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Cold Starting of IC Engines

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ABSTRACT

Studies of cold starting of IC engines carried out at Indian Institute of Petroleum (IIP) and field trials at high altitudes under sub-zero temperature conditions are described in this paper. Different operating factors influencing the cold starting of diesel engines and the role of starting aids developed at IIP have also been described. IIP device has given satisfactory starting performance upto temperature as low as –35°C.

1. INTRODUCTION

The general practice adopted to start the diesel trucks under low temperature conditions, was to tow the vehicle for about 15 to 20 minutes even after using special low temperature fuel, lubricating oil etc. This method obviously, is not reliable for emergency starting and not suitable for hilly areas as existing in Northern Borders.

Cold starting[1] of IC engines under sub-zero temperature conditions is a delicate operation. A little carelessness can damage the whole engine, but if proper precautions are taken and right type of lubricating oil, fuel, coolant, starting aid, etc. are used then a summer like start can be achieved. This paper describes the general problems involved at low temperature conditions, design aspects of the engine, the battery, starting aids and the results obtained during the tests and trials in actual field conditions.

2. SI ENGINES

Starting of SI engines at low temperatures[2] is easier than CI engines due to sparking systems in the combustion chamber and the fuel properties. By using the conventional lubricating oils, fuels, etc., the SI engines can easily be started by using the more volatile fuel having 10 per cent evaporation temperature at about 40°C.

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Addition of methyl alcohol[3] in the fuel absorbs the condensates and prevents freezing of water in the fuel lines and ice formation in the carburetor. The Willy's engine could easily be started upto –25°C without any aid and upto –37°C with fluid starter in the Institute's cold chamber.

3. CI ENGINES

It is the diesel engine which creates problems of cold starting at northern borders or hilly areas where the lowest temperature is experienced in winter. While studying the problem of cold starting, it was observed that four operating factors[4] influence the diesel engine starting : (i) engine design, (ii) properties of lubricating oils, fuels and coolant, (iii) battery conditions and starter motor, and (iv) use of starting aids.

3.1 Engine Design

Heat losses during cranking depends upon the ratio of surface area of the combustion chamber to its volume. Combustion chambers having higher ratios of surface area to volume are harder to start. This is the reason that the direct combustion chamber engines can start at a lower temperature than pre-combustion chamber engines. Also most of the direct combustion chamber engines have craters on the pistons which accumulate the fuel. This accumulated fuel raises the compression ratio, and improves sealing and subsequently increases compression temperature resulting in better starting. The cold starting results obtained on TMB pre-combustion chamber and direct combustion chamber are as follows :

	Without glow plugs	With glow plugs
TMB engine with pre-combustion chamber	+10°C	0°C
TMB direct combustion chamber (with app. same compression ratio and same type of fuel etc. used)	0°C	Not fitted

Cylinder bore size has also an important influence on starting characteristics, engines of small bore being much harder to start. Intake valve timing, valve tappet clearance, fuel injection timing and the conditions of engine parts have also an appreciable effect on engine starting under sub-zero temperature conditions.

3.2 Lubricating Oils

The engine cranking speed is inversely proportional to the oil viscosity. The largest load during cranking period is the force necessary to shear the oil film[5] when it is in the locking condition. Since this greater force required is due to increase in viscosity of the oil, it is vital to use the right grade of the oil under low temperature conditions.

Observations obtained during studies at IIP are as follows :

SAE 20 W	Suitable upto – 5°C
SAE 10 W	" " –15°C
SAE 10 W + 10% superior kerosene oil	" " –25 °C
SAE 10 W + 10% motor gasoline	" " –37°C

(upto which a positive start obtained).

SAE 5W was not available. Effect of oil viscosity on cranking speed is shown in Fig. 1.

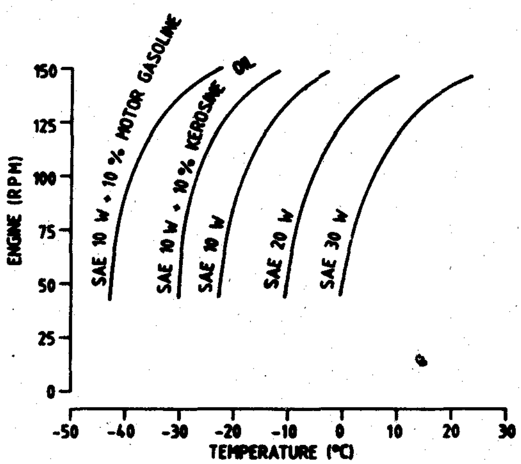

Figure 1. Effect of oil viscosity on cranking speed.

3.3 Fuels

The conventional HSDO had a pour point of about –3°C (now +6°C) which affects the pumpability of the fuel. Higher cetane number[6] and lower pour point are the main requirements for starting the CI engines at sub-zero temperatures. It was observed that starting with superior kerosene oil plus 2 per cent SAE 10 W oil of cetane No. 53.6 is easier than by using sub-zero diesel fuel (ATF plus 5 per cent HSDO) of cetane No. 47.5. HSDO (60 per cent) + kerosene oil (40 per cent) was satisfactory upto –5°C but this blend had frozen at –10°C. No injection of the fuel was possible. The characteristics of sub-zero diesel fuel which was used for the cold starting trails are given the Table 1.

3.4 Coolant

The conventional coolant of 55% ethylene glycol and 45% water was used during the cold starting trials in the cold chamber. The freezing point of the mixture of water and glycol are shown[7] in the Fig. 2.

3.5 Battery Condition

In a lead acid battery, viscosity of the electrolyte increases as temperature decreases which obstructs the flow of ions and diffusion of fresh electolyte into the

Table 1. Characteristics of sub-zero diesel fuel

Specific gravity at 15.6/15.6°C	0.7837
Flash point, °C	36.5
Pour point, °C	below – 50
Water and sediment, % vol.	Nil
Ash, % wt.	Nil
Distillation °C	
IBP	147.50
10%	160.60
50%	181.70
90%	217.95
FBP	274.50
Residue, %	1.5
Loss, %	0.5
Kinematic viscosity, cst at 37.8°C	1.10
Sulphur, % wt.	0.17
Corrosion	1a
Total acidity mg KOH/g	0.07
Cetane number	47.5
Calorific value k cal/kg	10,535

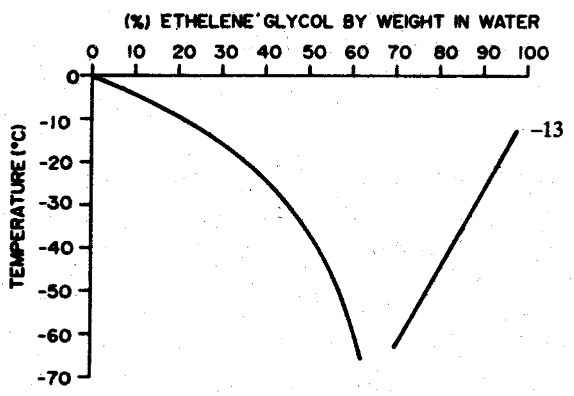

Figure 2. Freezing point of the mixture of water and glycol.

pores of the plates resulting in reducing battery performance. Consequently the batteries with more number of plates per cell have a better performance because more area comes into contact with the ions. At lower temperatures, the battery terminal voltage goes down and subsequently its capacity decreases which ultimately affects the cranking of an engine. If a battery is insulated with a wooden box or a gunny bag, it shows much better performance for cranking an engine under sub-zero temperature conditions. Batteries should be kept fully charged during cold weather in order to have the maximum amount of power available for cranking the engine and also to prevent freezing of the electrolyte.

3.6 Starter Motor

When an engine is started the starter motor has to overcome two forces[8] known as 'break away torque' and the 'resisting torque'. The break away torque is much higher than the resisting torque. At break away torque or under locking conditions, the starter has to overcome these forces and get the engine turning. The current consumption is extremely heavy because the torque of the motor is directly proportional to the current i.e. higher the starting torque, higher the current consumed. As the temperature is reduced, the break away torque is increased due to increase in oil viscosity. The cranking performance can be improved[9] by using 24 Volt motor and battery system. The sub-zero grease should be used in the bearings of the starter motor.

3.7 Starting Aids

Two types of aids are generally employed for cold starting – heaters and fluid starters.

3.7:1 Heaters

Under Antartica and Siberian conditions i.e. below –40°C, there is no substitute[10] for heat for achieving a positive start. Obviously it no longer remains cold starting when heaters are used. Heaters are quite costly and some heaters cause an extra strain on the battery and therefore, can be avoided under Indian conditions.

3.7.2 Fluid Starters

Fluid induction is one of the well known method of cold starting of IC engines by using a volatile fluid such as di-ethyl ether. Its beneficial effect is due to its low auto-ignition temperature and high volatility. For very low temperatures i.e. below –25°C, a special starter fluid is prepared by adding a small quantity of an additive in di-ethyl ether which can further reduce its auto-ignition temperature by 5 to 10°C and improves its ignition qualities. It is also considered as panacea for cold starting[11] of engines. The quick starting is obtained when the fluid is fumigated in an atomised form into the engine inlet manifold at the time of cranking. The fluid is supplied initially at a high rate to achieve a positive start in the shortest time and gradually reduced till the engine operates on its regular fuel alone.

Some imported aerozol type capsules were evaluated for cold starting. The biggest disadvantage with the use of such capsules is due to reduction in pressure inside it as temperature decreases under cold conditions which frequently results in inadequate pressure for its optimum utility. This ultimately results in the discard of the capsule even when it contains sufficient fluid. Also it is inconvenient for the operator to come out of the vehicle in that inhospitable climate to spray the fluid in the intake manifold. So a device operated from the driver's cabin is preferable.

An imported device 'Start-pilote' was also evaluated. This device delivers the fluid in a stream form and not in an atomised form. The effect of this starting aid was like pouring of the fluid in the inlet manifold. Further the capacity of the fluid capsule was only 20 ml which was not sufficient even for one start at –20°C and

Table 2. TMB Vehicle : cold starting data at high altitudes

Lube oil used	–	HD 10
Fuel	–	Diesel HPP sub-zero
Coolant	–	45% water, 55% ethylene glycol

Sl. No.	Altitude meters (ft.)	Ambient temp. (°C)	Coolant temp. (°C)	Lube oil temp. (°C)	Cranking speed (rpm)	Cranking current (Amp)	Quantity of fluid used (ml)	Total cranking time for successful start (sec)	No. of cranking required for starting	Remarks
1.	3353 (11000)	–18	–16	–	150	195	15	30	–	
2.	3353 (11000)	–10	–9	–8	160	145	10	20	1	
3.	3353 (11000)	–8	–7	–7	160	130	10	20	1	
4.	4267 (14000)	–11	–11	–9	150	175	25	40	1	
5.	4267 (14000)	–13	–10	–10	155	250	25	40	1	
6.	4267 (14000)	–17	–16	–15.5	150	250	30	80	2	Ist cranking of 1 min.
7.	3353 (11000)	–17	–14	–13	160	230	20	30	1	
8.	3353 (11000)	–4	–2	–1	156	195	8 app.	5	1	It started by just opening the fluid valve
9.	3353 (11000)	–7	–4.5	–3	150	200	10 app.	10	1	

Note : 1. All the above data was taken in actual field tests of high altitudes and low temperature in winter season.

2. Readings were taken at different places on different dates during the trial period.

3. The vehicle did not start even at –4°C without the help of the device.

4. All the above temperatures were noted between 5.00 to 6.00 A.M. on each day when we could get the lowest temperature and cold starting trials were carried at that time.

5. Two Exide batteries connected in parallel gave 13.5 V. Dischargement –1.5 V–HRD (High Rate Discharge).

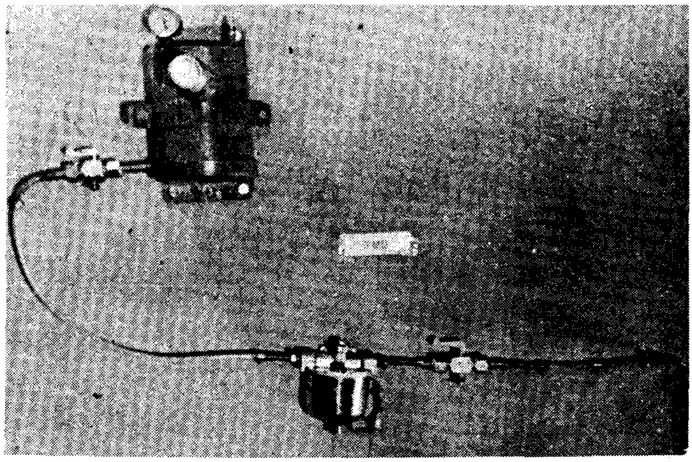

Figure 3. Fluid starter developed at IIP.

requiring reloading of the device again and again. The fluid has to be inducted not only to start the engine firing but also for achieving sustained speed.

A device (Fig. 3) was developed[12] in IIP and successfully evaluated under low temperature conditions in the cold chamber on TMB engine and also under actual field conditions of 4267 meters (14000 feet) altitude during winter. The TMB engine was not easy to start even using glow plugs at 0°C but it could be started at –35°C in the cold chamber using this IIP device. The TMB truck could easily be started at –18°C, the lowest temperature observed during the trial period at 3353 meter (11000 feet) in 30 seconds using 15 ml starter fluid. Such a successful start could be obtained even under the most arduous and windy conditions with this device. The test data on TMB truck is given in Table 2. The device comprises of (i) an air reservoir for compressed air by which air pressure is communicated to the fluid container, (ii) fluid container which stores the starter fluid and has a mixing head for air and starter fluid, and (iii) a delivery nozzle for supplying fine spray of the fluid to the inlet manifold. The air reservoir and the fluid container are mounted on the dash board in the driver's cabin, while the delivery nozzle is fitted into the inlet manifold.

The main advantages of the IIP device are that (i) it delivers the fluid in an atomised form; (ii) it is extremely convenient to the driver as he has to operate one valve from his cabin; (iii) the engines and vehicles can be reliable for positive start in emergency and the capacity of the container is sufficient to supply fluid for many starts; and (iv) it is extremely economical and battery requirements are reduced for starting the engine.

IIP also developed another starting device (Fig. 4) on the same principles by reducing the cost to suit the commercial or private vehicles plying on hilly areas where minimum temperature goes upto –10°C. A rubber bellow is used in place of an air reservoir, and the fluid container is made simple with smaller capacity. This device also supplies fluid in an atomised form and was evaluated successfully on trucks and

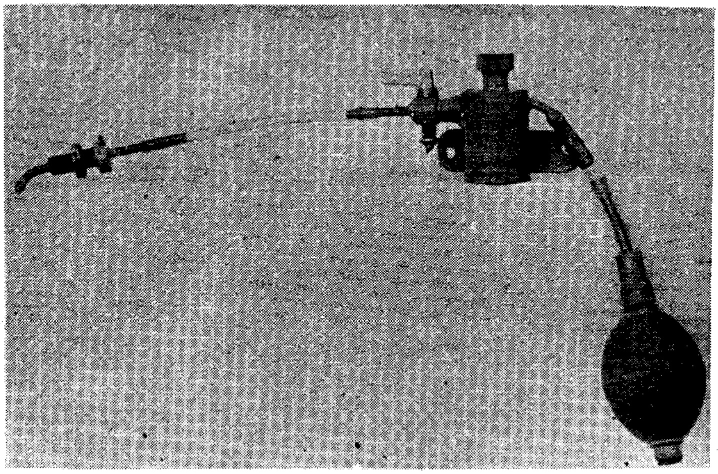

Figure 4. Fluid starter developed at IIP

buses at Uttarkashi (UP) at –6°C, Mandi (HP) at 0°C and Dehra Dun at +4°C during winter in the morning hours when the temperature were lowest.

4. CONCLUSION

Low temperature affects all the operating phases of the engine i.e. fuel, lubricating oil, coolant, combustion system, battery, etc. and if proper precautions are taken and proper starting aids are used, a quick start can be achieved at the lowest temperature experienced on Northern Himalayan borders.

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REFERENCES

1. Gupta, R.B., Trial report of IIP starter fluid induction device for cold starting of IC engines, IIP Report No. 4521, May 1971, pp.1–12.
2. Gupta, R.B., Status report on cold starting problem of IC engines, IIP Report No. 44/421, March 1970, pp.1–6.
3. Kasper, R.H. & Norrie, R.C., *SAE Journal,* **65,** August (1957), 74–75.
4. Blose, James F., *SAE Journal,* **60,** April (1962), 40–44.
5. Hamm, A.M., In the role of engine oil viscosity in low temperature cranking and starting – prepared by SAE Fuels and Lubricants Activity, Vol. 10, 1966, pp.15–19.

6. Derry, L.D. & Evan, E.B., *J. of the Inst. of Petroleum,* **36** (319), (1950), 389–421.
7. Beranger, Bobert & Jomard, Jean-Michel, L' influence de l'ethylene glycol sun le fonctionnement d' un moteur est considerable' Par MM. Ingenieurs De L' Automobile 12–68, April, 1968, pp.695–708.
8. Molley, E. & Lanchester, G.H., Automobile Engineer's Reference Book – Electric Starter Motors, Section 23, 1958, pp.2–16.
9. Report of CIMTC, Sub-committee XV-Winterization, *SAE Trans.,* **65** (1957), 349–376.
10. Shaw, Robert, *SAE Journal,* **68,** December (1960), 127–128.
11. Ainslex, W.G. & Young, C.U.S., Application for starting fluid internal combustion engine, Institut Francais du Petrole, pp.1–8.
12. Indian Patent No. 133261, Device for Cold Starting of IC Engines by Priming Starter Fluid, 1973, p.1–6.