Feasibility Tests for a Two-Stage Batch Dryer for Curing Farmer Stock Peanuts[1]

C. L. Butts[2*] and M. S. Omary

ABSTRACT

A two-stage batch dryer for farmer stock peanut was developed by a commercial grain dryer manufacturer and tested at a commercial peanut buying point during the 1996 and 1997 harvests. A 7.3-m diameter grain bin provided the superstructure for two peanut curing chambers. Each chamber had an approximate capacity of 18,000 kg of in-shell peanuts. Comparisons between conventional peanut curing wagons and the bin dryer were conducted. Recorded data included temperature and relative humidity in both type dryers, drying time, moisture content throughout curing, farmers stock grades, milling quality, and seed germination. A total of 451,717 kg were cured in the two-stage dryer and 215,460 kg in conventional dryers. The initial moisture content of peanuts averaged 19% wet basis and dried at an average moisture removal rate of 0.45%/hr. The moisture removal rates for the two dryers were not significantly different. The final moisture content averaged 11%. Moisture content at the time of grading averaged 9%. Farmers stock grades and milling quality were not significantly different. The average quota support price, including LSK for peanuts cured in conventional dryers, was \$630.47/1000 kg compared to \$636.08/1000-kg peanuts cured in the two-stage dryer. Seed germination averaged 75.8 and 76.1% for conventional and bin-dried peanuts, respectively. The two-stage batch dryer was comparable to the current wagon-drying system. A single batch in the two-stage dryer was equivalent to three peanut wagons.

Key Words: Drying, energy, quality.

Windrowing and bulk curing farmer stock peanut began in the late 1950s and early 60s (Duke and Teter, 1957; Coates *et al.*, 1958; Mills and Dickens,

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1958; Pierce and Mills, 1961). Nearly all peanuts grown in the U.S. are now windrowed and combined. Most U.S. peanuts are mechanically cured in bulk curing systems using wagons or trailers equipped with a perforated metal floor and plenum to force-heated air through the peanuts until they reach a marketable moisture content. The capacity of a typical peanut drying wagon is 4000-6000 kg. A typical peanut buying point in the southeastern U.S. owns 100-200 peanut drying wagons to handle the peanut crop as it is harvested.

Prior to 1989, commercial peanut combines were capable of harvesting a single windrow (two rows). Four-row combines were introduced in 1990, and by 1991 at least one major manufacturer ceased two-row combine production. Six-row machines were introduced in 1991 followed by the introduction of eight-row combines in 1996 (M. Mathis, pers. commun., 1997). Harvest capacity of two-row peanut combines currently in use is estimated to be 4 ha/d compared to 8 and 12 ha/d for four- and six-row combines, respectively (M. Mathis, pers. commun., 1997). Increased harvest capacity has dramatically increased the need for higher capacity curing systems.

The maximum recommended plenum temperature is 35 C (Beasley and Dickens, 1963; Young *et al.*, 1982; Samples, 1984; Cundiff *et al.*, 1991). Recommended minimum plenum humidity is approximately 50% (Samples, 1984; Troeger, 1989; Cundiff *et al.*, 1991). Later research showed that maintaining plenum humidity between 40 and 60% could reduce energy costs approximately 30% compared to a fixed temperature set point (Butts, 1996). Young *et al.* (1982) summarized air conditions determined by previous research to maintain high peanut quality while curing on the psychrometric chart (Fig. 1). Baker *et al.* (1993) and Butts *et al.* (1996) developed mathrate,

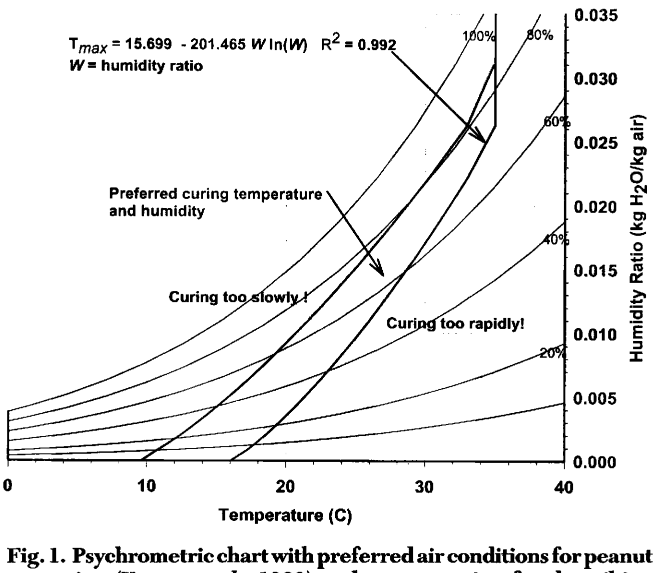

Fig. 1. Psychrometric chart with preferred air conditions for peanut curing (Young *et al.*, 1982) and an expression for describing T_{max}, the maximum desired plenum temperature (Butts *et al.*, 1996).

ematical expressions to describe the maximum desired plenum temperature.

In 1995, a grain dryer manufacturer adapted a 7.3-m diameter edible bean dryer for curing peanuts (Fig. 2). Holding capacity of the prototype two-stage batch dryer was estimated at 18,000 kg per stage. The prototype dryer was constructed for testing during the 1996 peanut harvest. The objective of this test was to compare the performance of the two-stage batch (TSB) dryer with conventional wagon dryers. Specifically, the drying capacity (1000 kg/hr), fuel consumption, moisture removal and resulting peanut quality were compared.

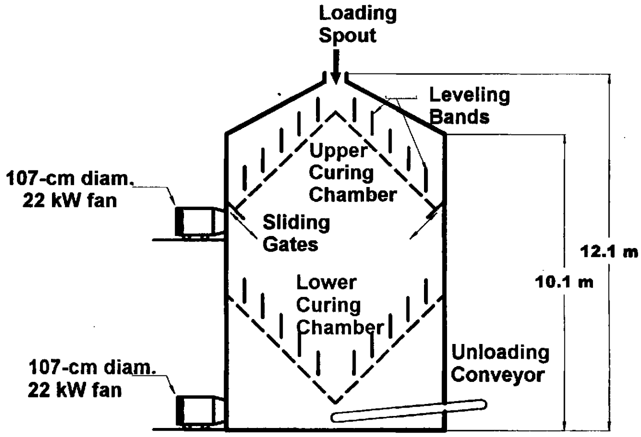

Fig. 2. Schematic of two-stage batch peanut dryer tested during the 1996 and 1997 harvests.

Materials and Methods

Tests were conducted at a commercial peanut curing facility to compare conventional wagon dryers to the TSB dryer during the 1996 and 1997 peanut harvests. Peanuts were combined and transported in semi-trailers from the field to the buying point at Colquitt, GA. The peanuts were weighed, then unloaded into a dump pit. Peanuts were transferred from the dump pit and into the upper unit of the TSB dryer using a bucket elevator. Peanuts were loaded into the TSB dryer until peanuts were 1.2 m deep and was equivalent to approximately four conventional 4.3-m peanut drying wagons. The remaining peanuts were loaded into a conventional peanut drying wagon.

The TSB dryer (Fig. 2) was designed to partially cure in the upper unit, then transfer peanuts through slide gates from the upper to the lower unit. As the gates open, peanuts flow off the top layer in the upper unit into the lower unit. This placed the wetter peanuts on the bottom of the mass of peanuts in the lower unit, effectively inverting the peanut mass. The gates were closed, and a second batch could then be loaded into the upper unit. Curing continued until peanuts in the lower unit reached the desired cutoff moisture. The desired cutoff moisture varied from 11.4 to 10.6% according to the expected length of time prior to marketing. The peanuts were unloaded from the lower unit into peanut wagons and marketed. After the lower unit was emptied, peanuts in the upper unit could be moved into the lower unit and the process repeated.

However, the desired curing schedule was followed only in two or three instances due to the sporadic and infrequent delivery of peanuts to the buying point in large batches. If more than one semi-load of peanuts was available, operators immediately transferred the first load from the semi-trailer directly into the lower unit, then loaded the upper unit with peanuts from the second load. If only one batch arrived at the buying point, it was placed in the upper unit, partially cured, then lowered to the lower unit with no other peanuts placed in the top. Temperature set points were 40 C according to the buying facilities normal operating procedures, exceeding the recommended 35 C maximum dryer temperature.

Peanuts loaded into conventional drying wagons were connected to gas-fired single unit dryers (Peerless Model 153, Shellman, GA). Dryers were operated using the same thermostat set point as the TSB dryer according to the buying point's normal practice. Buying point personnel monitored the dryers as normal and cutoff the dryers when the desired moisture content was reached.

Drying air temperatures were monitored using three Type T thermocouple junctions wired in parallel and spaced evenly in the dryer duct transition. This sensor arrangement sensed a spatially-averaged temperature of the drying air. Inlet air temperature and relative humidity were monitored at locations under the drying shed. Temperatures were sensed using Type T thermocouples. Relative humidity was measured using capacitance-type sensors. No reliable data concerning LP consumption for the conventional dryers were obtained during the 1996 tests. LP consumption was measured using temperature-compensated vapor meters during the 1997 harvest.

Temperature and relative humidity sensors were installed to measure the air conditions entering and exhausting from the peanuts in both the lower and upper units of the TSB dryer. Temperature and humidity were measured at six locations in each of the lower unit inlet, lower unit exhaust, and the upper exhaust. Only three sensors were installed to measure temperature and humidity of the air entering the peanuts in the upper unit because of difficult access. Ambient temperature and humidity also were recorded. All sensors were monitored and recorded using Campbell Scientific data loggers. Propane for each fan/burner unit of the TSB dryer was supplied by a separate 3785 L tank. During the 1996 tests, propane consumption for the TSB peanut dryer was determined from fuel purchasing records. LP consumption was measured and manually recorded during the 1997 tests using the same type meters as used on the conventional dryers. Drying times and the initial and final moisture contents for each load were recorded.

Sample Collection and Analysis. After the semi-trailers arrived from the field and as the peanuts were emptied into the dump pit to load the dryers, 22.5-kg samples were collected and transported to the USDA, ARS, Nat. Peanut Res. Lab. (NPRL) in Dawson, GA. The samples were then cured (dried) using ambient air in 0.11 m^3 sample dryers (Fig. 3) until the average moisture content was less than 10% wet basis (wb). The sample dryer consisted of four 0.028-m^3 boxes with perforated metal bottoms. These boxes were placed on a

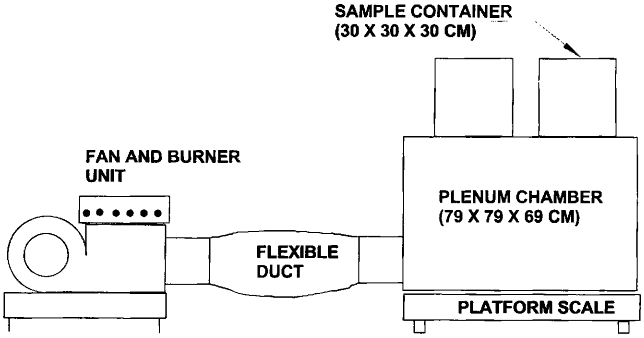

Fig. 3. Schematic of laboratory dryer used for drying peanut samples with ambient air during 1996 and 1997 harvests.

plenum with four 30 × 30-cm outlets. A centrifugal fan forced ambient air into the plenum and through the peanut samples. Platform scales monitored the mass of peanuts as they dried. The dryers were turned off automatically when they reached the desired moisture content.

During the normal marketing process, a 4.5-kg sample is extracted from each load of peanuts by Federal State Inspection Service (FSIS) personnel. Inspectors divide the 4.5-kg sample into two 2.3-kg subsamples. The first subsample is the official sample used to determine the peanut quality and establish the peanut value. The second subsample, or check sample, was obtained from each load of peanuts cured. The check samples were labeled according to the type of curing system used on that load of peanuts then transported to the NPRL for evaluation.

Each check sample and the corresponding air-dried sample was cleaned and shelled. The sample was separated into five categories during cleaning—loose shelled kernels (LSK), dirt, rocks, light trash, and peanut pods. Peanut pods were shelled using a Model 4 Sheller (Davidson and McIntosh, 1973). Kernels were separated into five commercial size categories for either runner- or virginia-type peanuts (USDA, 1993). Kernels with more than 25% of their skin missing were categorized as "bald kernels." The weight of bald kernels in each size category was recorded. Bald kernels usually split during subsequent handling and are undesirable in some manufacturing processes (McIntosh *et al.*, 1971).

Jumbo-, medium-, and number one-sized kernels from each sample were combined. Then samples were selected to represent each drying treatment (AIR, TSB, or conventional) from each batch, treated with a seed fungicide, and sent to the Georgia Seed Laboratory for germination analysis.

Results and Discussion

A total of 529,291 kg (net weight) of farmer stock peanuts were cured during the 1996 harvest and 137,112 kg were cured during the 1997 harvest. Net weight is defined as peanut pods and LSK at 7% w.b. Thirty-two batches of peanuts (451,717 kg) were cured in the TSB peanut dryer. Comparable loads (215,460 kg) were cured using conventional 4.3-m peanut wagons and single-trailer dryers. Partially-filled semi-trailers were delivered to the buying point for eight batches (3, 4, 9, 13, 15, 20, 21, and 23) during 1996. Peanuts from these loads were cured only in the TSB dryer and not in the conventional drying wagon. A summary of the dryer performance is shown in Table 1. Peanuts dried approximately 1 hr faster in the TSB dryer than in the conventional dryers. Based on the net weight of peanuts graded from each batch and the drying time, the average drying capacity for the TSB dryer was 1161 kg/hr. Similarly, the average drying capacity of a single drying wagon was 381 kg/hr. The throughput of the TSB dryer was approximately equivalent to three conventional drying wagons.

Table 1. Summary of conventional and two-stage batch (TSB) peanut dryer during the 1996 and 1997 harvest seasons.

	Conventional dryer	TSB	$P \geq \lvert T \rvert$
Initial moisture content (%)	19.1	19.7	0.427
Final moisture content (%)	11.0	11.3	0.167
Drying time (hr)	18.7	17.6	0.432
Drying rate (%/hr)	0.44	0.47	0.348
Drying capacity (1000 kg/hr)	0.38	1.16	0.053
Propane consumed (L/1000 kg)	45.7	41.3	0.613
Electricity consumed (kWh/1000 kg)	18.6	41.6	0.0001
Ambient temperature (C)	24.8	22.3	0.008
Ambient relative humidity (%)	67	74	0.007
Plenum temperature (C)	39.1	34.1	0.013
Plenum humidity (%)	33	40	0.00

Temperature and relative humidity of the curing air were measured in the plenum of the conventional dryer and the TSB dryer. Due to equipment failure, data were not recorded in TSB dryer batches 1-5 during 1996. The average plenum temperature in the TSB dryer was 34 C compared to 39 C in the conventional dryers (Table 1). Average ambient temperatures were 3 C cooler while the TSB dryer was in operation than when the conventional was operating. *Conventional dryers generally operated* from 1800 hr until 1330 hr the following afternoon, while the TSB dryer usually operated from 2000 until 1430 hr. The 2-hr lag in starting the TSB dryer resulted in slightly lower ambient temperatures and slightly higher ambient relative humidity. The relative humidity of the air after heating averaged 33 and 40% in the conventional and TSB peanut dryers, respectively (Table 1). The lower plenum relative humidity in the conventional dryers was caused by the higher average plenum temperature and the generally lower ambient relative humidity.

Peanuts cured in the TSB dryer required 13,026 L of propane during the 1996 harvest (45 L/1000 kg). Based on previous research by Blankenship and Chew (1979), single wagon peanut dryers require approximately 40 L/1000 kg to dry peanuts from 18 to 10% moisture content at 40 C. If the plenum temperature for the conventional dryers had been reduced to 35 C, then LP consumption would have been approximately 32 L/1000 kg (Blankenship and Chew, 1979). Fuel consumption for the TSB dryer exceeded estimated fuel consumption for conventional dryers as operated during 1996 by 7%. During 1997, the TSB dryer consumed 4182 L (36.2 L/1000 kg) while the conventional dryers consumed 1465 L (51.1 L/1000 kg). Over the 2-yr study, and including the estimated fuel consumption for the conventional dryers, the TSB consumed approximately 10% less propane per 1000 kg than the conventional dryers. The two 22-kW fans delivered an airflow rate greater than recommended for economical peanut curing. Based on the manufacturer's fan performance data, each fan delivered approximately 991 m^3/min. The specific air flow rate delivered to the lower unit was 9.7 m^3/minm^3 of peanuts. This air was not exhausted but continued through the peanuts in the upper chamber and was added to the air supplied by the upper level fan. Therefore, the upper unit had a combined airflow rate of 19.4 m^3/minm^3. This excessive airflow rate through the peanuts in the upper unit resulted in higher-than-expected fuel consumption. The controls for both fans were interlocked so that both fans were operated even if peanuts were only in one chamber. If peanuts were in the upper chamber only and the top fan was run, then heated air would have exhausted through the lower fan. Redesigning the air delivery system and fan controls to allow for independent operation would reduce propane use.

Except for loose shelled kernels and foreign material, official farmers stock grade factors of peanuts cured in the conventional dryers were not significantly different ($P \leq 0.1$) from peanuts cured in the TSB dryer system (*Table 2*). Differences in foreign material, loose shelled kernels (LSK), and sound splits may indicate damage while loading and unloading the TSB dryer (Turner *et al.*, 1965; Wright, 1968; Slay, 1976). The percentage foreign material was 4.5% in the conventionally dried peanuts, while the peanuts dried in the TSB dryer averaged 3.8% foreign material. LSK averaged 3.2 and 2.7% in the conventional and TSB dryer, respectively. The increased LSK in the conventional dryer was probably due to the wagon being loaded from the dump pit after the TSB had been loaded. This resulted in the wagon consistently getting the cleanout of the dump pit. Foreign material was reduced in the TSB by dirt and other fine particles sifting through the perforated flooring during transfer from the upper to lower chambers and while unloading from the lower chamber into wagons for grading. Sound mature kernels, sound splits, and other kernels were virtually the same for peanuts dried in both dryers. Using the 1996 loan schedule, the average farmer stock value for peanuts dried in the TSB dryer was \$655.35/1000 kg of clean peanut pods compared to \$653.23/1000 kg for peanuts dried in conventional dryers. The price per net metric ton (including LSK) averaged \$636.08 and \$630.47 for those cured in the TSB dryer and wagons, respectively.

Table 2. Summary of grade factors and farmers stock value of peanuts cured in conventional and TSB peanut dryers during 1996 and 1997 harvests.

Grade factor	Conventional	TSB	Pr ≥ |T|
Foreign material (%)	4.5	3.8	0.093
Loose shelled kernels (%)	3.2	2.7	0.020
Moisture content (%)	9.4	9.4	0.899
Sound mature kernels (%)	63.6	63.7	0.908
Sound splits (%)	4.6	4.8	0.715
Total sound mature kernels (%)	68.2	68.5	0.632
Other kernels (%)	5.8	5.6	0.465
Damaged kernels (%)	0.4	0.3	0.294
Total kernels (%)	74.1	74.3	0.678
Hulls (%)	25.7	25.7	0.993
Pod value (\$/1000 kg)	653.23	655.35	0.693
Net value incl. LSK (\$/1000 kg)	630.47	636.08	0.267

Milling outturns for the drying tests are shown in Table 3. In general, there were no differences between the peanuts dried in the conventional dryers and those dried in the TSB dryer. However, the peanuts samples cured using only ambient air at the laboratory were higher in quality. The air-dried samples generally had more jumbo- and medium-sized kernels and fewer splits. The splits in the air-dried samples averaged 8.7% compared to the 14.7% for conventionally dried peanuts and 14.1% for the TSB dried peanuts. The high split percentage for the air-dried samples indicated that excessive mechanical damage occurred during harvest and transportation to the buying point (Wright, 1968). No significant differences in split kernel percentages were observed between conventionally cured peanuts and those cured in the TSB dryer. Seed germination was approximately the same for air-dried samples (77%), wagon-dried samples (76%), and TSB dryer samples (76%).

Table 3. Summary of shelling outturns and seed germination for air-dried, conventionally dried, and TSB-dried samples obtained during the 1996 and 1997 harvests.[a]

Shelled component[b]	No heat	Conventional	TSB
Jumbo/ELK[c]	18.7 a	16.1 b	15.4 b
Medium[c]	30.6 a	25.6 a	27.6 a
No. 1[c]	7.8 a	7.8 ab	7.4 b
Splits	8.7 a	14.7 b	14.1 b
Bald kernels	0.0 a	1.3 b	1.3 b
Oil stock	6.8 a	7.1 ab	7.4 b
Hulls	26.5 a	26.7 a	26.3 a
Germination	76.6 a	75.8 a	76.1 a
Value[d] (\$/1000 kg)	946.62 a	926.55 b	928.83 b
Value[d] incl. LSK (\$/1000 kg)	933.47 a	902.40 b	909.08 b

[a]Means in the same row followed by the same letter are not significantly different at the P = 0.10 level.

[b]Shelling outturns are presented as percentage of initial pod weight.

[c]Percentage whole kernels shown have had percentage bald kernels subtracted.

[d]5-yr average shelled stock prices used for jumbo/ELK = \$1.43/kg, medium = \$1.41/kg, No. 1 = \$1.39/kg, splits = \$1.41/kg, oil stock, and LSK = \$0.22/kg.

The shelled stock value of peanuts was calculated using a 5-yr running average price for each commercial size runner peanut. The value of peanuts per 1000 kg of pods shelled for peanuts cured with ambient air was significantly higher (\$947/1000 kg) than either the TSB- or conventionally dried peanuts (\$929 and \$926, respectively). The value per 1000 kg of farmer stock peanuts (pods and LSK) was significantly higher for air-dried peanuts (\$933/1000 kg) compared to either of the commercial drying treatments. The value for conventionally dried peanuts (\$902/1000 kg) was not significantly different from that of peanuts dried in the TSB dryer (\$909/1000 kg).

The TSB dryer compared favorably with conventional dryers in terms of drying rate and resultant peanut quality. However, there were several operational drawbacks in managing the TSB peanut dryer. The logistics of loading and operating the prototype dryer as originally designed was difficult to maintain due to sporadic delivery of peanuts to the buying point. The current practice of transporting peanuts from the field in small wagons along with the desire to handle these loads individually made following the designed operating procedure difficult. Delivering peanuts to the buying point in semi-trailers or other large capacity haulers should allow the manager to keep the two-stage batch dryer operating at full capacity.

Other design problems included (a) the location and/or accuracy of temperature sensors in the plenum, (b) reducing the impact damage when peanuts are loaded into the upper unit and moved from the upper unit to the lower unit, and (c) having to operate both 22-kW fans when only one unit is in use. Impact force could be reduced using slides instead of a free fall or by reducing the distance between the upper and lower units. Research by Turner *et al.* (1968) and Slay (1976) indicated that damage caused by free fall impact increased proportionally to fall height. Slay (1976) stated that impact damage appeared to be cumulative. Therefore, minimizing impact damage in the curing process will improve product viability later in processing. Redesigning the airflow and heat delivery system so that fans could operate independently and possible reducing the heating capacity of the upper unit should reduce electrical and propane consumption. The upper fan also could be reduced in size to supplement the lower fan instead of as a stand alone system.

Summary and Conclusions

Data collected during the 1996 and 1997 peanut harvests indicated that the TSB dryer cured peanuts with reduced propane consumption at a throughput rate equivalent to three conventional drying units. Peanut quality at the first point of sale or after shelling was not significantly different. However, any differences in milling quality due to curing were dominated by mechanical damage incurred during harvest. Due to oversized fans, the TSB used more electrical energy than the conventional dryers. The major obstacle to adoption of this new two-stage batch dryer is the current system of delivery to the buying point and the logistics operating the two-stage batch dryer at full capacity. Technically, the TSB dryer is a suitable alternative to the current peanut curing system. However, equipment cost of the TSB must be considered and may cost more than the equivalent capacity conventional dryers.

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