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Engineering Control Concepts

I. INTRODUCTION

The application of control technology to air pollution problems assumes that a source can be reduced to a predetermined level to meet a regulation or some other target value. Control technology cannot be applied to an uncontrollable source, such as a volcano, nor can it be expected to control a source completely to reduce emissions to zero. The cost of controlling any given air pollution source is usually an exponential function of the percentage of control and therefore becomes an important consideration in the level of control required [1]. Figure 31.1 shows a typical cost curve for control equipment.

If the material recovered has some economic value, the picture is different. Figure 31.2 shows the previous cost of control with the value recovered curve superimposed on it. The plant manager looking at such a curve would want to be operating in the area to the left of the intersection of the two curves, whereas the local air pollution forces would insist on operation as far to the right of the graph as the best available control technology would allow.

Control of any air pollution source requires a complete knowledge of the contaminant and the source. The engineers controlling the source must be thoroughly familiar with all available physical and chemical data on the effluent

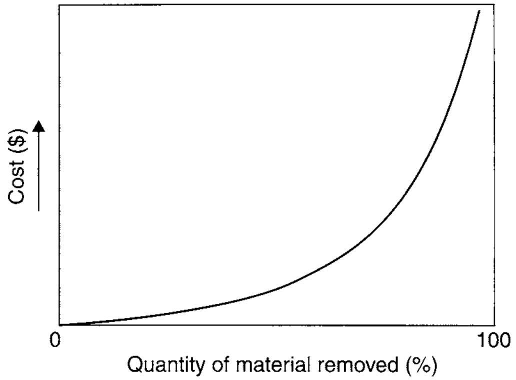

Fig. 31.1. Air pollution control equipment cost.

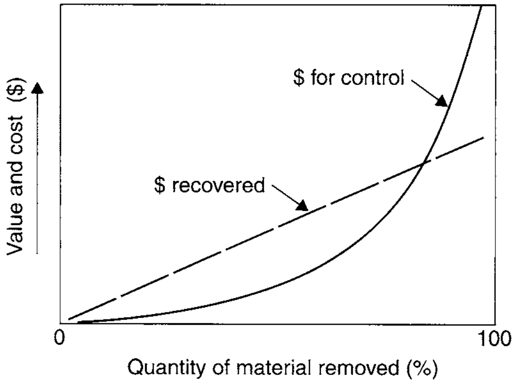

Fig. 31.2. Control equipment cost with value recovered.

from the source. They must know the rules and regulations of the control agencies involved, including not only the Air Pollution Control Agency but also any agencies, which may have jurisdiction over the construction, operation, and final disposal of the waste from the source [2].

In many cases, heating or cooling of the gaseous effluent will be required before it enters the control device. The engineer must be thoroughly aware of the gas laws, thermodynamic properties, and reactions involved to secure a satisfactory design. For example, if a gas is cooled there will be condensation when the temperature drops below the dewpoint. If water is sprayed into the hot gas for cooling, it adds greatly to the specific volume of the mixture. As the gases pass through hoods, ducts, fans, and control equipment, temperatures and pressures change and hence, also, specific volumes and velocities [3].

The control of atmospheric emissions from a process will generally take one of three forms depending on the process, fuel, types, availability of control equipment, etc. The three general methods are (1) process change to a less polluting process or to lowered emission from the existing process through a modification or change in operation, (2) change to a fuel that will give the desired level of emissions, and (3) installation of control equipment between the point of pollutant generation and its release to the atmosphere. Control may consist of either removal of the pollutant or conversion to a less polluting form [3].

II. PROCESS CHANGE

A process change can be either a change in operating procedures for an existing process or the substitution of a completely different process. In recent years, this has been labeled "pollution prevention." Consider a plant manager who for years has been using solvent A for a degreasing operation. By past experimentation, it has been found that with the conveyor speed at 100 units per hour, with a solvent temperature of 80°C, one gets maximum cleaning with solvent a loss that results in the lowest overall operating cost for the process.

A new regulation is passed requiring greatly reduced atmospheric emissions of organic solvents, including solvent A. The manager has several alternatives:

1. Change to another more expensive solvent, which by virtue of its lower vapor pressure would emit less organic matter.
2. Reduce the temperature of the solvent and slow down the conveyor to get the same amount of cleaning. This may require the addition of another line or another 8 h shift.
3. Put in the necessary hooding, ducting, and equipment for a solvent recovery system which will decrease the atmospheric pollution and also result in some economic solvent recovery.
4. Put in the necessary hooding, ducting, and equipment for an afterburner system which will burn the organic solvent vapors to a less polluting emission, but with no solvent recovery.

In some cases, the least expensive control is achieved by abandoning the old process and replacing it with a new, less polluting one. Any increased production and/or recovery of material may help offset a portion of the cost. It has proved to be cheaper to abandon old steel mills and to replace them with completely new furnaces of a different type than to modify the old systems to meet pollution regulations. Kraft pulp mills found that the least costly method of meeting stringent regulations was to replace the old, high-emission recovery furnaces with a new furnace of completely different design. The kraft mills have generally asked for, and received, additional plant capacity to offset partially the cost of the new furnace type.

III. FUEL CHANGE

In the past, for many air pollution control situations, a change to a less polluting fuel offered the ideal solution to the problem. If a power plant was emitting large quantities of SO_2 and fly ash, conversion to natural gas was cheaper than installing the necessary control equipment to reduce the pollutant emissions to the permitted values. If the drier at an asphalt plant was emitting 350 mg of particulate matter per standard cubic meter of effluent when fired with heavy oil of 4% ash, it was probable that a switch to either oil of a lower ash content or natural gas would allow the operation to meet an emission standard of 250 mg per standard cubic meter.

Fuel switching based on meteorological or air pollution forecasts was, in the past, a common practice to reduce the air pollution burden at critical times. Some control agencies allowed power plants to operate on residual oil during certain periods of the year when pollution potential was low. Some large utilities for years have followed a policy of switching from their regular coal to a more expensive but lower-sulfur coal when stagnation conditions were forecast.

Caution should be exercised when considering any change in fuels to reduce emissions. This is particularly true considering today's fuel costs. Specific considerations might be the following:

1. What are current and potential fuel supplies? In many areas natural gas is already in short supply. It may not be possible to convert a large plant with current allocations or pipeline capacity.
2. Most large boilers use a separate fuel for auxiliary or standby purposes. One actual example was a boiler fired with wood residue as the primary fuel and residual oil as the standby. A change was made to natural gas as the primary fuel, with residual oil kept for standby. This change was made to lower particulate emissions and to achieve a predicted slightly lower cost. Because of gas shortages, the plant now operates on residual oil during most of the cold season, and the resulting particulate emission greatly exceeds that of the previously burned wood fuel. In addition, an SO_2 emission problem exists with the oil fuel that never occurred with the wood residue. Overall costs have not been lowered because natural gas rates have increased since the conversion.
3. Charts or tables listing supplies or reserves of low-sulfur fuel may not tell the entire story. For example, a large percentage of low-sulfur coal is owned by steel companies and is therefore not generally available for use in power generating stations even though it is listed in tables published by various agencies.
4. Strong competition exists for low-pollution fuels. While one area may be drawing up regulations to require use of natural gas or low-sulfur fuels, it is probable that other neighboring areas are doing the same. Although there may have been sufficient premium fuel for one or two

Fig. 31.3. Trojan nuclear power plant. *Source*: Portland General Electric Company.

areas, if the entire region changes, not enough exists. Such a situation has resulted in extreme fuel shortages during cold spells in some large cities. The supply of low-sulfur fuels has been exhausted during period of extensive use.

Nuclear reactors (Fig. 31.3) used for power generation has been questioned from several environmental points of view. These appear to be relatively pollution free compared to the more familiar fossil fuel-fired plant, which emits carbon monoxide and carbon dioxide, oxides of nitrogen and sulfur, hydrocarbons, and fly ash. However, waste and spent-fuel disposal problems may offset the apparent advantages. These problems (along with steam generator leaks) caused the plant shown in Fig. 31.3 to close permanently in 1993.

IV. POLLUTION REMOVAL

In many situations, sufficient control over emissions cannot be obtained by fuel or process change. In cases such as these, the levels of the pollutants of concern in the exhaust gases or process stream must be reduced to allowable values before they are released to the atmosphere.

The equipment for the pollutant removal system includes all hoods, ducting, controls, fans, and disposal or recovery systems that might be necessary. The entire system should be engineered as a unit for maximum efficiency and economy. Many systems operate at less than maximum efficiency because a portion of the system was designed or adapted without consideration of the other portions [4].

Efficiency of the control equipment is normally specified before the equipment is purchased. If a plant is emitting a pollutant at $500\,\mathrm{kg\,h^{-1}}$ and the regulations allow an emission of only $25\,\mathrm{kg\,h^{-1}}$, it is obvious that at least 95% efficiency is required of the pollution control system. This situation requires the regulation to state "at least 95% removal on a weight basis." The regulation should further specify how the test would be made to determine the efficiency. Figure 31.4 shows the situation as it exists.

The efficiency for the device shown in Fig. 31.4 may be calculated in several ways:

$$\text{Efficiency, \%} = 100\left(\frac{C}{A}\right), \quad \text{but since } A = B + C \tag{31.1}$$

$$\text{Efficiency, \%} = 100\left(\frac{C}{B+C}\right) \text{ or } 100\left(\frac{A-B}{A}\right) \text{ or } 100\left(\frac{A-B}{B+C}\right) \tag{31.2}$$

The final acceptance test would probably be made by measuring two of the three quantities and using the appropriate equation. For a completely valid efficiency test the effect of hold-up (*D*) and loss (*E*) must also be taken into account.

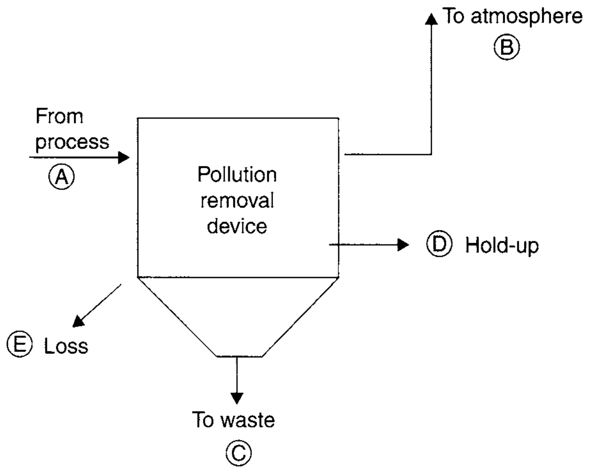

Fig. 31.4. Typical pollution control device as shown for efficiency calculations.

To remove a pollutant from the carrying stream, some property of the pollutant that is different from the carrier must be exploited. The pollutant may have different size, inertia, electrical, or absorption properties. Removal requires that the equipment be designed to apply the scientific principles necessary to perform the separation.

V. DISPOSAL OF POLLUTANTS

If a pollutant is removed from the carrying gas stream, disposal of the collected material becomes of vital concern. If the collected material is truly inert, it may be disposed of in a sanitary landfill. If it is at the other end of the scale, it is probably considered as a toxic waste and strict laws governing its disposal apply. Disposal of hazardous wastes is regulated by governmental agencies [7–13].

In the United States, the Resource Conservation and Recovery Act (RCRA) of 1976 is the major legislation covering the disposal of solid and hazardous wastes [2]. This act provides a multifaceted approach to solving the problems associated with the generation of approximately 5 billion metric tons of solid waste each year in the United States. It places particular emphasis on the regulation of hazardous wastes. This law established the Office of Solid Waste within the US Environmental Protection Agency and directed the agency to publish hazardous waste characteristics and criteria.

If a waste is designated as hazardous under the RCRA, regulations are applied to generators, transporters, and those who treat, store, or dispose of that waste. Regulations regarding hazardous wastes are enforced by the federal government, while the individual states are responsible for enforcing the provisions of the RCRA which apply to nonhazardous wastes. The act also provides for research, development, and demonstration grants for waste disposal.

The US Environmental Protection Agency, Office of Solid Waste Management Programs, defines hazardous waste as "wastes or combinations of wastes which pose a substantial present or potential hazard to human health or living organisms because they cause, or tend to cause, detrimental cumulative effects."

Hazardous wastes can be categorized in a way that shows their potential or immediate effect. A common system for categorizing substances is (1) toxic substances (acute or chronic damage to living systems), (2) flammable, (3) explosive or highly reactive, (4) irritating and/or sensitizing, (5) corrosive (strong oxidizing agents), (6) radioactive, (7) bioaccumulative and/or biomagnified substances (with toxic effects), and (8) genetically interactive substances (mutagenic, teratogenic, and carcinogenic). It is possible for a substance to be placed in any number of these categories, but placement in only one category is sufficient for it to be considered hazardous [7–13].

Table 31.1 indicates the four main types of hazardous material, with examples of substances of each type. Not presented in Table 31.1 are radioactive materials, which are considered as a separate type of hazardous waste [5].

TABLE 31.1

Hazardous Material Types

Miscellaneous inorganics	Halogens and interhalogens	Miscellaneous organics	Organic halogen compounds
Metals	Bromine pentafluoride	Acrolein	Aldrin
Antimony	Chlorine	Dinitrophenol	Chlordane
Bismuth	Chlorine pentafluoride	Tetrazene	1,1-dichloro-2,2-bis (*p*-chlorophenyl) ethane (DDD) Dichloro-diphenyl-trichloroethane (DDT)
Cadmium	Chlorine trifluoride	Nitroglycerine	Dieldrin
Chromium	Fluorine	Nitroaniline	Endrin
Cobalt	Perchloryl fluoride	Chloroacetophenone (CN tear gas)	Potassium cyanide
Copper			Heptachlor
Lead			Lindane
Mercury			Parathion
Nickel			Methyl bromide
Selenium			Polychlorinated biphenyls (PCBs)
Silver			
Tellurium			
Thallium			
Tin			
Zinc			
Nonmetallics			
Cyanide (ion)			
Hydrazine			
Fluorides			
Phosgene			

Table 31.2 lists some of the currently used pretreatments and ultimate disposal methods for hazardous wastes [6]. *Pretreatment* refers almost entirely to thickening or dewatering processes for liquids or sludges. This process not only reduces the volume of the waste but also allows easier handling and transport.

The general purpose of ultimate disposal of hazardous wastes is to prevent the contamination of susceptible environments. Surface water runoff, ground water leaching, atmospheric volatilization, and biological accumulation are processes that should be avoided during the active life of the hazardous waste. As a rule, the more persistent a hazardous waste is (i.e. the greater its resistance to breakdown), the greater the need to isolate it from the environment. If the substance cannot be neutralized by chemical treatment or incineration and still maintains its hazardous qualities, the only alternative is usually to immobilize and bury it in a secure chemical burial site.

TABLE 31.2

Ultimate Waste Disposal Methods

Process	Purpose	Wastes	Problems (remarks)
Cementation and vitrification	Fixation Immobilization Solidification	Sludges Liquids	Expensive
Centrifugation	Dewatering Consolidation	Sludges Liquids	
Filtration	Dewatering Volume reduction	Sludges Liquids	Expensive
Thickening (various methods)	Dewatering Volume reduction	Sludges Liquids	
Chemical addition (polyelectrolytes)	Precipitation Fixation Coagulation	Sludges Liquids	Can be used in conjunction with other processes
Submerged combustion	Dewatering	Liquids	Acceptable for aqueous organics
		Major Ultimate Disposal Methods	
Deep well injection	Partial removal from biosphere	Oil field brines; low toxicity, low-persistence wastes; refinery wastes	Monitoring difficulty Need for special geological formations
	Storage		Ground water contamination
Incineration	Volume reduction	Most organics	If poor process control, unwanted emissions produced
	Toxicity destruction		Can produce NO_x, SO_x, halo acids

Recovery	Reuse	Metals Solvents	Sometimes energy prohibitive
Landfill	Storage	Inert to radioactive	Volatilization
	Major Waste Disposal Methods		
Land application	Isolation		Leaching to ground water
Land burial	Dispersal		Access to biota
Ocean disposal	Dispersal	Acids, bases	Contact with ocean ecosystem
	Dilution	Explosives	Containers unstable
	Neutralization	Chemical war agents	
	Isolation (?)	Radioactive wastes	
	Minor Disposal Methods		
Biological degradation	Reduction of concentration Oxidation	Biodegradable organics	Most hazardous wastes do not now qualify
Chemical degradation (chlorination)	Conversion Oxidation	Some persistent pesticides	
Electrolytic processes	Oxidation	Organics	
Long-term sealed storage	Isolation Storage	Radioactive	How good are containers?
Salt deposit disposal	Isolation	Radioactive	Are salt deposits stable in terms of waste lifetimes?

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SUGGESTED READING

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QUESTIONS

1. For a given process at a plant, the cost of control can be related to the equation: dollars for control = $10\,000 + 10e^x$, where x = percent of control/10. The material collected can be recovered and sold and the income determined from the equation: dollars recovered = (1000) (percent of control):
   (a) At what level of control will the control equipment just pay for itself?
   (b) At what level of control will the dollars recovered per dollars of control equipment be the maximum?
   (c) What would be the net cost to the process for increased control from 97.0% to 99.5%?
2. Give three examples of conversion of a pollutant to a less polluting form or substance.

3. List the advantages and disadvantages of a municipal sanitary landfill and a municipal incinerator.
4. List the advantages and disadvantages of recovering energy, in the form of steam, from a municipal incinerator.
5. Show by means of a flow diagram or sketch how you would treat and dispose of the fly ash collected from a municipal incinerator. The fly ash contains toxic and nontoxic metals, nonmetallic inorganics, and organic halogen compounds.