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Control of Odors and Aerosols From Spent Grain Dryers

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The information contained in this paper is directed to research workers concerned with odor identification and the development of methods for removal of odorous components from hot, moist stack gases and to application engineers faced with the practical problem of selecting effective, yet economical, odor control equipment for industrial operations. The new techniques described here demonstrate the beneficial uses of gas phase reactions as a conditioning step preceding absorption in a chemically reactive solution. Cost comparisons show markedly lower costs for full-scale reactor-absorbers than for gas incinerators for equal contaminant removal. Other methods of removing odors at the source, e.g., injection of ozone, use of nonvolatile oxidizing agents in solution, and adsorption on activated charcoal, were found to be impractical, ineffective, or both. The application of reactor-absorbers to spent grain drying is discussed in detail and reference is made to the use of this technique for other food industry waste treatment processes including rendering and fish and poultry meal production.

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A number of grain processing industries, including distilling, brewing, and starch extracting, utilize only the starch content of the grain and end up with a product known as "spent grain" which contains almost all of the proteins, fats, minerals, vitamins, and fiber of the original cereals. The residues of the distilling industry contain, in addition, yeast cells and unidentified nutrients formed during the fermentation process. All of the spent grains have excellent nutritive values for the feeding of chickens, swine, cattle, and fur bearing animals.²

Income from the sale of spent grains is an important factor in the profitability of distilleries, breweries, and starch manufacturing plants and, consequently, economical processing of this by-product is of major importance to these industries. Formerly, fresh spent grains were fed to local farm animals, principally beef and dairy cattle, in the form of wet mash but the increasing size of breweries and distilleries and their concentration in urban centers has made it impossible to dispose of spent grains promptly in the wet state. When dried, spent grains lose none of their nutritional values and may be shipped conveniently and stored many months prior to use. The dry product contains about 25% protein, 8% fat, and an extensive list of vitamins and minerals.

In the distilling industry, de-alcoholized fermentation residues are discharged from the beer still, the first distillation step, as a mash containing about 7% solids. This product is screened and pressed to form a cake containing about 17% solids that goes to the dryer. The liquid fraction, containing about 4% solids plus soluble nutrients, is sent to multiple effect evaporators and concentrated to a thick, dark molasses-like syrup that is usually added to the pressed cake as it enters the dryer. In addition, about 80% of the dried material, containing approximately 90% solids, is recycled through the dryer to produce a combined feed stock containing up to 60% solids and provide the additional bulk needed for proper functioning of the dryer.

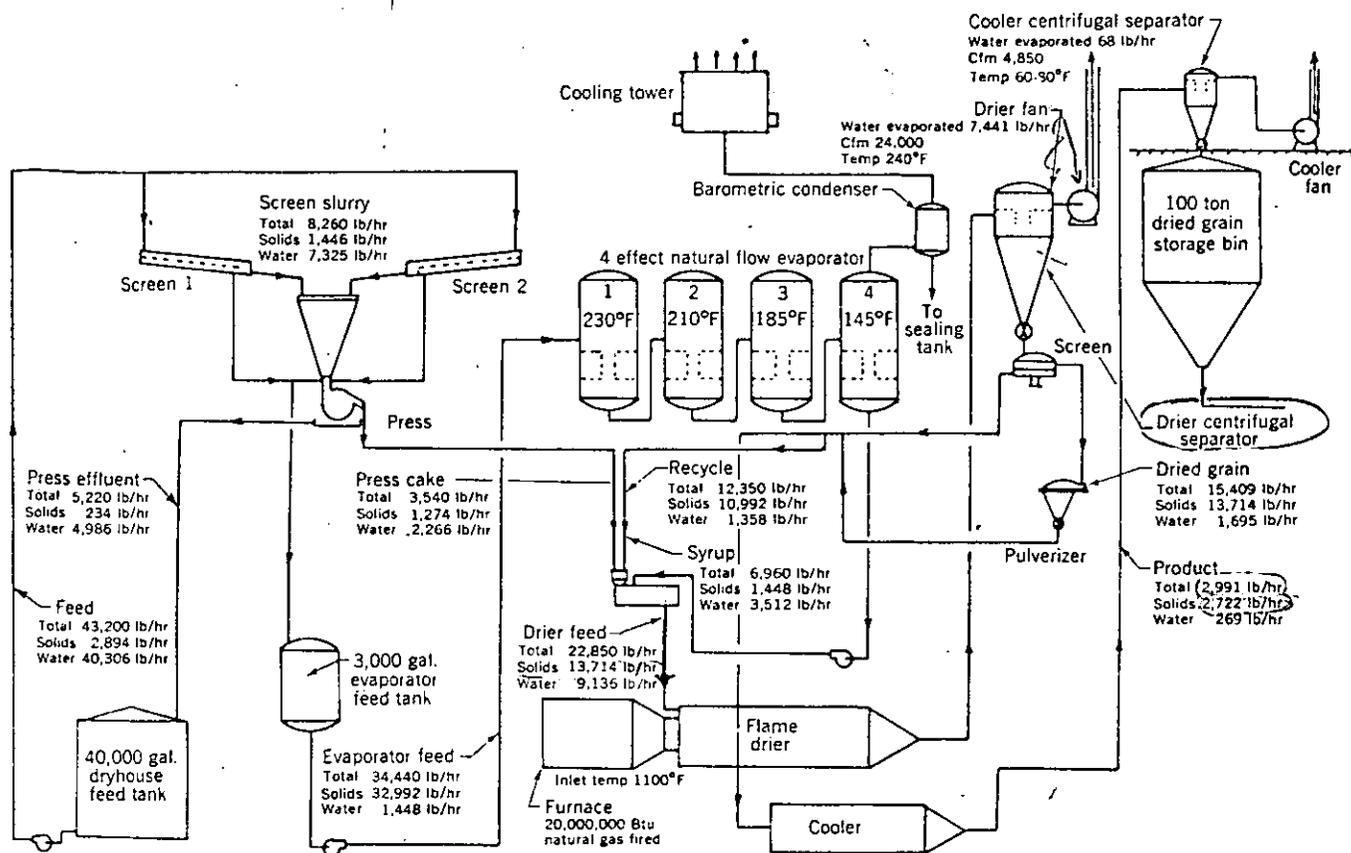


Figure 1. Typical distillery spent grain recovery system.

Dryers are of two general types: (1) Indirect heat cylindrical rotary shells have the heating elements, often steam jackets, separated from the wet cake flowing through on the inside. Flow rates are low, e.g., 2500 cfm, and exit temperatures are 185-205°F. Indirect heat grain dryers produce an excellent product but production rates are low. (2) Direct fired cocurrent rotary dryers are used most widely because of better fuel economy and higher production rates. Gas flow through the dryer ranges from 10,000 to 25,000 cfm, depending on size, and dryer exit temperature will be in the vicinity of 250°F. Direct fired units often use natural gas as the fuel (although distillate oil can be used) and the flame is directed into the rotating shell axially to heat the drying air (through which the grain showers under the action of the rotating cylinder) and to produce radiative heat transfer to the shell and its contents. As flame and product enter the dryer shell at the same point, some scorching and burning of the feed stock occurs and this produces a typical "burnt" odor. The effluent dryer gases contain numerous substances in addition to water vapor including: (a) combustion gases, (b) finely divided grain dust in amounts of a few pounds per hour that may be sufficient to give the discharge a tan color, (c) condensable vapors, also present in amounts of a few pounds per hour and principally composed of oils and waxes that give the discharge the appearance of a bluish-white haze, and (d) non-condensable vapors that contain most of the odorous properties of the discharge. Dryers volatilize a number of products which occur naturally in grain and syrup to produce typical "wet grain" or "mash like" odors which differ somewhat depending on the proportions of corn, rye, and barley in the original mixture. Neighborhood complaints are usually directed toward burnt grain odors. The bluish-

white haze and brown grain dust discoloration associated with dryer offgases are of concern to air pollution control agencies.

The discharge from the rotary dryer goes to a cyclone collector where all but the finest dried grain particles are separated from the moist, hot gases and sent to the product bins. Gases, vapors and some of the grain fines pass through an induced draft blower and are discharged to the atmosphere. Figure 1 shows a schematic of a typical spent grain recovery system for a distillery with mass balance figures for each step of the process.

The grain using industries have studied a number of effluent control methods over the past several years including destruction of the visible and odorous components by gas incineration, adsorption on charcoal, conversion to nonodorous compounds by ozone, and absorption in reactive scrubbing solutions. Gas incineration has been found to be effective for destroying all odorous compounds, as well as the bluish-white haze and the brown discoloration characteristic of the untreated dryer effluent, when gas temperature is maintained at 1400-1600°F for 0.5 sec, but fuel costs on the order of \$10/year/cfm of capacity for round-the-clock operation are considered unacceptable.* Efficient heat recovery devices can reduce gas incinerator fuel requirements substantially but some of this saving will be offset by increased equipment and maintenance costs.³ Natural gas, the ideal fuel for gas incineration, has been in short supply recently and future prospects are for increasingly severe shortages and higher

*June 1973 fuel costs.

prices. There is a good possibility that natural gas may become unavailable for this use in the future.

Gas adsorption charcoals have been investigated for application to effluents from indirect heat grain driers because they have lower off gas volumes relative to direct heat units (i.e., roughly an order of magnitude difference) and the number of products emitted is smaller as there is far less overheating and charring of grain and syrup. Chromatographic studies⁴ of vapors in the effluent from an indirect heat dryer showed six prominent peaks. After passing through charcoal, four peaks remained but odor was greatly reduced and it was concluded that the characteristic odor was associated with substances in the missing peaks. These substances were not identified and no studies were conducted to determine charcoal capacity, service life, or reactivation potential for this application. The presence of waxlike materials in the dryer effluent gases suggests that charcoal service life might be affected adversely. In addition, it would be necessary, for satisfactory charcoal service, to remove the fine grain solids that penetrate the centrifugal grain collectors customarily used in these processes.

Gas absorption in reactive chemical solutions has been studied extensively. It has been found that nonvolatile oxidizing chemicals, such as $KMnO_4$, are effective only after the odorous and haze producing substances have been absorbed in the scrubbing liquid, whereas a gaseous oxidizing agent, such as chlorine, can prepare compounds for absorption by chemical reactions in the gas phase and act as a powerful oxidizing agent in liquid phase reactions after absorption. Permanganate is a costly chemical and produces an insoluble MnO_2 reaction product which can clog the scrubbing equipment and plug the droplet carryover stage.

The use of ozone requires concentrations in the vicinity of 10 ppm to produce a sufficient concentration to effect a reasonable degree of oxidation of odorous vapors within an acceptable retention time. As the odorous compounds are present in fractions of a part per million (often less than a part per billion) most of the injected ozone would be emitted to the atmosphere, unchanged, without further treatment. This amount of ozone would constitute an excessive atmospheric emission in most air pollution control districts and a scrubber of some sort is required to remove excess ozone.

Chlorine, another gaseous oxidizing substance that can be added to the effluent from the grain dryer to induce gas phase reactions, has a number of advantages for this service: (1) less toxicity than ozone, (2) unreacted chlorine is easily removed by caustic scrubbing and the sodium hypochlorite that is formed reacts with absorbed materials, such as oils, to reduce vapor pressure of dissolved volatiles and prepares materials for disposal by changing oils and waxes to soluble sodium compounds, (3) chlorine, readily available as a compressed gas, can be injected into the dryer offgas stream through a simple manifold and automatic equipment for dispensing it in controlled amounts has been used universally over many decades for drinking water treatment and is relatively inexpensive and very reliable.

Pilot Plant Studies

A pilot study of spent grain dryer offgas cleaning was conducted at a distillery to determine if satisfactory deodorization and solids removal could be accomplished with a caustic scrubber unit containing an impingement stage to remove particulate matter, wetted fiber stages to remove absorbable gases, and a final dry fiber stage to prevent droplet carryover

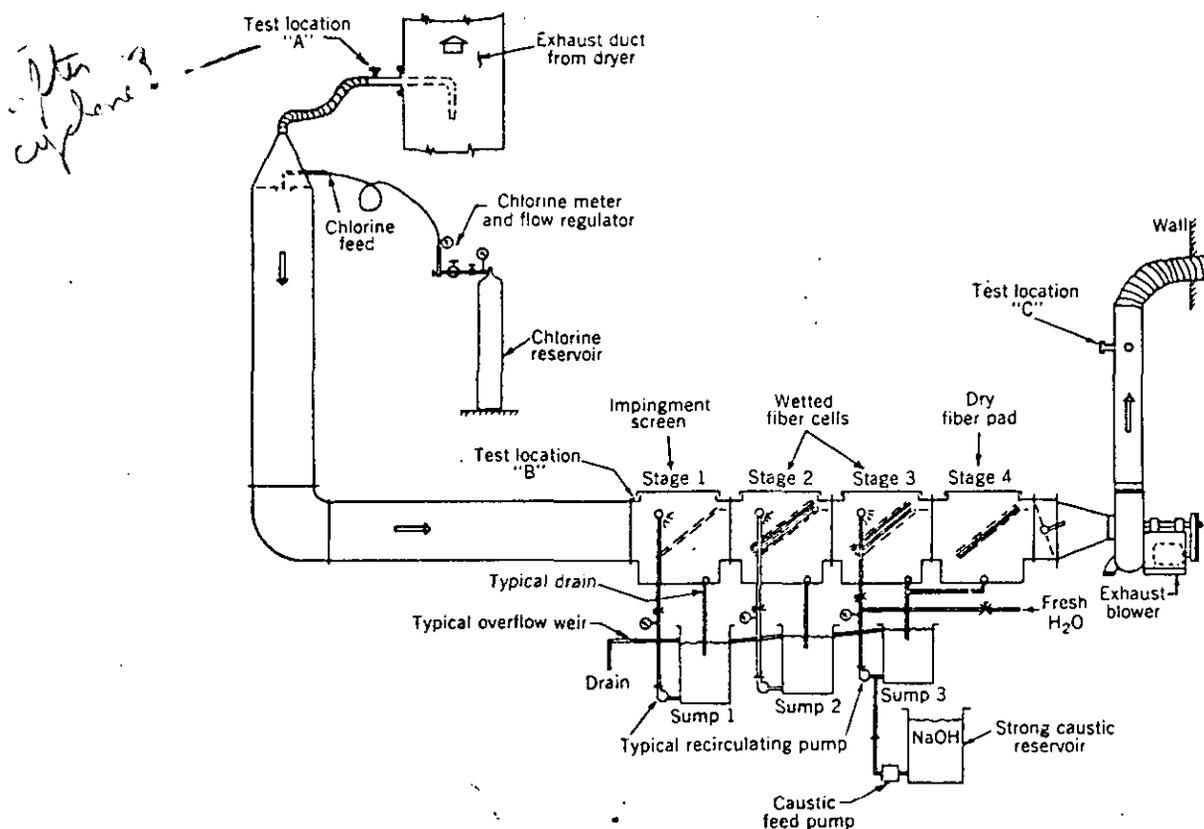


Figure 2. Schematic of pilot reactor-absorber.

to the stack. As the substances producing the characteristic odor associated with spent grain dryer offgases are mostly water insoluble, chlorine gas was added to the dryer effluent gases and long gas phase contact time between the water insoluble components and chlorine was built into the pilot scale air cleaner to make it possible for these compounds to react and become water soluble before reaching the caustic scrubber.

Evaluation was by sensory methods, i.e., odor reduction was judged by an odor panel and particulate removal by visual inspection of the stack discharge. Although substantial improvement in offgas quality was indicated by these methods, nothing of a quantitative nature could be deduced from these tests. Therefore, when an opportunity occurred to conduct additional pilot scale tests of a similar nature at another distillery, major emphasis was directed toward quantitative evaluation. As there is no known toxic substance emitted from spent grain dryers and as odor and opacity reduction remain major requirements, sensory responses continued to be of interest and importance and were retained as an essential part of the evaluation procedure.

Quantization was conducted by two methods: (1) particulate concentrations were evaluated by stack sampling at isokinetic sampling rates and collecting the particles in a filter located in the nose of the sampling probe, (2) gas and vapor concentrations were evaluated by gas chromatographic techniques using flame ionization and electron capture detectors.

Pilot Air Cleaner

The four stage pilot reactor-absorber used for this test program is shown schematically in Figure 2. In the direction of airflow, the first stage is a wetted double-impingement screen that performs the dual functions of removing particulate matter and absorbing gases. The next two wetted stages contain fibrous packings with large wetted surface areas for good gas absorption. The final stage is a dry fiber filter to prevent liquid carryover. A centrifugal blower, located downstream of the scrubber, discharges to the effluent stack. Liquid sumps are located below each of the wetted stages. They supply scrubbing liquid for each stage through individual recirculating pumps and provide means, through a series of overflow weirs, for cascading the scrubbing liquid from the last wetted stage (in the direction of airflow) to the second, the first, and then out of the system by way of the drain. Fresh water and fresh caustic enter the system at the last wetted stage by the connections shown in Figure 2. The effect of cascading the scrubbing liquid from the last wetted stage to the first is to create a temperature and caustic gradient such that the gas meets cooler and more alkaline scrubbing liquid as it proceeds through the unit. This helps to maintain maximum heat and mass transfer rates throughout the several stages of the scrubber.

A long entry duct is located between the dryer exhaust stack, from which the representative effluent stream is drawn, and the pilot unit to permit long gas phase reaction time between insoluble components in dryer offgases and chlorine. Chlorine is added in metered amounts from a compressed gas cylinder, as shown in Figure 2.

Each stage of the pilot scrubber was 12 x 15 in. in cross section and had a design airflow capacity of 270 cfm (although higher and lower air flow rates were feasible). The design liquid flow rate on each stage was 3 gpm/sq ft of face area. For each test, measurements were made of: gas and liquid temperatures at entry, exit, and in each stage of the scrubber; pH and liquid flow rate for each wetted stage; total gas flow rate; and pressure drop through each section of the apparatus.

Representative Samples

For pilot trials, representative samples of the grain dryer effluent gas stream were extracted from a location in the main discharge duct downstream of the exhaust blower. The general arrangement is shown in Figure 2. Initial pitot-static traverses of the proposed location indicated that flow was highly concentrated on one side of the duct by the centrifugal action of the blower wheel but by trial and error adjustments of individual damper blades located between the blower discharge and the draw-off point for the test stream, it was possible to readjust the flow pattern to make it satisfactory for these tests.

Particulate Matter Tests

Representative isokinetic samplings were conducted in the main discharge stack from the grain dryer to determine the average concentrations of grain dust. Three sets of sample traverses, taken from the centers of equal areas across the dryer exit duct, each showed less than 0.01 grains/normal cubic foot of dryer offgas. For a dryer discharge volume of 15,000 cfm at 230°F, this represented an emission rate of less than 1 lb/hr.

The high retention efficiency of the dried grain cyclone collector could be accounted for by the large size of the grains (only 0.0001% by weight less than 10 µm) and the known fact that high dust concentrations increase collector efficiency because of particle agglomeration and the additive effect of large particles "sweeping out" the smaller ones in their path.

Although the emission of solids from the dried grain collector was sufficiently low to be acceptable without further treatment, passage through an absorber (where impingement, cooling, and filtration take place) reduces condensable and non-condensable fractions by approximately one order of magnitude and provides a needed safety measure during upset conditions when large quantities of grain dust can be emitted in a short period from an uncontrolled stack.

Gas and Vapor Tests

A Varian gas chromatograph with a 6 ft packed column containing 5% ethylene glycol phthalate on Chemisorb-W was used to separate the several compounds contained in the dryer offgases. A flame ionization detector (FID), which is especially sensitive to carbon molecules in organic compounds, was used to quantitate up- and down-stream concentrations. An electron capture detector, which is especially sensitive to halides, was used to evaluate changes in composition induced by the addition of chlorine to the dryer offgases.

Sampling was conducted through heated copper sampling lines maintained at a temperature that would prevent condensation of water and condensable vapors at all points in the line. The objective was to keep the lines hot enough to prevent condensation but below a temperature that would induce cracking or other degradation of the organic compounds that were present. The instrument was equipped with a 6 port high temperature, zero dead volume sampling valve. A continuous flow of several liters per minute was maintained through the sampling valve with the assistance of a mechanical sampling pump and it was only necessary to activate the valve manually to inject a sample of uniform volume into the column. Inactive sampling lines were also maintained in a condition of continuous flow with the aid of additional vacuum pumps so that when connected into the automatic sampling valve of the chromatograph there would be a minimum time required to reach steady state conditions.

The primary interest in this series of tests was to compare up and down-stream concentrations by comparing the heights of the three recurring peaks. It would have been more exact

after cyclone load with non-condensables only

Table 1. Pilot test results of gas and vapor removal.

Run No.	Gas rate cfm	Absorber resist. in.w.g.	Caustic add'n gph	Chlorine add'n ppm	Peak height and overall efficiency				Sensory observations
					Peak 1 % Reduction	Peak 2 % Reduction	Peak 3 % Reduction	Sum of Peaks % Reduction	
1	278	5.50	0	0	0	12	13	18	Strong burnt caramel odor
2	278	6.00	0.75	0	95	91	0	91	Strong burnt caramel odor—not greatly different from water alone
3	278	5.88	0.75	1.9	90	97	34	91	Moderate burnt caramel odor—no chlorine or hypochlorite odor
4	288	5.56	0.75	5.7	91	99	0	95	Very low odor intensity with faint burnt odor. No chlorine or hypochlorite odor
5	280	5.25	0.75	9.0	89	99	27	94	Distinct hypochlorite odor but not sharp
6	318	9.25	0.75	8.5	98	79	0	96	Distinct hypochlorite odor but not sharp
7	318	9.25	0.75	4.7	98	86	0	95	Very low odor intensity with faint burnt odor. No chlorine or hypochlorite odor

to have compared areas under the peaks rather than peak heights but as the slope of the curves up and downstream of the pilot scrubber, as well as from test to test, remained substantially the same as long as the same sample volume, instrument attenuation, chart speed, temperature, etc. remained constant, only a small error was introduced by comparing peak heights rather than areas under the curves. Overall scrubber efficiency was determined by summing the peaks and comparing up and downstream results to calculate percent removal by weight.

Test Schedule

The tests were designed to compare the performance of the pilot scrubber under a variety of operating conditions: (1) using (a) plain water, (b) an alkaline solution, and (c) an alkaline hypochlorite solution as scrubbing liquor, all at a gas flow rate of 280 cfm, (2) using different dosages of chlorine to the gas phase over the range 2 to 9 ppm at a gas flow rate of 280 ppm, and (3) changing gas rate from 280 to 317 cfm, a gas volume change that is probably too small to be the basis for any firm conclusions.

A total of 7 tests was conducted to cover these several conditions. Pertinent operating data are summarized in Table I. Dryer temperature ranged between 230 and 236°F for these tests and this uniformity in dryer temperature is reflected in a similar steadiness in offgas, scrubber entry, and scrubber exit temperatures. Fresh water was added at a rate ranging from 2.0 to 3.1 gpm for the several tests. This is equivalent to 1.1 to 1.7 lb fresh water/lb of dryer offgas and produced a gas temperature drop of 90-100°F in the scrubber. This is a greater fresh water rate (and spent water discharge) than would be used for a full scale scrubber unit but water utilization in a small pilot unit (because of wall losses and failure of the nozzles to develop their full spray pattern) is less efficient.

In all cases but one, 20% NaOH was added to the last wet stage at the rate of 0.75 gph to maintain a pH in all three tanks between 11 and 12. A pH in excess of 11 in the last wet stage that contacts the gas is not required for satisfactory operation of the scrubber but as many hours of steady operation are required to reach steady state conditions, economy in caustic usage was not attempted for the pilot tests.

The results of the gas chromatograph tests are summarized in Table I. Efficiency has been calculated for each compound

based on the up and downstream heights of the peaks which appeared after the same column travel time and for all compounds based on summations of peak heights up and downstream of the pilot scrubber. Also included in Table I are observations of odor quality and odor intensity.

Table I shows clearly that scrubbing with plain water (Run No. 1) produced only a modest removal of volatile compounds: and observations of odor at the scrubber discharge indicated that odor quality and intensity were not perceptibly different from the untreated effluent drawn directly from the dryer exhaust duct. The addition of caustic to the scrubber water (Run No. 2) effected a large reduction in volatile emissions by chromatographic measurement but did not significantly lower odor intensity or change odor quality.

Run No. 3 of Table I was the first in which chlorine was added upstream of the absorber. The effect was to increase the efficiency for peaks 2 and 3 but there was a decrease in removal efficiency for peak 1. Reviewing the entire display of results in Table I, the high recorded efficiency for peak No. 1 when using caustic alone appears to be an anomaly in the data.

The effect on odor of adding 1.9 ppm of chlorine to the dryer offgas was to produce a marked reduction of odor intensity whereas increasing the chlorine addition to 5.7 ppm (Run No. 4) produced an effluent which was almost odorless, with no hint of a chlorine or hypochlorite odor. Overall reduction of the sum of the three peaks for Run No. 4 was 95%, indicating a high level of collector efficiency by chemical measurement as well as by sensory evaluation. The plume was colorless at the point of emission, but a few exit duct diameters from the discharge nozzle, condensing water vapor produced a faint haze until the plume was more completely mixed with the outside air. As the ambient temperature was in the vicinity of 90°F, this occurred promptly.

A larger addition of chlorine (9.0 ppm) to the reactor section produced an equally good overall removal efficiency chemically (Run No. 5) but the absorber effluent had a distinct hypochlorite odor which was not considered acceptable.

For Runs No. 6 and 7, gas flow through the absorber was increased from 280 to 318 cfm. High (8.5 ppm) and moderate (4.7 ppm) additions of chlorine were made upstream to compare performance with lower air flow rates under similar conditions. When adding 8.5 ppm of chlorine, the unit produced the same high overall reduction in chemical content

(96%) but retained the hypochlorite odor; whereas at 4.7 ppm Cl_2 , the hypochlorite odor disappeared and only a very faint burnt odor remained. The high gas flow rate with 4.7 ppm Cl_2 appeared to be as effective as the lower gas flow rate with an equivalent chlorine addition.

It was noted that although the upstream heights of each of the peaks varied over a range very nearly equal to one order of magnitude for Runs 4 through 7, the downstream concentrations were almost unchanged. This behavior is characteristic of an absorption process in which the rate of mass transfer is highly concentration dependent, i.e., the mass transfer coefficient is proportional to the concentration of solute in the gas phase. Other chemicals that exhibit this same tendency include NO_2 , for which the outlet concentration is almost independent of inlet concentration but only dependent on contact in the absorption apparatus.⁶ For processes of this nature, it would be preferable to express the results in terms of transfer units but there are too many unknowns at present to make this approach feasible.

Figure 3 shows some typical flame ionization detector traces. These have been identified by run number, whether up or downstream samples, and by peak number. Figure 4 shows typical electron capture detector traces before and after additions of chlorine. Although well defined changes in the number of compounds present after the addition of chlorine can be produced and demonstrated under laboratory conditions, the appearance of these new compounds is not easy to detect under the less than ideal conditions of field operation. Nonetheless, there are clear indications of new compounds being produced in the gas phase.

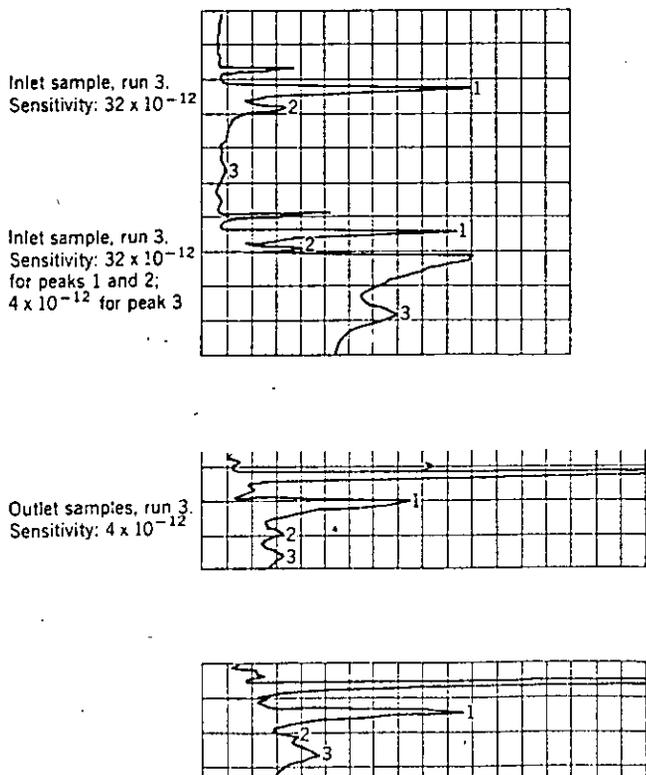
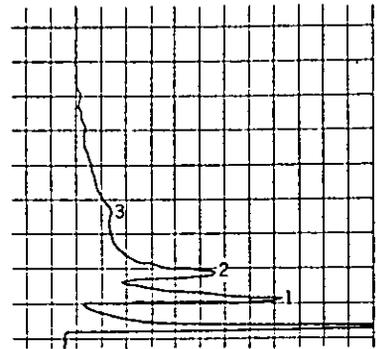
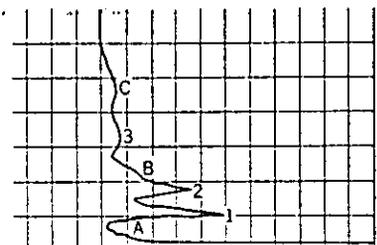


Figure 3. Typical flame ionization detector traces.

Grain drier offgas, run 4, before addition of chlorine. Sensitivity: 1×10^{-9}



Grain drier offgas, run 4, at entry to absorber after addition of chlorine. Sensitivity: 1×10^{-9}



Note number of new peaks and attenuation of the two prominent peaks in untreated sample, above. New peaks are labelled A, B & C

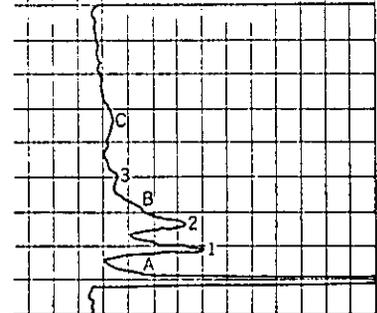


Figure 4. Typical electron capture traces.

Full Scale Reactor-Absorber

On the basis of the highly favorable pilot scale results conducted on a small portion of the grain dryer exhaust stream, a single full scale unit was installed at a distillery to handle the gas flow from two natural gas fired, direct heat rotary grain dryers. The dryers handle 60% distillers grain plus 40% by-products from an adjacent starch plant. The starch by-products include wet fiber, fed to the dryers directly, plus steep water converted to concentrated syrup in evaporators with the distillery's thin stillage. Each dryer discharges 14,000 cfm at 200°F and either may be operated alone, although it is usual to operate both together. The full-scale fiberglass reinforced polyester reactor-absorber is 56 ft long, 14 ft wide, and 9 ft high and requires a 60 hp exhaust blower to overcome the resistance of reactor-absorber, exterior piping, and stack (a pre-existing blower in each system overcomes the resistances of dryer, dried grain collector, and interior ductwork). Each wet stage is sprayed with 385 gpm of caustic kept to the correct alkalinity by an automatic pH controller. Liquid and gas flow counter-currently through the apparatus but cocurrently through each wet cell.

The full scale unit operates 7 days per week, 24 hours per day and already has been in service for over two years. It has performed exactly as the pilot tests predicted. Routine maintenance requires a 4 hr shutdown each week during which

time the scrubber is hosed to wash out accumulated grain particles and the entire system is flushed with sulfamic acid solution to remove precipitated alkaline carbonate salts (from CO₂ in the combustion gases) that may have deposited in nozzles and absorption packings. Operating costs are summarized in Table II.⁷ Two serious problems were encountered. (1) The first stage Neva-clog screens, fabricated of Monel metal, failed from the corrosive attack of chlorine and hypochlorite solution. Neva-clog screens fabricated from selected stainless steel alloys and titanium appear to be resistant and are a satisfactory replacement for Monel. (2) During the fuel shortage period of the winter of 1972-73, the natural gas supply was interrupted and the dryer burners were switched to No. 4 fuel oil. After 21 hr of oil burning, the inside of the unit was covered with a black waxy deposit and the final stage became plugged with this material to the point of total shutdown. It was apparent that the gas burners were unable to burn the fuel oil cleanly enough to prevent serious interference with the operation of the reactor-absorber and it was necessary to purchase a higher cost, non-interruptible gas service for the dryers. It is possible that burners designed specifically for distillate fuel oil burning would have performed satisfactorily in this service.

Discussion

Odorous emissions are associated with a number of widely employed food waste processing industries. These include, in addition to grain residues from brewing, distilling, and corn processing, the production of fish meal, poultry meal from offal and feathers, and rendering of slaughterhouse wastes. The last named processes frequently involve the use of putrid raw materials that possess substantial malodorous properties at the start and are degraded further during the several manufacturing steps, including dehydration in rotary direct-heat dryers. All of these industries produce odorous offgases containing dozens of poorly defined but foul-smelling compounds in the ppm and ppb concentration range that fall into several chemical classes known to contain malodorous substances, e.g., hydrogen sulfide, mercaptans, disulfides, aldehydes, and organic acids. Many of these industries, individually and through their trade associations, have investigated the several feasible methods of odor control for their particular problems⁹⁻¹¹ and each has concluded that charcoal is impractical because of short service life and gas incineration is too costly but that chemical scrubbing is a satisfactory method for reducing odors at an acceptable cost.

Applications of the techniques described here to spent grain drying, a final processing step for a number of important and widely dispersed industries, are of special significance because they demonstrate the beneficial uses of gas phase reactions as a conditioning step preceding absorption in chemically reactive solutions. These studies also point up the futility of attempt-

ing to solve these problems by gas phase reactions alone, as by injection of ozone, because these reactions are always incomplete in practical applications and a large excess of the injected gas phase reactant must be used. Ultimately this excess must be emitted to the atmosphere unchanged and will then behave as a pollutant in its own right. This makes it necessary to exercise extreme caution in the use of chemically active additives to stack effluent gases unless adequate means are provided for complete removal prior to emission to the atmosphere.

Applications of the reactor-absorber techniques and equipment to food waste processing industries, in addition to spent grain drying, have included rendering. Effectiveness has not been evaluated quantitatively in the manner of the grain dryers but neighborhood odor complaints have ceased since the system has been placed in operation and this is indicative that a substantial improvement has taken place. Initiation of gas phase reactions followed by absorption of the reaction products in chemically active solutions appears to be an air pollution control method that can be applied to a wide range of food waste processing industries that generate odorous gases and vapors and fine particulate contaminants in the untreated offgases.

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Table II. Weekly operating costs, full-scale reactor absorber.^a

Consumables	Cost per week
Water	\$200.00
Chlorine	40.00
Caustic	142.00
Sulfamic acid	24.00
Electricity	182.00
TOTAL	\$588.00

^a 7 day, around-the-clock, operation. Capacity, 28,000 cfm at 209°F.