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CARBON MONOXIDE POISONING FROM THE EXHAUST GASES OF MOTOR VEHICLES

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Approximately 5 to 10 percent of the exhaust gases from an average automobile or truck consists of carbon monoxide. The amount of the gas produced by different engines, and at different times by the same engine, varies considerably. In general, it tends to be less when the engine is operating efficiently. The proportion in the exhaust products depends to some extent on the air/fuel ratio. Some of the conditions of operation that tend to increase production of carbon monoxide include low temperature within the engine (i.e. before it has "warmed up"), idling or racing the motor, and operation at excessive speed or against a heavy load such as up a steep grade.

All standard fuels, including diesel oil and butane, may produce large amounts of carbon monoxide. The presence of tetraethyl lead anti-knock fluid in gasoline does not alter significantly its concentration in the exhaust gases. During a study of vehicles for carbon monoxide hazards conducted by the California Highway Patrol (1) several trucks using butane were examined in which the drivers were exposed to toxic quantities of carbon monoxide. These drivers were not aware of danger because the products of incomplete combustion of butane are practically odorless.

Occasionally, the interiors of moving passenger automobiles accumulate toxic quantities of carbon monoxide. In the two surveys made by the California Highway Patrol there were 30 automobiles among 1,078 tested in which concentrations of carbon monoxide of 100 p.p.m.¹ were found at the level of the driver's nose. One or more defects tending to permit carbon monoxide to pass into the vehicle existed in each of the 30 vehicles. The defects in these automobiles are summarized as follows:

Source of CO Contamination	Number of Cars Affected
Defective muffler	19
Leaky tail-pipe	17
Blow-by	11
Leaky manifold-pipe gasket	8
Leaky manifold-engine connection	7
Leaky exhaust pipe	5

Mufflers are sometimes made of a flat sheet of metal which is rolled up to form a cylinder, the edges of the sheet being sealed where they meet. This seal may be split

¹ 100 parts per million, capable of producing symptoms after exposure of some hours.

by backfire, after which it will leak dangerously. The mufflers of older automobiles often rust through, and conditions that predispose the accumulation of water in the muffler hasten this process. In order to prevent this accumulation of water, drainage holes are sometimes drilled into mufflers, but from the standpoint of the carbon monoxide hazard these purposeful holes are as dangerous as those which result from rust.

Leaks in the tail-pipe permit carbon monoxide to spread upward into an automobile, and it has been shown that carbon monoxide finds its way into the car with greater ease and frequency if the tail-pipe does not extend beyond the back of the car. Furthermore, the least likelihood of contamination of the air within the vehicle with carbon monoxide from this source was associated with the extension of the tail-pipe beyond the back bumper rather than to a point where the exhaust gases were rendered turbulent by impinging on the bumper.

"Blow-by" refers to gases escaping directly from the motor around defective piston rings and into the crank case, from which it passes out through the breather pipe. In motors which have overhead valves, there may be escape of gases through badly worn valve guides. The dangers of blow-by and of defective manifold connections are small if there are no leaks between the motor and the driver's compartment, and if the floor of the automobile is impervious to passage of gases.

In the presence of defects which allow the motor to discharge exhaust gases in front of the driver's compartment, the danger of carbon monoxide poisoning may be decreased by having the automobile windows open. Contrariwise, the opening of one or more windows when the defect is behind the cowl may lead to dangerous concentrations of carbon monoxide in the vehicles. The latter fact is not generally appreciated, and the immediate response to an odor of exhaust gases in an automobile is nearly always the opening of windows. In some of the vehicles tested in California, the opening of the windows of an automobile was followed by an increase of the concentration of carbon monoxide in the compartment from somewhat below to well above 100 p.p.m.

In the case of some vehicle heaters, the air is warmed in the chamber that surrounds a section of the manifold or the exhaust pipe. Such a heater is always potentially dangerous, for any leak of exhaust gases into it directs these gases into the driver's compartment. In one case that we investigated, a heater of this type had caused the deaths of three people and severe injury to a fourth when a crack in the manifold permitted the exhaust gases to pass into the heater.

Another source of danger has been noted in newer automobiles, related to the location of the intakes of their ventilators. These intakes are located under the radiator grill in some recent models. Experiments have revealed that high concentrations of carbon monoxide can be found in an automobile of this type when it is standing or moving slowly just behind another operating automobile, as in a line of traffic. Some manufacturers have warned of this danger in manuals distributed with each new automobile. We are aware of one serious accident that was caused by carbon monoxide intoxication of a driver from this source, and there is a record of a death from carbon monoxide in a vehicle that was parked behind a taxi while the latter had its engine idling (2).

TABLE I
CONCENTRATIONS OF CARBON MONOXIDE IN THE ATMOSPHERE*

Community and Area	Number of Samples	CO Concentration Range (p.p.m.)	Average
Baltimore, Maryland Downtown	7	0-15	10.
Cincinnati, Ohio Industrial and Downtown Areas	212	0-55†	9.5
Residential	373	0-25	7.5
Rural	43	0-15‡	<5.
Donora, Pennsylvania Downtown	9	0-trace	<5.

* From samples taken by staff of Kettering Laboratory, University of Cincinnati.

† One value of 200 p.p.m. was obtained as the exhaust gases of a motor bus were discharged near the sampler in the downtown area. This is not included in the determination of the average.

‡ Only 1 of these values was greater than 1 p.p.m.

Certain problems relating to atmospheric pollution have been investigated by members of the staff of the Kettering Laboratory, and some of the results dealing with carbon monoxide have been compiled by Cholak (3) (Table I). In general, the concentrations of carbon monoxide in the streets vary with the density of motor vehicle traffic, and there are considerable variations in the concentrations throughout the day, depending on the amount of traffic and the presence or absence of winds.

CARBON MONOXIDE HAZARD IN PRIVATE GARAGES

The operation of an automobile engine in a small garage is extremely dangerous, for toxic concentrations of the gas can fill a small room in a very short period of time, and lethal concentrations accumulate within minutes thereafter. We have conducted tests in which an automobile was in a garage with the end of the tail-pipe at the open door, prior to backing out the vehicle. After the engine had been allowed to idle for 5 minutes, the concentration of carbon monoxide at the front of the vehicle was 600 p.p.m., and at the end of 10 minutes, it was well above 1,000 p.p.m.² When the automobile had been backed into the garage and the engine was idled for 5 minutes, concentrations of carbon monoxide in excess of 1,000 p.p.m. were observed. Obviously, operation of the motor when the door is closed would permit an even more rapid rise in the concentration of the gas, and under these circumstances an individual would be rendered unconscious or even killed within a matter of a few minutes.

Fatal carbon monoxide poisoning may occur when one simply lies under the free end of the tail-pipe while the motor is idling. We have investigated two suicides accomplished by this method, one in an open garage and the other with the automobile standing out of doors.

² A concentration that produces dangerous blood levels within a few minutes of onset of its inhalation.

ILLNESS AND DEATH CAUSED BY CARBON MONOXIDE FROM MOTOR VEHICLES

It is not infrequent for the onset of symptoms of carbon monoxide poisoning to occur while the victims are in automobiles. Because of its protean manifestations, the poisoning may simulate many other conditions, and numerous instances of illness from inhalation of carbon monoxide probably remain unrecognized. Aside from the immediate problem of proper treatment for the poisoned person, failure to make the correct diagnosis may cause delay in repairing the predisposing defects of the automobile, so that other and perhaps more serious consequences may follow use of the vehicle.

The relation of symptoms of "car-sickness" to carbon monoxide poisoning has been studied by the California Highway Patrol (1). During their survey of motor vehicles for carbon monoxide hazards, they tested several automobiles in which sick infants and children were riding. A substantial concentration of carbon monoxide was found in each of these, and the officers also observed that small children were much less tolerant to carbon monoxide than are adults.

Several instructive cases of carbon monoxide poisoning occurring in automobiles have come to our attention. In one, a middle aged man was driving along a country lane, when his vehicle suddenly left the road and struck a tree. A witness stated that he had seen the driver slump over the wheel immediately before the accident. The man was dead when he arrived at a nearby hospital, and an autopsy was performed. Severe injuries of the organs of the chest were present, but no lesion was found that might have been responsible for loss of control of the automobile. Analysis of the blood revealed that 37 per cent of the hemoglobin was combined with carbon monoxide, a fact which led to the discovery that the corroded muffler had several holes in it.

Another case concerns a man, 53 years of age, who was brought into a hospital in an unconscious state. He had been found in his automobile early one morning beside a well travelled road. The engine was not running, and subsequently it could not be determined whether the ignition key was in the "on" position. Likewise, it is not known whether any gasoline remained in the tank. It was believed that he had suffered a "stroke", and after a period of 3 days in the hospital the patient died without having regained consciousness. Autopsy revealed brain damage of a type which is typical of carbon monoxide poisoning. Significant amounts of the gas were not found in the blood obtained at the autopsy, but the period of survival had been great enough for the gas to have been eliminated before death occurred. If carbon monoxide poisoning had been suspected at the time of his admission to the hospital, and it had been proved by an analysis of his blood, proper therapy might have saved this man's life.

The drivers of trucks and taxicabs not infrequently suffer mild intoxication from exhaust gases, and occasional fatal episodes of carbon monoxide poisoning have occurred in drivers of such vehicles. For example, we cite two essentially identical cases involving truck drivers both of whom died from the inhalation of carbon monoxide. The vehicles were parked at the side of the road, and the engine of each had been running, apparently in order to maintain heat within the cab. Accidents of this type are fairly common, and they provide ample warning to trucking concerns

that every effort should be made to discourage their drivers from parking with the engine idling. Regular and careful checking of truck exhaust and heating systems would also diminish the number of such cases. In one of the two instances mentioned above, examination of the truck revealed a defect in the manifold which allowed the exhaust fumes to mix directly with the air entering the cab through the heater.

In addition to the cases of illness or death recognized as having been caused by carbon monoxide, it is believed that some of the serious accidents in which trucks are involved are caused by carbon monoxide poisoning of the driver of the vehicle. For instance, Martland (4) cites the case of a truck driver who drove into the rear of a parked car for no apparent reason. When a sample of the truck driver's blood was analyzed, 20% of the hemoglobin was found to be saturated with carbon monoxide. The incidence of gas poisoning as a contributing factor in motor vehicle collisions will become apparent only when carbon monoxide determinations have been made on the blood of a large number of drivers who have been involved in serious or fatal accidents.

In order to establish the relationship, if any, of carbon monoxide to deaths which occur in, or are associated with, motor vehicles, certain toxicologic investigations must be made in every such case. Whenever a body is found within or near an automobile, a determination of the carbon monoxide concentration of the blood is important. In addition, a test should be carried out in all cases of fatal injury to the driver or passengers of an automobile which has been involved in an accident. If this were done by every coroner and medical examiner, we would begin to recognize that carbon monoxide is an important agent in predisposing some otherwise unexplained fatal accidents.

Exhaust gases are frequently utilized by persons wishing to commit suicide, and the circumstances rarely depart from one or another of two common methods. One involves the use of a hose to connect the tailpipe outlet with the inside of the automobile, all windows being tightly closed except for the slit in one window through which the hose is passed. The second situation is one in which the automobile is in a small enclosure, usually a garage, and the doors of the enclosure are tightly closed while the engine is operating.

Usually, persons committing suicide do so in isolated places where the bodies are not found for some hours, and the investigator should always ascertain immediately whether the ignition key is in the "on" position. If the engine is not operating when the body is found and the key is in the "off" position, or if there is still gasoline within the tank, suspicion is warranted that the death was not in fact a suicide or that there was tampering after the death. It is axiomatic that the circumstances and scene should be carefully investigated in deaths of this kind, and that a complete autopsy should be performed together with an analysis of the blood of the deceased for carbon monoxide and for alcohol.

Motor exhaust fumes have also been used to commit homicide. The circumstances of one case have been reported by Gerber (5). A young man and woman were in a cafe, and during the woman's absence from the table the man placed cantharides in her drink. They left the cafe in an automobile, and shortly thereafter the woman became comatose from the effects of the drug. The man became frightened and de-

cided to kill the woman with the exhaust fumes and then to simulate an accident. He passed a hose from the end of the tailpipe into a window of the automobile, closed the other window, and leaving the engine running he walked away for a short time. When he returned, the woman was dead. He discarded the hose and then drove the automobile onto the lawn of a police station where he opened the door and "fell out in a state of collapse." The coroner was called, and as part of his investigation he obtained a sample of blood from the heart of the woman and from a vein of the man, after which the latter was treated with inhalations of a mixture of oxygen and carbon dioxide. When the analyses of the blood were made, the sample from the woman was found to contain a lethal concentration of carbon monoxide, while the blood of the man contained only a minute amount. The coroner thereupon ordered an autopsy and toxicological analysis of the body of the woman, during which the aphrodisiac was detected. Interrogation of the man then led to a confession of the facts related above.

SUMMARY

1. Immense amounts of carbon monoxide are present in the exhaust gases from internal combustion engines, and poisoning can occur in persons within moving or standing automobiles, or in an area contaminated by automobile exhaust gases.
2. Some of the hazards of carbon monoxide from automobile exhausts are discussed, and the danger of poisoning in persons driving vehicles are emphasized.
3. The utilization of exhaust gases in accomplishing suicide or homicide is recounted.

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