
Control of Mobile Sources

I. INTRODUCTION

Because mobile sources of air pollution are capable of moving from one local jurisdiction to another, they are usually regulated by the national government. In the United States, state or local agencies can have more restrictive standards, if they choose. To date, only the state of California has established extensive standards more restrictive than the US federal standards, and these only for gasoline-powered automobiles.

II. GASOLINE-POWERED VEHICLES

Gasoline-powered motor vehicles outnumber all other mobile sources combined in the number of vehicles, the amount of energy consumed, and the mass of air pollutants emitted. It is not surprising that they have received the greatest share of attention regarding emission standards and air pollution control systems. Table 27.2 shows the US federal emission control requirements for gasoline-powered passenger vehicles.

Crankcase emissions in the United States have been effectively controlled since 1963 by positive crankcase ventilation (PCV) systems which take the

gases from the crankcase, through a flow control valve, and into the intake manifold. The gases then enter the combustion chamber with the fuel-air mixture, where they are burned.

Figure 35.1 shows a cross section of a gasoline engine with the PCV system.

Evaporative emissions from the fuel tank and carburetor have been controlled on all 1971 and later model automobiles sold in the United States. This has been accomplished by either a vapor recovery system which uses the crankcase of the engine for the storage of the hydrocarbon vapors or an adsorption and regeneration system using a canister of activated carbon to trap the vapors and hold them until such time as a fresh air purge through the canister carries the vapors to the induction system for burning in the combustion chamber.

The exhaust emissions from gasoline-powered vehicles are the most difficult to control. These emissions are influenced by such factors as gasoline formulation, air-fuel ratio, ignition timing, compression ratio, engine speed and load, engine deposits, engine condition, coolant temperature, and combustion chamber configuration. Consideration of control methods must be based on elimination or destruction of unburned hydrocarbons, carbon monoxide, and oxides of nitrogen. Methods used to control one pollutant may actually increase the emission of another requiring even more extensive controls.

Control of exhaust emissions for unburned hydrocarbons and carbon monoxide has followed three routes:

1. Fuel modification in terms of volatility, hydrocarbon types, or additive content. Some of the fuels currently being used are liquefied petroleum gas (LPG), liquefied natural gas (LNG), compressed natural gas (CNG), fuels with alcohol additives, and unleaded gasoline. The supply of some of these fuels is very limited. Other fuel problems involving storage, distribution, and power requirements have to be considered.
2. Minimization of pollutants from the combustion chamber. This approach consists of designing the engine with improved fuel-air distribution

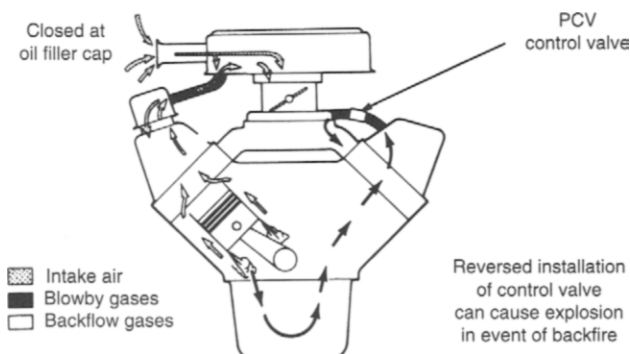


Fig. 35.1. Positive crankcase ventilation (PCV) system.

systems, ignition timing, fuel–air ratios, coolant and mixture temperatures, and engine speeds for minimum emissions. The majority of automobiles sold in the United States now use an electronic sensor/control system to adjust these variables for maximum engine performance with minimum pollutant emissions.

3. Further oxidation of the pollutants outside the combustion chamber. This oxidation may be either by normal combustion or by catalytic oxidation. These systems require the addition of air into the exhaust manifold at a point downstream from the exhaust valve. An air pump is employed to provide this air. Figure 35.2 illustrates an engine with an air pump and distribution manifold for the oxidation of CO and hydrocarbons (HC) outside the engine.

Beginning with the 1975 US automobiles, catalytic converters were added to nearly all models to meet the more restrictive emission standards. Since the lead used in gasoline is a poison to the catalyst used in the converter, a scheduled introduction of unleaded gasoline was also required. The US petroleum industry simultaneously introduced unleaded gasoline into the marketplace.

In order to lower emissions of oxides of nitrogen from gasoline engines, two general systems were developed. The first is exhaust gas recirculation (EGR), which mixes a portion of the exhaust gas with the incoming fuel–air charge, thus reducing temperatures within the combustion chamber. This recirculation is controlled by valving and associated plumbing and electronics, so that it occurs during periods of highest NO_x production, when some power reduction can be tolerated: a cruising condition at highway speed. Other alternatives are to use another catalytic converter, in series with the HC/CO converter, which decomposes the oxides of nitrogen to oxygen and nitrogen before the gases are exhausted from the tailpipe.

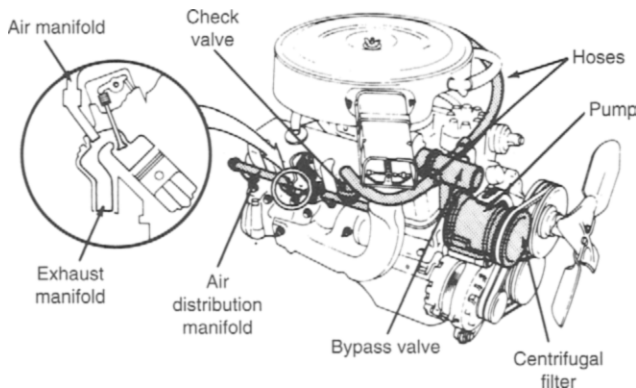


Fig. 35.2. Manifold air oxidation system.

III. DIESEL-POWERED VEHICLES

The diesel (compression ignition) cycle is regulated by fuel flow only, air flow remaining constant with engine speed. Because the diesel engine is normally operated well on the lean side of the stoichiometric mixture (40:1 or more), emission of unburned hydrocarbons and carbon monoxide is minimized. The actual emissions from a diesel engine are (1) oxides of nitrogen, as for spark ignition engines; (2) particulate matter, mainly unburned carbon, which at times can be excessive; (3) partially combusted organic compounds, many of which cause irritation to the eyes and upper respiratory system; and (4) oxides of sulfur from the use of sulfur-containing fuels. A smoking diesel engine indicates that more fuel is being injected into the cylinder than is being burned and that some of the fuel is being only partially burned, resulting in the emission of unburned carbon.

Control of diesel-powered vehicles is partially accomplished by fuel modification to obtain reduced sulfur content and cleaner burning and by proper tuning of the engine using restricted fuel settings to prevent overfueling.

Diesel fuel has begun to evolve in another, more sustainable, way. An increasing number of vehicles are running on so-called "bio-diesel" fuel. This is refined from plant-based hydrocarbons, especially from waste residues (e.g. from used cooking oils). With operational adjustments, bio-diesel is currently in use in buses as part of urban transit and college transportation systems.

Effective with the 1982 model year, particulate matter from diesel vehicles was regulated by the US Environmental Protection Agency for the first time, at a level of 0.37 g km^{-1} . Diesel vehicles were allowed to meet an NO_x level of 0.93 g km^{-1} under an Environmental Protection Agency waiver. These standards were met by a combination of control systems, primarily EGR and improvements in the combustion process. For the 1985 model year, the standards decreased to 0.12 g of particulate matter per kilometer and 0.62 g of NO_x per kilometer. This required the use of much more extensive control systems [1]. The Clean Air Act Amendments of 1990 [2] have kept the emission standards at the 1985 model level with one exception: diesel-fueled heavy trucks shall be required to meet an NO_x standard of 4.0 g per brake horsepower hour.

IV. GAS TURBINES AND JET ENGINES

The modified Brayton cycle is used for both gas turbines and jet engines. The turbine is designed to produce a usable torque at the output shaft, while the jet engine allows most of the hot gases to expand into the atmosphere, producing usable thrust. Emissions from both turbines and jets are similar, as are their control methods. The emissions are primarily unburned hydrocarbons, unburned carbon which results in the visible exhaust, and oxides of nitrogen. Control of the unburned hydrocarbons and the unburned carbon may be accomplished by redesigning the fuel spray nozzles and reducing cooling air to the combustion chambers to permit more complete combustion.

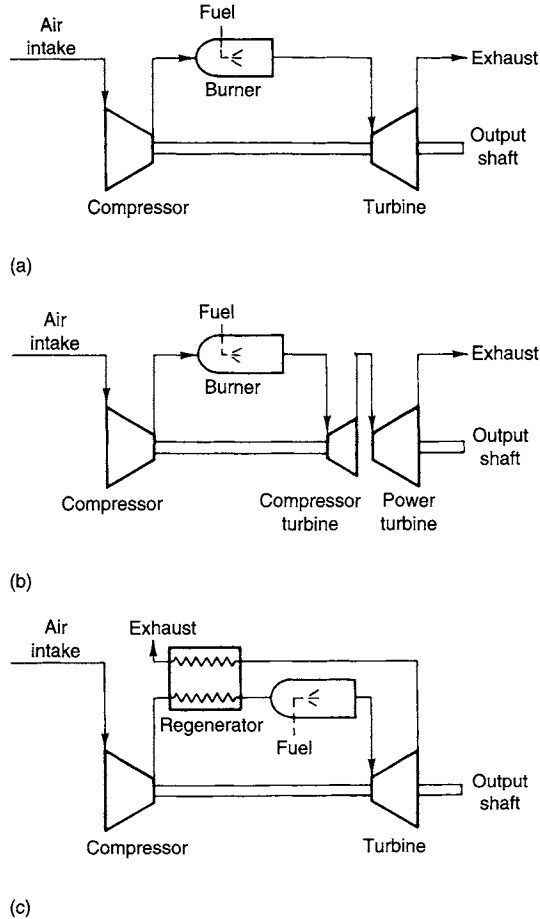


Fig. 35.3. Schematic diagrams of gas turbines: (a) simple gas turbine, (b) free-turbine engine, and (c) regenerative gas turbine.

US airlines have converted their jet fleets to lower-emission engines using these control methods. NO_x emissions may be minimized by reduction of the maximum temperature in the primary zone of the combustors.

US Environmental Protection Agency regulations for commercial, jet, and turbine-powered aircraft [3] are based on engine size (thrust) and pressure ratio (compressor outlet/compressor inlet) for the time in each mode of a standardized takeoff and landing cycle. Once the aircraft exceeds an altitude of 914 m, no regulations apply.

The gas turbine engine for automotive or truck use could be either a simple turbine, a regenerative turbine, a free turbine, or any combination. Figure 35.3 shows the basic types which have been successfully tried in automotive and truck use.

V. ALTERNATIVES TO EXISTING MOBILE SOURCES

The atmosphere of the world cannot continue to accept greater and greater amounts of emissions from mobile sources as our transportation systems expand. The present emissions from all transportation sources in the United States exceed 50 billion kg of carbon monoxide per year, 20 billion kg per year of unburned hydrocarbons, and 20 billion kg of oxides of nitrogen. If presently used power sources cannot be modified to bring their emissions to acceptable levels, we must develop alternative power sources or alternative transportation systems. All alternatives should be considered simultaneously to achieve the desired result, an acceptable transportation system with a minimum of air pollution.

One modified internal combustion engine which shows promise is the stratified-charge engine. This is a spark ignition engine using fuel injection in such a manner as to achieve selective stratification of the air/fuel ratio in the combustion chamber. The air/fuel ratio is correct for ignition at the spark plug, and the mixture is fuel lean in other portions of the combustion chamber. Only air enters the engine on the intake stroke, and the power output is controlled by the amount of fuel injected into the cylinder. Stratified-charge engines have been operated experimentally and used in some production vehicles [4]. They show promise as relatively low-emission engines. The hydrocarbon emission levels from this engine are quite variable, the CO levels low, and the NO_x levels variable but generally high.

An external combustion engine that has been widely supported as a low-emission power source is the Rankine cycle steam engine. Many different types of expanders can be used to convert the energy in the working fluid into rotary motion at a drive shaft. Expanders that have been tried or proposed are reciprocating piston engines, turbines, helical expanders, and all possible combinations of these. The advantage of the steam engine is that the combustion is continuous and takes place in a combustor with no moving parts. The result is a much lower release of air pollutants, but emissions are still not completely zero. Present technology is capable of producing a satisfactory steam-driven car, truck, or bus, but costs, operating problems, warmup time, and weight and size must be considered in the total evaluation of the system. A simple Rankine cycle steam system is shown diagrammatically in Fig. 35.4.

Electric drive systems have been tried as a means of achieving propulsion without harmful emissions. Currently, most battery-operated vehicles use lead-acid batteries, which give low power, limited range, and require frequent recharging. In power shortage areas this could be a severe additional load on the electrical system. Sulfuric acid, hydrogen, and oxygen emissions from millions of electric vehicles using lead-acid storage batteries for an energy source would be appreciable. Other types of batteries offer some promise, but their manufacture and costs present obstacles to their widespread

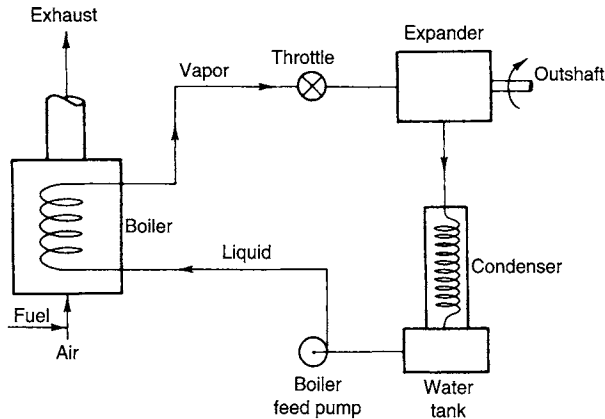


Fig. 35.4. Rankine cycle system.

automotive use. In fact, the nickel (Ni) based battery systems installed in many hybrid vehicles detract from the vehicles' overall environmental attractiveness. Viewed from a life cycle perspective, the mining of the Ni ore (e.g. from the extensive area near Sudsbury, Ontario), the processing of the ore and manufacture of Ni foam, and the shipping of the foam and other components many thousands of kilometers to vehicle assembly plants present large costs and make for a rather unsustainable network to support the batteries.

Hybrid systems consisting of two or more energy-conversion processes are now being increasingly used in very low-emission vehicles. A constant speed and load internal combustion engine driving a generator with a small battery for load surges could be made to emit less hydrocarbons, CO, and NO_x than a standard automobile engine, but the cost would be much higher. Other hybrid systems which have been proposed are steam-electric and turbine-electric. The problem associated with hybrid systems is the cost of the two engines plus the cost of the added controls and system integration [5]. However, the prices are beginning to equilibrate, and they have become more attractive to a broader consumer base since they provide a "green" alternative to ordinary internal combustion vehicles.

Fuel cells, which rely on electrochemical generation of electric power, could be used for nonpolluting sources of power for motor vehicles. Since fuel cells are not heat engines, they offer the potential for extremely low emissions with a higher thermal efficiency than internal combustion engines. Basically, a fuel cell converts chemical energy directly into electricity by combining oxygen from the air with hydrogen gas. The cell can keep producing electricity so long as hydrogen is available. The space program has used fuel cells for many decades. However, there are still obstacles to overcome before fuel cells attain widespread use. The federal government and others, especially California, have recently stated strong interests in making fuel cells more mainstream, in

the interests of energy savings (and national security), as well as for improvements in air quality.

Probably the ultimate answer to the problem of emissions from millions of private automobiles is an alternative transportation system. It must be remembered, however, that even rail systems and bus systems do emit some air pollution. Rail systems are expensive and lack flexibility. A quick calculation of the number of passengers carried per minute past a single point on a freeway in private automobiles will illustrate the difficulties of a rail system in replacing the automobile. Buses offer much greater flexibility at lower cost than rail systems, but in order to operate efficiently and effectively, they would require separate roadway systems and loading stations apart from automobile traffic.

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QUESTIONS

1. Would you expect to find the same chemical composition of the hydrocarbons from the exhaust of a gasoline-powered automobile as that of gasoline in the vehicle's tank? Why?
2. What would be the effect on emissions from a gasoline-powered vehicle if it was designed to be operated on leaded fuel and an unleaded fuel was used?
3. What would be the effect on emissions from a gasoline-powered vehicle if it was designed to be operated on unleaded fuel and a leaded fuel was used?
4. Why might you expect EGR on a diesel engine to increase the particulate matter emissions?
5. Considering the wide range of sizes of automotive engines, do you feel that an emission standard in g km^{-1} rather than $\mu\text{g m}^{-3}$ or ppm is equitable to all automobile manufacturers?
6. Discuss the emissions you would expect from a jet aircraft compared to those from a piston engine aircraft.
7. If a major freeway with four lanes of traffic in one direction passes four cars per second at 100 km h^{-1} during the rush period and each car carries two people, how often would a commuter train of five cars carrying 100 passengers per car have to be operated to handle the same load? Assume the train would also operate at 100 km h^{-1} .
8. An automobile traveling 50 km h^{-1} emits 1% CO from the exhaust. If the exhaust rate is $80 \text{ m}^3 \text{ min}^{-1}$, what is the CO emission in g km^{-1} ?
9. List the following in increasing amounts from the exhaust of an idling automobile: O_2 , NO_x , SO_x , N_2 , unburned hydrocarbons, CO_2 , and CO.
10. What are the advantages and disadvantages of bio-diesel use on a large scale? What can be done to overcome the obstacles?
11. What were problems associated with three different fuel additives? How can the lessons learned from these experiences help improve future fuel additives?