Peanut Science (1982) 9, 77-81

A Microprocessor Control System for Peanut Drying[1]

James L. Steele[2]

ABSTRACT

A microprocessor based peanut dryer control system to minimize energy consumption was developed and tested over a 3 year period. Hardware and software needs were described. First year tests were conducted to verify hardware performance. Energy control techniques were proposed and compared with conventional peanut dryer control procedures. In simultaneous comparative tests, the first energy control technique implemented reduced liquified petroleum gas (LPG) consumption 49 percent, electric energy 39 percent and increased time on the dryer 65 percent. Modification of the energy control technique reduced the unacceptable increase in time on the dryer to 10-20 percent while similar reductions in LPG and electric energy were maintained. The improved control technique produced similar results in tests the following year. No losses in peanut quality during drying were observed and the net saving was $5.61 per tonne or a 25 percent reduction in peanut drying costs for Virginia conditions.

Key Words: peanut, drying, controls, electronics, microprocessor, software.

Dryer operation and management is one of many problems a peanut producer is faced with at harvest time. A dryer operator must synchronize the peanut digging and combining operations with dryer capacity and drying rate. Unpredictable weather conditions frequently force operators to sacrifice least cost/tonne dryer operation for maximum drying rate operation, but certain operating constraints must be observed to maintain peanut quality and market grade (1, 5). These constraints, which vary with harvest moisture and ultimate utilization of the peanuts, are specified in terms of a minimum airflow rate per unit of peanuts and humidity and temperature limits for the drying air. They are intended to prevent mold contamination, drying too rapidly and the production of off-flavors.

In conventional drying systems, these constraints are met by the dryer design and burner controls provided by the manufacturer. Dryer controls are frequently set at the beginning of harvest and operated without change throughout the drying season. Fan operation is continuous throughout the drying period. Artificial drying under average Virginia conditions requires 64.3 L of liquid propane gas (LPG) per tonne of in-shell peanuts harvested at 30 percent moisture content (m.c.) (8). At 1981 energy rates, LPG and fan energy costs are approximately $16.32 per tonne. Adding fixed costs ($0.121/hour-tonne for 52 hours), which depend on dryer utilization, produces a total drying cost of approximately $22.71 per tonne. Minimization of costs mandates full utilization of the dryer during the harvest season and conservation of LPG and fan energy with maintenance of peanut quality.

Energy optimization of the drying process requires periodic adjustment of the burner control set points and selective operation of the fan during the drying period. Minimal operation of the fan during periods of high ambient humidity is suggested to reduce energy consumption and prevent undesirable biological activity. Progressively less fan operation is prudent as the peanuts approach an acceptable storage moisture level or whenever drying efficiency is very low. Fan cycle limitations in terms of initial moisture and estimated energy savings therefrom were reported by Troeger (9). The prevention of excessive drying also must be considered (2).

Several recent studies to improve agricultural process with new electronics technology have been reported (3, 4, 6, 10, and 11). These suggest a rapid transition to microprocessor based control systems. However, the literature on microprocessor applications in agriculture is predominantly technical papers and manufacturers' manuals as suggested by McClure (7). The implementation of peanut dryer control strategies for energy optimization and quality maintenance is within the realm of microprocessor capability.

A project was initiated in 1979 to investigate the microprocessor requirements to energy optimize peanut dryer control while maintaining peanut quality. The specific objectives were to assemble the necessary hardware to control a commercially available peanut dryer, develop software to implement certain energy conservaiton techniques and to compare performance data with conventional drying procedures.

Materials and Methods

Microprocessor and Control Equipment

The control system included a microcomputer, data acquisition hardware and a control console (Fig. 1). The microcomputer, a National Semiconductor rack mount 80/204, included a single board level microprocessing system, power supplies, front panel controls, serial input/output (I/O), six programmable parallel I/O ports, 4k x 8-bit random access memory (RAM), provision for 8k of user installed read only memory (ROM), a card cage and backplane assembly and a monitor. The monitor consisted of software in two on-board ROM's for use with a video or teletypewriter console. The monitor provided interactive control to display areas of memory, display processor register contents, modify memory and register contents, insert instructions in memory, move blocks of data in memory, load hexidecimal data from paper tape, dump hexidecimal data from memory to paper tape, initiate execution of user programs and insert breakpoints into user programs. Two of the I/O ports were bi-directional.

The data acquisition hardware consisted of a SANLAB SL110 linearizing analog/digital (A/D) converter, two SANLAB SL102 ten-channel copper-constantan termocouple or millivolt scanners, a power supply and card cage for up to 16 ten-channel scanners. The linearizing A/D converter also provided communication between the microprocessor and the scanners. The 12-bit converter communicated with the microprocessor with an 8-bit bi-directional data bus, five command strobe lines and ground. With appropriate strobes, the converter accepted two 8-bit commands from the processor, issued commands to the scanners, initiated scanner sampling, linearized and digitized the resulting scanner output and stored the result in on-board memory for processor re-

---

[1]Cooperative investigation by the Agricultural Research Service, U. S. Department of Agriculture and the Tidewater Research and Continuing Education Center, Virginia Polytechnic Institute and State University, Suffolk, Virginia.

[2]Research Agricultural Engineer, Agricultural Research Service, U. S. Department of Agriculture, Suffolk, Virginia.

[3]Mention of firm names or trade products does not imply that they are endorsed or recommended by the Department of Agriculture over other firms or similar products not mentioned.

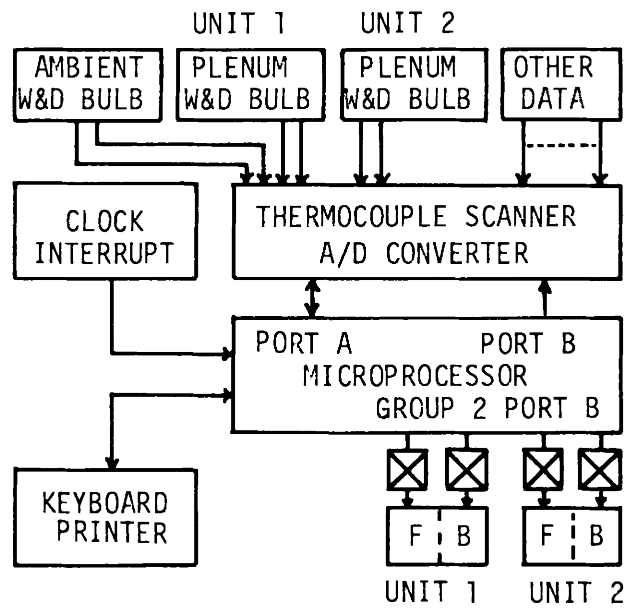

Fig. 1. Block diagram of microprocessor based peanut dryer control system.

trieval. With appropriate strobes, the converter returned these results to the microprocessor in two 8-bit words.

The SANLAB SL102 scanner, a solid state measuring instrument, accepted analog signal inputs from any one of ten thermocouple junctions or millivolt wire pairs. The instrument included an isothermal reference junction, a low-thermal multiplexer, control logic and a provision to virtually eliminate time-based and temperature-based zero drift. Under program control, error offsets may be digitized, stored and used to algebraically correct data for drift.

A Teletype model 43 with a paper tape reader and punch was used for the control console. Solid state optical relays activated by ouput port bits were added to control the fan and burner of each drying unit.

Acquisition of data on a real time schedule was preferred and required the fabrication of a real time clock with software, crystal controlled oscillator, counters and a processor interrupt signal. The clock board was designed to provide manually selectable interrupt time periods.

Software for the system was developed in stages; communication software for the microprocessor and A/D converter, a real time clock service routine and a peanut dryer control service routine. Other subroutines were developed as necessary in each segment for console input, message output, binary to ASCII decimal conversion, real time data acquisition, output data formating, etc. As the segments were developed, a main program segment was developed for system initialization and continuous execution of the clock service, data acquisition and control service routines.

All software was written in assembly language, stored and assembled with a central computer system and then transferred to the microcomputer via punched paper tape. Editing, relocating and linking of the routines were completed on the central computer system. As the routines were developed and debugged, they were burned into erasable and programmable ROM circuits for permanent installation.

Drying Equipment and Tests

In 1979, preliminary tests were conducted to verify system performance before proceeding with software development and prototype tests. The system was interfaced to a small drying unit and programmed to execute conventional peanut dryer control procedures. The drying unit had a 0.74 kW fan and a 17-29 kW LPG burner. The unit was programmed to turn the burner off if the plenum temperature or plenum wet bulb (WB) depression exceeded upper limits. The fan was operated continuously or on a fixed number of minutes each hour for the duration of each drying test. The safety features of all fan and burner units were left intact and operational.

For the 1980 tests, two single trailer fan and burner units were used. The fans were 61 cm in diameter, the electric motors were rated at 3.7 to 5.2 kW, and air delivery was about 222 m^3/min. The LPG burners were operated with a maximum temperature rise of 8.3 C or about 35 kW. The microprocessor controlled both units, one was programmed to operate under conventional drying procedures and the second was programmed to reduce energy usage.

Additional comparative tests were conducted in 1981 to verify the energy control technique developed and tested in 1980. The air delivery was increased to about 285 m^3/min.

Control Techniques

The conventional and energy control techniques (ECT) implemented by the software are summarized in Tables 1 and 2, respectively. Conventional procedures included a low temperature limit to turn the fan off during periods of low ambient temperature. This procedure, which is not generally provided by manufacturers, was included to prevent losses in seed quality. The energy control technique was identical to conventional control plus time and ambient drying potential functions. The time function decreased fan operation and increased plenum wet bulb depression in proportion to time on the dryer. The ambient drying potential function minimized fan operation during periods of low ambient drying potential. The second break point in the ambient drying potential function was implemented after reviewing the results of ECT1 and was the primary difference between ECT1 and ECT2 as explained in the results section.

Table 1. Conventional control procedures.

```
FAN:

  Off - Amb temp < lower limit(LL)

BURNER:

  Off - Fan off
  Off - Plenum temp => upper limit(UL)
  Off - Plenum WB dep'n => set point(SP)
```

Table 2. Control procedures for energy conservation.

```
FAN:
  Off - Amb temp < lower limit(LL)
  Off - Min of h < fan off min/h

BURNER:
  Off - Fan off
  Off - Plenum temp => upper limit(UL)
  Off - Plenum WB dep'n => set point(SP)

TIME FUNCTION:
  Fan off min increased 1 min/2 h (45 min max)
  Plenum WB dep'n increased 1.1 C/day (6.7 C max)

AMBIENT DRYING POTENTIAL FUNCTION:
  X = Amb WB dep'n (°C)
  Fan off min = 48,            X < 2.2
              = variable, 2.2 <= X < 3.9
              = 0,        3.9 <= X (ECT2 only)
```

The microprocessor and software activity schedule to implement the control routines is outlined in Table 3. Every six seconds, the real time clock generated an interrupt which initiated the activities shown. These activities required approximately two seconds of microprocessor time leaving four seconds for the microprocessor to run in a continuous loop which tested for the other activities listed. If any of the loop activities required more than four seconds, the activities were halted by the next interrupt and resumed after completion of the six-second activities. Interruptions may occur several times before completion of the loop activities. The one-hour activity was programmed to occur at 58 minutes of the hour, the two-hour activity on even hours and the daily activity at 12 noon.

Ambient and control thermocouples were placed in each trailer as shown in Fig. 2. Set points, elapsed time clocks, control and performance data were periodically printed and punched on paper tape at 10 or 30 minute intervals.

Results

No hardware problems were observed in the prelimi-

Table 3. Microprocessor activity schedule.

Interval	Activity
INTERRUPT: 6 sec	Update real time clock Acquire control data Set output control bits Update fan and burner clocks
LOOP: 10 min	Update amplifier offset values Scan, print and punch data
1 h	Set fan off min for next h
2 h	Increase variable fan off min
1 day	Increase plenum WB dep'n limit

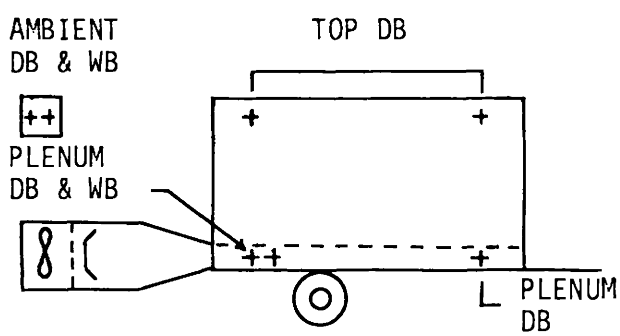

Fig. 2. Dry bulb (DB) and wet bulb (WB) thermocouple locations for peanut dryer control and performance data.

nary tests conducted in 1979, but additional software needs were identified. In successive runs, fan and burner energy per unit of peanuts dried was reduced 20 percent by fan cycling when compared to continuous fan operation. However, time on the dryer increased by 44 percent which identified an undesirable compromise on the energy saving techniques used.

Only 2 of the 4 tests completed in 1980 were appropriate for direct comparison of the energy control techniques (ECT) with conventional control procedures because of drought and an inadequate supply of peanuts. The initial and final m.c.'s and mass for these tests were approximately equal (Table 4). Plenum, ambient, upper limit and lower limit temperatures for the first energy control technique are shown in Fig. 3 along with cumulative fan and burner operation time. Ambient, plenum, and set point wet bulb depressions are shown in Fig. 4. Similar results are shown for the conventionally controlled unit in Fig. 5.

Table 4. Initial and final m.c.'s and mass for 1980 tests.

		Initial		Final	
Test	Control	Moisture Content %	Peanut Mass Mg	Moisture Content %	Peanut Mass Mg
1	ECT1	30	4.04	8	3.07
	CONV	29	3.87	7	2.98
2	ECT2	30	3.40	11	2.68
	CONV	31	3.65	10	2.79

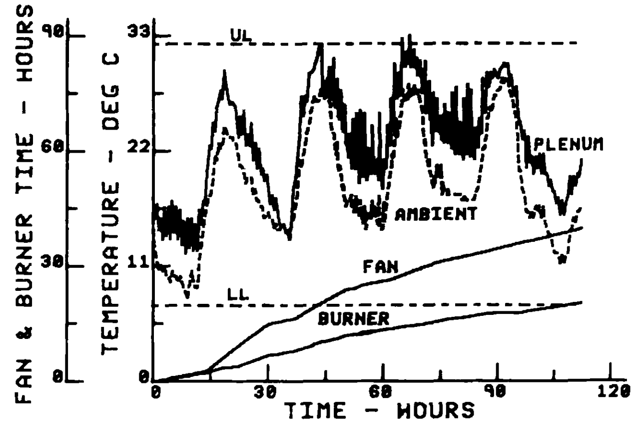

Fig. 3. Plenum and ambient temperature, upper and lower limits and fan and burner operating time vs time on the dryer for ECT1, 1980.

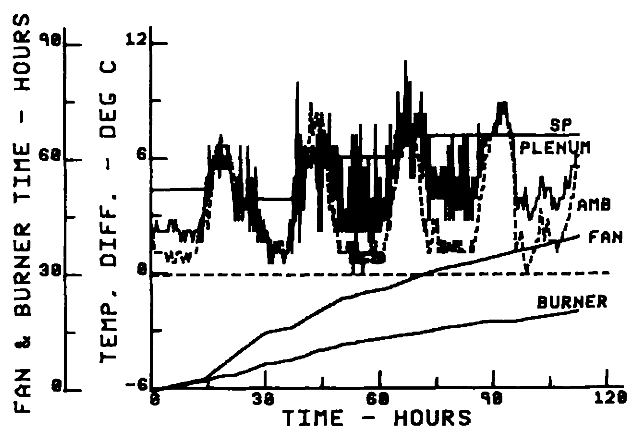

Fig. 4. Plenum and ambient wet bulb depressions, set point depression and fan and burner operating time vs time on the dryer for ECT1, 1980.

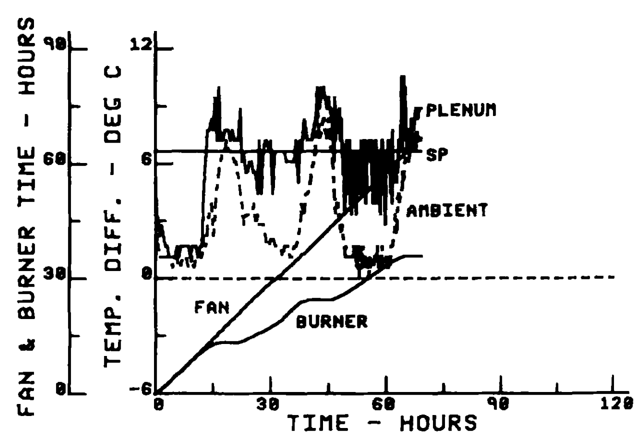

Fig. 5. Plenum and ambient wet bulb depressions, set point depression and fan and burner operating time vs time on the dryer for CONV1, 1980.

These figures illustrate the performance of the control systems implemented. For example, in Fig. 3, the slope of the cumulative fan operating time curve indicated a significant reduction in the percent of fan operating time near the end of the test. Whenever the ambient wet bulb depression was below the 2.2 C level (Fig. 4), the fan and burner operated at the minimal 20 percent on time level. Rapid fluctuations in the plenum wet bulb depression were the result of minimal fan operation during these periods while recording data on a fixed time schedule. Some manual changes in the plenum wet bulb depression set point were made in addition to the programmed increments at noon each day. This set point was at its maximum allowable value at the end of the test. For the conventionally controlled unit (Fig. 5), the slope of the cumulative fan curve corresponds to continuous fan operation. A burner safety feature malfunctioned and prevented burner operation in the early hours of this test. The software does not verify fan or burner operation, therefore the cumulative time curves were not always accurate. Purge cycle time for the burner also was included in the results shown.

The first energy control technique, which did not include the second break point in the ambient drying potential function, required a 65 percent increase in drying time over the conventional. To minimize this difference, the energy control technique was altered to include a second breakpoint for fan operation. In this technique, the fan operated continuously whenever the ambient wet bulb depression was greater than 3.9 C. The results of this addition are shown by the 45 slope segments of the cumulative fan operating curve in Fig. 6. A complete shut down of the unit when ambient temperature was less than the lower limit of 7.2 C is illustrated during the early hours of the test.

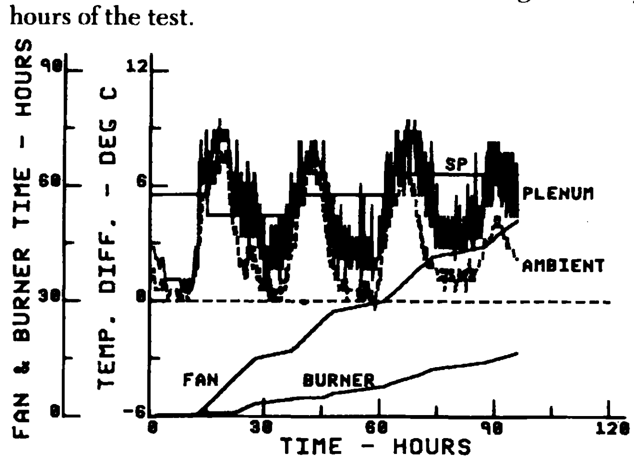

Fig. 6. Plenum and ambient wet bulb depressions, set point depression and fan and burner operating time vs time on the dryer for ECT2, 1980.

Time on the dryer, fan and burner operating time and LPG consumption are summarized in Table 5 for the comparative tests conducted in 1980. The times were from the recorded data and the LPG measurements were from the supply truck meter. ECT1 required a 65 percent increase in drying time over the conventional whereas ECT2 required a 10 percent increase. Fan operating time was reduced by 39 and 33 percent respectively for the two techniques implying similar fan energy reductions. Based on the LPG meter measurements, gas consumption was reduced by 49 percent by both techniques. Based on burner operating times, the gas consumption was reduced 44 and 37 percent respectively by the two techniques when compared to conventional procedures.

The recorded data were used to compute energy estimates based on airflow and temperature differences. Air entering each unit was throttled to about 21 $m^3/min \cdot m^2$ of trailer floor area. An airflow of 222 m^3/min was assumed

Table 5. Operating times and LPG consumption for 1980 tests.

Control	Time on Dryer h	Fan Oper. Time h	Burner Oper. Time h	LPG L
ECT1	112	40	20	98
CONV	68	66	36	193
ECT2	96	51	17	95
CONV	84	76	27	185

for the energy estimates (Table 6). Ambient air drying input was based on ambient air wet bulb depression and summed only during periods of fan operation. ECT1 captured 43 percent of the ambient energy available for drying while the fan operated only 36 percent of the time. ECT2 was significantly better capturing 80 percent while the fan operated 53 percent of the time. This was a 7 percent improvement in ambient energy capture per hour of fan operation and indicated a significant improvement for the second technique.

Table 6. Energy estimates from temperature difference summations during periods of fan operation for the 1980 tests.

Control	Amb. Air[a] Drying Input GJ (%)	Fan & [b] Burner Input GJ	Plenum Air[c] Drying Potential GJ	Used To[d] Remove Water GJ (%)
ECT1	2.41 (43)	3.25	4.47	2.50 (55)
CONV	3.28 (98)	6.16	6.32	2.34 (37)
ECT2	3.29 (80)	3.58	5.01	1.87 (37)
CONV	3.47 (98)	6.87	7.15	2.36 (33)

a/ Based on ambient wet bulb depression temperature.
b/ Based on plenum minus ambient air temperatures.
c/ Based on plenum wet bulb depression temperature.
d/ Based on plenum minus exhaust air temperatures.

Similar estimates were computed for fan and burner input, plenum air drying potential and the energy used to remove water (Table 6). Based on 25.1 MJ/L of LP gas, the fan energy averaged 22 and 33 percent of the total fan and burner input in tests 1 and 2 respectively. Both energy control techniques resulted in greater thermal efficiencies when compared to conventional procedures. The energy used to remove water averaged 2633 kJ/kg of water. The energy control techniques required approximately one-half as much energy per unit of peanuts dried when compared to conventional procedures. The fan and burner energy utilization comparisons were 1058/2070 and 1335/2460 kJ per kg of peanuts dried for each test respectively.

The 1981 results for ECT2 were similar to those of 1980. When compared to conventional procedures, the average reduction in LPG and fan energy was 47 and 22 percent respectively. The average increase in drying time was 21 percent.

Discussion

The most difficult task encountered was software development. The preparation of assembly language routines, conversion to loadable microprocessor code and debugging were very time demanding. Without some provision for computer assembly and memory address record keeping, this task would have been insurmountable. The software presently in use required 8k of 8-bit memory. Approximately 2k was occupied by the monitor, 1k for data acquisition communication, 1k for the dryer control routines and the balance included the real time clock software, data print format, variable storage locations, etc. The software consisted of 580 labels or branch points and 3400 lines of assembly language code.

Both control techniques achieved a significant reduction in electric and LPG energy over conventional control procedures. The second technique decreased the drying time significantly when compared to the first technique. The energy values, utilization and efficiencies estimated from recorded temperature differences supported the energy reduction estimates based on fan operating time and LPG consumption.

From a typical cost analysis (8), conventional drying costs per tonne of peanuts initially at 35 percent m.c. were $13.45 for LPG, $2.87 for electric energy and $6.39 for depreciation. Based on the 1980 ECT2 results, these costs translate to $6.86 for LPG, $1.92 for electric energy and $7.03 for depreciation. The net drying cost reduction was then $6.90 per tonne or 30 percent. These estimates were based on $0.185 per liter of LPG, $0.07 per kW h of electric energy and a four-trailer, 12.7 tonne drying system ($13,000 investment) used 35 days per year for 10 years. The drying cost reduction was dependent on the conditions assumed and the estimated control system pay back rate was $6.90 per tonne of peanuts dried.

Several improvements were made in the software for the 1981 season. The routines were modified to permit conventional or energy optimized control of either drying unit and continuous monitoring of the LPG consumption. Additional routines were added for easy entry of control set points. The 1981 results confirmed the energy savings potential of ECT2. The LP gas and fan energy reductions were significant but required a greater increase in drying time when compared to 1980 results. This increase was attributed to a difference in ambient drying potential which averaged 15 percent less in 1981 when compared to 1980. The 1981 results translate to an average drying cost reduction of $5.61 per tonne or 25 percent.

The microprocessor based control system was more elaborate than necessary to satisfy versatility and research needs. Performance data monitoring, full keyboard console and paper tape output are not required for dedicated peanut dryer control. Minimal hardware costs for dedicated peanut dryer control are estimated at less than $1500 per fan and burner unit.

Conclusions

Careful hardware selection and extensive software development were required for effective microprocessor control of the peanut drying process. Both control techniques, which included time and ambient control functions, reduced the LPG and electric energy required when compared to conventional procedures. The second control technique required a minimal increase in drying time (10 percent) while attaining a 49 percent reduction in LPG and a 33 percent reduction in electric energy. These results translated to a net savings of $6.90 per tonne in peanut drying costs for Virginia conditions. Second year results confirmed the energy savings potential and translated to a net savings of $5.61 per tonne or a 25 percent reduction in drying costs. The net savings was dependent on the relative cost of energy to fixed costs, initial m.c.'s, and ambient conditions.

The savings resulting from a 90 tonne per year dryer operated for five years is estimated at $2500. Minimal hardware costs for dedicated microprocessor control is estimated at $1500 for a peanut dryer of this capacity. With present electronic technology and continued relative energy costs, dedicated microprocessor control systems for peanut drying are within the limits of practicality. Greater savings may be possible with implementation of other strategies and refinement of control set points.

Acknowledgements

The use of two fan and burner units and four peanut trailers provided by Peerless Manufacturing Company, Shellman, Ga. was greatly appreciated. The production and harvest of significant quantities of peanuts by A. R. Butler, Carrsville, Va., were essential to the conduct of this project. Technical assistance from the Seed Laboratory, Virginia Department of Agriculture and Consumer Services, Richmond, Va., and other staff, Tidewater Research and Continuing Education Center, Suffolk, Va. was invaluable and is hereby acknowledged.

Literature Cited

1. Beasley, E. O. and J. W. Dickens. 1963. Engineering research in peanut curing. N. C. Agricultural Experiment Station Technical Bulletin Number 155.
2. Blankenship, P. D. and J. I. Davidson, Jr. 1980. A method for automatic cutoff of laboratory peanut dryers. Transactions of ASAE. 23(6) 1530-1531, 1537.
3. Cox, S. W. R. 1980. Microprocessor - an aid in livestock production systems. ASAE Paper No. 80-3501, presented at the Annual Winter Meeting of the ASAE, Chicago, IL.
4. Hunter, J. H. and R. J. Rowe. 1980. Microprocessor managed monitoring and control for potato storages. ASAE Paper No. 80-4523, presented at the Annual Winter Meeting of the ASAE, Chicago, IL.
5. Lambert, A. J. 1969. Curing Virginia peanuts. Extension Division, Virginia Polytechnic Institute and State University, Publication Number 269.
6. Lillevik, S. L. and B. P. Christie. 1979. Microcomputer - controlled furrow irrigaiton. Proceedings of the International Micro and Mini Computer Conference, Houston, TX, p 43-45.
7. McClure, W. F. 1981. The textbook dilemma in computer technology. Agricultural Engineering, 62(11):13-14.
8. Steele, J. L. 1981. Optimum peanut harvest moisture. Virginia-Carolina Peanut News, 27(4):7,16.
9. Troeger, J. M. and J. L. Butler. 1978. Airflow interruption during peanut drying. Proc. Amer. Peanut Res. and Educ. Assoc. 10:38-44.
10. Wilcke, W. F., G. A. Kranzler, C. J. Bern, and M. E. Anderson. 1979. Digital electronic control system for a low-temperature corn dryer. ASAE Paper No. 79-3028, presented at the Annual Summer Meeting of the ASAE, Winnipeg, Canada.
11. Willits, D. H., T. K. Karnoski and W. F. McClure. 1980. A microprocessor-based control system for greenhouse research. Transactions of ASAE, 23(3):688-698.

Accepted September 3, 1982