DESIGN AND PERFORMANCE DATA FOR LUMMUS GIN DRYING SYSTEMS

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Abstract

Cotton gin dryers impact both raw cotton market value and spinning value. Improper drying systems can have a positive influence on raw cotton market value while negatively impacting the spinning value. This paper describes Lummus Corporation's drying system designs to optimize both raw cotton market value and spinning value. Thermodynamic and psychrometric principles are discussed to support Lummus drying system designs.

Introduction

When we were asked to participate in this panel to discuss Lummus' recommendations for drying systems, we were somewhat hesitant as the subject is quite controversial, with gin drying theories a dime a dozen. However, Bill Mayfield convinced us that our industry needs more factual information to back up the various sales pitches being offered. I therefore promise not to criticize other approaches to drying, but rather I will attempt to give scientifically supportable reasons for Lummus dryer designs. We have chosen our approach to gin drying attempting to incorporate the best combination of features after considering all the various drying concepts. I will first describe what we think should be the broad objectives of a good drying system. Then, at the risk of boring you, I will discuss the heat transfer principles involved in accomplishing these objectives. Finally, I will describe the Lummus drying system designs, showing how they accomplish the objectives using these thermodynamic principles.

Gin Dryer Objectives

Broadly speaking, cotton gin dryers have two major practical functions. The first is to increase the value of the cotton for the cotton producer. It has been well demonstrated that in all but very arid areas, gin dryers enhance the trash separation processes and reduce the appearance of "prep" in the lint. They also increase the turn-out by aiding the gin saws in reducing the "tags" on the ginned seeds. The second function of cotton gin drying is to improve the rate of processing, particularly at the gin stands. There is a third broad function of drying systems that should be observed although it is not currently rewarded in the marketing system. This is to preserve the spinning quality of the cotton for the textile mills. Abusive drying using excessively high temperatures can reduce the spinning value, whereas a good drying system will enhance the cotton market value and the ginning process without fiber degradation.

To maximize these broad drying system functions, there are important detail features that should be incorporated in a good gin drying system. In most cotton growing areas, the moisture conditions vary widely throughout the harvesting season. A good drying system should be flexible to accommodate these varying moisture conditions. Drying systems should be designed to accommodate the most extreme moisture conditions without slowing down the ginning process, or being abusive to the cotton under very dry conditions. This can be accomplished by using heaters that have high turn-down ratios that can maintain a steady flame even when operating at only five percent of their full capacity. A good gin dryer should also be economical, both in initial investment and operating costs. A good drying system should minimize mechanical and pneumatic cotton working before thorough drying to reduce the possibility of "roping" the cotton that can result in rough preparation in the lint.

Drying Principles

To have a better understanding of gin drying systems we need to examine the physical phenomena involved. When we first think of drying, we think only of water removal from an object. But now let us take a closer look at the needs of the gin drying process. Figure 1 shows the heat energy in a pound of water when it is heated from just above the freezing point to over 212°F (100° centigrade). The definition of a Btu (British thermal unit) is the amount of heat energy required to raise the temperature of one pound of water 1°F. Water only exists between 32°F and 212°F, at atmospheric pressure. Below 32°F it is ice and above 212°F it is dry steam. Dry steam is a slightly better dryer than air. In the drying process, then, the challenge is to transform water into steam or water vapor. Note the heat energy required to elevate the temperature of one pound of water all the way from 70°F to the boiling point is only 142 Btu's. At 212°F, however, a dramatic increase in heat energy, 970 Btu's, is required to transform the water to steam. In a gin dryer then, the major requirement is to furnish sufficient heat energy to transform the water on the seed cotton to steam. So long as we have heat energy exposed to the surface of the cotton fibers at temperatures over 212°F any water on the surface will be transformed immediately to dry steam as water at atmospheric pressure cannot exist above 212°F.

All current drying systems use air to transfer the heat energy required by the drying process. Therefore, all drying systems must furnish sufficient air volumes to contain the necessary heat energy to dry without using abusively high temperatures. As we have seen from Figure 1, it takes about 1,100 Btu's to transform water from 70°F to steam (water

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vapor) at 212°F per pound of water. Now let us look at Figure 2, a portion of which has been in your *Cotton Ginner's Handbook* for a number of years, and is again included in the new *Handbook*. This chart shows the cubic feet of air per minute, at standard conditions, required to absorb various amounts of heat at different temperatures. All the major gin dryer suppliers agree that we should attempt to limit the temperature of air exposed to the cotton to 350°F under normal conditions. Therefore, in designing a drying system that will gently dry cotton, we should limit our design maximum temperature at the cotton mix point to 350°F. From this chart we can see that it will take about 18,000 cubic feet of air per minute to absorb 6,000,000 Btu's of heat per hour, limiting the mix point temperature to 350°F, allowing for a slight heat loss from the heater to the mix point.

Now let us discuss how much water we should expect to vaporize at various rates of ginning. We at Lummus have chosen to use 30, 45 and 60 bales per hour as typical ginning capacities. This simplifies our drying system sizes, as 60-bale-per-hour drying systems are simply two 30-bale-per-hour systems in parallel. Our 45-bale-per-hour system is simply 50 percent wider and, therefore, carries 50 percent more air volume than our 30-bale-per-hour system.

Let us, then, examine our typical 30-bale-per-hour system to determine its drying capacity. Figure 3 shows the cross-section of a typical seed lock. The foreign matter, of course, is in contact with the outer ends of the lint fibers, so the areas we want to be most concerned with are the surfaces of the fibers and the surfaces of the trash. The condition of dryness from the cotton conditioning standpoint is a surface phenomenon. Deep internal drying of the fibers and the trash is not necessary or desirable so long as their surfaces remain dry. While moisture in the seed will slowly migrate out into the fibers, there is no trash directly against the seed surfaces. It is neither desirable nor practical to attempt to thoroughly dry the seed in the 10 or 15 seconds the cotton is in each air conveyed drying system. Recently U.S.D.A. scientists conducted tests to determine the drying rates of the various components of seed cotton. These tests confirmed the fact that the lint fibers in vigorous convection air currents at safe elevated temperatures will lose 12 percent moisture in ten seconds, whereas, the seeds, sticks and burrs lose hardly any moisture at all internally. This is desirable because complete drying of the foreign matter would make it brittle and shatter into small segments. Heat energy would be wasted if the seed were thoroughly dried. An illustration of this drying phenomenon is to compare a seed lock of cotton to a baked Alaska dessert, Figure 4. The recipe for baked Alaska calls for a block of ice cream encased in a layer of meringue, baked in an oven from 3-5 minutes at 500°F until the surface of the meringue is brown. Some minutes later when the baked Alaska is served, the ice cream is still solid and the brown surface of the meringue is dry to the touch.

It would be simple to calculate the heat energy necessary to evaporate the required amount of water if it were free-standing. But this moisture is on the surface of the fibers and on the surface of the trash, so we must also consider that we must heat the lint fibers and the trash up to the boiling point in order for the moisture to be evaporated. In this process we will also warm the seed, but as anybody knows who has caught the seed falling from the gin stand, the seed is just comfortably warm to the hand, say around 100°F at that point. Typically there are about 150 pounds of trash in a bale of machine-picked seed cotton. Adding this to the 480 pounds of lint, we have 630 pounds of lint and trash per bale, which has a specific heat of about .3 Btu's per pound. Specific heat is the amount of heat required to raise the temperature of one pound of the material 1°F. Therefore, to raise 630 pounds of lint and trash from the standard air temperature of 70°F to 212°F without evaporation at 30 bales per hour will require about 810,000 Btu's per hour. Some heat, of course, will flow into the seed in the short time the cotton is exposed in airflow drying systems, but this is a relatively small amount. On the other hand, some of the thicker trash will not be heated internally. We then, conservatively, allow a total of about 1,000,000 Btu's per hour required to heat the lint and trash to the boiling point and partially heat the seed. This 1,000,000 Btu's must now be added to the Btu's required to evaporate the moisture.

This 1,000,000 Btu's of heat per hour required to heat the lint and trash to the boiling point should not be considered as wasted energy. In almost all modern gins, this heat in the lint and trash and the small amount of accompanying air provide a very useful function of heating the subsequent machinery after the hot air cleaners of drying systems. If this machinery following the drying systems is not heated, the cold metal surfaces can cool the cotton and air, which is now laden with moisture, down to the dew point and cause recondensation of the moisture from the dry vapor state back to the liquid or wet state.

In addition to heating the lint and trash up to the boiling point the hot air must also heat the piping, the dryer and the hot air cleaner in the drying system. This is a wide variable depending upon the surface areas of the drying system and the room temperature. This heat loss can also be minimized with insulation. We should, however, reserve about 500,000 Btu's per hour for this heat loss through the drying system surfaces. We now have a total of 1,500,000 Btu's of heat that must be transferred from the air in a 30-bale-per-hour machine picked cotton drying system, in addition to the heat required to vaporize the moisture.

Now let us calculate the water vaporizing capacity of the 18,000 CFM of air heated to 350°F with 6,000,000 Btu's of heat we cited in Figure 2. We have set our maximum temperature at 350°F and we now need to set our desired air exit temperature at the hot air cleaner. We chose 175°F as the desirable exit temperature at full capacity because below this temperature air loses most of its vigorous heat transferring capacity, both for vaporizing further moisture and for providing heat to the cotton to heat the machinery following the drying system. Having set our upper and lower temperature limits, from 350°F maximum to 175°F minimum, at full drying capacity, we can now determine the moisture absorbing capability of the air. From Figure 5 it can be shown that if all the heat energy of 18,000 cubic feet per minute of air could be used in evaporating the moisture from the lint only, the 18,000 CFM could remove 12 percent of the moisture in the lint at the rate of 58.33 Bales per hour. However, as we discussed earlier, at the rate of 30 bales per hour and using 6,000,000 Btu's of heat and 18,000 CFM of air, we should allow about 1,500,000 Btu's of the heat to be used in heating the lint, trash and walls of the drying system with some energy going into the seed as well. We need then, to allow about 25% of the 6,000,000 Btu's initial heat for other than evaporating the moisture from the cotton. Referring now to Figure 6, we see, at point a, the heat energy, known as enthalpy, in the air at 175°F in the condition it would be if all the heat energy of the burner had gone to evaporating moisture only. Here we see the water vapor in the air is .050 Pounds per pound of dry air (from Figure 5). The enthalpy is 91 Btu's per pound of dry air. But we must reduce this heat energy by 25% due to the uses of the heat other than to evaporate moisture [(91-10) x .75 + 10 = 70.75]. This then, drops the condition of the air down to point b, where we have .032 Pounds of water vapor per pound of dry air. Figure 7 shows this psychometric action graphically with the final air condition at 175°F with each pound of air containing about .032 Pounds water vapor resulting in a relative humidity of about 8%, a good exit air condition. Figure 8 shows the resulting calculation of the moisture removal that we obtain in an 18,000 CFM Drying system, taking into consideration all the heat uses and losses in the drying system. We see that with all of these factors considered, *we have a capability of over 33 bales per hour ginning rate, removing 12 percent moisture, while limiting our maximum temperature to 350°F at the mix point*.

The Lummus Drying System

To accomplish this drying in the short time available in a pneumatic conveying drying system, we must have vigorous, turbulent convection air currents blowing through the fibers of well opened cotton to constantly replenish the spent air adjacent the cotton fibers with fresh hot air. Figure 9 shows the cross section of the complete Lummus first stage drying system. The immediate impact is the simplicity and compactness of the Lummus system. Upon closer examination, however, it can be seen that we optimize the heat transfer process at every point, with minimum moving parts and other complexities. To minimize mechanical or pneumatic handling prior to introducing the cotton to the drying system, we drop the cotton directly from the module feeder into a short control feed hopper equipped with a disperser cylinder that breaks up the wads of cotton so the drying air can intimately contact the individual seed locks. If there is a telescope system, the separator from the telescope can be mounted directly over the module feeder discharge section, using the same control feed hopper to provide a well-opened and also uniform flow of seed cotton to the drying system. The cotton then drops down through a vacuum wheel into the first hot air stream where the mix point sensor limits the maximum temperature to 350°F. The cotton and air then flow to a high-efficiency combination large-trash remover and turbulent air dryer (Figure 10) where a secondary air stream coming from the same single large heater provides the trash-separating air stream as well as the cross currents of hot turbulent air to enhance the drying process. The heavy trash and some of the seed cotton drop down into a lower section where a third stream of air, coming directly from the burner, buoys up the cotton out of the heavier trash and moves it back into the air stream. Double dump valves automatically operate from a timer. The double dump valves allow the final air stream to enter at the lowest point above the upper dump valve to provide the most efficient trash separation action. Vacuum wheels do not allow this type of separation, and much good cotton can be lost in these systems. The drying process is well under way as the seed cotton leaves this combination turbulent hot air dryer and large trash remover unit. Here the seed cotton enters the new Lummus Tower Dryer with 27" high shelves to accommodate 18,000 CFM in our 4' wide model and 27,000 CFM in our 6' wide model. Here in the tower dryer, figure 11 shows the classic cross-flow of air that occurs every time the cotton passes off a shelf forcing the hot air to flow through the fibers, accelerating the drying process. From the high volume tower dryer the cotton flows to the hot air cleaner or split hot air cleaners. The entire 18,000 CFM or 27,000 CFM pass on to the first stage hot air cleaner(s) to enhance the air wash action in the hot air cleaners and to provide as much heat as possible to the seed cotton for heating the stick machine and other machines that may follow the first drying system.

This entire drying system is "pull through" which not only keeps the cotton gin atmosphere noticeably cleaner than "push - pull" systems, but also enables Lummus to use only one heat source, for not only all the first drying system just described, but also to supply the heat for the second stage drying system. The second drying system is also a pull-through system, and the degree of heat going to the second system is simply regulated by bleeding in whatever degree of ambient air is desired to maintain the cotton in a drying environment. There should be sufficient heat not only to heat the cylinder cleaners or extractor cleaners following the second stage system but also to heat the conveyor distributor, the extractor feeders over the gin stands and the gin stands themselves. We optionally recommend smaller cross-section tower dryers in the second system to thoroughly drive the heat into the fibers, but the major drying should be done in the first drying system. For a 30-bale-per-hour drying system, we dedicate about 7,000,000

Btu's to the first drying system and about 3,000,000 Btu's to the second drying system, thus providing additional drying capacity for extreme conditions. Since all this heat is provided by a single source this ratio can very easily be changed by merely adjusting the slide valves going into the second system I mentioned earlier. Note also that in the Lummus drying systems the hot air going to the second drying system is fresh, clean, dry air directly from the heater, not re-used air from the first system that is laden with moisture and fine dust. This provides a clean air rinse and a vigorous heating action at a lower temperature in the second drying system.

References

1. Zimmerman, O. T., and Lavine, Irvin. Psychrometric tables and charts. Industrial Research Service, Inc.

2. Laird, J. W., and Barker, G. L. 1995. Time relationships for drying cotton. ASAE meeting presentation. Paper no. 95-1565.

HEAT ENERGY OF H_2O (ENTHALPY) VS. TEMPERATURE

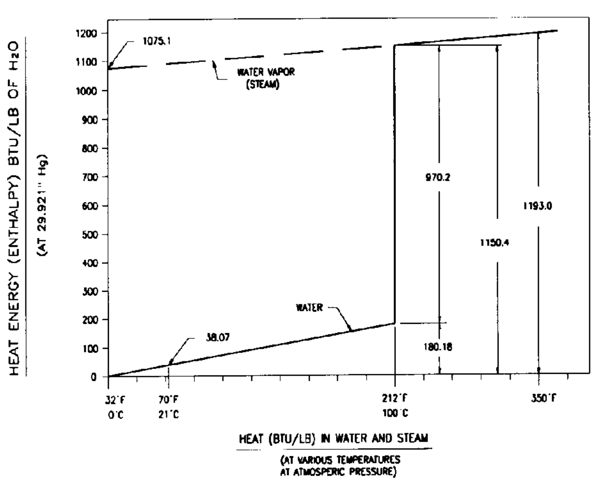

FIGURE 1

Heat-to-Temperature Relationship for Air

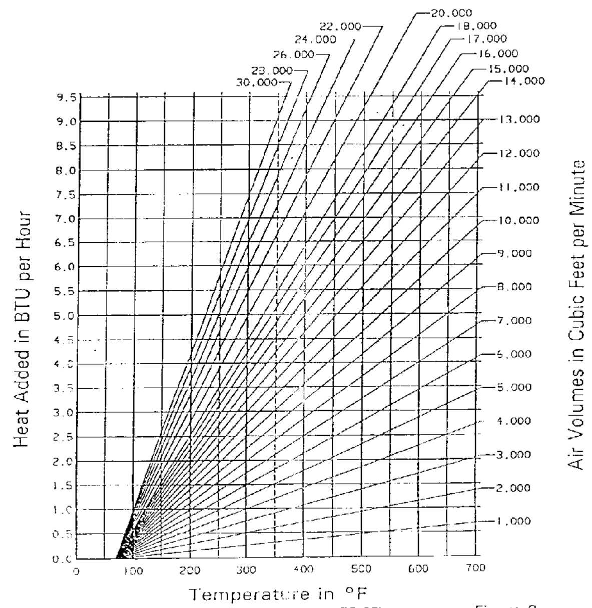

Figure 2

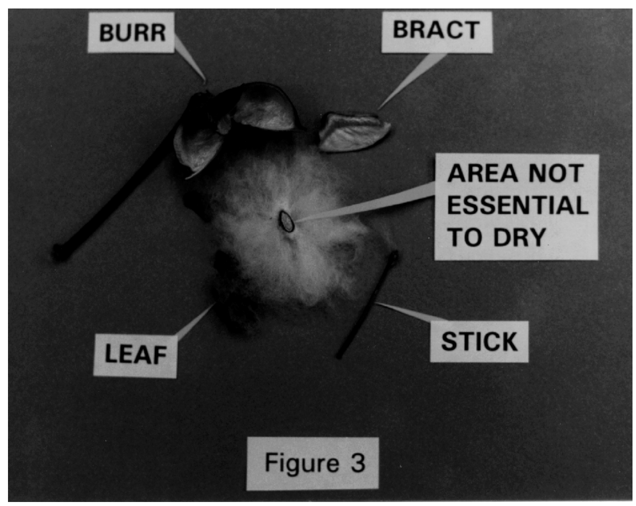

Figure 3

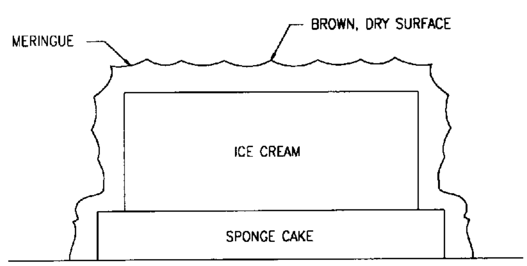

FIGURE 4

ADIABATIC SATURATION AND PERCENTAGE SATURATION CURVES
(TEMPERATURE RANGE, 0 TO 500°F; PRESSURE, 29.921" Hg)

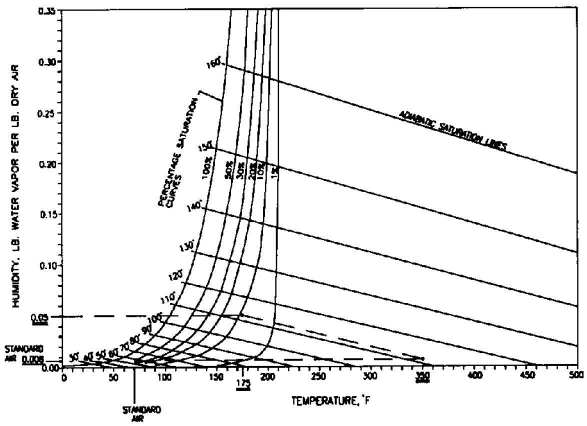

FIGURE 5

HEAT ENERGY (ENTHALPIES) OF AIR-WATER VAPOR MIXTURES
(TEMPERATURE RANGE, 0 TO 250F; PRESSURE, 29.921" Hg)

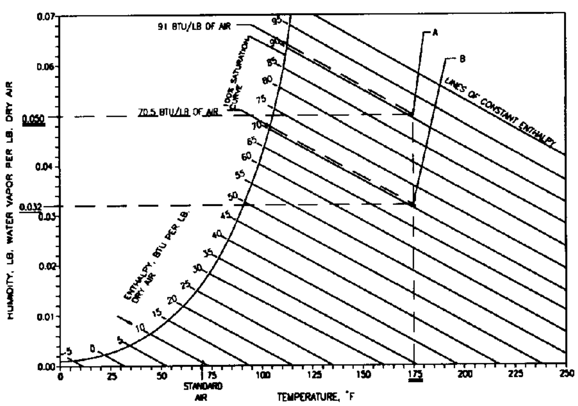

FIGURE 6

ADIABATIC SATURATION AND PERCENTAGE SATURATION CURVES
(TEMPERATURE RANGE, 0 TO 500°F; PRESSURE, 29.921" Hg)

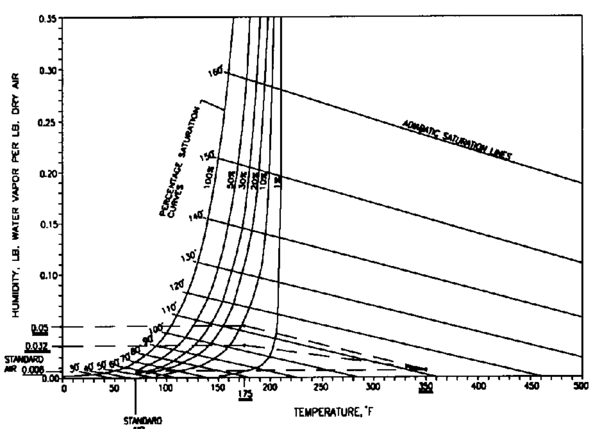

FIGURE 7

Calculation Of Moisture Removal Using Psychrometric Charts (Figures 5 & 6)

Assumptions:

- 18,000 C.F.M. Ambient Air
- 350°F Mixpoint Temperature
- 175°F Exit Temperature
- 12% Moisture Removal From Lint
- 25% of Heat Energy to heat Lint, Trash, Seed,& Drying System Heat Losses

Bales/Hr at 12% Lint Moisture Removal $= \frac{\text{C.F.M.} \times (WV_{175} - WV_{70}) \times 60}{D_A \times 480 \times .12} =$

$\frac{18{,}000 \times (.032 - .008) \times 60}{13.5 \times 480 \times .12} = 33.3$ **Bales/Hr**

Where:

C.F.M = Drier Air Volume at 70°F

WV_{175} = Water Vapor per Pound Dry Air in Air Heated from 70°F to 350°F and Cooled to 175°F using 75% of its Heat Energy to Vaporize Water

WV_{70} = Water Vapor per Pound Dry Air in 70°F, 50% R.H. Air

D_A = Density of Air at 70°F

Figure 8

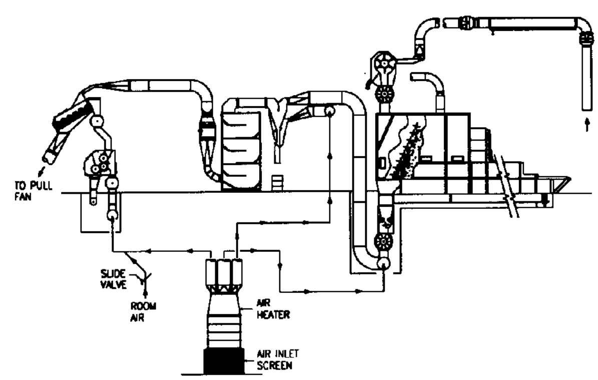

FIGURE 9

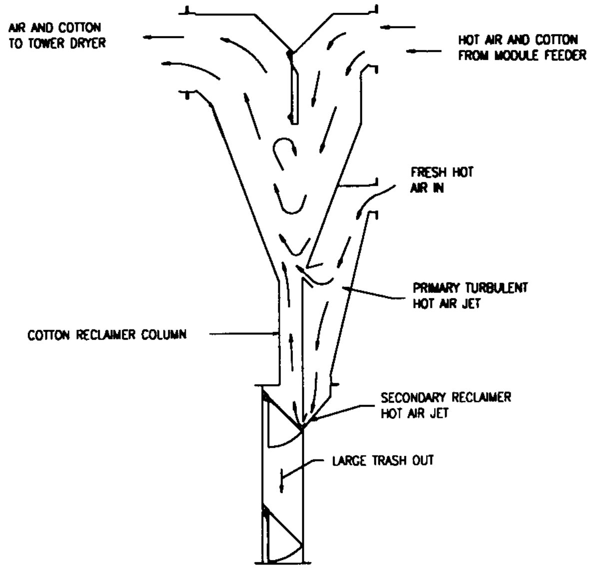

FIGURE 10

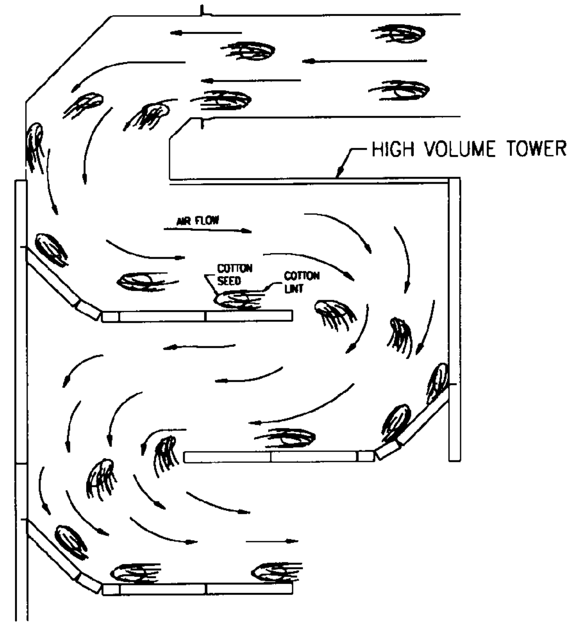

FIGURE 11