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KNOCKING IN GAS-FUMIGATED DUAL-FUEL DIESEL ENGINE

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SUMMARY

Alternative fuels having higher spontaneous ignition temperature than diesel fuel, may be introduced into a diesel engine by gas-fumigated dual-fuel method. In this method, a pilot quantity of diesel fuel is injected during the compression stroke to ignite the mixture. The maximum amount of alternative fuel to be used by this method is restricted by the knocking tendency of the engine. Introducing more alternative fuel causes severe "shrill" knocking in the engine. Together with this "shrill" knocking, this paper describes two other types of knocking, viz. "diesel knock" and "spark knock" which could be present in the dual-fuel engine. These could result in reduced engine life. "Shrill" knocking is brought about by a reduction in the rate of combustion during the initial stage of the combustion process as compared to that for full diesel operation. The combustion process in the dual-fuel engine is in between that for CI and SI engine. This results in introduction of both "diesel knock" and "spark knock" in some dual-fuel engines.

1. Introduction

The use of alternative fuels in internal combustion engines received renewed interest following the first oil crisis in 1973. Since then many types of alternative fuel have been tried both in spark-ignition(SI) and in compression-ignition(CI) engines. Various methods have been used in introducing alternative fuels into engines. The dual-fuel method has been used in CI engines. In the most common system, the alternative fuel is mixed with the air outside the combustion chamber and the fumigated mixture is drawn into the combustion chamber. A pilot quantity of diesel fuel is injected to ignite the gas-air mixture towards the end of the compression stroke. The advantage of using the dual-fuel method is that the engine can run on pure diesel whenever there is a shortfall of alternative fuel. By this method the diesel fuel can be replaced by alternative fuel up to the point where the engine starts knocking.

Both experimental and computer analysis[1,2,3,4] have been carried out in studies of combustion characteristics of the dual-fuel engine. To the authors knowledge, few works have been reported in relation to the various types of knocking process which come about in the dual-fuel engine. Knocking in spark ignition engines running with methane as the alternative fuel was studied by Karim and Ali[2]. In this particular work knocking means auto-ignition of the end gas, which has not been consumed by the normal flame front. According to their work, the onset of knocking could be eliminated by retarding the spark timing.

In this investigation natural gas has been used as the alternative fuel. Experiments have been performed to study the performance of the dual-fuel engine with different diesel quantities as pilot injection. In this research it was found that at different alternative/diesel fuel ratio there could be three distinctive types of knocking in the engine. These are "diesel knock", "spark knock" and a distinctive third type, which is very "shrill" and can have severe consequences in the engine.

2. Experimental Set-up

The engine used in this study was a Petter model AC1 (4.80 kW at 3600 rev/min), four stroke, single cylinder diesel engine. The engine was air-cooled, naturally aspirated with a Lanova air-cell combustion chamber with overhead valves. The natural gas was first mixed with the intake air and then passed to the engine. The gas was mixed with a mixer, which was a 1/4" O.D. copper tube with a number of holes on its circumference. It was placed perpendicular to the air flow. Measurements of cylinder pressure were

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obtained by installing a "Kistler" 601A water-cooled piezo-electric pressure transducer, into the air cell of the combustion chamber. The signal from the transducer was transmitted to the Multi-purpose Indicator TE28. The indicator was also connected to a shaft encoder mounted on the crank-shaft. The encoder produced a marked pulse at top dead centre (TDC), and a total 720 pulses were produced per revolution, in order to synchronize the measured pressure data with the crank position. Knocking in the engine was detected by virtue of its audibility in the form of engine roughness and also in the pressure-crank-angle diagram of the oscilloscope.

3. Knocking in Gas-Fumigated Dual-Fuel Engine

In practice, most diesel engine have a rate of pressure rise sufficiently high to cause audible noise. When such noise becomes excessive in the opinion of the observer, the engine is said to "detonate" or "knock". In the diesel engine, the maximum pressure inside the cylinder is limited to a certain value (usually established experimentally) for the particular size and design in question. Therefore, when replacing diesel fuel by alternative fuels, the maximum pressure and also the rate of pressure rise should not be sufficient to cause any damage to the engine. In the gas-fumigated dual-fuel engine, there are three distinctive types of knocking. These may be classified as "diesel knock", "spark knock" and "shrill knock". For better performance and longer life of the engine, all types of knocking should be avoided.

3.1 Diesel Knock in Dual-Fuel Engine

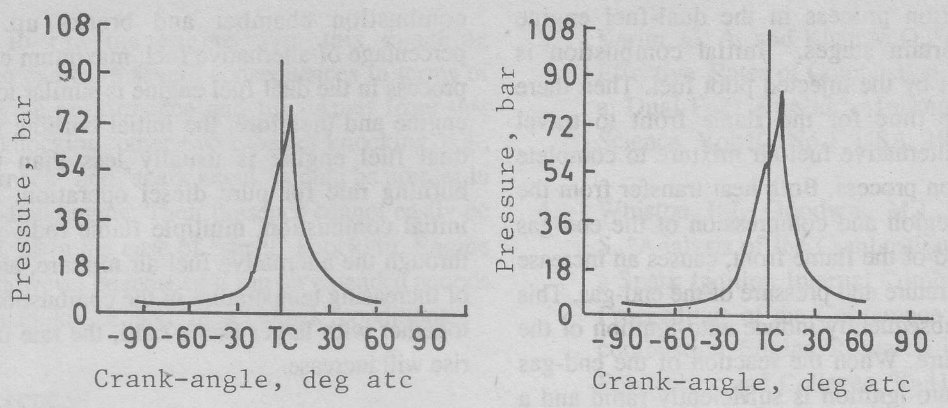
In pure diesel engines, knocking occurs in the early stage of the combustion process, just after the delay period. The main reason for "diesel knock" is the accumulation of diesel fuel injected during the delay period. When the delay is long, more and more fuel will be injected during the delay period, and when ignition occurs the burning rate becomes very high, resulting in high rates of pressure rise, and even sometimes high peak pressure. Consequently, the high rate of pressure rise will cause knocking in the engine.

In a conventional diesel engine, as long as evaporation of the injected fuel is not completed before ignition, the quantity of fuel injected hence the air-fuel ratio has no direct effect on the delay period. And, also the peak pressure after the delay period is little effected by the fuel-air ratio as long as a fraction of the total fuel is injected during the delay period[5,6].

In the dual-fuel engine, as the percentage of alternative fuel is increased gradually replacing diesel fuel, then up to a certain point, the burning rate of *just diesel fuel* will be independent of the amount of the diesel fuel injected and therefore, will not decrease because of reduced diesel quantity. But the diesel fuel is surrounded by alternative fuel-air mixture. So, when the flammability limit of this mixture is higher than the lower flammability limit, this mixture will be involved in the early stage of combustion. The burning rate of the overall mixture at the early stage of combustion will thus be higher than for pure diesel operation. The rate of pressure rise will also be higher than for pure diesel engine operation and so, occasionally will be the maximum pressure. As measured by the author[7] Figure-1 shows the pressure-crank-angle diagrams for pure diesel operation and for dual-fuel (38% natural gas and 62% diesel) operation at 390 kPa bmep. For this particular run of the dual-fuel mode, the peak pressure of the cylinder increases by about 5% and it is clear from the figure that the rate of pressure rise also increases. If this rate of pressure rise is excessive it will cause knocking in the engine. The overall noise of the engine will increase, but unless excessive, it should not be harmful to the engine.

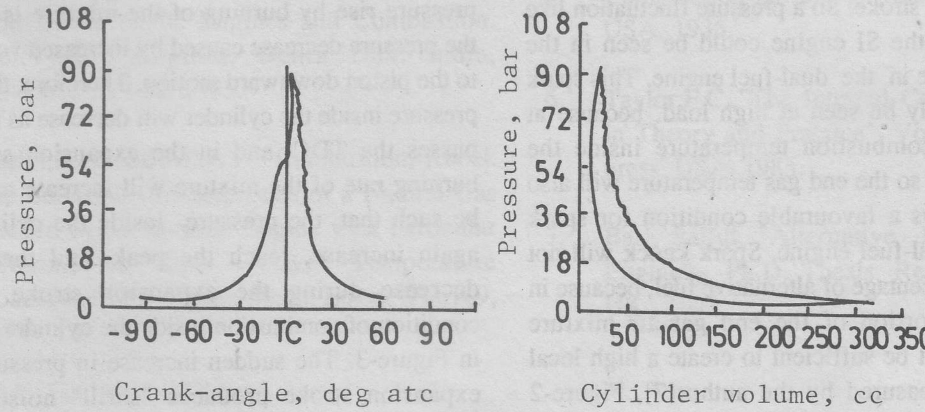
3.2 Spark Knock in Dual-Fuel Engine

In the SI engine, combustion of the premixed mixture is initiated by spark created by the spark plug. Combustion in the SI engine is characterized by the more or less rapid development of a flame that starts from the ignition point and then spreads in a continuous manner outward. But when the mixture appears to ignite and burn ahead of the flame, the phenomenon is called auto-ignition, and when there is a sudden increase in the reaction rate, accompanied by measurable pressure waves, the phenomenon is called knocking. The frequency of this pressure wave decreases as the piston moves outward in the expansion stroke. So when there is spark knocking in the SI engine, a pressure fluctuation will be seen in the expansion stroke in the pressure-crank-angle diagram.



(a) full diesel operation (b) dual-fuel operation

Figure-1: Pressure-crank-angle diagrams (a) full diesel operation and (b) dual-fuel (38% natural gas and 62% diesel) operation at 390 kPa bmep.



(a) pressure-crank-angle diagram (b) pressure-volume diagram

Figure-2: (a) Pressure-crank-angle diagram and(b) pressure-volume diagram with spark knocking in the dual-fuel engine with 71% natural gas and 29% diesel operation at 390 kPa bmep.

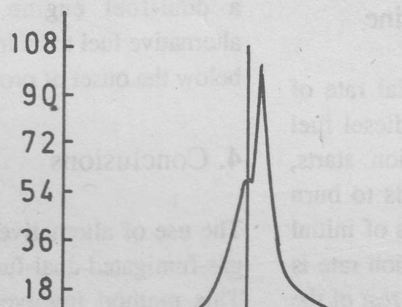


Figure-3: Pressure-crank-angle diagram showing the "shrill" knocking in the dual-fuel engine with 80% natural gas and 20% diesel fuel at 390 kPa bmep.

The combustion process in the dual-fuel engine occurs in certain stages. Initial combustion is brought about by the injected pilot fuel. Then there exits a finite time for the flame front to travel through the alternative fuel-air mixture to complete the combustion process. Both heat transfer from the combustion region and compression of the end-gas mixture, ahead of the flame front, causes an increase in both temperature and pressure of the end-gas. This effect may subsequently induce auto-ignition of the end-gas mixture. When the reaction of the end-gas mixture by auto-ignition is sufficiently rapid and a sufficient amount of end gas is involved, a high local pressure will occur and the portion of the gas in question will subsequently expand rapidly, sending a pressure wave across the chamber. The frequency of this wave will decrease as the piston moves outward in the expansion stroke. So a pressure fluctuation like spark-knock in the SI engine could be seen in the expansion stroke in the dual-fuel engine. This spark knock could only be seen at high load, because at high load the combustion temperature inside the cylinder is high, so the end gas temperature will also be high which is a favourable condition for spark knock in the dual-fuel engine. Spark knock will not occur at low percentage of alternative fuel, because in this case the portion of the end gas-air mixture involved will not be sufficient to create a high local pressure. As measured by the author[7], Figure-2 shows the pressure-crank-angle diagram and pressure-volume diagram with spark knock in the dual-fuel engine with 71% natural gas and 29% diesel, when operated at rated speed of 3600 rev/min.

3.3 "Shrill" Knock in Dual-Fuel Engine

In a conventional diesel engine, the initial rate of burning depends on the accumulated diesel fuel during the delay period. Once combustion starts, the whole accumulated diesel fuel tends to burn simultaneously which results in high rates of initial pressure rise. But the subsequent combustion rate is controlled by the injector which injects the rest of the fuel in a controlled manner. In spark ignition engine, pre-mixed mixture is drawn into the cylinder. Combustion is usually started by one or multiple sparks and then the flame front travels through the gas-air mixture. The initial rate of burning is not as high as in the case the of diesel engine, but the reaction rate increases as the flame front radius increases until the flame front touches the wall of the combustion chamber and breaks up. At high percentage of alternative fuel, maximum combustion process in the dual-fuel engine is similar to that of SI engine and therefore, the initial burning rate in the dual fuel engine is usually less than the initial burning rate for pure diesel operation. Following initial combustion, multiple flame radii will travel through the alternative fuel-air mixture, and because of increasing temperature in the combustion chamber together with larger flame radii, the rate of pressure rise will increase.

In the dual-fuel engine, as the percentage of alternative fuel is increased replacing more and more diesel fuel, a point might be reached where the overall initial burning rate of the mixture is such that, after the piston passes TDC, starts going down, the pressure rise by burning of the mixture is less than the pressure decrease caused by increased volume due to the piston downward motion. Therefore, the overall pressure inside the cylinder will decrease as the piston passes the TDC, and in the expansion stroke the burning rate of the mixture will increase and it will be such that, the pressure inside the cylinder will again increase, reach the peak, and then it will decrease during the expansion stroke. Such a condition of combustion inside the cylinder is shown in Figure-3. The sudden increase in pressure in the expansion stroke produces "shrill" noises in the engine. This "shrill" knocking becomes more prominent as the quantity of alternative fuel is increased. The engine cannot be run with this "shrill" noise due to its objectionable nature, especially for the operator, and also it is harmful for the engine. In a dual-fuel engine, the maximum amount of alternative fuel to be introduced is restricted to a point below the onset of production of "shrill" noise.

4. Conclusions

The use of alternative fuels in IC engines using the gas-fumigated dual-fuel method is common practice. This method involves fewer modifications to the engine when compared to the other methods of using alternative fuels in engines. Also the engine could be run on pure diesel fuel whenever there is a short fall of the alternative fuel. It is however important that the ratio of alternative fuel to diesel be limited to avoid the onset of "shrill" knocking. This "shrill" knocking is audible, and both power and speed fluctuation occur when running under this condition.

Trying to run the engine with this knocking condition can have severe consequences in terms of both engine performance and life. Apart from this "shrill" knocking, other two types of knocking, e.g., "diesel knock" and "spark knock", could be present in the dual-fuel engine. Their presence cannot easily be detected, as in the case of "shrill" knocking. Engine life can however be reduced if run for extended periods under "spark knock" and "diesel knock" conditions.

5. References

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