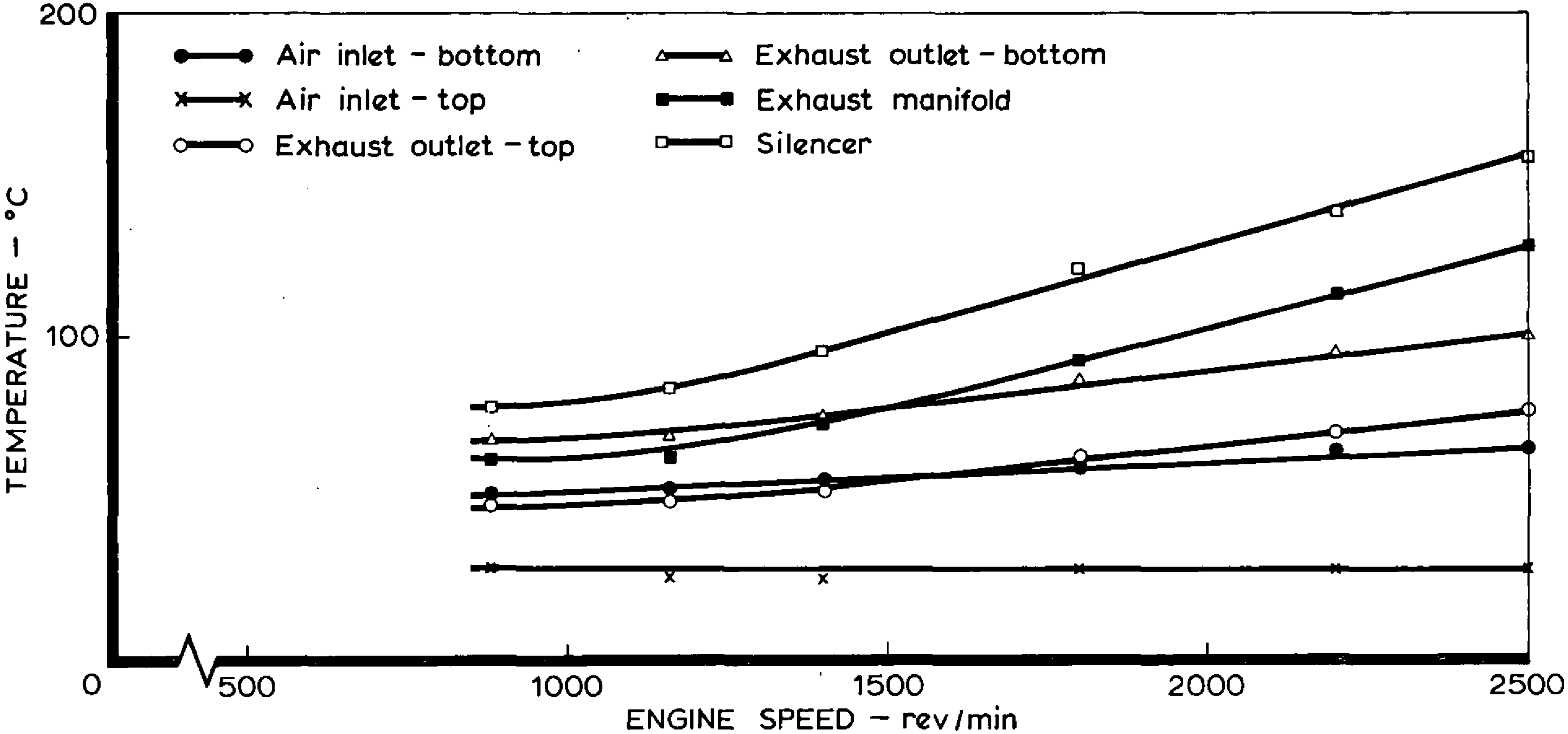

FIG. 5 SURFACE TEMPERATURES OF A DIESEL ENGINE FITTED WITH A SILENCER OF 16 GAUGE METAL – NO LOAD

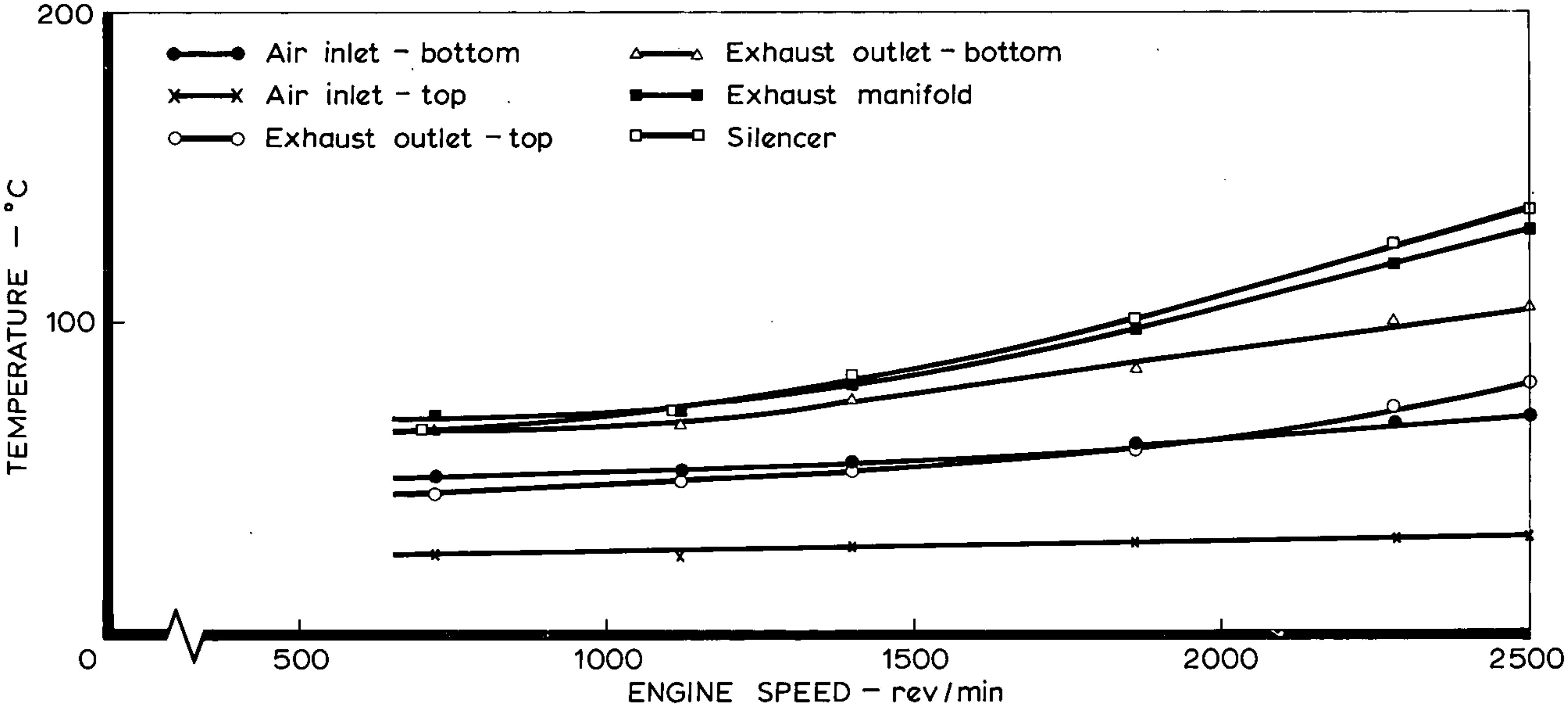

FIG. 6 SURFACE TEMPERATURES OF A DIESEL ENGINE FITTED WITH A SILENCER OF CAST ALUMINIUM ALLOY — NO LOAD

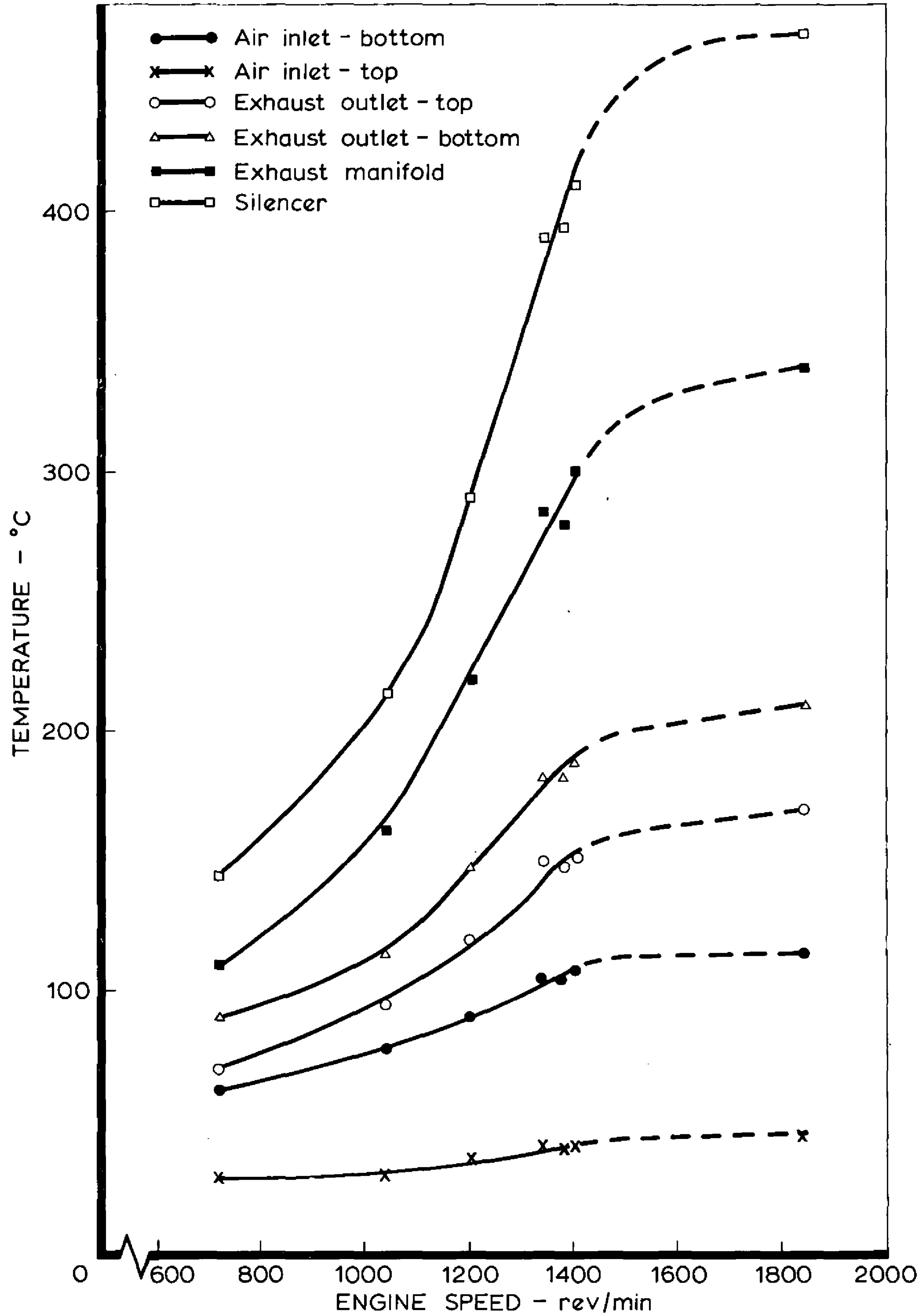

FIG. 7 SURFACE TEMPERATURES OF A DIESEL ENGINE FITTED WITH A SILENCER OF 16 GAUGE SHEET METAL — ENGINE LOADED

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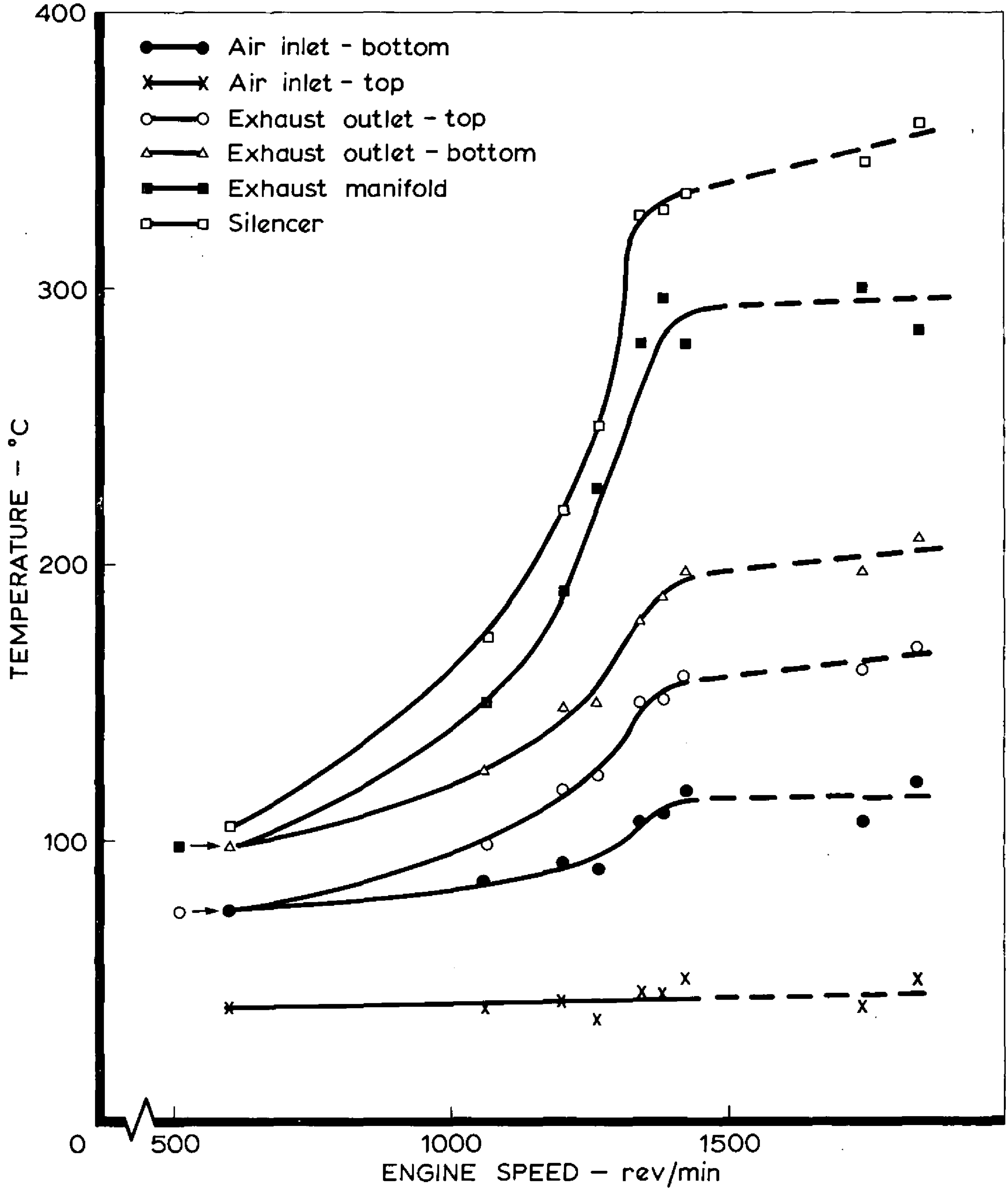

FIG. 8 SURFACE TEMPERATURES OF A DIESEL ENGINE FITTED WITH A SILENCER OF CAST ALUMINIUM ALLOY - ENGINE LOADED

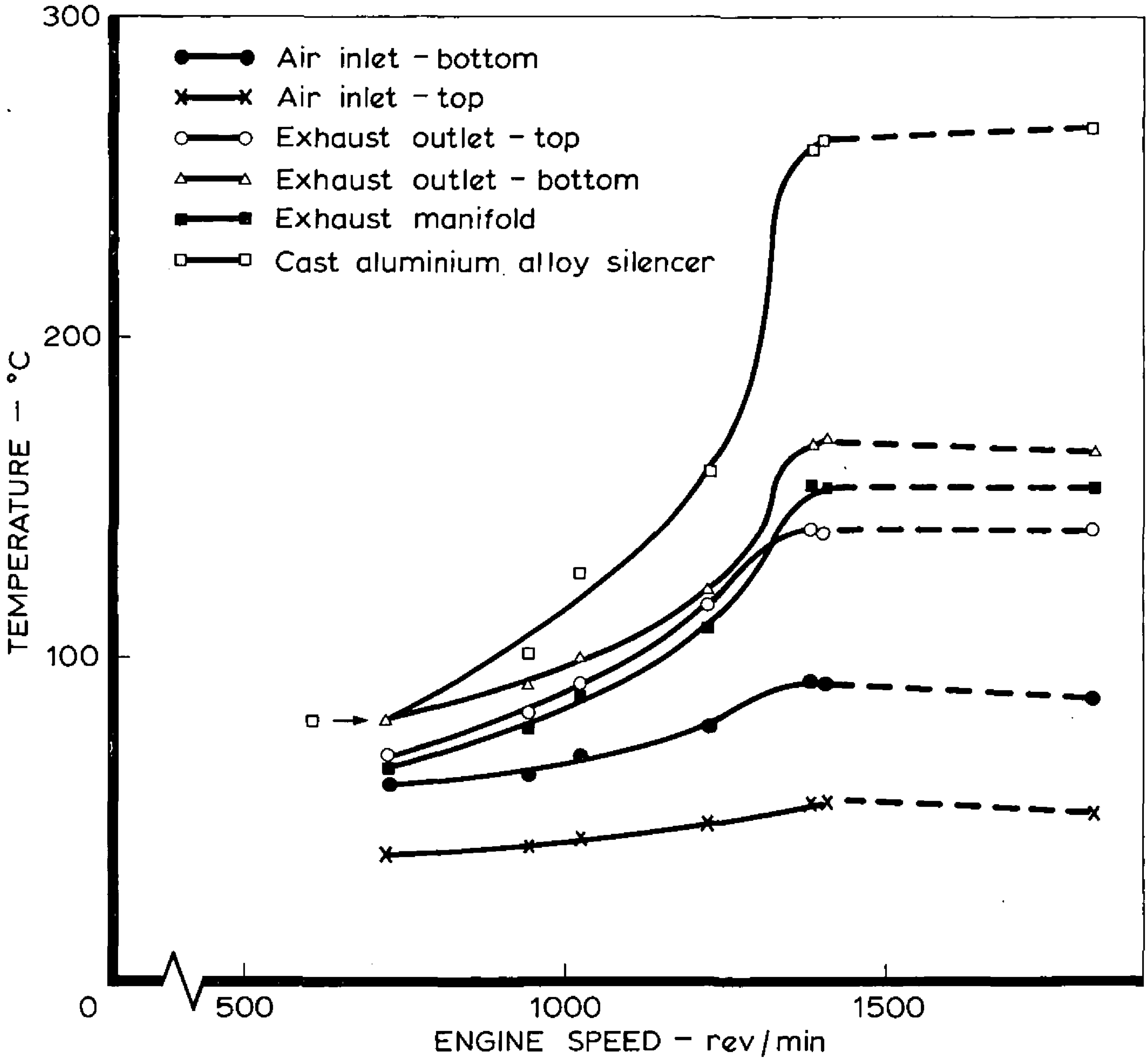

FIG. 9 SURFACE TEMPERATURES FOR A DIESEL ENGINE WITH A MODIFIED AIR COOLING SYSTEM

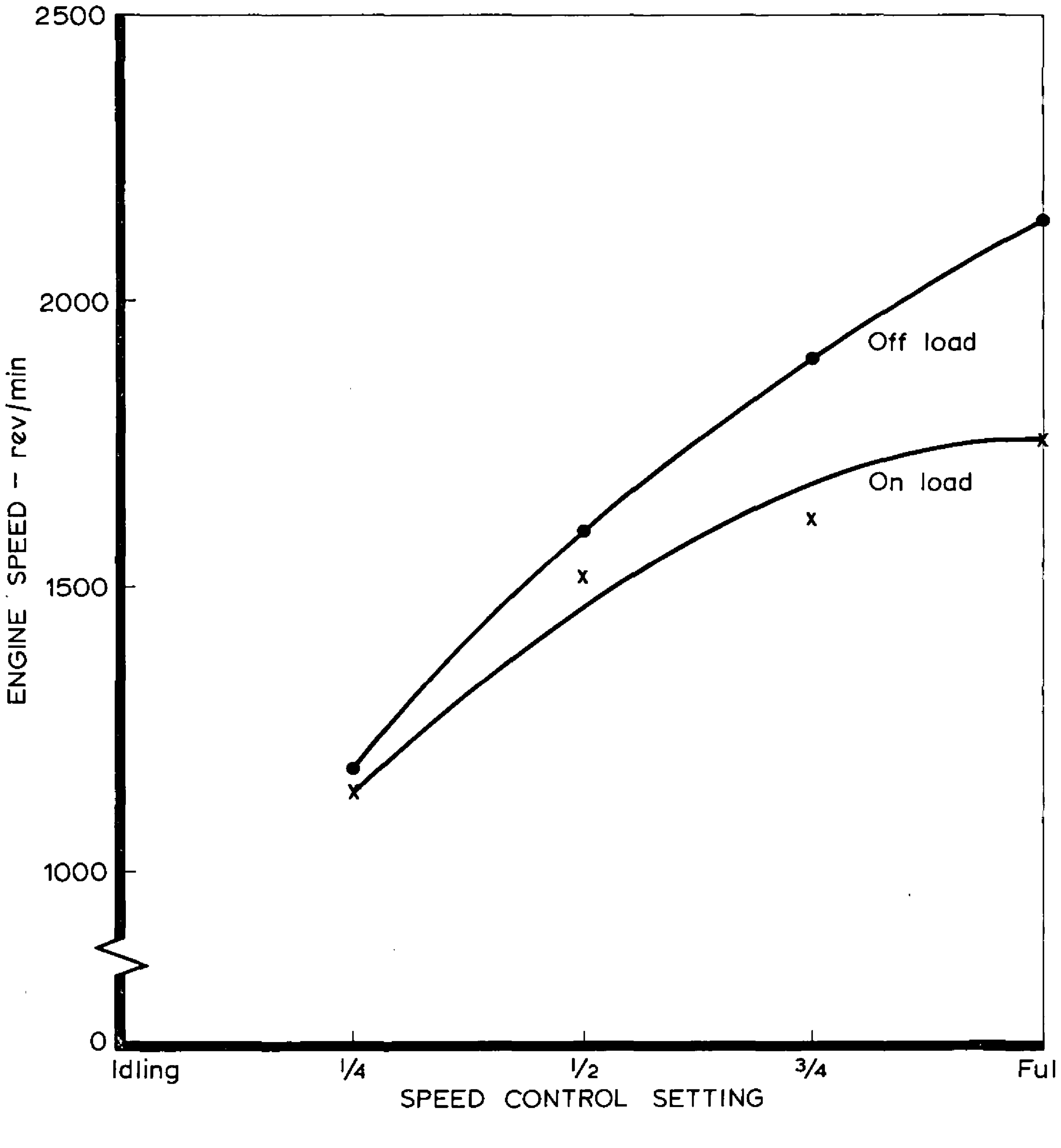

FIG. 10 THE EFFECT OF LOADING ON THE SPEED OF A DERATED DIESEL ENGINE

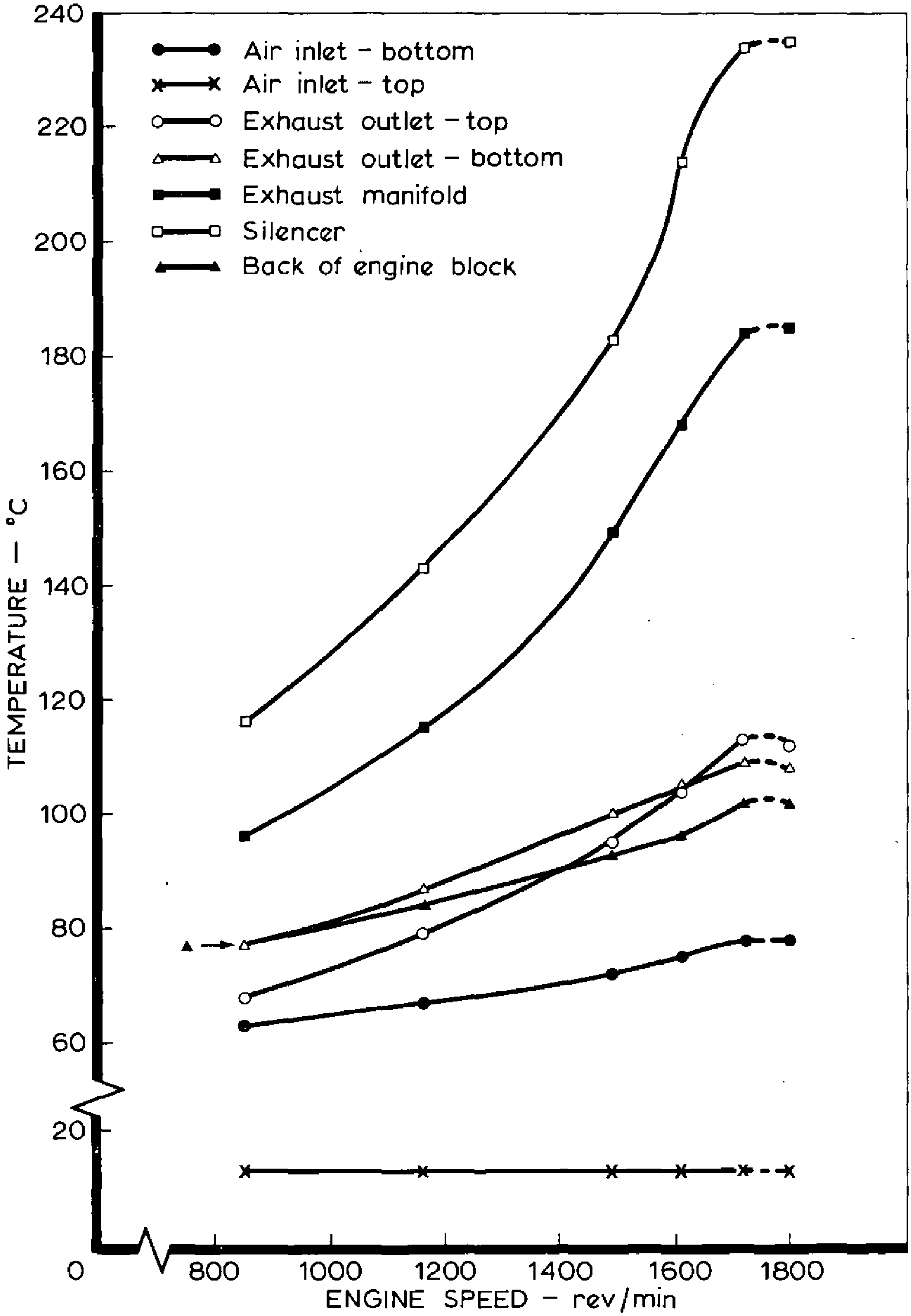

FIG. 11 SURFACE TEMPERATURES OF A DERATED DIESEL ENGINE FITTED WITH A SILENCER OF 16 GAUGE METAL

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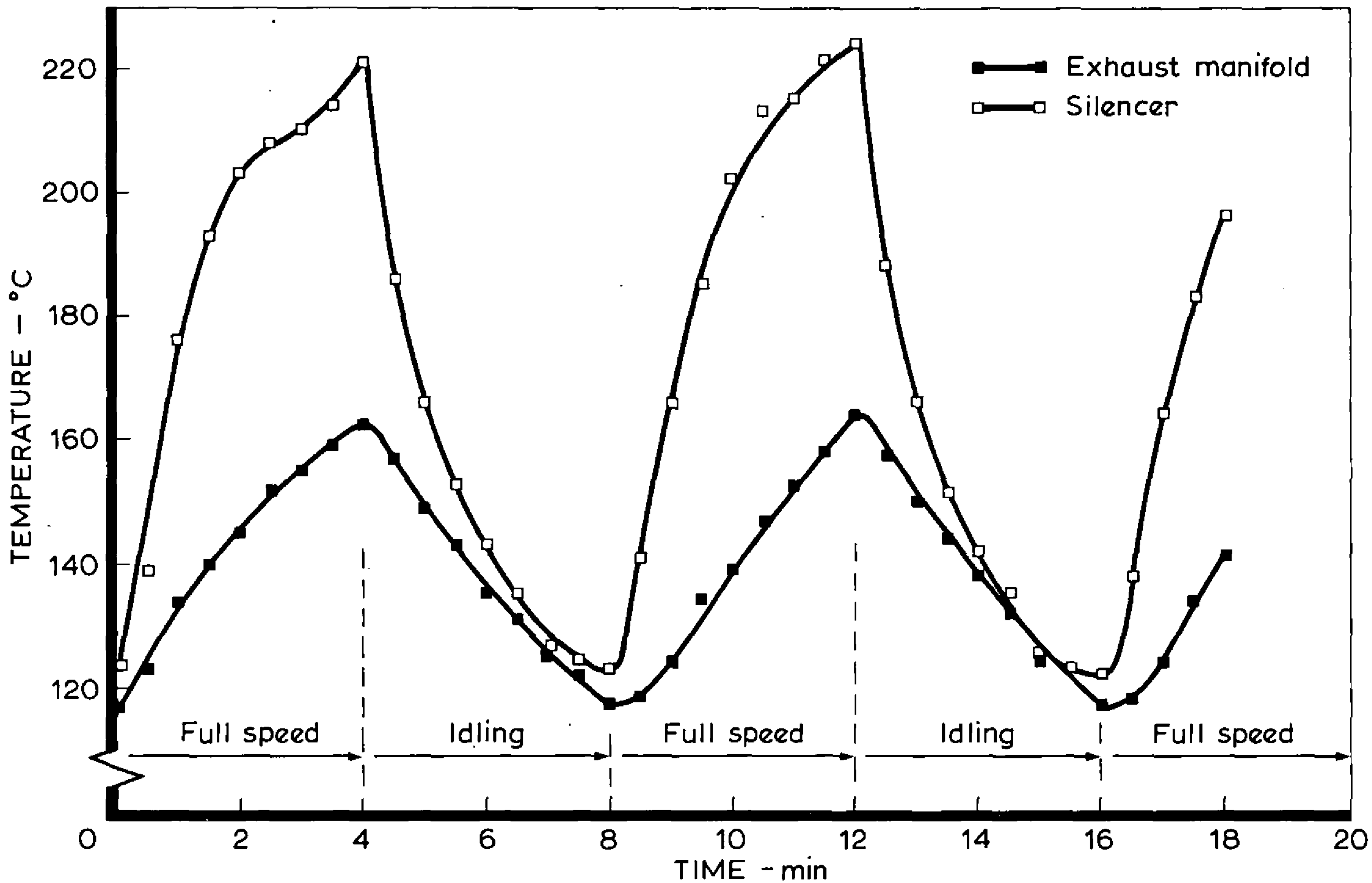

FIG. 12 SURFACE TEMPERATURES OF THE EXHAUST MANIFOLD AND SILENCER FITTED TO A DERATED DIESEL ENGINE
ALTERNATING PERIODS OF IDLING AND FULL SPEED RUNNING