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Examining the Use of Additives to Control Grain Dust

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Fire and Explosion Research Report

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Notes from Oil Addition Document

Grain	APCD Status	Control Level	Dust Readings (g/m^3) Gallery	Drop	Bin	Table
Corn	On	None	0.01	0.30	3.0	8
Corn	Off	None	1.3	0.41	3.2	8
Corn	On	.17% H_2O	0.01	0.19	2.0	9
Corn	On	.18% H_2O	.006	0.11	2.7	9
Corn	On	.3% H_2O	.017	.15	2.4	9
Corn	Off	.18% H_2O	0.21	0.18	1.9	9
Corn	Off	.3% H_2O	.26	0.13	1.9	9
Corn	Off	.33% H_2O	.12	0.09	2.0	9
Corn	On	.03% SO	.004	.007	.975	11
Corn	On	.06% SO	.006	.004	.585	11
Corn	On	.10% SO	.003	.003	.921	11
Corn	Off	.03% SO	.082	.008 ~~.008~~	.711	11
Corn	Off	.06% SO	.060	.007 ~~.007~~	.585	11
Corn	Off	.10% SO	.075	.003	.835	11
Corn	On	.02% MO	.002	.011	.684	13
Corn	Off	.02% MO	.043	.01	.981	13
Corn	Off	.04% MO	.056	.005	.432	13
Corn	Off	.08% MO	.024	.01	.391	13

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p 2

Grain	APCD Status	Control Level	Dust readings (g/M^3) Gallery	Drop	Bin	Table
Wheat	On	None	0.007	0.10	2.2	19
	Off	None	0.10	0.073	1.8	17
	off	.02%50	0.36	0.40	1.2	26
	on	0.03%50	0.005	0.006	1.1	20
	off	0.03%50	0.032	0.005	0.28	20
	off	0.06%50	0.032	0.003	0.23	20
Soybeans	On	None	0.017	0.15	5.6	22
	Off	None	1.1	0.014	4.3	22
	On	0.03%50	0.005	0.002	0.66	23
	Off	0.03%50	0.062	0.0665	0.75	23
	Off	0.06%50	0.079	0.002	0.47	23

EXAMINING THE USE OF ADDITIVES TO CONTROL GRAIN DUST

FINAL REPORT

Submitted to
Fire and Explosion Research Council
National Grain and Feed Association
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by

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EXECUTIVE SUMMARY

A series of tests were conducted to study the effectiveness of water, deodorized soybean oil, and mineral oil as dust controlling additives in large scale grain handling operations of corn, wheat, and soybeans. All additives were sprayed on grain as it was transferred from one storage bin to another. The flow rates of the additives were regulated through a control valve by compressed nitrogen. It was found that the additives were best applied by continuously spraying both the top and the underside of the grain stream, at the first belt transfer point after the grain left the storage bin. In extremely cold weather, it was necessary to heat the additives to achieve efficient spraying.

Between 0.03 and 0.10% by weight of soybean oil applied to all three grains and 0.02 and 0.08% by weight of mineral oil applied to corn were effective in reducing dust emissions. The ability of mineral oil to control dust in corn was not reduced after a three months' storage of the treated grain. The amount of oil needed for optimum effectiveness ranged from 0.02 to 0.05%. Adding 0.17 to 0.30% water by weight to corn was temporarily effective in controlling dust emissions. The average weight loss of the grain stream due to dust dispersion was approximately 0.14% each time a grain was handled. When an additive was present, this loss was reduced to 0.035% or less. An application level of 0.3% water to corn reduced the gallery floor dust concentration by at least 80%, and an application rate of 0.03% soybean or mineral oil at the same location reduced the dust concentration by more than 90%.

Minimum modifications of the existing facilities were needed to undertake these trials, and under normal conditions the operation of an additive spraying unit should be entirely automatic and require only periodic inspection to ensure proper mechanical functioning and flow rates.

I. INTRODUCTION

Whenever grain is handled or processed, dust is generated. This situation produces the potential for a dust explosion (Aldis and Lai, 1979) and causes the deterioration of air quality in and near handling and processing facilities (Rankin et al., 1979). These hazards and the resulting financial losses are of major concern to the grain industry.

Dust collection is a means of checking grain dust emission by controlling the ventilation in a specifically confined space wherever grain is handled. However, in many existing grain elevators, grain is not loaded or unloaded in a confined or controlled space. Furthermore, ventilation dust control may sometimes allow explosible mixtures to occur under adverse conditions (Bartknecht, 1981). In addition, the energy required to employ ventilation controls may exceed the energy required to move the grain.

Although separating dust from ventilated dust-laden air by bag filters, electronic precipitators, and cyclone collectors has been proven effective (Brown and Reed, 1926; Martin and Stephens, 1977), the costs of installation, operation, and maintenance of ventilation equipment are high. Capital costs for installation have been estimated at between $3 and $5 per cubic feet per minute (cfm) of desired air control, which amounts to between $250,000 and $1,000,000, depending on the size of the grain elevator. Annual operating costs add an additional 20% to the capital investment cost (Maness, 1978). Thus, this method of dust control is extremely costly.

The idea of applying liquid sprays over grain to control dust generation is not new. As early as 1908, water and oil were used to suppress the formation of dust on highways (Hubbard, 1908). Moen and Dalquist (1952) were granted a patent for the batch process of applying an oil-water emulsion of 0.02-0.08% to grain, and agitating the grain as it was applied. Cocke et al. (1978) applied mineral oil to wheat grain in a small batch rotating cylinder and found that the application of as little as 0.07% oil reduced dust levels by more than 92%. The additives also reduced dust levels in shelled corn and soybeans.

Pilot-scale studies conducted at the U.S. Grain Marketing Research Laboratory (Lai, et al., 1979; Lai et al., 1981) also tested the effectiveness of liquid additives in controlling grain dust. Results showed that when corn and wheat were treated with 0.02 and 0.06% soybean or mineral oil, the dust emitted during handling was drastically reduced. Laboratory analyses of the treated wheat revealed no adverse effect on milling or baking quality of the flour caused by the application of oil.

This study sought to determine those application levels at which oil and water were effective in controlling airborne dust in an operating grain elevator. Edible oil (deodorized soybean oil), mineral oil, and water were applied to corn, wheat, and soybeans during conventional handling in a commercial grain elevator (The Ohio Farmers' Grain and Supply Assoc., P. O. Drawer M., Fostoria, OH 44830).

II. MATERIALS AND METHODS

A. Test Facilities

1. Grain Handling System

Figure 1 is a diagram of the grain handling system at The Ohio Farmers' Grain Elevator in Fostoria, Ohio, where the tests were conducted. Grain was moved from a storage bin on a 36-inch wide enclosed conveyor belt running at 400 ft/min. At site A the first belt transferred grain onto a second similar belt (A, Fig. 1). From site A the grain was moved 100 feet to site B, the end of the second belt (B, Fig. 1). Grain was discharged from the belt into 25 feet of spouting where it fell by gravity and entered the boot on the descending side of the bucket elevator. It was then elevated 240 feet at a flow rate of 10,000 bu/hr and discharged into spouting. The grain fell through the spouting into a 2500-bushel garner and then into a 2500-bushel scale. From the scale, the grain entered a distributor that directed the flow to site C, the beginning of the gallery belt (C, Fig. 1). The vertical distance of the fall of grain from the head of the leg to the gallery belt was 100 feet. Grain was then moved 85 feet from site C to site D, the location of the first tripper, where it was transferred to the house belt (D, Fig. 1). The time required for grain to move from site A to sites B, C, and D was 15, 40, and 50 sec., respectively. Grain was continuously moved on the house belt to site E, the location of the second tripper. The second tripper was stationed at the entrance to one of three similar test bins (E, Fig. 1). Each test bin was 114 feet deep and had a capacity of 9,000 bushels. Distances from site D to the three bin sites were 25, 310, and 320 feet. Total lapsed times for grain to move from site A to each of the three bin sites were 40, 70, and 71 seconds, respectively.

2. In House Dust Control Systems

The grain elevator was equipped with several dust control systems employing bag house filters to separate dust from air. After the dust was separated from the air, it was discharged through ducts into a dust bin. The lower system collected dust through ducts located at the end of the second enclosed belt and in the boot of the bucket elevator (B, Fig. 1). The upper system collected dust from the head of the bucket elevator and the garner (C, Fig. 1). The dust control system for the gallery collected dust from hoods over the beginning of the gallery belt and the first tripper (C & D, Fig. 1). The system in the headhouse collected dust from the hoods over the beginning of the house belt and second tripper (D & E, Fig. 1).

3. Additive Spraying System.

Liquid was applied by nozzles from a pressurized, heated 60-gallon tank; its flow rate was controlled by a pressure regulator (Fig. 2). Nozzles were selected from a set of floodjet tips Nos. TK 1.5, TK 2, TK 2.5, TK 3, TK 5, TK 7.5, TK 10, TK 15, and TK 20 (Spray System Co., Wheaton, IL 60187) ranging in delivery capacity from 0.15 to 4.0 gal/min. The different size tips were used to accommodate the wide range in application rate of additives. The nozzle TK 2 was selected specifically because it produced a uniform coverage at low spraying heights and pressures, and it provided an adjustable spray angle. A cylinder of compressed nitrogen served as a pressure source in order to avoid the possible oxidation of soybean oil by compressed air. However, compressed air would have been adequate for practical purposes since the application time was kept relatively short. The pressurized tank was wrapped in insulation and provided with an electric immersion heater (0.5 kW) in order to preserve the fluidity of the oil in the freezing temperatures anticipated during the winter experiment. A thermometer was installed in the line leading to the nozzles. All plumbing in the spraying system was ½-inch in diameter.

4. Test Sites

a. Dust collection sites

The dust discharge duct at each of the sites at B, C, between C and D, and between D and E (Fig. 1) was bypassed so that the dust could be collected in bags.

b. Additive application site

At site A (Fig. 1) panels were removed from the conveyor enclosures so that two wide angle flat spray nozzles (TK 2) could be installed to spray liquid on the moving grain. One nozzle sprayed the top surface of grain near the end of the first belt; the second sprayed the opposite surface of grain falling vertically from the first belt to the second belt (A, Fig. 1).

c. First grain and dust sampling site

At site B (Fig. 1) there was an inspection door about 10 feet from the end of the enclosed belt through which samples could be scooped from the moving grain. Midway between the doorway and the end of the belt there was a 12-inch square inspection hole that provided an access for monitoring dust emissions. Airborne dust samples were collected by a Hi-Vol air sampler that sucked air from the inspection opening. Dust was collected on an 8- by 10-inch type A fiberglass filter mounted face down directly over the opening. The Hi-Vol air sampler at site B sampled dust concentrations inside the enclosed belt housing. There was a dust control duct about 4 feet from the opening and the grain surface was about 18 inches below the opening.

d. Second grain and dust sampling site

Site C (Fig. 1) provided a second location to scoop samples from the moving grain. In addition to grain sampling, a second Hi-Vol air sampler was placed near the trolley belt to monitor dust emissions. This sampler was mounted three feet above the floor on a stand with the 8- by 10-inch filter facing up. In contrast to the location of measurements at site B, site C was in the open area about 3 feet from the belt and about 6 feet from the point where grain was received onto the belt.

e. Test bin sites

Each test bin, site E (Fig. 1), had two bin openings. One opening was used by the tripper to deliver grain to the bin. The second opening provided access for the equipment monitoring the dust emissions inside the bin. A Hi-Vol air sampler was used to collect airborne dust samples from inside a test bin 18 inches from the top of the bin. The filter holder inside the bin was connected to the Hi-Vol motor outside the bin by a 10-foot long, 2-inch diameter pipe. The airflow gauge was calibrated in the laboratory with the calibration orifices on the end of the extension pipe.

Dust cloud opacity inside the bin was measured with a light-beam system developed at the U.S. Grain Marketing Research Laboratory (Lee et al., 1981). Two light-beams were suspended by aircraft cables at distances of 5 and 15 feet from the roof of the bin. The top lightbeam was about 1.5 feet underneath the Hi-Vol sampler.

B. Test Procedures

A test sequence included two control lots of grain without additives, one with the dust control system on, and one with the dust control system off. High, medium, and low levels of additives were tested with the dust control system off. At least one test with each additive was run with the dust control system on to obtain data on the difference in amount of dust collected by the in-house dust control system.

1. Grain Lots

Corn, wheat, and soybeans that had been received into storage in the summer and fall of 1980 were selected for the study. The yellow dent corn was from the 1980 fall harvest in Ohio. It had a moisture content ranging between 14.5 and 15.5% and a BCFM content ranging between 1 and 11%. Moisture content ranged between 11.4 and 12.6% for wheat and between 11.1 and 11.7% for soybeans.

2. Additives

Water, deodorized soybean oil, and mineral oil were selected as dust control additives. Carnation mineral oil, which is not subject to either hydrolytic or oxidative rancidity, was obtained from Witco Chemical Corp. (Petrolia, PA). Deodorized soybean oil was obtained from Archer Daniels Midland (ADM) (Decatur, IL). All three additives were applied to corn. Only soybean oil was applied to soybeans and wheat.

3. Application Techniques

In existing grain elevators, the dust control zones are located at transfer points. Typical locations are bin exits, belt-to-belt transfers, bucket elevator boots, etc. These transfer points are dusty primarily because when grain passes through, air movements cause particulate matter to separate from the bulk material. More fine particles are released at each subsequent transfer. For this reason, it is important to introduce the additive close to or at the origin of grain movement. Moreover, agitation of grain at a transfer point effectively mixes the grain and the additive, a process which continues through each transfer. In the experimental arrangement, a single spray site was selected to provide the ease of access and to vary the distance between grain bin exits. Nozzles were located at the end of the belt coming from storage bins, a point which made several grain test lots available for treatment. After treatment each grain was handled almost identically except for the final distance to receiving bins.

At a flow rate of 10,000 bu/hr, the depth of the grain on a 36-inch wide belt was about 6 inches at the center of the belt. One nozzle sprayed additive on the top surface of the grain (Fig. 3). Four feet downstream, the grain dropped to another transfer belt and a second nozzle sprayed the underside of the grain stream as it fell. Thus, the grain stream was sprayed from both top and bottom. Some immediate agitation and mixing occurred when the grain stream dropped onto the second belt. Although oil droplets were seen to bounce off the grain stream and adhere to the belt, we did not observe any accumulation of oil on the enclosed conveyor system.

C. Sample Analysis Procedure

1. Grain Samples

A quart grain sample was collected near the end of a test at site B (Fig. 1). These samples were placed in quart glass canning jars for analysis at the U.S. Grain Marketing Research Laboratory after each test. At the laboratory, the fine material content of these samples were measured after sieving for 30 strokes on a Dean Gamet shaker. A 12/64-inch round hole sieve was used for corn and soybeans and a 0.064 x 3/8-inch oblong hole sieve was used for wheat. These samples were then shipped to a U.S. Board of Appeals office for determination of the grade.

Approximately 2 pints of grain sample were scooped from the belt at the beginning, middle and end of grain flow at site C (Fig. 1). Immediately after each sample was collected, the moisture content was measured with a Motomco moisture meter. Additional 2 cubic inch (33 ml) samples were collected at site C for an immediate drop test dustiness analysis using a HIAC particle counter (High Accuracy Particle Counter Co., Menlo Park, CA).

The HIAC drop test analysis involved the creation of a dust cloud by causing dusty material to fall through air and hit a surface. If two materials which differ in dustiness are handled in an identical manner, the two resulting dust clouds will differ with respect to number and size of particles. Should there be no difference in number or size of particles in the dust cloud, the two materials are considered equally dusty. In the drop test, a 2 cubic inch volume (33 ml) of grain was dropped 20 inches (50 cm) and reached a velocity of 600 ft/min (304 cm/sec) at the point of impact. The dust cloud was confined inside a 1.6-inch (4.1 cm) diameter column where it was sampled. The HIAC particle counter computed the number of particles that fell within a calibrated size range, and from the number and size of dust particles measured, the particle size distribution and concentration are calculated.

The sampling for the drop test started at the beginning of grain flow and proceeded at 2-minute intervals. Dust concentrations from the 7 or 8 drop test measurements were averaged to obtain a single value for each test.

The drop test provided a measurement of dustiness dependent only on the grain and independent of the grain handling facility. For example, if fugitive dust from grain handled outside a given test environment was introduced into a test environment, the test monitoring sites would measure the fugitive dust plus the dust generated during the test. Only the dust originating from grain samples was detected by the drop test, and fugitive dust from grain handled outside the test environment was prevented from interfering in the total counts.

2. Dust Samples

a. Tailing dust

For tests in which the dust control system was on, dust was collected in the basement, gallery, garner, and D house dust control system outlets, put into 50-pound bags, and weighed. The weight of the dust collected from those locations was a measure of the dustiness of the grain during handling. Approximately 7 ounces (200 gms) of the dust from each dust control system was placed in a plastic bag for later analysis of particle size distribution at the laboratory. The coarse particle size analysis was determined after 10 minutes of sieving on a Fisher-Wheeler sieve shaker, using a set of U.S. standard No. 18-, 35-, 60-, and 120-mesh sieves. The dust that passed through the 120-mesh sieve was further sized using a sedimentation method with MSA equipment (Mine Safety Appliance, Pittsburgh, PA 15208).

b. Hi-Vol sampler dust

Whenever the quantity of dust on an 8- by 10-inch Hi-Vol filter exceeded 10 grams, the dust layer was removed for partial size analysis using a sedimentation method with MSA equipment. The sedimentation analyses expressed results in terms of the geometric median particle size and the geometric standard deviation, the two parameters of the log-normal distribution function (see e.g. Stockham, 1977). The coefficient of determination,

r^2, represented the degree of log-normality of the particle size distribution and a value of 1.0 for r^2 represented a perfect log-normal distribution.

3. Calibration of Instruments

a. Drop test HIAC particle counter

Air was drawn from the dust cloud into a HIAC model D-5-150 sensor at 78 ml/min and particles were counted and sized as they cast a shadow on the photodetector (Fig. 4). Constant airflow was maintained by a gear driven syringe pump operated by a syncronized motor. At the vena contractor of the nozzle, a collimated light source was directed through a window on one side onto a photodetector behind a window on the opposite side. The area of the particle divided by the area of the window was proportional to the light that was blocked out. As the particles passed through, a momentary change in signal from the photodetector occurred which equalled

$$E_p = \frac{A_p}{A_w} E_b \qquad (1)$$

where

E_p = pulse amplitude from photodetector

E_b = base output from photodetector

A_p = projected area of the particle

A_w = area of the window

For a spherical particle, the above equation became

$$E_p = \frac{0.7854d^2}{S^2} E_b \qquad (2)$$

where

S = side of square window

d = diameter of the spherical particle

b. Hi-Vol sampler

Before the additive tests began, each air sampler calibration was checked in the USGMRL laboratory. Using a Bendix 3-1155-21 orifice-type calibration assembly and a differential manometer, the pressure-type airflow gauge was set to read 29.0 cubic feet per min at a manometer reading of 2.90 inches of water. This setting was taken from the calibration data supplied by the manufacturer. A Variac transformer was used to control the motor speed. The calibration setting was confirmed at two motor speeds: one was with a 5-hole orifice plate to simulate a dirty filter, and the other was without an orifice plate to simulate a clean filter. After tests in Ohio were completed, the air samplers were rechecked and it was confirmed that their calibrations had not changed.

c. LED-PT probe

The LED-PT probe was calibrated with neutral-density filters inserted into the light beam. This method of calibration made concentration measurements relatively independent of the particular LED-PT pair chosen. The light transmitted by the neutral density filters had been previously emitted by the LED. It was found that the variation of light transmission was a linear function of voltage drop across the PT ($r^2 = 0.96$ with 5 degrees of freedom). Thus, the voltage measurements could be used directly to obtain the ratio of light attenuation at any given time to light attenuation at the beginning of settling.

d. Additive spray nozzles

Calibration of the amount of oil and water added to the grain was conducted before each test. Two nozzles were removed from the installation and placed in a container to collect the liquid. At a preset liquid pressure, the liquid was allowed to flow for one minute. The pressure and the amount of liquid collected were recorded and checked with readings from the volumetric flow recorder. The liquid pressures measured were 10, 20, 30, and 40 psi. All tests were conducted in duplicate. The following correlation equation was assumed:

$$p = aw^b \quad (3)$$

where

p = liquid pressure

w = liquid capacity in gal/min

a,b= constants correlation

The correlation coefficient was significant at 0.99. Given the predetermined percentage of treatment, x, the amount of liquid needed was determined by

$$w = G \cdot 56 \cdot x/60 \quad (4)$$

where

G = grain flow rate in bu/hr

x = application rate

w = liquid flow rate in lb/min

Consequently, by entering w from Eqn (4) into Eqn (3), we were able to determine the liquid pressure setting. This pressure setting corresponded to the predetermined treatment dosage.

4. Dust Emission Measurement

When grain was flowing, dust emissions were monitored by Bendix model 550, Hi-Vol, high volume air samplers (Bendix Environmental & Process Instrument Div.) at sites B, C, and E (Fig. 1). When the grain flow began, samplers were started and the clock time was recorded. When the grain flow ended the samplers were stopped and the clock time was again recorded. The airflow was held constant at 28 cubic feet per minute by an operator who monitored the airflow gauge and adjusted a Variac transformer connected to the Hi-Vol motor. The operator was also instructed to stop Hi-Vol sampling and record the time in the event that the filter became loaded with dust to the point that gauge flow rate could not be maintained at the designated value of 28 cfm. Type A fiberglass filters used in the samples were weighed just before the start of a test and again at the end.

The dust cloud concentration inside the test bins, site E (Fig. 1), were also measured by a Hi-Vol air sampler. Since one of the most serious shortcomings of the data taken from Hi-Vol air samplers is their lack of information on the temporal and spatial characteristics of the dust dispersion, we added an array of two light-emitting-diode, phototransistor (LED-PT) pairs to give more information on the dust distribution (Martin et al., 1980). Dust concentration was monitored by the attenuation of light emitted from the light-emitting-diode (LED). The light was detected by a phototransistor (PT) matched to the spectral output of the LED (peak wavelength ≈ 930 nm). This procedure was used by Liebman et al. (1977) to monitor dust concentration during the propagation of coal dust fires and explosions. However, our probe differed from the one described by Liebman et al. (1977) by being windowless and was designed to operate with a longer light path to increase sensitivity.

Figure 5 is a sketch of the probe mounted on aluminum plates which in turn are mounted on four aluminum rods 0.5 inch (1.26 cm) in diameter. We chose a high-power LED that delivered 6 mW at a 10° beam angle and an appropriate detector (Texas Instruments TIL 31 and TIL-81, respectively). The distance between the LED and PT was 1.00 m. Dust was prevented from collecting on the optical surfaces of the LED and PT by a stream of air through the collimator from the compressed air supply, which did not affect the dust distribution significantly, because of its low flow rate. The airflow was adjusted so that a pressure equilibrium was reached between the collimator and the monitoring space whenever dust was dispersed. The air stream systems were checked at least twice each day during the test to make sure that the airsweeps were effective in preventing dust buildup.

The LED and PT were both powered by a 5V d.c. power supply. The electrical circuit is shown schematically in Fig. 6. The resistor R was chosen to give a light intensity that allowed the PT to operate in a linear range. Linearity of the response was tested and confirmed with a series of neutral-density filters inserted into the light beam. The 10 mΩ load resistor, R_2, was chosen to give maximum sensitivity and to allow isolation if multiple PT circuits were powered from the same power supply. The large value of R_2 reduced the response time of the circuits to approximately 5 ms, an adequate time for most explosion tests. If faster time response had been needed, a lower value of R_2 may have been used, at the expense of sensitivity.

III. RESULTS AND DISCUSSION

A. Ambient Conditions

Tests were conducted at Fostoria, Ohio, between December 7 and 12, 1980. Snow had fallen the week before. Daytime temperatures were in the middle 40's and night time temperatures in the upper 20's. Temperature in the basement of the grain elevator where the oil was applied was 30° F.

B. Time Sequence of Tests

Thirty-eight tests were conducted with corn, wheat, and soybeans using water, soybean oil, and mineral oil as test additives. The time sequence of the tests is given in Table 1 and in Figs. 7(1)-7(38). The dust concentration as measured by two LED-PT pairs are given in Figs. 7(1) through 7(38) for all 38 tests. The data show that adding soybean or mineral oil reduced dust emission at the bin overspace, an observation consistent with our findings from the high-volume air samplers.

In each of the first four runs, 5000-bushel lots were used. It was assumed initially that airborne dust inside the test bin would take the longest time to reach equilibrium and remain suspended longer after grain stopped flowing than that of the dust at sample sites B and C. Site B was vented through a dust control duct whereas the bin was not vented. Site C was an open area where windows and other infiltration sources caused natural ventilation. The light attenuation data from the four initial tests showed a consistant and rapid dust cloud build-up rate during the first minute of grain flow followed by a fluctuating but relative constant dust cloud (Fig. 7(1)-7(4). When grain flow stopped, the rate of dust cloud dissipation was much slower than the rate of accumulation. It was also observed that even though the dust cloud concentration did not return to background or pretest level between successive replicated tests, the next test produced the same attenuation pattern and was essentually an extension of the first pattern. In other words, tests could be run back to back without introducing errors due to carry-over. Consequently, after the first four runs 2500-bushel lots were used to produce a grain flow rate of 10,000 bushels/hr at a running time of about 15 minutes.

Because we were limited by a tight schedule, we conducted tests continually. We realized that with this procedure some fine dust from a previous run was probably hanging in the air when the next test was started, and therefore, dust was carried from one test to the next. It would have been beneficial to have conducted an identical test on the grain handling system with no grain present, in order to have made an estimate of the background dust concentration and accumulation in the system.

C. Grain Samples

The moisture content and broken corn and foreign material content of corn samples are given in Table 2. All moisture contents were under 15.5%, the limit for No. 2 corn, and ranged between 14.3 and 15.5%. The 5000-bushel test lots for tests 1-4 had over 3.0% broken corn and foreign material which would make these lots grade less than No. 2 corn. Most 2500-bushel corn test lots had less than 3.0% BCFM. Test No. 37 had the highest BCFM with 4.1%, but the sample sent to the BAR (Board of Appeals and Review) had only 3.0% and was graded No. 2 corn. The application of up to 0.33% water did not increase the moisture contents above the levels measured in the controls.

After the tests, samples of both the control corn and treated corn were sent in plastic bags to the Board of Appeals and Review for grading. The results are given in Table 3. For test No. 1, control test, the odor was rated COFO (commercially objectionable foreign odor). Test No. 37 odor was graded musty and test No. 36 odor was graded COFO, even though both were treated with mineral oil. The other three samples were graded No. 2 corn despite the fact that they were treated with vegetable oil. Because of the odor, samples from tests Nos. 36 and 37 were graded as sample grade yellow corn. Test No. 1 was graded sample grade because of high BCFM (>7%).

The moisture and fine material content of wheat are given in Table 4. The moisture content ranged between 11.5 and 12.2%, and the fine material content ranged from 0.26% to 1.58%. Board of Appeal gradings of those samples are given in Table 5. Only the 0.06% level sample treated with vegetable oil was graded as COFO.

The moisture content and fine material content of soybeans are given in Table 6. The moisture content ranged from 11.2% to 11.7%. Test No. 31 had the highest fine material content (9.01%). BAR gradings of the samples are given in Table 7. No objectionable odor was detected and all the samples were graded as No. 1 yellow soybeans.

D. Dust Emission

1. Corn

a. Dust concentrations

Table 8 presents the concentrations inside the enclosed transfer belt before entering the boot, at the open gallery, and inside the bin overspace where the bin was being filled, as well as the dustiness of each control grain sample measured by the drop test. For comparison, data were recorded when the dust control system of the elevator was turned on and when it was off. The Hi-Vol sampler at the gallery (C, Fig. 1) was operated at 28 cfm during the first 4 tests, and from test No. 5 on, was operated at 60 cfm (full voltage). However, the Hi-Vol sampler installed at the enclosed belt (B, Fig. 1), had no Variac transformer available to control motor speed (airflow rate). The data in Tables 8 and 9 show that higher dust concentrations were measured at 28 cfm than were measured at 60 cfm. In other words, a 60 cfm airflow rate in the open area removed dust particles faster than that of 28 cfm airflow rates.

Water was applied at levels of 0.17%, 0.30%, and 0.33% (Table 9). When the dust control system was off, the dust concentration inside equipment at the pre-leg averaged 0.860 gm/m^3 and was reduced to 0.459 gm/m^3 when the system was on. The percentage of reduction was 41.2% for 0.18% added water and 52.1% for 0.30% added water (Table 10). This reduction indicates that the effect is evident 15 seconds after application (it took 15 seconds for the grain to travel from the point of application to the point of dust measurement) and that it has taken effect before the grain entered the boot of the leg when the dust control system is off. When the dust control system was on, an application of 0.18% water reduced the dust concentration at the gallery from 0.008 gm/m^3 to 0.006 gm/m^3 and application of 0.30% reduced it further to 0.0017 gm/m^3. This reduction corresponds to 20.0% for 0.18% added water and 77.3% for 0.30% added water. Grain dustiness was decreased substantially by at least one order of magnitude.

When the dust control system was off, concentration of dust at the pre-leg was substantially increased, but the concentration in the bin overspace remained the same. This observation is expected because there was no control system inside the grain bin. The drop tests for grain dustiness were not measurably affected by turning off the dust control system. This observation is consistent with the fact that the dust control system was not intended to remove any dust from the grain.

The results found with oil additives are similar to those found for 0.3% water. Concentration of dust in experimental lots of corn treated with soybean oil are described in Table 11. Three levels of oil were used, 0.03, 0.06, and 0.10%. The dust concentration at the pre-leg was not affected much by the application rate, which might have been due to inadequate mixing. After entering the boot, the dust concentration at the gallery was reduced by half, and at the bin overspace it was reduced by one order of magnitude. Significantly, the dustiness of the grain itself was reduced by at least two orders of magnitude. Again the dust concentration in the bin overspace did not increase when the dust control system was turned off.

When the dust control system was on, an application rate of 0.03% soybean oil reduced the dust concentration at pre-leg by 17.2% (Table 12). The percentage of reduction increased to 46.7% when the concentration was measured at the gallery. The most dramatic reduction was shown by the drop test (97.4%). The reduction of dust in the bin overspace was 70.9%. When the dust control system was on, the reduction in dust concentration at gallery, drop test, and bin overspace remained the same. However, the reduction in pre-leg dust concentration was by 42%. This observation is identical to that seen when water was added.

The dustiness of experimental lots of corn treated with mineral oil are described in Table 13; percentage reductions are given in Table 14. We observed the same reductions in dust emission when the corn was treated with soybean oil.

b. Particle size analysis

The air velocity at the surface of the Hi-Vol filters at the designated sampling rate was 25.6 cm/sec (28 cfm x 12 x 12 x 254)/(8 x 10 x 60), the terminal velocity of an 85μ diameter particle, the downward settling velocity of the particles, due to gravity, being greater than the upward capture air velocity. All the particle size analyses of the dust collected by Hi-Vol air samplers showed that less than 1% of the particles were larger than 85μ diameter. All the particle size analyses of the tailing dust collected showed that the total weight of particles greater than 125μ diameter exceeded 6.5%. The difference in quantity of large dust particles between Hi-Vol samples and tailing dust samples points out one difficulty in obtaining representative sampling inside enclosed equipment with Hi-Vol air samplers. The dust collecting system, with its large airflow rates and high air velocities, was designed to control and collect much larger dust particles than a Hi-Vol air sampler was designed to sample.

Representative results of the particle size analysis of Hi-Vol dust samples from corn in the enclosed belt are given in Table 15. When the dust control system was on, the diameter of dust particle collected by the Hi-Vol filter at the enclosed belt averaged 8.2μ compared to 12μ for similar tests with the dust control system off. We conclude from the data that the dust concentration measured by the Hi-Vol samplers in the enclosed belt were lower than the concentration would have been if higher airflow rates were maintained during the sampling. However, in most tests with the dust control system off, the Hi-Vol filter in the enclosed belt became loaded with dust before the test was completed. Those dust concentrations were representative of the first one-third to two-thirds of the test.

Results from the laboratory and pilot tests conducted at USGMRL showed that additives reduced significantly the amount of dust particles with diameters less than 125μ in diameter (Lai et al., 1981). There was a similar reduction in fine dust emissions in these tests. The particle size distribution of dust collected at the enclosed belt site (site B, Fig. 1) with the dust control system off are given in Table 16. The largest reduction of fine dust emission occurred in corn treated with mineral oil after 3 months of storage. The reduction may be due to the additional mixing as a result of extra handling of the grain from the storage bin through the bucket elevator and return to the bin. The 0.30% water treatment had a greater effect in reducing fine dust 15 seconds after application than did the application of either oil at any level tested. The treatment with vegetable oil appeared to have very little effect on any of the three grains at the enclosed belt site.

The particle size distribution for the dust collected from the open belt site (site C, Fig. 1) with the dust control system off is given in Fig. 17. The application of 0.30% water also significantly reduced the amount of fine dust collected. The additional mixing and tempering allowed both oil treatments to increase in benefit and equal that of water treatment at the open belt site.

The particle size distribution for dust collected inside the test bin (site E, Fig. 1) with dust control system off is given in Table 18. Every oil treatment at this site was more effective than at sites B and C as evidenced by the reduction in fine particle emission. In Table 16, the data show that corn treated with mineral oil continued to diminish in fine particle emission during the 3-month interval, but at site C (Table 17) and site E (Table 18) the improvement appeared to decrease during the second handling. Apparently the factors of aging and absorption had reduced the ability of mineral oil to contain fine dust.

2. Wheat

Dustiness of control lots of wheat without additives are summarized in Table 19. The dust control system of the facility significantly affected the dust concentration at the pre-leg belt and gallery belt. The dustiness of the grain as measured by the drop test also appeared to be affected significantly by the dust control system and indicates that the dust control system removed substantial amounts of dust and fine material from the wheat, although the difference could also have been caused by variations in dustiness of different lots of grain. When soybean oil was applied to wheat, the reduction in dust concentration was similar to that of corn (Table 20). The differences in reduction due to varying oil concentrations (0.03 or 0.06%) were insignificant. Any additional mixing of the oil and wheat appeared to be less effective on wheat than on either soybeans or corn. Yet, we found that the use of 0.03% oil significantly and consistently reduced dust emission. However, when we tested grain dustiness, the grain samples treated with 0.06% oil were less dusty than those treated with 0.03% oil.

Three levels of soybean oil were added to wheat. They were 0.02, 0.03, and 0.06%. The percentage reduction in dust concentration at the pre-leg ranged from 21.3% to 63.3% (Table 21). The percentage reduction at the gallery ranged from 28.6% to 75.0%. The drop test consistently showed a 95.9% reduction of dust. A significant reduction of fine particle emission occurred at the test bin (Site E, Fig. 1), but took longer than either soybean or corn. This comparative delay for wheat compared to corn or soybeans could be related to the larger surface area for wheat. The reduction in bin overspace dustiness was 89.3% at 0.06% soybean oil when the dust control system was turned off. These percentages of reduction clearly indicate the value of oil treatments in reducing the concentration of dust that a control system must handle.

3. Soybeans

Dustiness of control lots of soybeans without additives are recorded in Table 22. The dust concentration in the bin overspace significantly increased whether the dust control system was turned on or off. However, drop tests showed that when the dust control system was off the dustiness of the grain was lower than when the system was on. The discrepancy may be due to the variation in dustiness between lots of soybeans or to the segregation of fine material into one lot. Table 23 gives the reduction in dust emission from the application of soybean oil to soybeans. The results are similar to those observed for wheat treated with soybean oil.

The percentage of reduction in dust concentration from the application of soybean oil to soybean is given in Table 24. Variations in grain lot dustiness may explain the dust reduction of only 1.8% when 0.03% soybean oil was employed. The percentage of dust reduction at gallery and bin overspace locations appeared to be consistent with those for corn and wheat.

E. Collected Tailing Dust

The amount of dust collected at four locations (work floor, garner, gallery floor, and D house) inside the facilities are summarized in Table 25. The dust saved (lb. dust from control lot minus lb. dust from treated lot) is also given. Without an additive, the dust collected by the dust control system was on the order of 400/5000/56 = 0.14%. In other words, the loss through the dust control system was approximately 0.14% each time grain was handled. When an additive was used, the loss was reduced to 0.035% or less. This observation means only one-fourth of the dust component of grain was dispersed when oils or water were added.

The effect of different additives and different levels of treatment on controlling the tailing dust collected by the dust control system at the work floor is given in Fig. 8. Apparently soybeans treated with vegetable oil were hardly affected. Corn treated with soybean oil showed some effect at early mixing. Similar plots for the dust collected at the gallery floor, garner, and grain bin are given in Figs. 9, 10, and 11, respectively. The total dust collected is given in Fig. 12.

The particle size distribution of grain dust collected at the work floor after 2500 bushels of grain had been handled is given in Table 26. The total weight of dust collected from grain treated with water was greater than the weight of the dust collected without an additive, inferring that a substantial amount of water was probably in the dust. In our previous pilot test (Lai et al. 1979), the moisture content of dust treated with 0.5% water was found to range between 40 and 50%. Similarly, the dust collected at the garner per 2500 bushels of grain handled is given in Table 27. There was a substantial reduction in the fine dust collected. The data were consistent with the fact that during the test the observer was able to see the grain flowing for those cases when grain was treated with additives. The particle distribution of grain dust collected at gallery for handling 2500 bushels of grain is given in Table 28. Similarly, the dust collected in the enclosed bin space is given in Table 29. The trend is consistent with those at work floor.

There were large differences in the total amount of tailing dust collected on the first test and collected after the grain had been stored for 3 months both for the test lots and control lots (Table 25). The total weight of dust collected always increased according to the amount of water added during treatment, obviously due to high moisture content. After 3 months of storage, no dust was collected by the work floor dust control system. The oil-treated corn was handled first followed by the control test (without additive). Because both of these factors produce a significant margin of error, any results derived from data on the amount of tailing dust collected by the dust control system should be interpreted with caution. Similarly, the errors due to inefficient by-pass alteration of the dust control system introduced during the collection of individual samples are difficult to assess.

F. Effect of Additive Treatment

We evaluated the effects of water and oil treatment separately, since the application levels for the two additives were quite different. In general, the treatment with water required an amount one order of magnitude greater than treatment with either mineral or deodorized soybean oil.

1. Water

Water effectively reduced dust emission at the pre-leg belt, especially when the level of treatment was 0.3% (Fig. 13). At the gallery floor, dust emission also was reduced significantly (Fig. 14). However, when the dust control system was off, the dust emission was less predictable. The dust concentration in the bin overspace was affected less significantly by the level of treatment, either with the dust control system on or off (Fig. 15). This observation was consistent with the readings from the drop tests (Fig. 16), which is predictable since in essence the measurement of dust concentration in the bin overspace is a large-scale drop test. Based on the correlation equation (Fig. 16), the effective level of water as an additive should be around 0.5%. However, no data were available to verify this prediction. Moreover, the effect of this level of treatment on the mold growth and insect infestation has not yet been studied. Based on the data of this experiment, it is safe to state that the application of 0.3% water would effectively reduce dust concentrations.

2. Oil

Treatment with mineral oil or deodorized soybean oil had little effect on reduction of dust emission at the enclosed belt site (Figs. 17-23).

At the pre-leg belt, either with the dust control system on or off, the level of oil treatment did not affect the dust concentration (Figs. 17 and 18), but after the grain entered the boot and passed through the bucket elevator, the resultant mixing produced a significant reduction in gallery dust concentration. From the data in Figs. 19 and 20, we conclude that the most effective level of oil treatment is approximately 0.03%. The data from bin overspace (Figs. 21 and 22) and drop tests (Fig. 23) support that conclusion.

G. Effects of 3 Months' Storage of Corn After Treatment with Mineral Oil

We combined lots of corn treated with 0.02 and 0.06% mineral oil into a single lot and stored the combined corn lots for 3 months. The average oil concentration was 0.04% since no additional oil was added after 3 months of storage. We also stored the control lot for 3 months and then made a total of 3 tests for the control lot and 4 tests for the corn treated with mineral oil (Table 21). Because the drop test instrument malfunctioned after 4 tests, we were not able to obtain data for the last 3 runs with the dust control system off. The data shown in Table 30 clearly indicate that the effect of storage in diminishing dust control was insignificant. In fact, because of the extra mixing action of handling, the dust emission was much lower after storage. But, in this case as in all the tests, it is difficult to access just how much of the differences observed in the results are due to variations in equipment, individual operators, and grain lots.

IV. CONCLUSIONS

1. Water applied at a level of 0.3% to corn reduced the dust concentration by at least 80% on the gallery floor. At the same location soybean oil or mineral oil applied at a level of 0.05% reduced dust by more than 90%.

2. Water had the most effect at the pre-leg site shortly after application but was less effective at the gallery and bin overspace. The situation was reversed for oil treatments.

3. The effectiveness of mineral oil as a dust controlling additive was not reduced after grain had been stored for 3 months.

4. Thorough mixing of the grain following the application of an additive is one of the most critical elements in the success of controlling dust. The treatment should be applied at an early stage of grain flow from a bin. The modifications required for effective application in existing installations are minimal.

5. Little oil accumulated on the equipment or the walls. This was due to proper mixing and to the low treatment level (<0.06%).

6. Board of Appeals did not consistently detect the presence of soybean oil or mineral oil on corn or wheat.

7. The dustiness index developed in this work to measure the dustiness of grain consistently correlated with other methods of dust measurement.

8. There were no variations made in the degree of mixing in the tests, and thus no conclusions can be made concerning the amount of mixing necessary to achieve optimal results.

RECOMMENDATIONS

1. Additional research focusing on the feasibility of an oil-water additive treatment would be beneficial (e.g. 90% water and 10% oil at a treatment level of 0.3%).

2. The dust collected from grain treated with an additive contains some of the additive. The explosibility characteristics of such dust should be determined.

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30. Effect of 3 months' storage on dustiness of corn treated with mineral oil.

Table 1. Time sequence of tests[a]

Date	Test No.	Clock time & grain flow at gallery Start	Stop	Grain	Additive	Level %	Dust control	Test bin
Dec. 9, 1980	1	14:09	14:34	corn	none	none	on	360
	2	15:02	15:30	corn	none	none	on	371
	3	15:54	16:17	corn	water	.17	on	370
	4	16:51	17:16	corn	water	.17	on	360
Dec. 10, 1980	5	9:45	10:00	corn	water	.30	on	360
	6	10:18	10:33	corn	water	.30	off	360
	7	11:02	11:18	corn	water	.18	on	370
	8	11:33	11:48	corn	water	.18	off	370
	9	12:06	12:21	corn	none	none	on	371
	10	12:36	12:51	corn	none	none	off	371
	11[b]	14:46	14:51	corn	water	.33	off	371
	12	15:05	15:20	corn	none	none	on	371
	13	16:15	16.30	corn	veg. oil	.10	off	371
	14	16:38	16:53	corn	veg. oil	.10	on	371
Dec. 11, 1980	15	9:20	9:33	corn	veg. oil	.06	off	371
	16[c]	9:47	10:02	corn	veg. oil	.06	off[d]	371
	17	10:17	10:32	corn	veg. oil	.06	on	371
	18	10:52	11:07	corn	veg. oil	.03	on	360
	19	11:16	11:31	corn	veg. oil	.03	off	360
	20	13:19	13:34	wheat	none	none	off	360
	21	13:39	13.54	wheat	none	none	on	360
	22	14:04	14:19	wheat	veg. oil	.06	off	371
	23	14:28	14:43	wheat	veg. oil	.03	off	371
	24	14:59	15:14	wheat	veg. oil	.03	on	370
	25	15:23	15:36	wheat	veg. oil	.02	off	370
	26	16:00	16:15	soybeans	none	none	off	360
	27	16:22	16:37	soybeans	none	none	on	360
Dec. 12, 1980	28	8:45	9:00	soybeans	veg. oil	.06	off	370
	29	9:12	9:27	soybeans	veg. oil	.03	on	370
	30	9:42	9:57	soybeans	veg. oil	.03	off	370
	31	10:21	10:36	soybeans	veg. oil	.03	off	360
	32	10:53	11:08	wheat	veg. oil	.08	off	371
	33	11:23	11:38	wheat	veg. oil	.04	off	371
	34	11:52	12:07	wheat	veg. oil	.02	off	371
	35	14:19	14:34	corn	min. oil	.02	on	360
	36	14:44	14:59	corn	min. oil	.08	off	360
	37	15:07	15:22	corn	min. oil	.04	off	371
	38	15:34	15:44	corn	min. oil	.02	off	360

[a] Lot size for Tests Nos. 1-4 is 5,000 bushels; tests Nos. 5-38, 2,500 bushels.

[b] Wet corn plugged spout after 5-6 min.

[c] Spray on top of grain stream only.

[d] Dust control system on at work level.

Table 2. Moisture contents and BCFM of corn samples

Test No.	Level %	Additive	Moisture content: First[a] %	Middle[b] %	Last[c] %	Average	BCFM: USGMRL %	BAR %	Moisture: BAR %
1[d]	0.0	--					10.5	11.3	14.8
2[d]	0.0	--					5.3		
3[d]	0.17	water					7.2		
4[d]	0.17	water					6.5		
5	0.3	water	15.19	15.09	15.29	15.2			
6	0.3	water	14.75	14.50	14.55	14.6			
7	0.18	water	14.85	14.61	14.22	14.8			
8	0.18	water	15.01	14.71	14.81	14.9			
9	0.0	--	14.81	15.20	15.06	15.0			
10	0.0	--	15.25	15.06	15.01	15.1			
11	0.33	water	15.20	15.06	15.29	15.2			
12	0.0	--	15.45	15.14	15.34	15.3			
13	0.1	vegetable oil	14.99	14.50	14.55	14.7	3.3	2.3	15.0
14	0.1	vegetable oil	14.55	14.75	14.95	14.8			
15	0.06	vegetable oil	14.81	15.40	15.40	15.2	2.2	1.4	14.8
16	0.06	vegetable oil	15.20	14.95	15.14	15.1	1.9		
17	0.06	vegetable oil	14.81	14.95	15.01	14.9	1.1		
18	0.03	vegetable oil	14.95	15.01	14.91	15.0	1.4		
19	0.03	vegetable oil	14.71	14.71	14.71	14.7	1.5	1.4	14.5
35	0.02	mineral oil	14.97	14.63	15.02	14.9	2.4	2.4	14.5
36	0.08	mineral oil	15.01	15.28	14.88	15.1	2.7	1.3	14.6
37	0.04	mineral oil	15.36	14.95	14.91	15.1	4.1	3.0	14.6
38	0.02	mineral oil	14.91	14.82	15.22	15.0	2.5		
A[g]	0.04[e]	mineral oil	15.62	15.03	14.92	15.2	2.7		
B[g]	0.04[f]	mineral oil	15.03	15.64	15.51	15.4	3.0		
C[g]	0.04[f]	mineral oil	15.44	15.44	15.24	15.4	2.6		
D[g]	0.04[f]	mineral oil	15.24	14.85	14.85	15.0	2.8		
E[g]	0.0	--	14.65	14.16	14.44	14.4	2.3		
F[g]	0.0	--	14.05	14.36	14.75	14.4	3.7		
G[g]	0.0	--	14.46	14.25	14.26	14.3	2.6		

[a]Samples collected at the beginning of the test.

[b]Samples collected at the middle of the test.

[c]Samples collected at the end of the test.

[d]Samples were not collected.

[e]From test No. 37.

[f]Average of test Nos. 35, 36, 38.

[g]After 3 months' storage.

Table 3. Board of Appeals and Review grade of corn samples

Test No.	Level %	Additive	Class	Test weight lb/bu	Moisture content %	Odor	Damaged kernels (total) %	Broken kernels and foreign material %	Grade
1	0.0	--	YC	58.0	14.8	COFO[a]	0.8	11.3	SG YC
35	0.02	min. oil	YC	56.0	14.5	OK	1.5	2.4	2 YC
37	0.04	min. oil	YC	56.0	14.6	musty	0.8	3.0	SG YC
36	0.08	min. oil	YC	55.5	14.6	COFO[a]	0.5	1.8	SG YC
19	0.03	veg. oil	YC	58.0	14.5	OK	0.9	1.4	2 YC
15	0.06	veg. oil	YC	55.0	14.8	OK	0.6	1.4	2 YC
13	0.10	veg. oil	YC	55.5	15.0	OK	0.4	2.3	2 YC

[a]Commercially objectionable foreign odor.

Table 4. Moisture and fine material contents of wheat samples

Test No.	Level %	Additive	Moisture content First[a] %	Middle[b] %	Last[c] %	Average %	Fine materials %
20	0.0	—	11.71	11.85	12.38	12.0	0.26
21	0.0	—	12.38	12.22	12.13	12.2	0.34
22	0.06	veg. oil	12.09	12.36	11.99	12.1	0.36
23	0.03	veg. oil	11.61	11.84	11.65	11.7	0.38
24	0.03	veg. oil	11.61	11.36	11.51	11.5	0.49
25	0.02	veg. oil	11.75	12.09	12.27	12.0	0.31
32	0.06	veg. oil	11.55	11.41	11.41	11.5	0.39
33	0.03	veg. oil	11.56	12.03	11.70	11.8	0.53
34	0.02	veg. oil	11.69	11.98	12.63	12.1	1.58

[a]Samples collected at the beginning of the test.

[b]Samples collected at the middle of the test.

[c]Samples collected at the end of the test.

Table 5. Board of Appeals and Review grades of wheat samples

Test No.	Level %	Additive	Class	Dockage %	Test weight lb/bu	Moisture content %	Odor	Damaged kernels (total) %	Foreign material %	Shrunken and broken kernels %	Total defects	Grade
20	0.0	--	SRW	0.14	62.0	12.4	OK	0.1	0.0	0.2	0.3	#1SRW
24	0.03	veg. oil	SRW	0.18	59.5	12.0	OK	0.5	0.1	0.3	0.9	#2SRW
22	0.06	veg. oil	SRW	0.19	59.9	12.2	COFO[a]	0.0	0.0	0.2	0.2	SGSRW

[a]Commercially objectionable foreign odor.

Table 6. Moisture and fine material contents of soybean samples

Test No.	Level %	Additive	Moisture content First[a] %	Middle[b] %	Last[c] %	Average %	Fine materials %
26	0.0	--	11.13	11.24	11.15	11.2	2.36
27	0.0	--	11.41	11.15	11.07	11.2	1.49
28	0.06	veg. oil	11.18	11.29	11.69	11.4	1.68
29	0.03	veg. oil	11.29	11.28	11.32	11.3	2.34
30	0.03	veg. oil	11.31	11.19	11.14	11.2	1.91
31	0.03	veg. oil	11.60	11.64	11.73	11.7	9.01

[a]Samples collected at the beginning of the test.

[b]Samples collected at the middle of the test.

[c]Samples collected at the end of the test.

Table 7. Board of Appeals and Review grades of soybean samples

Test No.	Level %	Additive	Class	Test weight lb/bu	Moisture content %	Odor	Damaged kernels (total) %	Coarse %	Fine %	Foreign material %	Splits %	Grade
26	Control		YSB	57.0	11.5	OK	0.3	0.15	0.82	1.0	3.0	#1 YSB
30	0.03	veg. oil	YSB	56.5	11.5	OK	0.2	0.0	1.01	1.0	5.0	#1 YSB
28	0.06	veg. oil	YSB	56.5	11.4	OK	0.4	0.1	0.7	0.8	4.0	#1 YSB

Table 8. Control lots of corn without additives

Dust control system	Pre-leg enclosed belt dust concentration gm/m^3	Gallery open belt dust concentration gm/m^3	Drop test dust concentration gm/m^3	Bin overspace enclosed dust concentration gm/m^3
on[a]	--[b]	0.013	0.334	2.77
on[a]	--[b]	0.012	0.347	2.55
on	--[b]	0.007[d]	0.310	3.08
on	0.860	0.008[d]	0.227	3.63
off	17.01[c]	1.317[d]	0.406	3.17

[a]5,000-bushel test lot.

[b]Data not available.

[c]Filter became loaded and sampling was stopped before end of test.

[d]Hi-Vol sampling rate at 60 cfm.

Table 9. Experimental lots of corn treated with water as an additive

Level of additive	Dust control system	Pre-leg enclosed belt dust concentration gm/m^3	Gallery open belt dust concentration gm/m^3	Drop test dust concentration gm/m^3	Bin overspace enclosed dust concentration gm/m^3
0.17[a]	on	--[b]	0.010	0.217	1.98
0.17[a]	on	--[b]	0.011	0.168	2.00
0.18	on	0.506	0.006[d]	0.109	2.69
0.30	on	0.412	0.017[d]	0.150	2.35
0.18	off	13.50[c]	0.214[d]	0.177	1.90
0.30	off	3.38	0.265[d]	0.133	1.92
0.33	off	6.50[c]	0.117[d]	0.090	1.98

[a] 5,000-bushel test lots.

[b] Data not available.

[c] Filter became loaded and sampling was stopped before end of test.

[d] Hi-Vol sampling rate at 60 cfm.

Table 10. Percentage reductions in dust concentration for experimental lots of corn treated with water as an additive

Level of additive %	Dust control system	Pre-leg enclosed belt dust concentration %	Gallery open belt dust concentration %	Drop test dust concentration %	Bin overspace enclosed dust concentration %
0.17[a]	on	—[b]	20.0	36.4	25.6
0.17[a]	on	—[b]	12.0	50.7	24.8
0.18	on	41.2	20.0	59.5	19.8
0.30	on	52.1	77.3	44.2	30.0
0.18	off	23.3	83.8	56.4	40.1
0.30	off	80.1	79.9	67.2	39.4
0.33	off	61.8	91.1	77.8	37.5

[a]5,000-bushel test lots

[b]Data not available

Table 11. Experimental lots of corn treated with soybean oil as an additive

Level of additive %	Dust control system	Pre-leg enclosed belt dust concentration gm/m^3	Gallery open belt dust concentration gm/m^3	Drop test dust concentration gm/m^3	Bin overspace enclosed dust concentration gm/m^3
0.03	on	0.712	0.004[d]	0.007	0.975
0.06	on	0.662	0.006[d]	0.004	0.585
0.10	on	0.746	0.003[d]	0.003	0.921
0.03	off	9.87[c]	0.082[d]	0.008	0.711
0.06	off	12.06[c]	0.060[d]	0.007	0.585
0.10	off	10.12[c]	0.075[d]	0.003	0.835
0.06[a]	off[b]	0.919	0.099[d]	0.003	0.717

[a]Top sprayer on only.

[b]Dust control system on at pre-leg belt only.

[c]Filter became loaded and sampling was stopped before end of test.

[d]Hi-Vol sampling rate at 60 cfm.

Table 12. Percentage reduction in dust concentration for experimental lots of corn treated with soybean oil as an additive

Level of additive %	Dust control system	Pre-leg enclosed belt dust concentration %	Gallery open belt dust concentration %	Drop test dust concentration %	Bin overspace enclosed dust concentration %
0.03	on	17.2	46.7	97.4	70.9
0.06	on	23.0	20.0	98.5	82.6
0.10	on	13.3	60.0	98.9	72.5
0.03	off	42.0	93.8	98.0	77.6
0.06	off	29.1	95.4	98.3	81.5
0.10	off	40.5	94.3	99.3	73.7
0.06[a]	off[b]	94.6	92.5	99.3	77.4

[a]Top sprayer on only.

[b]Dust control system on at pre-leg belt only.

Table 13. Experimental lots of corn treated with mineral oil as an additive

Level of additive %	Dust control system	Pre-leg enclosed belt dust concentration gm/m³	Gallery open belt dust concentration gm/m³	Drop test dust concentration gm/m³	Bin overspace enclosed dust concentration gm/m³
0.02	on	0.593	0.002[b]	0.011	0.684
0.02	off	7.52[a]	0.043[b]	0.01	0.981
0.04	off	6.43[a]	0.056[b]	0.005	0.432
0.08	off	7.37[a]	0.024[b]	0.01	0.391

[a]Filter became loaded and sampling was stopped before end of test.

[b]Hi-Vol sampling rate at 60 cfm.

Table 14. Percentage reduction in dust concentration for experimental lots of corn treated with mineral oil as an additive

Level of additive %	Dust control system	Pre-leg enclosed belt dust concentration %	Gallery open belt dust concentration %	Drop test dust concentration %	Bin overspace enclosed dust concentration %
0.02	on	31.0	73.3	95.9	79.6
0.02	off	55.8	96.7	97.5	69.1
0.04	off	62.2	95.7	98.8	86.4
0.08	off	56.7	98.2	97.5	87.7

Table 15. Log-normal particle size distribution parameters of Hi-Vol dust samples from corn at the enclosed belt site

Level %	Additive	Dust control off				Dust control on			
		Test No.	r^2[a]	$\bar{d}$[b]	s.d.[c]	Test No.	r^2[a]	$\bar{d}$[b]	s.d.[c]
0.0	--	G	0.992	10.4	1.66	E	0.996	8.5	1.64
0.0	--	10	0.994	11.9	1.71	9	0.971	8.2	1.61
0.03	veg. oil	19	0.981	10.9	1.68	18	0.968	8.4	1.54
0.06	veg. oil	15	0.993	12.3	1.66	17	0.965	7.9	1.55
0.10	veg. oil	13	0.983	12.1	1.57	14	0.987	8.6	1.56
0.04	min. oil	37	0.991	12.3	1.70	37[a]	0.996	8.4	1.68
0.30	water	6	0.990	13.8	1.59	5	0.986	7.7	1.53

[a]coefficient of determination.

[b]geometric median diameter in micrometers.

[c]geometric standard deviation.

[d]after 3 months of storage.

Table 16. Log - normal particle size distribution parameters of Hi-Vol dust samples from enclosed belt site with the dust control system off.

Level %	Additive	Corn Test No.	Corn r^{2a}	Corn $\bar{d}^{b}$	Corn s.d.[c]	Wheat Test No.	Wheat r^{2a}	Wheat $\bar{d}^{b}$	Wheat s.d.[c]	Soybeans Test No.	Soybeans r^{2a}	Soybeans $\bar{d}^{b}$	Soybeans s.d.[c]
0.0	--	10	0.994	11.9	1.71	20	0.943	10.1	1.75	26	0.991	10.4	1.76
0.03	veg. oil	19	0.981	10.4	1.68	23	0.979	11.6	1.89	30	0.991	10.5	1.77
0.06	veg. oil	15	0.993	12.1	1.66	22	0.987	11.0	1.87	28	0.994	9.4	1.70
0.10	veg. oil	13	0.986	12.1	1.57								
0.02	min. oil	38	0.992	11.5	1.64								
0.04	min. oil	37	0.991	12.3	1.70								
0.08	min. oil	36	0.994	12.6	1.69								
0.30	water	6	0.990	13.8	1.59								
0.04[d]	min. oil	D	0.991	16.9	1.85								

[a]Coefficient of determination.

[b]Geometric median diameter in micrometers.

[c]Geometric standard deviation.

[d]Average of tests #35, 36, and 38.

Table 17. Log-normal particle size distribution parameters of Hi-Vol dust samples from open belt site with dust control system off

Level %	Additive	Corn				Wheat				Soybeans			
		Test No.	r^{2a}	$\bar{d}^b$	s.d.[c]	Test No.	r^{2a}	$\bar{d}^b$	s.d.[c]	Test No.	r^{2a}	$\bar{d}^b$	s.d.[c]
0.0	--	10	0.985	11.2	1.62	20	0.965	11.7	1.85	26	0.987	11.2	1.88
0.03	veg. oil	19	0.996	12.3	1.80	23	0.988	10.8	2.09	30	0.989	13.1	2.05
0.06	veg. oil	15	0.983	14.2	1.97	22	0.983	10.9	1.95	28	0.989	11.1	2.22
0.10	veg. oil	13	0.988	12.3	1.71								
0.02	min. oil	38	0.987	14.5	1.79								
0.04	min. oil	37	0.994	13.6	1.76								
0.08	min. oil	36	0.996	13.2	1.70								
0.30	water	6	0.977	13.1	1.54								
0.04[d]	min. oil	D	0.988	12.3	1.59								

[a]Coefficient of determination.

[b]Geometric median diameter in micrometers

[c]Geometric standard deviation.

[d]Average of tests #35, 36, and 38.

Table 18. Log-normal particle size distribution parameters of Hi-Vol dust samples from the enclosed test bin with dust control system off.

Level %	Additive	Corn				Wheat				Soybeans			
		Test No.	r^{2a}	$\bar{d}^b$	s.d.[c]	Test No.	r^{2a}	$\bar{d}^b$	s.d.[c]	Test No.	r^{2a}	$\bar{d}^b$	s.d[c]
0.0	--	10	0.983	8.3	1.55	20	0.990	9.3	1.72	26	0.971	8.8	1.66
0.03	veg. oil	19	0.972	11.3	1.60	23	0.963	17.5	1.71	30	0.978	16.3	1.92
0.06	veg. oil	15	0.965	13.9	1.63	22	0.925	16.7	1.66	28	0.964	16.7	1.72
0.10	veg. oil	13	0.984	13.2	1.57								
0.02	min. oil	38	0.995	15.2	1.83								
0.04	min. oil	37	0.995	13.8	1.71								
0.08	min. oil	36	0.990	12.6	1.68								
0.30	water	6	0.982	10.4	1.61								
0.04[d]	min. oil	D	0.987	12.2	1.59								

[a]Coefficient of determination.

[b]Geometric median diameter in micrometers.

[c]Geometric standard deviation.

[d]Average of tests #35, 36, and 38.

Table 19. Control lots of wheat without additives

Dust control system	Pre-leg enclosed belt dust concentration gm/m^3	Gallery open belt dust concentration[a] gm/m^3	Drop test dust concentration gm/m^3	Bin overspace enclosed dust concentration gm/m^3
on	0.367	0.007	0.104	2.22
off	5.480[b]	0.100	0.073	1.76

[a]Hi-Vol sample rate was 60 cfm.

[b]Filter became loaded and sampling was stopped before end of test.

Table 20. Experimental lots of wheat treated with soybean oil as an additive

Level of additive %	Dust control system	Pre-leg enclosed belt dust concentration gm/m^3	Gallery open belt dust concentration[a] gm/m^3	Drop test dust concentration gm/m^3	Bin overspace enclosed dust concentration gm/m^3
0.02	off	2.01	0.023	0.003	0.515
0.02	off	14.04[b]	0.704	0.794	1.874
0.03	on	0.289	0.005	0.006	1.09
0.03	off	3.07[b]	0.025	0.003	0.261
0.03	off	3.42[b]	0.040	0.007	0.304
0.06	off	3.12[b]	0.029	0.003	0.262
0.06	off	2.46[b]	0.036	0.003	0.189

[a]Hi-Vol sample rate was 60 cfm.

[b]Filter became loaded and sampling was stopped before end of test.

Table 21. Percentage reduction in dust concentration for experimental lots of wheat treated with soybean oil as an additive

Level of additive %	Dust control system	Pre-leg enclosed belt dust concentration %	Gallery open belt dust concentration %	Drop test dust concentration %	Bin overspace enclosed dust concentration %
0.02	off	63.3	77.0	95.9	70.7
0.02	off	-156.2	-604.0	-987.7	6.5
0.03	on	21.3	28.6	94.2	50.9
0.03	off	44.0	75.0	95.9	85.2
0.03	off	37.6	60.0	90.4	82.7
0.06	off	43.1	71.0	95.9	85.1
0.06	off	55.1	64.0	95.9	89.3

Table 22. Control lots of soybeans without additive

Dust control system	Pre-leg enclosed belt dust concentration gm/m^3	Gallery open belt dust concentration[a] gm/m^3	Drop test dust concentration gm/m^3	Bin overspace enclosed dust concentration gm/m^3
on	1.12	0.017	0.147	5.60
off	7.88[b]	1.07	0.074	4.33[a,c]

[a]Hi-Vol sample rate was 60 cfm.

[b]Filter became loaded and sampling was stopped before end of test.

Table 23. Experimental lots of soybeans treated with soybean oil as an additive

Level of additive %	Dust control system	Pre-leg enclosed belt dust concentration gm/m³	Gallery open belt dust concentration[a] gm/m³	Drop test dust concentration gm/m³	Bin overspace enclosed dust concentration gm/m³
0.03	on	0.266	0.005	0.002	0.662
0.03	off	2.71[b]	0.030	0.002	0.456
0.03	off	7.74[b]	0.093	0.011	1.440
0.06	off	5.86[b]	0.079	0.002	0.466

[a]Hi-Vol sample rate was 60 cfm.

[b]Filter became loaded and sampling was stopped before end of test.

Table 24. Percentage reduction in dust concentration for experimental lots of soybeans treated with soybean oil as an additive

Level of additive %	Dust control system	Pre-leg enclosed belt dust concentration %	Gallery open belt dust concentration %	Drop test dust concentration %	Bin overspace enclosed dust concentration %
0.03	on	76.3	70.6	98.6	88.2
0.03	off	65.6	97.2	97.3	89.5
0.03	off	1.8	91.3	85.1	66.7
0.06	off	25.6	92.6	97.3	89.2

Table 25. Tailing dust collected during grain handling

	Level %	Additive	Work floor pounds	Garner pounds	Galley floor pounds	D house pounds	Total pounds	Dust saved pounds	Additive used pounds	Dust to additive ratio
5000 bu corn	none	none	183.75	---[a]	238.5	47	469.25	0	0	--
5000 bu corn	none	none	149.00	---[a]	188.5	56	393.5	0	0	--
5000 bu corn	.17	water	139.5	---[a]	169.5	67.5	376.5	92.75	457	.20
5000 bu corn	.17	water	83	---[a]	162.5	41	286.5	107.00	465	.23
2500 bu corn	.30	water	32.5	279.5	65.5	26.5	404.0	---[b]	422	
2500 bu corn	.18	water	32.25	153.0	55.0	39.0	279.5	21	257	.08
2500 bu corn	none	none	22.75	176.0	72.0	38.5	309.25	0	0	--
2500 bu corn	none	none	24.0	159.0	63.5	42.0	288.5	0	0	--
2500 bu corn	.10	veg. oil	13.5	77.0	19.5	19.5	129.5	170	154.2	1.10
2500 bu corn	.06	veg. oil	14.75	68.5	21.5	16.5	121.25	179	81.4	2.20
2500 bu corn	.03	veg. oil	15.25	71.5	24.0	10.0	120.75	179	43.5	4.10
2500 bu wheat	none	none	1.25	60.0	19.0	12.0	92.25	0	0	--
2500 bu wheat	.03	veg. oil	1.75	21.5	13.5	13.5	50.25	42	45.0	.93
2500 bu beans	none	none	6.5	58.0	31.0	15.0	110.5	0	0	--
2500 bu beans	.03	veg. oil	2.0	31.0	24.5	28.5	86.0	24	37.55	.64
2500 bu corn	.03	min. oil	55.25	73.0	30.0	12.0	170.25	129	43.3	3.00
2500 bu corn[c]	.04	min. oil	47.50	13.0	11.5	10.5	82.50	--	--	--
2500 bu corn[c]	none	none	15.00	17.0	39.0	23.5	94.5	--	--	--
2500 bu corn[c]	none	none	0.00	24.0	30.0	29.5	83.5	--	--	--

[a]Data not available. First 4 tests had different dust collecting dust arrangement.

[b]More dust collected than with control.

[c]After 3 months' storage grain was handled again.

Table 26. Particle distribution of grain dust collected per 2500-bushel test lot at work floor

Test No.	Grain	Level %	Additive	>1.0mm lbs	>0.5mm lbs	>0.25mm lbs	>0.125mm lbs	<0.125mm lbs	Total dust lbs
9	Corn	0.0	—	0.9	1.1	1.3	3.0	16.5	22.8
12	Corn	0.0	—	1.2	1.0	1.0	1.1	19.7	24.0
7	Corn	0.18	Water	1.2	1.0	1.2	1.8	27.1	32.3
5	Corn	0.30	Water	0.3	0.4	0.5	1.0	30.4	32.5
18	Corn	0.03	Veg. oil	1.4	1.4	2.2	7.8	2.4	15.3
17	Corn	0.06	Veg. oil	1.7	3.3	8.3	0.4	1.1	14.8
14	Corn	0.10	Veg. oil	0.9	0.8	8.9	0.8	2.0	13.5
35	Corn	0.02	Min. oil	1.2	2.0	35.5	11.2	5.3	55.3
B	Corn	0.04	Min. oil	7.6	12.7	25.3	1.0	1.0	47.5
E	Corn	0.0	—	3.0	2.1	4.5	4.4	1.0	15.0
F	Corn	0.0	—	0.0	0.0	0.0	0.0	0.0	0.0
21	Wheat	0.0	—	0.4	0.2	0.3	0.1	0.2	1.2
24	Wheat	0.03	Veg. oil	0.4	0.3	0.4	0.5	0.2	1.8
27	Soybeans	0.0	—	1.1	0.9	1.0	0.9	2.5	6.5
29	Soybeans	0.03	Veg. oil	0.5	0.3	0.5	0.4	0.2	2.0

Table 27. Particle distribution of grain dust collected per 2500-bushel test lot at garner

Test No.	Grain	Level %	Additive	>1.0mm lbs	>0.5mm lbs	>0.25mm lbs	>0.125mm lbs	<0.125mm lbs	Total dust lbs
9	Corn	0.0	—	18.5	12.8	10.1	10.5	124.2	176.0
12	Corn	0.0	—	20.0	11.9	9.2	7.6	110.0	159.0
7	Corn	0.18	Water	36.7	18.4	13.8	10.7	73.4	153.0
5	Corn	0.30	Water	30.0	29.9	47.7	59.3	112.6	279.5
18	Corn	0.03	Veg. oil	13.2	11.5	42.9	1.0	2.9	71.5
17	Corn	0.06	Veg. oil	16.2	17.4	28.6	1.0	5.0	68.5
14	Corn	0.10	Veg. oil	17.1	9.7	10.1	29.5	10.6	77.0
35	Corn	0.02	Min. oil	13.4	11.5	28.6	13.8	5.7	73.0
B	Corn	0.04	Min. oil	1.1	1.9	8.8	0.8	0.4	13.0
E	Corn	0.0	—	1.8	1.6	2.2	7.2	4.3	17.0
F	Corn	0.0	—	3.0	2.3	3.3	9.5	6.0	24.0
21	Wheat	0.0	—	9.2	5.2	5.9	16.9	22.7	60.0
24	Wheat	0.03	Veg. oil	5.4	2.8	3.0	5.4	4.4	21.5
27	Soybeans	0.0	—	15.7	4.1	4.0	4.7	29.5	58.0
29	Soybeans	0.03	Veg. oil	16.2	3.3	2.6	5.8	3.0	31.0

Table 28. Particle distribution of grain dust collected per 2500-bushel test lot at gallery

Test No.	Grain	Level %	Additive	>1.0mm lbs	>0.5mm lbs	>0.25mm lbs	>0.125mm lbs	<0.125mm lbs	Total dust lbs
9	Corn	0.0	—	3.6	4.2	6.4	8.1	49.7	72.0
12	Corn	0.0	—	4.5	4.5	6.2	6.8	41.6	63.5
7	Corn	0.18	Water	4.5	4.8	6.1	6.4	33.2	55.0
5	Corn	0.30	Water	4.0	4.6	6.2	9.1	41.7	65.5
18	Corn	0.03	Veg. oil	3.4	4.7	13.7	0.9	1.3	24.0
17	Corn	0.06	Veg. oil	3.1	5.4	11.3	0.7	1.0	21.5
14	Corn	0.10	Veg. oil	5.4	4.7	8.1	0.4	0.9	19.5
35	Corn	0.02	Min. oil	4.1	5.3	7.9	10.1	2.5	30.0
B	Corn	0.04	Min. oil	1.8	2.6	5.5	1.1	0.5	11.5
E	Corn	0.0	—	5.3	5.2	6.1	12.0	10.4	39.0
F	Corn	0.0	—	3.2	3.2	4.2	8.6	10.8	30.0
21	Wheat	0.0	—	1.6	2.5	5.9	4.7	4.3	19.0
24	Wheat	0.03	Veg. oil	1.5	2.0	4.6	3.5	1.9	13.5
27	Soybeans	0.0	—	4.9	4.9	5.5	5.4	10.4	31.0
29	Soybeans	0.03	Veg. oil	5.0	5.5	7.0	4.1	3.0	24.5

Table 30. Effect of 3 months' storage on dustiness of corn treated with mineral oil

Dust control system	Pre-leg enclosed belt dust concentration gm/m^3	Gallery open belt dust concentration gm/m^3	Drop test dust concentration gm/m^3	Bin overspace enclosed dust concentration gm/m^3
Control				
off	25.74 [a]	0.547	1.076	4.29
on	0.518	0.009	1.534	1.76
on	1.252	0.006	1.454	1.97
Mineral oil treatment (0.04%)[b]				
off	1.591	0.024	---[c]	0.533
off	1.986	0.022	---[c]	0.664
off	1.098	0.021	---[c]	0.750
on	0.036	0.003	0.106	0.428

[a]Filter became loaded and sampling was stopped before end of test.

[b]Average of the grain lot treatment, no additional oil added.

[c]Data not available.

LIST OF FIGURES

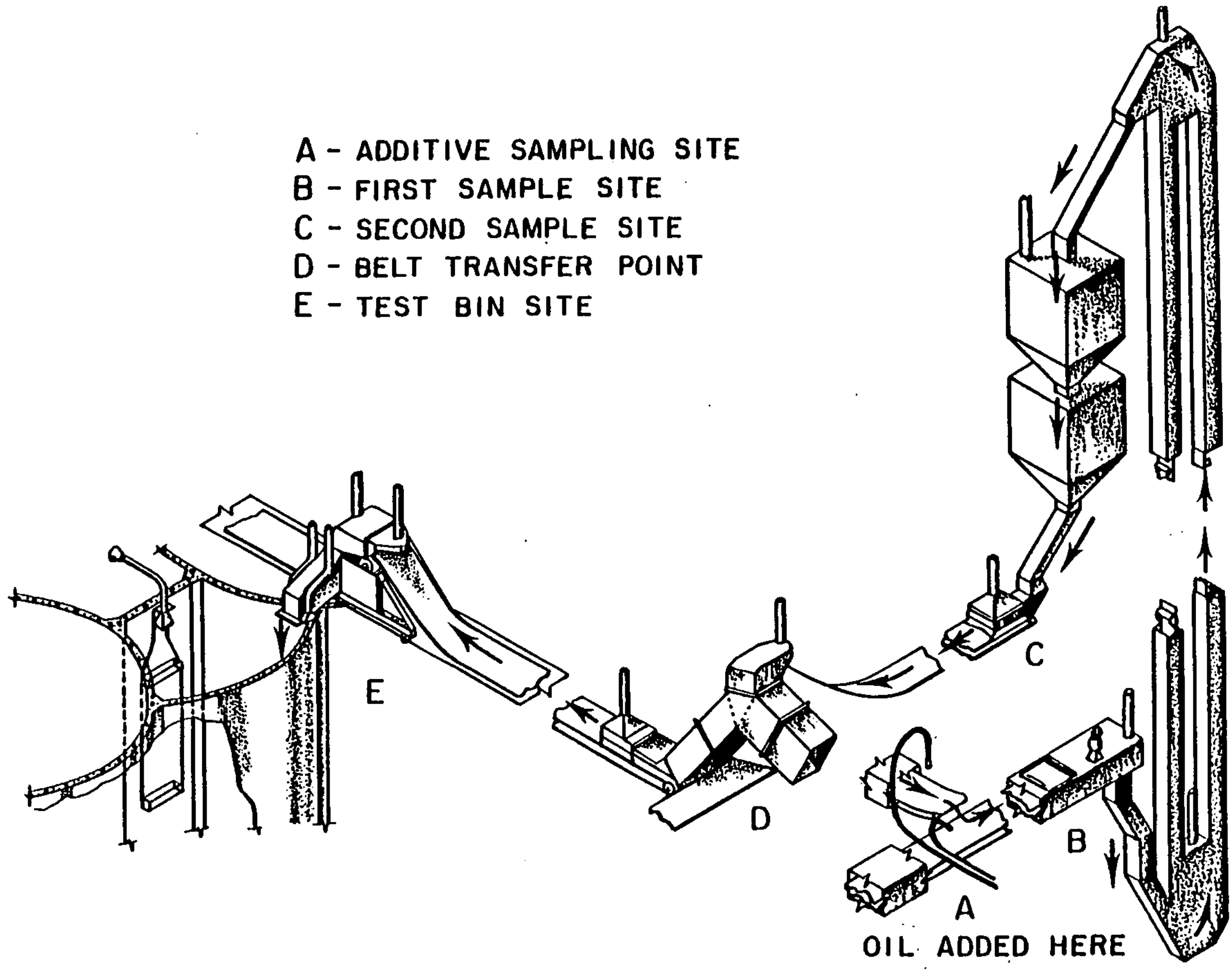

FIG. I Test facilities of grain handling systems for additive study.

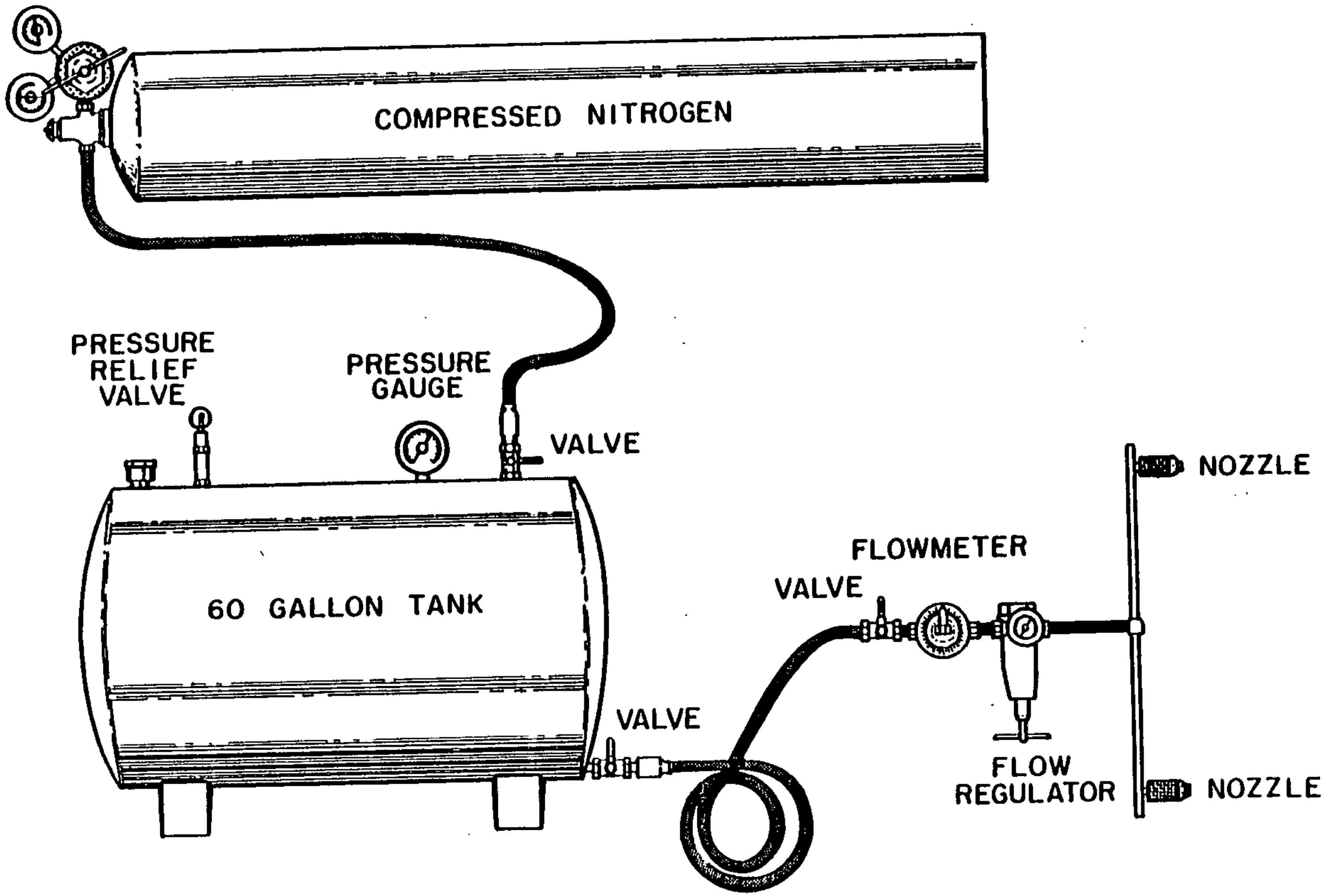

FIG. 2 Liquid additive spraying system.

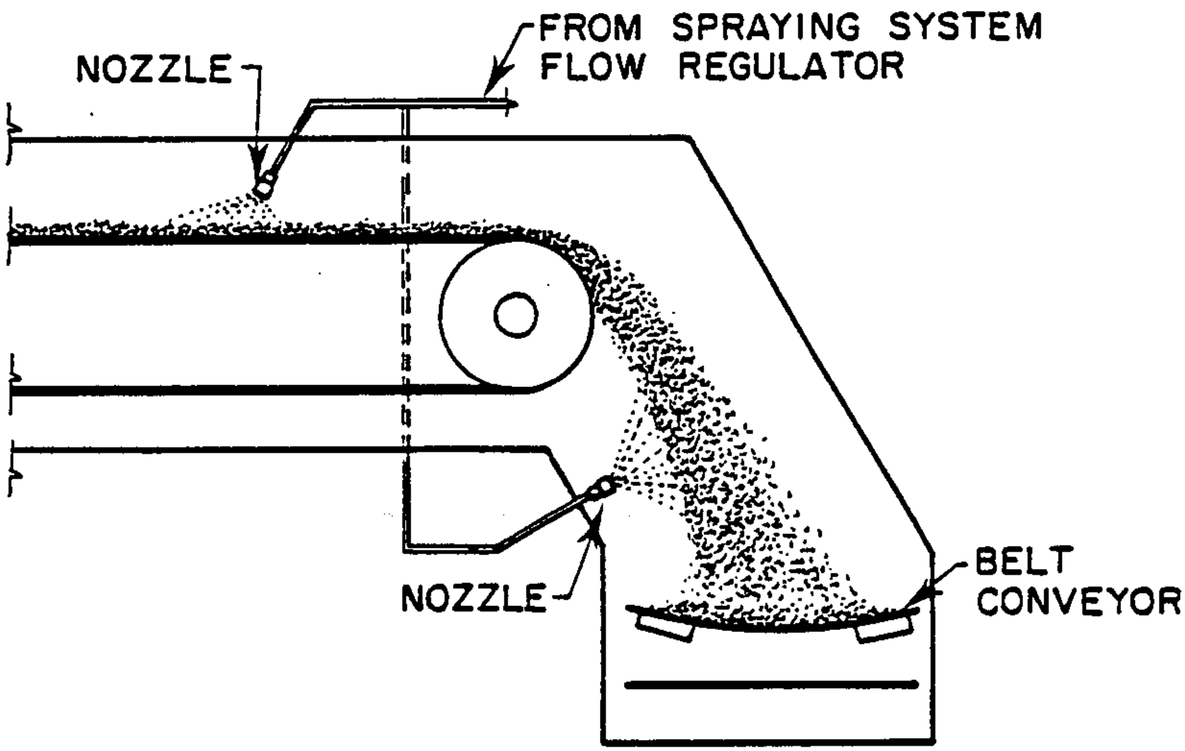

FIG. 3 Additive spraying site.

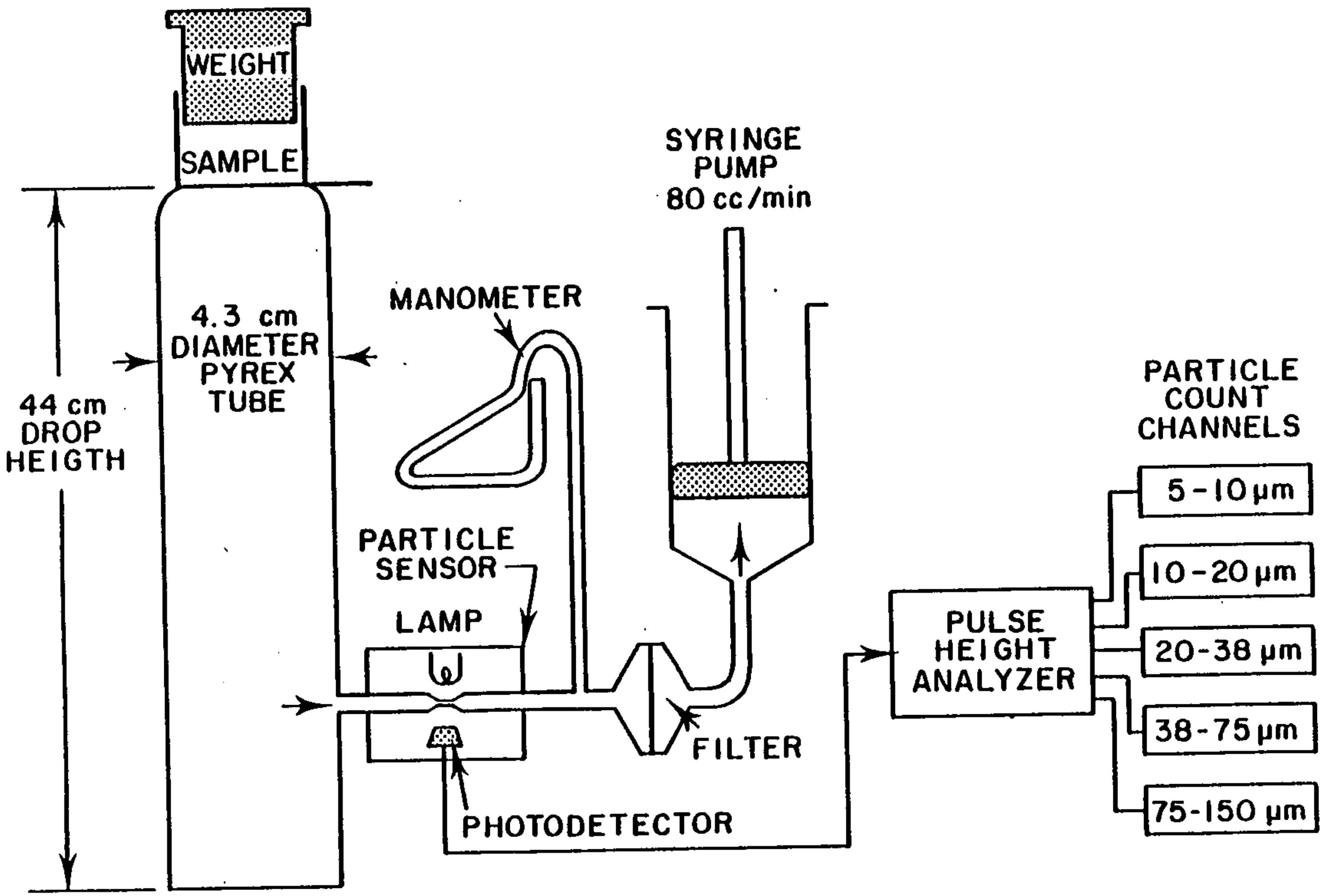

Fig. 4 APPARATUS FOR MEASURING DUSTINESS OF SMALL SAMPLES

Table 29. Particle distribution of grain dust collected per 2500-bushel test lot in enclosed bin overspace

Test No.	Grain	Level %	Additive	>1.0mm lbs	>0.5mm lbs	>0.25mm lbs	>0.125mm lbs	<0.125mm lbs	Total dust lbs
9	Corn	0.0	—	3.6	4.2	6.4	8.1	49.7	72.0
12	Corn	0.0	—	4.5	4.5	6.2	6.8	41.6	63.5
7	Corn	0.18	Water	4.5	4.8	6.1	6.4	33.2	55.0
5	Corn	0.30	Water	4.0	4.6	6.2	9.1	41.7	65.5
18	Corn	0.03	Veg. oil	3.4	4.7	13.7	0.9	1.3	24.0
17	Corn	0.06	Veg. oil	3.1	5.4	11.3	0.7	1.0	21.5
14	Corn	0.10	Veg. oil	5.4	4.7	8.1	0.4	0.9	19.5
35	Corn	0.02	Min. oil	4.1	5.3	7.9	10.1	2.5	30.0
B	Corn	0.04	Min. oil	1.8	2.6	5.5	1.1	0.5	11.5
E	Corn	0.0	—	5.3	5.3	6.1	12.0	10.4	39.0
F	Corn	0.0	—	3.2	3.2	4.2	8.6	10.8	30.0
21	Wheat	0.0	—	1.6	2.5	5.9	4.7	4.3	19.0
24	Wheat	0.03	Veg. oil	1.5	2.0	4.6	3.5	1.9	13.5
27	Soybeans	0.0	—	4.9	4.9	5.5	5.4	10.4	31.0
29	Soybeans	0.3	Veg. oil	5.0	5.5	7.0	4.1	3.0	24.5

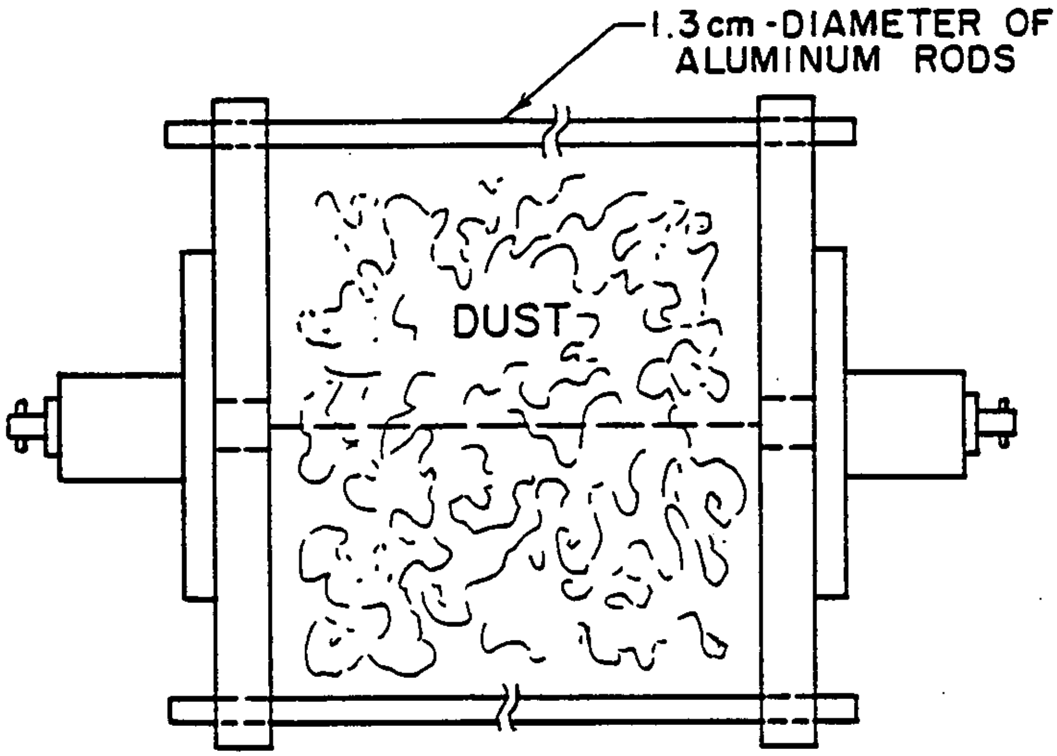

Fig. 5 Mounting brackets for field measurements. The light path can be varied by changing the length of the Aluminum rods.

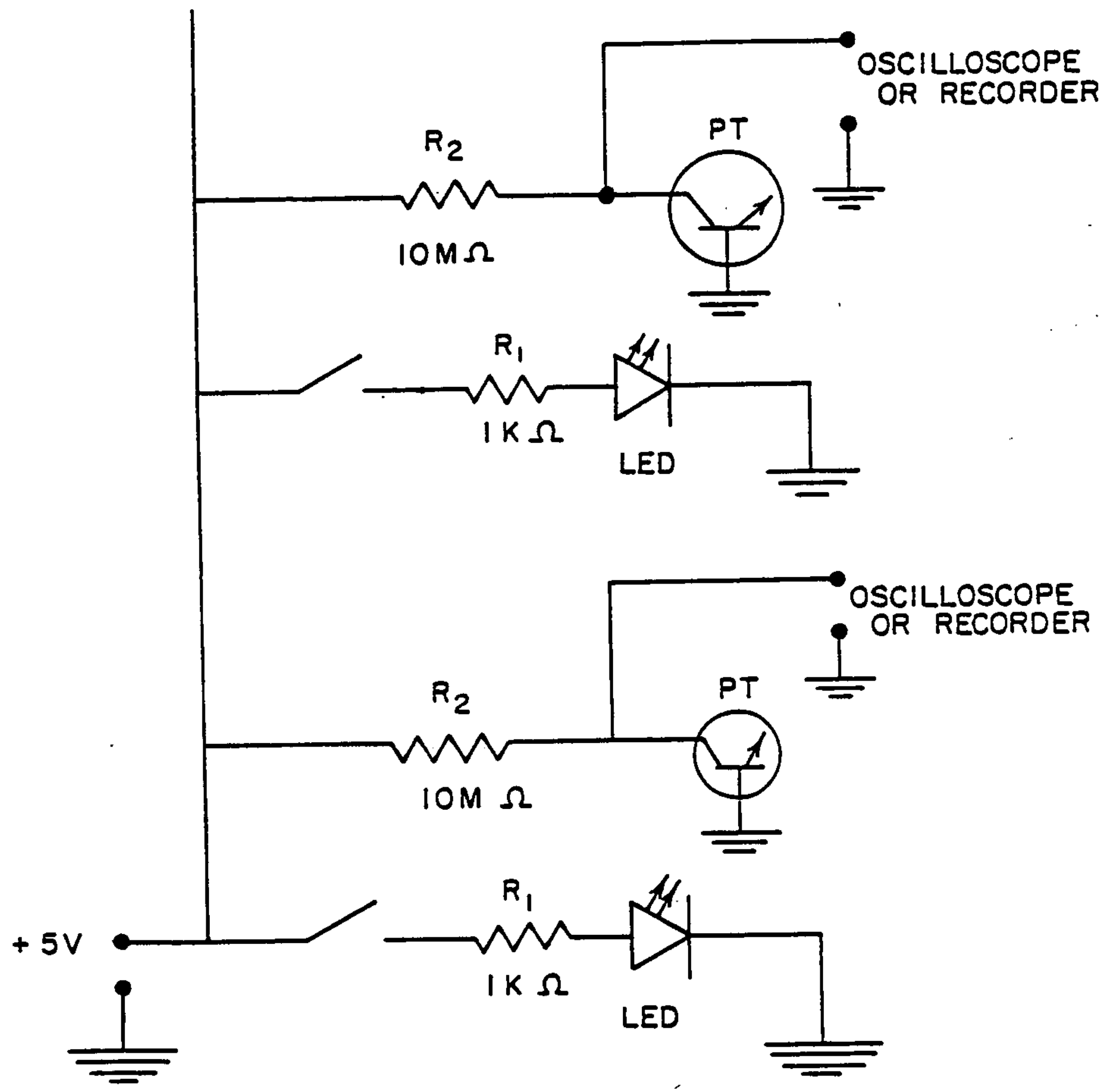

Fig. 6 Schematic of the PT circuit. The same power supply is used to power multiple probes.

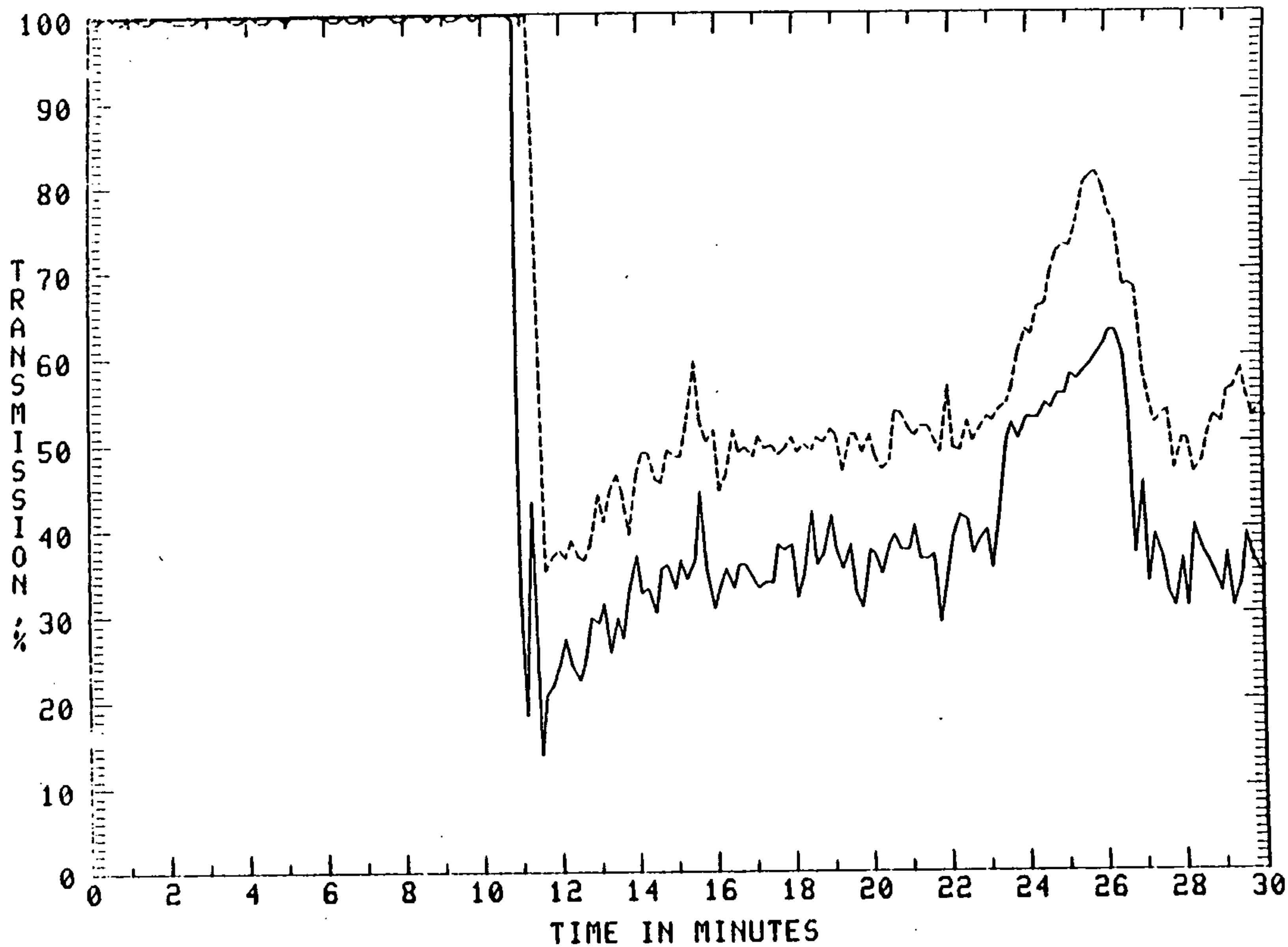

Fig. 7(1). TEST NO.1. CORN WHITHOUT ADDITIVE WITH DUST CONTROL SYSTEM ON

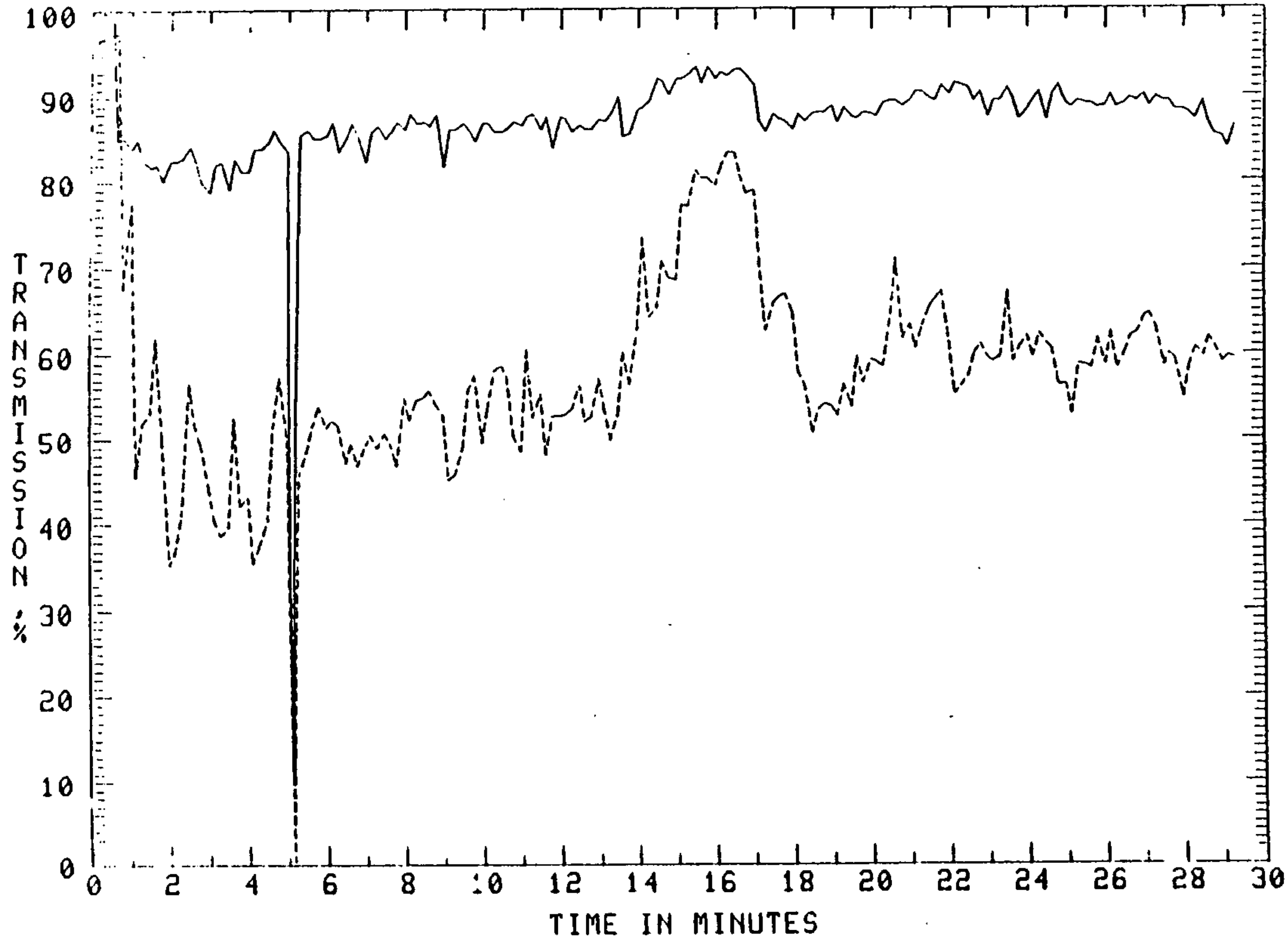

Fig. 7(2). TEST NO.2. CORN WITHOUT ADDITIVE WITH DUST CONTROL SYSTEM ON

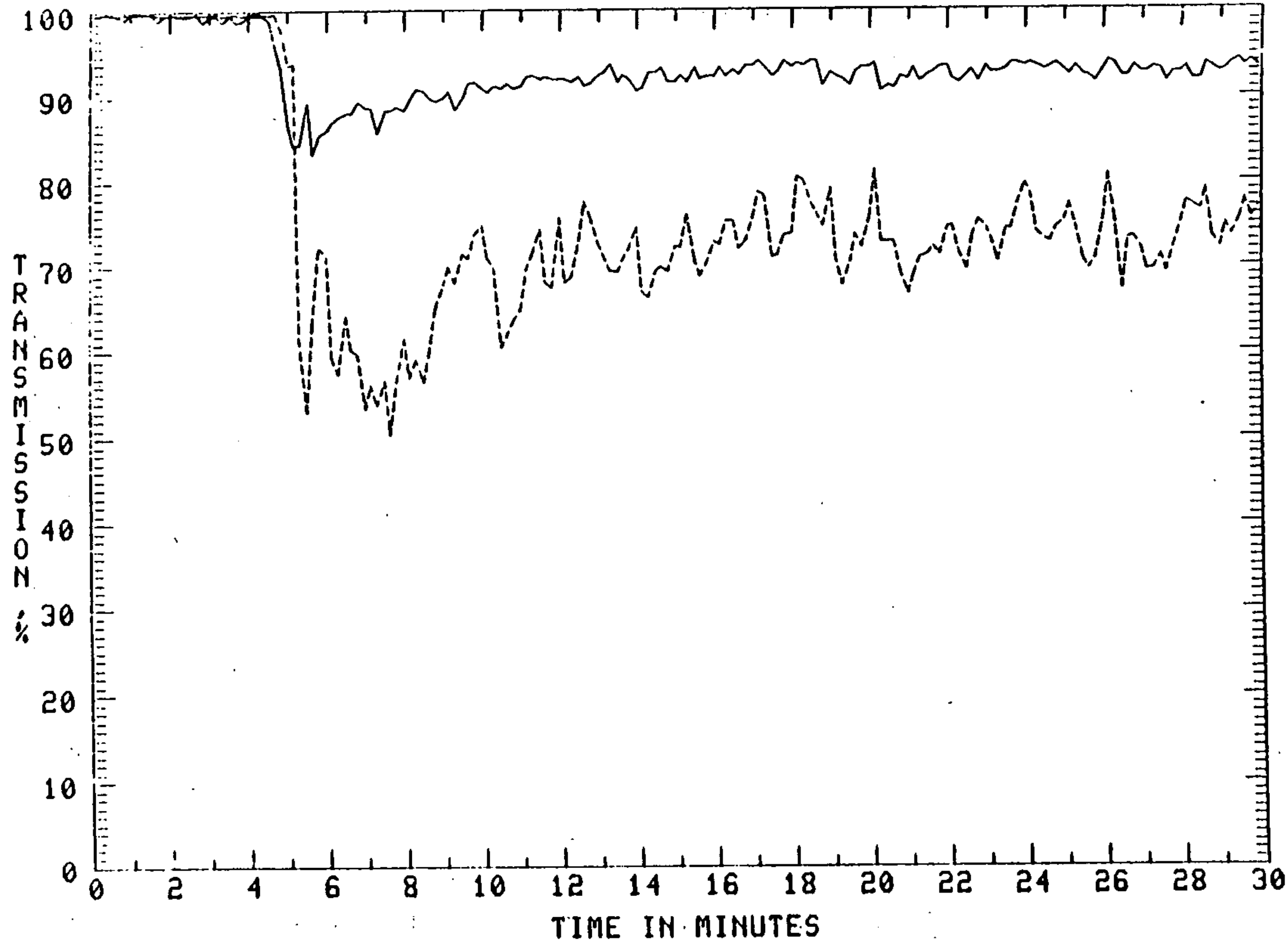

Fig. 7(3). TEST NO.3. CORN WITH .17 % WATER DUST CONTROL SYSTEM ON

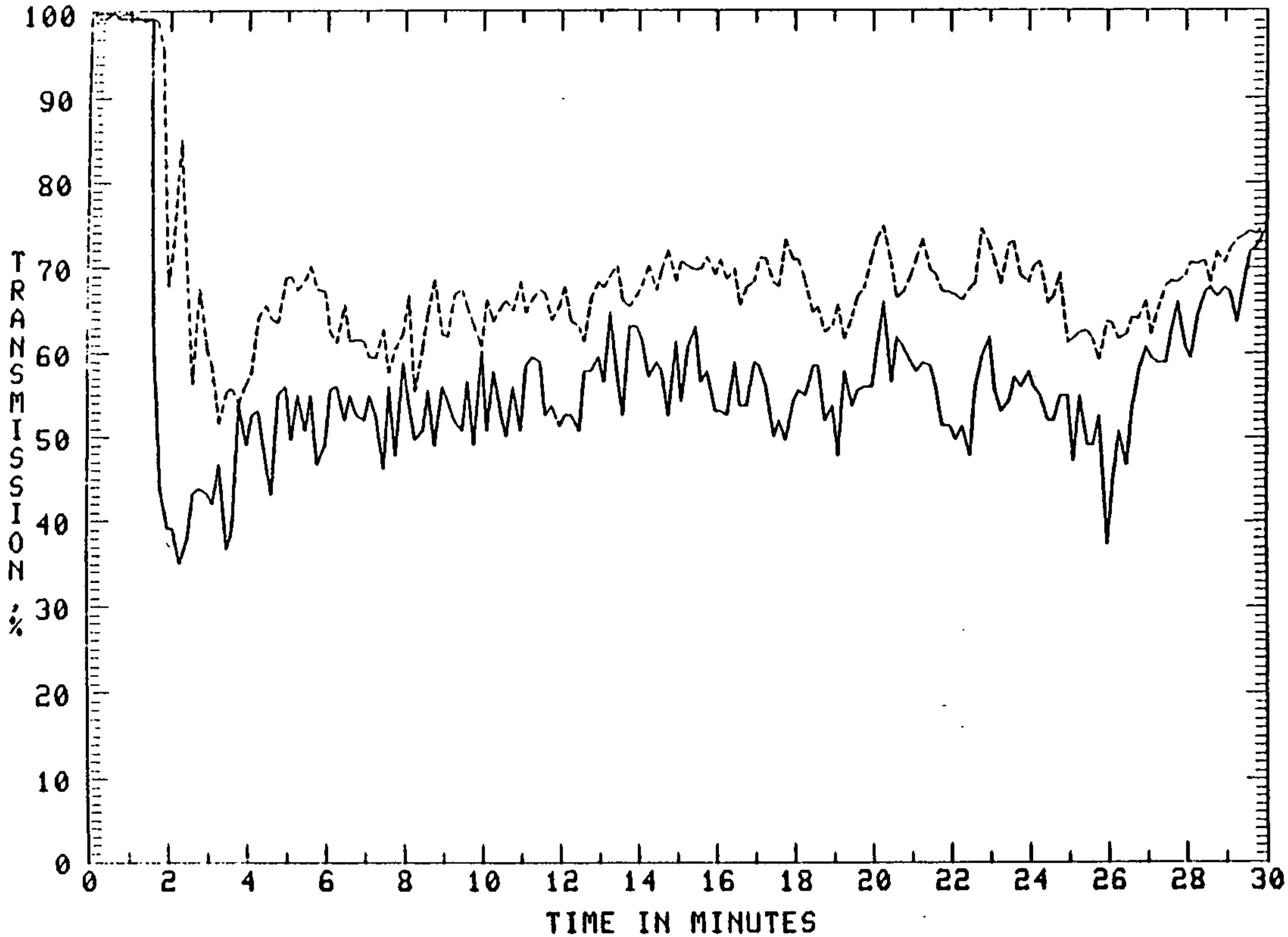

Fig. 7(4). TEST NO.4. CORN WITH .17 % WATER DUST CONTROL SYSTEM ON

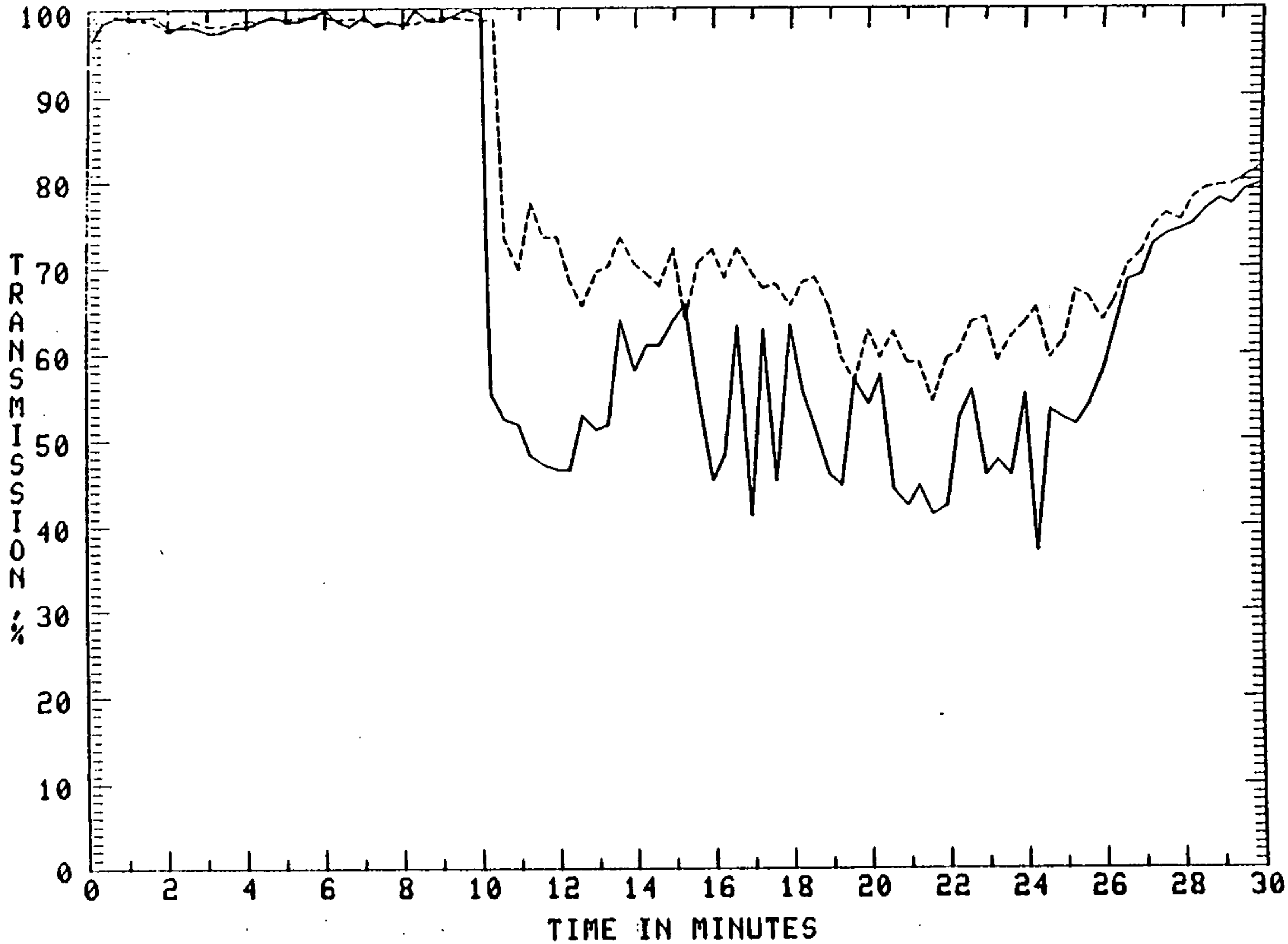

Fig. 7(5). TEST NO.5. CORN WITH .30 % WATER DUST CONTROL SYSTEM ON

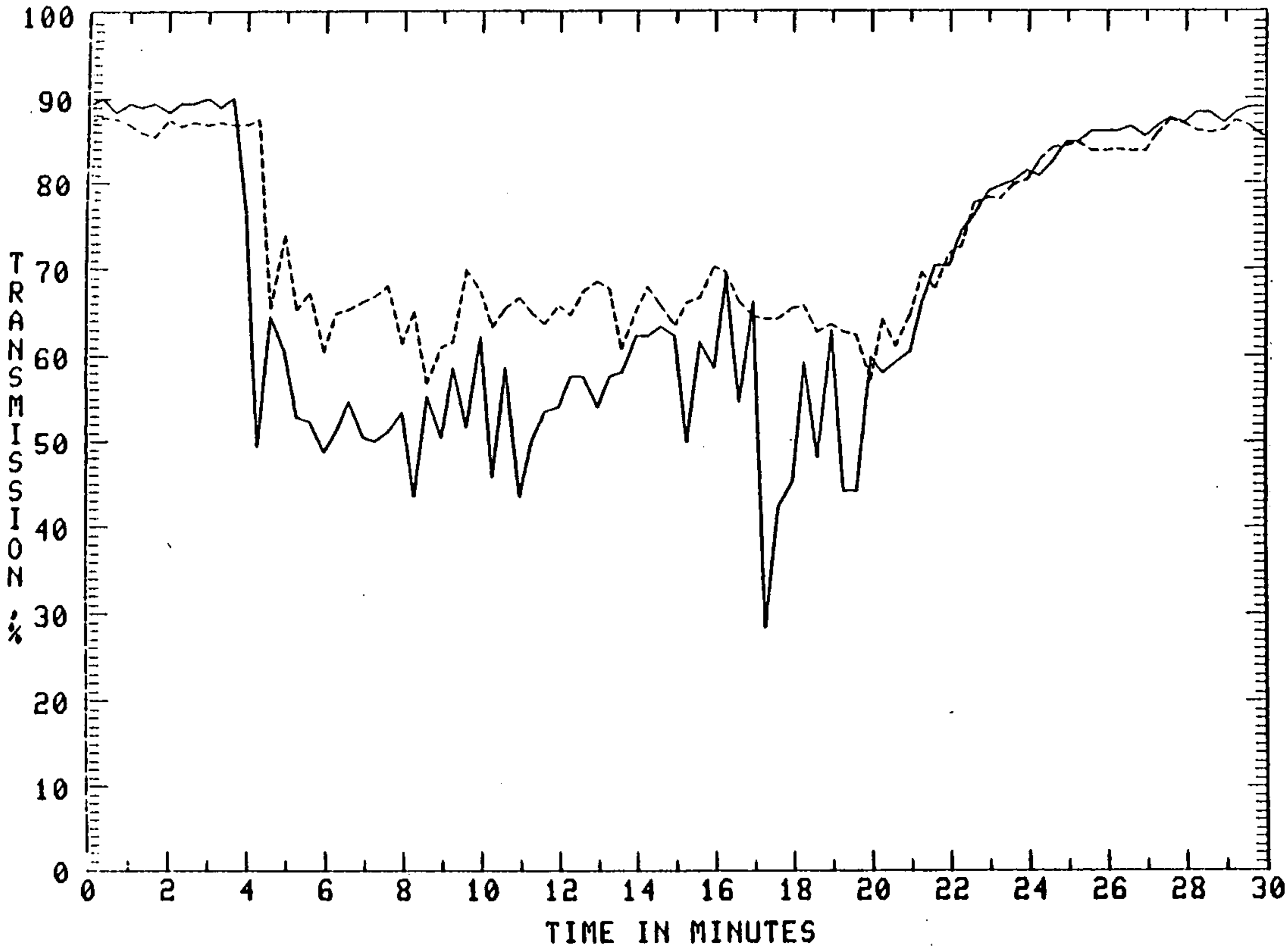

Fig. 7(6). TEST NO.6. CORN WITH .30 % WATER DUST CONTROL SYSTEM OFF

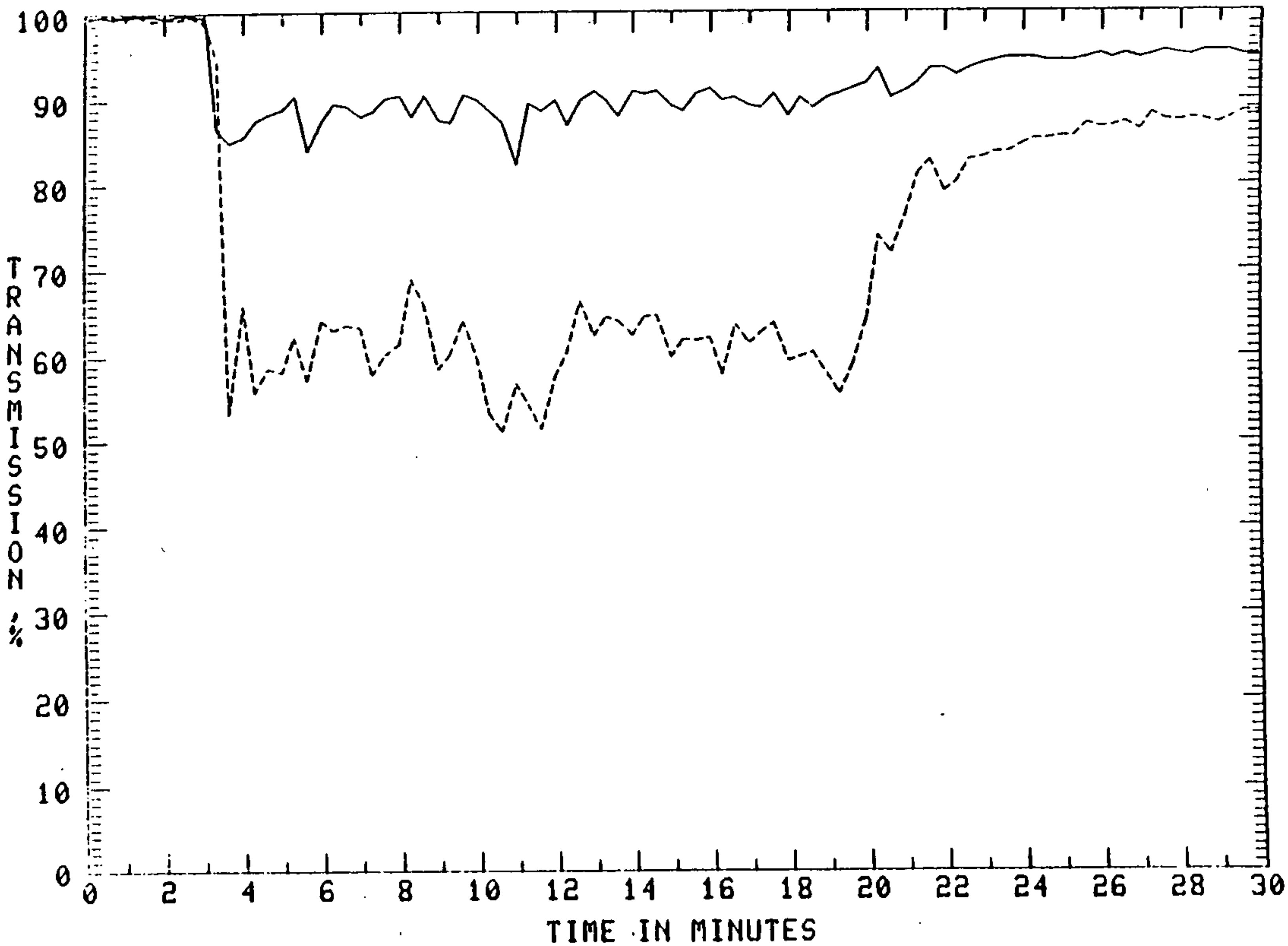

Fig. 7(7). TEST NO.7. CORN WITH .18 % WATER DUST CONTROL SYSTEM ON

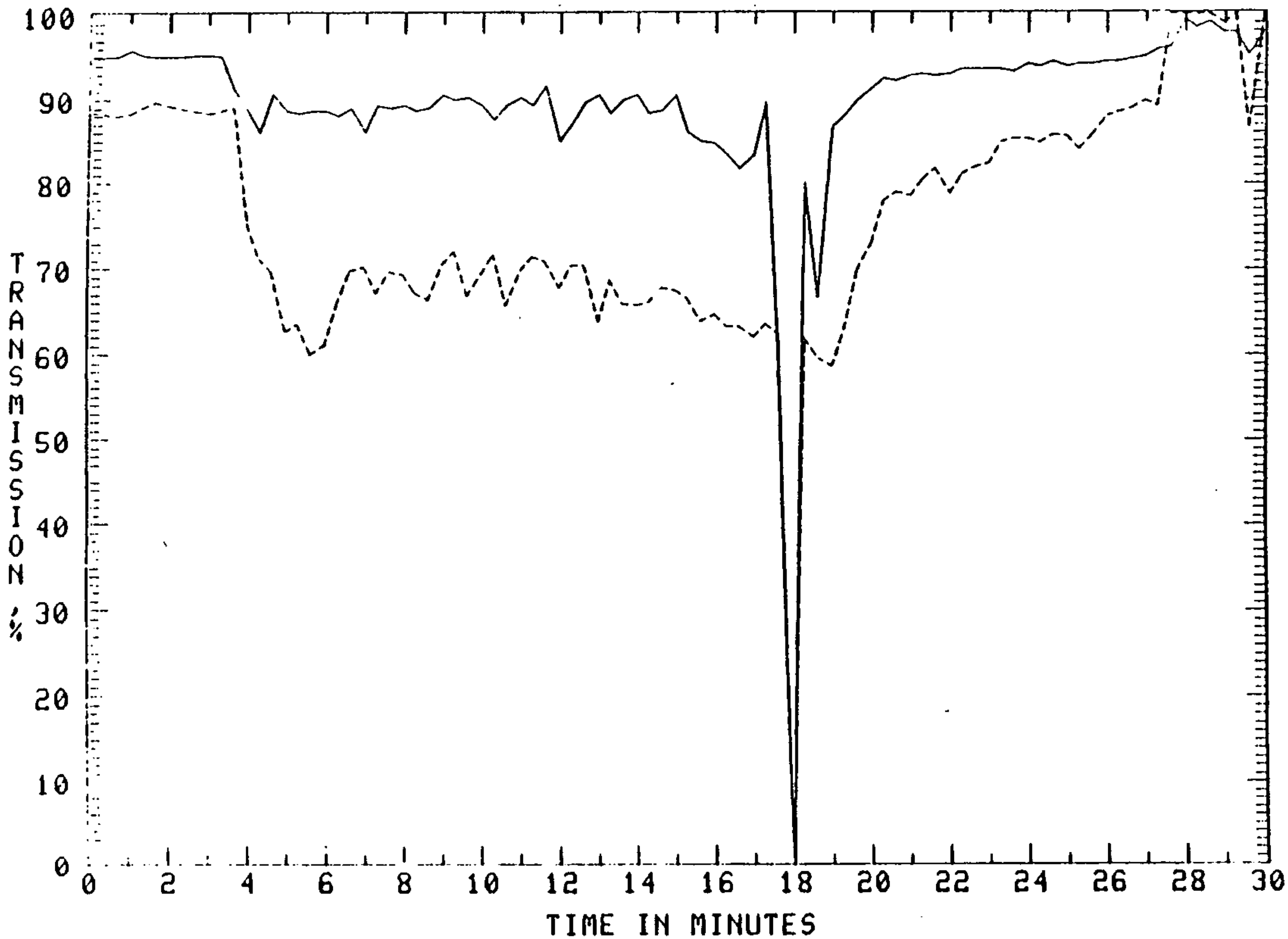

Fig. 7(8). TEST NO.8. CORN WITH .18 % WATER DUST CONTROL SYSTEM OFF

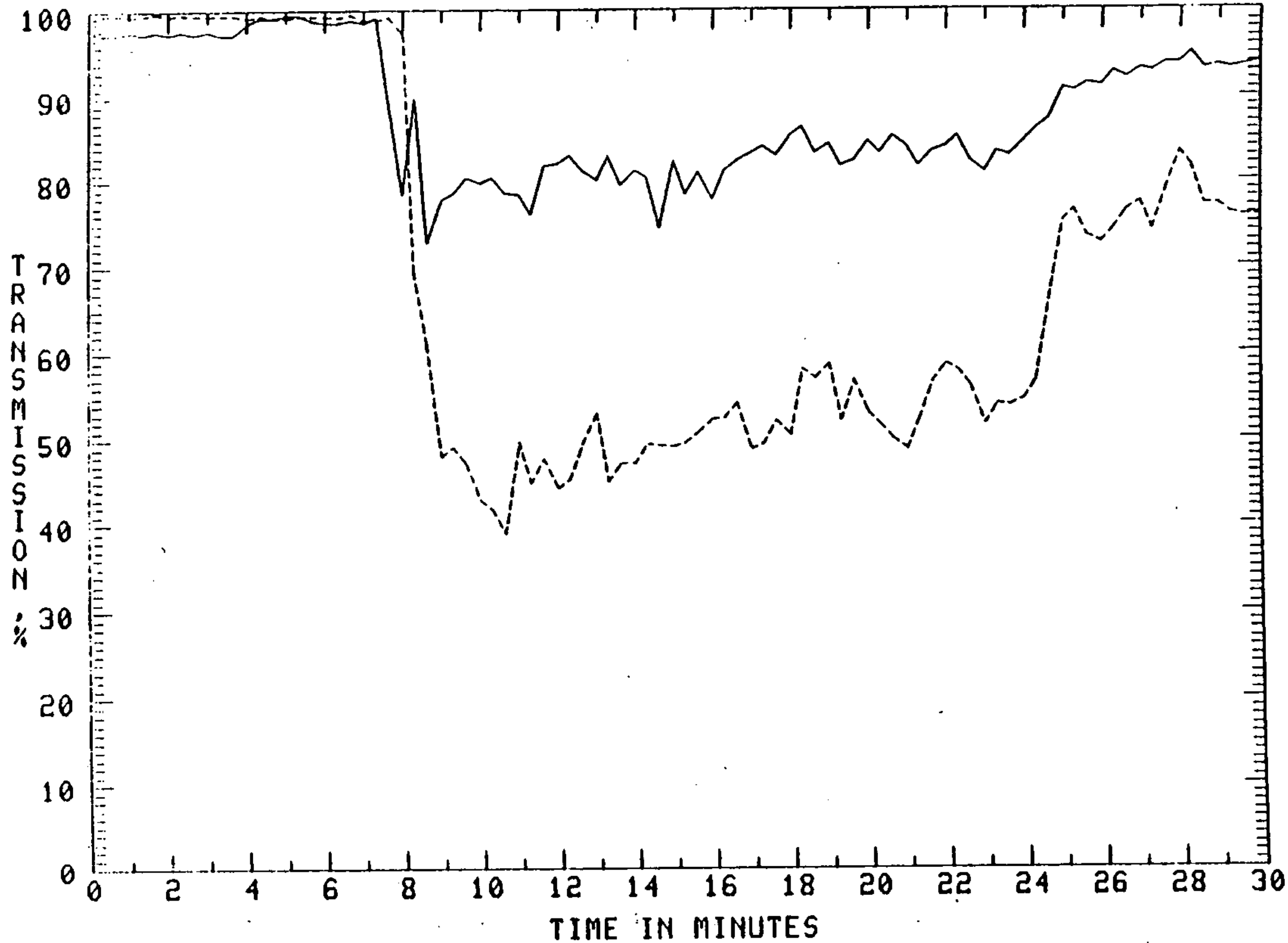

Fig. 7(9). TEST NO.9. CORN WITHOUT ADDITIVE DUST CONTROL SYSTEM ON

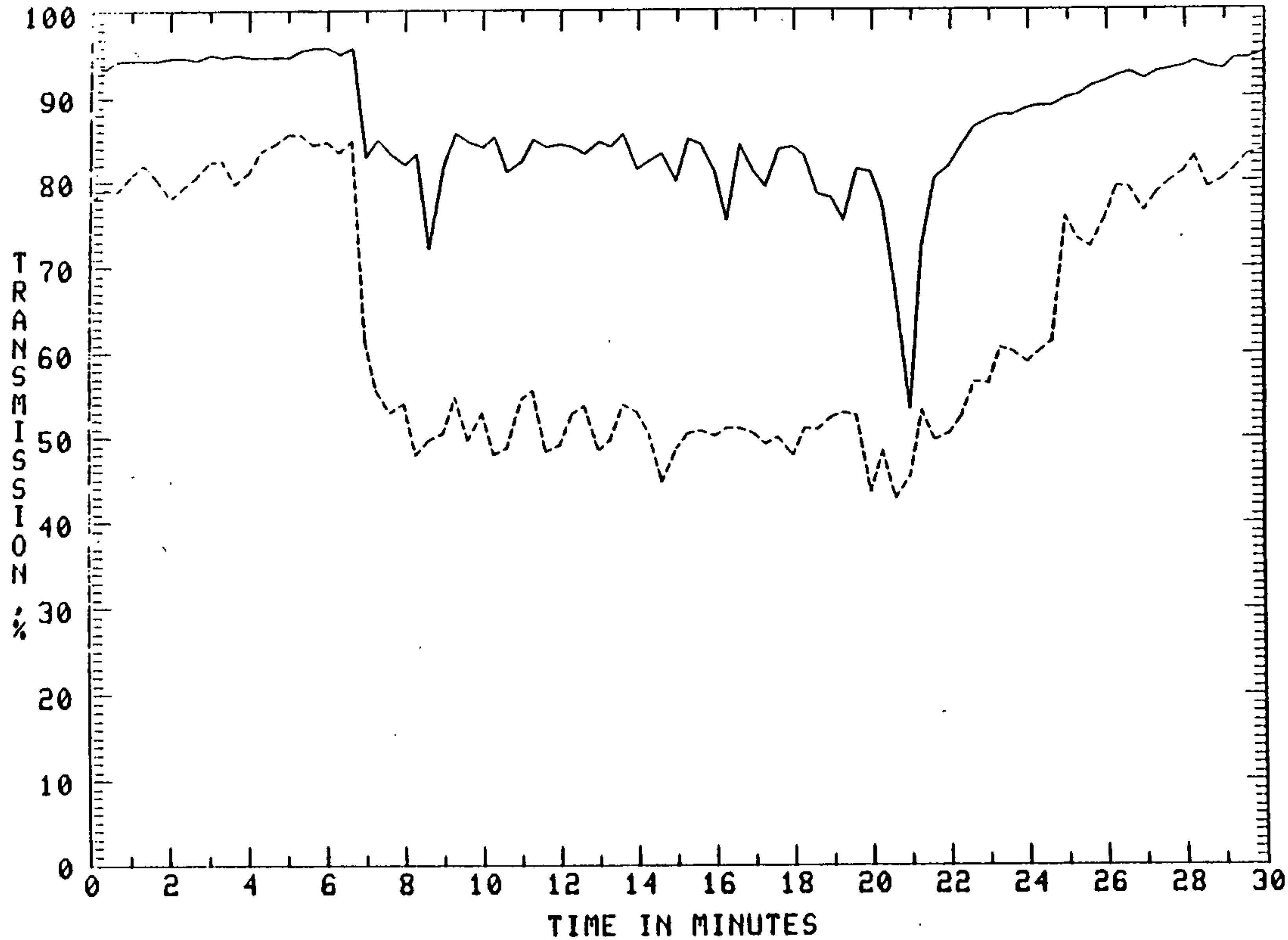

Fig. 7(10). TEST NO.10. CORN WITHOUT ADDITIVE DUST CONTROL SYSTEM OFF

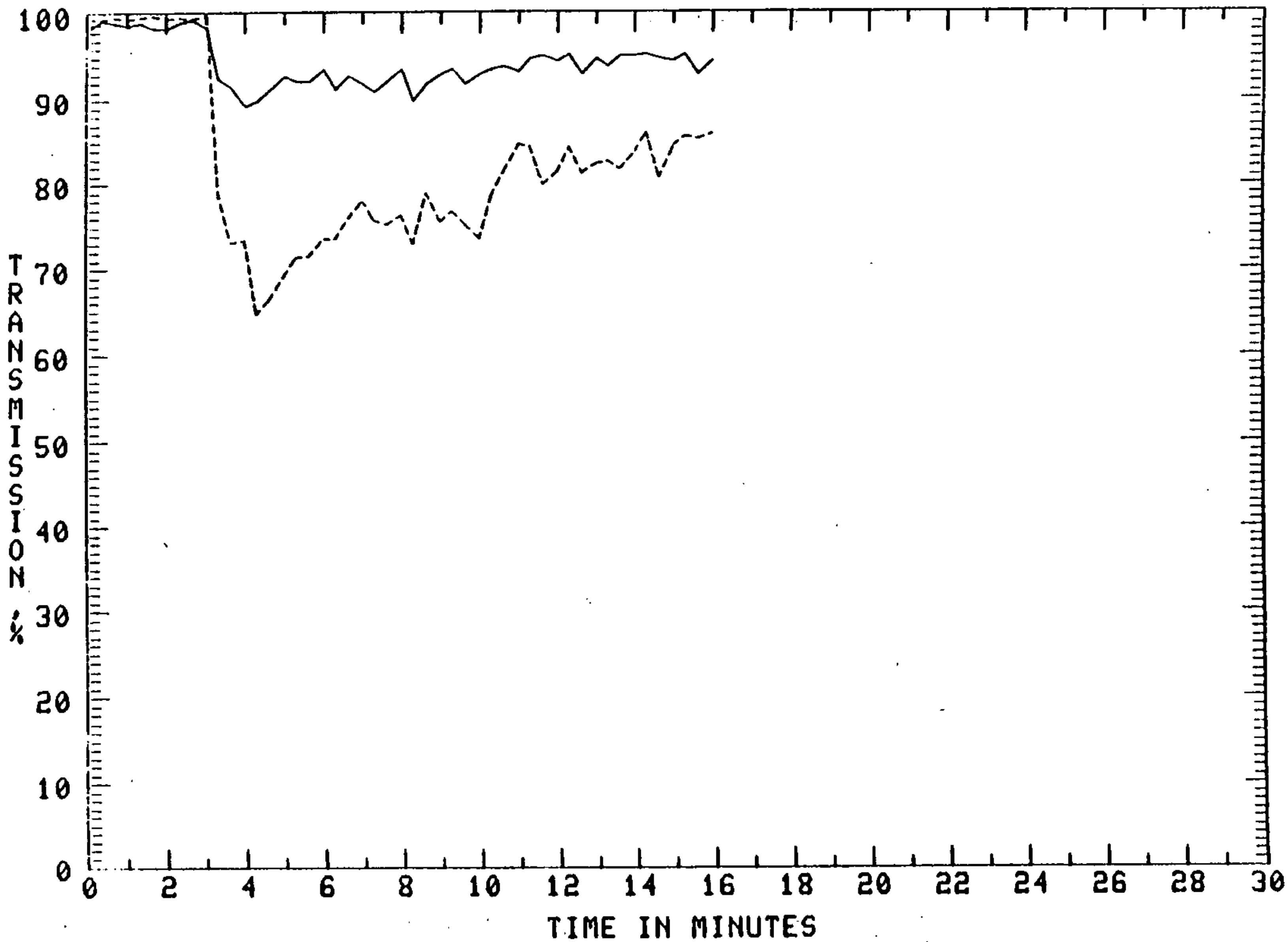

Fig. 7(11). TEST NO.11. CORN WITH .33 % WATER DUST CONTROL SYSTEM OFF

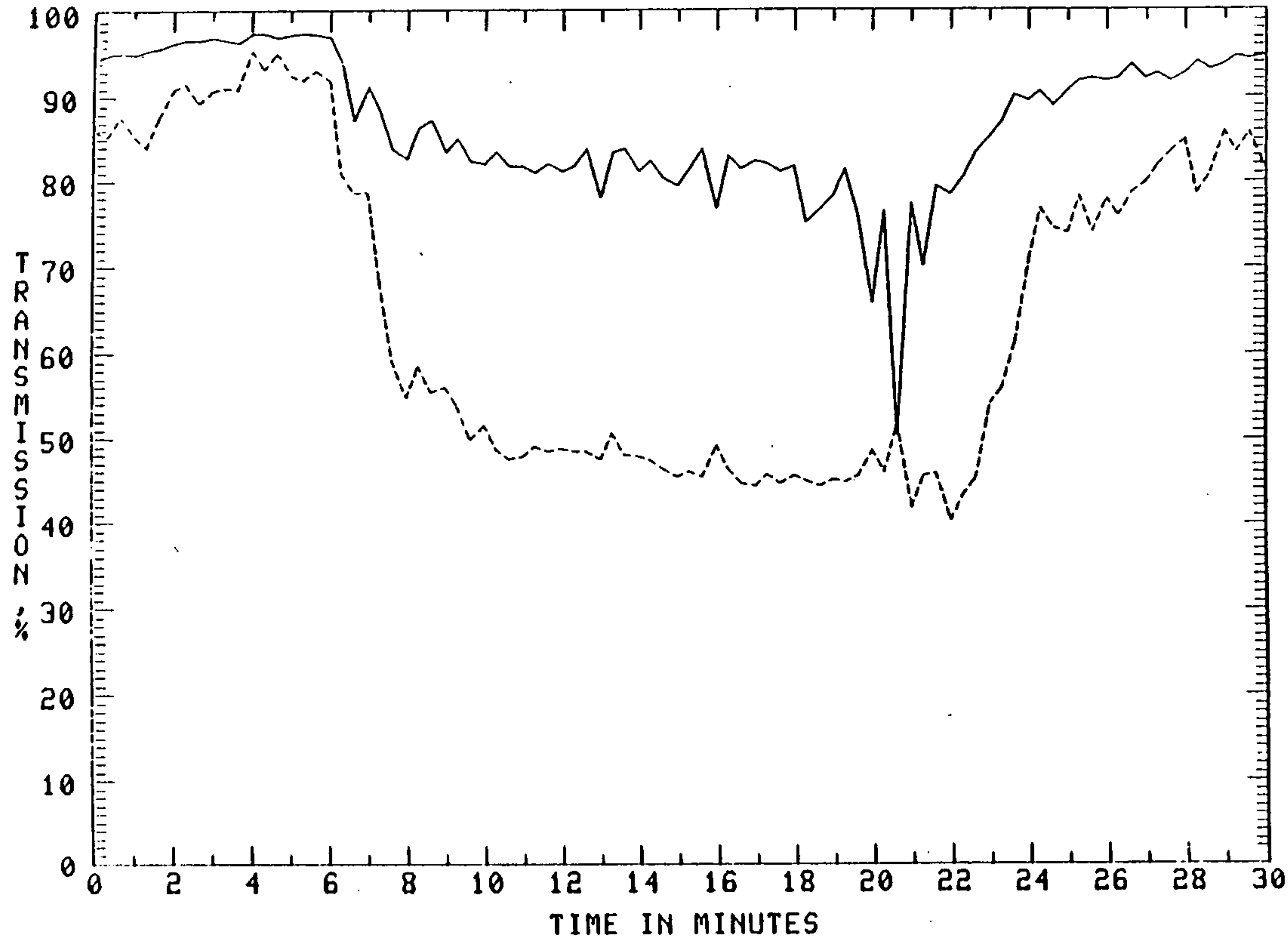

Fig. 7(12). TEST NO.12. CORN WITHOUT ADDITIVE DUST CONTROL SYSTEM ON

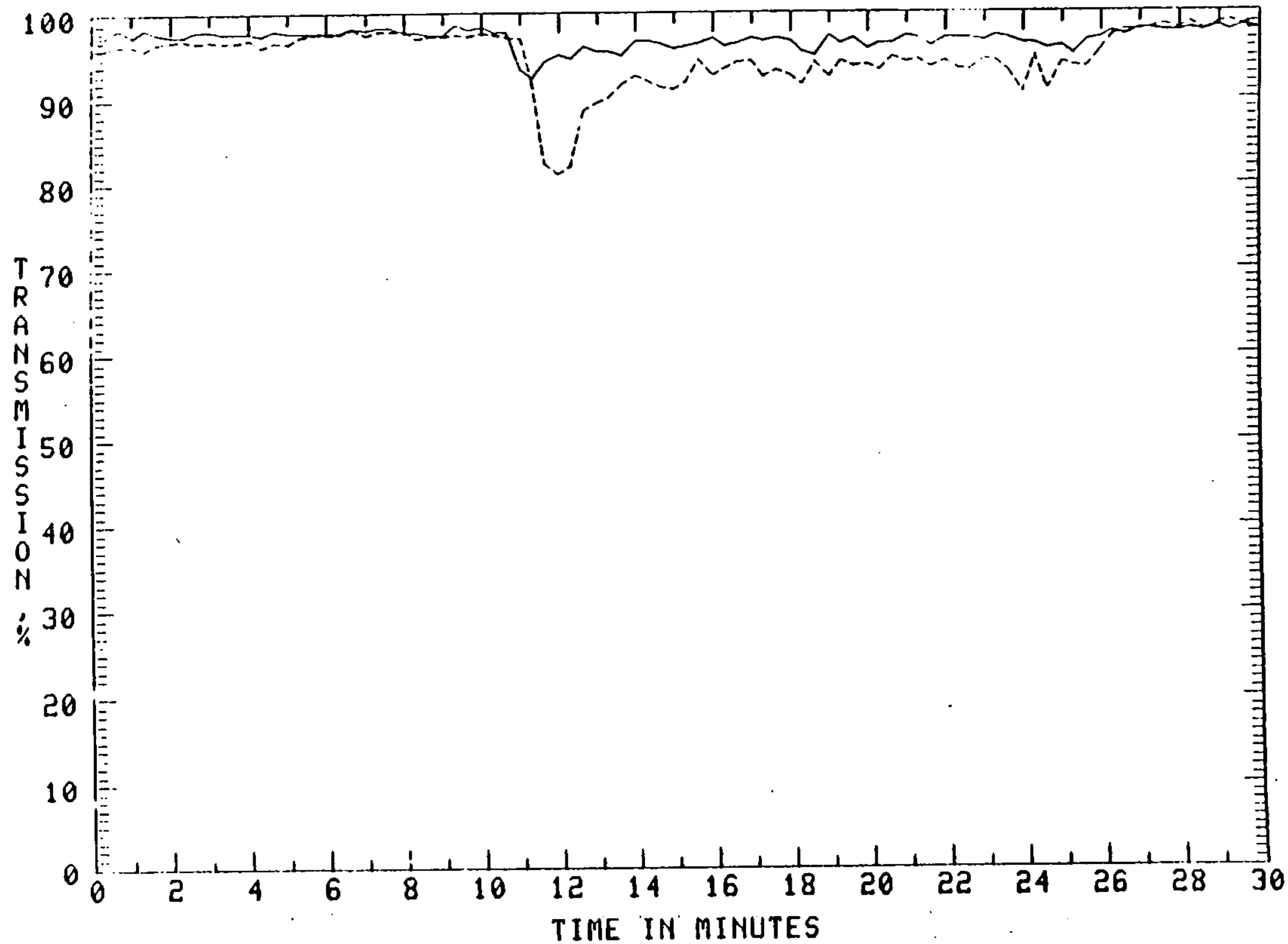

Fig. 7(13). TEST NO.13. CORN WITH .10 % SYOBEAN OIL DUST CONTROL SYSTEM OFF

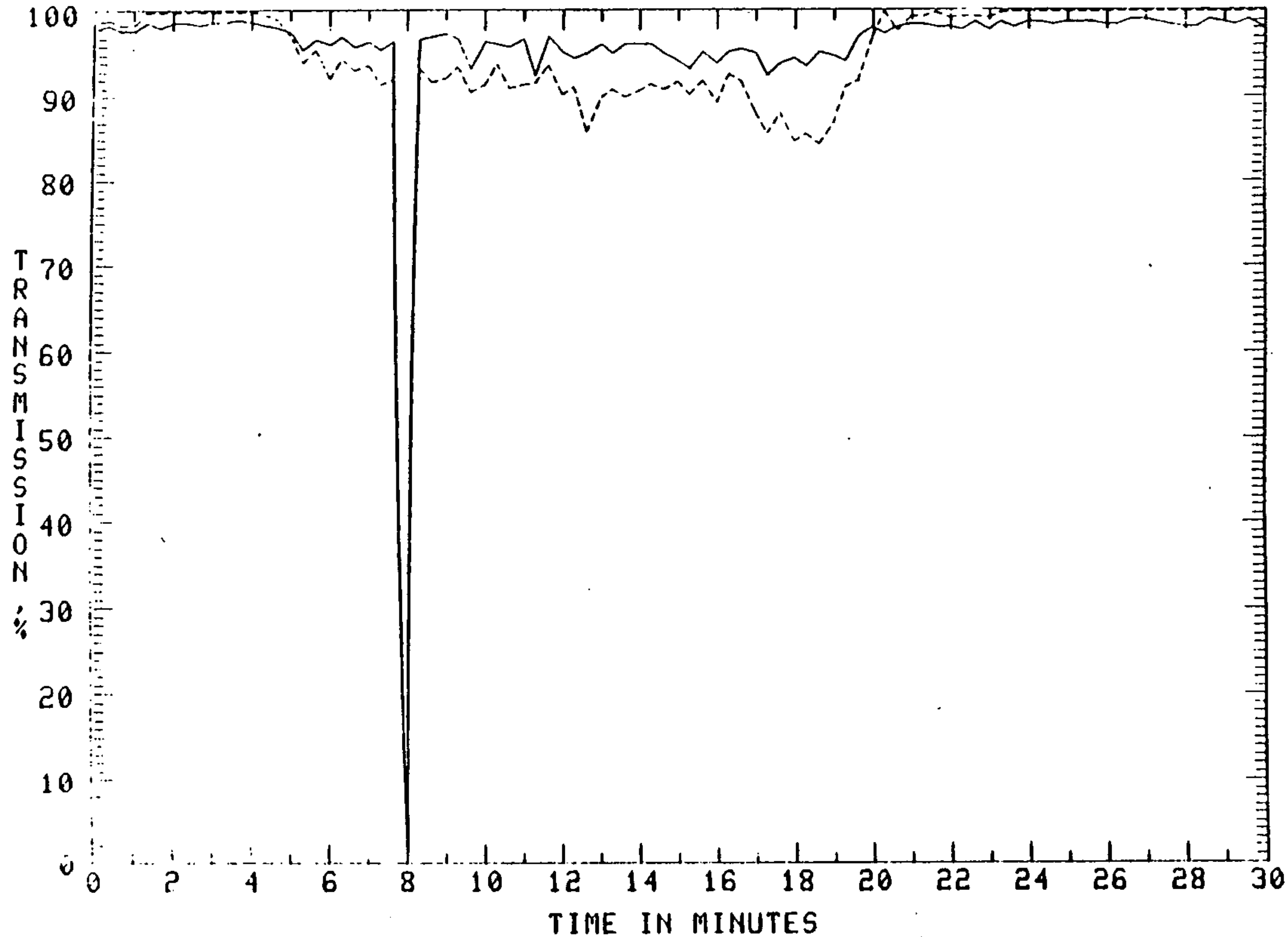

Fig. 7(14). TEST NO.14. CORN WITH .10 % SOYBEAN OIL DUST CONTROL SYSTEM ON

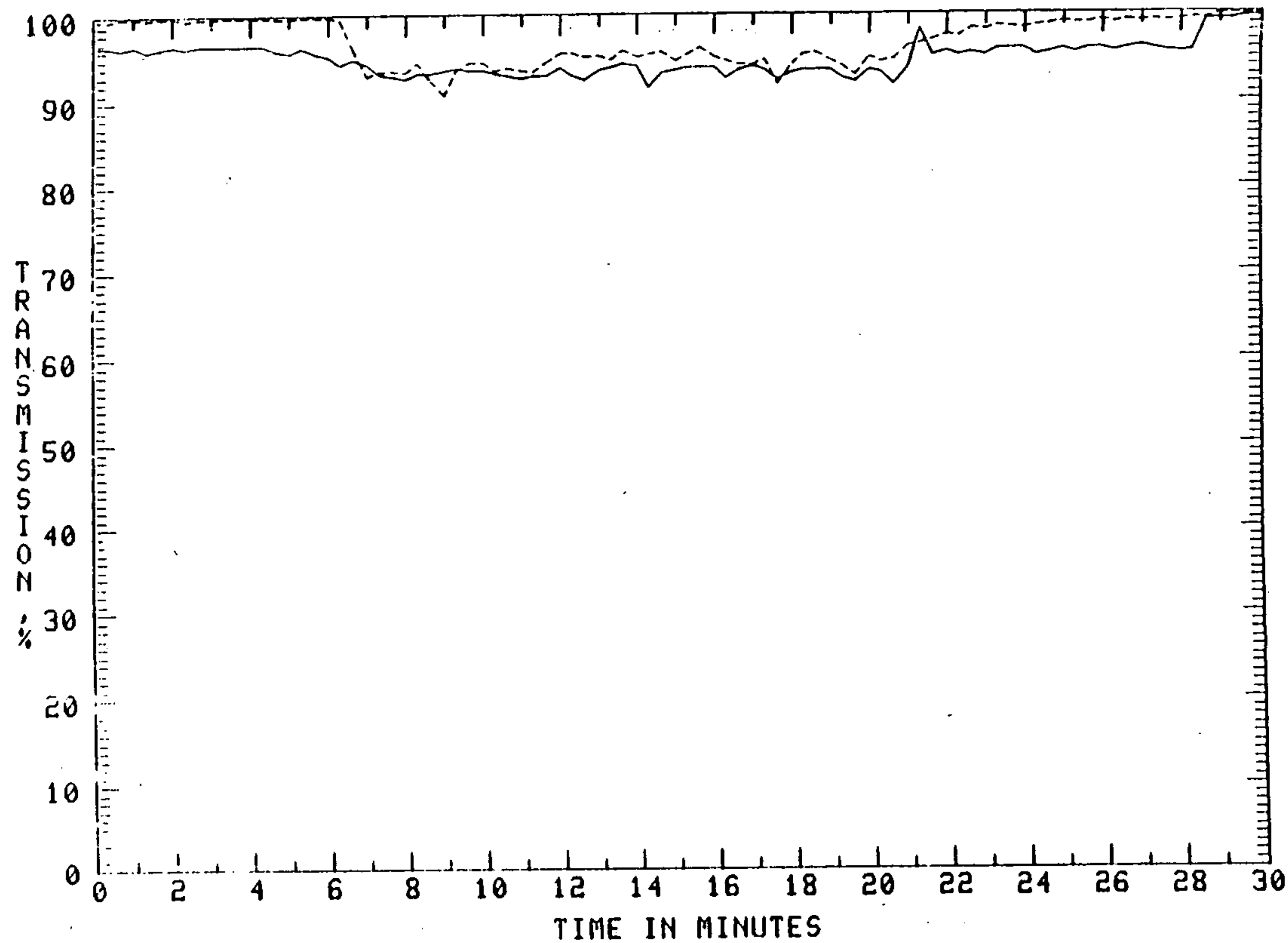

Fig. 7(15). TEST NO.15. CORN WITH .06 % SOYBEAN OIL DUST CONTROL SYSTEM OFF

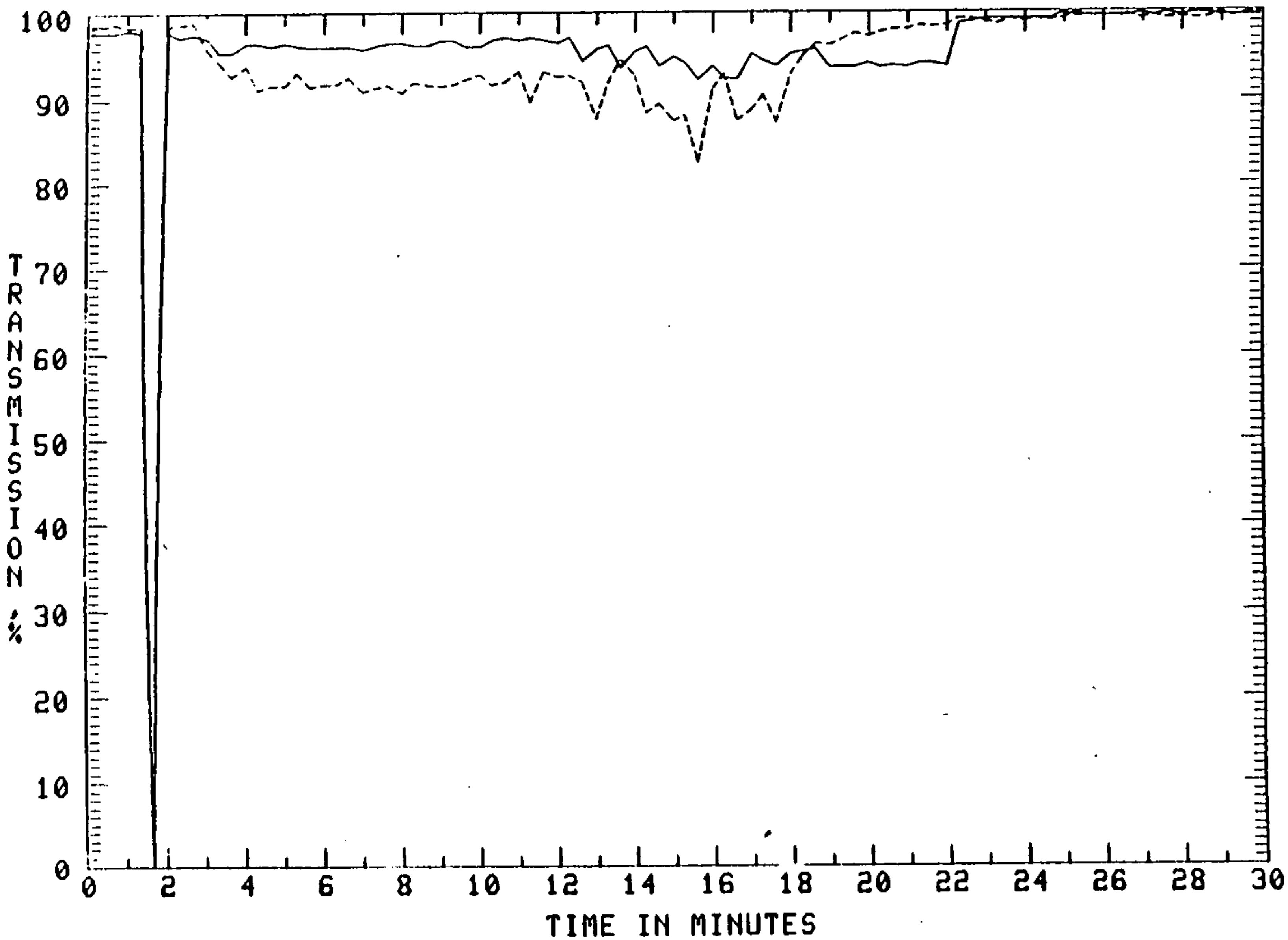

Fig. 7(16). TEST NO.16. CORN WITH .06 % SOYBEAN OIL DUST CONTROL SYSTEM OFF

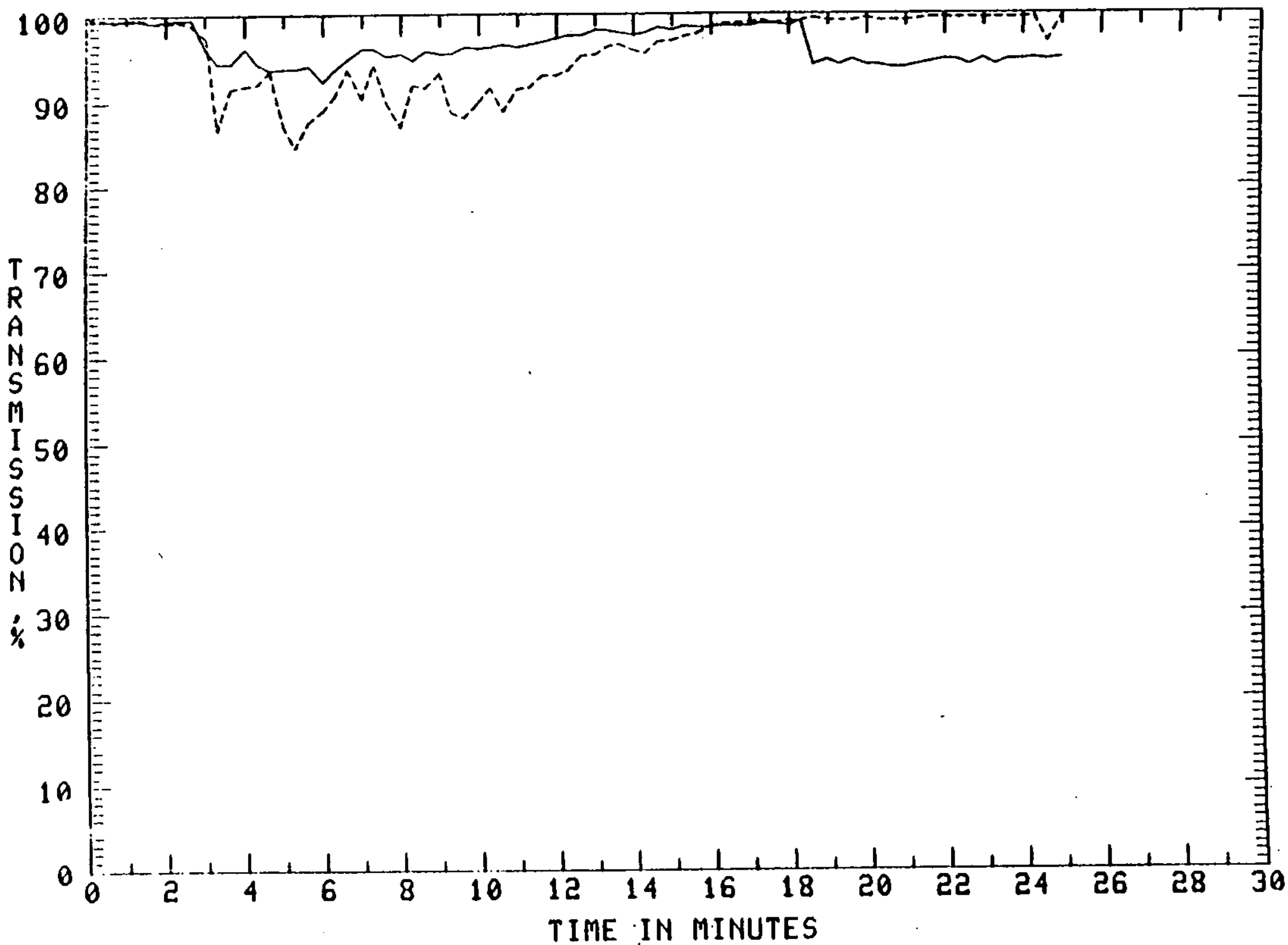

Fig. 7(17). TEST NO.17. CORN WITH .06 % SOYBEAN OIL DUST CONTROL SYSTEM ON

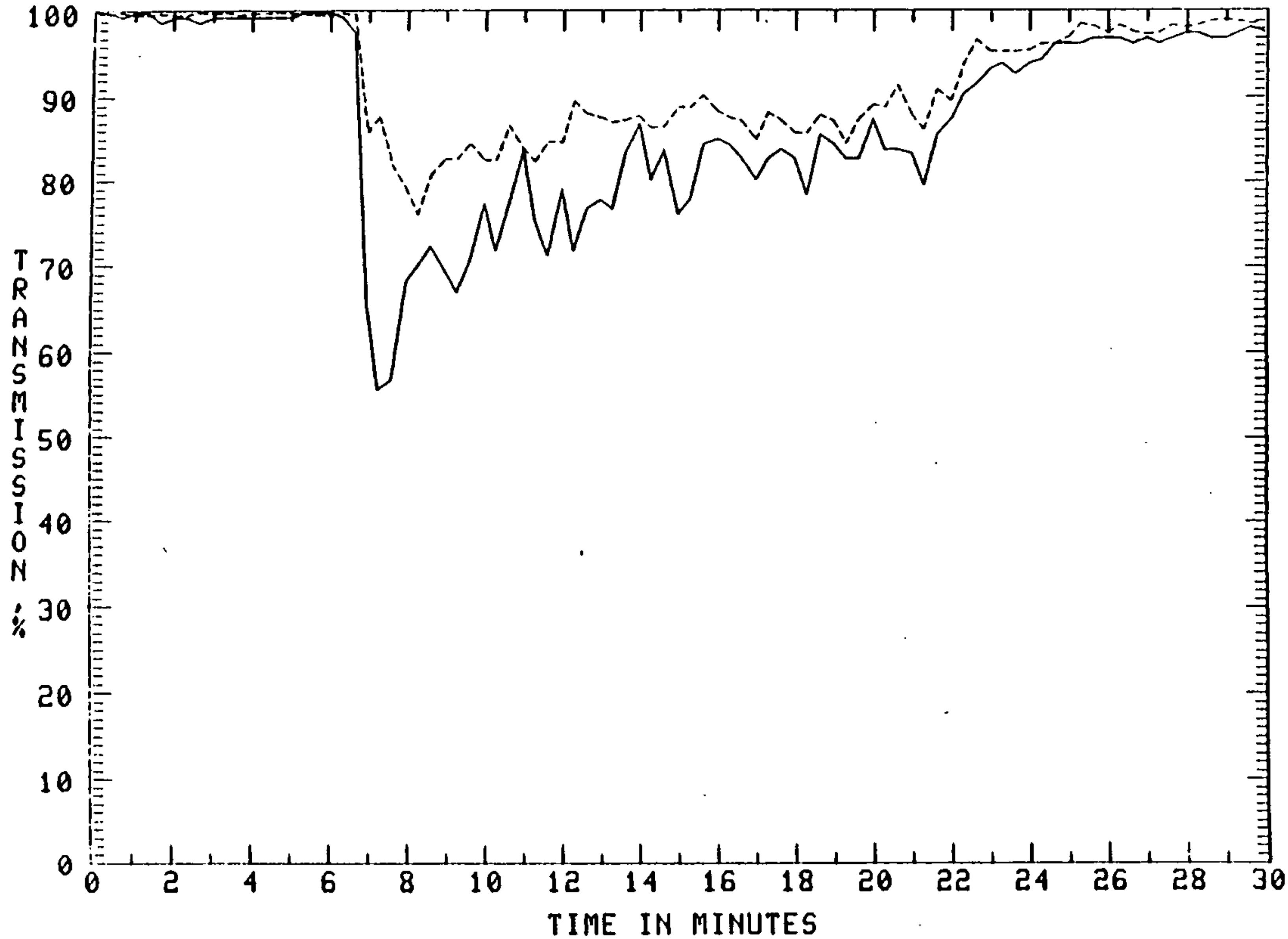

Fig. 7(18). TEST NO.18. CORN WITH .03 % SOYBEAN OIL DUST CONTROL SYSTEM ON

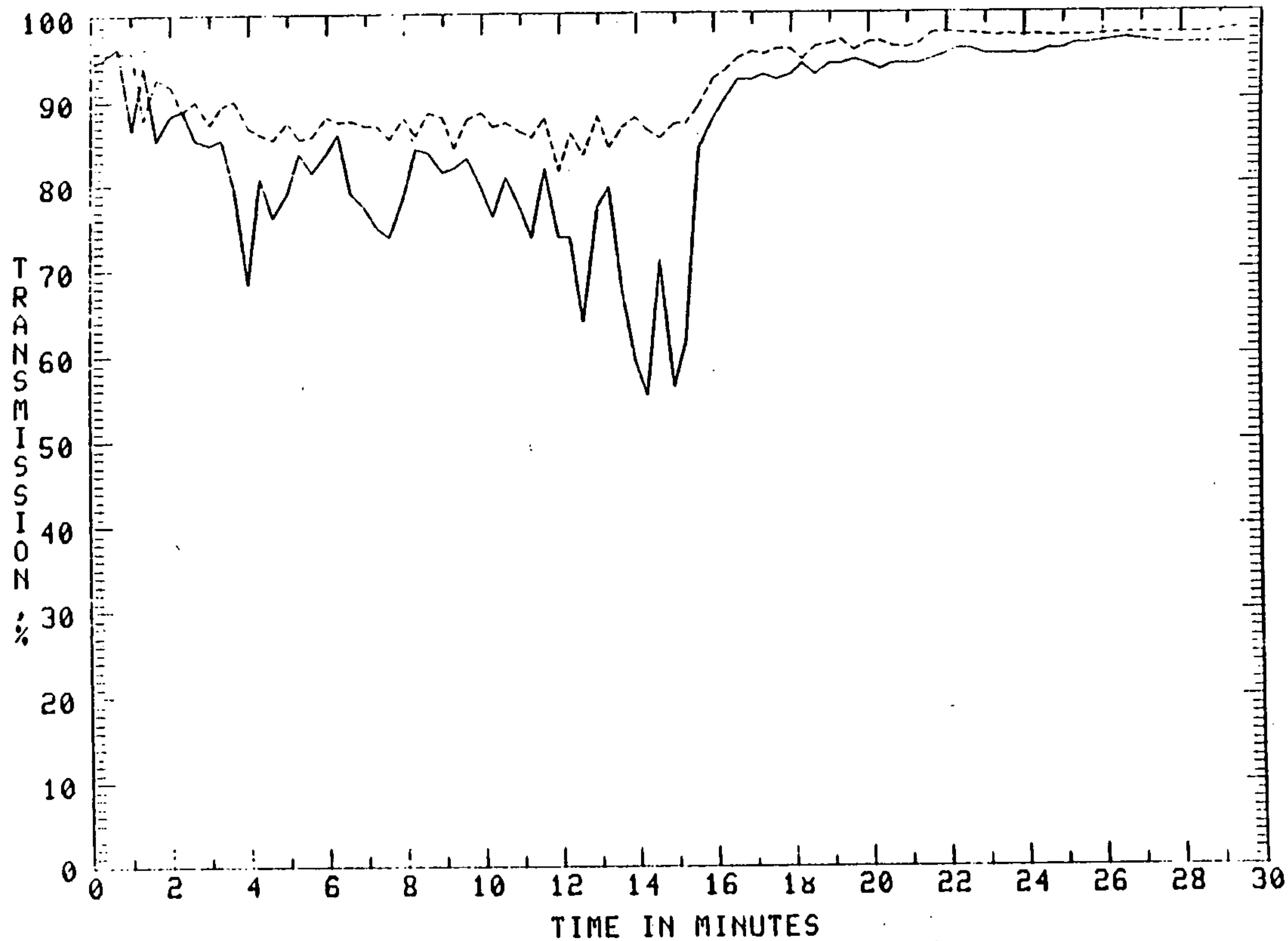

Fig. 7(19). TEST NO.19. CORN WITH .03 % SOYBEAN OIL DUST CONTROL SYSTEM OFF

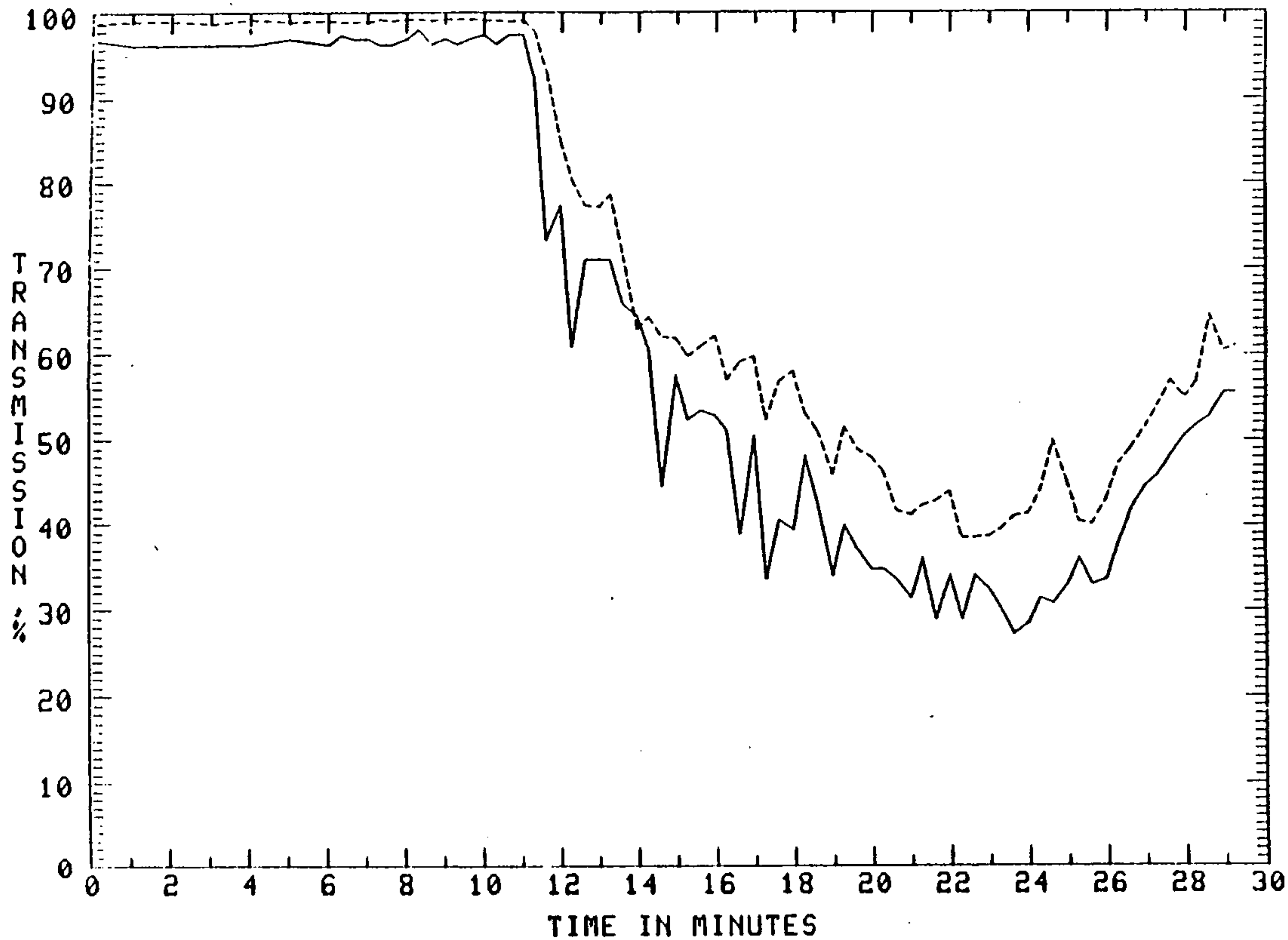

Fig. 7(20). TEST NO.20. WHEAT WITH NO ADDITIVE DUST CONTROL SYSTEM OFF

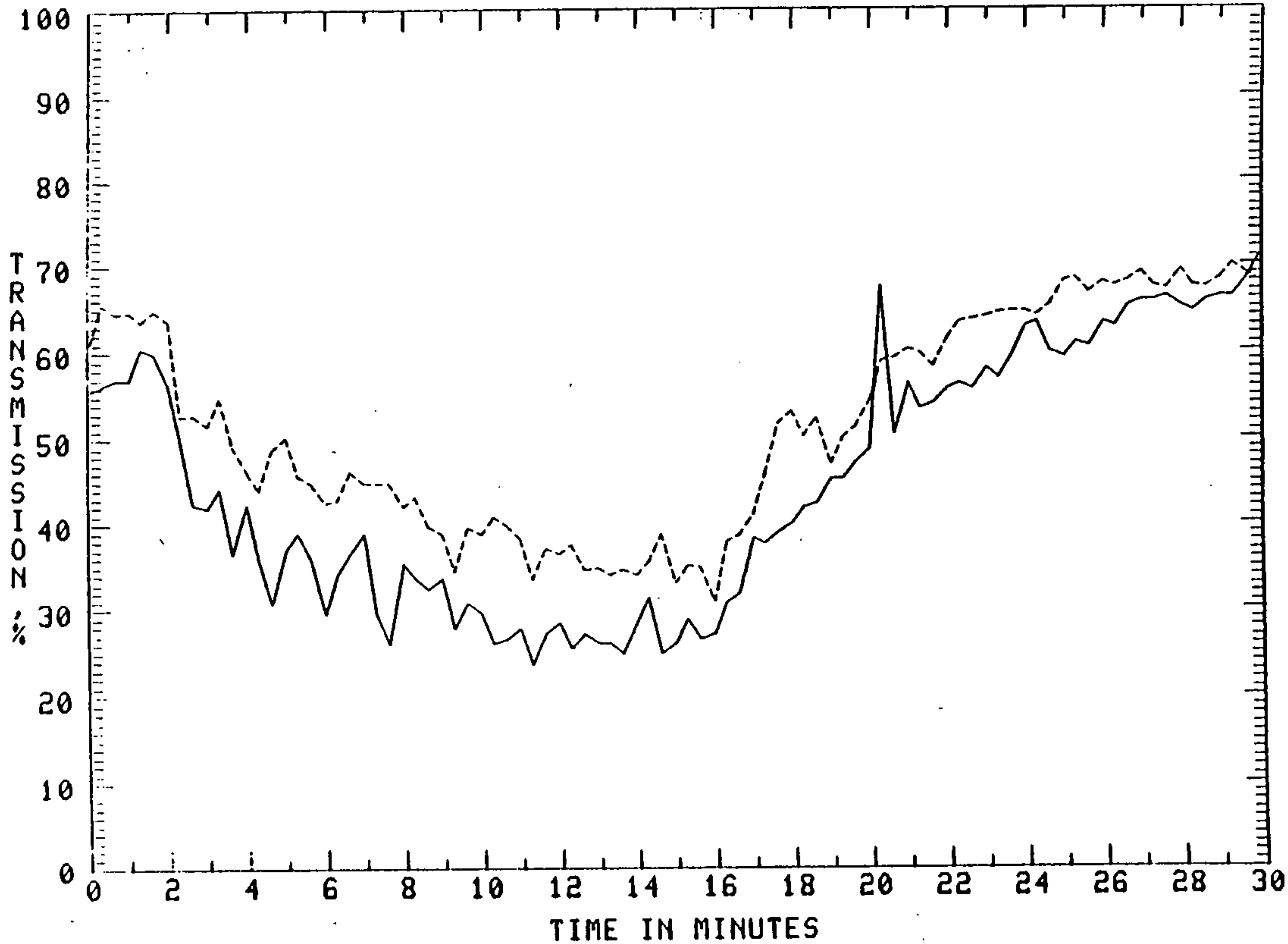

Fig. 7(21). TEST NO.21. WHEAT WITH NO ADDITIVES DUST CONTROL SYSTEM ON

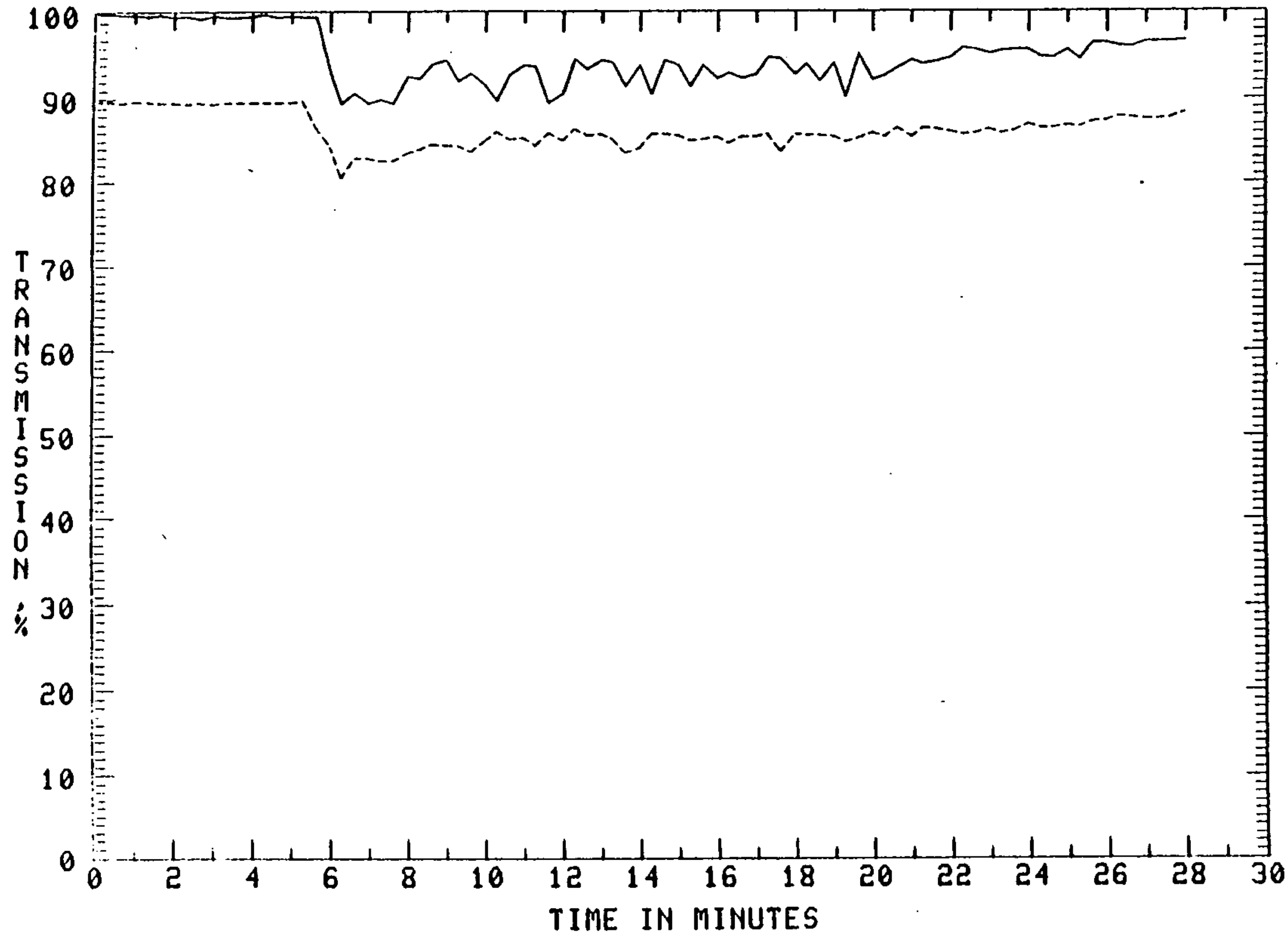

Fig. 7(22). TEST NO.22. WHEAT WITH .06 % SOYBEAN OIL DUST CONTROL SYSTEM OFF

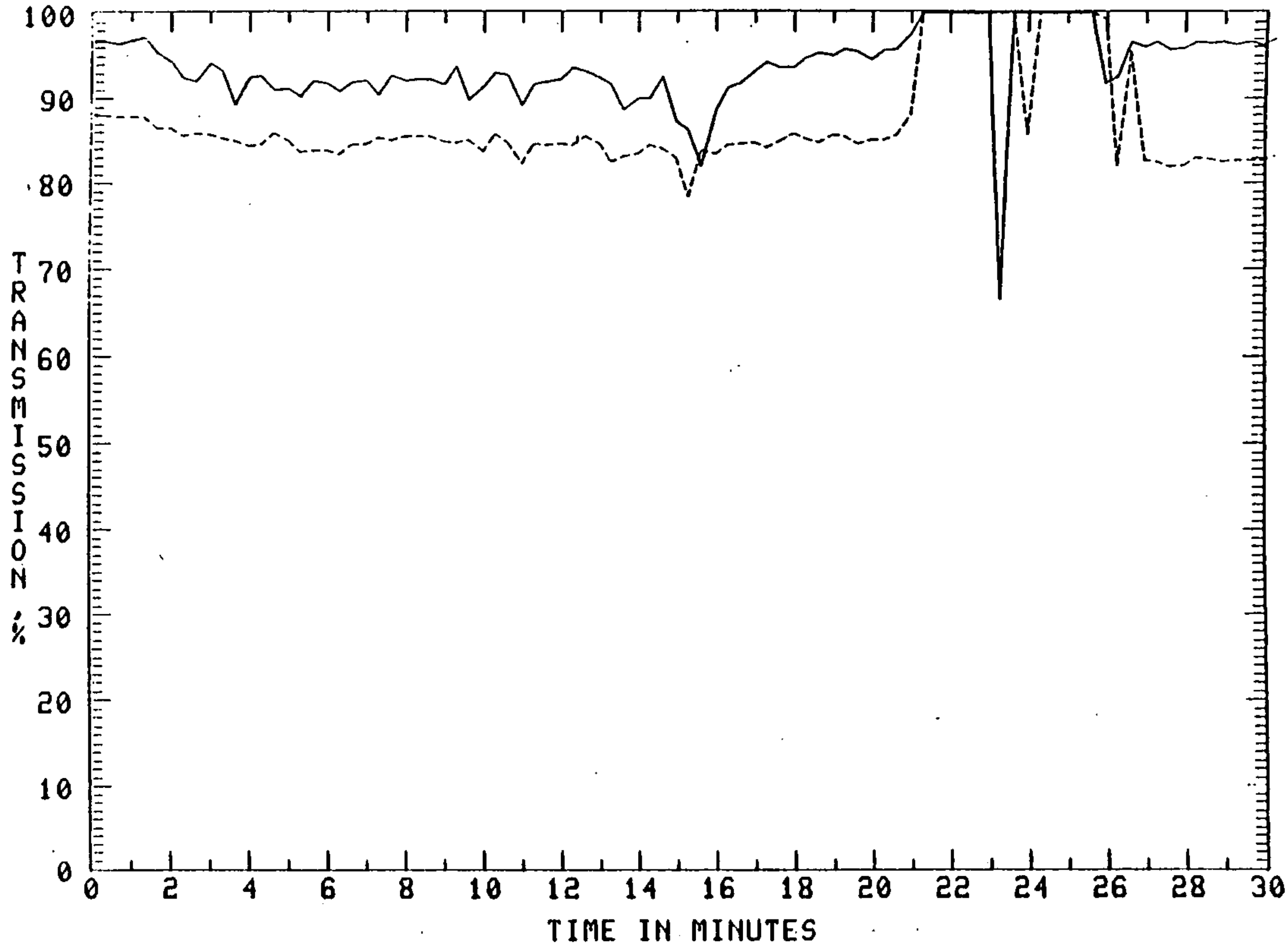

Fig. 7(23). TEST NO.23. WHEAT WITH .03 % SOYBEAN OIL DUST CONTROL SYSTEM OFF

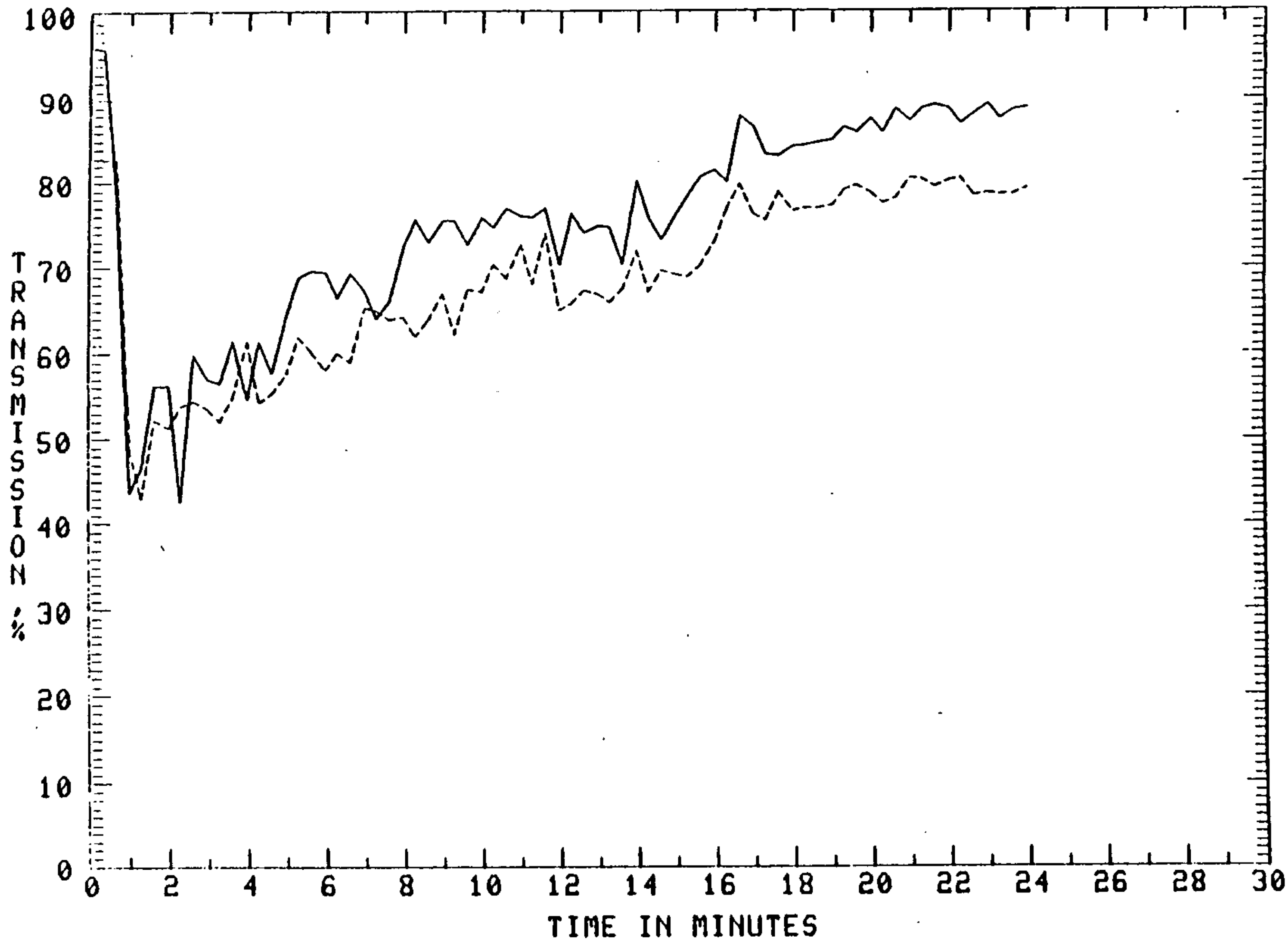

Fig. 7(24). TEST NO.24. WHEAT WITH .03 % SOYBEAN OIL DUST CONTROL SYSTEM ON

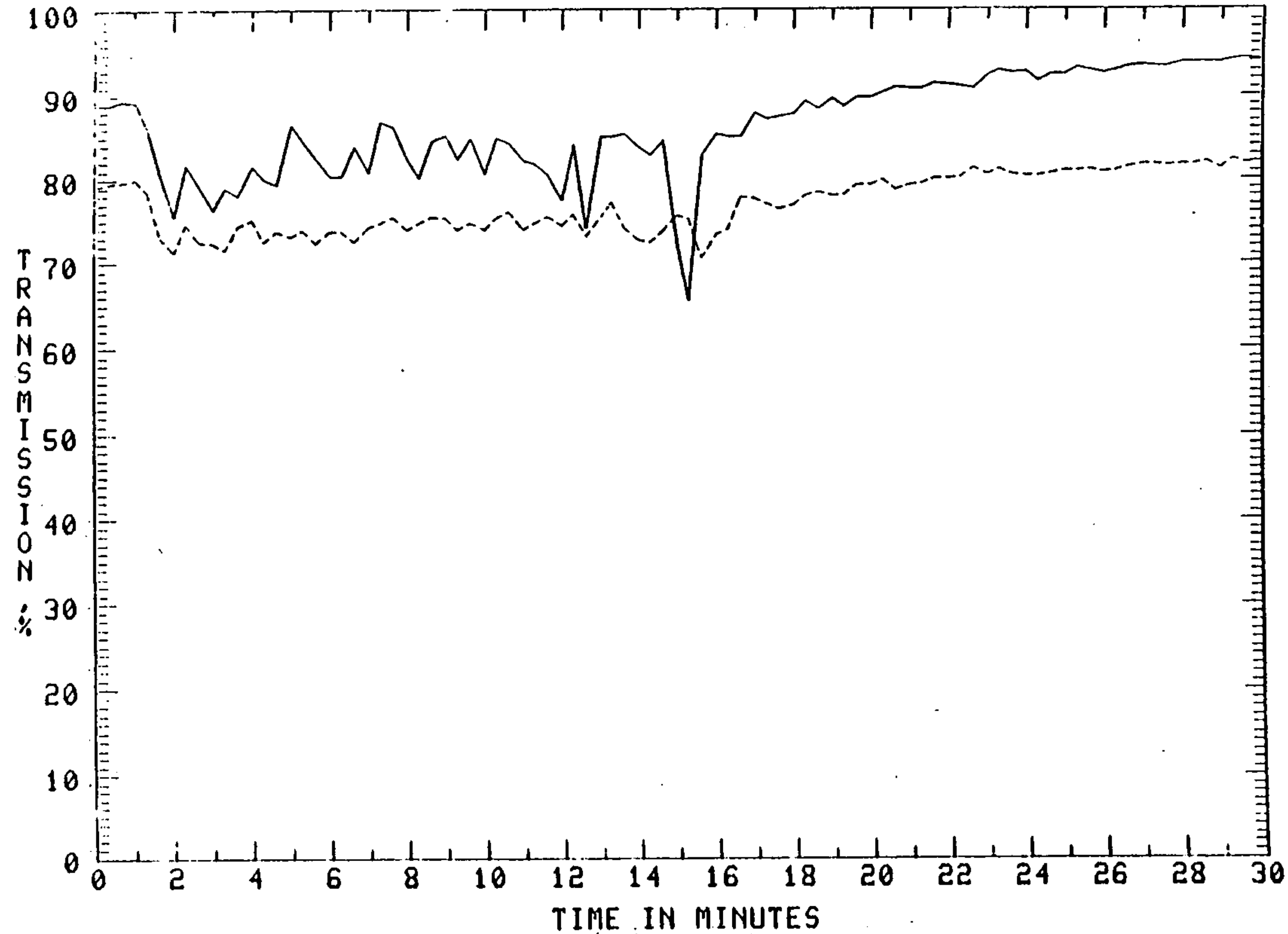

Fig. 7(25). TEST NO.25. WHEAT WITH .02 % SOYBEAN OIL DUST CONTROL SYSTEM OFF

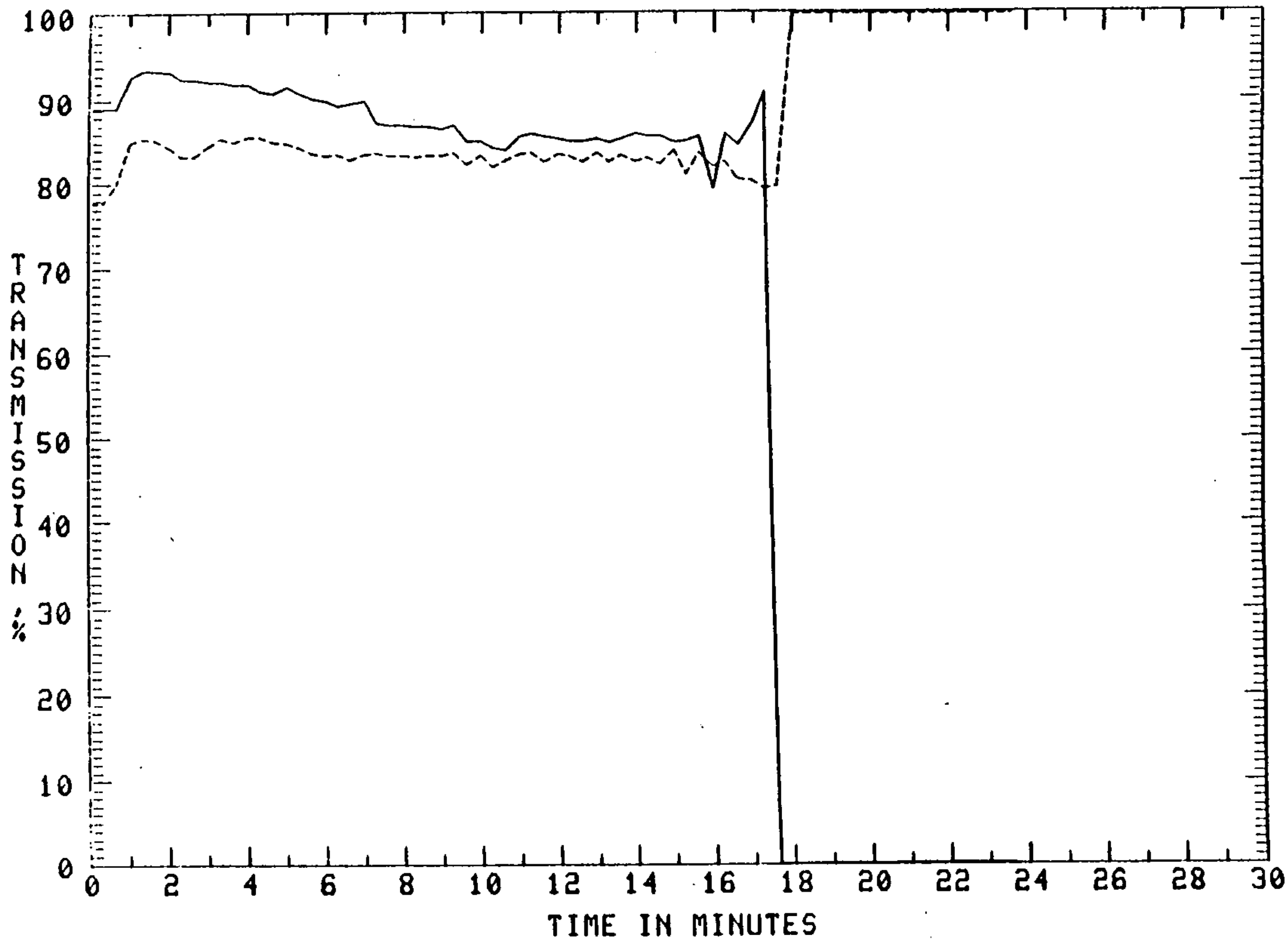

Fig. 7(33). TEST NO.33. WHEAT WITH .03 % SOYBEAN OIL DUST CONTROL SYSTEM OFF

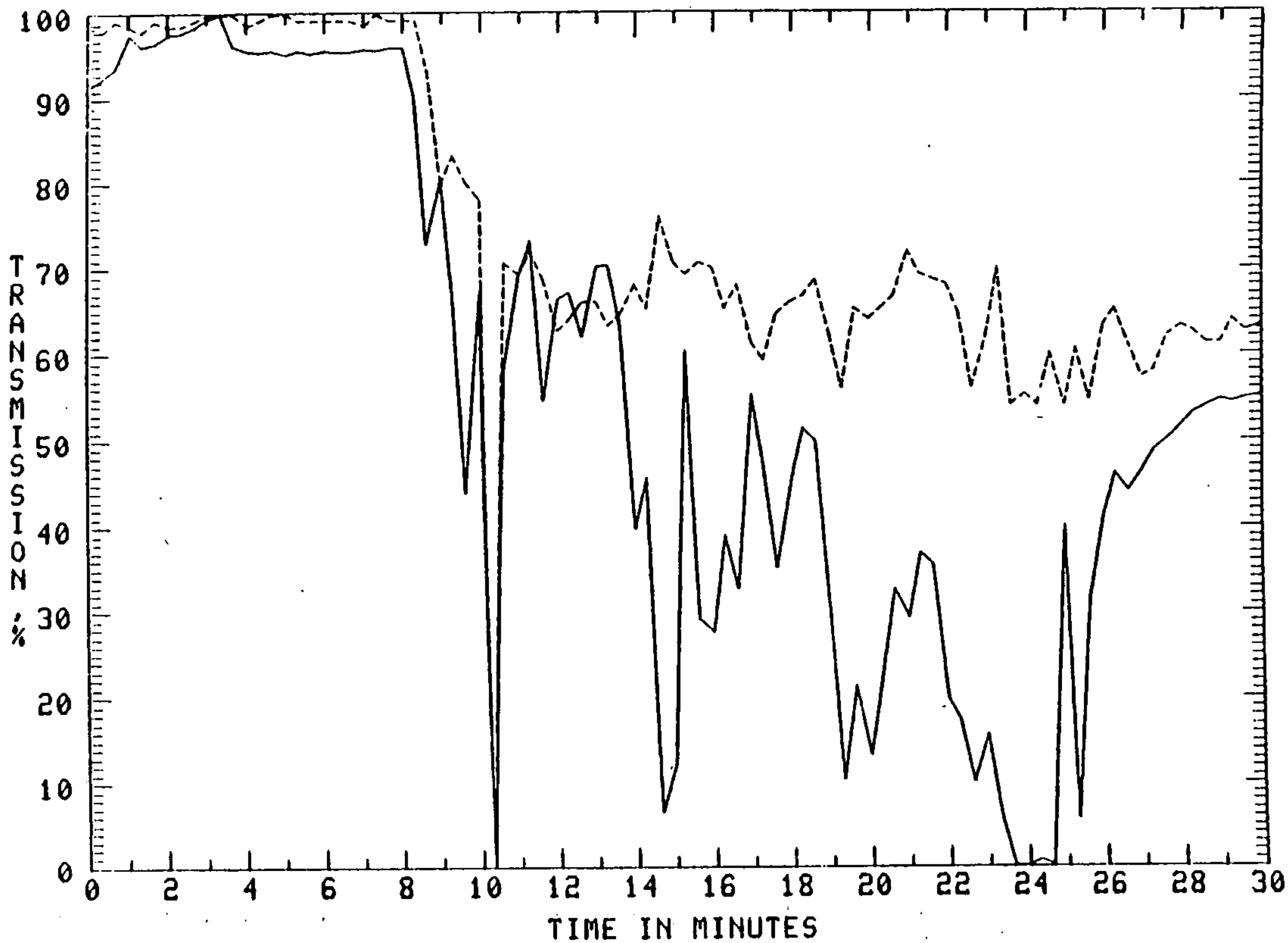

Fig. 7(34). TEST NO.34. WHEAT WITH .02 % SOYBEAN OIL DUST CONTROL SYSTEM OFF

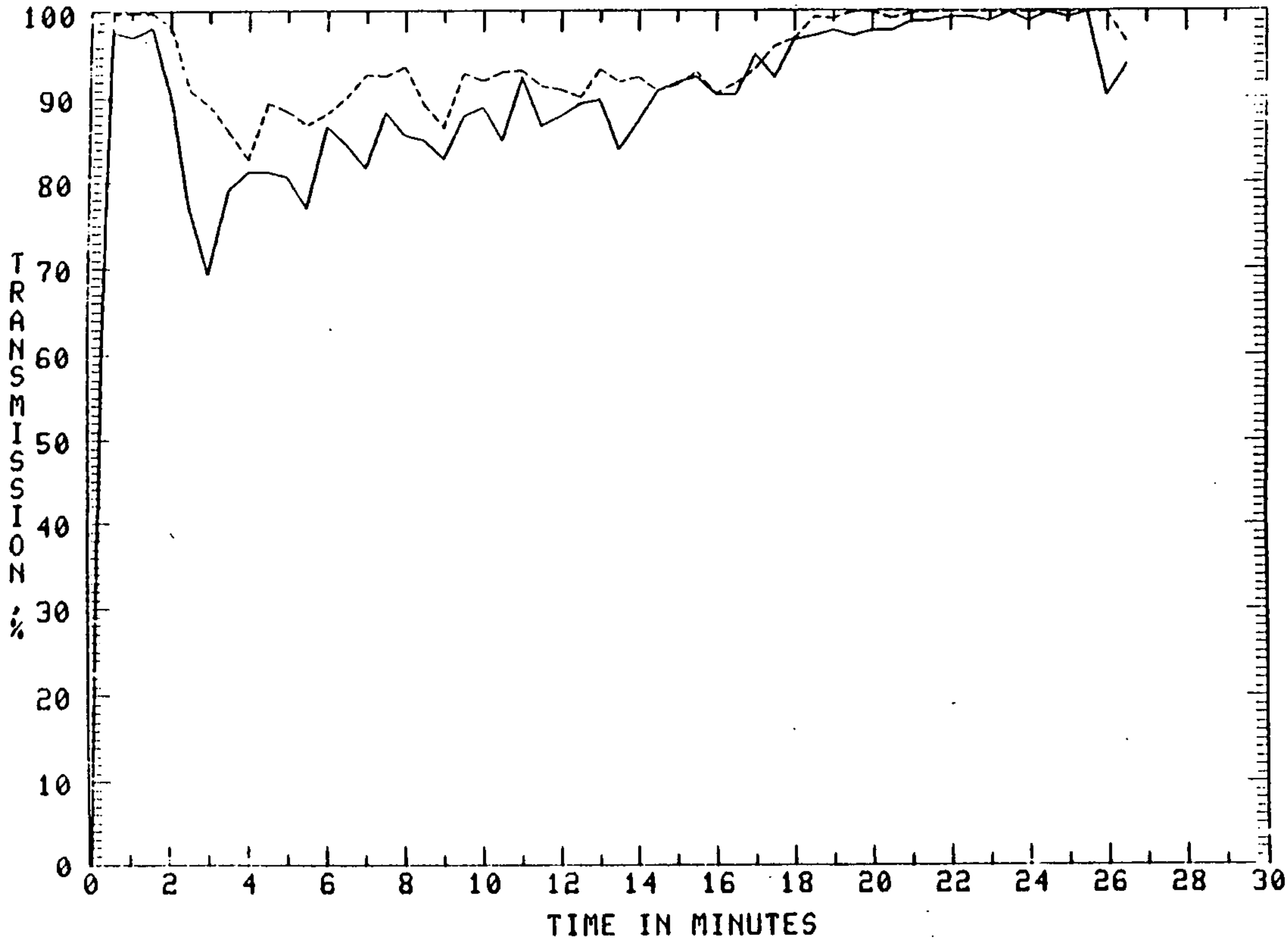

Fig. 7(35). TEST NO.35. CORN WITH .02 % MINERAL OIL DUST CONTROL SYSTEM ON

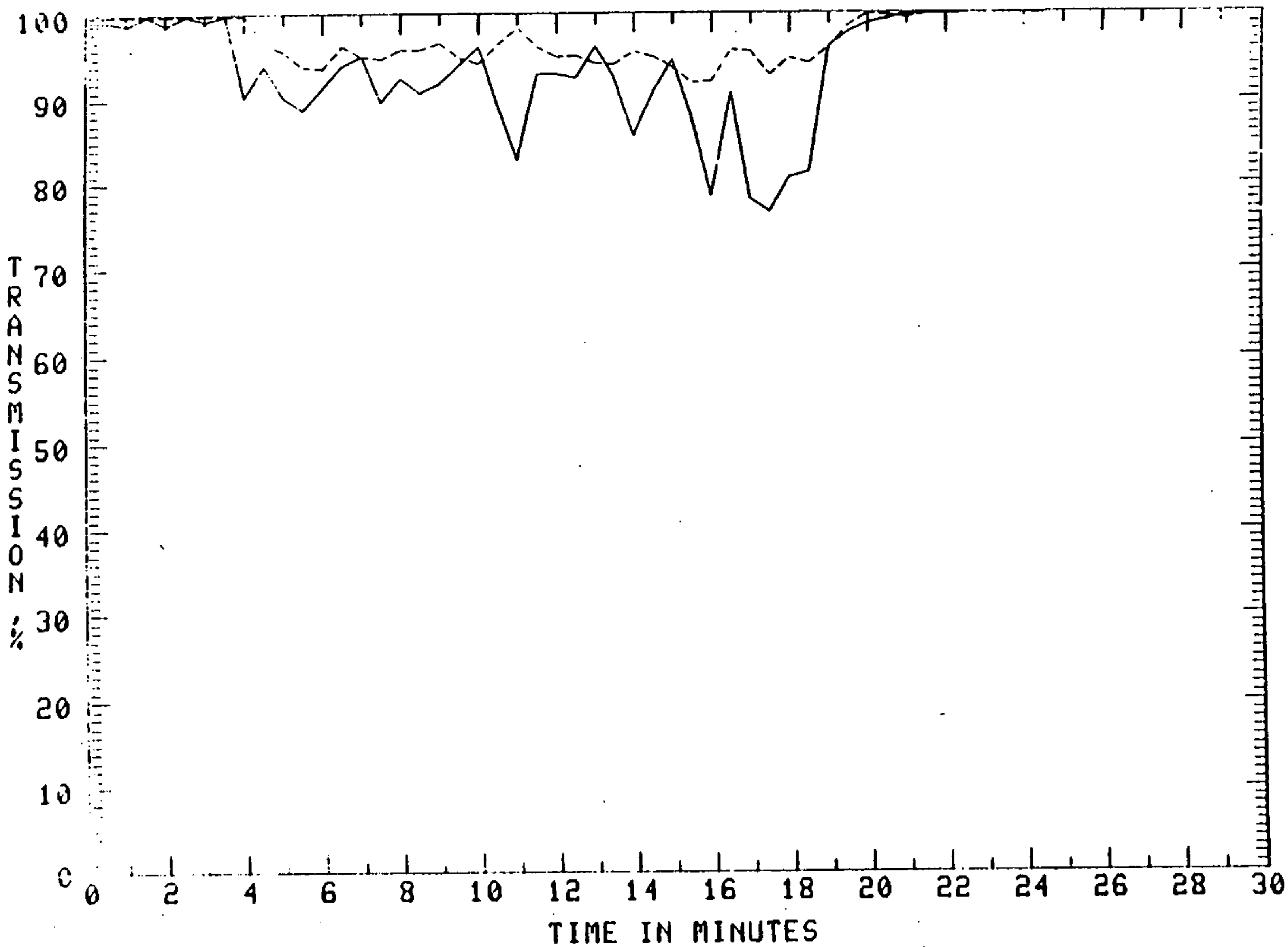

Fig. 7(36). TEST NO.36. CORN WITH .08 % MINERAL OIL DUST CONTROL SYSTEM OFF

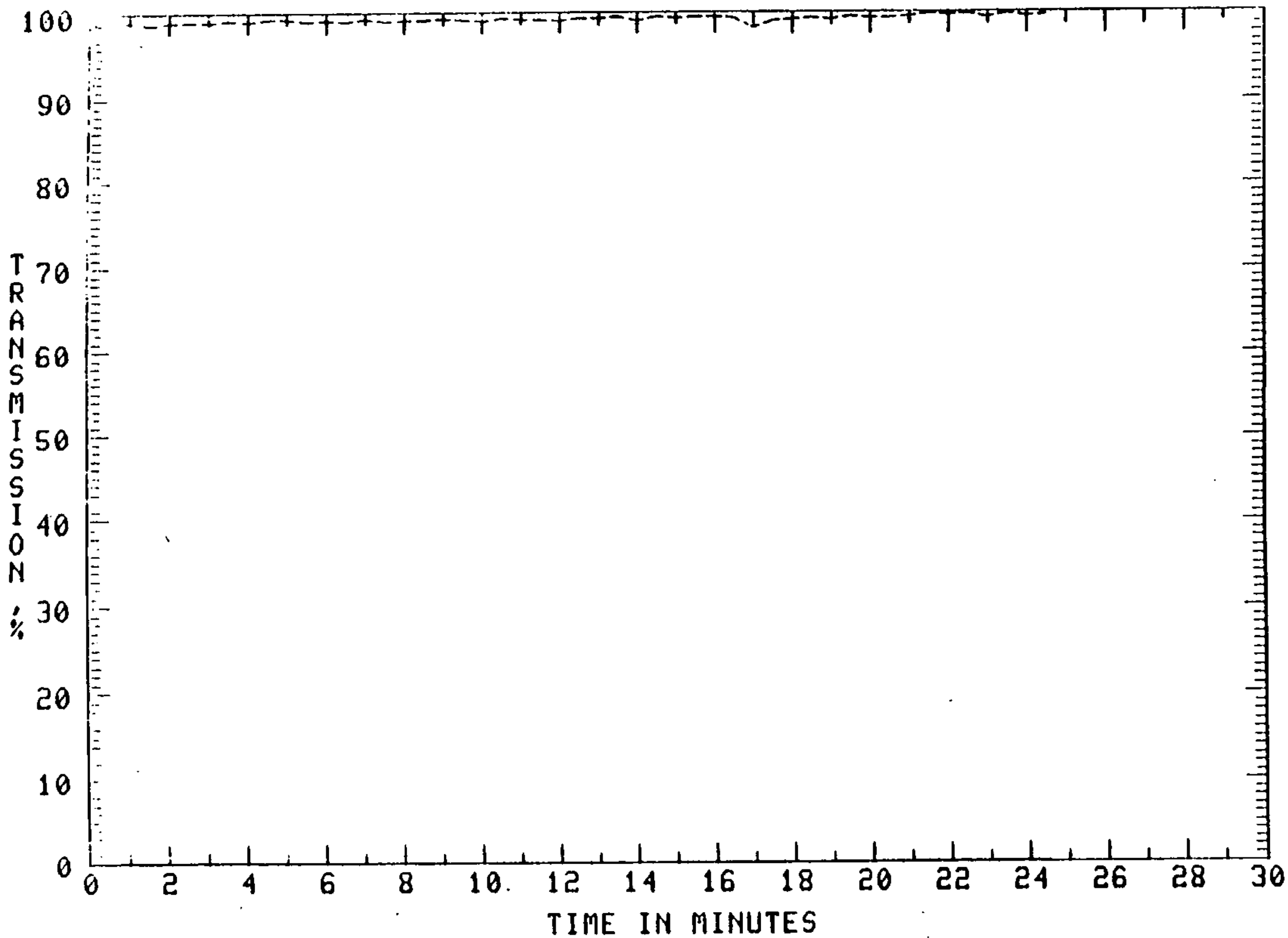

Fig. 7(37). TEST NO.37. CORN WITH .04 % MINERAL OIL DUST CONTROL SYSTEM ON

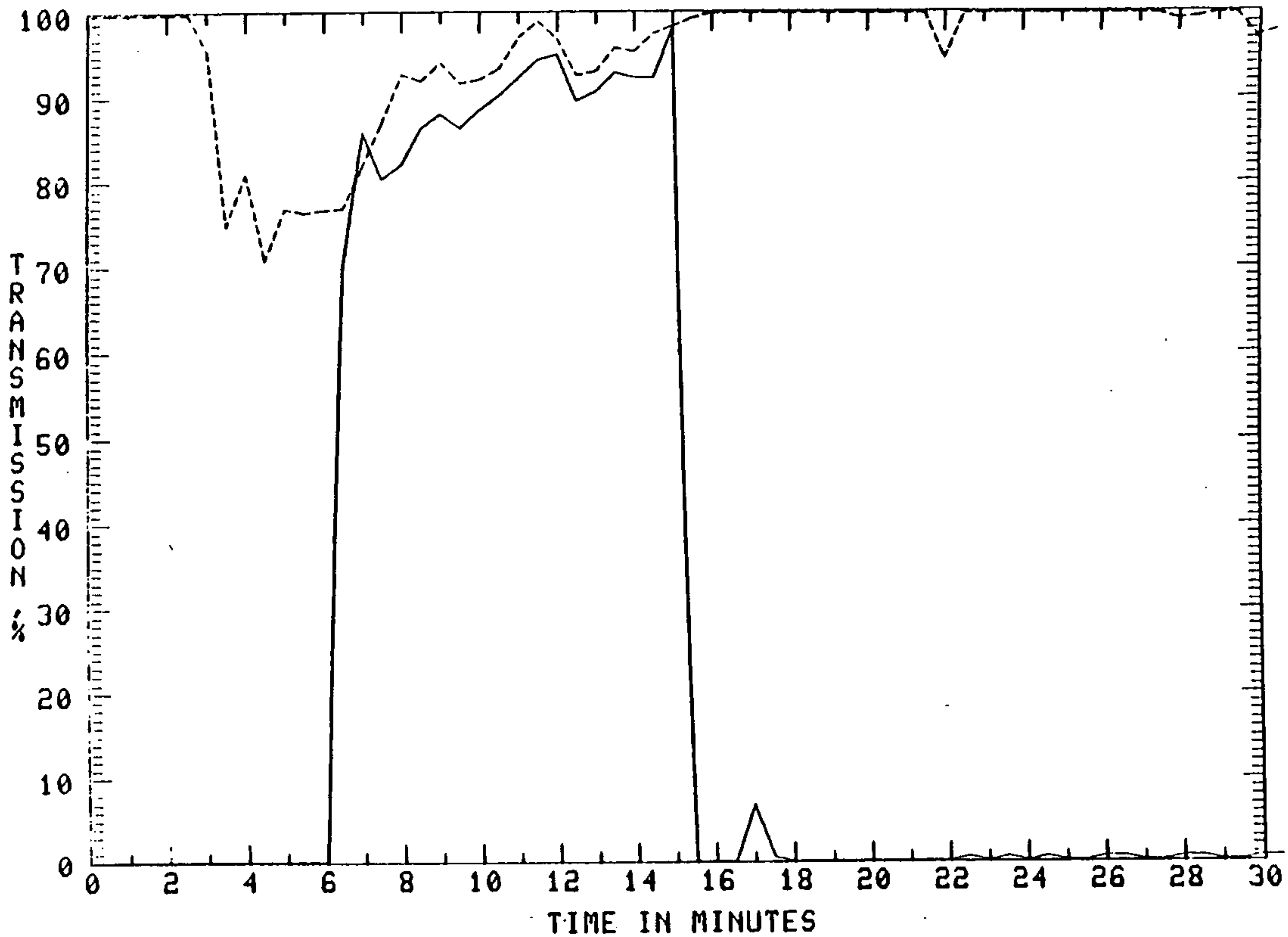

Fig. 7(38). TEST NO.38 CORN WITH .02 % MINERAL OIL DUST CONTROL SYSTEM ON

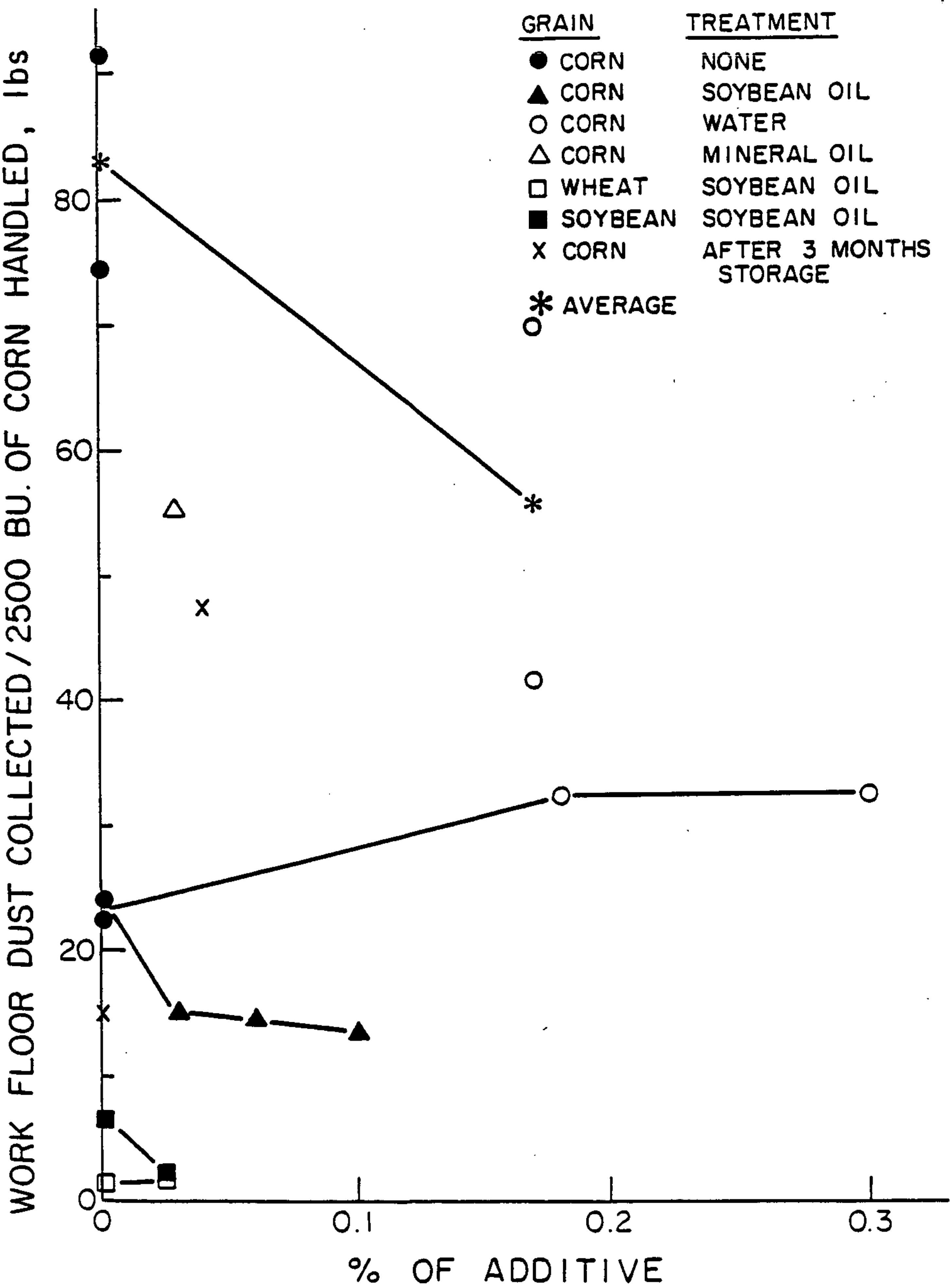

Fig. 8. Work floor dust collected per 2500 bu. of corn handled, lbs.

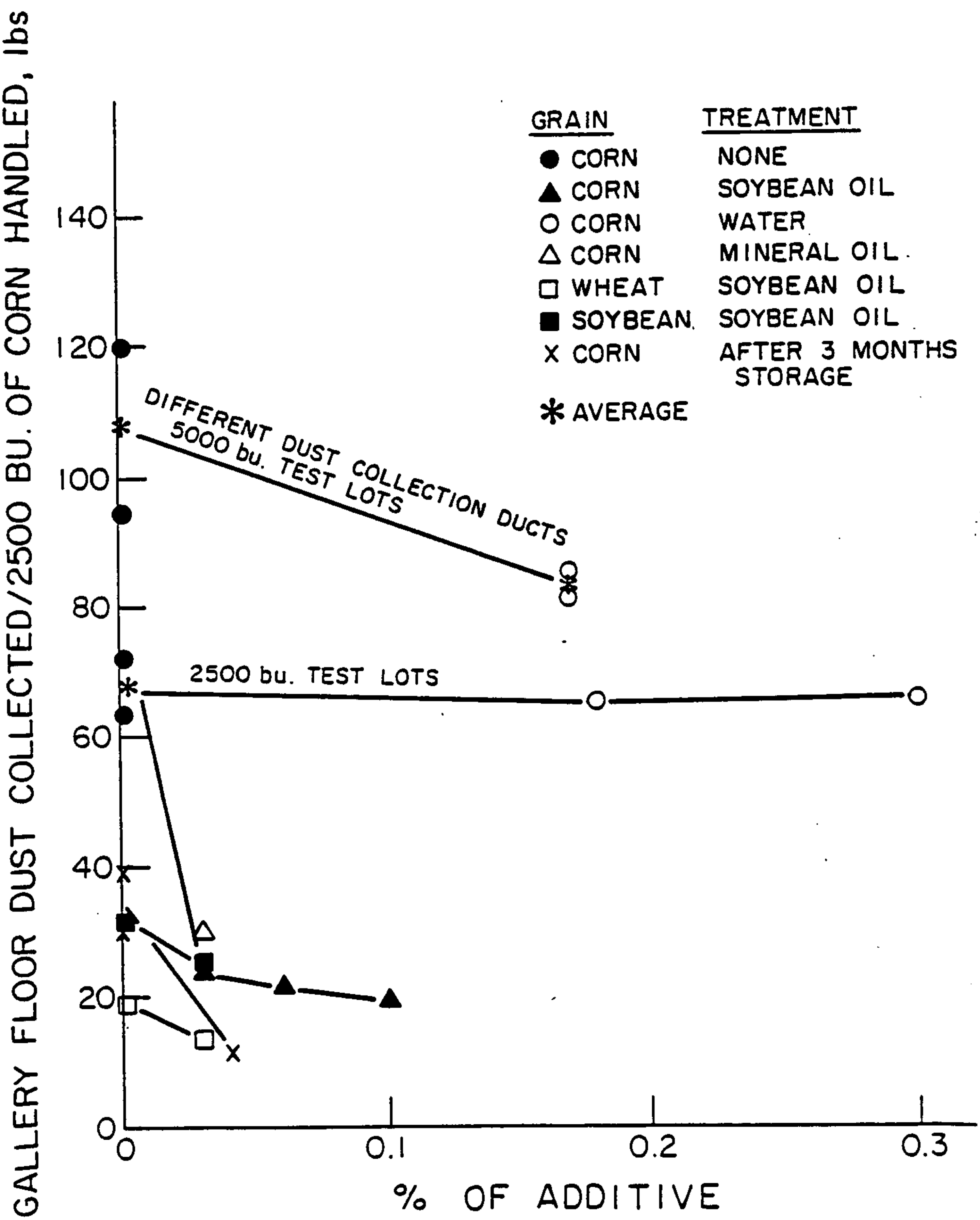

Fig. 9. Open gallery floor dust collected per 2500 bu. of corn handled, lbs.

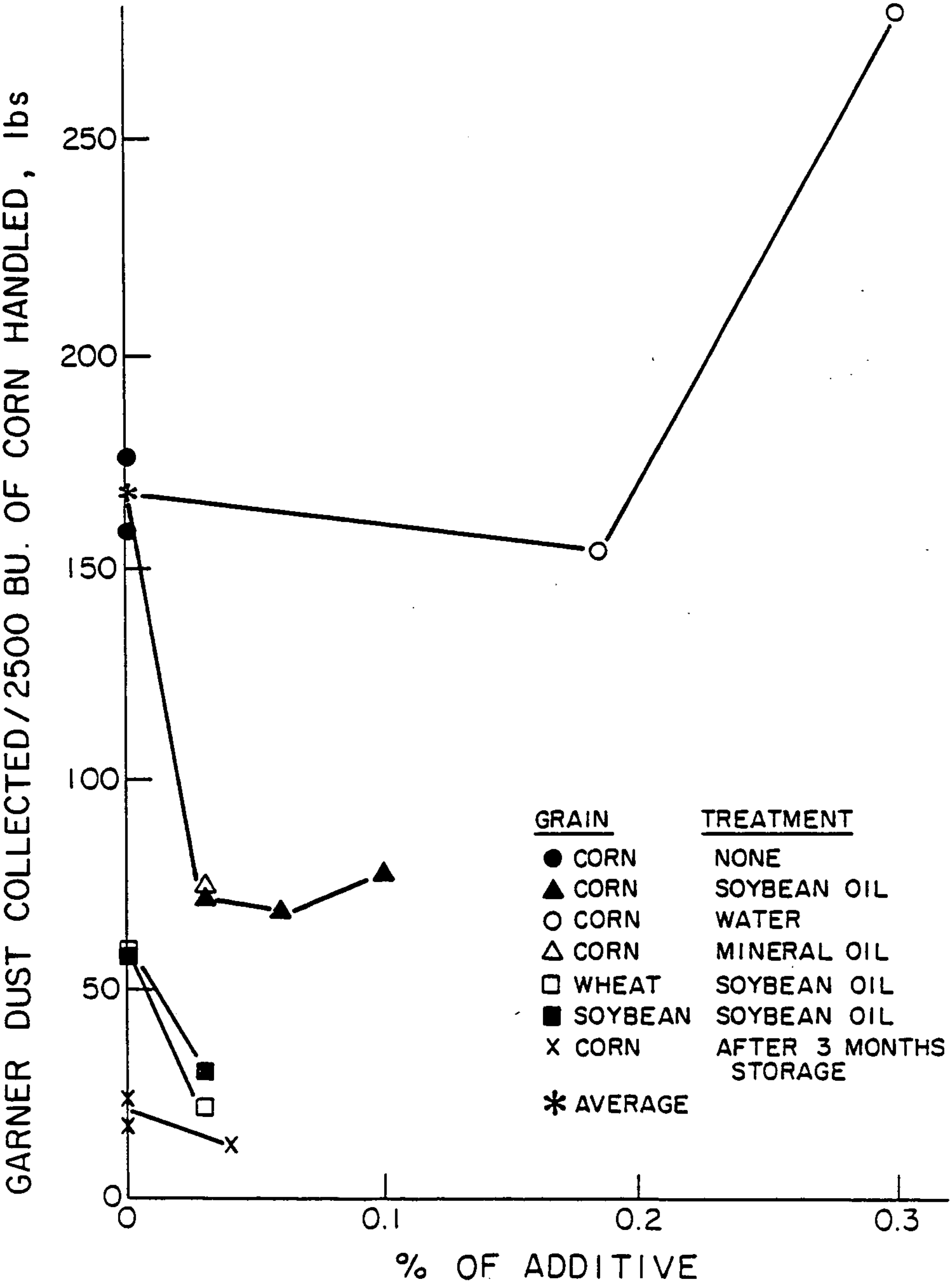

Fig. 10. Garner dust collected per 2500 bu. of corn handled, lbs.

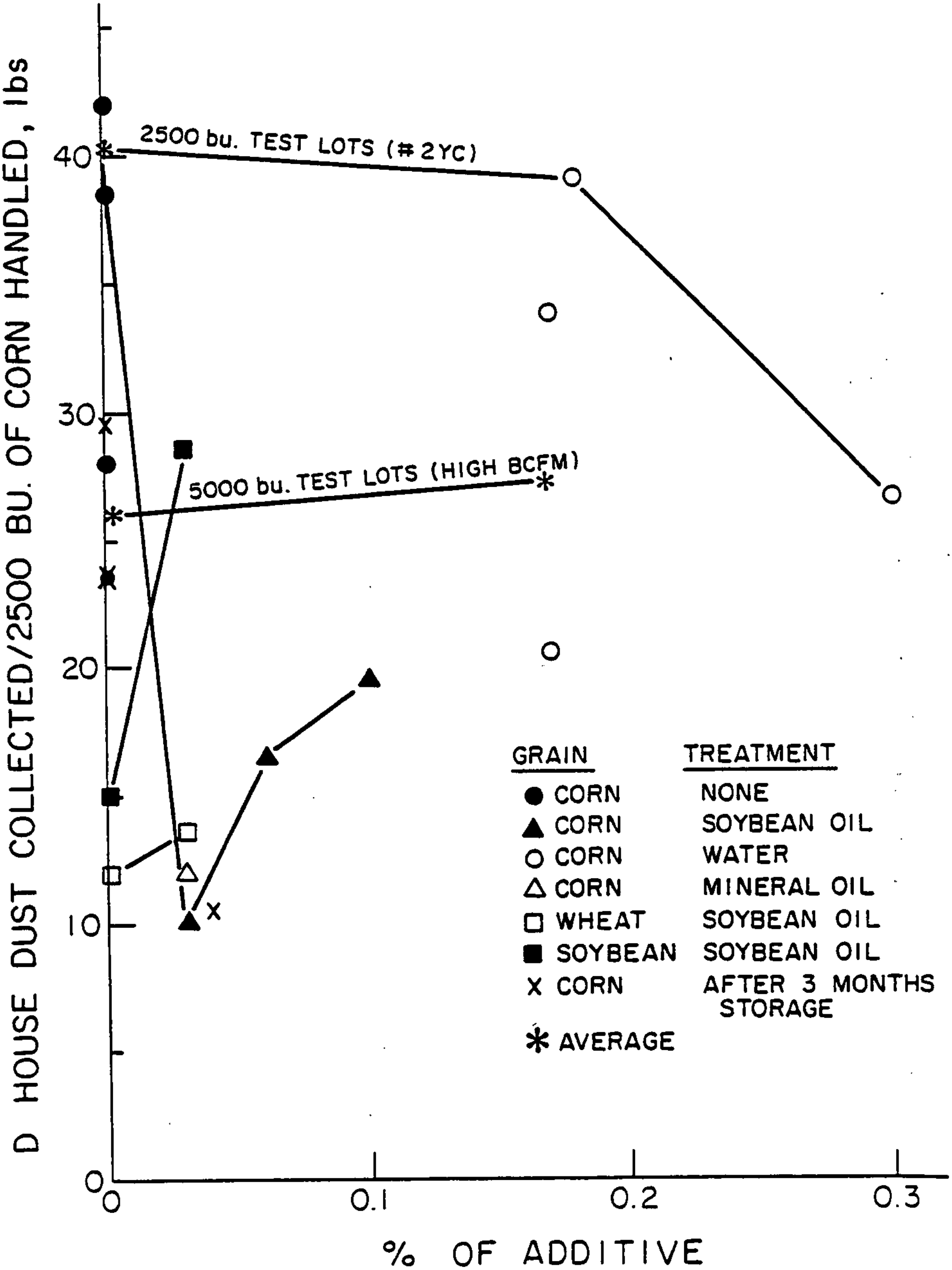

Fig. 11. D house dust collected per 2500 bu. of corn handled, lbs.

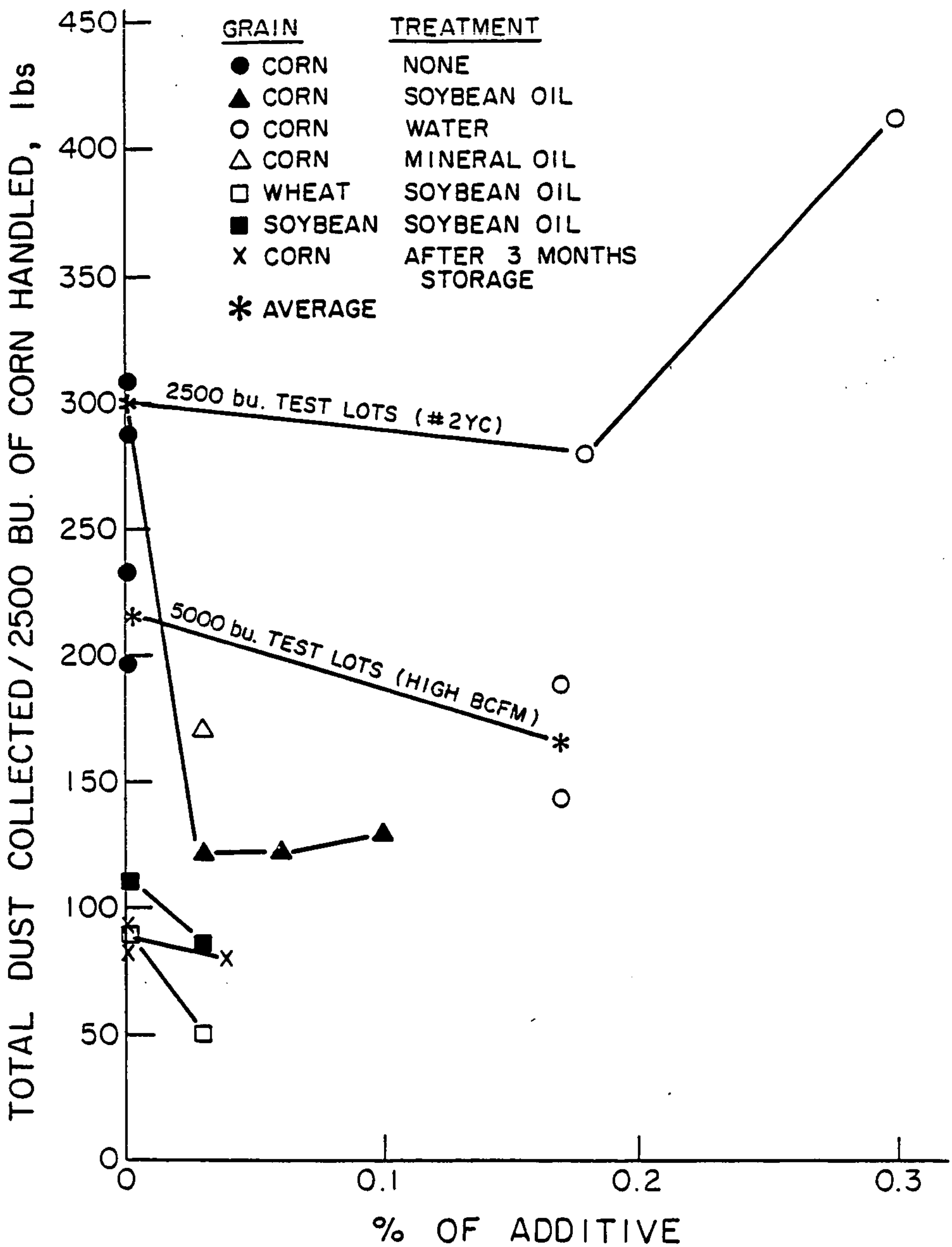

Fig. 12. Total dust collected per 2500 bu. of corn handled, lbs.

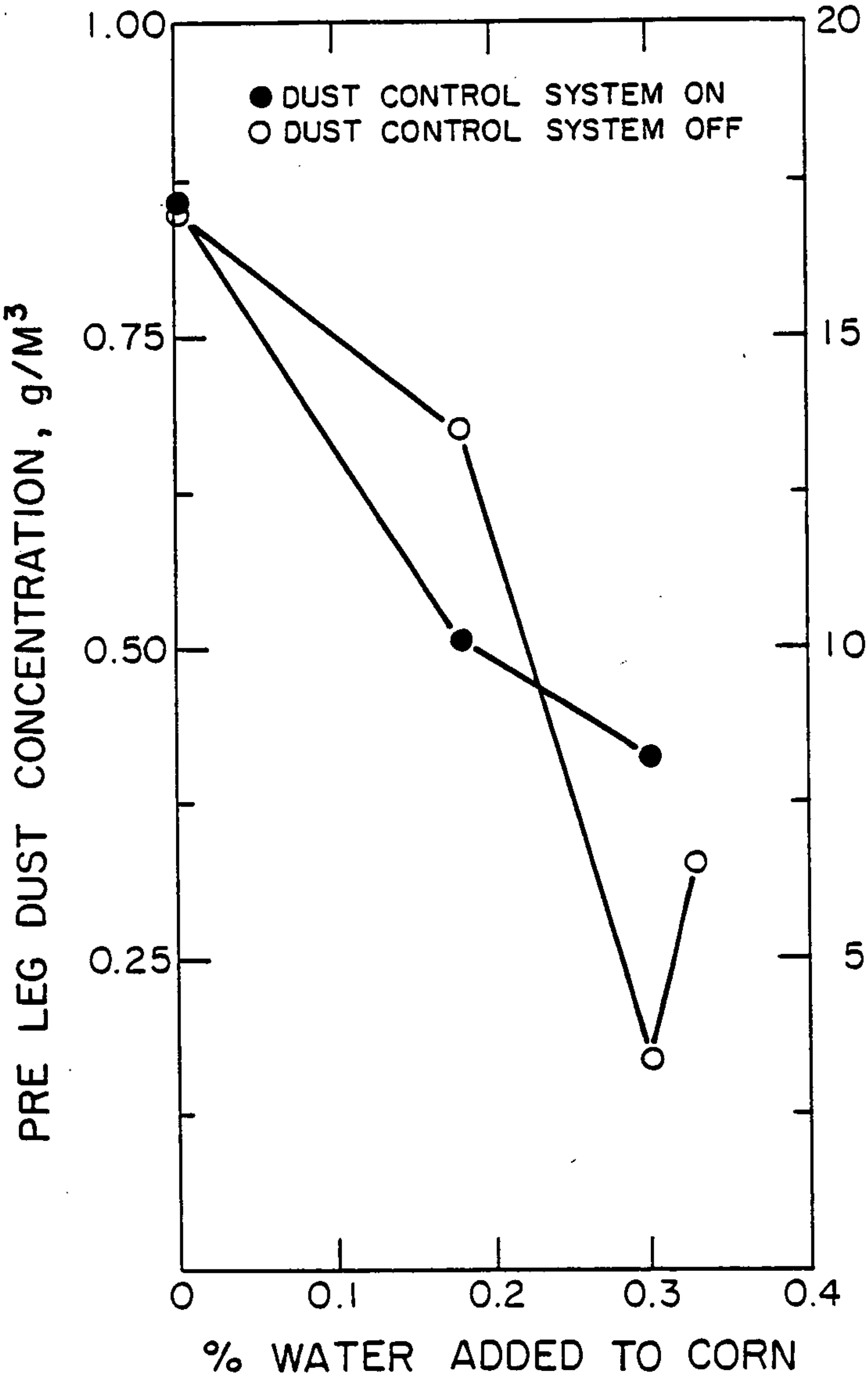

Fig. 13. Enclosed belt dust concentration, g/m^3.

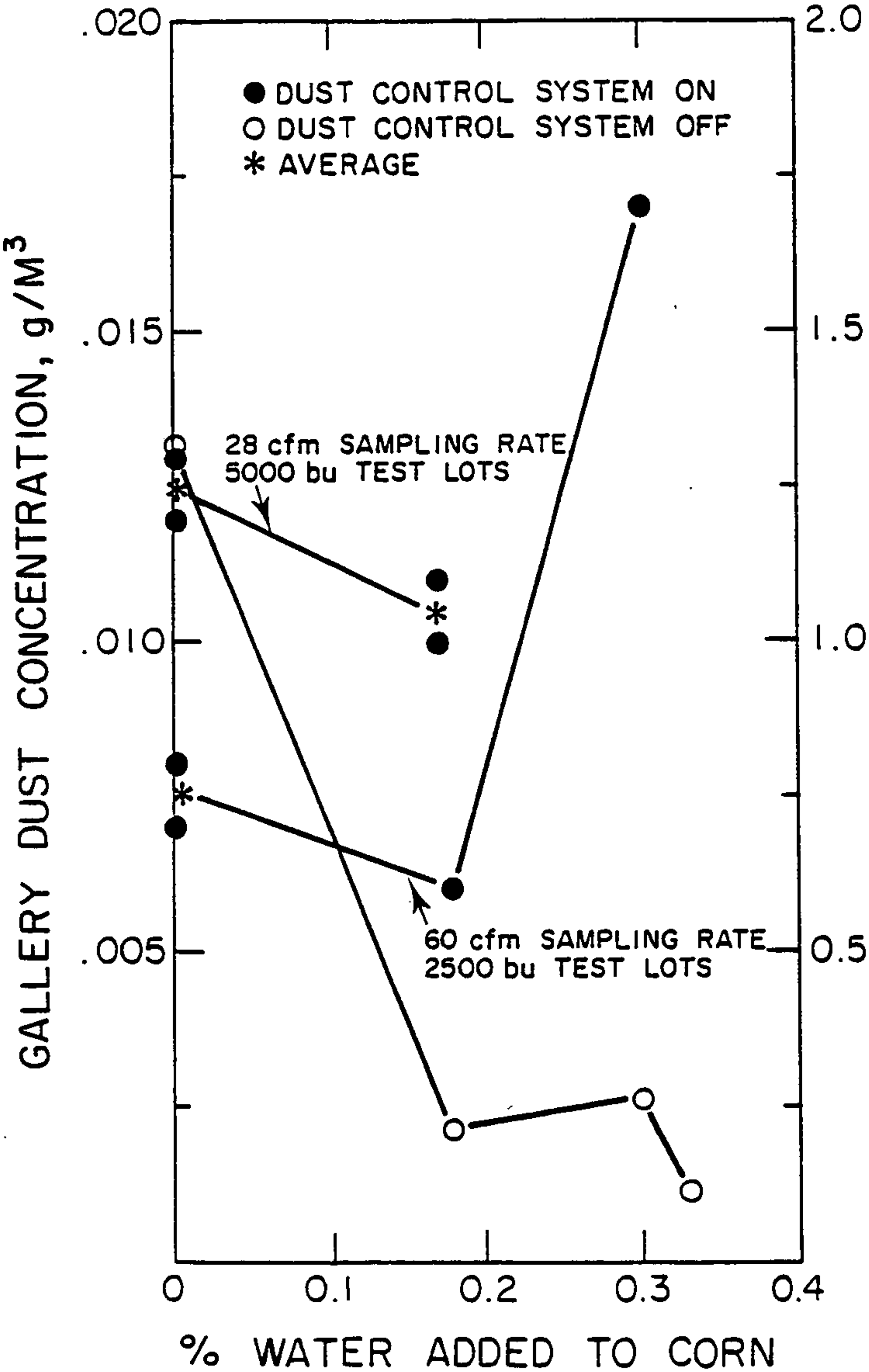

Fig. 14. Open gallery dust concentration, g/m³.

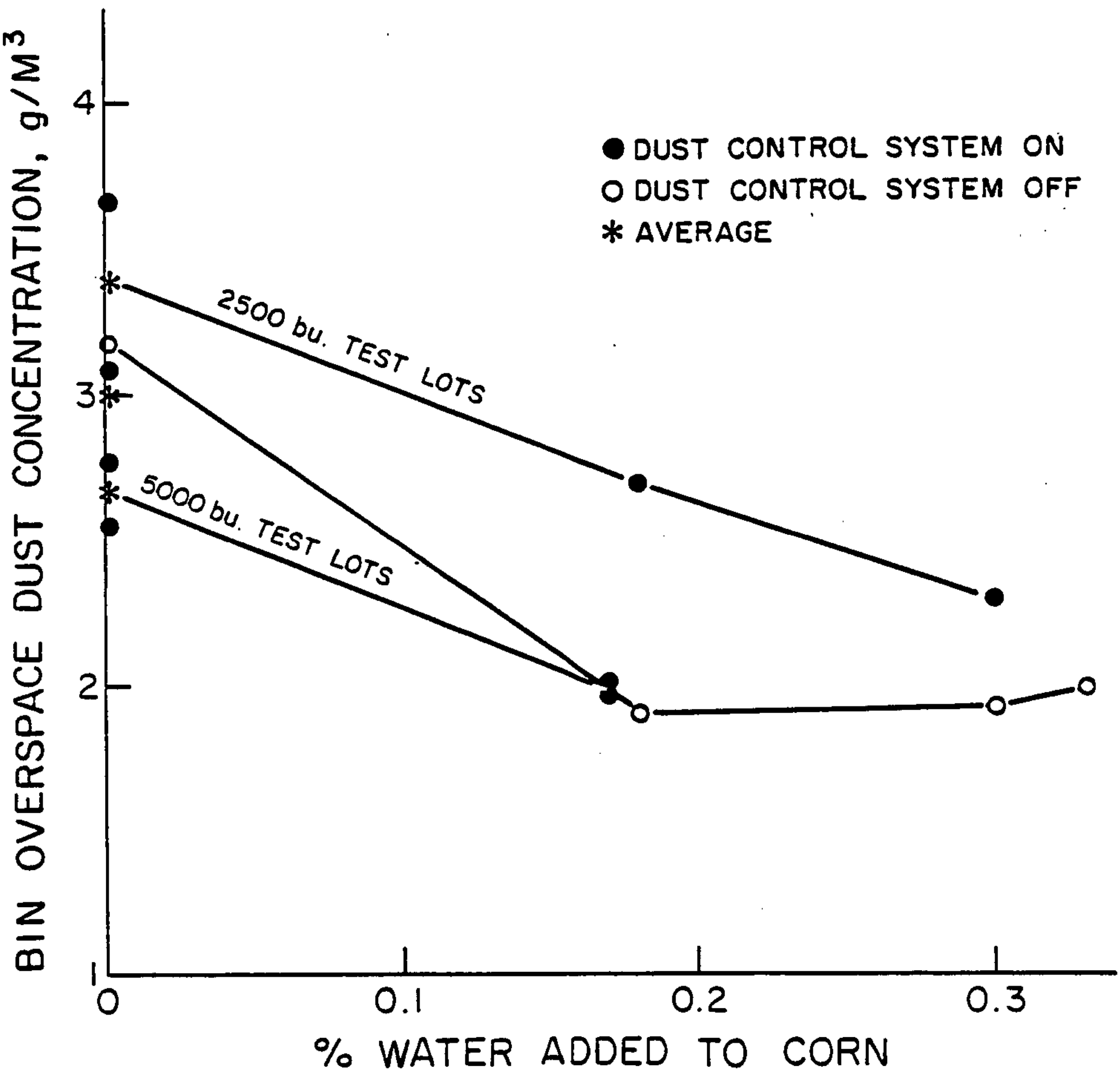

Fig. 15. Enclosed bin overspace dust concentration, g/m^3.

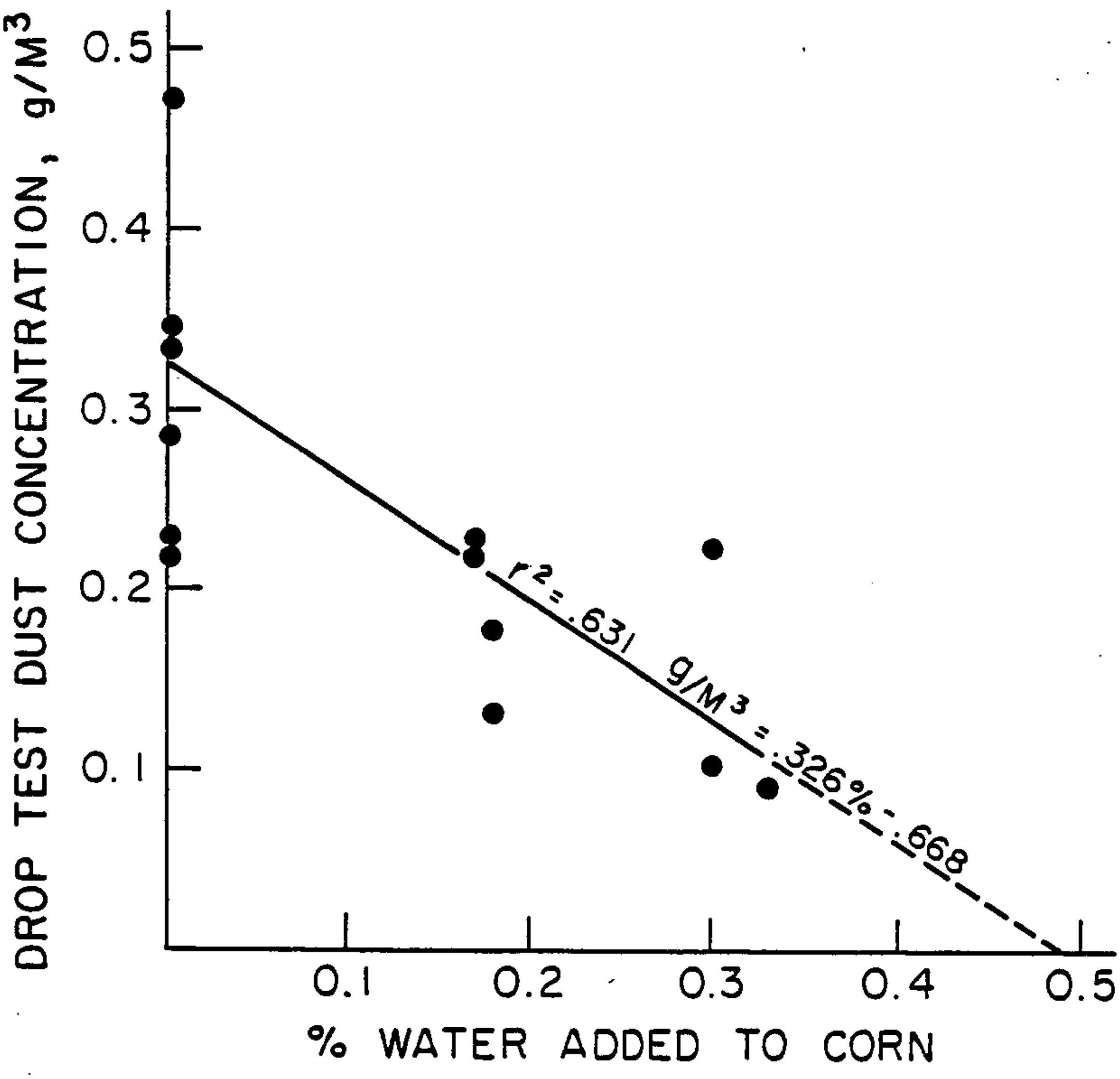

Fig. 16. Drop test concentration, g/m^3.

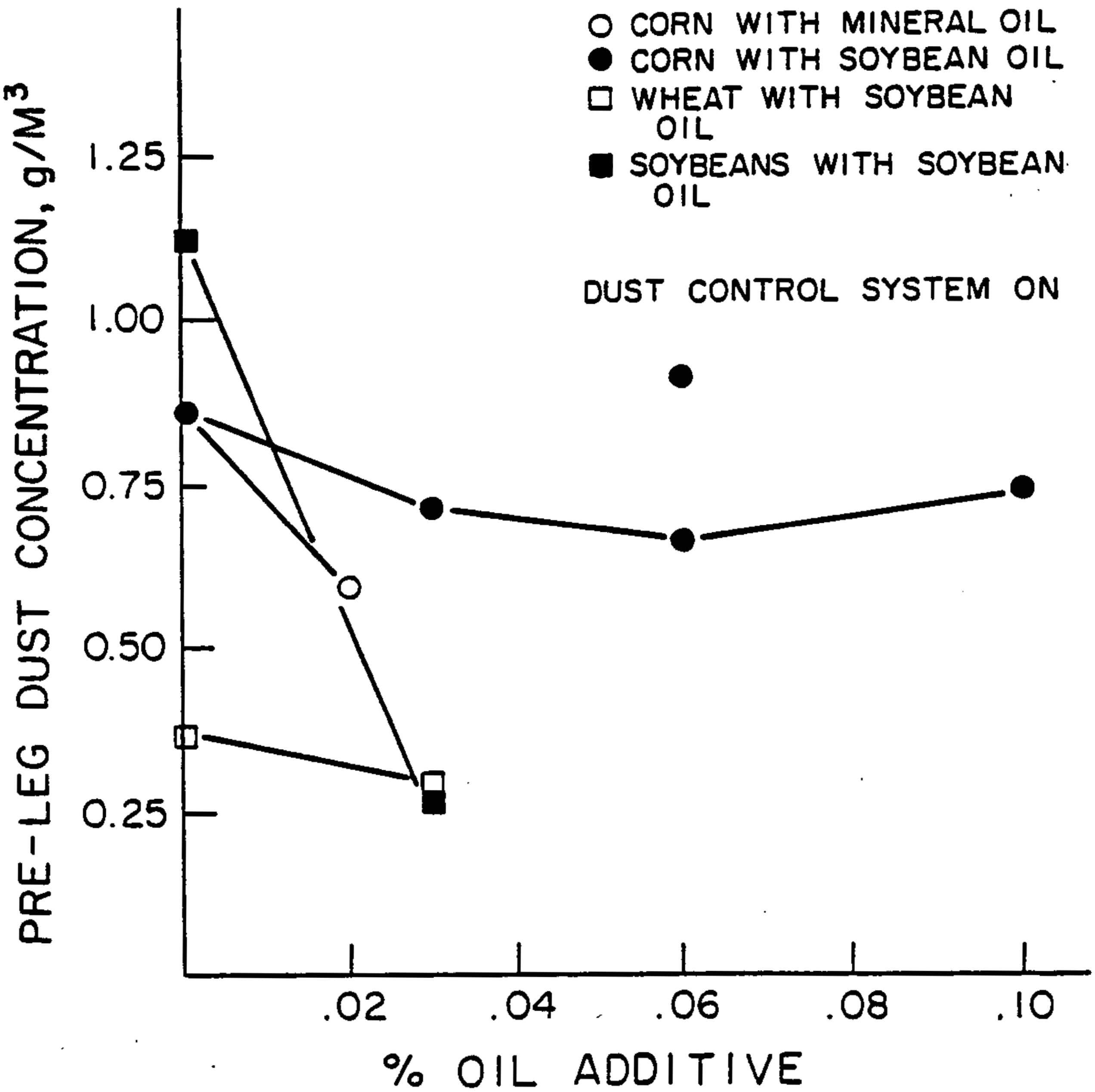

Fig. 17. Enclosed belt dust concentration, g/m^3.

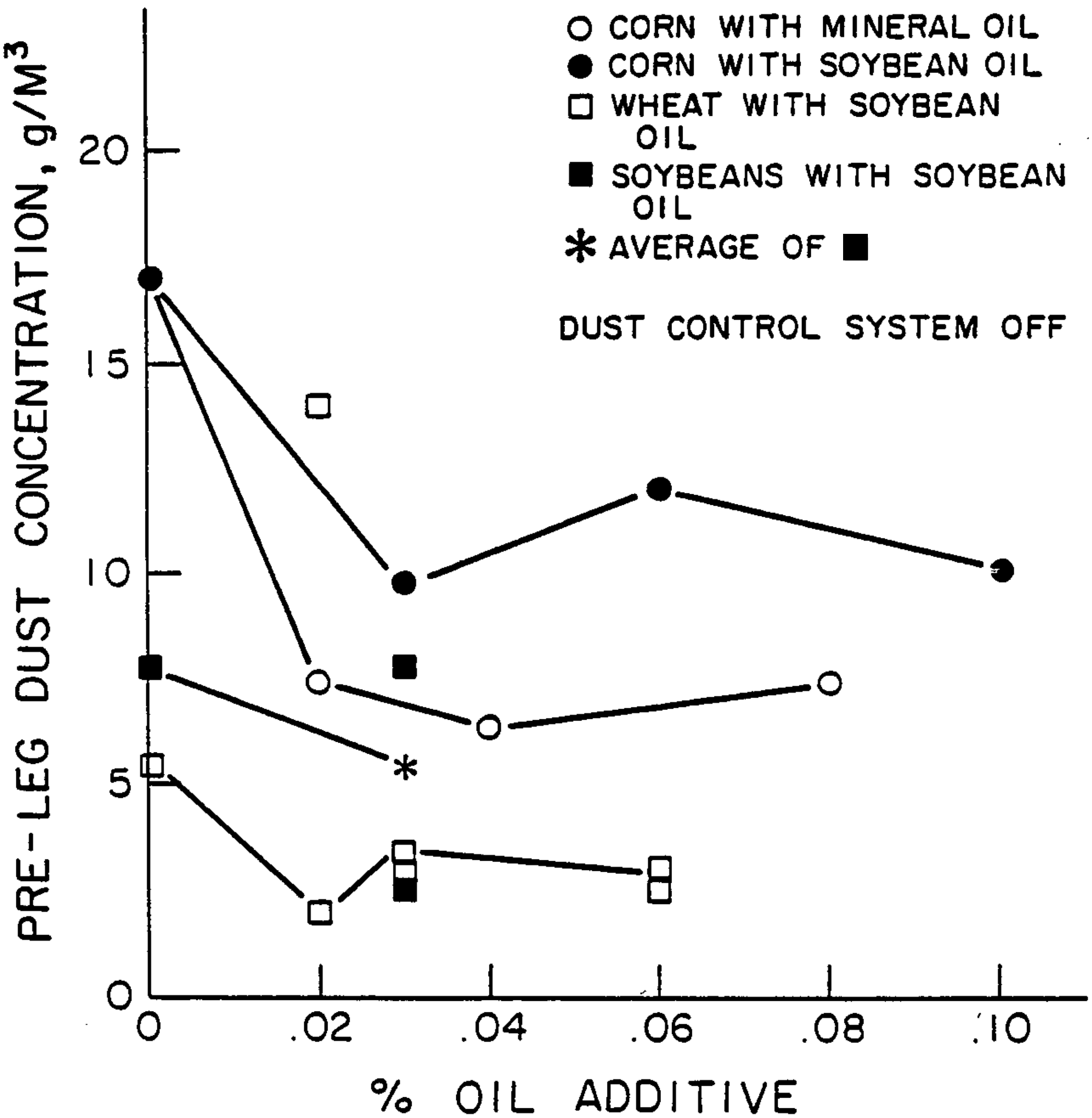

Fig. 18. Enclosed belt dust concentration, g/m^3.

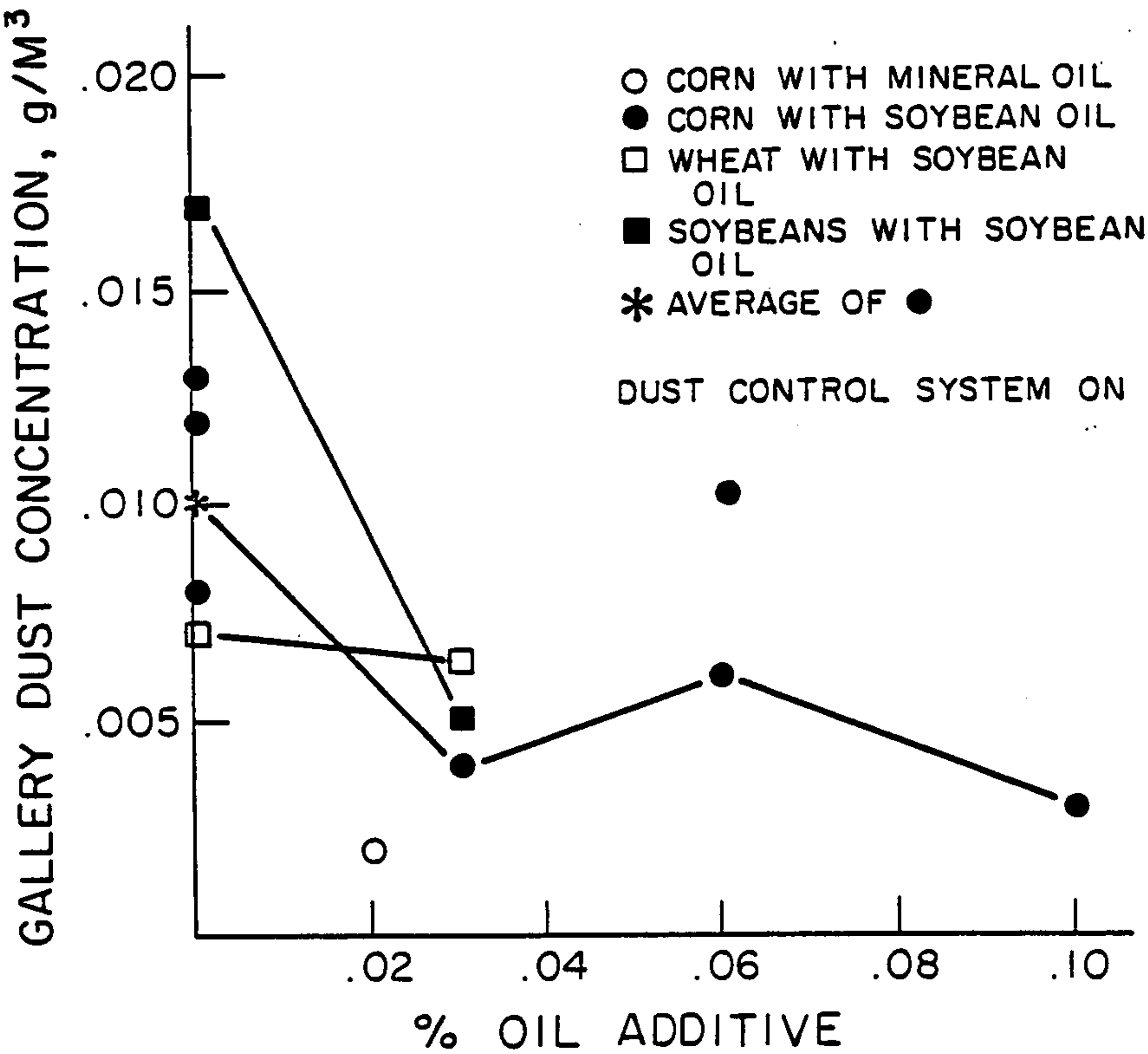

Fig. 19. Open gallery dust concentration, g/m^3.

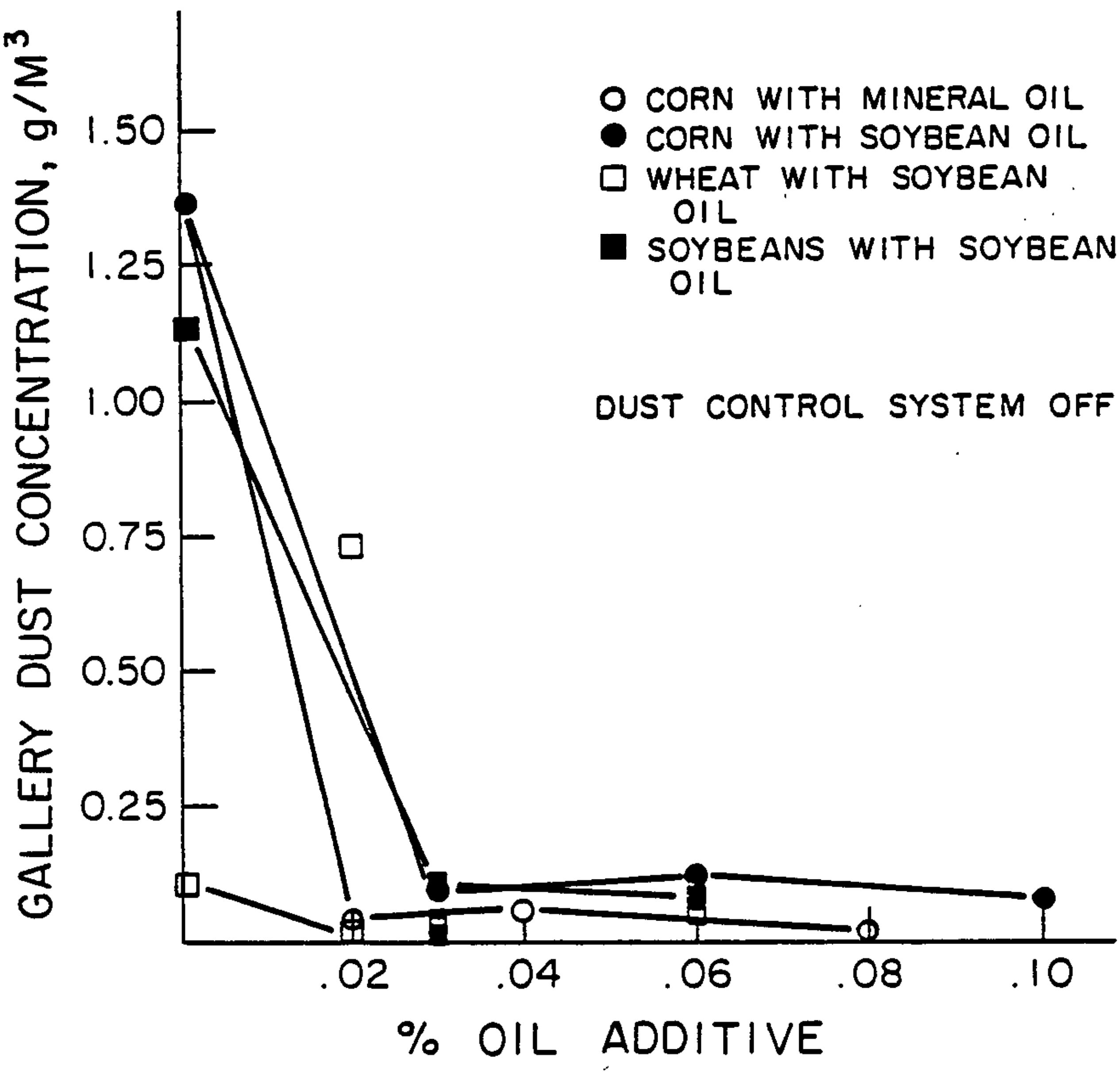

Fig. 20. Open gallery dust concentration, g/m^3.

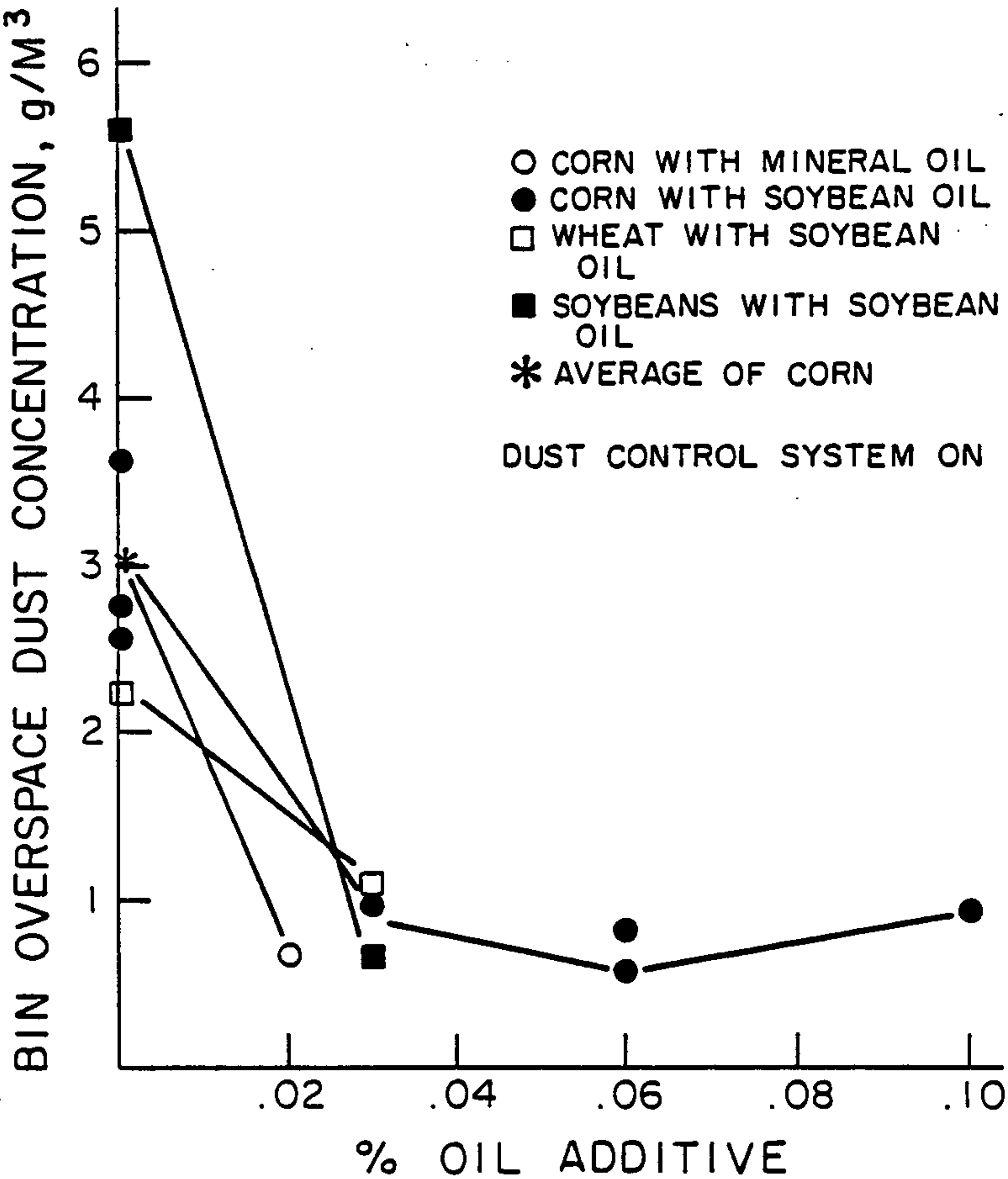

Fig. 21. Enclosed bin overspace dust concentration, g/m^3.

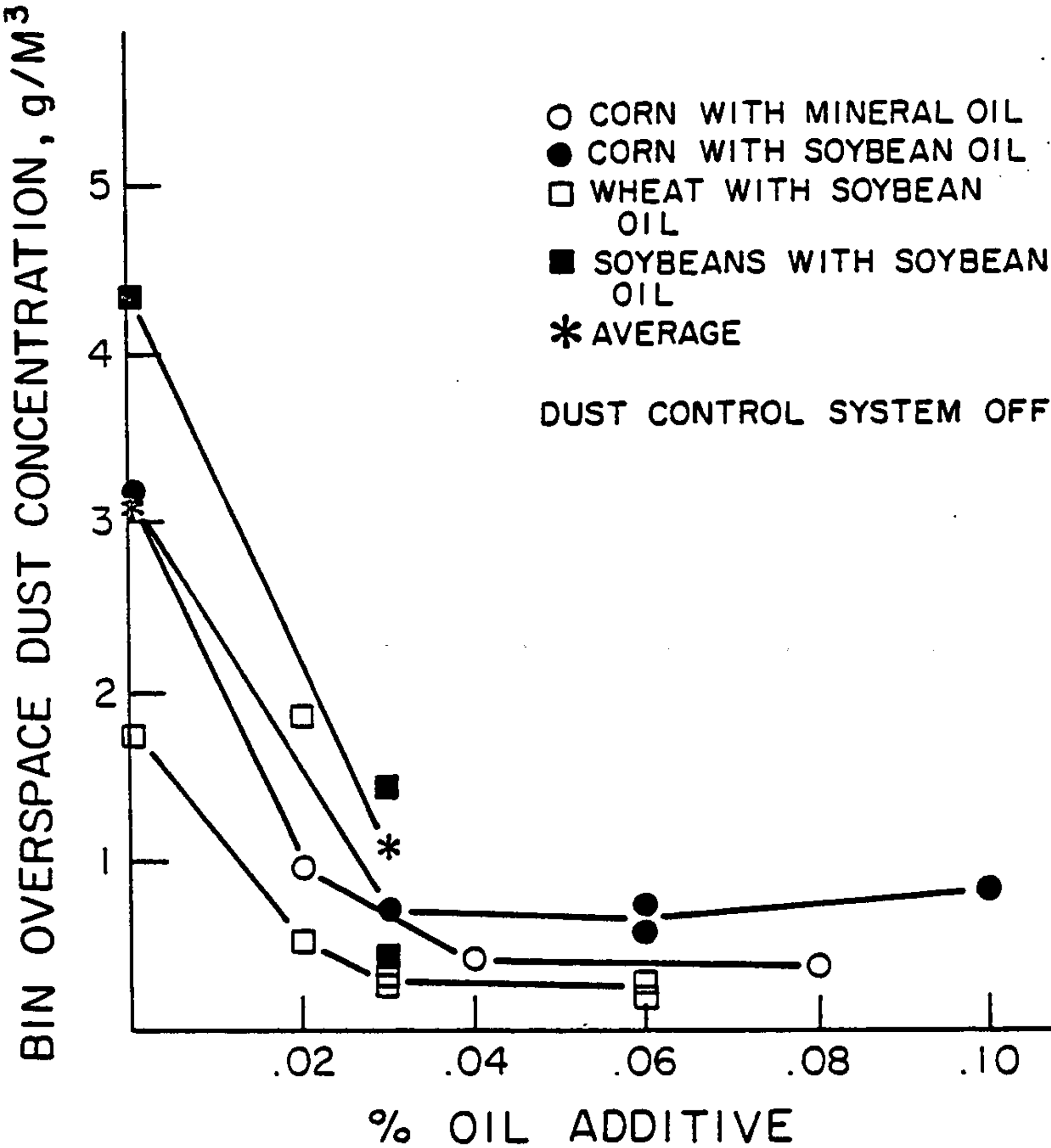

Fig. 22. Enclosed bin overspace dust concentration, g/m^3.

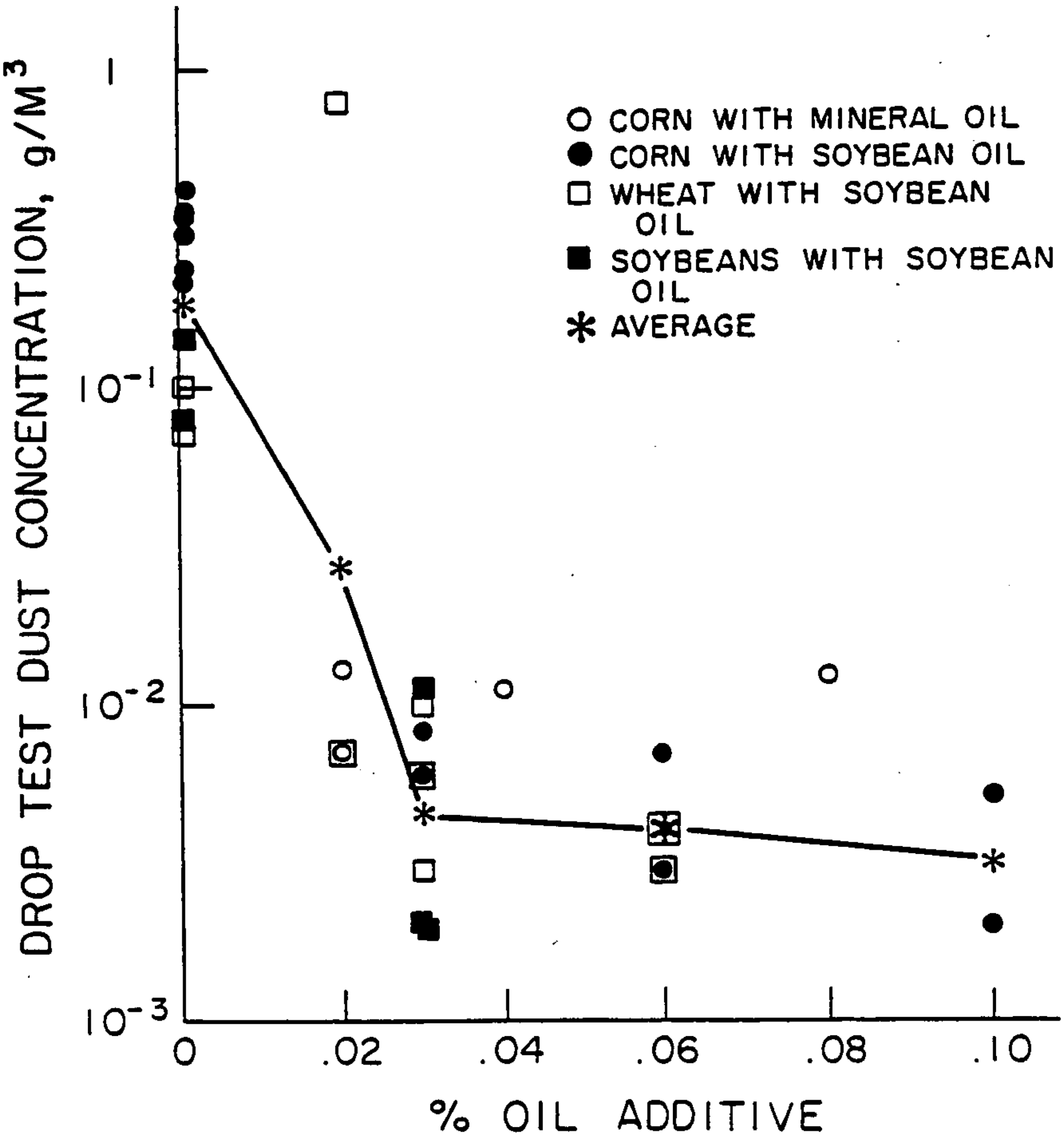

Fig. 23. Drop test dust concentration, g/m^3.

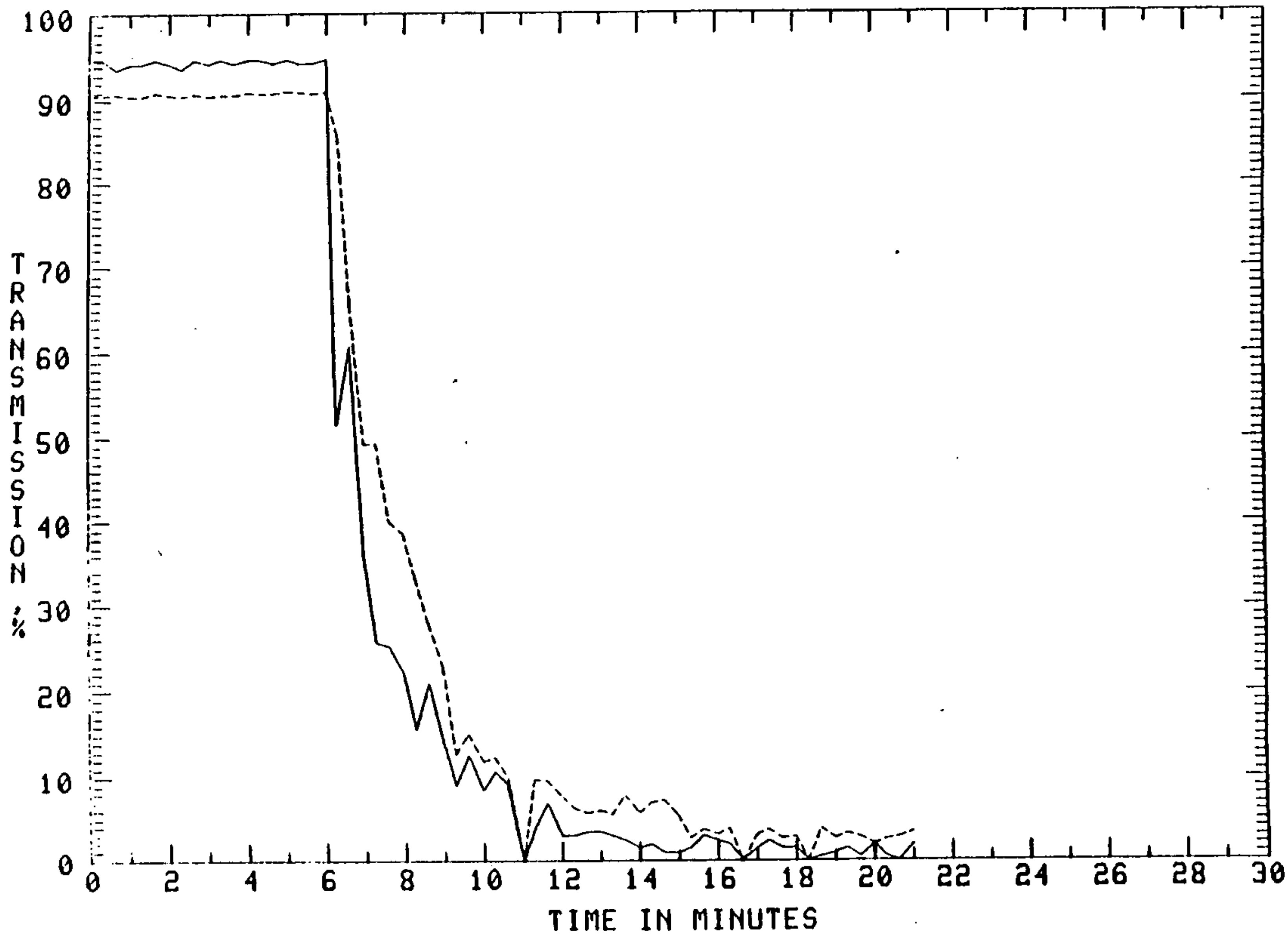

Fig. 7(26). TEST NO.26. SOYBEANS WITH NO ADDITIVES DUST CONTROL SYSTEM ON

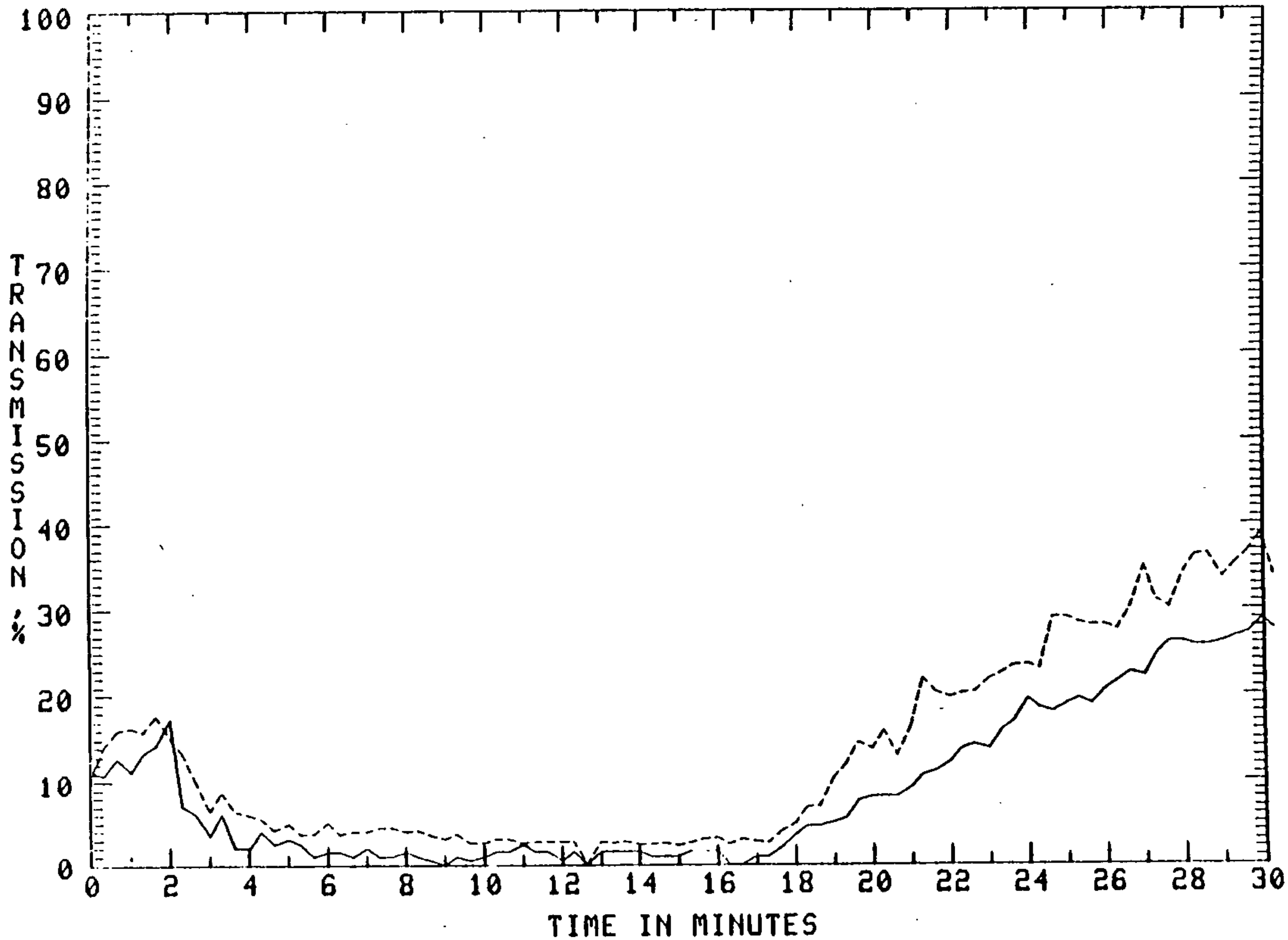

Fig. 7(27). TEST NO.27. SOYBEANS WITH NO ADDITIVES DUST CONTROL SYSTEM ON

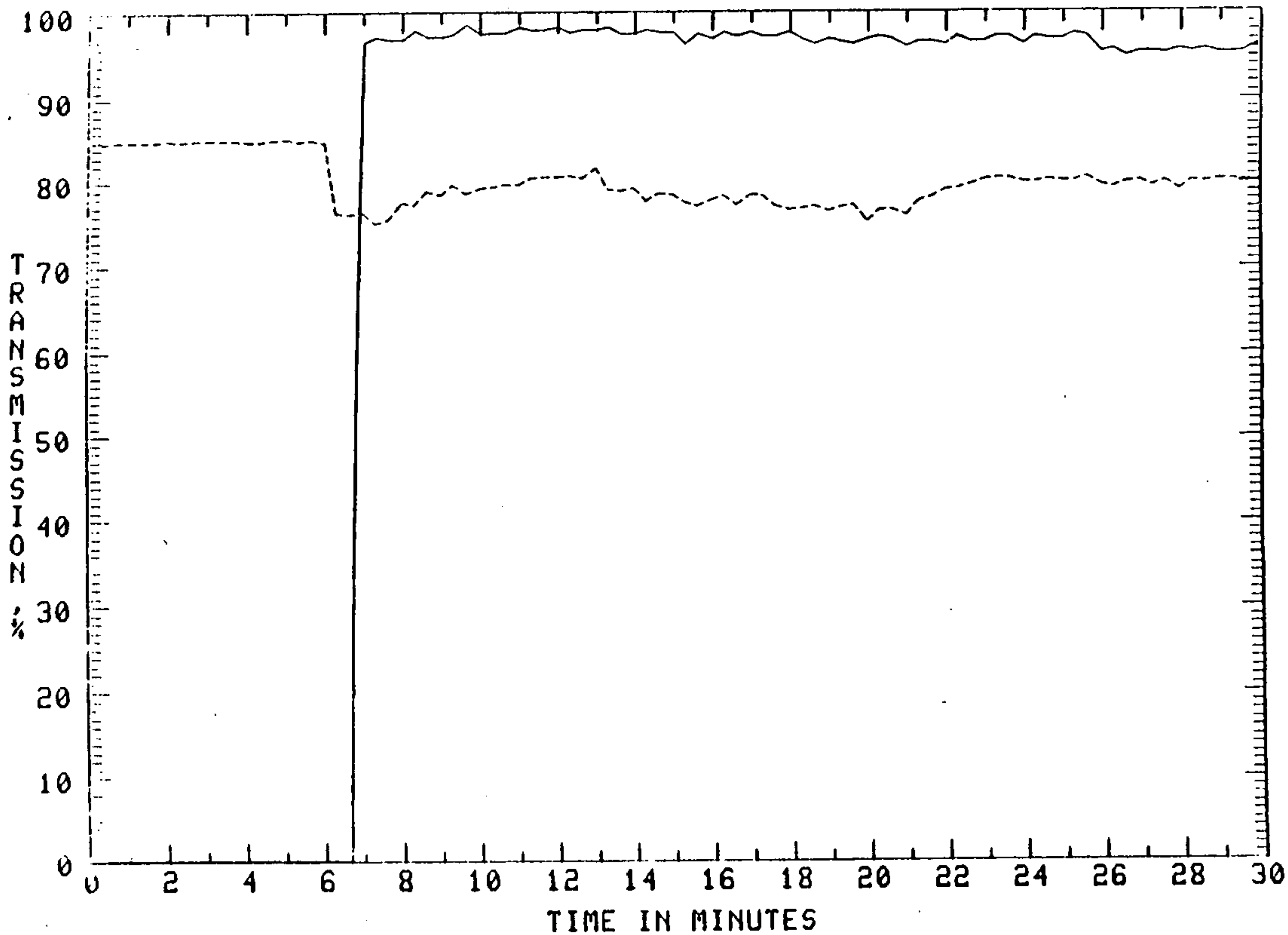

Fig. 7(28). TEST NO.28. SOYBEANS WITH .06% SOYBEAN OIL DUST CONTROL SYSTEM OFF

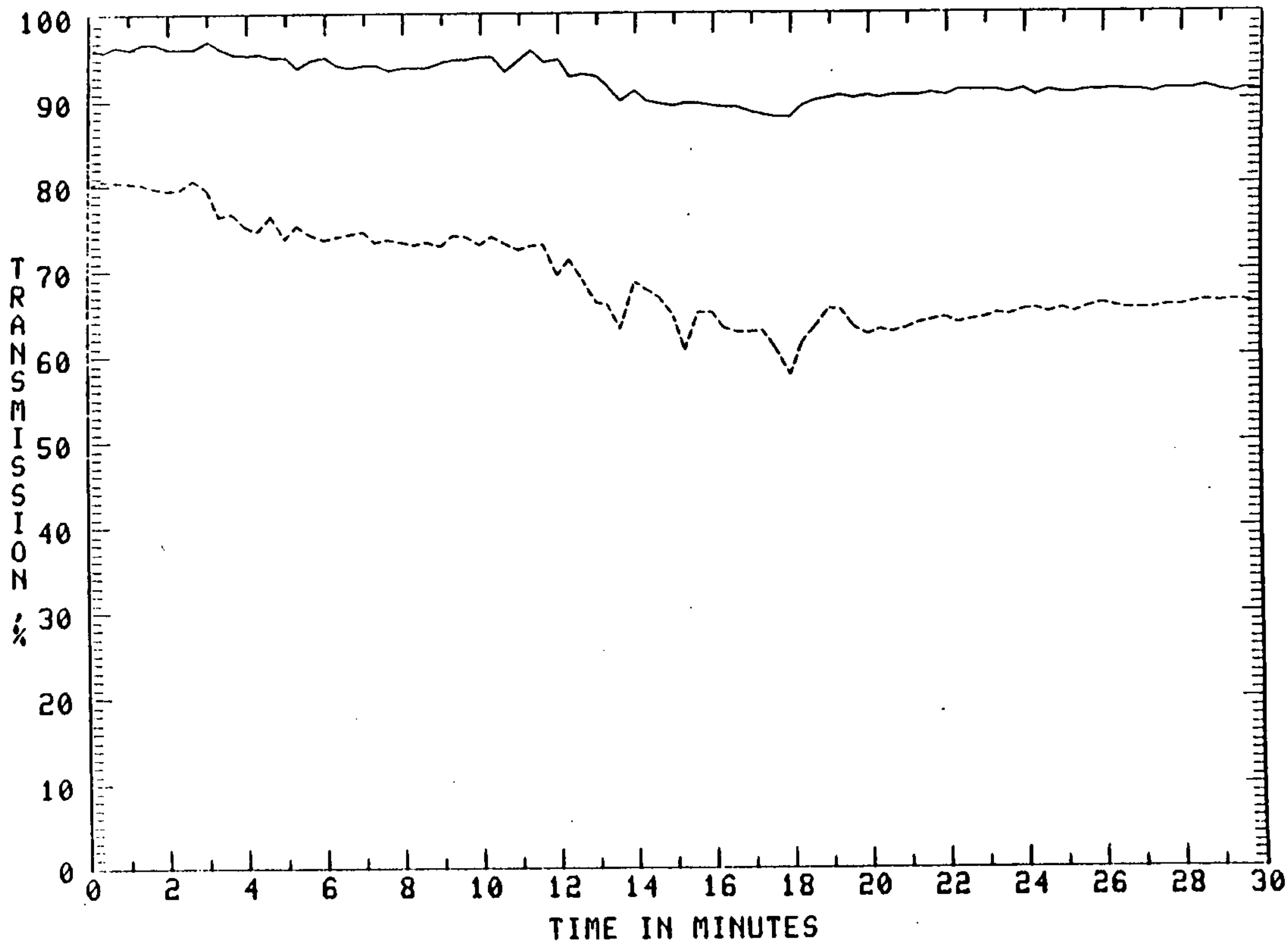

Fig. 7(29). TEST NO.29. SOYBEANS WITH .03 % SOYBEAN OIL DUST CONTROL SYSTEM ON

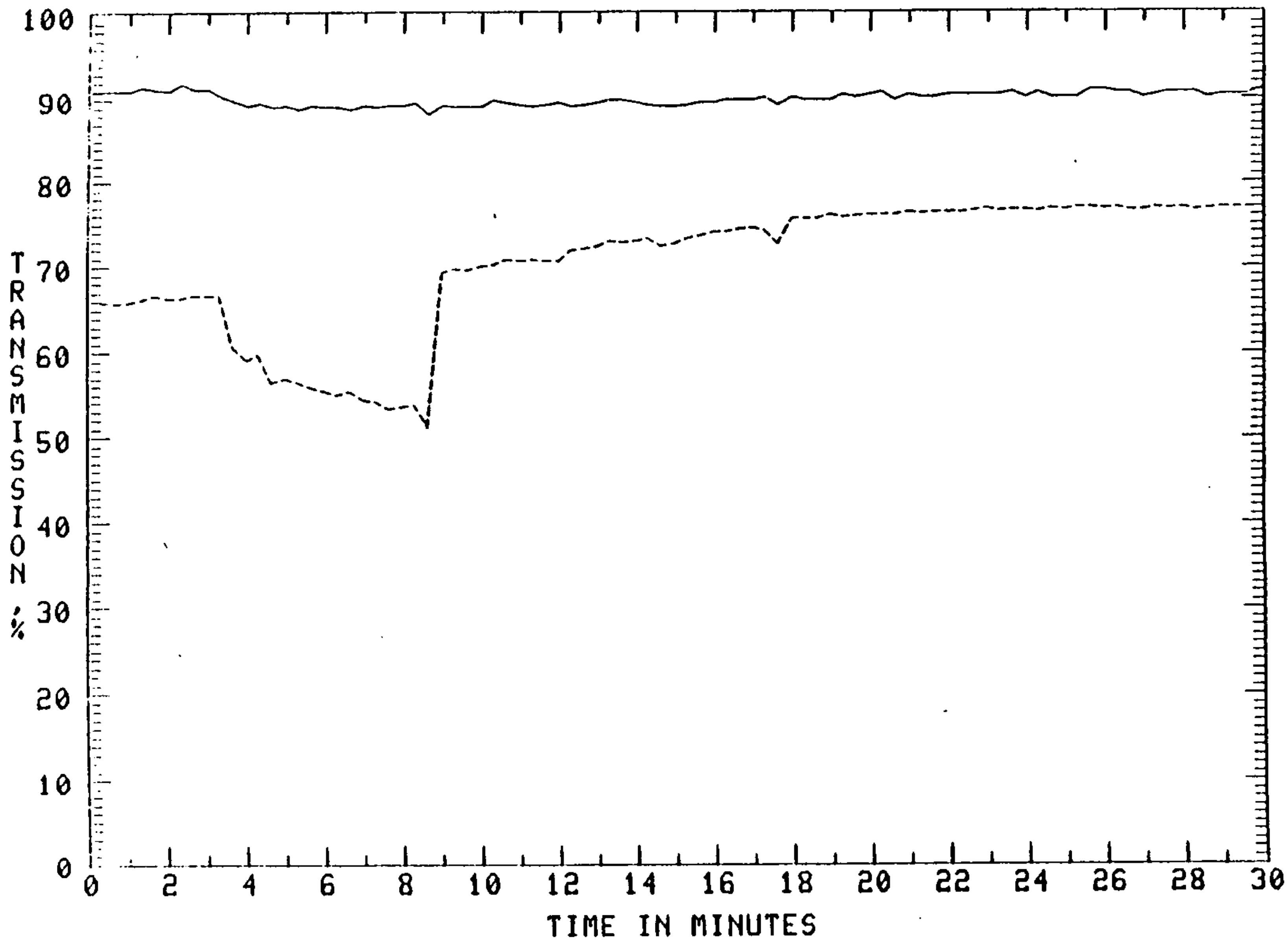

Fig. 7(30). TEST NO.30. SOYBEANS WITH .03% SOYBEAN OIL DUST CONTROL SYSTEM OFF

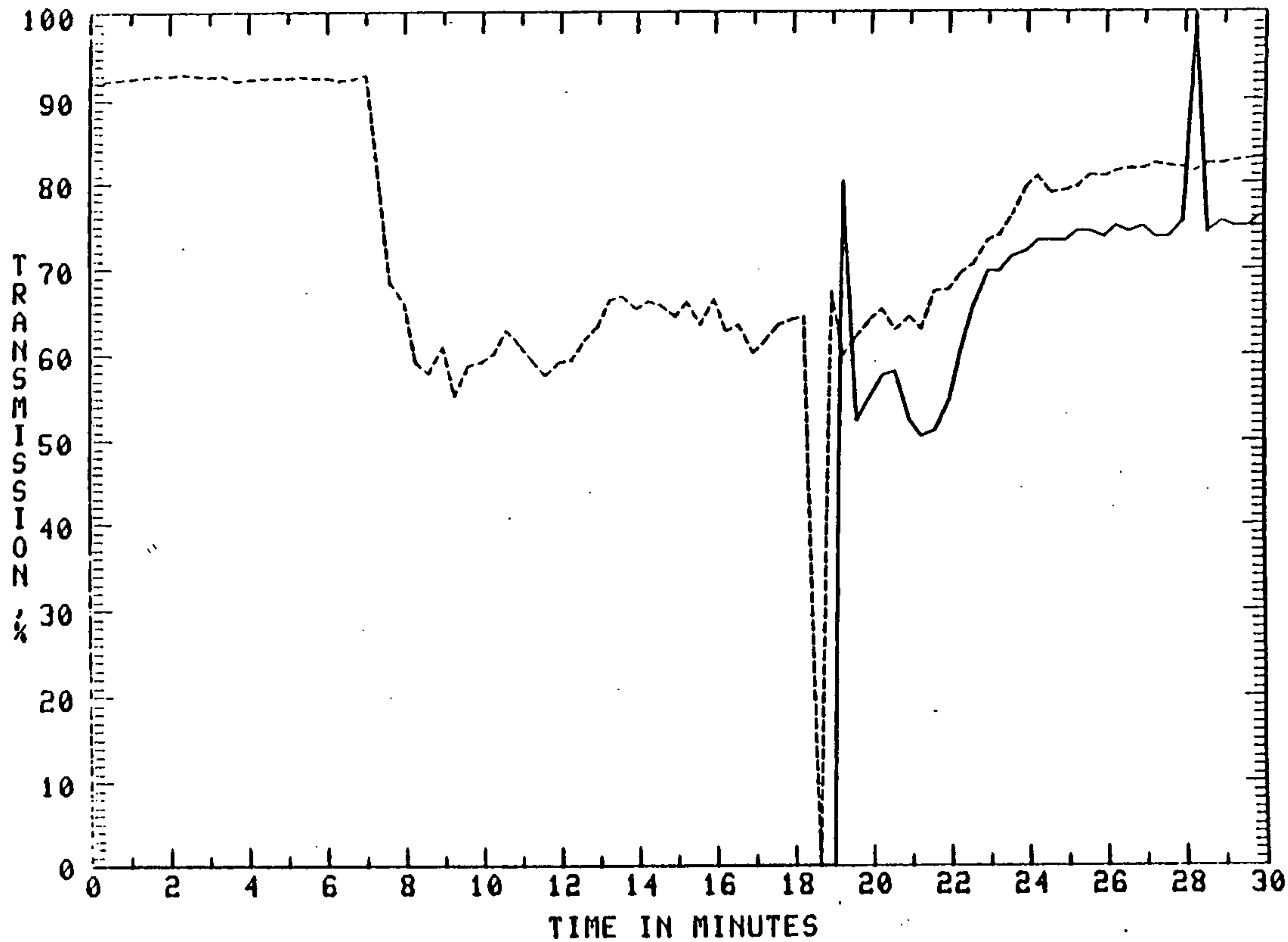

Fig. 7(31). TEST NO.31. SOYBEANS WITH .03% SOYBEAN OIL DUST CONTROL SYSTEM OFF

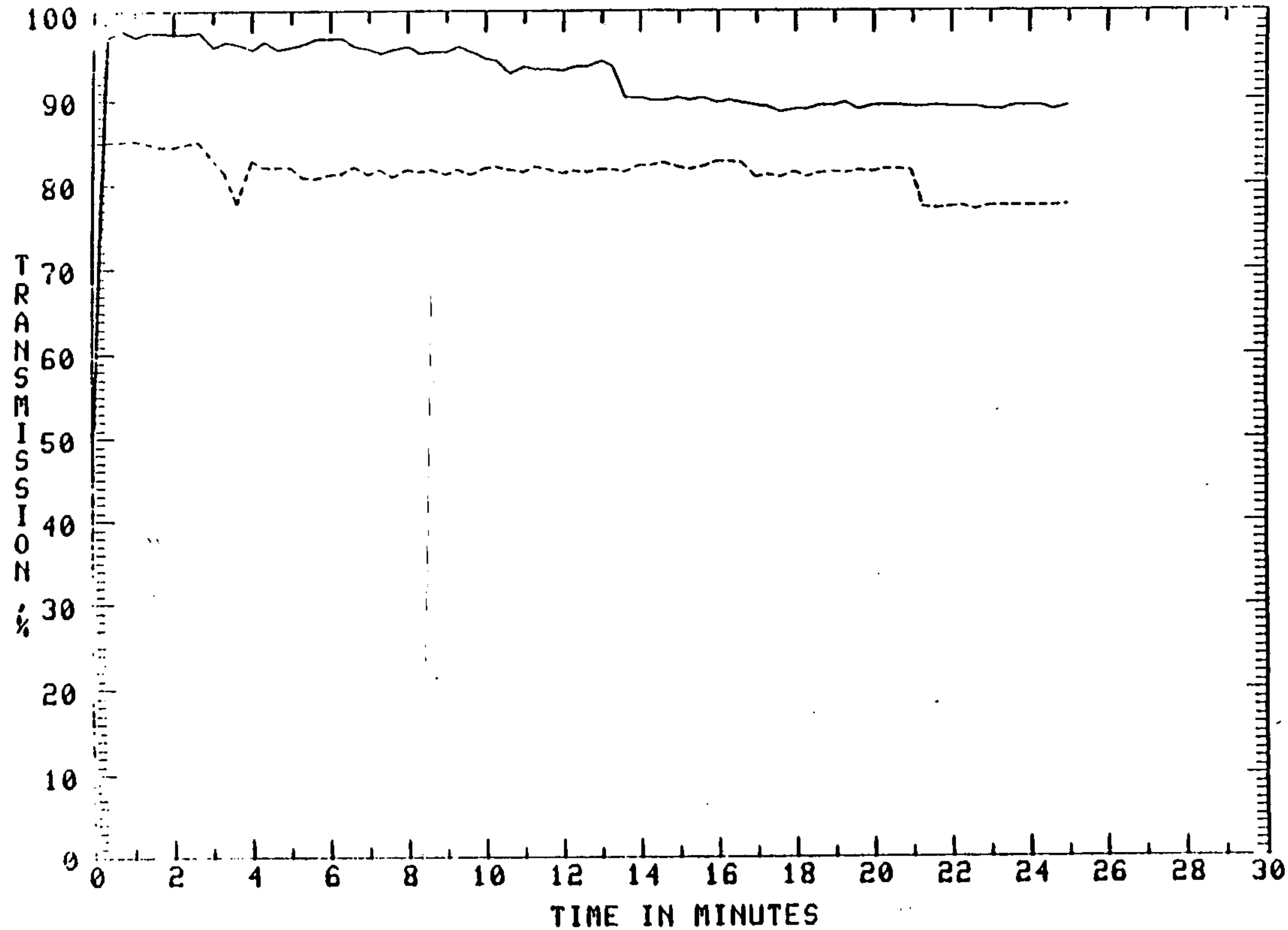

Fig. 7(32). TEST NO.32. WHEAT WITH .06 % SOYBEAN OIL DUST CONTROL SYSTEM OFF