FERTILIZER TECHNOLOGY

Countercurrent Versus Cocurrent Drying of Granulated Mixed Fertilizers

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An experimental continuous mixed fertilizer granulation unit was operated with both countercurrent and cocurrent drying. Comparisons were made of fume formation, chemical composition of the product, and fuel consumption; the countercurrent method gave more favorable results in each case.

Most mixed fertilizer granulation processes include a dryer, which is a direct-fired rotary tube equipped with lifting flights. Combustion gas enters either at the material feed end (cocurrent drying) or at the material discharge end (countercurrent drying). An objectionable fume is often vented to the atmosphere as part of the exhaust gases from either arrangement (*2*, *6*). The cocurrent dryer is more widely used than the countercurrent dryer (*3*), because it does not overheat the material when exposed to the hot inlet (throat) gases from the furnace. Overheating is undesirable because it can result in nitrogen loss from some of the materials as well as fume formation (*1*, *8*).

Previous investigations have considered various aspects of fertilizer drying (*1*, *4*, *5*). This paper reports the results of laboratory and pilot plant scale tests conducted to determine the causes of visible dryer exhaust fume and to compare cocurrent and countercurrent drying.

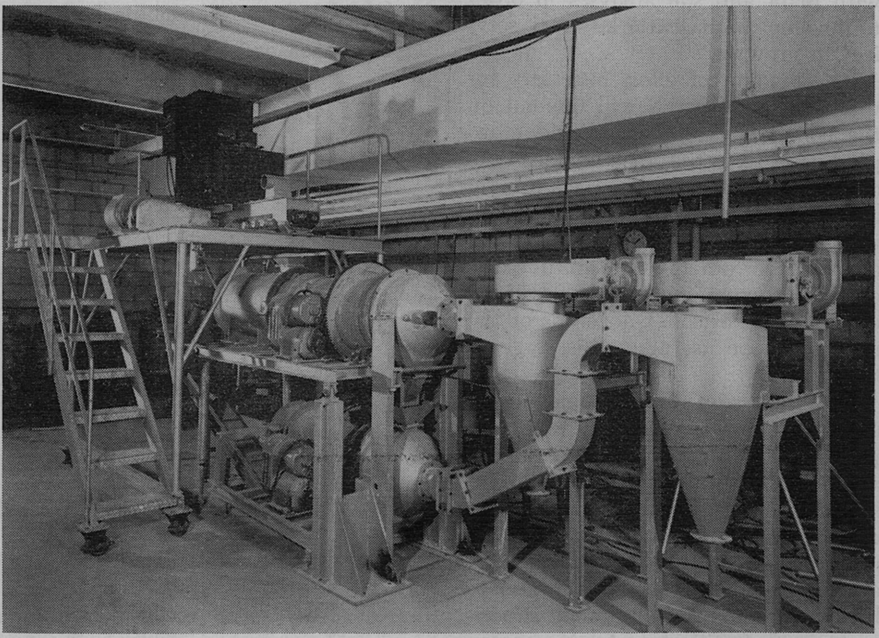

Figure 1. Experimental mixed fertilizer unit

Laboratory Studies

Laboratory equipment was used to determine the temperature of the initially visible fume evolution from various granulated mixed fertilizers. For each test, 50 grams of fertilizer were placed in a 200-ml. beaker which was partially submerged in a sand bath. A thermocouple, located at the bottom of the material and connected to a potentiometer, was used to determine the different temperatures. Heat was applied slowly from a gas burner, so that material temperatures above 275° F. increased at a rate of approximately 0.5° F. per minute. A glass rod suspended in the fume collected enough material on its surface for x-ray diffraction analyses.

The temperatures of the initially visible fume evolution for six granulated mixed fertilizer grades are as follows:

Grade	*Temp., °F.*
10–10–10	296
8–16–16	305
5–10–5	452
3–12–12	473
8–16–0	497
15–15–15	506

Shortly after the initial evolution of fume, its intensity became very heavy.

Results of x-ray diffraction analyses of the fume showed that its major constituent for all grades, except 8–16–0, was ammonium chloride. Ammonium fluosilicate and an unidentified phase were present to a smaller extent; however, they were the major constituents of the fume from the 8–16–0 grade.

The fact that fume evolution began in the 300° to 500° F. range, and that its intensity was great even with the small fertilizer samples, suggested that most of the fume from plant scale fertilizer dryers could be evolved from a relatively small proportion of the fertilizer that was overheated, even though the bulk of the material remained below this temperature range. Possible circumstances that would permit this are: very small particles of fertilizer suspended in the inlet combustion gas, which may be at 1200° F. or higher, fertilizer sticking to the dryer feed chute or flights, and fertilizer spilling into the furnace. Consequently, pilot plant tests were carried out to determine the influence of these factors on fume evolution.

Pilot Plant Studies

Pilot plant studies were carried out with a small scale fertilizer processing unit (Figure 1), patterned after the Davison Trenton process (*7*). Preblended dry raw materials and recycle materials are fed continuously to the double paddle shaft pug mixer by a gravimetric feeder. The liquids are metered continuously to the pug mixer through variable area float-type flow meters. The hot, damp granulated material feeds by gravity from the pug mixer to the direct-fired rotary dryer tube, 18 × 54 inches long, which can be operated either cocurrent, as shown, or countercurrent by simply rearranging the feed and discharge chutes, reversing the tube, and relocating the upper operations platform, which is portable. From the dryer tube the hot dried material discharges by gravity into a conventional rotary cooler and from there it is fed onto a product classifying screen. The production rate is from 50 to 200 pounds per hour of classified product.

Causes of Fume. With the cocurrent arrangement, a thick paste of wet 6–8–4 grade fertilizer was plastered on the surfaces of the feed chute, feed flights, and retention ring. Temperatures of the throat region and of material surfaces exposed to hot throat gases were measured with thermocouples connected to a recorder. Gas sampling apparatus arranged as shown in Figure 2 was used to determine and photograph variations in exhaust fume intensity which resulted from varying throat and material temperatures. The exhaust fume became barely visible when the material temperature reached 275° F. and the throat temperature was 290° F. As these temperatures were increased, fume intensity also increased, and at 450° F. material temperature and 500° F. throat temperature, a dense cloud of exhaust fume evolved.

Tests to demonstrate the influence of small particles in the dryer feed material on exhaust fume were made using both cocurrent and countercurrent drying. Previously manufactured 6–8–4 fertilizer, classified to 100% −6 +20-mesh U. S. standard sieves, was the control material. The test material was the same except that 20% of it had been ground through a 60-mesh U. S. standard sieve. For each test run the material, wetted to approximately 8% moisture with cold water, was fed continuously to the dryer at a 200 pound per hour rate. The feed chute, flights, and other parts exposed to cocurrent throat temperatures were cleaned before each operation to avoid formation of fume from decomposition of materials clinging there. The throat temperature was varied from 300° to 1200° F., while the temperature of the material leaving the dryer was controlled to 190° to 210° F.; this was accomplished by adjusting the material retention time. The influence of throat temperatures on the coarse and on the dusty materials for both cocurrent and countercurrent drying was observed and photographed using the apparatus shown in Figure 2. To simulate actual production conditions, the procedure was repeated while granulating 6–8–4 from raw materials.

Table I. Formulations

	Ingredient		
		Lb./Ton	
	Analysis, %	*6–8–4*	*12–12–12*
Normal superphosphate	20.4 available P_2O_5	784	562
Triple superphosphate	45.7 available P_2O_5		274
Nitrogen solution	37.0 K_2O	341	541
Ammonium sulfate	20.0 K_2O		249
Potassium chloride	58.5 K_2O	138	407
Sulfuric acid	60° Bé.	62	129
Filler		782	
Total		2107	2162
Evaporation		107	162
Product		2000	2000
Product moisture, %		2.5	1.0
Ammoniation rate, lb. NH_3/unit available P_2O_5			
Normal superphosphate		5.0	6.0
Triple superphosphate			3.3

Basis: $\frac{H_2SO_4}{2.88}$ = lb. NH_3 reacted

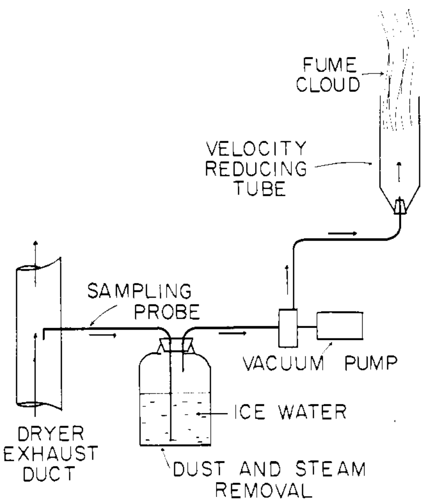

Figure 2. Apparatus for viewing fume intensity

Dusts from previously manufactured and from freshly manufactured 6–8–4 grade material entering the cocurrent dryer caused a barely visible exhaust fume at 350° F. throat temperature. The exhaust fume initially became moderate at 375° to 425° F. for the previously manufactured 6–8–4 grade and at 400° to 450° F. for the freshly manufactured 6–8–4 grade material. Reasons for this small difference were not investigated. Higher throat temperatures caused increased fume intensities.

With countercurrent drying, intensity of the fume from both the freshly and the previously manufactured material was greatly reduced at corresponding throat temperatures, being barely visible at 700° F. and moderate at 1000° F. Eddy currents into the furnace, which caused dryer exhaust fume, were eliminated by changes in the furnace design. After these changes, the 6–8–4 grade was granulated from raw materials without visible exhaust fume, even at throat temperatures of 1200° F.

Cocurrent *vs.* Countercurrent Drying. The pilot plant granulation unit was used for tests comparing cocurrent and countercurrent drying while producing 6–8–4 and 12–12–12 grades with formulas shown in Table I. Five cocurrent and six countercurrent runs were made to compare fume evolution, nitrogen losses, fuel usages, and general operating performance. A gas sampling assembly shown in Figure 3 was used to determine fume evolution. The sampled dusts settled out in a 3-gallon borosilicate glass jar which also permitted visual observation of fume intensity. Very fine dusts and fume were collected in 43 × 123 mm. cellulose thimbles. Smith-Greenberg impingement apparatus using dilute sulfuric acid solution collected the ammonia. Nitrogen losses were determined from chemical analyses of material entering and leaving the dryer. A bellows-type dry gas meter was used to measure propane gas fuel consumption. A start-up and lining-out operation preceded each test run to level out granulation, retention in the dryer, exhaust gas flow rate, and temperature of the material leaving the dryer. By controlling these variables to predetermined levels, the influence of type of drying on the remaining variables during the drying operation was determined. For each test, a run lasted precisely one hour, the dryer exhaust gas flow was approximately 60 cubic feet per minute (N.T.P.), and the production rate was 100 pounds per hour. The recycle rate was 50 pounds per hour for the 6–8–4 grade and 80 pounds per hour for the 12–12–12 grade. Dryer feed and discharge samples were taken separately in triplicate at 10-minute intervals. Each exhaust gas sample was taken continuously during the 1-hour test run.

Figure 4 shows the rapidly increasing

concentration of fume in the exhaust gases as the temperature of the material leaving the dryer increased. Averages from six test runs using both types of drying with the 6-8-4 grade showed that fume concentration at material temperatures of 275° to 290° F. was eight times greater than at the normal temperatures at which the material left the dryer (200° F.), and at 340° F. the concentration was 25 times greater than at 200° F. Fume with countercurrent drying was less than with cocurrent drying. With material leaving the dryer at 200° to 220° F., countercurrent fume for the 6-8-4 and 12-12-12 grades was 50% of the cocurrent fume concentration. The concentration at which the fume was initially barely visible was approximately 0.06 to 0.08 grain per cubic foot (N.T.P.).

In these tests the borosilicate glass jar was used for visually studying the intensity of the fume instead of the open discharge apparatus shown in Figure 2. With the borosilicate glass jar, the fume did not become visible until it had reached much greater intensities than were necessary with the open discharge apparatus. Consequently it was not possible to compare visible intensities from the two tests. When the apparatus of Figure 2 was used, visible fume was observed at lower product and throat temperatures than with the borosilicate glass jar method.

The nitrogen losses in the drying operations were calculated from the initial and final ratios of nitrogen to total phosphorus pentoxide as described by Bridger and Burzlaff (*7*). Figure 5 compares average nitrogen losses for both types of drying with the 6-8-4 and 12-12-12 grades at various product temperatures (material leaving the dryer). The retention time for the 6-8-4 grade with both types of drying was 25 minutes for the 200° F. product temperature tests, 12 minutes for the 275° to 290° F. tests, and 8 minutes for the 340° F. tests. That with the 12-12-12 grade was 11 minutes for the 200° F. tests and 13 minutes for the 220° F. tests for both types of drying. The data were not sufficient to permit precise interpretation of differences in nitrogen loss at the various temperatures and losses were considered to be substantially equal for the two types of drying with less than 2% of nitrogen loss in all cases, when the material leaving the dryer was at 220°F. or less.

The fuel requirements for both types of drying are:

	Thousands of B.t.u./ Ton of Dryer Throughput	
	6-8-4	*12-12-12*
Cocurrent drying	800	570
Countercurrent drying	450	310

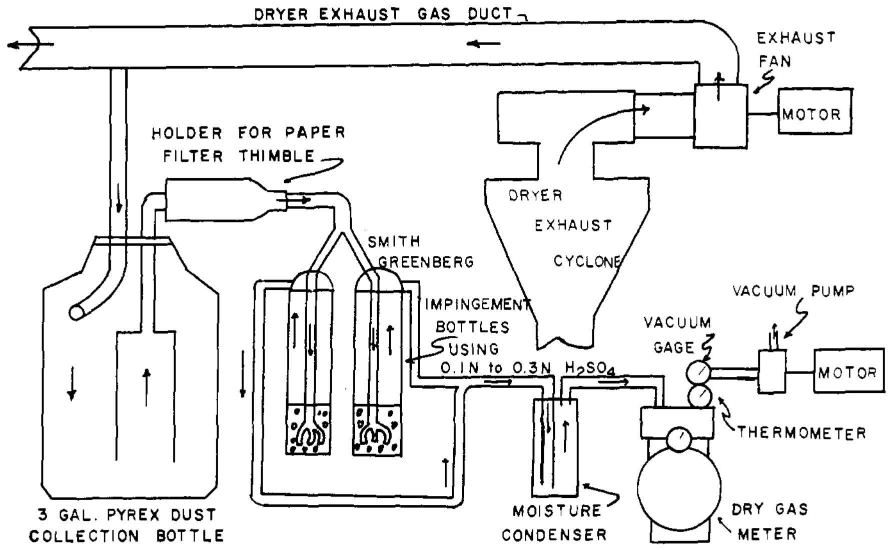

Figure 3. Dryer exhaust gas sampling apparatus

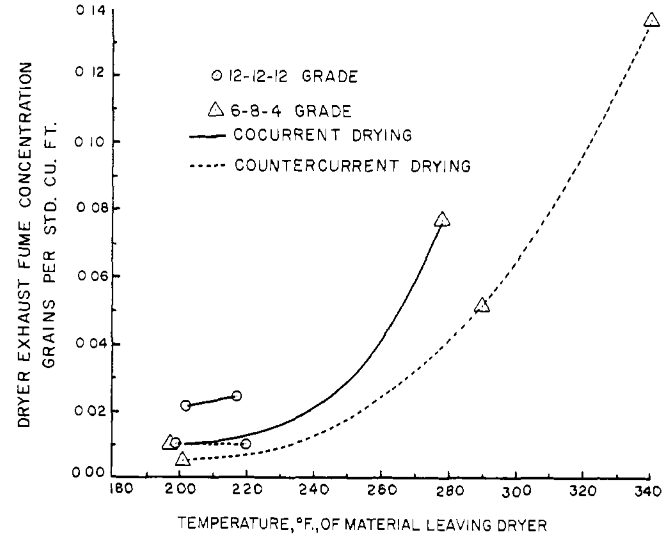

Figure 4. Effect of material temperature on dryer exhaust fume concentration

For each type of drying of the 6-8-4 grade, the fuel consumption was averaged as B.t.u. per ton of material throughput, during two runs made at 200° F. product temperature and one run made at 275° to 290° F. Cocurrent drying required approximately 44% more fuel than countercurrent. Moisture losses for the two approaches were approximately equal. For the 12-12-12 grade, tests included both the 200° and the 220° F. product temperature. Cocurrent drying required 46% more fuel than countercurrent drying. The large radiation losses from the small scale equipment, of course, exaggerated the fuel savings of the countercurrent approach. It is believed that countercurrent drying would offer approximately 20 to 25% savings in plant operation.

The difference in fuel requirements was reflected in throat temperatures and in exhaust gas temperatures. Figure 6 compares throat temperatures for the various tests. Countercurrent drying required 300° to 500° F. less throat temperature than cocurrent to achieve the same product temperatures. The exhaust gas temperatures were also significantly lower for countercurrent drying as shown in the following tabulated averages from four cocurrent and four countercurrent tests conducted while drying the material at 200° to 220° F. leaving the dryer:

Exhaust Gas Temperatures for Co- and Countercurrent Tests

	Material Temperature, °F.		*Exhaust Gas Temp., °F.*	*Retention Time, Minutes*
	Entering dryer	*Leaving dryer*		
Cocurrent	156	206	217	16
Countercurrent	146	207	163	16

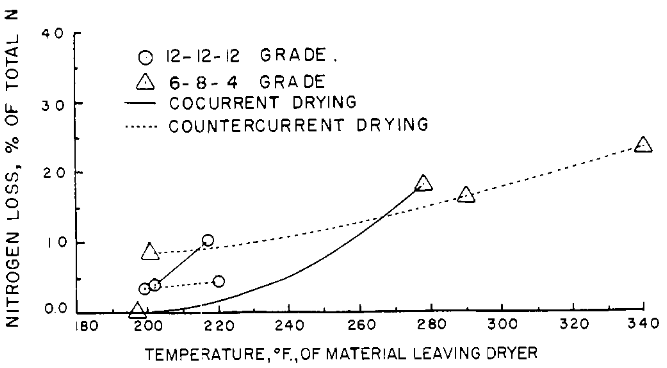

Figure 5. Nitrogen losses from material at various material temperatures

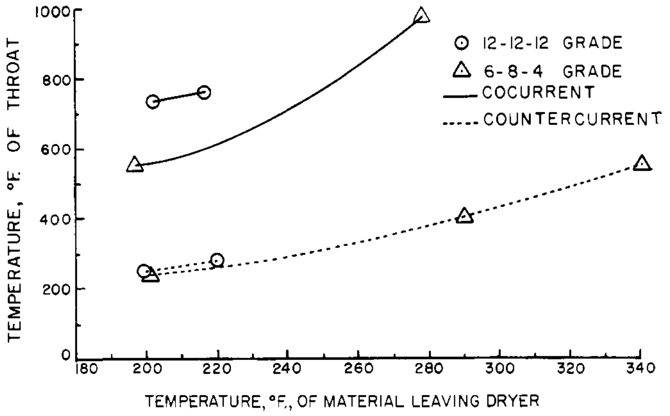

Figure 6. Throat temperatures required for various material temperatures

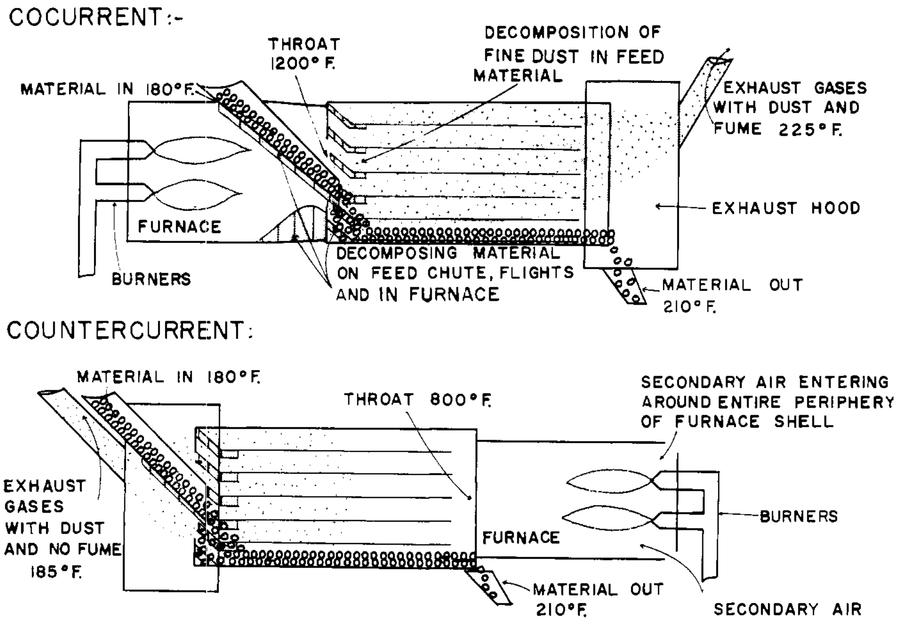

Figure 7. Major sources of fume and their elimination using countercurrent drying

Operationally, countercurrent drying in the pilot plant presented three difficulties, all of which could be eliminated by simple design changes: Eddy currents of air carried fertilizer dust into the furnace. The decomposition of this dust could cause serious fume evolution. More precise fuel usage control was required than with cocurrent drying. A relatively small change in the fuel usage rate resulted in large temperature changes in the material leaving the countercurrent dryer. With care, the operators were able to manually control the material temperature to within 5° F. limits. However, properly regulated automatic control would probably be essential to good plant operation. Dust collected in the countercurrent dryer exhaust hood in sufficient amounts to spill onto the operating floor in a continuous stream. This might be caused by exhaust hood (breeching) design which permitted exhaust gas velocity changes to cause air-borne dusts to drop out.

The use of countercurrent drying with mixed fertilizers has been reported to lead to dust build-up in the dryer exhaust duct and the cyclone dust collector, because the dust has a higher moisture content than with cocurrent drying. This difficulty was not encountered in the present study, but should be taken into account in any proposed plant installation.

A diagrammatic representation of the sources of fume formation in a cocurrent dryer and their elimination by use of a countercurrent dryer are shown in Figure 7. With cocurrent drying, a small proportion of the fertilizer is subjected to decomposition temperatures by adhesion to the feed chute and flights, as fine particles in the inlet air stream, and by spillage into the furnace. With countercurrent drying the fertilizer which adheres to the feed chute and flights, and that caught as fine particles by the air stream, are in a low temperature zone. Furthermore, in the hot zone of the countercurrent dryer, air temperatures are several hundred degrees lower than in the cocurrent dryer.

Conclusions

Visible fume was evolved from granulated mixed fertilizers at temperatures above the 275° to 506° F. range, depending on their composition. Hot dryer throat gases caused fume by decomposing fertilizer materials. The sources of fume in a cocurrent dryer were small feed particles and materials adhering to the feed chute and feed flights. Countercurrent dryer fume was caused primarily by eddy currents carrying fertilizer dust into the furnace. Countercurrent drying caused less fume, required less fuel, but demanded more precise fuel usage control. Nitrogen losses from both were approximately equal and were less than 2% of the total nitrogen at product temperatures of 200° F. Cocurrent drying throat temperatures required were 300° to 400° F. higher than those for countercurrent drying. Design of the countercurrent dryer was important for fume elimination.

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