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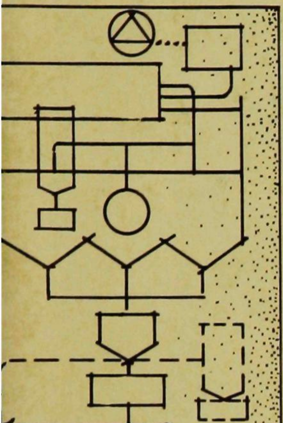

Air Pollution in the Coffee Roasting Industry

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service

AIR POLLUTION

IN THE

COFFEE ROASTING INDUSTRY

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Division of Air Pollution

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

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FOREWORD

This pamphlet is one of a series of studies undertaken by the Public Health Service to provide information concerning air pollution encountered in specific industries. It is intended as a compilation of facts regarding the nature and extent of air pollution resulting from the processing of coffee and current methods available for control of atmospheric emissions from typical installations.

Many people have contributed their time and knowledge toward making the publication of this pamphlet possible. Gratitude is extended to all; in particular to Messrs. Frank A. Bell, Jr. and Walter Smith, Public Health Service; The National Coffee Association, for guidance and photographs of plant operations; Jabez Burns -- Gump Division of Blaw-Knox Company, for technical information on modern processing and control equipment; members of the industry for their counsel; and all the state and local health officials who generously relayed their knowledge and experience in this area.

ABSTRACT

This review provides a guide for the inventorying and control of emissions arising from coffee processing. Information was collected from published literature and other sources. Emission factors were established for the various processes involved, i.e. roasting, stoning, and cooling. The air pollution aspects of the production of regular grades, instant, and decaffeinated coffee are discussed. Also discussed are the types and operating characteristics of control equipment used.

AIR POLLUTION
IN THE
COFFEE ROASTING INDUSTRY

INTRODUCTION

Coffee is roasted from coast to coast and from the northern tier of states to the Rio Crande. The extent of possible air pollution from this industry is of general interest in the United States, although the bulk of the coffee is processed in and around New York, Los Angeles, Chicago, and New Orleans. During November and December 1961, city air pollution control and health agencies were queried in regard to their experiences with air pollution caused by the processing of coffee. The survey indicated that of 37 cities responding 18 cities have, or have had, problems with that source of air pollution. Some indicated the problem was of relatively minor importance to them. Officials in 15 cities reported receiving no complaints. Four of the responses gave no information about the complaints.

Coffee roasters are finding that although they may have been located on the outskirts of communities at one time, they now are being engulfed by burgeoning residential growth. This has created pollution "receptors" where formerly there were none and a concomitant demand for control.

Coffee processing produces four types of emissions: dust, chaff, odor, and smoke. Dust is generated in the handling of green beans, which are bagged in cloth. Chaff consists of the outer covering, or skin, that bursts when the bean swells during roasting. The odor and smoke are combinations of organic constituents volatilized at roasting temperatures and steam produced when the roast is quenched with water. Further processing to produce instant coffee causes an additional emission in the form of powdered coffee, which escapes during the drying process. During decaffeination, odors can be produced by trichloroethylene, the solvent used in extracting caffeine from the green coffee beans.

SUMMARY

Emission inventory factors are presented in Table 1. These factors can be used to approximate the gross amount of particulate matter emitted from a typical roasting plant with or without control equipment.

Particulate emissions are held well within generally prescribed limits when cyclone collectors are employed. Odor-laden smoke presents a more difficult problem, however. Smoke density often exceeds No. 2 Ringelmann (black smoke) or 40 percent opacity (other than black smoke), the limit usually established in smoke regulation codes. Smoke emissions have been lessened by the development of a roaster that recirculates effluent gases through the flame of the roaster burner. Currently, the best method of smoke elimination involves use of a separate

afterburner. Powdered coffee particulate, being highly soluble, can be effectively controlled by means of a simple water scrubber.

Table 1. EMISSION INVENTORY FACTORS FOR COFFEE PROCESSING

Process	Solid emissions, lb/1000 lb green beans	
	With no control	With usual control
Roaster		
Direct fired	3.8	1.1[a]
Indirect fired	2.1	0.6[a]
Stoner and cooler	0.7	0.2[a]
Instant coffee spray dryer	Control always employed	0.7[b]

[a]Cyclone. [b]Cyclone and wet scrubber.

In summary, the most effective means of control now available are centrifugal collectors for dust and chaff, afterburners for smoke and odor, and water scrubbers for instant coffee particulate.

PROCESSING COFFEE

PREPARING THE COFFEE CHERRY

Before arrival at a roasting plant in the United States, the coffee cherry (the fruit) is prepared by one of two methods.[1] The older, "dry" method consists of spreading the cherries on flat, drying grounds called "barbecues," which often have brick or cement surfaces. The cherries are raked until they are dried thoroughly by the wind and sun. Artificial drying has supplanted natural sun drying on many plantations.

The modern, "wet" method utilizes a fermentation process. Cherries are depulped in water, and the mixture of pulp and liberated seeds is allowed to ferment for periods lasting from hours to days. This loosens the tough, parchment shell of the beans (See Figure 1). Then, the beans are dried and the shell and silver skin removed by mechanical rubbing.

REGULAR COFFEE

A flow diagram for a typical coffee roasting operation is shown in Figure 2.

Cleaning Green Beans

Although the beans are cleaned before they are exported to this country, dirt enters the bags during transit. Other trash accumulates from repeated handling. Dust, lint, and strings become mixed with the beans when the bags are opened. This trash must be removed at the plant not only to ensure a quality product, but to eliminate hazards in the roasting process.[1] Bits of combustible material can cause serious fires in the roasters, clog up conveyors and piping, and otherwise reduce production efficiency. Small stones and pieces of metal, if not eliminated, could ruin the grinders.

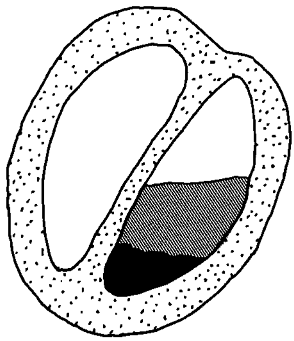

Figure 1. Cross section of a coffee cherry showing outer skin, mucilaginous matter, or pulp, (dotted); parchment cover (white); silver skin (shaded); and coffee bean (black). (Reference 1).

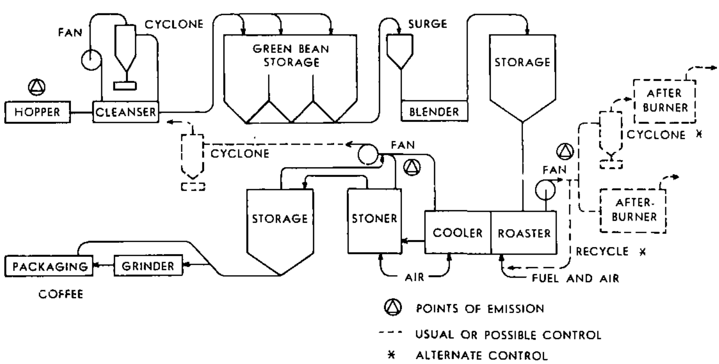

Figure 2. Flow diagram of coffee roasting plant.

Much dust is generated in dumping the green coffee from coarse, cloth bags. Dust from the dumping pit can be controlled by means of a hood and exhaust system vented to a cyclone collector.

Cleaning was formerly carried out by screening methods dependent on the difference in the size of the green beans and attendant trash. These inefficient methods were unsatisfactory. Presently, excellent separation is achieved by utilizing differences in specific gravity of the beans and that of foreign materials. Before roasting, only those materials lighter than the bean, i.e., dust, string, etc., are removed. An air stream, at a carefully regulated pressure, is drawn up through a rectangular duct. The beans are introduced into this air stream through a slit in the duct. As the beans fall through the duct to a bin below, material lighter than the beans is carried up the duct and discharged from the process.[1,2]

During roasting, the coffee beans lose weight while gaining about 50 percent in volume, thus the specific gravity of the bean is decreased by about one-half. Those pieces of material that closely matched the specific gravity of the green bean and, therefore, escaped the first cleaning step would, after roasting, be about twice as dense as the bean. This new disparity in the density of the "stones" and the roasted beans is employed to remove these materials during a "stoning" operation, which is described later.

Blending

After the green beans have been cleaned, they are generally lifted by bucket conveyor to the highest point in the plant to permit gravity feed to succeeding operations. The blender consists of a hollow cylinder, mounted horizontally.[1,3] The proper weight of each grade of coffee for the blend is charged and the cylinder is rotated. The batch is mixed in a few minutes by helical flanges inside the blender. Any dust or chaff loosened by the mixing is removed by an exhaust system. The blended coffee then goes to holding bins or to feed hoppers over the roasters.

Roasting

Roasting is the most important step in coffee making because it develops the flavor. For the average roast, about 370 Btu of heat energy is required per pound of green coffee. More than 95 percent of modern roasters are gas-fired; the remainder are oil-fired.[1,2]

A roaster consists of a perforated, horizontal cylinder with internal helical flanges enclosed in a metal jacket. Of the three types of roasters in use, two are batch-fed. They roast up to 1,500 pounds per hour in 500-pound batches that require 15 to 20 minutes of roasting time each. The older, direct-fired roasters utilize a gas jet inside the cylinder, which operates at an air temperature of about 2,000°F (Figure 3), and

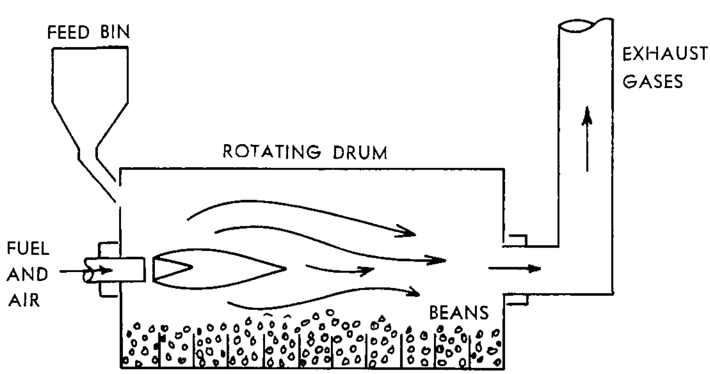

Figure 3. Simplified drawing of direct fired roaster.

heats the roaster by radiation. In the newer, indirect-fired roasters, the gas burner is located in a separate chamber behind the cylinder. Hot combustion gases are recirculated, thus effecting more efficient heat transfer. This reduces the operating temperature range to 850° to 900°F and produces a more uniform, higher quality roast (Figure 4).

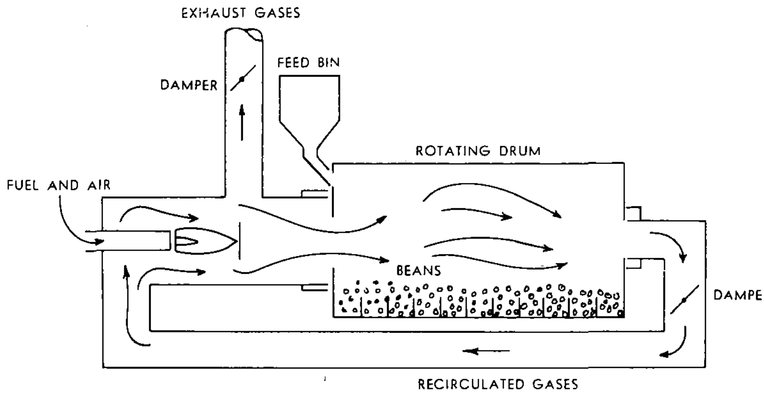

Figure 4. Simplified drawing of indirect fired roaster.

The third type, and the most modern, is a continuous roaster with a rated capacity of up to 10,000 pounds per hour and a roasting time of only 5 minutes; it is operated at 450° to 500°F.[3]

During the first 10 minutes of batch-fed roasting, the charge heats at a fairly uniform rate and moisture is driven off. In the last 5 to 10 minutes, the temperature rises rapidly and the chemical degradation, which produces the familiar odor and flavor, occurs. The beans swell and turn brown. While the beans are roasting, the operator constantly compares samples from the roaster with beans of a standard prescribed by cup testers as having the desired flavor. At the moment the color of the roasting beans matches that of the standard beans, the operator applies a water quench to stop the roasting action. Because of the high temperature in the roaster, the water flashes off and passes out of the stack as steam. Roasters that perform the roasting operation automatically, i.e., that heat to a predetermined temperature and then quench the batch, are also used extensively. The changes that occur in the chemical composition of the coffee beans during roasting are listed in Table 2.

Cooling

When the roasting process has been completed, the batch is dumped into a cooler where the temperature of the brown beans drops until no further chemical changes occur.[1] The cooler usually consists of a bin wherein the beans can be agitated while a draft of cool air is drawn through them. Chaff and residual smoke are picked up by the air stream and discharged from the cooler.

Table 2. CHANGES IN COFFEE COMPOSITION ON ROASTING[a]

	Solids on basis of dry weight of green coffee, %	
	Before	After
Water	10.73	2.16
Sugar	8.62	0.75
Crude fiber	24.00	13.03
Ether extract	11.08	13.75
Water extract	30.35	12.62
Ash	3.00	4.03
Caffeine	1.22	1.31
Chlorogenic acid	7.8	4.5
Trigonelline	1.02	0.73
Total nitrogen	2.34	2.45
Total sulfur	0.10	0.11

[a]References 3 and 4.

Stoning

This step would more properly be called "de-stoning" because heavy materials, which were not removed in the green bean cleaner, are removed during the stoning operation. The principle is the same as that used to remove light-weight debris. The actual operation is different in that the air flow is regulated to lift the roasted beans and leave the bits of rock and metal behind. The "stones" fall into a receptacle and the beans are "airveyed" up the duct to bins above the grinders. The air is then discharged from the process.

INSTANT COFFEE

Unit Operation

Production of instant coffee is an extension of the roasting process. The operation basically is an extraction. Apparently, all instant coffee installations are custom designed; however, enough similarities exist to allow general treatment.

About 3.5 pounds of green coffee are required to make 1 pound of instant coffee. The roasted beans are ground very coarsely. The moisture is allowed to remain much higher than that of beans used to make regular grades of coffee; this promotes immediate dissolution of the coffee solubles.

Stainless-steel cylinders, some as large as 2 feet in diameter, with a capacity of 10,000 pounds of coffee, are filled with the coarse grounds.[6] (Figure 5). Zeolite-softened water at 300°F is introduced under pressure, usually 10 to 12 atmospheres, at the top of the cylinder. The water travels through the bed, extracting the solubles. Leaving the bottom of the first cylinder, the stream of liquor enters the top of the cylinder. The water travels through the bed, extracting the solubles. Leaving the bottom of the first cylinder, the stream of liquor enters the top of the second cylinder. The liquor stream always enters a cylinder of fresher grounds. This provides a maximum concentration gradient at all points in the system. When a cylinder is exhausted, after about 6 hours of extraction, it is bypassed in the line and the spent grounds are blown out with steam.

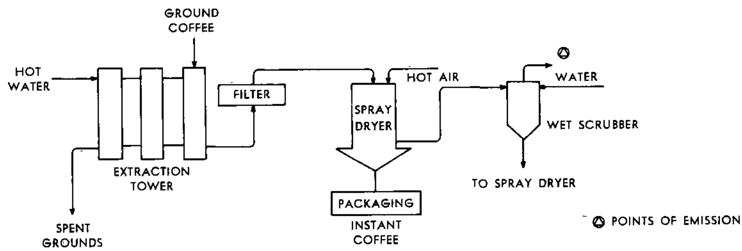

Figure 5. A typical instant coffee process.

Concentrated liquor is drawn off in 500- to 600-pound batches. At this point, the extract is a brownish fluid containing 30 to 35 percent solids. It is filtered to remove residual grounds, and sometimes further purified by use of a centrifugal clarifier.

In the final step, the coffee concentrate is spray-dried and becomes a powder recognizable as the familiar instant coffee. The liquor is sprayed through an atomizer into a huge metal chamber. The evaporator chamber may be as tall as 80 feet and have a diameter as great as 20 feet. Figure 6 is a schematic diagram showing such a drying process. As the droplets enter the chamber, they meet a blast of hot air and are dried as they fall. Inlet and outlet temperatures of the drying air, which range respectively from 500° to $700^{\circ}F$ and 200° to $400^{\circ}F$, determine the color, taste, and final moisture content of the product. To prevent the moistened, hot air from rewetting the dried powder, cold air is introduced near the bottom of the evaporator. This forms a "dam" that diverts the hot air and creates a calm zone where the particles settle out. To recover fines, the exiting air stream is passed through a cyclone collector and a high-efficiency multiple-cyclone in series. Effluent from the secondary collector is usually exhausted into the atmosphere. The powdered coffee is screened to remove lumps, and stored under controlled humidity (35 to 50 percent at $75^{\circ}F$) until it is packaged.[6, 7]

Disposal of Spent Grounds

Disposal of spent grounds has been a major problem to the industry. The most prevalent method is simple elimination into a sewer. A less economical alternative is transferring the waste to a sanitary landfill. Another method, under study recently, is an incineration process.

DECAFFEINATED COFFEE

Decaffeinated coffee represents only a small fraction of the industry's total production and is limited to only a few major plant sites,

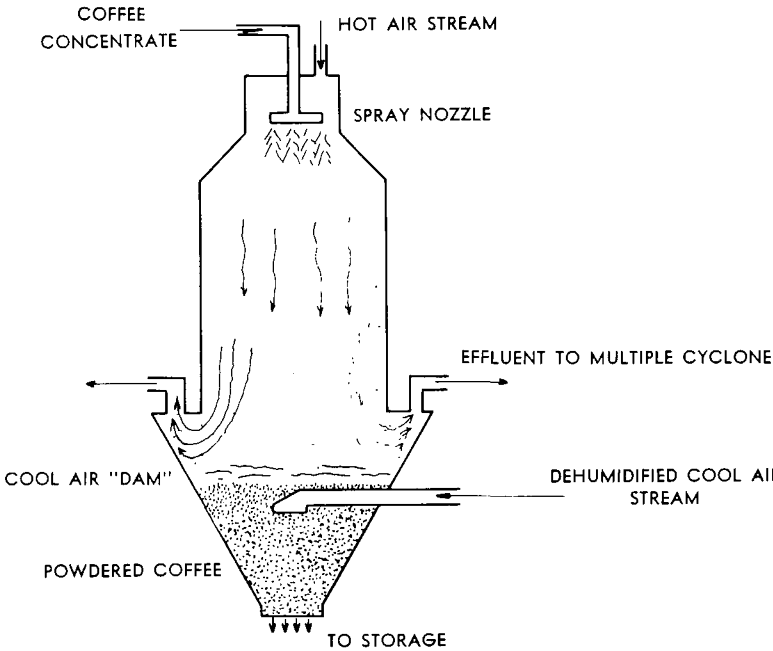

Figure 6. Schematic diagram of instant coffee spray-dryer.

and therefore will be discussed briefly. Figure 7 shows the process units used in extracting the caffeine. The procedure consists of five main steps:[8]

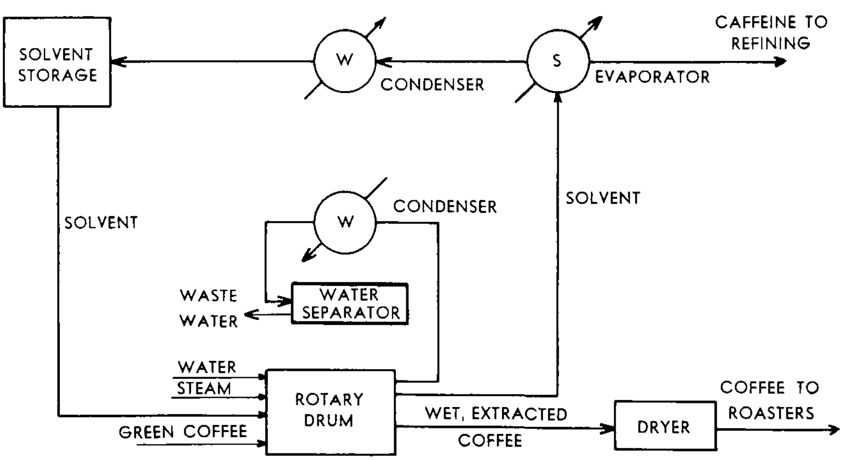

Figure 7. Decaffeinated coffee process (W, water; S, steam).

1. Raising the moisture content of the green bean from 10 percent to about 18 percent.
2. Extraction with trichloroethylene at 160°F.
3. Removal of the solvent by steaming the coffee for several hours.
4. Drying the extracted beans.
5. The usual roasting process.

Approximately 97 percent of the caffeine is removed and is recovered from the solvent as a valuable byproduct.

NATURE AND EXTENT OF AIR POLLUTION

CHEMISTRY OF COFFEE

The characteristic odor and flavor of coffee result from the formation of esters of chlorogenic acid, furfuryl derivatives, and other aromatic substances. Coffee contains 1 to 2 percent caffeine (trimethylxanthin). The caffeine seems to occur in combination with tannic and caffetannic acids rather than alone. Five crystalline derivatives of coffee that are important in its use as a beverage are caffeine, potassium chlorogenate, caffalic acid, valeric acid, and trigonellin. There are also some pyridine-like bodies, furfural, furfuralcohol, and certain others described generally as "caffeol," which may be a pure substance or, more likely, a mixture of volatile alcohols and derivatives.

As shown in Table 2, many changes occur in coffee during roasting. There is a great loss of water; the sugar is caramelized and largely disappears; and there is a considerable loss of crude fiber, caused by destructive distillation. About 90 percent of the loss in weight results from elimination of water vapor and crude fiber. Also, during roasting, there is a slight gain in the percentage composition of nitrogenous substances, sulfur, and caffeine because they are not broken down or driven off at roasting temperature.

Oils and fatty substances are present in considerable quantity. These fats, mostly olein with small amounts of palmitin and stearin, are of both the saturated and unsaturated varieties. Of the saturated fats, which make up about 40 percent of the total fatty matter, the compounds of palmitic acid comprise 25 to 28 percent of the total; compounds of carnaubic acid, 20 percent; capric acid, 5 percent; and daturic acid, 1 percent. Of the unsaturated, fatty acids, compounds of oleic and linoleic acids comprise the greater portion, linoleic and its compounds making up 50 percent of the total fatty material.[3, 9, 10]

The ash of coffee is alkaline, consisting largely of phosphate and carbonate of potash; in Mocha coffee, salts of magnesium and calcium also are found.

COFFEE ROASTING

Coffee chaff is similar to peanut skin and is dark brown. The particles are large in relation to most airborne particulates, attaining a maximum size of about 0.5 inch.[1] Probably 80 to 90 percent of the ıacroparticles are in the order of 0.125 inch in diameter. Smoke and odor are also produced in the roaster. These are emitted intermittently because of the cyclic nature of the roasting process and are composed of minute droplets of condensed, organic volatiles. A weight loss of about 16 percent occurs during roasting, of which 2 to 5 percent is dry weight loss. The amount of emission is a function of the grades of coffee, the method of curing, and the degree and type of roasting.

Stack Emissions

Data available concerning emission rates from coffee roasters are limited. Emissions from different sources in several plants are compared in Table 3.

Table 3. PARTICULATE EMISSIONS FROM THE COFFEE ROASTING PROCESS

Processes	Run	Solid emissions		Condensed tar, %	Control equipment	Reference number
		gr/scf	lb/1000 lb of green beans			
Direct-fired roaster	1	0.213	1.26	75	Cyclone	10
	2	0.173	0.97	87	Cyclone	10
	Avg	0.193	1.12	81	Cyclone	
Indirect-fired roaster	1	0.137	0.44		Cyclone	12
	2	0.091	0.29	-	Cyclone	12
	3	0.153	1.00	36	Cyclone	13
	Avg	0.127	0.58	36	Cyclone	
Cooler	1	0.036	0.29	-	None	10
Stoner	1	0.097	0.37		None	10
Stoner and cooler combined	1	0.026	0.22	16	Cyclone	10
	2	0.008	0.10	38	Cyclone	13
	Avg	0.017	0.16	27	Cyclone	

As shown in Table 3, the use of low-draft-loss cyclone collector to treat the effluents of the cooler and stoner reduces total emissions by about 70 percent, as compared with corresponding effluents discharged directly into the atmosphere.

Smoke emission from plants, with and without cyclone collectors, has been studied. Typical smoke desities are illustrated in Figure 8. In general, during each cycle, which averages 15 minutes, the opacity is 0-1 Ringelmann at the beginning of each roast; this opacity increases gradually for about 10 minutes, then rapidly for 1 to 3 minutes. At the end of the cycle, characterized by a large cloud of steam from the water quench, the smoke density returns to 0-1 Ringelmann. In contrast with indirect-fired units (Figure 8), the 1- to 3-minute peak smoke emission from direct-fired roasters usually does not exceed No. 2 Ringelmann.

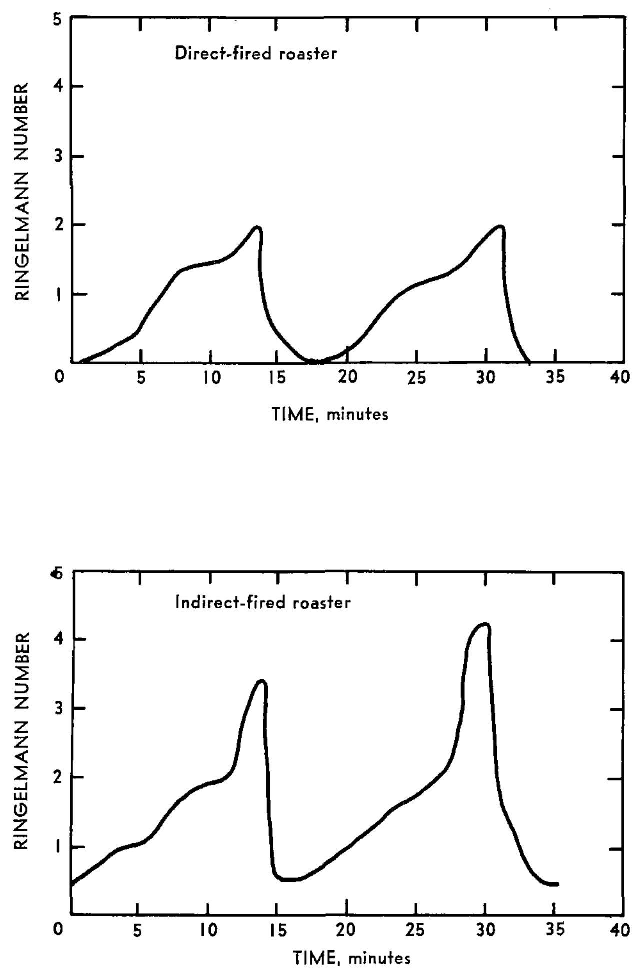

Figure 8. Variation of smoke with time batch roasters (References 10 and 12).

Kuratsune[11] analyzed soot deposits taken from roaster stacks for various polycyclic, aromatac hydrocarbons; he discovered the presence of benzopyrene (about 0.2 ppm by weight), a substance known to produce cancer in experimental animals.

INSTANT COFFEE

The effluent stream from the spray dryer used in the production of instant coffee contains fine, particulate matter. The amount emitted is dependent on the efficiency of the multicyclone collection system through which the effluent stream passes and the rate of plant production. Naturally, this emission is held to a minimum, as any loss is loss of salable product. This resolves to a consideration of the cost of a highly efficient collection system versus economic return. For a plant producing 1 ton of soluble coffee per hour, the particulate loading of exit streams would be about 0.02 grains per cubic foot at 60°F and 1 atmosphere, or 0.7 pounds of particulate per 1,000 pounds of green beans.

In operations where spent coffee grounds are disposed of by incineration, smoke and odor problems are likely to occur.

DECAFFEINATION

Loss of solvent is the only emission from the decaffeination process. This solvent, trichloroethylene, is a colorless, nonflammable liquid, has an odor like chloroform, and is a narcotic and anesthetic.[8] In a closed plant operation, this would be of more concern to the industrial hygienist than to air pollution control personnel. It should be remembered that in both decaffeination and production of instants the roasting process is also employed and that its attendant emissions may be expected to be present in these operations.

METHODS OF CONTROLLING EMISSIONS

PARTICULATE AND SMOKE EMISSIONS

Because of the size and nature of the dust and chaff particulate, cyclone collectors provide a simple, economic means of emissions control. A simple cyclone will handle, with great efficiency, emissions of a size greater than 20 to 40 microns. It can tolerate temperatures to 750°F and accommodate flow rates in excess of 25,000 cfm.[14] Care must be exercised in removing the collected solids so that another air pollution problem is not generated. In some locations, the chaff is burned, with the inherent possibility of creating more smoke and odor.

Even where cyclones are employed, the submicron particles in the smoke and the odor leaving the roaster are not controlled. There is, however, the so-called "smokeless roaster." Its manufacturers claim that this roaster eliminates smoke and odor completely; however, all do not accept this claim as entirely true. A damper system recirculates the combustion gases that are ordinarily vented directly into the atmosphere through the gas flame of the roaster. The additional heat required increases fuel consumption about 40 percent.[16] This modification is shown in Figure 4. Better smoke control is experienced with an afterburner in the roaster stack, but fuel requirements are increased 100 to 150 percent over that for a conventional roaster.

Other methods of emission control, such as catalytic oxidation, scrubbers, and ultrasonic agglomeration of submicron particles to the point that they be handled by conventional collection equipment, have been attempted. They have failed for various reasons, usually poor economics or poor performance.

In modern coffee plants, cyclones are included as an integral part of the roaster design. Particularly in installations of small capacity, however, the effluent air streams from the cleaning, cooling, and stoning processes may have no such individual collection system. In general, these can be connected in manifold to a common exhaust stack and serviced by a single cyclone collector. Efficiency ratings as high as 97 percent may be expected from such devices. In some communities, however, the remaining 3 percent may constitute a nuisance problem. In such situations, water scrubbers have been used to eliminate the remaining emission.[15]

SOLUBLE COFFEE EMISSIONS

Emissions from the production of soluble coffee consist of the fine, spray-dried particles that escape the multicyclone system. This collecting device has an expected efficiency of 95 percent for particles with a median diameter greater than 10 to 30 microns.[14] Thus, the particulates emitted would be expected to be smaller than 10 microns. Measurements have shown that these particles range from 2 to 10 microns. The powder is very hygroscopic, which precludes the use of a bag filter installation since the porosity of any cloth filter would be seriously impaired by the sticky particles covering its surface. Cleaning the filters would be impractical by conventional methods. The control method currently used is water scrubbing. This takes the form of a simple, gravity scrubber in which the particle-laden effluent rises countercurrently to water droplets falling through an empty tower. Such a scrubber is usually constructed of corrosion-resistant material, such as stainless steel, because the dissolved coffee is slightly acidic (pH 4.8 to 5.2) and can cause corrosion.

The efficiency of the gravity scrubber, which is dependent on water droplet size and contact time, decreases rapidly for particles smaller than 5 microns. More effective treatment is produced by a Venturi scrubber, which costs more initially but consumes only half as much water as the gravity scrubber and controls the smaller particulates with a higher efficiency than a gravity scrubber.

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