Emission Factor Documentation for AP-42 Section 9.9.7

Corn Wet Milling

Final Report

For U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Emission Inventory Branch

EPA Contract No. 68-D2-0159
Work Assignment No. II-03

MRI Project No. 4602-03

October 1994

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For U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Emission Inventory Branch
Research Triangle Park, NC 27711

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NOTICE

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PREFACE

This report was prepared by Midwest Research Institute (MRI) for the Office of Air Quality Planning and Standards (OAQPS), U.S. Environmental Protection Agency (EPA), under Contract No. 68-D2-0159, Assignment Nos. 005, I-08, and II-03. Mr. Dallas Safriet was the EPA Work Assignment Manager.

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SECTION 1

INTRODUCTION

The document *Compilation of Air Pollutant Emission Factors* (AP-42) has been published by the U.S. Environmental Protection Agency (EPA) since 1972. Supplements to AP-42 have been issued to add new emission source categories and to update existing emission factors. The EPA also routinely updates AP-42 in response to the needs of Federal, State, and local air pollution control programs and industry.

An emission factor relates the quantity (weight) of pollutants emitted to a unit of source activity. Emission factors reported in AP-42 are used to:

1. Estimate areawide emissions;
2. Estimate emissions for a specific facility; and
3. Evaluate emissions relative to ambient air quality.

This background report provides background information from test reports and other information to support the development of Section 9.9.7, Corn Wet Milling. The new section was based on a review of the existing data base as well as new information collected during a search of the available literature. Also, this update modifies Section 6.9.1, Grain Elevators and Grain Processing Plants, by removing the discussion of corn wet milling from that section.

This report contains five sections. Following this introduction, Section 2 gives a description of the corn wet milling industry, including a brief characterization of the industry, an overview of corn wet milling operations, and the identification of emission sources and emission control technology. Section 3 describes the literature search, screening of emission source data, and the EPA quality ranking system for emission data and emission factors. Section 4 describes the documents reviewed for developing new or revised emission factor(s) for corn wet milling operations. Section 5 presents the proposed AP-42 Section 9.9.7, Corn Wet Milling. Report excerpts and hand calculations for the cited references are presented in Appendices A through F.

SECTION 2

INDUSTRY DESCRIPTION

The first subsection (2.1) of this chapter characterizes the corn wet milling industry, including the number and location of facilities. The second subsection (2.2) describes the steps involved in corn wet milling. The third subsection (2.3) describes air pollutant emissions from sources in the corn wet milling industry. The fourth subsection (2.4) describes the emission control technologies typically applied to air emission sources in the corn wet milling industry.

2.1 INDUSTRY CHARACTERIZATION[1]

Corn wet milling operations are classified under standard industrial classification (SIC) code 2046, Corn Wet Milling. Establishments in this category are engaged primarily in producing starch, syrup, oil, sugar, and byproducts, such as gluten feed and meal, from wet milling of corn and sorghum. However, facilities that produce starch from vegetables and other grains, such as potatoes and wheat, are also included within the SIC code. In 1994, 27 corn wet milling facilities were reported to be operating in the United States. Table 2-1 identifies States with corn wet milling facilities and the number of facilities in those States. Table 2-2 lists those corn wet milling facilities operating in 1994 that were identified by the Corn Refiners Association. These facilities are classified under source classification code (SCC) 3-02-007.

2.2 PROCESS DESCRIPTION[1-4]

The corn refining or wet milling industry has grown in its 150 years of existence into the most diversified and integrated of the grain processing industries. The corn refining industry produces hundreds of products and byproducts, such as high fructose corn syrup (HFCS), corn syrup, starches, animal feed, oil, and alcohol.

In the corn wet milling process, the corn kernel is (see Figure 2-1) separated into three principal parts: (1) the outer skin, (called the bran or hull); (2) the germ (containing most of the oil); and (3) the endosperm (gluten and starch). From an average bushel of corn weighing 25 kilograms (kg) (56 pounds [lb]) approximately 14 kg (32 lb) of starch is produced, about 6.6 kg (14.5 lb) of feed and feed products, about 0.9 kg (2 lb) of oil, and the remainder is water. The overall corn wet milling process consists of numerous steps or stages, as shown schematically in Figure 2-2.

TABLE 2-1. CORN WET MILLING FACILITIES IN THE UNITED STATES[a]

State	No. of facilities
U.S. Total	27
Iowa	7
Illinois	4
Indiana	4
Tennessee	2
Colorado	1
Ohio	1
Missouri	1
Texas	1
Alabama	1
California	1
Minnesota	1
Nebraska	1
New York	1
North Carolina	1

[a]Source: Reference 1.

TABLE 2-2. CORN WET MILLING PLANTS (1994)[a]

Plant name	Plant location
ADM Corn Processing	Cedar Rapids, Iowa
	Clinton, Iowa
	Decatur, Illinois
	Montezuma, New York
American Maize-Products Company	Decatur, Alabama
	Dimmitt, Texas
	Hammond, Indiana
Cargill, Incorporated	Cedar Rapids, Iowa
	Dayton, Ohio
	Eddyville, Iowa
	Memphis, Tennessee
CPC International Inc.	Argo, Illinois
	Stockton, California
	Winston-Salem, North Carolina
Golden Technologies	Johnstown, Colorado
Grain Processing Corp./Kent Feeds, Inc.	Muscatine, Iowa
Minnesota Corn Processors	Marshall, Minnesota
	Columbus, Nebraska
National Starch and Chemical Company	Indianapolis, Indiana
	North Kansas City, Missouri
Pekin Energy Co.	Pekin, Illinois
Penford Products Company	Cedar Rapids, Iowa
Roquette America, Inc.	Keokuk, Iowa
A. E. Staley Manufacturing Company	Decatur, Illinois
	Lafayette, Indiana (2 plants)
	Loudon, Tennessee

[a]Source: Reference 1.

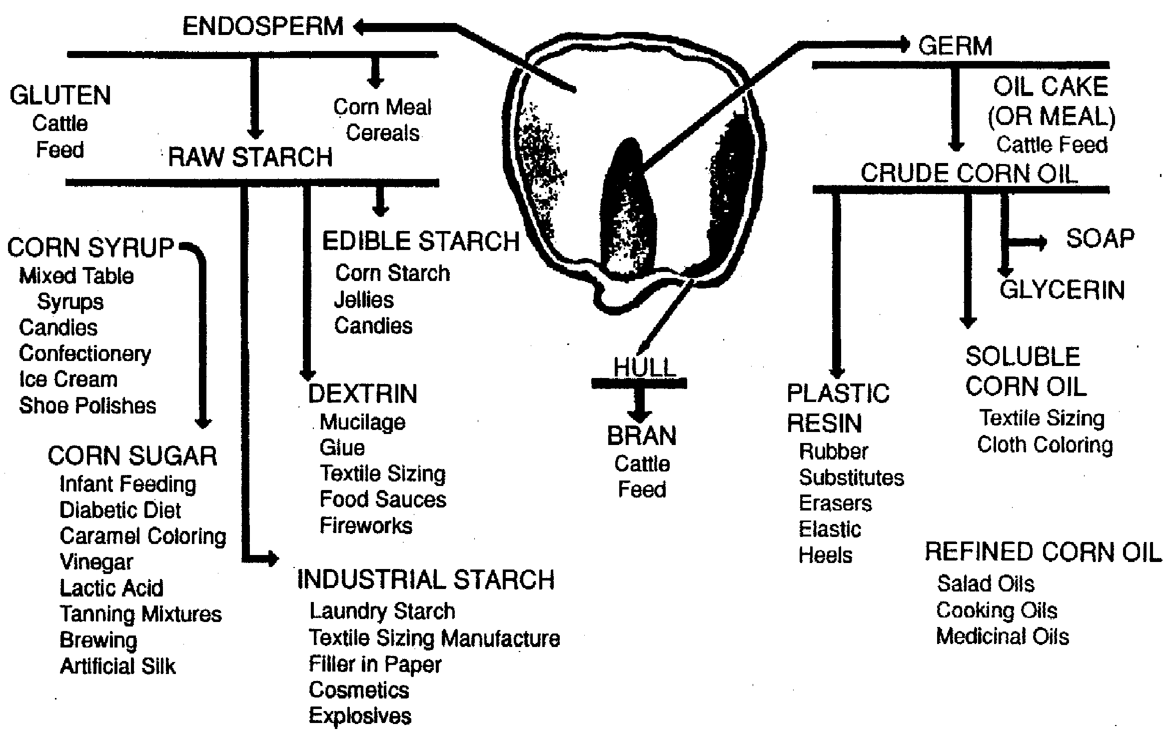

Figure 2-1. Various uses of corn.

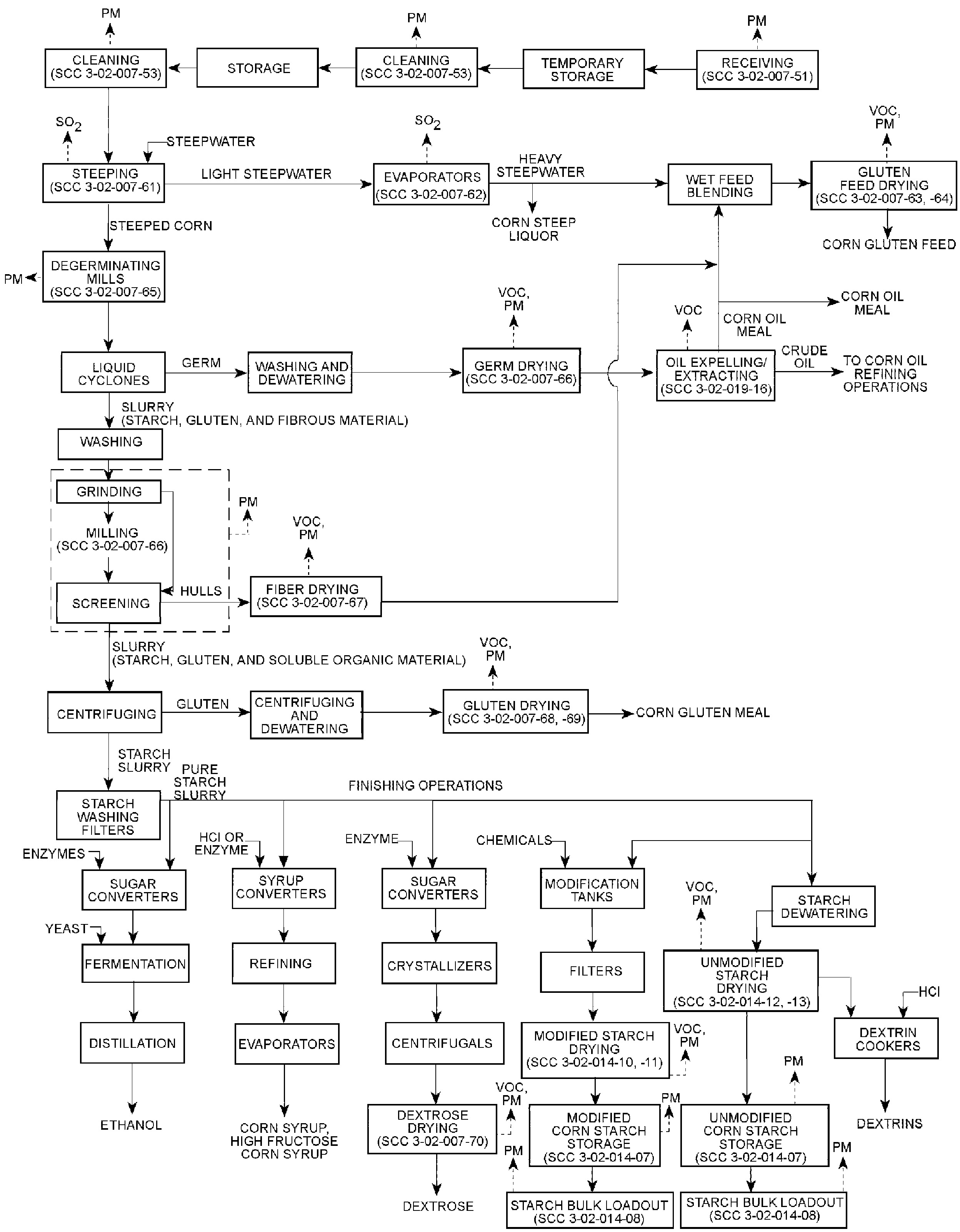

Figure 2-2. Corn wet milling process flow diagram.
(Source Classification Code in parentheses)

Shelled corn is delivered to the wet milling plant primarily by rail and truck and unloaded into a receiving pit. The corn is then elevated to temporary storage bins and scale hoppers for weighing and sampling. The corn then passes through mechanical cleaners designed to separate unwanted material, such as pieces of cobs, sticks, and husks, as well as meal and stones. The cleaners agitate the kernels over a series of perforated metal sheets where the smaller foreign materials drop through the perforations, a blast of air blows away chaff and dust, and electromagnets remove any nails and bits of metal. Coming out of storage bins, the corn is given a second cleaning before going into "steep" tanks. The cleaning operations are similar to those used in dry corn milling.

Steeping, the first step in the process, conditions the grain for subsequent milling and recovery of corn constituents. This process softens the kernel for milling, helps break down the protein holding the starch particles, and removes certain soluble constituents. Steeping consists of a series of tanks, usually referred to as steeps, which are operated in continuous-batch process. Each steep holds about 70.5 to 458 cubic meters (m^3) (2,000 to 13,000 bushels [bu]) of corn, which is submerged in a dilute sulfurous acid solution flowing countercurrently at a temperature of about 52°C (125°F).

As a fully steeped tank of corn is discharged for further processing, fresh corn is added to that steep tank. Incoming water to the total steeping system is derived from recycled water from other operations at the mill and is first introduced into the tank with the "oldest" corn (in terms of steep time), and then passes through the series of steeps to the newest batch of corn. Total steeping time ranges from 28 to 48 hours.

Water drained from the newest corn steep is discharged to evaporators as so-called "light steepwater" containing about 6 percent of the original dry weight of grain. On a dry-weight basis, the solids in the steepwater contain 35 to 45 percent protein and are worth recovering for feed supplements. Such recovery is accomplished by concentrating the steepwater to 30 to 55 percent solids in multiple-effect evaporators. The resulting steeping liquor, or heavy steepwater, is usually added to the fibrous milling residue, which is sold as animal feed. Some steepwater may also be sold for use as a nutrient in fermentation processes.

The steeped corn passes through degerminating mills, which tear the kernel apart to free the germ and about half of the starch and gluten. The resultant pulpy material is pumped through liquid cyclones to extract the germ from the mixture of fiber, starch, and gluten. The germ is subsequently washed, dewatered, and dried; the oil extracted; and the spent germ sold as corn oil meal or as part of corn gluten feed. More details on corn oil production are contained in Section 9.11.1, "Vegetable Oil Processing."

The product slurry passes through a series of washing, grinding, and screening operations to separate the starch and gluten from the fibrous material. The hulls are discharged to the feed house where they are dried for use in animal feeds.

At this point, the main product stream contains starch, gluten, and soluble organic materials. The lower density gluten is separated from the starch by centrifugation, generally in two stages. A high-quality gluten of 60 to 70 percent protein and 1.0 to 1.5 percent solids, is then centrifuged, dewatered, dried, and added to the animal feed. The centrifuge underflow containing the starch passes to starch washing filters to remove any residual gluten and solubles.

The pure starch slurry is now directed into one of three basic finishing operations, namely, ordinary dry starch, modified starches, and corn syrup and sugar. In the production of ordinary dry starch, the starch slurry is dewatered using vacuum filters or basket centrifuges. The discharged starch cake has a moisture content of 35 to 42 percent and is further thermally dewatered by one of several different types of dryers. The dry starch is then packaged or shipped in bulk, or a portion may be used to make dextrin.

Modified starches are manufactured for various food and trade industries for special uses for which unmodified starches are not suitable. For example, large quantities of modified starches go into the manufacture of paper products serving as binding for the fiber. Modifying is accomplished by treating the starch slurry with selected chemicals, such as hydrochloric acid to produce acid-modified starch, sodium hypochlorite to produce oxidized starch, and ethylene oxide to produce hydroxyethyl starches in modification tanks. The treated starch is then washed, dried, and packaged for distribution.

Across the corn wet milling industry, about 80 percent of the starch slurry is diverted to corn syrup, sugar, and alcohol production The relative amount of starch slurry used for corn syrup, sugar, and alcohol production varies widely by plant. Syrups and sugars are formed by hydrolyzing the starch—partial hydrolysis resulting in corn syrup and complete hydrolysis producing corn sugar. The hydrolysis step can be accomplished using mineral acids or enzymes, or a combination of both. The hydrolyzed product is then refined, a process which consists of decolorization with activated carbon and removal of inorganic salt impurities with ion exchange resins. The refined syrup is concentrated to the desired level in evaporators and cooled for storage and shipping.

The production of dextrose is quite similar to corn syrup production, the major difference being that the hydrolysis process is allowed to go to completion. The hydrolyzed liquor is refined with activated carbon and ion exchange resins to remove color and inorganic salts, and the product stream is concentrated to the 70 to 75 percent solids range by evaporation. After cooling, the liquor is transferred to crystallizing vessels where it is seeded with sugar crystals from a previous batch. The solution is held for several days while the contents are further cooled and the dextrose crystallizes. After about 60 percent of the dextrose solids crystallize, they are removed from the liquid by centrifuges, dried, and packed for shipment.

A smaller portion of the syrup refinery is devoted to the production of corn syrup solids. In this operation, refined corn syrup is further concentrated through evaporation to a high dry substance level. The syrup is then solidified by rapid cooling and subsequently milled to form an amorphous crystalline product.

Corn is one of the preferred raw materials for conversion to alcohol in the United States. In alcohol production from corn, the starch slurry is treated with enzymes (e.g., α-amylase and glucoamylase) to hydrolyze the starch to fermentable sugars. Following hydrolysis, yeast is added to the solution to initiate the fermentation process. Strains of *Saccharomyces cerevisiae* are among the yeasts commonly used in industrial ethanol production. After fermentation for about two days, approximately 90 percent of the starch is converted to ethanol. The fermentation broth is transferred to a still where the ethanol (about 50 vol%) is distilled. Subsequent distillation and treatment steps produce 95 percent ethanol, absolute ethanol, or denatured ethanol. A more detailed discussion of this ethanol production process, emissions, and emission factors is contained in Section 6.21, "Ethanol."

2.3 EMISSIONS[1,2,4]

The main pollutant of concern in grain storage and handling operations in corn wet milling facilities is particulate matter (PM). Organic emissions (e.g., hexane) from certain operations at corn oil extraction facilities may also be significant. These organic emissions (and related emissions from soybean processing) are discussed in AP-42 Section 9.11.1. Other possible pollutants of concern are volatile organic compounds (VOC) and combustion products from grain and product drying, sulfur dioxide (SO_2) from corn wet milling operations, and organic materials from starch production. The following sections focus primarily on PM sources for grain handling operations. Sources of VOC and SO_2 are identified although no data are available to quantify emissions.

The diversity of operations in corn wet milling results in numerous and varied potential sources of air pollution. It has been reported that the number of process emission points number well over 100 at a typical plant. Table 2-3 presents some of the potential sources of air pollution in corn wet milling plants.

Emission sources associated with grain receiving, cleaning, and storage are similar in character to those involved in all grain elevator operations, and other PM sources are comparable to those found in other grain processing plants as described

TABLE 2-3. POTENTIAL SOURCES OF AIR EMISSIONS IN CORN WET MILLING PLANTS[a]

I. Grain receiving, cleaning, drying, and storage: 1. Grain unloading 2. Elevator leg vents 3. Garner and scale vents 4. Trippers, conveyor transfer points 5. Grain cleaner III. Conversion process: 1. Dextrose drying 2. Corn syrup solids drying 3. Spent carbon regenerator	II. Separation process: 1. SO_2 absorption tower 2. Steep tanks 3. Germ drying 4. Gluten drying 5. Feed drying 6. Feed pellet mill (if used) 7. Pellet cooler (if used) 8. Starch modification 9. Starch drying 10. Starch milling

[a]Reference 2.

in Section 9.9.1 of AP-42. However, corn wet milling operations differ from those other processes in that they are sources of SO_2 and VOC emissions as described below.

The corn wet milling process uses about 1.1 to 2.0 kg of SO_2 per megagram (Mg) of corn (0.06 to 0.11 lb/bu). The SO_2 is dissolved in process waters, but its pungent odor is present in the slurries, necessitating the enclosing and venting of the process equipment. Vents can be wet-scrubbed with an alkaline solution to recover the SO_2 before the exhaust gas is discharged to the atmosphere. The most significant source of VOC emissions and also a source of PM emissions from corn wet milling is the exhaust from the different drying processes. The starch modification procedures also may be sources of acid mists and VOC emissions, but data are insufficient to characterize or to quantify these emissions.

Dryer exhausts exhibit problems with odor and blue haze (opacity). Germ dryers emit a toasted smell that is not considered objectionable in most areas. Gluten dryer exhausts do not create odor or visible emission problems if the drying temperature does not exceed 427°C (800°F). Higher temperatures promote hot smoldering areas in the drying equipment, creating a burnt odor and a blue-brown haze. The drying of feeds where steepwater is present results in environmentally unacceptable odor if the drying temperature exceeds 427°C (800°F). The formation of a blue haze is a concern when drying temperatures are high. These exhausts contain VOC with acrid odors such as acetic acid and acetaldehyde. Rancid odors can come from butyric and valeric acids, and fruity smells emanate from many of the aldehydes present.

2.4 EMISSION CONTROL TECHNOLOGY[5-8]

The objectionable odors indicative of VOC emissions from process dryers have been reduced to commercially acceptable levels with ionizing wet-collectors, in which particles are charged electrostatically with up to 30,000 volts (V). An alkaline wash is necessary before and after the ionizing sections. Another approach to odor/VOC control is thermal oxidation at approximately 750°C (1382°F) for 0.5 sec followed by some form of heat recovery. This hot exhaust can be used as the heat source for other dryers or for generating steam in a boiler specifically designed for this type of operation. The incineration can be accomplished in conventional boilers by routing the dryer exhaust gases to the primary air intake. The limitations are potential fouling of the boiler air intake system with PM and derating the boiler capacity due to low oxygen content; these limitations severely restrict the possibility of this practice. At least one facility has attempted to use a regenerative system, in which dampers divert the gases across ceramic fill so that exhaust heat is used to preheat the fumes to be incinerated. The size of the incinerator can be reduced 20 to 40 percent by recycling some of the dryer exhaust back into the dryer furnace. Recycling of 60 to 80 percent of the dryer exhaust may be done by chilling it to condense the water before recycling.

The PM emissions generated from grain receiving, handling, and processing operations at corn wet milling facilities can be controlled by process modifications designed to prevent or inhibit emissions, by application of capture collection systems, or by dust suppression with mineral oil application or by some combination of these three measures. The first two measures are applied on a source-specific basis as outlined in Table 2-4. Dust suppression via oil application is generally achieved by applying the oil at a transfer station near the receiving area, thereby suppressing dust release throughout the remaining handling operations. The paragraphs below briefly describe the three control measures; additional details are presented in the background report for Section 9.9.1.

The fugitive emissions from grain handling operations generated by mechanical energy imparted to the dust by the operations themselves and by local air currents in the vicinity of the operations can be controlled by modifying the process or facility to limit the effects that produce the fugitives. The primary preventive measures that facilities have used are construction and sealing practices that limit the effect of air currents and minimizing grain free fall distances and grain velocities during handling and transfer. Some recommended construction and sealing practices that minimize emissions are: (1) enclosing the receiving area to the degree practicable; (2) specifying dust-tight cleaning and processing equipment; (3) using lip-type shaft seals at bearings on conveyor and other equipment housings; (4) using flanged inlets and outlets on all spouting, transitions, and miscellaneous hoppers; and (5) fully enclosing and sealing all areas in contact with products handled.

TABLE 2-4. PROCESS CONTROL AND EXHAUST SYSTEMS FOR GRAIN HANDLING AND PROCESSING OPERATIONS[a]

Grain handling and processing operation	Potential control mechanism(s)[b]
Receiving	Grain flow control Capture/collection
Belt conveyors	Enclosure Flow control Capture/collection
Elevator legs	Capture/collection
Distributors	Capture/collection
Cleaners	Enclosure/exhaust
Scales	Enclosure/exhaust
Hammermills	Capture/collection
Roller mills	Capture/collection
Mixers	Capture/collection

[a]Source: Reference 6.
[b]Capture/collection refers to a forced ventilation system consisting of a capture device (hood or enclosure) connected via ductwork to a dust collector.

While preventive measures can reduce emissions, most facilities also require ventilation, or capture/collection, systems to reduce emissions to acceptable levels. In fact, air aspiration (ventilation) is a part of the dead box system described above. Almost all grain handling and processing facilities use capture/collection on the receiving pits and cleaning operations. Generally, milling operations are ventilated, and some facilities use hooding systems on all handling and transfer operations. The control devices typically used in conjunction with capture systems for grain handling and processing operations are cyclones (or mechanical collectors) and fabric filters. Both of these systems can achieve acceptable levels of control for many grain handling and processing sources. However, even though cyclone collectors can achieve acceptable performance in some scenarios and fabric filters are highly efficient, both devices are subject to failure if they are not properly operated and maintained. Also, malfunction of the ventilation system can lead to increased emissions at the source.

The emission control methods described above rely on either process modifications to reduce dust generation or capture collection systems to control dust emissions after they are generated. An alternative control measure that has developed over the last 10 years is dust suppression by mineral oil. Generally, these dust suppression systems use either white mineral oil or soybean oil. Currently, the Food and Drug Administration restricts application rates of mineral oil to 0.02 percent by weight and soybean oil to 0.01 percent by weight. The oil is applied to the grain by a spray system at the end of the transfer belt from the receiving area.

REFERENCES FOR SECTION 2

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SECTION 3

GENERAL DATA REVIEW AND ANALYSIS PROCEDURES

This section describes the literature search to collect emissions data and the EPA quality rating systems applied to data and to any emissions factors developed from those data.

3.1 LITERATURE SEARCH AND SCREENING

A literature search was performed to collect pertinent emissions data for grain elevators and processing facilities. This search included data contained in the open literature (e.g., National Technical Information Service); source test reports and background documents located in the files of the EPA's Office of Air Quality Planning and Standards (OAQPS); data base searches (e.g., SPECIATE); and MRI's own files (Kansas City and North Carolina).

During the review of each document, the following criteria were used to determine the acceptability of reference documents for emission factor development:

1. The report must be a primary reference:

    a. Source testing must be from a referenced study that does not reiterate information from previous studies.

    b. The document must constitute the original source of test data.

2. The referenced study must contain test results based on more than one test run.

3. The report must contain sufficient data to evaluate the testing procedures and source operating conditions.

3.2 DATA QUALITY RATING SYSTEM[1]

Based on OAQPS guidelines, the following data are always excluded from consideration in developing AP-42 emission factors:

1. Test series averages reported in units that cannot be converted to the selected reporting units;

2. Test series representing incompatible test methods; and

3. Test series in which the production and control processes are not clearly identified and described.

If there is no reason to exclude a particular data set, data are assigned a quality rating based on an A to D scale specified by OAQPS as follows:

A—This rating requires that multiple tests be performed on the same source using sound methodology and reported in enough detail for adequate validation. Tests do not necessarily have to conform to the methodology specified by EPA reference test methods, although such methods are used as guides.

B—This rating is given to tests performed by a generally sound methodology but lacking enough detail for adequate validation.

C—This rating is given to tests that are based on an untested or new methodology or that lack a significant amount of background data.

D—This rating is given to tests that are based on a generally unacceptable method but may provide an order-of-magnitude value for the source.

The following are the OAQPS criteria used to evaluate source test reports for sound methodology and adequate detail:

1. Source operation. The manner in which the source was operated should be well documented in the report, and the source should be operating within typical parameters during the test.

2. Sampling procedures. The sampling procedures should conform to a generally accepted methodology. If actual procedures deviate from accepted methods, the deviations must be well documented. When this occurs, an evaluation should be made of how such alternative procedures could influence the test results.

3. Sampling and process data. Adequate sampling and process data should be documented in the report. Many variations can occur without warning during testing and sometimes without being noticed. Such variations can induce wide deviations in sampling results. If a large spread between test results cannot be explained by information contained in the test report, the data are suspect and are given a lower rating.

4. Analysis and calculations. The test reports should contain original raw data sheets. The nomenclature and equations used are compared to those specified by EPA (if any) to establish equivalency. The depth of review of the calculations is dictated by the reviewer's confidence in the ability and conscientiousness of the tester, which in turn is based on factors such as consistency of results and completeness of other areas of the test report.

3.3 EMISSION FACTOR QUALITY RATING SYSTEM[1]

The EPA guidelines specify that the quality of the emission factors developed from analysis of the test data be rated utilizing the following general criteria:

A—Excellent: The emission factor was developed only from A-rated test data taken from many randomly chosen facilities in the industry population. The source category was specific enough to minimize variability within the source category population.

B—Above average: The emission factor was developed only from A-rated test data from a reasonable number of facilities. Although no specific bias was evident, it was not clear if the facilities tested represented a random sample of the industries. As in the A-rating, the source category was specific enough to minimize variability within the source category population.

C—Average: The emission factor was developed only from A- and B-rated test data from a reasonable number of facilities. Although no specific bias was evident, it was not clear if the facilities tested represented a random sample of the industry. As in the A-rating, the source category was specific enough to minimize variability within the source category population.

D—Below average: The emission factor was developed only from A- and B-rated test data from a small number of facilities, and there was reason to suspect that these facilities did not represent a random sample of the industry. There also may be evidence of variability within the source category population. Limitations on the use of the emission factor are footnoted in the emission factor table.

E—Poor: The emission factor was developed from C- and D-rated test data, and there was reason to suspect that the facilities tested did not represent a random sample of the industry. There also may be evidence of variability within the source category population. Limitations on the use of these factors are footnoted.

The use of the above criteria is somewhat subjective depending to a large extent on the individual reviewer. Details of how each candidate emission factor was rated are provided in Section 4.

REFERENCE FOR SECTION 3

1. *Technical Procedures for Developing AP-42 Emission Factors and Preparing AP-42 Sections*, EPA-454/B-93-050, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, October 1993.

SECTION 4

AP-42 SECTION DEVELOPMENT

This section describes the test data and methodology used to develop pollutant emission factors for the new AP-42 Section 9.9.7, "Corn Wet Milling." This new section was the result of a review and analysis of the data base used to formulate the current emission factors for corn wet milling in the existing AP-42 section 6.4 and of new data obtained during the literature search. Excerpts from the test reports and hand calculations used to reduce the data to an appropriate format for emission factor development are contained in Appendices A through F.

4.1 REVIEW OF SPECIFIC DATA SETS

During the literature search, 15 reference documents were collected and reviewed. These documents are listed in the reference section at the end of Section 4. The original group of documents were reduced to a single report using the criteria outlined in Section 3.1. For those documents not used, Table 4-1 summarizes the basis for their rejection. The data contained in the primary reference is described below. All raw test data (and subsequent hand calculations, if required) are presented in the units in which they were originally published.

4.1.1 Reference 5 (1981)

Reference 5 is a survey report of dryers used in the production of animal feed. Section 5 of this report provides a compilation of emission data "provided by plants and state and local air pollution control agencies" for three different corn wet milling facilities. The uncontrolled dryer emission rates presented in the report range from 0.5 to 1.5 kg/hr (1.1 to 3.3 lb/hr) for indirect-fired rotary dryers with emission rates for direct-fired units being 1.25 kg/h (2.75 lb/hr) for the facilities tested (Table 4-2).

The origin and quality of the data provided are not specified in the document, nor are any details provided about the tests conducted to generate the data. Attempts to locate the original information in internal project files were unsuccessful.

Normally, data such as those provided in Reference 5, which does not contain original data, would not be used for emission factor development. However, because these data were used to develop total PM emission factors for dryers in corn wet milling plants during the last revision, the information contained in Reference 5 was

TABLE 4-1. DOCUMENTS NOT INCLUDED IN EMISSION FACTOR DEVELOPMENT

Reference No.	Cause(s) for rejection
1	Background document for 1988 revision to Section 6.4 that contained no original data; however, primary references from Reference 1 were reviewed as a part of this study.
2	Secondary data from other sources with no original data and no information specific to grain handling and processing; not used in this study.
3	Contains no direct emission data; emission estimates could not be verified so they were not used in subsequent analyses.
4	General process descriptions only; not used for this study.
6	Background report for emission factors for Section 6.4 in earlier AP-42 edition with no original test data; original references reviewed if they could be located.
7	Not original source of test data; inventory estimates based on emission factors from Reference 6.
8	No air emission data; good process description for milling plants.
9	No original test data; original references reviewed if they could be located.
10	Process data in the test report were insufficient to calculate emission factors.

included in MRI's analysis. A summary of these data is shown in Table 4-2. Because of the lack of suitable documentation, a rating of D was assigned to the test data. Applicable portions of the report can be found in Appendix A.

4.1.2 Reference 11 (1993)

Reference 11 is a partial test report for a compliance test conducted at the exhaust stack of a starch flash dryer in a corn wet milling facility in Cedar Rapids, Iowa. The test was conducted using EPA Method 5 to determine compliance with State regulations. The starch dryer is equipped with a cyclone for product recovery and an Entoleter scrubber with a 6 in. H_2O pressure drop for PM control. The average filterable PM emission factor for the three test runs was 0.55 lb/ton of wet starch processed.

Although the test report was incomplete in that it contained neither a comprehensive process description nor detailed data sheets, the data appeared to have been collected with standard methods. However, process data were not available for individual runs, and the mechanism used to determine the process weight was unclear. Because of these deficiencies, the test data were rated C. Selected pages from the test report that contain emission data and process rates are included in Appendix B.

TABLE 4-2. PARTICULATE MATTER EMISSION TEST DATA FOR DRYERS USED IN CORN WET MILLING[a]

Plant	Date of test	Number of tests	Dryer type	Control type	Dryer process weight, Mg/h (tons/h)	Uncontrolled emission rate, kg/h (lb/h)	Controlled emission rate, kg/h (lb/h)	Calculated emission factor, kg/Mg (lb/ton)[b]
Plant A	1976	3	Direct-fired rotary	Cyclone[c]	9.4 (10.4)	1.25 (2.76)	—	0.13 (0.27)
Plant B[d]	1979	3	Direct-fired rotary	Venturi scrubber	N/A	—	27.2 (60)	—
	1979	3	Direct-fired rotary	Venturi scrubber	N/A	—	37.2 (82)	—
	1980	3	Direct-fired rotary	Venturi scrubber	N/A	—	33.1 (73)	—
	1980	3	Direct-fired rotary	Venturi scrubber	N/A	—	24.9 (55)	—
Plant C[d]	1977	3	Rotary steam tube (No. 7)	—	3.96[e] (4.36)	0.60 (1.33)	—	0.15 (0.30)
	1977	3	Rotary steam tube (No. 8)	—	4.11 (4.53)	0.72 (1.59)	—	0.17 (0.35)
	1977	3	Rotary steam tube (No. 9)	—	4.16 (4.59)	0.66 (1.33)	—	0.16 (0.29)
	1981	3	Rotary steam tube (No. 5)	—	6.15 (6.78)	0.69 (1.53)	—	0.11 (0.23)
	1977	9	Rotary steam tube	Mill cyclone[c]	4.11 (4.53)	0.69 (1.53)[e]	—	0.17 (0.34)
	1981	3	Rotary steam tube	Mill cyclone[c]	4.22 (4.66)	0.50 (1.10)	—	0.12 (0.24)
	1977	9	Rotary steam tube + hammermill	Product cyclone[c]	4.04 (4.45)	0.97 (2.14)	—	0.24 (0.48)
	1981	3	Rotary steam tube + hammermill	Product cyclone[c]	4.28 (4.72)	1.50 (3.30)	—	0.35 (0.70)
	1980	3	Rotary steam tube		1.02 (1.12)	0.74 (1.63)	—	0.73 (1.5)

[a]Reports provided by plants and control agencies per Reference 5.
[b]From hand calculations in Appendix A.
[c]Used primarily for product recovery.
[d]Data presented for total catch (front-half and back-half) of EPA Method 5 sample train per Iowa regulation.
[e]Seems to be miscalculated in original report—assumed to be typographical error. Value shown calculated from corresponding data in other units.

4.1.3 Reference 12 (1993)

Reference 12 contains relatively complete summary information from a test of filterable PM emissions in the exhaust stream from a ring flash dryer at a corn wet milling facility in Hammond, Indiana. The test was conducted using EPA Method 5 to demonstrate compliance with State regulations. The exhaust from the dryer is routed through a series of cyclones for product recovery and a wet scrubber (type unspecified) for PM control. The scrubber operated at pressure drops of 6.75, 9.75, and 11.25 in. H_2O during the three test runs. Sufficient process data were presented in the report to develop emission factors for each run. The filterable PM emission factors for the three runs were 0.81, 0.37, and 0.37 lb/ton of wet starch dried with an average of 0.52 lb/ton dried.

Although the test report did not contain a comprehensive process description, the data appeared to have been collected with standard methods, and the test results were well documented. Because of the limited process information and the lack of information on scrubber type, the test data were rated B. Selected pages from the test report that contain emission data and process rates are included in Appendix C.

4.1.4 Reference 13 (1986)

Reference 13 is a complete test report for a PM compliance test conducted on the exhaust from a ring flash dryer. The exhaust from the dryer is routed through a series of cyclones for product recovery and then through a wet scrubber for PM control. No information was provided in the test report on either the scrubber design or on the operating pressure drop during the test. Process data sheets in the test report provided sufficient information to calculate emission factors for each test run. The filterable PM emission factors for runs 1 through 3, respectively, were 0.71, 0.71, and 0.65 lb/ton of wet starch dried, with an average emission factor for the three runs of 0.69 lb/ton dried.

Although the test report did not contain a comprehensive process description, the data appeared to have been collected with standard methods, and the test results were well documented. Because of the limited process information and the lack of information on scrubber design and operation, the test data were rated B. Selected pages from the test report that contain emission data and process rates are included in Appendix D.

4.1.5 Reference 14 (1992)

Reference 14 is a comprehensive test report that presents the results of filterable PM sampling on the exhaust stack of a starch spray dryer at a corn wet milling facility in Loudon, Tennessee. Tests were conducted using EPA Method 5. No process description is included in the test report, but attached permit information indicates that a fabric filter is used for PM control. Because the emission test was conducted to demonstrate compliance with the permit limits, the testing is presumed to have been conducted at the baghouse outlet. A letter attached to the test report indicates that dry material/product handling sources, including product bins, filter receiver bin, rail-receiver bin, and the unloading receiver bin, were also ducted to the same fabric filter and were operational during the test. However, because the air flow from these material handling operations represents only about 2.5 percent of the total air flow through the control system, the contribution of sources other than the dryer is considered to be negligible. Process data from the source were only available for the average process rate during the three runs. Based on the average emission rate for the three runs and the average process rate, the filterable PM emission factor for the drying operation was calculated to be 0.16 lb/ton of wet starch dried.

The test report contained no process description, and process rates were contained in an attached letter with supporting data printouts that were not readable. However, the test program was well documented, the data appeared to have been collected with standard methods, and the test results were well documented. Because of the limited process information and the presence of other emissions in the exhaust stream, the test data were rated B. Selected pages from the test report that contain emission data and process rates are included in Appendix E.

4.1.6 Reference 15 (1992)

Reference 15 contains portions of a test report that documents the results of filterable and condensible PM sampling on the exhaust stacks for two material handling operations--the starch storage bin and the starch loadout operation--for a corn wet milling operation in Cedar Rapids, Iowa. The tests were conducted using EPA Method 5. The test report does not contain a process description that describes how emissions are captured, but the process data sheets do indicate that emissions are controlled with fabric filters. Only average process rates for the three runs at each site are available. Based on these data and on the average emission rates for each operation, the filterable PM emission factors are 0.0014 lb/ton of starch stored for the storage bin and 0.00049 lb/ton of starch loaded for the loadout operation. The condensible PM emission factors (which were calculated as a difference between total PM and filterable PM emission factors are 0.0016 lb/ton of starch stored for the storage bin and 0.00061 lb/ton of starch loaded for the loadout operation.

Although the test report was incomplete in that it contained neither a comprehensive process description nor detailed data sheets, the data appeared to have been collected with standard methods. However, process data were not available for individual runs, and the mechanism used to determine the process weight was unclear. Because of these deficiencies, the test data were rated C. Selected pages from the test report that contain emission data and process rates are included in Appendix F.

4.2 REVIEW OF EXISTING EMISSION FACTORS

The basis for the current emission factors for corn wet milling operations, which are contained in existing Section 6.4 of AP-42, are summarized in References 9 (1976) and 1 (1987). In general, Reference 9 outlines the derivation of emission factors for total front-half PM (filterable PM), and Reference 1 provides new or revised filterable PM emission factors for indirect-fired rotary dryers in corn wet mills based on information obtained since 1976. Reference 1 does not, however, review or re-evaluate the existing data base for grain and feed operations or provide an overall assessment of emission factor applicability and quality.

As a part of this study, the basis for all of the existing AP-42 emission factors provided in Tables 6.4-1 to 6.4-7 of existing Section 6.4, which included PM emission factors for many handling and processing operations, were evaluated. The following discussion provides a brief overview of the existing corn wet milling emission factors and how they were derived.

The emission factors developed prior to 1987 shown in Table 6.4-6 were taken from Table 3 of Reference 9 (1976). The derivation of these factors is discussed in detail in Appendix B of that report. The data base used to develop the various factors was limited, and a number of engineering assumptions were made to produce factors for a variety of corn wet milling processes. Although the assumptions generally appear to be reasonable, the available emission data base is inadequate to validate them.

4.3 DEVELOPMENT OF EMISSION FACTORS

The following subsections outline the data analysis methodology used to develop filterable PM emission factors for corn wet milling facilities. No emission data are available for other pollutants.

4.3.1 Data Analysis for Filterable PM

Useful test data for filterable PM emissions were found in Reference 5, 10, 12, 13, 14, and 15 for corn wet milling facilities. The data from Reference 5 were assigned a rating of D, indicating generally questionable or inadequate data quality. Data from the other references are all B or C rated data. To derive the candidate filterable PM emission factors, average emission factors were obtained for each test series either directly from the text of the report or by hand calculation from the experimental data (see Appendices A-F). The individual factors obtained from the reference documents were then tabulated according to emission source and control equipment and the arithmetic mean calculated.

The data used to develop emission factors developed by the above method are provided in Table 4-3 for corn wet milling. The filterable PM emission factors

TABLE 4-3. DATA USED TO DEVELOP FILTERABLE PM EMISSION FACTORS FOR CORN WET MILLING FACILITIES

Emission source	Type of control	Reference No.	Average measured filterable PM emission factor[a] lb/ton	Average measured filterable PM emission factor[a] kg/Mg	Data quality rating
—Rotary dryers (gluten) (direct-fired)	Cyclone	5	0.265	0.133	D
—Rotary dryers (gluten) (indirect-fired)	Cyclone[b]	5	0.30	0.15	D
			0.35	0.17	D
			0.29	0.16	D
			0.23	0.11	D
			0.34	0.17	D
			0.24	0.12	D
			0.48	0.24	D
			0.70	0.35	D
			1.5	0.73	D
—Flash dryer[c] (starch)	Wet scrubber	11	0.55	0.275	C
—Ring flash dryer[c] (starch)	Wet scrubber	12	0.52	0.26	B
		13	0.69	0.345	B
—Spray dryer[c] (starch)	Fabric filter	14	0.16	0.08	B
—Starch storage bin[d]	Fabric filter	15	0.0014	0.0007	C
—Starch bulk loadout[e]	Fabric filter	15	0.00049	0.00025	C

[a]Weight of total particulate matter per unit-weight of corn gluten feed produced, unless noted. Number of significant figures presented are variable depending on raw test data.
[b]Dryers vented through product recovery cyclones, which are part of the milling process.
[c]Emission factor in kg/Mg (lb/ton) of starch produced.
[d]Emission factor in kg/Mg (lb/ton) of starch stored.
[e]Emission factor in kg/Mg (lb/ton) of starch loaded.

ultimately were obtained by averaging all data sets for a particular source/control combination regardless of quality.

As also shown by Table 4-3, the emission data used to derive the emission factors are somewhat variable. Also, the quantity of available data is limited and generally of questionable quality, which is reflected in the low rating assigned to the filterable PM emission factors. Appropriate footnotes are provided explaining the applicability of each emission factor determined in the analysis.

4.3.2 Emission Factor Development

Using the results of the data analyses described above, emission factors were compiled for inclusion in Section 9.9.7 of AP-42. The test specific emission factors provided in Table 4-3 were averaged to obtain the emission factors presented in Table 4-4 for corn wet milling emission source/control combinations. Each emission factor is also rated, and footnotes are provided to give the reader the maximum amount of useful information relating to the source of the factor and its applicability. The paragraphs below describe how the data from Table 4-3 were used to obtain the emission factors in Table 4-4.

The emission factor for direct-fired (gluten) rotary dryers was obtained by extracting a single value from Table 4-3. This emission factor is rated E.

The emission factor for indirect-fired rotary (gluten) dryers is the average of the data from the nine D-rated tests given in Table 4-3. Because all of the tests are rated D, the emission factor is rated E.

The emission factor for flash (starch) dryers equipped with wet scrubbers was obtained by averaging the two B-rated and one C-rated data points in Table 4-3. Because the three data points were relatively consistent and because two of the three were B-rated, the emission factor is rated D.

The emission factor for spray (starch) dryers equipped with a fabric filter is taken from the single B-rated data point in Table 4-3. Because only a single test is available, the emission factor is rated E.

In the case of dryers used in corn wet mills, separate emission factors have been provided in Table 4-4 for gluten drying (direct- and indirect-fired rotary dryers) and for starch drying (scrubber-controlled flash dryers and fabric filter-controlled spray dryers). This listing departs from the current version of AP-42 Table 6.4-6, which provides only a single factor for indirect-fired dryers.

In addition to the emission factors for product dryers, emission factors are included for grain receiving, grain handling, and grain cleaning. These emission factors are taken from AP-42 section 9.9.1, Grain Elevators and Grain Processing

TABLE 4-4. SUMMARY OF FILTERABLE PM EMISSION FACTORS FOR CORN WET MILLING FACILITIES

Emission source	Type of control[a]	Filterable PM emission factor[b]		Emission factor rating
		lb/ton	kg/Mg	
Grain receiving[c] (trucks) (SCC 3-02-007-51)	Fabric filter	0.033	0.016	E
Grain handling[c] (legs, belts, etc.) (SCC 3-02-007-52)	None	0.87	0.43	E
Grain cleaning[d] (SCC 3-02-007-53)	None	1.6	0.82	E
Grain cleaning[d] (SCC 3-02-007-53)	Cyclone	0.17	0.086	E
Starch storage bin[e] (SCC 3-02-014-07)	Fabric filter	0.0014	0.0007	E
Starch bulk loadout[e] (SCC 3-02-014-08)	Fabric filter	0.00049	0.00025	E
Gluten drying				
— Direct-fired rotary dryers[g] (SCC 3-02-007-63, -68)	Product recovery cyclone	0.27	0.13	E
— Indirect-fired rotary dryers[g] (SCC 3-02-007-64, -69)	None[h]	0.49	0.25	E
Starch drying				
— Flash dryers[j] (SCC 3-02-014-10, -12)	Wet scrubber	0.59	0.29	D
— Spray dryers[k] (SCC 3-02-014-11, -13)	Fabric filter	0.16	0.080	E

[a]Type of technology used to reduce particulate emissions. For grain transfer and handling operations, all data are for an aspirated collection system consisting of one or more capture hoods connected via ductwork to a particulate collection device. Uncontrolled emissions may be overestimated from that occurring without such a system, due to natural removal processes.
[b]Emission factors in kg/Mg and lb/ton of corn throughput, unless noted.
[c]Assumed to be similar to country grain elevators (see AP-42 section 9.9.1).
[d]Assumed to be similar to country grain elevators (see AP-42 section 9.9.1). If two cleaning stages are used, emission factor should be doubled.
[e]Reference 15. Emission factor in kg/Mg and lb/ton of starch stored.
[f]Reference 15. Emission factor in kg/Mg and lb/ton of starch loaded.
[g]Reference 5. Type of material dried not specified but expected to be gluten meal or gluten feed. Emission factor in kg/Mg and lb/ton of gluten meal or gluten feed produced.
[h]Includes data for four (out of nine) dryers known to be vented through product recovery cyclones, and other systems are expected to have such cyclones. Emission factor in kg/Mg and lb/ton of gluten meal or gluten feed produced.
[j]References 11-13. Type of material dried was starch but the references did not identify whether the starch was modified or unmodified. Emission factor in kg/Mg and lb/ton of starch produced.
[k]Reference 14. Type of material dried was starch but the references did not identify whether the starch was modified or unmodified. Emission factor in kg/Mg and lb/ton of starch produced.

Plants. The emission factors for grain receiving, grain handling, and grain cleaning operations at corn wet mills are assumed to be similar to these operations at country grain elevators. Emission factors for starch storage operations and starch loadout operations controlled by fabric filters were developed using the single test values in Table 4-3. Because only a single C-rated test was available for each source, each of these emission factors was rated E.

The emission factors presented in Table 4-4 have been incorporated in the new AP-42 section shown in Section 5 of this report.

REFERENCES FOR SECTION 4

1. G. LaFlam, *Documentation for AP-42 Emission Factors: Section 6.4, Grain Elevators and Processing Plants*, Final Report, EPA Contract No. 68-02-3887, Work Assignment No. 54, Pacific Environmental Service Inc., Durham, North Carolina. (Reference No. 1 in existing section 6.4)

2. J. Zoller et al., *Assessment of Fugitive Particulate Emission Factors for Industrial Processes*, EPA-450/3-78-107, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, September 1978.

3. Research Corporation of New England, *Determining Input Variables for Calculation of Impact of New Source Performance Standards: Worksheets for Food and Agricultural Industries*, EPA-450/3-76-018c, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, April 1977.

4. *Technical Guidance for Control of Industrial Process Fugitive Particulate Emissions*, EPA-450/3-77-010, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, March 1977.

5. *Source Category Survey: Animal Feed Dryers*, EPA-450/3-81-017, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, December 1981. (Reference No. 22 in existing section 6.4).

6. *Emission Factor Development for the Feed and Grain Industry*, EPA-450/3-75-054, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, October 1974.

7. *Emissions Control in the Grain and Feed Industry: Volume II. Emissions Inventory*, EPA-450/3-73-003b, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, September 1974. (Reference No. 6 in existing Section 6.4.)

8. *Development Document for Effluent Guidelines and New Performance Standards for the Grain Processing Segment of the Grain Mills Point Source Category*, EPA-440/1-74-028a, U. S. Environmental Protection Agency, Washington, DC, March 1974.

9. M. P. Schrag et al., *Source Test Evaluation for Feed and Grain Industry*, EPA-450/3-76-043, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, December 1976. (Reference No. 11 in existing Section 6.4)

10. Beling Consultants. Test summary from Report No. 33365. Starch Flash Dryer. Cargill Incorporated facility, Cedar Rapids, IA. Test date October 2, 1991.

11. Beling Consultants. Test summary from Report No. 33405. Starch Flash Dryer No. 2. Cargill Incorporated facility, Cedar Rapids, IA. Test date February 24, 1993.

12. The Almega Corporation. Test Report No. I-7231-1 dated May 14, 1993. No. 4 Starch Flash Dryer. American Maize Products Company facility, Hammond, IN. Test date April 13, 1993.

13. Burns & McDonnell. Test Report No. 86-177-3 dated August 1986. No. 1 Starch Flash Dryer. National Starch & Chemical Company facility, North Kansas City, MO. Test date August 5, 1986.

14. Mostardi-Platt Associates, Incorporated. Test Report for Project No. 21511 dated August 12, 1992. Starch Spray Dryer. A. E. Staley facility, Loudon, TN. Test date July 17, 1992.

15. Beling Consultants. Test summary from Report No. 33402. Starch Storage Bin and Loading System. Cargill Incorporated facility, Cedar Rapids, IA. Test date November 18, 1992.

9.9.7 CORN WET MILLING

9.9.7.1 General[1]

Establishments in corn wet milling are engaged primarily in producing starch, syrup, oil, sugar, and byproducts such as gluten feed and meal, from wet milling of corn and sorghum. These facilities may also produce starch from other vegetables and grains, such as potatoes and wheat. In 1994, 27 corn wet milling facilities were reported to be operating in the United States.

9.9.7.2 Process Description[1-4]

The corn wet milling industry has grown in its 150 years of existence into the most diversified and integrated of the grain processing industries. The corn refining industry produces hundreds of products and byproducts, such as high fructose corn syrup (HFCS), corn syrup, starches, animal feed, oil, and alcohol.

In the corn wet milling process, the corn kernel (see Figure 9.9.7-1) is separated into three principal parts: (1) the outer skin, called the bran or hull; (2) the germ, containing most of the oil; and (3) the endosperm (gluten and starch). From an average bushel of corn weighing 25 kilograms (kg) (56 pounds [lb]), approximately 14 kg (32 lb) of starch is produced, about 6.6 kg (14.5 lb) of feed and feed products, about 0.9 kg (2 lb) of oil, and the remainder is water. The overall corn wet milling process consists of numerous steps or stages, as shown schematically in Figure 9.9.7-2.

Shelled corn is delivered to the wet milling plant primarily by rail and truck and is unloaded into a receiving pit. The corn is then elevated to temporary storage bins and scale hoppers for weighing and sampling. The corn then passes through mechanical cleaners designed to remove unwanted material, such as pieces of cobs, sticks, and husks, as well as meal and stones. The cleaners agitate the kernels over a series of perforated metal sheets through which the smaller foreign materials drop. A blast of air blows away chaff and dust, and electromagnets remove bits of metal. Coming out of storage bins, the corn is given a second cleaning before going into "steep" tanks.

Steeping, the first step in the process, conditions the grain for subsequent milling and recovery of corn constituents. Steeping softens the kernel for milling, helps break down the protein holding the starch particles, and removes certain soluble constituents. Steeping takes place in a series of tanks, usually referred to as steeps, which are operated in continuous-batch process. Steep tanks may hold from 70.5 to 458 cubic meters (m^3) (2,000 to 13,000 bushels [bu]) of corn, which is then submerged in a current of dilute sulfurous acid solution at a temperature of about 52°C (125°F). Total steeping time ranges from 28 to 48 hours. Each tank in the series holds corn that has been steeping for a different length of time.

Corn that has steeped for the desired length of time is discharged from its tank for further processing, and the tank is filled with fresh corn. New steeping liquid is added, along with recycled water from other mill operations, to the tank with the "oldest" corn (in steep time). The liquid is then

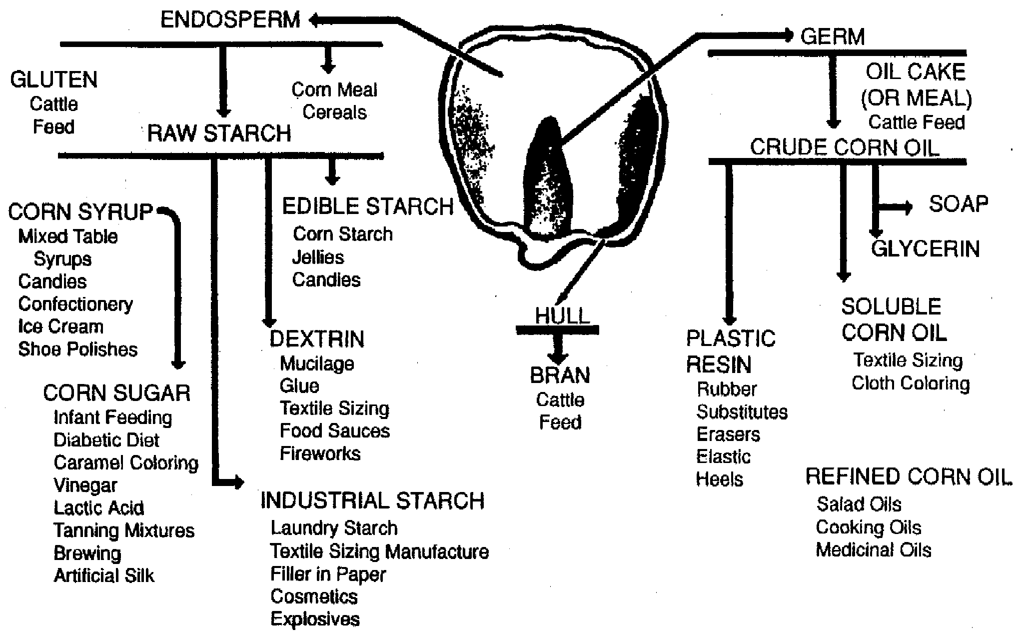

Figure 9.9.7-1. Various uses of corn.

passed through a series of tanks, moving each time to the tank holding the next "oldest" batch of corn until the liquid reaches the newest batch of corn.

Water drained from the newest corn steep is discharged to evaporators as so-called "light steepwater" containing about 6 percent of the original dry weight of grain. By dry-weight, the solids in the steepwater contain 35 to 45 percent protein and are worth recovering as feed supplements. The steepwater is concentrated to 30 to 55 percent solids in multiple-effect evaporators. The resulting steeping liquor, or heavy steepwater, is usually added to the fibrous milling residue, which is sold as animal feed. Some steepwater may also be sold for use as a nutrient in fermentation processes.

The steeped corn passes through degerminating mills, which tear the kernel apart to free both the germ and about half of the starch and gluten. The resultant pulpy material is pumped through liquid cyclones to extract the germ from the mixture of fiber, starch, and gluten. The germ is subsequently washed, dewatered, and dried; the oil extracted; and the spent germ sold as corn oil meal or as part of corn gluten feed. More details on corn oil production are contained in Section 9.11.1, "Vegetable Oil Processing".

The product slurry passes through a series of washing, grinding, and screening operations to separate the starch and gluten from the fibrous material. The hulls are discharged to the feed house, where they are dried for use in animal feeds.

At this point, the main product stream contains starch, gluten, and soluble organic materials. The lower density gluten is separated from the starch by centrifugation, generally in two stages. A high-quality gluten, of 60 to 70 percent protein and 1.0 to 1.5 percent solids, is then centrifuged, dewatered, and dried for adding to animal feed. The centrifuge underflow containing the starch is passed to starch washing filters to remove any residual gluten and solubles.

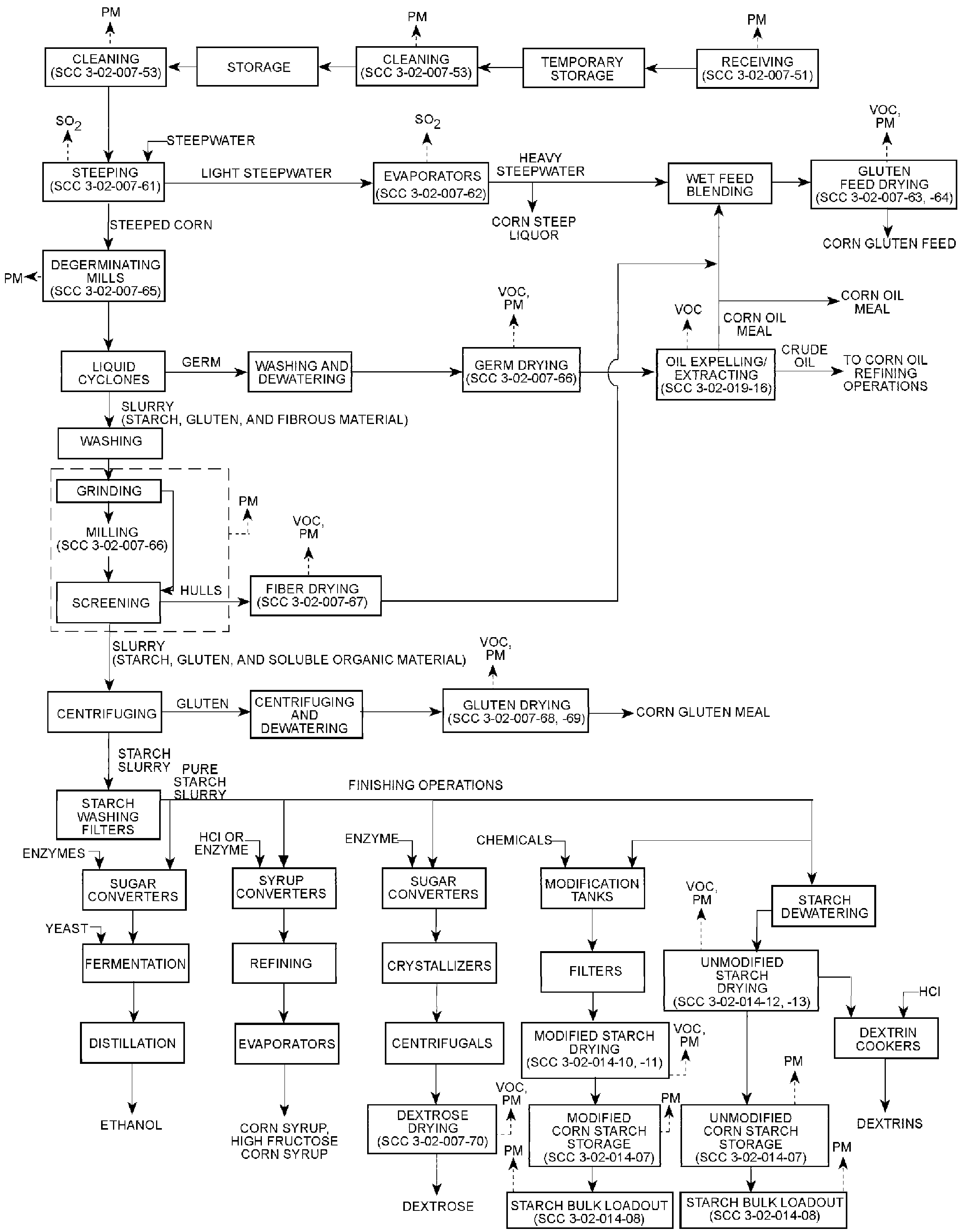

Figure 9.9.7-2. Corn wet milling process flow diagram.[1-4]
(Source Classification Codes in parentheses.)

The pure starch slurry is now directed into one of three basic finishing operations, namely, ordinary dry starch, modified starches, and corn syrup and sugar. In the production of ordinary dry starch, the starch slurry is dewatered with vacuum filters or basket centrifuges. The discharged starch cake has a moisture content of 35 to 42 percent and is further dewatered thermally in one of several types of dryers. The dry starch is then packaged or shipped in bulk, or a portion may be kept for use in making dextrin.

Modified starches are manufactured for various food and trade industries for which unmodified starches are not suitable. For example, large quantities of modified starches go into the manufacture of paper products as binding for the fiber. Modifying is accomplished in tanks that treat the starch slurry with selected chemicals, such as hydrochloric acid, to produce acid-modified starch; sodium hypochlorite, to produce oxidized starch; and ethylene oxide, to produce hydroxyethyl starches. The treated starch is then washed, dried, and packaged for distribution.

Across the corn wet milling industry, about 80 percent of starch slurry goes to corn syrup, sugar, and alcohol production. The relative amounts of starch slurry used for corn syrup, sugar, and alcohol production vary widely among plants. Syrups and sugars are formed by hydrolyzing the starch — partial hydrolysis resulting in corn syrup, and complete hydrolysis producing corn sugar. The hydrolysis step can be accomplished using mineral acids, enzymes, or a combination of both. The hydrolyzed product is then refined, which is the decolorization with activated carbon and the removal of inorganic salt impurities with ion exchange resins. The refined syrup is concentrated to the desired level in evaporators and is cooled for storage and shipping.

Dextrose production is quite similar to corn syrup production, the major difference being that the hydrolysis process is allowed to go to completion. The hydrolyzed liquor is refined with activated carbon and ion exchange resins, to remove color and inorganic salts, and the product stream is concentrated by evaporation to the 70 to 75 percent solids range. After cooling, the liquor is transferred to crystallizing vessels, where it is seeded with sugar crystals from previous batches. The solution is held for several days while the contents are further cooled and the dextrose crystallizes. After about 60 percent of the dextrose solids crystallize, they are removed from the liquid by centrifuges, are dried, and are packed for shipment.

A smaller portion of the syrup refinery is devoted to the production of corn syrup solids. In this operation, refined corn syrup is further concentrated by evaporation to a high dry substance level. The syrup is then solidified by rapid cooling and subsequently milled to form an amorphous crystalline product.

Ethanol is produced by the addition of enzymes to the pure starch slurry to hydrolyze the starch to fermentable sugars. Following hydrolysis, yeast is added to initiate the fermentation process. After about two days, approximately 90 percent of the starch is converted to ethanol. The fermentation broth is transferred to a still where the ethanol (about 50 vol%) is distilled. Subsequent distillation and treatment steps produce 95 percent, absolute, or denatured ethanol. More details on this ethanol production process, emissions, and emission factors is contained in Section 6.21, "Ethanol".

9.9.7.3 Emissions And Controls[1-2,4-8]

The diversity of operations in corn wet milling results in numerous and varied potential sources of air pollution. It has been reported that the number of process emission points at a typical plant is well over 100. The main pollutant of concern in grain storage and handling operations in corn wet milling facilities is particulate matter (PM). Organic emissions (e. g., hexane) from certain operations at corn oil extraction facilities may also be significant. These organic emissions (and related emissions from soybean processing) are discussed in Section 9.11.1, "Vegetable Oil Processing". Other possible pollutants of concern are volatile organic compounds (VOC) and combustion products from grain drying, sulfur dioxide (SO_2) from corn wet milling operations, and organic materials from starch production. The focus here is primarily on PM sources for grain handling operations. Sources of VOC and SO_2 are identified, although no data are available to quantify emissions.

Emission sources associated with grain receiving, cleaning, and storage are similar in character to those involved in all other grain elevator operations, and other PM sources are comparable to those found in other grain processing plants as described in Section 9.9.1, "Grain Elevators And Processing". However, corn wet milling operations differ from other processes in that they are also sources of SO_2 and VOC emissions, as described below.

The corn wet milling process uses about 1.1 to 2.0 kg of SO_2 per megagram (Mg) of corn (0.06 to 0.11 lb/bu). The SO_2 is dissolved in process waters, but its pungent odor is present in the slurries, necessitating the enclosing and venting of the process equipment. Vents can be wet-scrubbed with an alkaline solution to recover the SO_2 before the exhaust gas is discharged to the atmosphere. The most significant source of VOC emissions, and also a source of PM emissions, from corn wet milling is the exhaust from the different drying processes. The starch modification procedures also may be sources of acid mists and VOC emissions, but data are insufficient to characterize or to quantify these emissions.

Dryer exhausts exhibit problems with odor and blue haze (opacity). Germ dryers emit a toasted smell that is not considered objectionable in most areas. Gluten dryer exhausts do not create odor or visible emission problems if the drying temperature does not exceed 427°C (800°F). Higher temperatures promote hot smoldering areas in the drying equipment, creating a burnt odor and a blue-brown haze. Feed drying, where steepwater is present, results in environmentally unacceptable odor if the drying temperature exceeds 427°C (800°F). Blue haze formation is a concern when drying temperatures are elevated. These exhausts contain VOC with acrid odors, such as acetic acid and acetaldehyde. Rancid odors can come from butyric and valeric acids, and fruity smells emanate from many of the aldehydes present.

The objectionable odors indicative of VOC emissions from process dryers have been reduced to commercially acceptable levels with ionizing wet-collectors, in which particles are charged electrostatically with up to 30,000 volts. An alkaline wash is necessary before and after the ionizing sections. Another approach to odor/VOC control is thermal oxidation at approximately 750°C (1382°F) for 0.5 seconds, followed by some form of heat recovery. This hot exhaust can be used as the heat source for other dryers or for generating steam in a boiler specifically designed for this type of operation. Incineration can be accomplished in conventional boilers by routing the dryer exhaust gases to the primary air intake. The limitations of incineration are potential fouling of the boiler air intake system with PM and derated boiler capacity because of low oxygen content. These limitations severely restrict this practice. At least one facility has attempted to use a regenerative system, in which dampers divert the gases across ceramic fill where exhaust heats the fumes to be incinerated. Incinerator size can be reduced 20 to 40 percent when some of the dryer exhaust is fed back into the dryer furnace. From 60 to 80 percent of the dryer exhaust may be recycled by chilling it to condense the water before recycling.

The PM emissions generated from grain receiving, handling, and processing operations at corn wet milling facilities can be controlled either by process modifications designed to prevent or inhibit emissions or by application of capture collection systems.

The fugitive emissions from grain handling operations generated by mechanical energy imparted to the dust, both by the operations themselves and by local air currents in the vicinity of the operations, can be controlled by modifying the process or facility to limit the generation of fugitive dust. The primary preventive measures used by facilities are construction and sealing practices that limit the effect of air currents, and minimizing grain free fall distances and grain velocities during handling and transfer. Some recommended construction and sealing practices that minimize emissions are: (1) enclosing the receiving area to the extent practicable; (2) specifying dust-tight cleaning and processing equipment; (3) using lip-type shaft seals at bearings on conveyor and other equipment housings; (4) using flanged inlets and outlets on all spouting, transitions, and miscellaneous hoppers; and (5) fully enclosing and sealing all areas in contact with products handled.

While preventive measures can reduce emissions, most facilities also require ventilation or capture/collection systems to reduce emissions to acceptable levels. Milling operations generally are ventilated, and some facilities use hood systems on all handling and transfer operations. The control devices typically used in conjunction with capture systems for grain handling and processing operations are cyclones (or mechanical collectors) and fabric filters. Both of these systems can achieve acceptable levels of control for many grain handling and processing sources. However, even though cyclone collectors can achieve acceptable performance in some scenarios, and fabric filters are highly efficient, both devices are subject to failure if not properly operated and maintained. Ventilation system malfunction, of course, can lead to increased emissions at the source.

Table 9.9.7-1 shows the filterable PM emission factors developed from the available data on several source/control combinations. Table 9.9.7-2 shows potential sources of VOC and SO_2, although no data are available to characterize these emissions.

Table 9.9.7-1 (Metric And English Units).
PARTICULATE MATTER EMISSION FACTORS FOR CORN WET MILLING OPERATIONS[a]

EMISSION FACTOR RATING: E

Emission source	Type of control	Filterable PM[b]	
		kg/Mg	lb/ton
Grain receiving[c] (trucks) (SCC 3-02-007-51)	Fabric filter	0.016	0.033
Grain handling[c] (legs, belts, etc.) (SCC 3-02-007-52)	None	0.43	0.87
Grain cleaning[d] (SCC 3-02-007-53)	None	0.82	1.6
Grain cleaning[d] (SCC 3-02-007-53)	Cyclone	0.086	0.17
Starch storage bin[e] (SCC 3-02-014-07)	Fabric filter	0.0007	0.0014
Starch bulk loadout[f] (SCC 3-02-014-08)	Fabric filter	0.00025	0.00049
Gluten feed drying			
Direct-fired rotary dryers[g] (SCC 3-02-007-63)	Product recovery cyclone	0.13	0.27
Indirect-fired rotary dryers[g] (SCC 3-02-007-64)	Product recovery cyclone[h]	0.25	0.49
Starch drying			
Flash dryers[j] (SCC 3-02-014-10, -12)	Wet scrubber	0.29	0.59
Spray dryers[k] (SCC 3-02-014-11, -13)	Fabric filter	0.080	0.16
Gluten drying			
Direct-fired rotary dryers[g] (SCC 3-02-007-68)	Product recovery cyclone	0.13	0.27
Indirect-fired rotary dryers[g] (SCC 3-02-007-69)	Product recovery cyclone	0.25	0.49
Fiber drying (SCC 3-02-007-67)	ND	ND	ND
Germ drying (SCC 3-02-007-66)	ND	ND	ND
Dextrose drying (SCC 3-02-007-70)	ND	ND	ND
Degerminating mills (SCC 3-02-007-65)	ND	ND	ND
Milling (SCC 3-02-007-56)	ND	ND	ND

[a]For grain transfer and handling operations, factors are for an aspirated collection system of one or more capture hoods ducted to a particulate collection device. Because of natural removal processes, uncontrolled emissions may be overestimated. ND = no data. SCC = Source Classification Code.
[b]Emission factors based on weight of PM, regardless of size, per unit weight of corn throughput unless noted.
[c]Assumed to be similar to country grain elevators (see Section 9.9.1).
[d]Assumed to be similar to country grain elevators (see Section 9.9.1). If two cleaning stages are used, emission factor should be doubled.
[e]Reference 9.
[f]Reference 9. Emission factor based on weight of PM per unit weight of starch loaded.
[g]Reference 10. Type of material dried not specified, but expected to be gluten meal or gluten feed. Emission factor based on weight of PM, regardless of size, per unit weight of gluten meal or gluten feed produced.
[h]Includes data for four (out of nine) dryers known to be vented through product recovery cyclones, and other systems are expected to have such cyclones. Emission factor based on weight of PM, regardless of size, per unit weight of gluten meal or gluten feed produced.
[j]References 11-13. EMISSION FACTOR RATING: D. Type of material dried is starch, but whether the starch is modified or unmodified is not known. Emission factor based on weight of PM, regardless of size, per unit weight of starch produced.
[k]Reference 14. Type of material dried is starch, but whether the starch is modified or unmodified is not known. Emission factor based on weight of PM, regardless of size, per unit weight of starch produced.

Table 9.9.7-2 (Metric And English Units).
EMISSION FACTORS FOR CORN WET MILLING OPERATIONS

Emission source	Type of control	VOC		SO_2	
		kg/Mg	lb/ton	kg/Mg	lb/ton
Steeping (SCC 3-02-007-61)	ND	ND	ND	ND	ND
Evaporators (SCC 3-02-007-62)	ND	ND	ND	ND	ND
Gluten feed drying (SCC 3-02-007-63, -64)	ND	ND	ND	ND	ND
Germ drying (SCC 3-02-007-66)	ND	ND	ND	ND	ND
Fiber drying (SCC 3-02-007-67)	ND	ND	ND	ND	ND
Gluten drying (SCC 3-02-007-68, -69)	ND	ND	ND	ND	ND
Starch drying (SCC 3-02-014-10, -11, -12, -13)	ND	ND	ND	ND	ND
Dextrose drying (SCC 3-02-007-70)	ND	ND	ND	ND	ND
Oil expelling/extraction (SCC 3-02-019-16)	ND	ND	ND	ND	ND

ND = no data. SCC = Source Classification Code.

References For Section 9.9.7

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APPENDIX A

REPORT EXCERPTS AND HAND CALCULATIONS FOR REFERENCE 5

(MRI, 1981)

APPENDIX B

REPORT EXCERPTS AND HAND CALCULATIONS FOR REFERENCE 11

(BELING, 1993)

APPENDIX C

REPORT EXCERPTS AND HAND CALCULATIONS FOR REFERENCE 12

(ALMEGA, 1993)

APPENDIX D

REPORT EXCERPTS AND HAND CALCULATIONS FOR REFERENCE 13

(BURNS AND McDONNELL, 1986)

APPENDIX E

REPORT EXCERPTS AND HAND CALCULATIONS FOR REFERENCE 14

(MOSTARDI-PLATT, 1992)

APPENDIX F

REPORT EXCERPTS AND HAND CALCULATIONS FOR REFERENCE 15

(BELING, 1992)