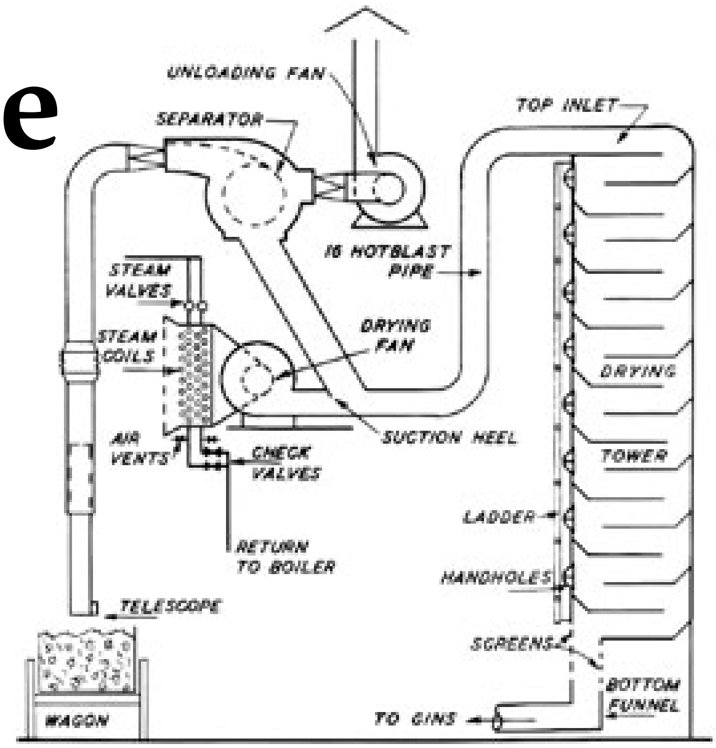
Retrospective View of Cotton Gin Dryers



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RETROSPECTIVE VIEW OF COTTON GIN DRYERS[1]

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ABSTRACT

This paper reviews gin dryer designs and compiles most of the significant research conducted on the drying of seed cotton at cotton gins since about 1929. It describes the operation of various types of dryers and gives a critical appraisal of dryer designs that may be useful at current cotton gins. The compiled information and recommendations should prove useful to scientists planning future gin drying studies, and to engineers selecting dryer designs for commercial gins.

Keywords: cotton ginning, drying systems, gin drying, seed cotton drying.

INTRODUCTION

The first seed-cotton dryers appeared in cotton gins during the late 1920s. The United States Department of Agriculture (USDA) began to study artificial seed cotton drying procedures in 1926. It established the U.S. Cotton Ginning Laboratory at Stoneville, MS, in 1930 to investigate drying and ginning problems. In 1931 only about 15 gins in the U.S. were equipped with dryers (Gerdes et al., 1941).

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Some of the dryers developed for gins included a horizontal zigzag belt dryer supported on rollers (1924); a chemical, calcium-chloride heatless dryer (1926); and a horizontal distributor-dryer (1928). Types of drying apparatus built and tested by engineers of the USDA from 1926-1930 included the horizontal and vertical tray-type dryers, and the horizontal and vertical drag-type dryers. In the horizontal drag type dryer, skeleton conveyers dragged seed cotton along four or six sheet-metal floors through which heated air flowed (Bennett, 1962).

The tray and drag-type dryers were superseded by the USDA developed vertical dryer, which was used on the 1932 crop. It became well known as the "Government Tower-Drier". The vertical dryer contained "floors" or shelves over which a continuous current of hot air transported the seed cotton (Bennett and Gerdes, 1936).

Other seed-cotton dryers used at cotton gins during the 1930's included an improved design roller dryer (1930); vertical, conceal drier, with heater (1931); twin rotary tubular units (1932); unit distributor (1932); feeder-extractor-cleaner (1934); and the Continental conveyer-distributor (1934). Dryers developed or in operation in 1936 were a stub tower, cleaner, and feeders, two stage drying; three types with hot air in cleaner, and a fourth type with stub tower and cleaner; a 16-cylinder spider-arm cleaner with concurrent hot air flows; and a thermo-cleaner dryer, also combined with one or two Government Tower units for multi-stage drying. The Big-Reel cleaner drier was introduced in 1937; as was the multiunit Tower Dryer, upper section with plain shelves and lower section with beaters. In 1938, several manufacturers began building various type of Government tower dryers (Bennett, 1962).

OBJECTIVE

This paper reviews and compiles most of the significant research conducted on the drying of seed cotton since about 1929. It describes the operation of various types of dryers and gives a critical appraisal of dryer designs that may be useful at current cotton gins. Materials from the review are arranged chronologically into two sections, Gin – Dryer Research and Cotton Gin Dryers. The compiled information and recommendations should prove useful to scientists planning future gin drying studies, and to engineers selecting dryer designs for commercial gins. It also provides some guidance for gin owners in balancing the cost of a drying system against the needs of the gin.

GIN – DRYER RESEARCH

Background Information

Cotton Quality

A study was conducted at the U.S. Cotton Ginning Research Laboratory (USCGL), ARS, USDA, Stoneville, MS, to determine the effect of fiber moisture content on breaking strength of individual cotton fibers. The results showed that cotton fibers are weaker at lower moisture content than at higher moisture levels. Therefore, cotton ginned at low moisture levels is certain to contain more broken fibers than cotton ginned at higher moisture levels. It was recommended that gin dryers should be adjusted to produce lint at the gin stand with moisture content at about seven percent. It was also suggested that moisture might be added to seed cotton of less than six percent fiber moisture before it reaches the fiber-separation process in order to improve the ginning quality of the cotton. Ginning with fiber moisture content above eight percent is expected to give operating difficulties and rough preparation (Moore and Griffin, 1964).

Basics of Drying

The mechanisms involved in the removal of moisture from seed cotton are described by researchers in the vapor pressure theory of drying. As the temperature of the seed cotton increases the vapor pressure inside the seed-cotton components increases, and there is a flow of moisture from points of high to points of low vapor pressure. The amount of flow is approximately proportional to the vapor pressure differences between the cotton and surrounding atmosphere (Hall, 1957).

Cotton dries at a falling rate, which is why the drying rate is highest at the beginning of the drying period and decreases as the cotton is dried. At a temperature of about 250º F or higher, the cotton surface moisture is removed during the first three seconds of drying. The airflow should be sufficient to carry off the evaporated moisture so that a low relative humidity can be maintained in the heated air stream (Griffin and Mangialardi, 1961; Leonard, 1964).

The four basic factors that determine the effectiveness of seed cotton drying systems are drying air temperature, air volume, time of exposure, and the relative speed of the air and the cotton (slip). Various gin cotton drying systems offer varying levels of these basic factors. There are many combinations of these factors, which will satisfactorily dry cotton (Mayfield, 1996).

Design Concepts

Parallel-Flow Dryer

Most cotton gins still dry seed cotton utilizing the shelf-type tower dryer. The dryer operates on the parallel-flow principle where the drying air is also the conveying medium. Current tower dryers contain 16-24 shelves and conveying air velocities through the shelves are generally in the 1,000 to 2,000-ft/min range. Two centrifugal fans in a push-pull fan arrangement provide hot conveying air through the serpentine passageways (shelves) in the tower dryer. Conveyed seed cotton impacts the dryer walls as it changes direction between each shelf. This action improves the drying process by agitating the seed cotton, forcing the hot air to pass through the cotton, and helps to lengthen the exposure period. Seed cotton may be in a dryer up to about 12 seconds. For wet seed cotton, it is usually necessary to employ two stages of tower dryers for adequate moisture control. Traditional tower dryers use about 20 cubic feet of hot air per pound of seed cotton (Baker and Griffin, 1983).

Multiple-Path Drying

A 1959 experiment at the USDA Stoneville Laboratory with a 300-foot pipe drying system revealed that moisture evaporation is very rapid for 2 or 3 seconds. These data indicated that the drying curve breaks sharply when the cotton surface moisture has been removed. The pipe-drying and other research led to the design and construction of a multiple-path tower dryer capable of path selection (Franks and Shaw, 1962).

The multiple-path drying system consisted of a conventional 24-shelf tower dryer, modified to provide three drying paths (Figure 1). Cotton could be fed into the dryer at the top for 24 shelves of drying, into the center of dryer for 13 shelves, or at the bottom of the tower for 1 shelf of drying. In a 1960 experiment, using a temperature of 250º F at the mixpoint the multiple-path dryer reduced seed cotton moisture content from 12.6 percent at the wagon to 11.0, 10.5, and 10.1 percent at the feeder apron after the cotton passed through the short, middle, and long paths, respectively.

Monoflow System

The Monoflow cotton ginning system was developed at the USDA Southwestern Cotton Ginning Research Laboratory, Mesilla Park, NM about 1963. There are two air streams in the monoflow system, although only one enters and leaves the gin building. The entering air stream is the seed-cotton handling air. It enters the wagon suction pipe and conveys the seed cotton to the wagon separator. This air is cleaned, and then reused and recleaned after passage through each seed-cotton cleaning separator. After the final seed-cotton separator, this air stream is exhausted to the outside. The air must be moisture conditioned one or more times during cleanings. It is heated if the cotton is to be dried, or humidified if moisture is to be added or restored to the cotton. An inline air filter was used in the air stream ahead of every direct-fired burner (Leonard and Gillum, 1968).

The second air stream is used to convey the lint from the gin stands to the lint cleaners, and thence to the press condenser. This second air stream is pulled from the gin room and recirculated within the gin building; it may be cleaned and moisture removed or added.

In a later experiment, with natural gas as the fuel, the monoflow air system was successfully used with two stages of seed-cotton drying. The monoflow operational mode used 20-percent less total fuel than the conventional two-tower mode, and there were no differences between the modes in seed-cotton drying. In the monoflow mode heat recovery was achieved by feeding the warm exhaust air from the first stage of drying to the intake of the second stage (Leonard et al., 1979).

Moving Bed Dryer

A moving bed wire belt dryer was designed and constructed at the USDA Cotton Ginning Research Laboratory, Stoneville, MS, in 1963. Airflow was arranged so there was virtually no temperature gradient from cotton inlet to cotton outlet. The drying factors air-to-cotton mass ratio, temperature, and exposure period were studied. Comparison experiments showed the moving bed dryer to be less efficient in moisture removal than the two-tower drying system. Both procedures utilized 20 seconds of exposure. The principal conclusion drawn from the experiments was that some agitation--tumbling or stirring--of a seed-cotton mass during drying provides more rapid and more uniform drying than that provided by heated air moving through an unagitated bed of cotton where new surfaces are not continuously exposed by the tumbling action (Mangialardi and Griffin, 1968). This reinforces the contribution of “slippage” as one of the four basic factors of drying (Mayfield, 1996).

Vacuum Drying

A continuous-flow vacuum dryer was constructed and tested at the USCGL, ARS, USDA, Stoneville, MS, in 1968-69. A lobe-type rotary blower produced a vacuum pressure of approximately eight inches of mercury within a chamber through which three flexible steel conveyor belts transported a batt of seed cotton. Exposure time in the partial-vacuum chamber was controlled by the speed of the conveyor belts. The average seed-cotton moisture content decreased from 11.4 to 9.5 percent in one test series after four minutes of drying, and from 7.8 to 6.3 percent in a second series after eight minutes of drying. It was determined that the procedure is too slow to be practicable in ginneries (Mangialardi and Griffin, 1974). Vacuum drying at gins might become feasible if the ginning system is redesigned to allow longer drying periods, and more individual cotton locks are exposed by greater agitation of the seed-cotton batt. Vacuum plus heated air might have some merit as vacuum would lower the "boiling point" of the moisture.

Belt Dryer

A workable belt dryer was developed in Texas about 1983. The equipment used consisted of a 50 foot long by two-foot wide flat wire mesh belt conveyor with air plenums enclosing the areas above and below the belt. In experiments a drying front was forced through an 18-inch depth of cotton in about 65 seconds with downward aeration of 50 cubic feet of air per minute per square foot of belt surface. Aeration downwards through the cotton was nearly twice as effective in reducing moisture content as aeration upward. Heat utilization efficiency for the belt dryer was approximately twice that reported for a tower dryer system (Laird and Smith, 1992).

Counter-Flow Drying

An experimental counter-flow dryer was built and tested at the USDA Southwestern Cotton Ginning Research Laboratory, Mesilla Park, NM, about 1985. The counter-flow dryer used rotating spiked cylinder cleaner type cylinders to convey seed cotton 20 feet against a counter flowing heated air stream. Seed cotton had a dryer residency time of approximately 14 seconds. Using an air temperature of 200º F and seed cotton of 13 to 17-percent moisture content, the experimental dryer could dry the lint fraction of the seed cotton down to an average of 7.4

percent. Possible advantages to the industry could be conveying, drying, and cleaning in one compact operation; or a reduction in horsepower required for present systems (Hughs et al., 1986).

Cross-Flow Dryer

A cross-flow dryer-belt transport system was tested in New Mexico about 1985. In addition to drying, the belt-conveyor procedure moved cotton from the module into the gin. Packing density of machine-stripped cotton on the belt was approximately two pounds per cubic foot, and air velocity through the batt was about 50 feet per minute. Results showed that about 48 seconds gave adequate drying for depths of 12 to 14 inches of seed cotton on the belts, and approximately 60 seconds would be needed for 18 inches of depth. In one experiment a 60-second pass over the belt at 300 degrees F with 15 bales of 20.2-percent moisture content seed cotton resulted in trouble-free ginning (Hughs et al., 1986).

Drying System Improvements

Automatic Control

Automatic control of seed-cotton drying at cotton gins was demonstrated at Stoneville in 1960. A moisture detector measured the electrical resistance of seed cotton passing between two rotating electrodes as an index to fiber moisture content. Based on the measured moisture content, the detector changed the drying exposure period by throwing directional valves in a three-path (multipath) dryer. The moisture detector used a servomotor to position a recording pen, then through cams and snap-action switches, energized solenoids that activated pneumatic cylinders to operate the 3-path dryer directing valves. The automatic system caused dry cotton to bypass the dryer (1 shelf), damp cotton to bypass half of the dryer (13 shelves), and damper cotton to bypass none of the dryer (24 shelves) (Griffin and Mangialardi, 1961).

This automatic drying procedure was expanded into a complete moisture control system in 1967 by integrating moisture restoration. In addition to drying damp seed cotton in the three-path dryer, the detector activated a moisture restoration unit when dry cotton was processed and introduced humid air at about 85-percent relative humidity into the seed-cotton batt between conveyor distributor and extractor feeder. Thus, the moisture content of dry cotton (below 5-percent) was increased before fiber-seed separation in the gin stand (Griffin and Mangialardi, 1967).

Airflow Rates

A cotton-handling pipe system of eight-inch diameter was designed and installed at the USCGL, ARS, USDA, Stoneville, MS, in 1972 to ascertain the minimum air velocities and air-to-cotton ratios that would be sufficient to convey seed cotton at the range of moisture levels encountered at gins. Seed cotton was conveyed through the pipe by suction. Results showed that at a seed-cotton moisture content of about 10 percent, average air velocities of 900 or 1,000 ft/min at the center of the pipe were inadequate to convey seed cotton in mass and moved only a few cotton locks a few feet. Air velocity appeared to be more important than the air-to-cotton ratio (ft^3 air/lb seed cotton) in maintenance of normal cotton flow. With an average air velocity of 2,550 ft/min at an air-to-cotton ratio of 9.3 seed cotton of 22.2-percent moisture content flowed normally (Mangialardi, 1977).

Further experiments in 1978-79 showed that the minimum quantity of conveying air at 230 - 240º F would also be sufficient for adequate moisture removal in shelf drying systems. Two 24-shelf dryers were used in the study. Seed cotton was transported through each dryer by two fans in a push-pull arrangement. The study showed that the minimum air velocity in the shelf dryer, measured under standard air conditions, should be about 1,200 ft/min for seed cotton at 18-percent moisture and about 1,000 ft/min for cotton at 10-percent moisture. These velocities would be used with air-to-cotton ratios of 11 to 13 ft^3 air/lb seed cotton. It was indicated that problems with cotton flow could be expected at velocities below 900 ft/min and air-to-cotton ratios below about 9.7 ft^3/lb (Mangialardi, 1986).

Equilibrium Moisture

A part of the ginning research program at the U.S. Cotton Ginning Research Laboratory, USDA, Stoneville, MS, involved determining the equilibrium moisture content of cotton approaching equilibrium from very dry and very wet initial conditions. In the experiment, lint ginned from newly harvested samples was preconditioned dry (1.3 percent) or wet (19.5 percent) and then exposed to atmosphere covering a range of relative humidities. After being subjected to atmosphere of 12, 33, 53, 75, and 94 percent relative humidity, the preconditioned dry samples averaged 2.4, 4.4, 6.2, 8.8, and 15.2 percent moisture content, respectively. Corresponding lint moisture contents for the preconditioned wet samples were 3.8, 6.3, 8.1, 10.6, and 16.3 percent (Griffin, 1974).

Later work at the Cropping Systems Laboratory, Cotton Production and Processing Research Unit, USDA, Lubbock, TX, demonstrated the effect of drying temperature on the equilibrium moisture contents for raw cotton. Satisfactory lint cotton absorption equilibrium data was obtained for four temperature ranges. Results showed that as temperature increases, the equilibrium moisture content of the lint decreases for constant values of relative humidity up to 85%. For temperatures greater than 47° C and relative humidities above 85%, the moisture content increased with increasing temperature (Barker, 1992).

Heat Recovery

A heat-recovery incineration system performed well in tests at Stoneville, MS, in 1975. The heat exchanger, as designed by the USDA Cotton Ginning Research Laboratory, was capable of recovering and delivering to the gin drying system about 31 percent of the available heat from combustion. The recovered heat is equivalent to 2,100 Btu/lb of gin trash burned (McCaskill et al., 1977).

The system was composed of a continuous trash feeder, two burning chambers, a heat exchanger in the stack, a modulating hot-air mixing value, and a conventional gin drying system. The multichamber incinerator was a Consumat Model C-125 rated at 470 lb/hr of type "O" waste. Particulate emission from the system was calculated to be 0.36 grain per dry standard cubic foot, corrected to 12-percent CO_2. No conclusions were reached pertaining to the expected life of the system, nor had it undergone the prolonged operation that would be encountered at a commercial cotton gin.

Insulating Dryers

Investigations in 1977 and 1978 with a 24-shelf tower dryer showed that the rate of heat loss from an uninsulated drying system may be reduced 24 to 28 percent by using Thermal Insulating Wool type II in thickness of 1.5 and 3.0 inches, respectively. It was determined that with insulation, more of the heat supplied to gin dryers would be available for evaporating moisture from damp cotton than would be available without insulation. This allows using lower set-point temperatures and, thus, less fuel would be required for drying cotton in an insulated dryer than in an uninsulated dryer (Griffin, 1979).

Heat Recapture

Five commercial cotton gins in Texas were surveyed during the 1979 ginning season to obtain information on the temperature profiles within gin buildings and to estimate the heat recovery potential. It was found that a large pool of hot air collected in the upper part of the buildings, and that reclaiming the hot air might provide up to 30 percent of the heat needed for the gins drying systems. Results at one gin showed that the heat saving accomplished over an extended period through heat recovery with upper level air intake, averaged 16.7 percent compared to outside air intake. The heat saving above floor level intake within the building averaged 6.4 percent. It was recommended that heat recovery be considered in designing a new gin plant or when rearranging an existing plant (Laird and Baker, 1983).

Energy Used

A survey was conducted during the 1987 season to determine the fuel energy used at gins for drying. Fuel requirements averaged 2.33 gallons of LP gas or 247.8 cubic feet of natural gas per bale. Costs associated in 1987 with these fuel requirements were $1.17 and $1.16, respectively, for LP gas and natural gas (Anthony, 1988).

Variable costs from 221 gins for the 1997 crop were determined by survey and grouped according to four cotton production regions and three cotton ginning capacities. For the four regions representing the Mid-South, Southeast, Southwest and California, dryer fuel costs averaged $1.22, $1.09, $0.96 and $0.77/bale, respectively. When the gins were grouped into three capacities of 15 bale/hr or less, 16-24 bale/hr and 25 bale/hr and up, the corresponding fuel costs averaged $1.09, $1.03 and $0.93/bale. Dryer fuel types were LP or natural gas (Mayfield, et al., 1999).

Comparison Tests

The conventional tower, blow box, and Fountain dryer systems were evaluated in field trials in California and New Mexico about 1988. Neither the blow box system nor the Fountain dryer was as effective as the tower dryer based on the testing criteria used. For the three systems tested, the tower dryer appeared to have the best potential for low temperature drying. The blow box system tested required excessive temperature to dry modestly wet seed cotton and, therefore, may be incapable of drying very wet seed cotton. The Fountain system required less air power than the blow box and three tower systems, but a two-tower system would have been comparable. The blow box system used about 1.5 times as much air power as the other two systems (Abernathy et al., 1989a). Certain aspects of the testing criteria were a controversial issue and entered into several debates and industry panel discussions at the time.

Computer Control

A computer-based dryer control was developed and tested in two cotton gins in Mississippi during the 1990 ginning season. The drying temperature setpoint was adjusted based on the seed cotton moisture content before and after drying as measured by infrared moisture meters. The control system adjusted the air temperature by opening and closing the modulator valve on the gas line feeding the burner. About 60 hours of testing of the control system in a commercial gin indicated good reliability of the system. In the study the seed cotton moisture content was rarely as much as 0.5 percent wet basis from the setpoint (Byler and Anthony, 1992).

Dryer Control

Cotton should be dried in the gin at the lowest temperature that will allow satisfactory gin operation. Laboratory tests have shown that fibers will scorch at 450-500 ºF, ignite at 450 ºF, and flash at 550-600 ºF. In no case should the temperature in any portion of the drying system exceed 350 ºF. Fiber exposure to temperatures above 350 ºF causes irreversible fiber damage (Grant, et al., 1962; Hughs, et al., 1994; Anthony and Griffin, 2001).

The typical source of heat for drying cotton is a burner flame in the stream of drying air. The burner’s maximum output must be adequate for the system used. The ratio of fuel flow rate at maximum burner output to the fuel flow rate that provides the lowest dependable flame is referred to as the "turndown ratio". This ratio is highly important in drying cotton. If the burner will not turn down to a low flame, the result will be overdried cotton or intermittently dried cotton as the burner flame blows out and reignites. A good drying burner will have a guaranteed turndown ratio of at least 15:1, but the ratio can be as high as 35:1, depending on the manufacturer.

Although a cotton gin burner may have been designed and built with an excellent turndown ratio, these ratios are calculated with laminar air flow characteristics around the burner head. If the burner is placed in the direct blast of a push fan (a common scenario), the turndown ratio suffers tremendously. It is not uncommon to see a turndown ratio of 35:1 reduced to an effective ratio of 3 or 2:1, or even less in cases where the air blast is extreme. A ginner should consult with the relevant burner manufacturer for solutions to avoid this problem so common to cotton gins.

The location of temperature control sensors is important. These sensors modulate the gas valve on the heater to control the burner’s flames and thus the drying temperature. It is preferable to use dual sensors to prevent scorching and excessive damage to the cotton. One sensor should be a high-limit temperature controller (set for 350 ºF) located ahead of the heated air and seed-cotton mixpoint. This should be an analog type of temperature control to permit temperatures to be maintained very close to the limit without nuisance shutdowns. The second sensor would be the primary control sensor and should be located downstream of the mixpoint. At this location the second sensor will allow the heaters controller to respond to the amount and wetness of the cotton. In tower dryer systems a recommended practice is to locate the control sensor at the top of the dryer (American Society of Agricultural Engineers, 2000).

Related Drying

Closed-Boll Drying

A two-year study, 1980-81, was conducted at the USCGL, Stoneville, MS, to develop temperature and time parameters for drying of closed green bolls. The objectives were related to preserving the fiber and cottonseed quality during gin processing, and reducing the incidence of byssinosis among workers handling cotton. Closed green cotton bolls were dried in an electric laboratory oven for six hours at temperatures ranging from 100º to 260º F (Mangialardi, 1984).

The more mature bolls began to open after 0.5 hour but only about 20 percent of the bolls had opened after two hours. The amount of moisture evaporated from the bolls in six hours was 30 percent of the boll weight as harvested. Results showed that bolls might be safely dried for six hours at temperatures up to 150º F without lint discoloration and up to 110º F without harm to seed germination potential. There were indications that mature bolls harvested and heated-air dried at 140º F for six hours would open sufficiently for dehulling by conventional ginning machinery.

Cottonseed Drying

A cottonseed drying project conducted from 1947 to 1958 at the USCGL, ARS, USDA, Stoneville, MS, indicated that seed containing 16 percent moisture could be sufficiently dried to store for planting when necessary. However, the use of high temperatures can kill viability in cottonseed. Tests proved that the viability of the seed may be endangered within four minutes exposure at internal seed temperatures above 140º F, and that the mortality rate increases with increases of internal seed temperature above 140º F. When seed having a moisture content of 17 to 20 percent was heated to a temperature of 180º F, the germination of the seed was completely destroyed. Considerably higher temperatures were required to kill viability of low-moisture content seed than in high-moisture content seed. Therefore, a seed temperature of 140º F was established as the crucial temperature level (Shaw and Franks, 1962).

The cottonseed drying project involved the drying of ginned seed for several minutes. These results would probably not relate to cotton gin drying. At the gin the seed in seed cotton form is exposed to the hot drying air for only 10 to 30 seconds.

COTTON GIN DRYERS

Earlier Systems

Government Tower Dryer

A USDA developed vertical dryer was used on the 1932 crop (Figure 2). It became known as the "Government Tower-Dryer". The vertical dryer had no moving parts, and passing cotton through the dryer a second time could dry very wet cotton. A tower dryer contained 13-20 "floors" or shelves through which a continuous current of hot air transported the seed cotton. This hot air traveled through the drying tower at approximately 800 to 1,200 linear feet per minute. The locks of cotton impinged upon the hot sheet-metal walls of the tower at each reversal of direction from floor to floor which caused the drying air to pass through the cotton. The temperature of the drying air ranged from 150° to 200° F. Steam coils provided heat to the dryer. A tower could be placed either within the gin building or out of doors (Bennett and Gerdes, 1936).

The Government vertical dryer was designed for the 1932 average battery of four 80- saw gin stands. This gin plant handled about 100 pounds of seed cotton per minute. Damp seed cotton was treated with a continuous current of hot air at the rate of from 40 to 100 cubic feet of hot air for each pound. Tower shelf dimensions were 5.25 ft (length) by 4 ft (width) with 15-inch spacing between shelves. From the bottom floor of the tower, the dried cotton was thrown against a cleaning screen where some of the foreign matter was cast out.

Boardman Vertical Cotton Dryer

The Boardman Vertical Cotton Dryer used the principles and features discovered by the USCGL, ARS, USDA, Stoneville, MS, in its development of the "Government Process" vertical tower dryer (Figure 3). This is probably the first tower-type dryer to be manufactured commercially. It dried damp, handpicked seed cotton before processing the cotton through the extractor-feeder and gin stand. Cotton from the dryer generally went to the overflow telescope. (Boardman Co., 1932).

Continental Conveyor Distributor Dryer

The Continental Conveyor Cotton Dryer consisted of two or four trough sections (Figure 4). A double unit (four-trough) installation was made by placing two single (two-trough) units beside each other and connecting the discharge opening of the first unit to the intake opening of the second unit. Screw conveyors of special design handled the seed cotton when the cotton traveled through the units. This dryer was first used across the cotton belt about 1934 (Continental Gin Company, 1960b).

In a typical single two-trough section dryer, hot air from the heater was drawn through a pipe into one side of a trough section. Seed cotton was deposited into the same trough from above through a separator. The seed cotton and hot air were drawn from the side of the second trough section through a pipe to a second separator over the gin system. A gin system consisted of a seed-cotton cylinder cleaner followed by the gin stands, since only minimum seed-cotton cleaning was needed in the early installations. Moisture-laden air left the separator through a pipe and was discharged from the gin building.

Lummus Thermo Cleaner

The Thermo Cleaner came into use about 1936. It was developed mainly for handling rough harvested cotton (Figure 5). It could be equipped with a moisturizer to obtain either drying or humidifying or for killing static electicity. High-speed paddles broke open wads while conveying the cotton from the inlet to the discharge end. Rod type grids removed sand and fine trash. The Thermo Cleaner was available in single units with two cylinders and dual units with four cylinders. (Lummus Cotton Gin Co., 1942).

Murray Reel-Type Dryer

The Murray Reel-Type Dryer machine combines both cleaning and drying where needed, or it can be operated as a cleaner only (Figure 6). It came into use about 1937. A grid cylinder in this dryer removes sticks and both large and fine trash. This cotton dryer contains a large 84-inch diameter grid cylinder, which is mounted on a steel frame and revolves within an insulated jacket (Murray Company of Texas, Inc., 1957).

Pressure is maintained within the hot air manifold and feeds heated air through a narrow air nozzle, which extends through the side of the dryer to a point close to the reel-cleaning cylinder. Heat penetrates the locks of seed cotton many times as the cotton is slowly carried through the reel-cleaning cylinder. As seed cotton is conveyed through the reel, it turns upward as it passes the hot air nozzle on the manifold side of the dryer. The force of the hot air blasts against the cotton, carrying it across to the opposite side of the cylinder. This helps to separate the small light trash which falls through the cylinder.

The larger foreign matter is sifted out by the trembling motion of the cotton. A conveyor in the bottom of the dryer discharges the dirt and trash to a trash fan.

Stacy Cotton Cleaning System with Drying Attachments

In the Stacy Cleaner and Dryer, hot air from a manifold is blown downward through the cotton by means of nozzles extending across the cleaner (Figure 6). Nozzles are located between each cleaning cylinder, similar to the nozzles on airblast gins. This blast of hot air dries the cotton, and also increases the cleaning by forcing the dirt, leaf trash, and stems through a screen. The moist air does not follow the cotton. Sometimes, the wire screen is replaced by grid bars to allow removal of larger trash. Each drying unit is made with six or eight cleaning cylinders. Two stages of drying and 16 cylinders of cleaning can be obtained by putting two single units in series. A separator directs the seed cotton onto the first cleaning cylinder. Stacy cleaner/dryers were built from about 1940 to 1965 (Stacy Company, Inc., 1949).

Cen-Tennial Tower Drying

The Cen-tennial Cotton Gin Co. used an 18-shelf government-type tower dryer ahead of an eight-cylinder seed cotton cleaner in the late 1940s. The cylinder cleaner was mounted above the conveyer distributor and gin stands. Later, Cen-tennial used two tower dryers in its Thinstream Ginning System. The first tower dryer used 23 shelves and the second tower dryer had 18 shelves (Cen-tennial Cotton Gin Co., 1950).

Continental Vertical Counterflow Dryer

The Continental Counterflow Dryer uses the principle of passing the cotton and warm air in opposite directions through the vertical dryer casing (Figure 8). The counterflow dryer was designed to require only 2,000 ft^3/min of heated air for efficient drying, compared to about 6,000 ft^3/min for conventional tower dryers. Thus, the fuel consumed by the heater and the power required to drive the fan is reduced more than half (Continental Gin Company, 1960a).

As seed cotton leaves the dryer separator it falls onto a directing cylinder which breaks up wads and throws the loosened cotton across the casing in a broad stream. The cotton slides down several sections made of long thin-fingered baffles and directing cylinders, where the opening actions are repeated. Warm dry air enters at the lower end of the dryer casing, passes upwardly through the falling stream of cotton, and is exhausted through an air port in the top of the casing. Since the hot air does not follow the cotton through the dryer, removed moisture cannot be redeposited in the cotton. A 3-cylinder cleaner section at the lower end of the dryer removes some loose trash between smooth, round grid bars.

A Single Drum Vertical Counterflow Dryer was designed for special applications (Figure 9). It operates on the same principle as the full-size machine. However, it is several feet shorter than the full-size machine and thus can be used above overhead cleaners or automatic suction control bins.

Hinckley Dryer-Cleaner

The 72-C Hinckley Dryer-Cleaner is sometimes referred to as the Neverchoke or Fan Drum Dryer-Cleaner (Figure 10). By featuring feeder control and fan drum preparation, the unit regulates the flow of cotton through itself and subsequent machines in the cotton process. From hot air chambers, heated air is directed into rotating fan drums which blow fine pin trash out of the flowing seed cotton and through lower cleaning screens. Moist air and trash exits to the dirt fan. Cotton travel reduces cotton machining between cylinders, and can reduce horsepower (Hinckley Gin Supply Co., 1952).

Lummus Super Volume Cotton Conditioner

The Super Volume Cotton Conditioner is designed to operate as a single drying and conditioning unit, or in combination with other conditioning equipment (Figure 11). Damp cotton passes through the Super Volume Conditioner slowly, being exposed to about four times the amount of heated air normally used in a tower dryer at a given throughput capacity. Two cleaners with reclaimer units separate trash from the cotton by the sling-off method. Reclaimer units return clean cotton to the system. Large passages allow the cotton to flow freely, and early removal of large pieces of trash helps improve the efficiency of subsequent cleaning machinery in the ginning system. The Super Volume Cotton Conditioner is also designed to be economical to operate. About three-fourths of the heated air is recirculated, reducing fuel cost (Lummus Cotton Gin Co., 1960b).

Tower Dryer Attachments

The Hardwicke-Etter Company manufactured a Fluff-and-Clean Attachment for use with its tower dryers (Figure 12). The attachment with its two cleaning cylinders opens up and fluffs the cotton; and removes some burs, dirt, trash, sticks, and leaves. Its intent was to enhance drying and ease the job of other components in the ginning system (Hardwicke-Etter Company, 1975).

Lummus Cotton Gin Co. designed the Tower-Dryer Opener Cleaner (T-Doc) Attachment for use with its tower dryer (Figure 13). Seed cotton, moving through the tower, flows into the T-Doc where it is opened, fluffed, and cleaned by one cleaning cylinder. Two of these one-cylinder T-Doc attachments are used on a tower dryer, one in the upper section and the second near the center of the tower (Lummus Cotton Gin Co., 1960a).

Gentle Giant Drying System

A "Gentle Giant" moving bed dryer, manufactured by the Samuel Jackson Mfg. Corp., was installed in a California and Alabama gin about 1965 (Figure 14). In this system as soon as seed cotton enters the gin plant, it is dropped into the Gentle Giant where it forms a slowly moving bed. Warm air is blown upward through the bed of cotton. Moving the drying air upward is designed to loosen and expand the bed of seed cotton so a large air volume can be used with little power consumption (Samuel Jackson Mfg. Corp., 1965).

The Gentle Giant dryer itself is 30 feet long, six feet wide, and 12 feet high. A 25 hp vaneaxial fan pushes about 24,000 ft^3/min of air through the dryer. An independent thermostat prevents the entering air temperature from exceeding 200 ºF.

A principal fault in this method is the drying front, which advances through the bed during the drying process. Behind this front, the cotton is very dry. Ahead of the front, the cotton can be wetted by the drying process. Thus, belt speed and bed depth must be carefully monitored (Samuel Jackson, Inc., 2000).

Fountain Dryer

The Samuel Jackson Fountain dryer is designed to replace the shelf-type tower dryer. It was introduced about 1988. A Fountain dryer does not have shelves. It floats the seed cotton in the hot air within the dryer and then re-accelerates the cotton (Figure 17). Its main drying effect takes place, not in the dryer, but at its exit. The Fountain dryer uses high air volumes (50 cu. ft./lb of seed cotton). It achieves a high air/cotton ratio by use of a skimmer. It takes a stream of air at the end of the drying process, and by centrifugal force, diverts all of the seed cotton and about half the air to the first-stage incline cleaner. The remainder of the air is used to pick up the cotton under the first-stage stick machine to go to the second-stage cleaners. Since this dryer creates less static pressure than traditional tower dryers, only pull fans are used rather than the push/pull fans needed on most tower dryers (Jackson, 1996).

Current Systems

Twenty-Four Shelf Tower Dryer

Several manufacturers build tower dryers. They are generally built in sturdy steel sections and are completely self-supporting.

Continental/Murray's tower dryers are available in two models. One model is six feet wide and six feet long (Figure 16), and the second is six feet wide and 11 feet long. Their sectional design provides any number of shelves, from 11 to 24. Alternate outlet openings permit even or odd shelf installation allowing selective piping arrangements (Continental Murray Ginning Systems, 1988).

Continental/Murray also builds a tower dryer that has 12-inch shelf spacing. It is 6 feet wide and 11 feet long and features 19 or 20 shelves. This tower was built for use with high volumes of air (10,000 - 12,000 ft^3/min) and controlled low temperatures.

Blow Box

A high-speed blow-box dryer was tested in California about 1988 (Figure 17). It was intended that the new blow-box system would replace the traditional tower dryer at gins. The blow-box principle involves a jet of high-speed air, in excess of 10,000 fpm, directed horizontally, transverse to the width of a feed controller, causing seed cotton to open as it is suddenly accelerated down a rectangular duct. The rationale was that the high-velocity (jetted) hot air in the blow box opens and removes moisture from damp cotton more rapidly than the lower-velocity and somewhat lower temperature in the shelf-type dryer. Tests showed that the high-velocity blow box system required more air horsepower than uniform-velocity ones (fountain or shelf-type). To improve blow-box dryers it was suggested that a spiked-beater wheel could help to break up clumps, and designing the box with negative static pressure at the pickup point would allow omission of the vacuum dropper wheel (Abernathy et al., 1989b).

Hot Shelf Dryer

The Turbulent Flow Hot Shelf drying system uses smaller volumes of air than some drying systems, because the temperature drop throughout the system is avoided (Figure 18). This is accomplished through an arrangement of heat chambers between the shelves, from which heat is transferred to the shelves conveying the cotton. The tower has nine shelves with 12-inch spacings. Seed cotton enters at the top of the tower and exits at the bottom of the dryer. Generally, heated air enters at the bottom of dryer and exits near the top of the tower. However, this heated air used for the heat chambers can be re-circulated through the system on a continuous basis, or combined with the primary air line to pick up the cotton at the mixpoint and convey it to the tower (Vandergriff, 1996).

Kimbell Belt Dryer

Operation of a belt dryer in a commercial gin in Virginia in 1995 helped refine the technology for this system (Figure 19). The design was based on the dryer developed in Texas (Laird and Smith, 1992). It was found that installing a metal-flighted doffing roller with the flights approximately one inch from the belt helped break up wads of damp seed cotton and spread the discharge flow more uniformly. The open half by half-modified flat wire belt allowed dirt and fine pin trash to drop from the cotton through the belt as the conveyor undulated over the support grid work. It was indicated that a belt dryer would run horizontal or inclined up to 20 degrees with a maximum incline of 25 degrees. The best location for a belt dryer in an existing gin is probably overhead (Gray, 1996).

High-Volume Tower Dryer

The Lummus High Volume Tower drying system uses six shelves of 27-inch spacing and the inlet transition acts as the seventh shelf (Figure 20). This allows using a pull-through fan system, eliminating the need for a push fan and reducing dust in the gin plant. In the first stage, an air velocity of 2,000 ft per minute is used with about 25 cubic feet of drying air per pound of seed cotton. A Turbulent Dryer Trap is located ahead of the dryer to provide initial turbulent drying and to remove green bolls, rocks, etc. The secondary air needed to operate the Turbulent Dryer Trap allows the burner control to be more responsive to moisture changes in the cotton. Two stages of drying are recommended with the heated air temperature and volume reduced somewhat in the second stage. The Turbulent Dryer Trap is not used in the second stage (Van Doorn, 1996).

Two sizes of the high-volume tower dryer are manufactured. One tower dryer is 48-in. wide with a 40-in. turbulent dryer trap on the inlet, and the second tower dryer is 72-in. wide with a 60-in. wide turbulent trap on the inlet. Air volumes are 18,000 and 27,000 cfm in the 4 ft and 6 ft tower dryers, respectively (Lummus Corporation, 2001).

Rules of thumb for the Lummus systems in humid areas with machine-picked cotton are that the first-stage drying system should have at least 4 million Btu's of heat and 9,000 cfm of air at

2,000 fpm in the dryer for every 15 bales per hour. The second-stage drying system may have the heat and air capacity reduced to 2 million Btu's and 6,000 cfm per 15 bales per hour. Air velocities of approximately 1,500-2,000 fpm can be used in the second-stage drying system.

Hi-Slip Dryer

The Belt Wide Hi Slip drying machine uses the principle that turbulence and high velocities between the cotton and drying air increase the drying rate (Figure 21). A spike or lugged cylinder retards the cotton flow, but allows heated air to pass through the cotton, creating a high slip rate. According to its operation, the venturi effect created by the nozzle, which injects the hot air into the lugged cylinder, allows the cotton to be mixed into the airstream without a vacuum wheel or rotary air lock (Mayfield, 1996).

Collider Dryer

The Samuel Jackson Collider Dryer is a modification of the Fountain Dryer (Figure 22). It is a negative pressure (pull-through) dryer that seeks to take advantage of hot air and seed cotton mixing with a maximum amount of turbulence. Suction brings cotton and hot air from the module feeder into an upper chamber where a direct collision with additional drying air takes place. Following this point of turbulence, the seed cotton and hot air mixture is divided and taken through a second collision just above the outlet to the skimmer. The pressure drop is somewhat higher in the Collider Dryer than in the traditional Fountain, but the design is to magnify the drying effect because of multiple collisions and turbulence (Samuel Jackson, Inc., 2000).

Vertical Flow Dryer

Seed cotton enters the top of the Continental Vertical Flow Dryer with the drying air (Figure 23). As the seed cotton enters, it falls onto a directional cylinder arranged to break up wads and create a loosened stream of seed cotton. The loosened seed cotton slides down baffles made of long thin fingers, with air spacing between each finger. This cotton falls to another cylinder which throws the seed cotton in another direction. This alternating action is repeated five more times (Continental Eagle Corporation, 2000).

There are no shelves, screens or grids in the dryer. The opening and fluffing by the directional cylinders causes the locks of seed cotton to open to increase the drying action of the dryer. After passing downward through the dryer with the seed cotton, the drying air transports the cotton to the next process.

Even Heat Tower Dryer

The Vandergriff Even Heat Tower Dryer, manufactured by the Consolidated Cotton Gin Co., Inc., was used in several cotton gins in 2000 (Figure 24). It is built in four widths--three, four, five, and seven feet, and the shelves are eight feet long (Consolidated Cotton Gin Co., Inc., 2001).

In the Even Heat Tower Dryer there are seven progressive-spaced deep shelves, with a heat jacket for hot air injection at three points. The operating principle is to add heat downstream in the tower to maintain a drying temperature throughout the drying cycle.

In the drying stage, air from the heater is split into two streams. A portion of the air picks up the seed cotton and conveys it to the top shelf of the Even Heat Dryer. The other portion is injected at the ends of the second, fourth, and sixth shelves, providing multiple mix-points. Heated air is injected with nozzles at a velocity of 4,000 ft/min. Shelf spacing increases as the total air increases to maintain a desired 2,000 - 2,500 ft/min. conveying velocity in the tower. There are vanes and bump-ups on the floor of the tower shelves to increase drying capabilities. The drying air then conveys the seed cotton from the bottom of the Even Heat Tower Dryer to an inclined cleaner for air and cotton separation.

SUMMATION

Many dryer designs have been used to dry seed cotton at cotton gins since the late 1920s. These various gin-drying systems offer varying levels of the four basic factors that determine the effectiveness of seed-cotton dryers. The four basic factors are drying air temperature, air volume, time of exposure, and the relative speed of the air and the cotton (slip). There are many combinations of these factors, which will satisfactorily dry cotton.

Research results show that cotton fibers are weaker at lower moisture content than at higher moisture levels. Therefore, cotton ginned at low moisture levels is certain to contain more broken fibers than cotton ginned at higher moisture levels. It is recommended that gin dryers be adjusted to produce lint at the gin stand with moisture content at about seven percent.

For quality preservation, cotton should be dried at the lowest temperature that will allow satisfactory gin operation. In no case should the temperature in any portion of the drying system exceed 350 °F. Cotton is irreversibly damaged at temperatures above 300 ºF. Some drying is obtained when conveying seed cotton with low relative humidity ambient air.

It can be argued that the four basic factors of drying are embodied in the 24-shelf tower dryer system. The tower dryer was developed in 1931. In this system hot air conveys seed cotton through the shelves, with seed cotton impacting the dryer walls and changing direction between each shelf. This action helps to open the cotton and provide slippage between cotton and air. Each stage of drying requires two centrifugal fans in a push/pull arrangement to handle the created static pressure. Two stages of tower dryers are usually adequate to dry wet seed cotton.

Several types of dryer designs are used in gins. Most other designs create less static pressure than tower dryers, and so only require one centrifugal pull fan to operate. These generally use higher air volumes and expose the seed cotton to hot air for shorter periods than a tower dryer system. The negative pressure (one fan) systems would be expected to require less investment, use less fan horsepower, and maintain a cleaner gin building. However, there have been indications that some of the systems that don't properly open the cotton or use adequate exposure periods may experience problems in handling very damp cotton.

Drying systems used in most newer gin installations (1990-present) include the High Volume Tower Dryer, high-speed blow boxes, Fountain and Collider dryers, Belt dryer, Hi-Slip dryer, Turbulent-Flow Hot-Shelf Tower Dryer, Even Heat Tower Dryer, and Vertical Flow Dryer.

Today most growers harvest and store seed cotton in modules for later ginning. If this cotton is harvested when its fiber moisture content is at about eight percent and the cottonseed moisture content does not exceed 10 percent, minimum drying at the cotton gin would be needed. One of the lower cost dryer designs giving minimum exposure to the drying air would be adequate for proper moisture removal. A more elaborate design would be required to handle the damper cottons.

There is no best drying system for all gins. A best dryer design is the one that will meet the demands for that gin plant. Two concerns in selecting a dryer type will be the location of the gin and the condition of the seed cotton to be processed. A gin plant located in a humid area and ginning damp cotton will require a more demanding and elaborate dryer system than a plant ginning relatively dry modules in arid regions.

The cost of a drying system must be balanced against the needs of the gin. A selected system must use sufficient low temperature drying air to evaporate adequate moisture, a procedure for opening and exposing seed cotton locks, adequate exposure time for moisture to migrate from within the fiber, and a high rate of slip between the cotton and the drying air.

DISCLAIMER

Mention of a trade name, proprietary product or specific equipment does not constitute a guarantee or warranty by the U.S. Department of Agriculture and does not imply approval of a product to the exclusion of others that may be suitable.

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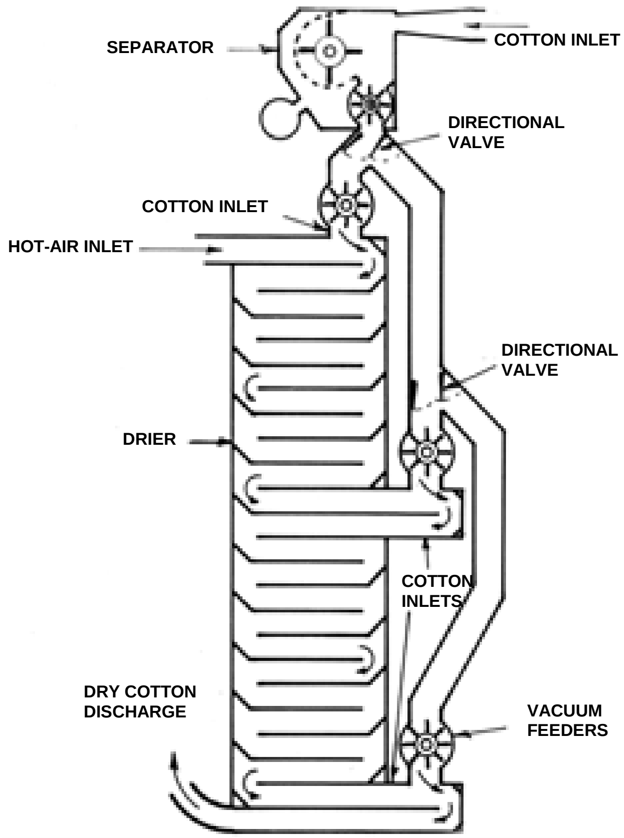

Figure 1. Multi-path Tower Dryer.

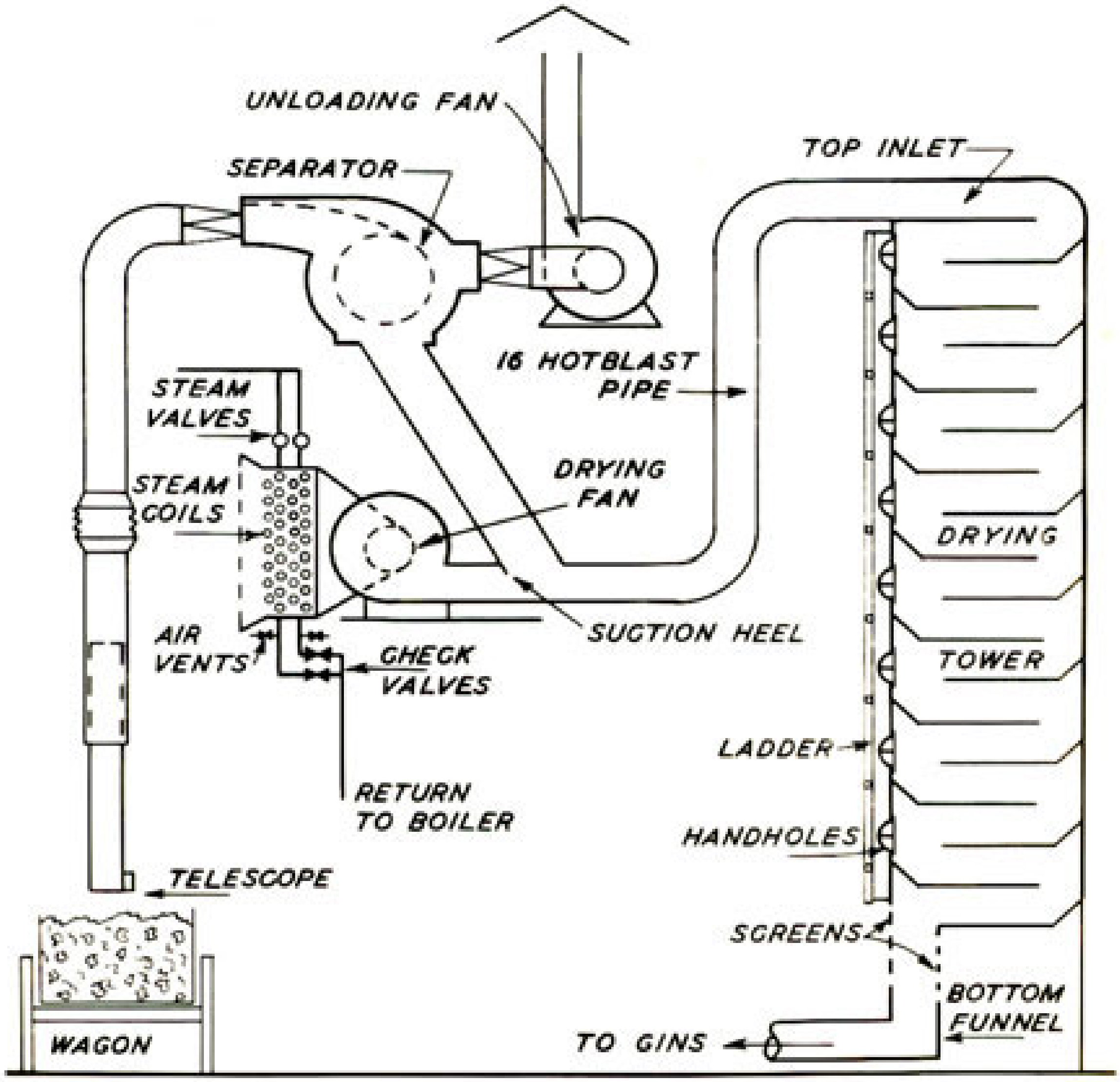

Figure 2. Government Tower Dryer.

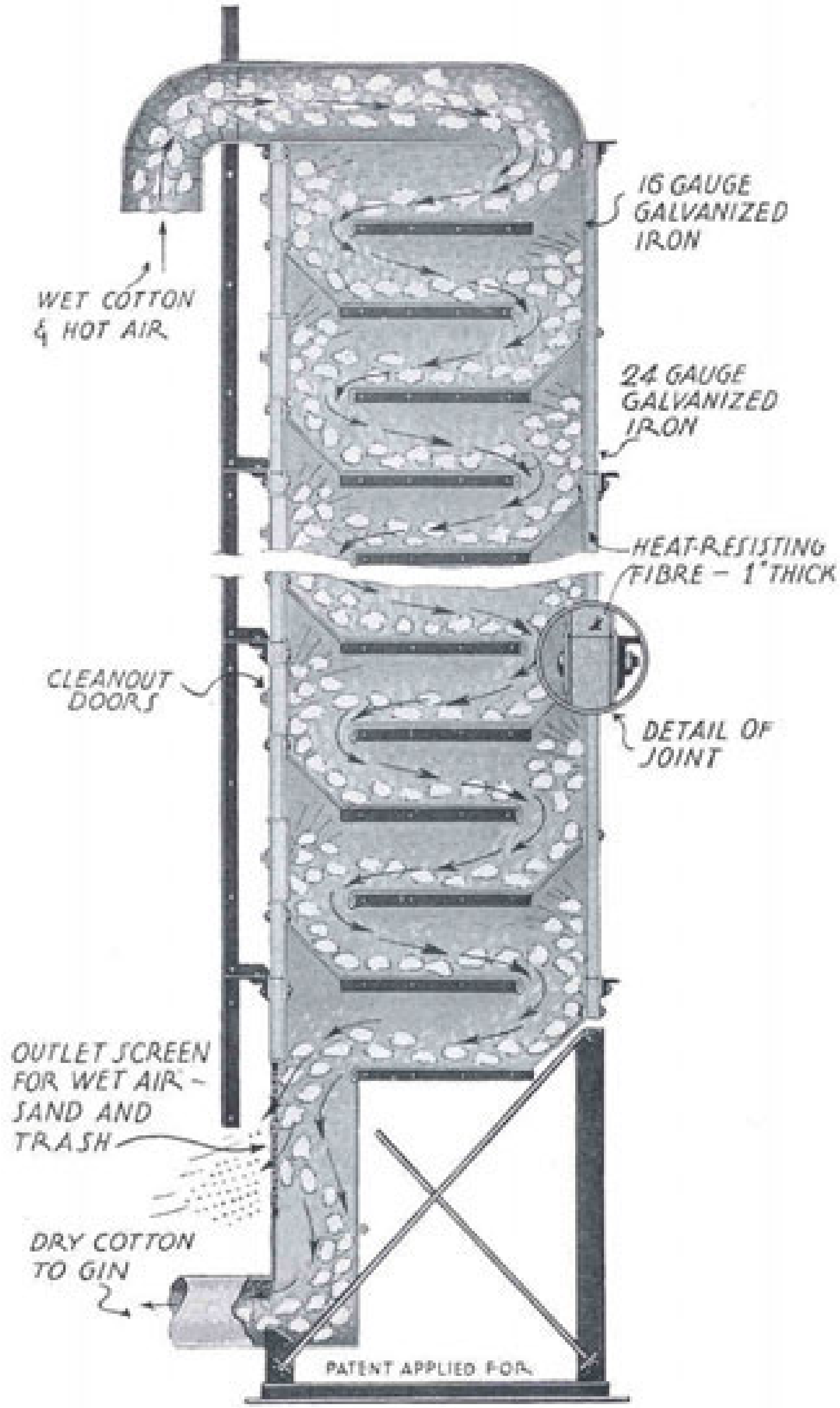

Figure 3. Boardman Vertical Dryer.

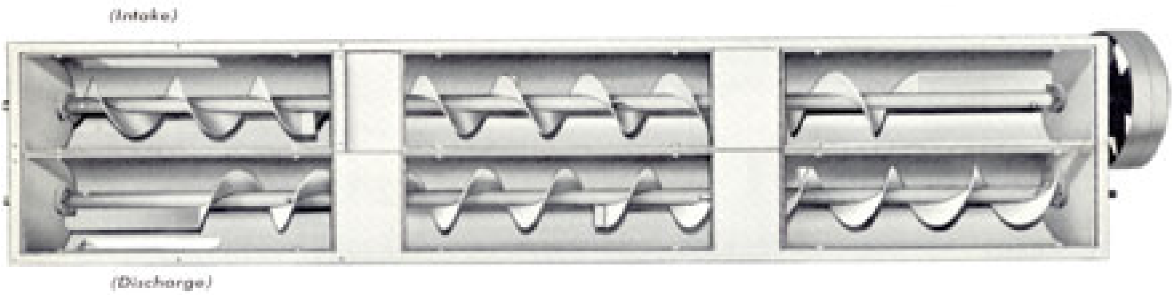

Figure 4. Continental Conveyor Distributor Single Unit (two-through) Dryer.

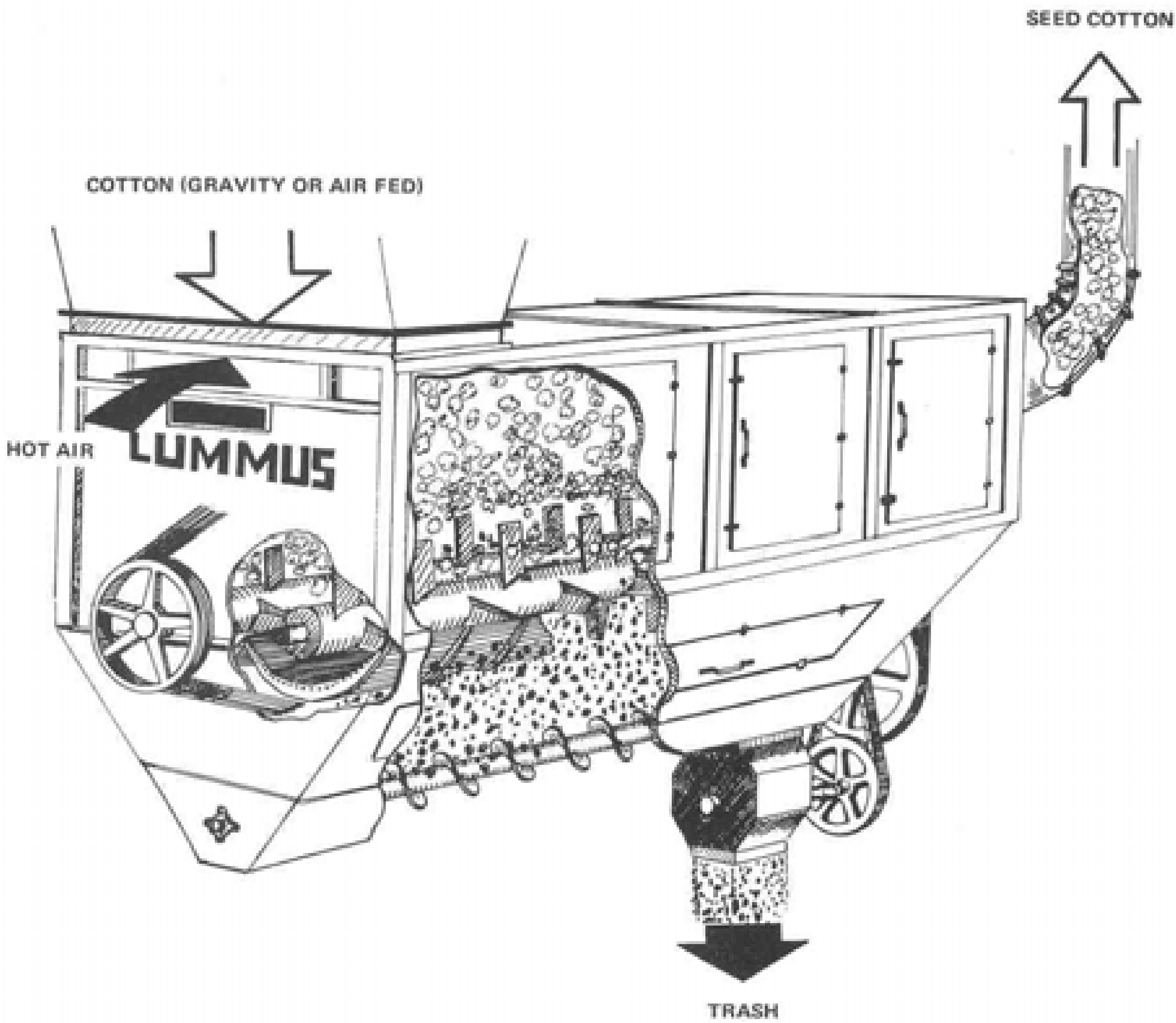

Figure 5. Lummus Thermo Cleaner.

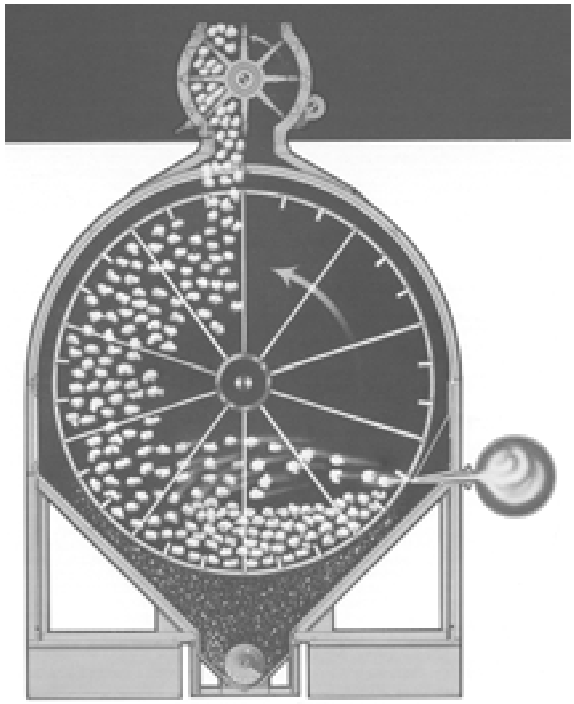

Figure 6. Murray Reel Type Dryer.

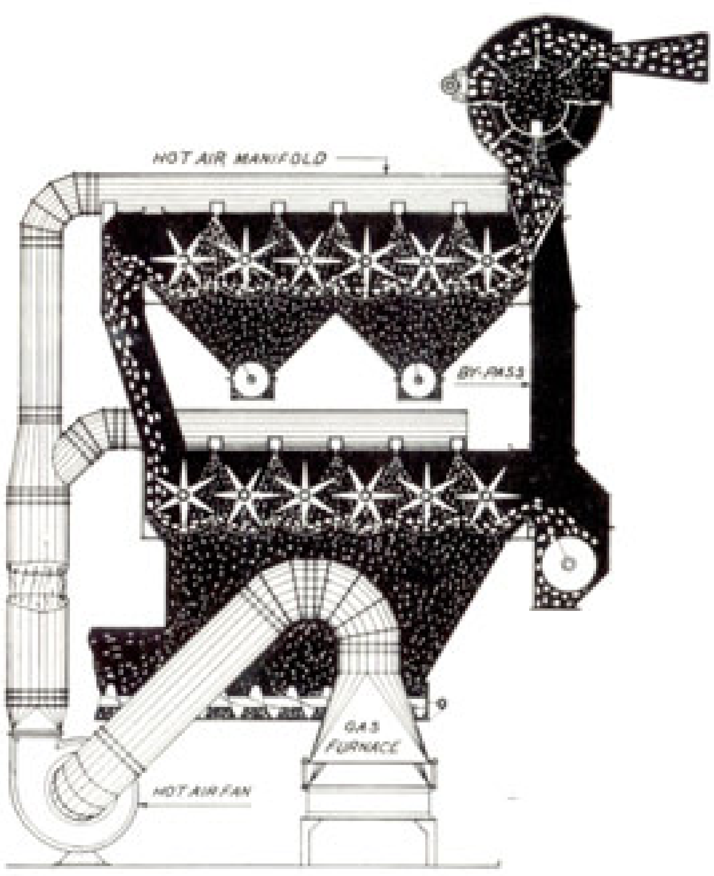

Figure 7. Stacy Cotton Cleaner and Dryer.

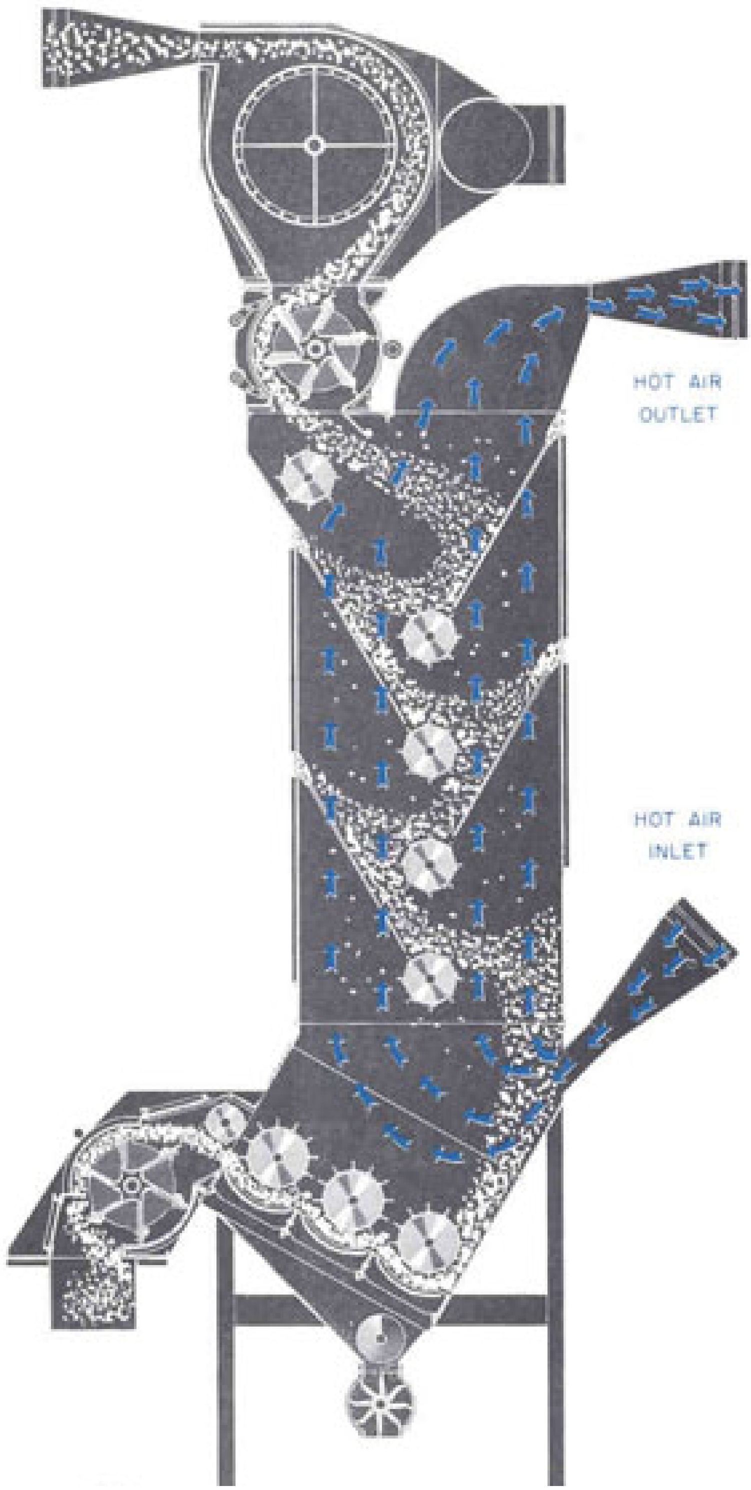

Figure 8. Continental Vertical Counterflow Dryer.

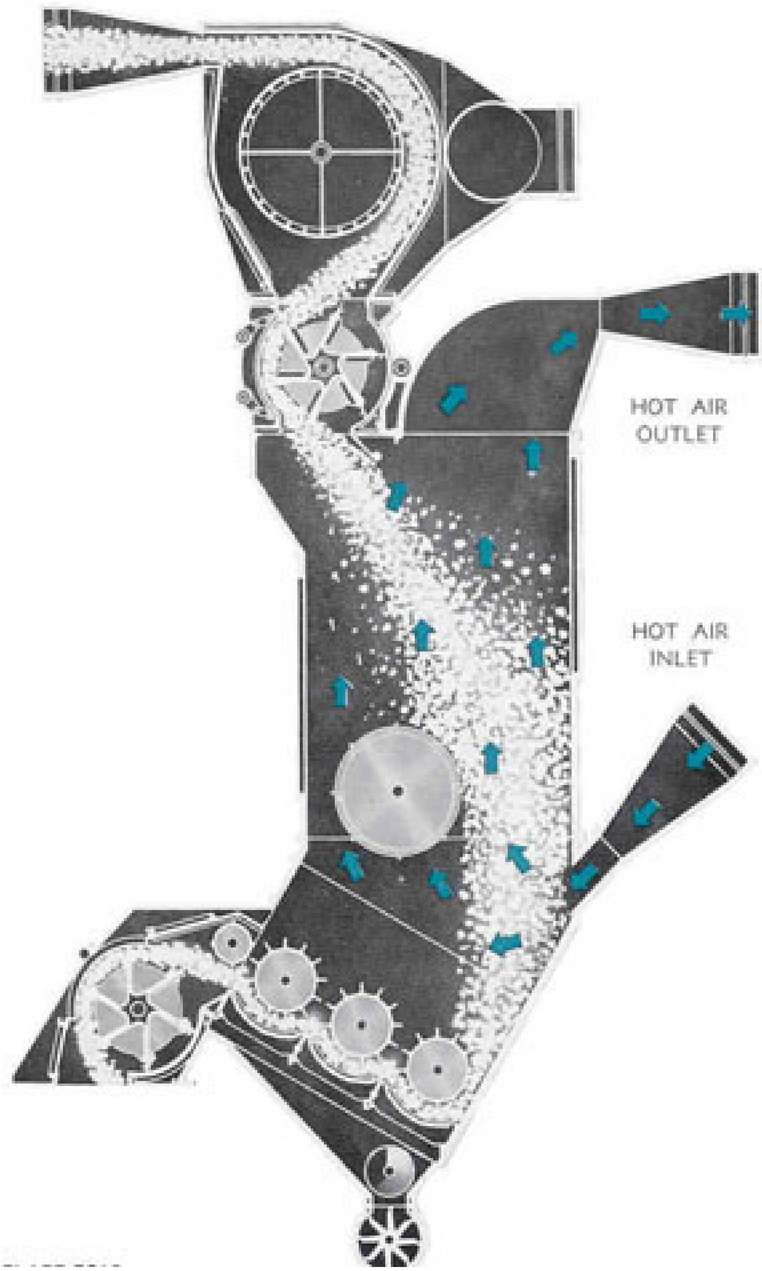

Figure 9. Continental Single Drum Counterflow Dryer.

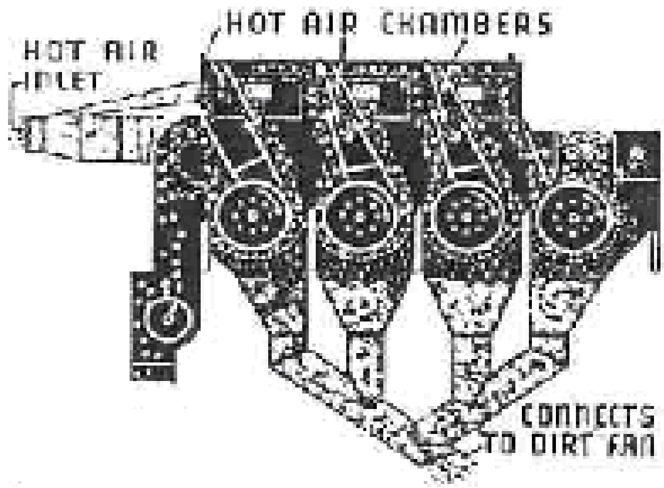

Figure 10. 72-C Hinckley Drier-Cleaner.

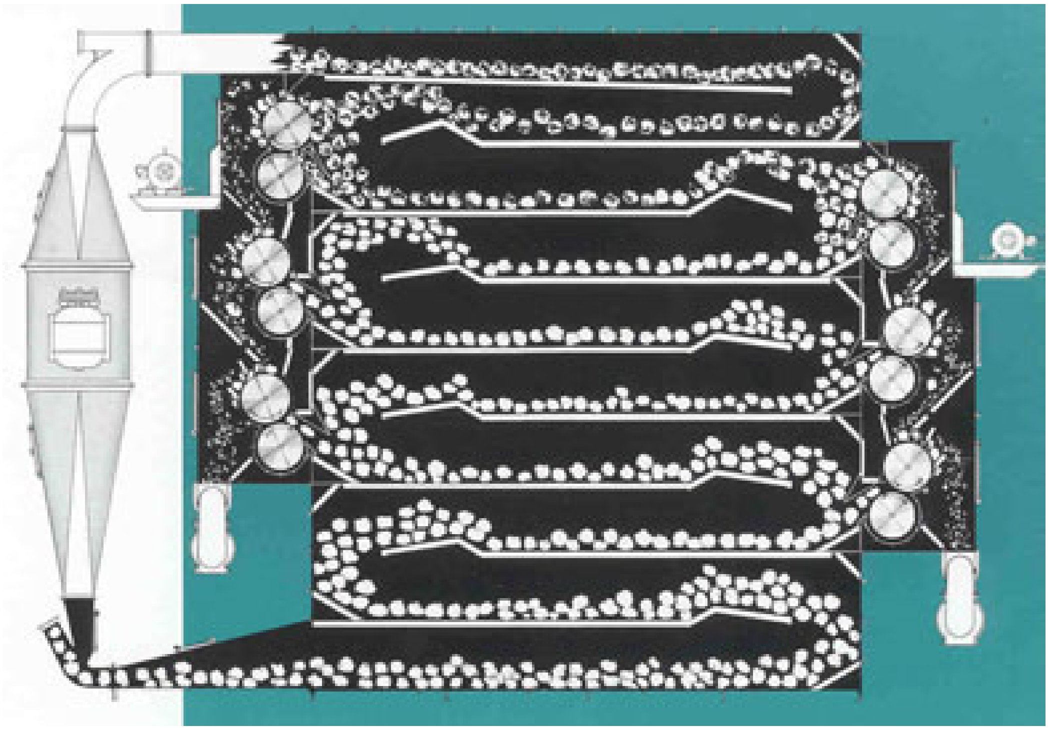

Figure 11. Lummus Super Volume Cotton Conditioner.

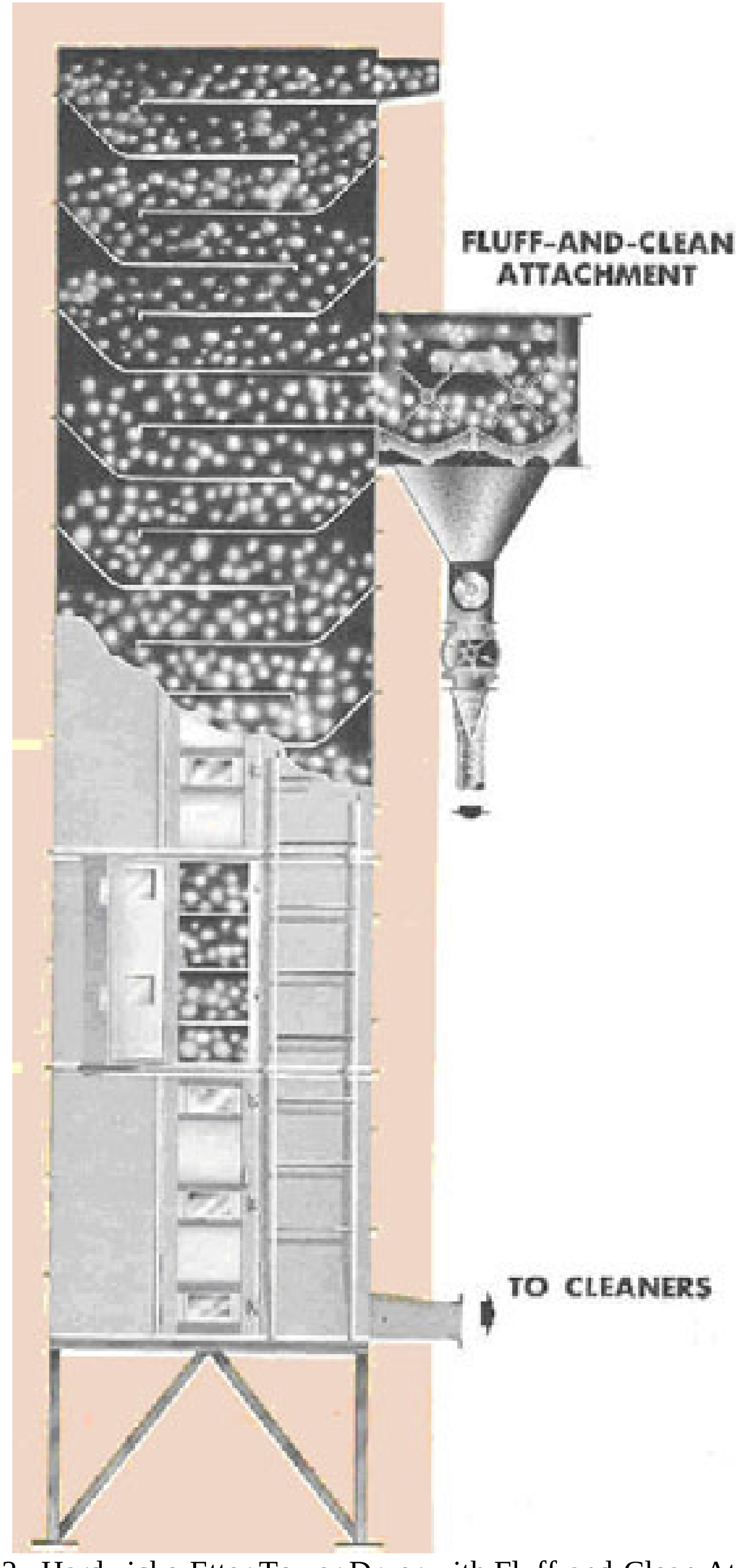

Figure 12. Hardwicke-Etter Tower Dryer with Fluff-and-Clean Attachment.

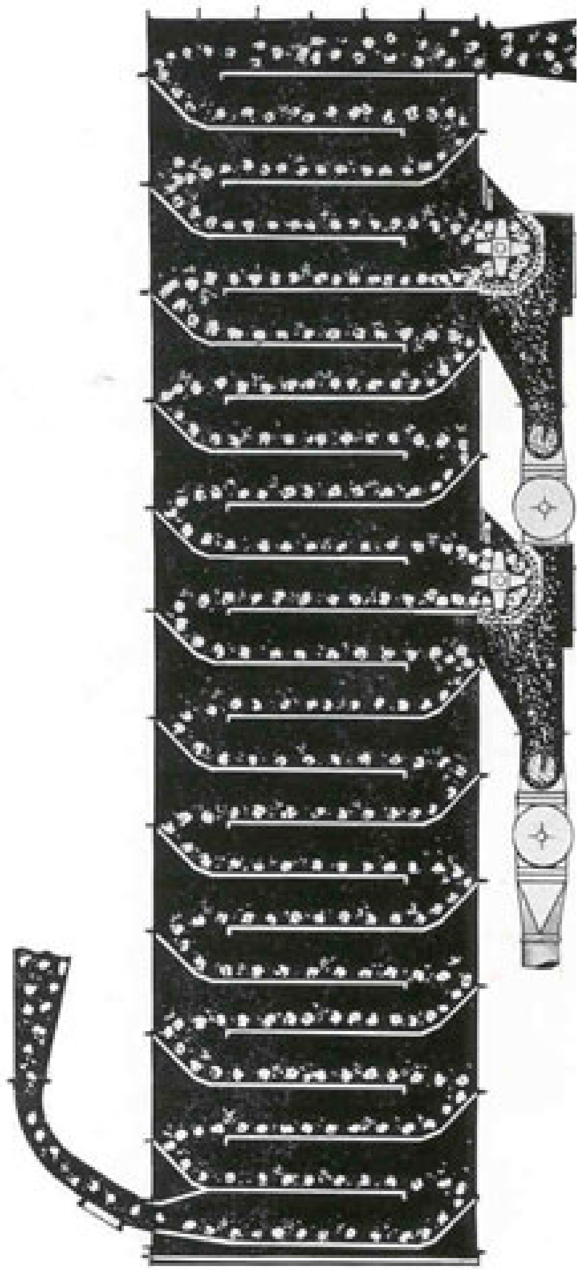

Figure 13. Lummus Tower Dryer with T-Doc Attachments.

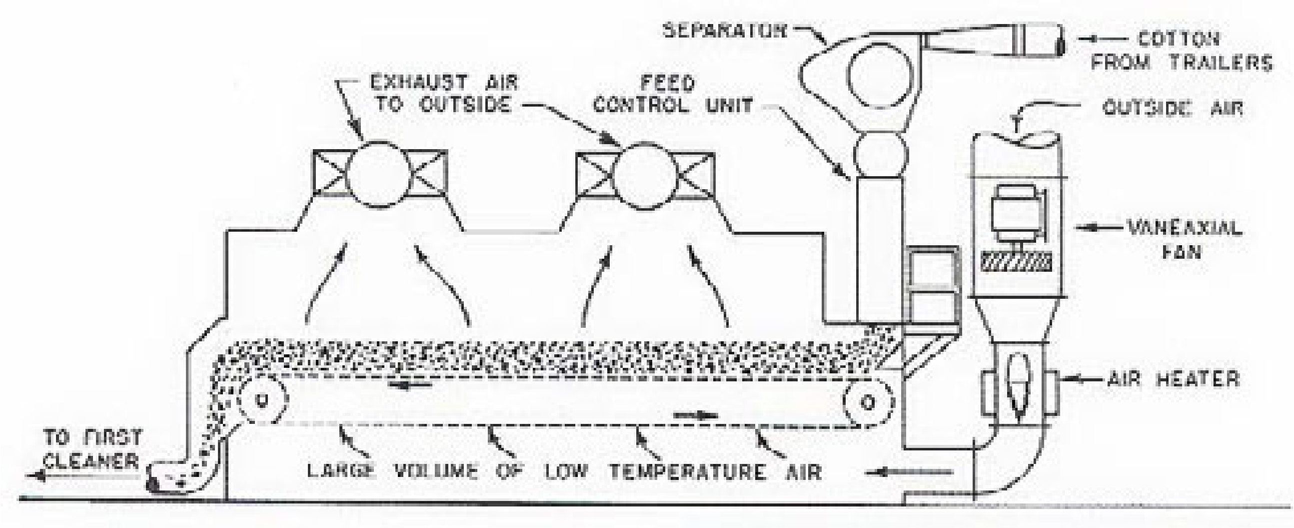

Figure 14. Samuel Jackson Gentle Giant Drying System.

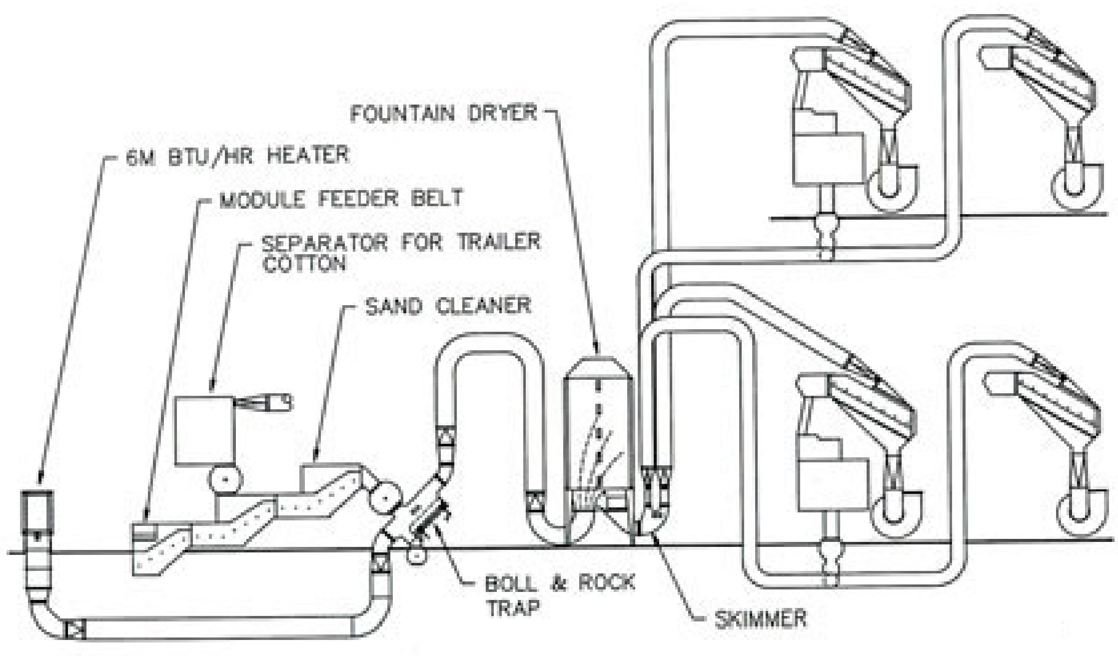

Figure 15. Fountain Cotton Drying System.

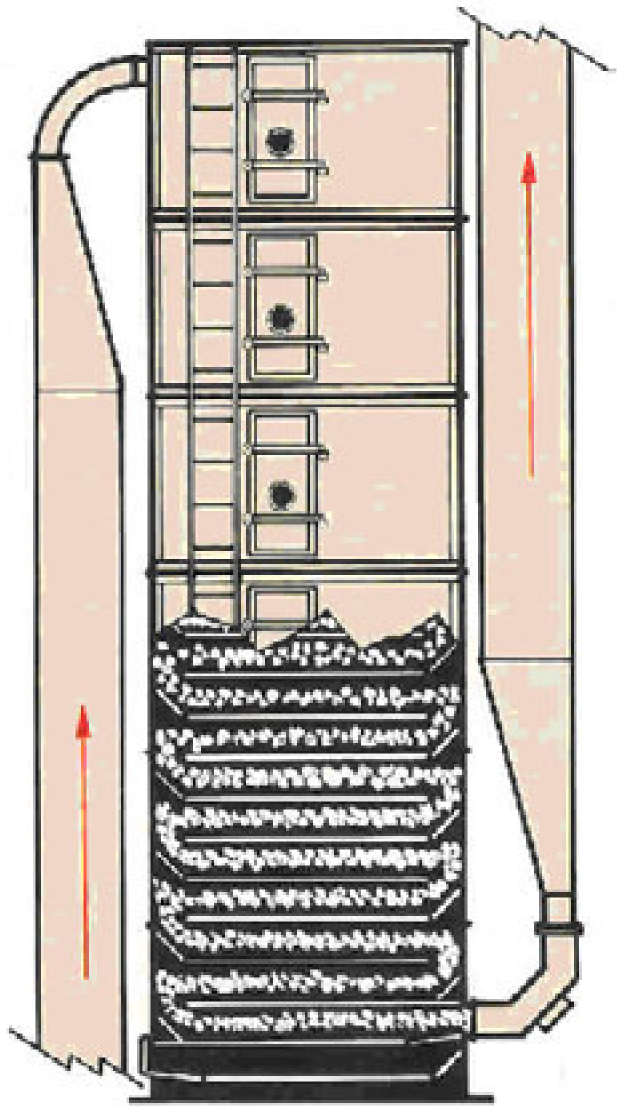

Figure 16. Continental/Murray Twenty-Four Shelf Tower Dryer.

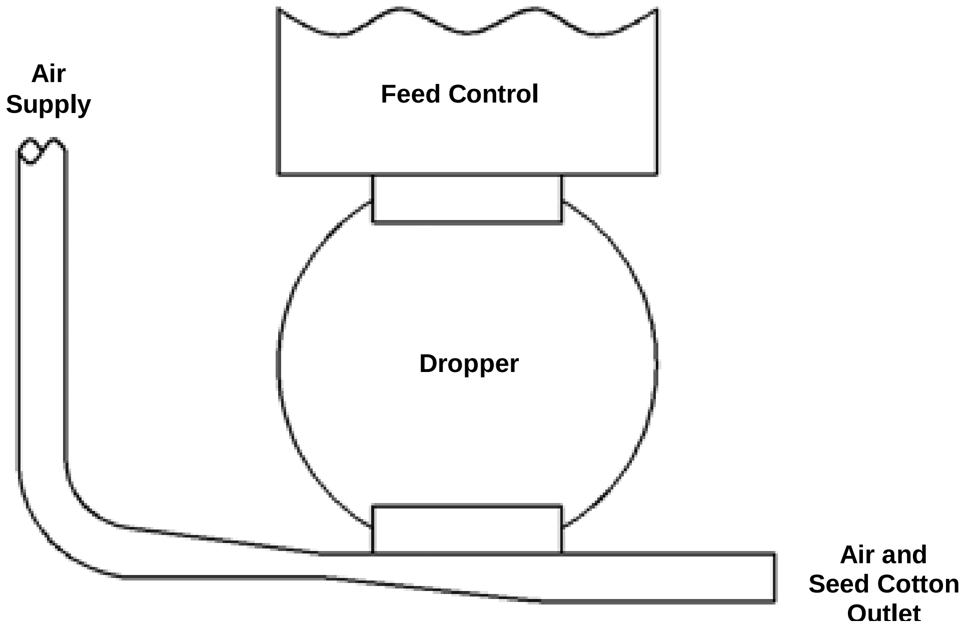

Figure 17. Schematic sketch of one High Velocity Blow Box that was evaluated.

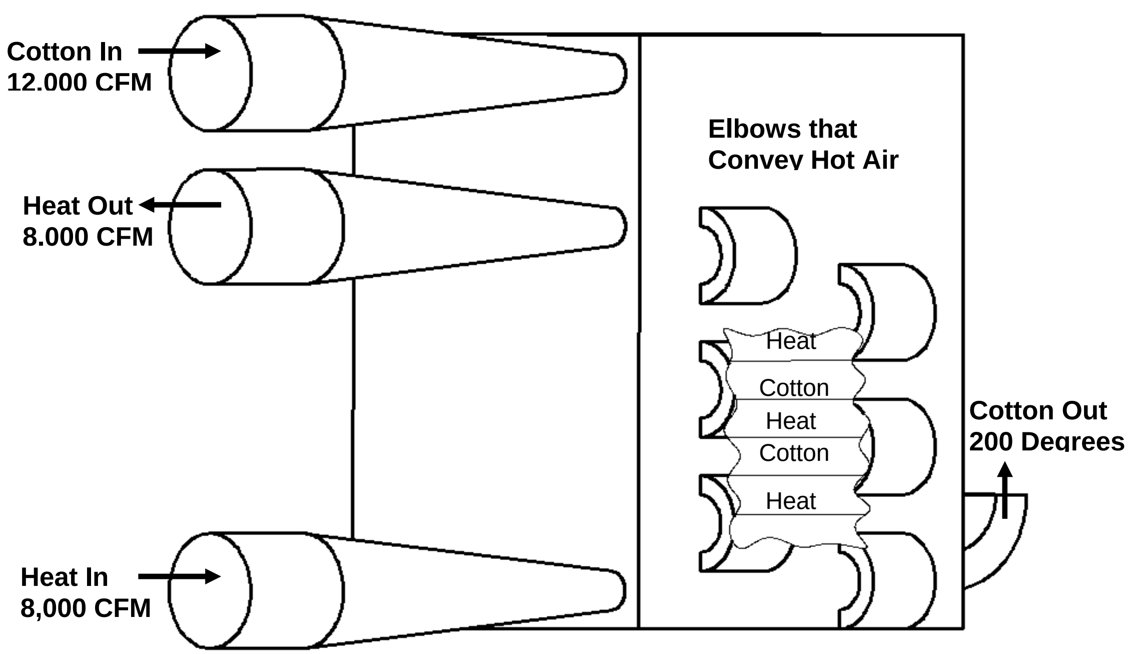

Figure 18. Turbulent Flow, Hot Shelf Tower Dryer.

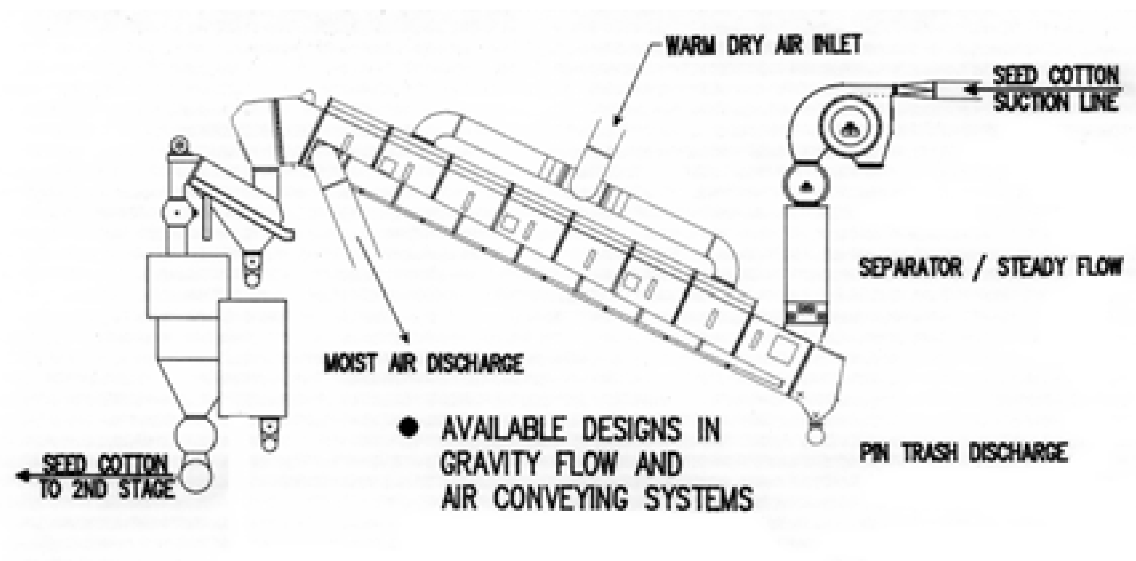

Figure 19. Kimbell Belt Dryer.

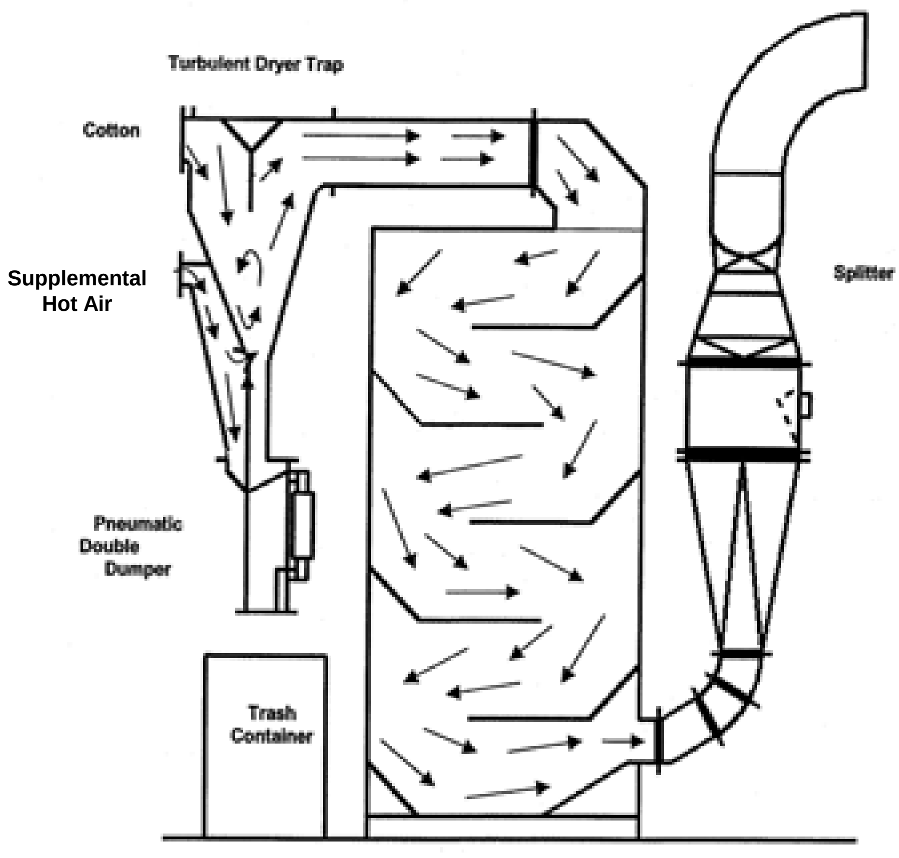

Figure 20. Lummus High Volume Tower Dryer

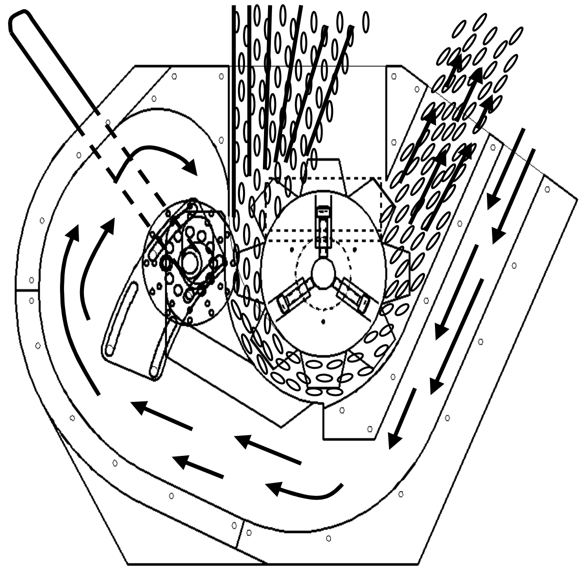

Figure 21. Hi-Slip Dryer.

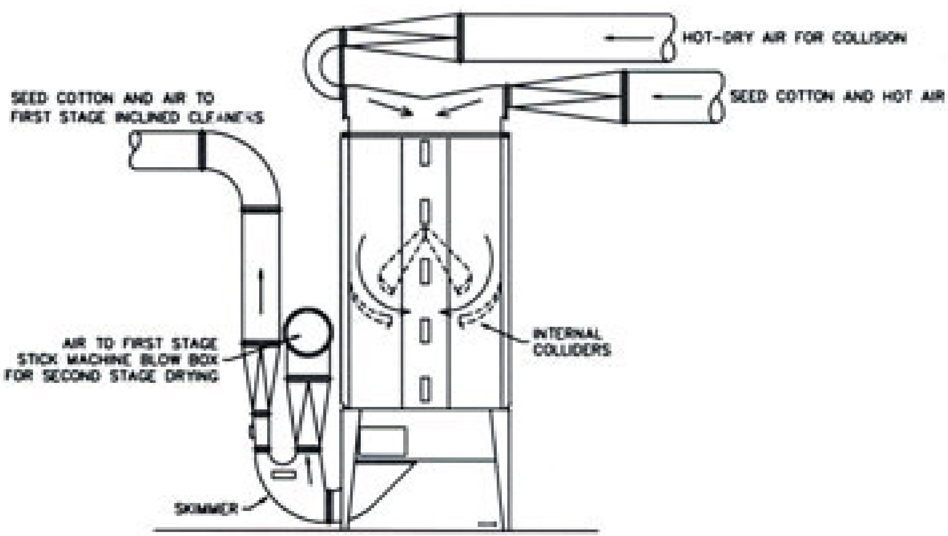

Figure 22. Collider Dryer.

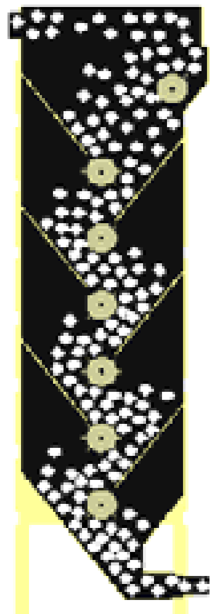

Figure 23. Continental Eagle Vertical Flow Dryer.

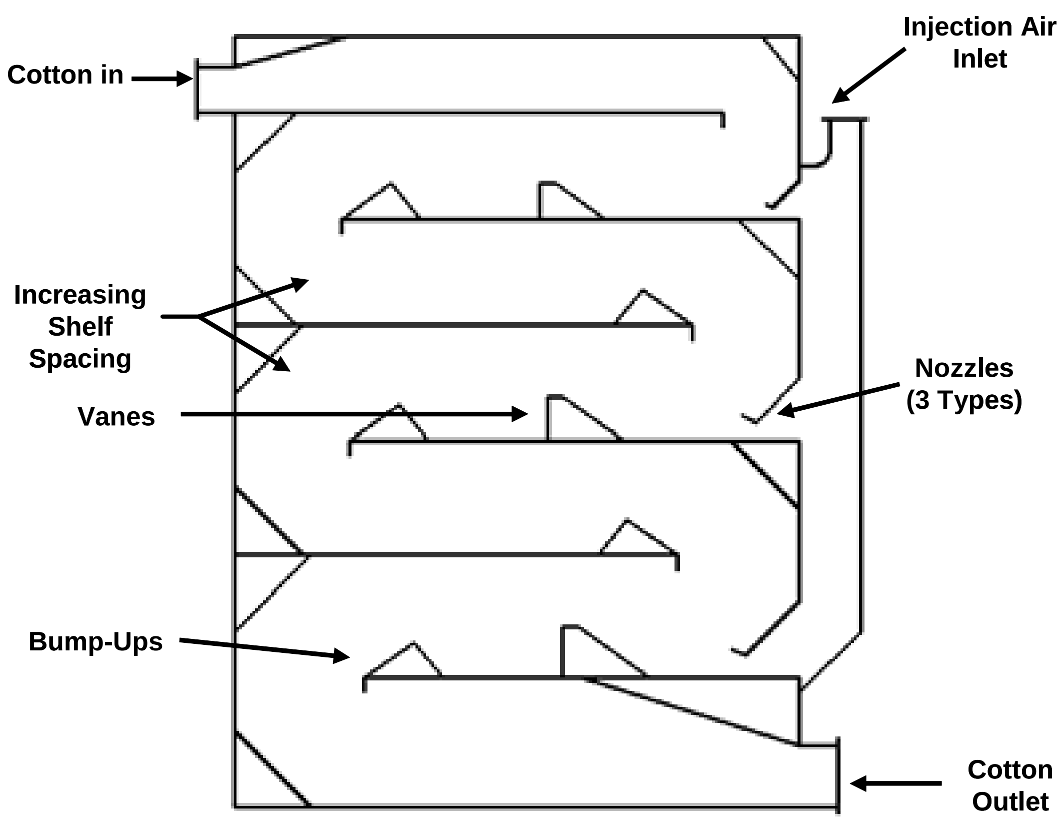

Figure 24. Even Heat Tower Dryer.