AN EVALUATION OF A PROTOTYPE APPLE HYDROHANDLING SYSTEM

Thesis for the Degree of M. S.

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PAUL FREDERICK BERGDOLT

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THESIS

AN EVALUATION OF A PROTOTYPE APPLE HYDROHANDLING SYSTEM

by

Paul Frederick Bergdolt

AN ABSTRACT OF A THESIS

Submitted to the Colleges of Agriculture and Engineering of
Michigan State University
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IN

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ABSTRACT

AN EVALUATION OF A PROTOTYPE APPLE HYDROHANDLING SYSTEM

by Paul Frederick Bergdolt

A prototype hydrohandling system for sorting and sizing apples before storage was developed previously and was used during the apple harvesting season in 1966. The system was carefully studied and evaluated, and records of performance were maintained.

The objectives of this study were to evaluate the economic return of the system during operations in 1966, to analyze a hypothetical system by use of a computer, and to study proposed improvements in the accumulation of the apples after sizing and sorting has been completed.

The ownership and operating costs of the system were calculated and compared to the economic return possible by use of the system. Two factors that can provide a profit with the removal of cull and utility fruits are: (1) a savings in CA storage costs, and (2) a potential gain from utilization of the additional storage space for storage of good quality fruit. The analysis showed a very slight profit. An increased volume of fruit through the system could increase the profit which can be obtained.

A computer program was written to provide an economic analysis of a hypothetical system. Six variables were allowed to assume a range of values, and a total of 1296 combinations of these variables were computed. These variables were: (1) cost of the

system, (2) efficiency of operation, (3) total volume using the system, (4) rate of operation, (5) gradeout percentages of the fruit, and (6) variety mix of the fruit. The costs were calculated as was gross return and net return. The effects of the variables on net return were studied. The results indicated that total volume and gradeout percentages were the most important factors.

In the operation of the prototype system, it was observed that a problem existed in determining accumulator fill. Bulk boxes removed from the machine were often overfilled or underfilled. A study of a measuring device was conducted using three accumulators. In each case, it was attempted to relate volume of the apples to the buoyant force produced by the fruit. Two accumulators used a pressure sensing device, one contained an inner tube within the accumulator, the other used an air pillow placed above the accumulator. A manometer was used to measure pressure changes. The third accumulator was designed with a spring scale as a means of measuring the buoyant force. The accumulators were tested with three apple varieties. The results showed good correlation of manometer and scale deflections with the sample volumes for all three accumulators. Linear relationships existed in each case.

Approved: B A Stout
Major Professor

Approved: Carl W. Hall
Department Chairman

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INTRODUCTION

Mechanization of the fruit and vegetables industries has been an important topic of research within the past decade. As "stoop labor" becomes more difficult to obtain, emphasis has been placed on reducing hand operations in picking, packing, and moving produce. Research is being conducted in production techniques, harvesting, handling, storage, packaging, and marketing.

Apple production in Michigan in 1965, totaled 16 million bushels with a value of 24.6 million dollars (Michigan Agricultural Statistics, 1966). The value and importance of this crop has prompted further research in the apple production industry. The principle of hydrohandling of fruit was employed by Pflug and Dewey (1960) with a hydrodumper, which utilizes water as a means of floating fruit from bulk boxes. This method successfully minimized fruit bruising and suggested the possibility of a complete sizing and sorting operation with water as the handling medium.

Further studies were conducted by Matthews (1963) and Dewey, et al. (1966), in which various components of a hydrohandling system were evaluated, and a proposed design of a complete system was given. The final design and construction of the equipment was completed and the system was installed at a storage and packing warehouse (Stout, et al., 1966).

Preliminary tests were conducted with the equipment with satisfactory results. The system was then utilized during the 1966 harvest season for approximately 35,000 bushels of fruit. Evaluations and further studies were made during this operation. The effect of the system on fruit quality was also studied.

The objectives of this study were: (1) to determine the economic value of the system for the tests conducted during fall, 1966, (2) to evaluate a hypothetical system by a computer analysis, and (3) to study measurement principles for more accurately determing the accumulator fill.

LITERATURE REVIEW

An economic study for a presizing and presorting system was conducted by Nichols (1965). This analysis presents the effects of operating cost, pregrading efficiency, storage size, and variety mix on net gain and also discusses the general effects of gradeout percentage and price differentials. Under the conditions assumed, the study shows that a system can increase profits.

The importance of large volumes in apple packing operations is shown by Carman (1964). Substantial cost reductions per package are possible as the volume of fruit packed in a plant is increased.

Stout and Kline (1966) presented an economic feasibility study of several vegetable harvesting machines utilizing a computer analysis. Several machine and crop variables were studied. Minimum and maximum values for potential net income were obtained with the varying conditions stated.

Cooper (1962) utilized a spring scale and an inverted wire basket to measure buoyant force of a sample of apples. Using the values obtained for buoyant force and the weights of the samples in air, he determined specific gravity of the fruit.

Matthews (1963) investigated several bulk box filling devices while studying components of a proposed hydrohandling system. The accumulator method proved most successful, but no studies were conducted in a method to measure the amount of fill.

ECONOMIC ANALYSIS OF THE PROTOTYPE APPLE HYDROHANDLING SYSTEM

A presizing and presorting operation for controlled atmosphere (CA) storage has been shown to be economically profitable (Nichols, 1965) under certain crop and storage conditions. However, in this study, many assumptions leading to the variables were presented. A prototype apple hydrohandling system has been built and installed (Stout, et al., 1966) adjacent to an apple storage and packing warehouse (Figure 1). The system was studied during commercial operations for the 1966 season. A total of 35,554 bushels of apples were run through the machine over a period of seven weeks. The following analysis is based on the data and information collected during this study. The limitations of an experimental machine and a single season's operation must be realized when interpreting the results.

Factors Considered in the Analysis

Expenses for the system can be separated into two categories, ownership costs and operating costs. Ownership costs can be subdivided into depreciation, interest on the investment, insurance, property taxes, and shelter (Bainer, 1955). Operating costs include labor requirements, utilities, maintenance, repair, and additional equipment.

Profit from utilization of the system can also be separated into two categories. The elimination of cull and utility fruit prior to storage will reduce storage costs, since these fruit do not increase their sale value sufficiently during the CA storage season

Figure 1. The prototype apple hydrohandling system. The platforms along the sides were built for a demonstration of the system.

to pay for their storage cost. With the removal of cull and utility apples, storage space becomes available for U.S. No. 1 and better grades, which will increase their sale value and provide a higher profit following a CA storage period. This can be regarded as a potential storage gain and is so designated in the analysis

Assumptions

In the calculation of ownership costs it is necessary to assume a service life for the system and also a salvage value. Study of farm machinery shows a common method for evaluating depreciation as a straight-line relationship with the service life at ten years and the salvage value as ten percent of the initial cost of the machine (Bainer, 1955). These values will be utilized in the analysis. Interest on the investment will be calculated at the current rate, which is taken as six percent. Insurance and taxes can also be rated on an annual basis and shall be taken as one percent of the initial cost (Bainer, 1955).

Utility costs (electrical power and water) are based on current rates for utilities, \$0.02 per kwh for electricity and \$0.20 per 100 cubic feet for water. The system is rated for 65 amps at 220 volts at full power, which is a requirement of 14.3 kw per hour. The system has a water capacity of 20,200 gallons or 2700 cubic feet, and the water should be changed after approximately 20,000 bushels of apples.

Some studies were conducted by Nichols (1965) on the market value of apples between the fall harvest season and following CA storage. The findings were averaged over the three year period, 1961-1963, for the three varieties of McIntosh, Jonathan, and Red Delicious. These results are presented in Table 1 and will be utilized in calculating storage cost savings and potential storage gain.

A CA storage cost of $0.55 per bushel is used. An estimated minimum cost of $0.50 per bushel is given by Dalrymple (1956) while storage charges for CA were estimated at $0.65 per bushel.

Table 1. Price differential between sale at harvest and upon removal from CA storage for three varieties of apples. (1961-1963 season average by Nichols)

Variety	Grade	Price increase, $/bu.
McIntosh	U.S. No. 1 and better	1.34
	Utility	0.17
Jonathan	U.S. No. 1 and better	1.38
	Utility	0.38
Red Delicious	U.S. No. 1 and better	0.95
	Utility	0.27
All varieties	Cull	0.12

Cost Analysis

A. Ownership costs

1. Depreciation - the total cost of the system will be used and this includes the price of the machine, facilities necessary to accommodate it, installation of utilities, installation of the machine, and incidental expenses incurred.

    a. approximate machine price $ 30,000.00*

*This figure is not to be considered as a retail price for a commercially available machine.

b. concrete slab			3,535.00
c. utility installation			
(1) electricity			1,213.58
(2) water			165.46
d. installation of machine			1,902.00*
e. incidental expenses			563.76**
Total		$	37,379.80
Annual depreciation cost =			
(37,379.80 - 3,737.98)/10	=	$	3,364.18
2. Interest on investment			
$0.06\left(\frac{37379.80 + 3737.98}{2}\right)$	=		1,233.53
3. Insurance 0.0025 (37379.80)	=		93.45
4. Property taxes 0.0075 (37379.80)	=		280.35
5. Shelter (covering sorting rolls)			
814.75/10	=		81.48
Total ownership cost		$	5,052.99

B. Operating costs

1. Labor (record of Belding Fruit Storage Co.)	$	3,034.75
2. Utilities		
a. electricity (118.25 hours of machine operation)		33.82
b. water (1 change, 5400 $ft.^3$ used)		10.80

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*680 hours labor at $2.50/hr, $55.00 for back hoe to dig pits and drain trench, $147.00 for hand labor on pits and drain trench.

**$156.13 for filling and grading lot, $179.28 for gravel, $228.35 for additional lumber and steel.

3.	Maintenance and repair	90.00
4.	Additional equipment (3 lift trucks for 3 weeks at $60.00 per week per truck)	540.00
	Total operating cost	$ 3,709.37

C. Savings in storage cost - Table 2 is a summary of utility and cull fruit removed with the hydrohandling system during operations in fall, 1966.

Table 2. Apples removed by use of hydrohandling system. (Values are from data recorded by Belding Fruit Storage Co.)

Variety	Grade	Bushels Removed
McIntosh	Utility	2516
	Cull	1388
Jonathan	Utility	551
	Cull	2511
Red Delicious	Utility	1060
	Cull	1196

The storage cost savings is calculated as the product of the number of bushels removed and the net loss per bushel resulting if poorer quality fruit is stored.

Saving =	2516 (0.55 - 0.17)	=	956.08
	1388 (0.55 - 0.12)	=	596.84
	1060 (0.55 - 0.27)	=	296.80
	1196 (0.55 - 0.12)	=	514.28
	551 (0.55 - 0.38)	=	93.67
	2511 (0.55 - 0.12)	=	1079.73
	Total	=	$3537.40

D. Potential storage gain - the potential storage gain is calculated as the product of the number of bushels removed and the net gain per bushel resulting from CA storage of U.S. No. 1 or better quality fruit.

Gain =	(2516 + 1388) (1.34 - 0.55)	=	3084.16
	(1060 + 1196) (0.95 - 0.55)	=	902.40
	(551 + 2511) (1.38 - 0.55)	=	2541.46
	Total	=	$6528.02

<u>Results</u>

Summing the costs for ownership and operation we have:

	$ 5052.99
	3709.37
Total =	$ 8762.36

The gross return which could be realized with the use of the hydro-handling system is the sum of storage cost savings and potential storage gain which is:

	\$ 3537.40
	6528.02
Total =	\$10065.42

The net profit is the difference of gross return and total cost which equals \$ 1303.06.

Conclusions

The net profit which can be attained in this analysis is almost negligible when compared to the investment necessary. However, a good indication of an existing problem is the comparison of the ownership and operating costs. This shows the ownership cost at 1.6 times as great as the operating cost. An increased volume of apples through the system would not affect the ownership cost, but it would provide considerably greater savings in storage cost and additional storage space for higher quality fruit.

Other factors which may lead to higher costs are unexpected breakdowns due to inexperienced labor operating the machine, and necessary design changes.

This analysis is not intended to justify the use of the present hydrohandling techniques since no studies of fruit quality and condition have been presented. From studies conducted by the Department of Horticulture, Michigan State University, it has been found that there may be an increase in fruit bruising and skin breaks (stem punctures) due to presizing and presorting with the hydrohandling system. Continued tests are being conducted to substantiate the results being obtained.

COMPUTER ANALYSIS OF A HYDROHANDLING SYSTEM

A hypothetical study of a system can provide valuable information in many cases. With the aid of computers, the task of carrying out many repetitions of tedious calculations becomes unnecessary, since a simple program can give such results in a very short time. The objective of this analysis is to combine variable crop and machine conditions, perform calculations to determine costs and profits and obtain a net profit or return. From the computer results, one can then see what minimum conditions are required for a minimum profit acceptable for the owner of the system.

Variables

Six variables are considered, three relate to the crop conditions and three relate to machine and operating conditions.

Crop variables are:

1. Total volume of apples utilizing the equipment.
2. Gradeout percentages of U.S. No. 1,* utility, and cull grades.
3. Variety mix of apples received at the storage plant.

The total volume of apples utilizing the system depends on the volume of the apple crop for the season and also is affected by gradeout percentages. The gradeout percentages are the percent of U.S. No. 1, utility, and cull apples in a given lot and are an indication of the quality

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*This denotes apples of U.S. No. 1 or better grades.

of the fruit. With high quality fruit in the orchards, it may not be profitable to presize and presort the fruit. The total volume through the system may be decreased. The variety mix is the breakdown by percentage of the varieties which are being received at the storage plant.

Machine variables are:

1. The cost of the hydrohandling system.
2. The operating rate of the machine.
3. The efficiency of the presizing and presorting operation.

Since we are dealing with a system which is not commercially available, an estimate must be made for the initial cost. The operating rate of the machine is expressed in bushels per hour, the maximum value is the rated capacity of the system. The efficiency of the operation can be expressed as the quotient of the number of cull and utility apples removed by presizing and presorting and the actual number of cull and utility apples present in the lot.

Values assigned to the variables are presented in Table 3.

Table 3. Values assigned to crop and machine variables in a computer analysis of a hydrohandling system.

Variable designation	Description	Assigned values
TOBU	Total volume of apples utilizing the system, bu.	30000, 70000, 110000
GOP1, GOPU, GOPC	Gradeout percentages for U.S. No. 1, utility, and cull grades	70-20-10 75-20-5 80-15-5
VMR, VMJ, VMM	Variety mix of apples received at the storage plant (Red Delicious, Jonathan, McIntosh)	25-30-45 0-50-50 50- 0-50 50-50-0

COSY	Cost of hydrohandling system, $	50000, 60000, 70000
RATE	Operating rate of machine, bu./hr.	300, 450, 600
EFF	Efficiency of the operation, %	65, 75, 85, 95

Assumptions

The assumptions for the computer analysis closely follow those of the previous section. The depreciation is taken as initial cost minus salvage value divided by service life, where salvage value is ten percent of the initial cost and service life is ten years. Interest is taken as 6%. Annual costs for insurance and taxes are 0.25% and 0.75% of the initial cost, respectively. An annual charge for maintenance, repairs, and lubrication is assumed as 4% of the initial cost (Bainer, 1955). The annual cost for additional equipment is calculated on the basis of a four week operating period with three additional lift trucks required for the hydrohandling system. A current weekly rental rate for a lift truck is used.

Utility charges are again based on local rates, $0.02 per kwh for electricity and $0.20 per 100 cubic feet for water. Labor charges are made in accordance with the expense incurred during actual operating conditions at Belding Fruit Storage Company. The average wage for labor was $1.62 per hour and an average work force was 14 workers. An additional charge for supervisory labor was $3.50 per hour.

Calculations for savings in storage costs and potential storage gains utilized the price differential values given in Table 1, and an assumed storage cost for CA storage of $0.55 per bushel.

A final assumption used in the analysis is that only the three varieties of Red Delicious, Jonathan, and McIntosh are being considered in the variety mix of the storage warehouse. These varieties are the most popular existing in Michigan (Michigan Agricultural Statistics, 1966).

Method of Analysis

The computer variable names, descriptions, and units which were used in the program are presented in Table 4.

Table 4. Designations, descriptions, and units for variables in a computer analysis of a hydrohandling system

Variable Designation	Description	Units
GEG	Gross economic return	$
OPCS	Operating cost of the system	$
OWCS	Ownership cost of the system	$
ANR	Annual net return	$
SCO	Storage cost	$/bu.
EFF	Efficiency of the operation	%
COSY	Cost of hydrohandling system	$
SLIF	Service life of the system	yrs.
DEP	Annual depreciation value of the system	$
AIN	Annual interest	$
AIS	Annual insurance	$
ATAX	Annual tax	$
AWAT	Annual water cost	$

AAE	Annual cost for additional equipment	$
AMRL	Annual cost for maintenance, repair and lubrication	$
HLAB	Hourly labor cost	$/hr.
HELP	Hourly electrical power cost	$/hr.
RATE	Operating rate of machine	bu./hr.
TOBU	Total volume of apples utilizing the system	bu.
TIME	Operating time of the system	hr.
SSCO	Savings in storage cost by removal of cull and utility fruits	$
PSG1	Potential storage gain of U.S. No. 1 apples stored in place of cull and utility	$
PDR1	Price differential, Red Delicious, U.S. No. 1	$/bu.
PDRU	Price differential, Red Delicious, utility	$/bu.
PDJ1	Price differential, Jonathan, U.S. No. 1	$/bu.
PDJU	Price differential, Jonathan, utility	$/bu.
PDM1	Price differential, McIntosh, U.S. No. 1	$/bu.
PDMU	Price differential, McIntosh, utility	$/bu.
PDC	Price differential, all varieties, cull	$/bu.
VMR	Variety mix, Red Delicious	%
VMJ	Variety mix, Jonathan	%
VMM	Variety mix, McIntosh	%
GOP1	Gradeout percentage, U.S. No. 1, all varieties	%
GOPU	Gradeout percentage, utility, all varieties	%
GOPC	Gradeout percentage, cull, all varieties	%

To obtain the annual net return, we subtract operating and ownership costs from gross economic return. These variables are calculated with the following expressions:

$$\text{SALV} = 0.10\,(\text{COSY})$$

$$\text{DEP} = (\text{COSY-SALV})/\text{SLIF}$$

$$\text{AIN} = 0.06\left(\frac{\text{COSY + SALV}}{2}\right)$$

$$\text{AIS} = 0.0025\,(\text{COSY})$$

$$\text{ATAX} = 0.0075\,(\text{COSY})$$

$$\underline{\text{OWCS}} = \text{DEP + AIN + AIS + ATAX}$$

$$\text{AMRL} = 0.04\,(\text{COSY})$$

$$\text{AWAT} = (\text{TOBU}/20000)(5.40)$$

$$\text{TIME} = (\text{TOBU/RATE})$$

$$\underline{\text{OPCS}} = \text{TIME (HELP + HLAB) + AMRL + AWAT + AAE}$$

$$\begin{aligned}\text{SSCO} = {} & \text{TOBU (EFF)[GOPU(VMR)(SCO-PDRU) + GOPU(VMJ)} \\ & \text{(SCO-PDJU) + GOPU(VMM)(SCO-PDMU) + GOPC(SCO-PDC)]}\end{aligned}$$

$$\begin{aligned}\text{PSG1} = {} & \text{TOBU(GOPU+GOPC)[VMR(PDR1 -SCO) + VMJ(PDJ1 -SCO)} \\ & \text{+ VMM(PDM1 -SCO)]}\end{aligned}$$

$$\underline{\text{GEG}} = \text{SSCO + PSG1}$$

$$\underline{\text{ANR}} = \text{GEG - OWCS - OPCS}$$

The analysis generates a total of 1296 combinations of variables, each giving a different set of conditions and providing a unique result. Values printed in the computer output are ANR, GEG, OPCS, OWCS, COSY, EFF, TOBU, RATE, GOP1, GOPU, GOPC, VMR, VMJ, and VMM. A sample of the printout is shown in Figure 2. The computer program is listed in Appendix I.

-5197.50	9495.00	5292.50	9310.00	70000	0.75	30000	450	0.70	0.20	0.10	0.00	0.50	0.50
5189.17	22155.00	7655.83	9310.00	70000	0.75	70000	450	0.70	0.20	0.10	0.00	0.50	0.50
15485.83	34815.00	10019.17	9310.00	70000	0.75	110000	450	0.70	0.20	0.10	0.00	0.50	0.50
-4646.40	9495.00	4651.40	9310.00	70000	0.75	30000	600	0.70	0.20	0.10	0.00	0.50	0.50
6218.40	22155.00	6626.60	9310.00	70000	0.75	70000	600	0.70	0.20	0.10	0.00	0.50	0.50
17103.20	34815.00	7601.80	9310.00	70000	0.75	110000	600	0.70	0.20	0.10	0.00	0.50	0.50
ANR	CEF	OOCS	U/CS	COST	EFF	TORU	RATE	GOP1	GOPU	GOPC	VMR	VMJ	VMM
-2235.70	9789.00	5174.70	4650.00	50000	0.85	30000	300	0.70	0.20	0.10	0.00	0.50	0.50
7276.70	22841.00	8914.80	4650.00	50000	0.85	70000	300	0.70	0.20	0.10	0.00	0.50	0.50
16789.10	35803.00	12653.90	4650.00	50000	0.85	110000	300	0.70	0.20	0.10	0.00	0.50	0.50
-1353.50	9789.00	4402.50	4650.00	50000	0.85	30000	450	0.70	0.20	0.10	0.00	0.50	0.50
9335.17	22841.00	6655.84	4650.00	50000	0.85	70000	450	0.70	0.20	0.10	0.00	0.50	0.50
20023.83	35803.00	7219.17	4650.00	50000	0.85	110000	450	0.70	0.20	0.10	0.00	0.50	0.50
-912.40	9789.00	4151.40	4650.00	50000	0.85	30000	600	0.70	0.20	0.10	0.00	0.50	0.50
10344.40	22841.00	5626.60	4650.00	50000	0.85	70000	600	0.70	0.20	0.10	0.00	0.50	0.50
21641.20	35803.00	7601.80	4650.00	50000	0.85	110000	600	0.70	0.20	0.10	0.00	0.50	0.50
-3944.70	9789.00	5774.70	7980.00	60000	0.85	30000	300	0.70	0.20	0.10	0.00	0.50	0.50
5546.70	22841.00	2314.30	7980.00	60000	0.85	70000	300	0.70	0.20	0.10	0.00	0.50	0.50
15059.10	35803.00	10053.90	7980.00	60000	0.85	110000	300	0.70	0.20	0.10	0.00	0.50	0.50
-3083.50	9789.00	4802.50	7980.00	60000	0.85	30000	450	0.70	0.20	0.10	0.00	0.50	0.50
7605.17	22841.00	7255.83	7980.00	60000	0.85	70000	450	0.70	0.20	0.10	0.00	0.50	0.50
18293.83	35803.00	9619.17	7980.00	60000	0.85	110000	450	0.70	0.20	0.10	0.00	0.50	0.50
-2642.40	9789.00	4451.40	7980.00	60000	0.85	30000	600	0.70	0.20	0.10	0.00	0.50	0.50
8634.40	22841.00	6226.60	7980.00	60000	0.85	70000	600	0.70	0.20	0.10	0.00	0.50	0.50
19911.20	35803.00	7201.80	7980.00	60000	0.85	110000	600	0.70	0.20	0.10	0.00	0.50	0.50
-5695.70	9789.00	6174.70	9310.00	70000	0.85	30000	300	0.70	0.20	0.10	0.00	0.50	0.50
3816.70	22841.00	6714.30	9310.00	70000	0.85	70000	300	0.70	0.20	0.10	0.00	0.50	0.50
13329.10	35803.00	12253.90	9310.00	70000	0.85	110000	300	0.70	0.20	0.10	0.00	0.50	0.50
-4813.50	9789.00	5202.50	9310.00	70000	0.85	30000	450	0.70	0.20	0.10	0.00	0.50	0.50
5875.17	22841.00	7655.83	9310.00	70000	0.85	70000	450	0.70	0.20	0.10	0.00	0.50	0.50
-4372.40	9789.00	4651.40	9310.00	70000	0.85	30000	600	0.70	0.20	0.10	0.00	0.50	0.50
6994.40	22841.00	6626.60	9310.00	70000	0.85	70000	600	0.70	0.20	0.10	0.00	0.50	0.50
18191.20	35803.00	5601.80	9310.00	70000	0.85	110000	600	0.70	0.20	0.10	0.00	0.50	0.50
ANR	CEF	OOCS	O CS	COST	EFF	TORU	RATE	GOP1	GOPU	GOPC	VMR	VMJ	VMM
-1941.70	10083.00	5174.70	4650.00	50000	0.95	30000	300	0.70	0.20	0.10	0.00	0.50	0.50
7962.70	23527.00	8914.50	4650.00	50000	0.95	70000	300	0.70	0.20	0.10	0.00	0.50	0.50
17867.10	36971.00	12653.90	4650.00	50000	0.95	110000	300	0.70	0.20	0.10	0.00	0.50	0.50
-1059.50	10083.00	4402.50	4650.00	50000	0.95	30000	450	0.70	0.20	0.10	0.00	0.50	0.50
10021.17	23527.00	6855.64	4650.00	50000	0.95	70000	450	0.70	0.20	0.10	0.00	0.50	0.50
21191.83	36971.00	7219.17	4650.00	50000	0.95	110000	450	0.70	0.20	0.10	0.00	0.50	0.50
-618.40	10083.00	4151.40	4650.00	50000	0.95	30000	600	0.70	0.20	0.10	0.00	0.50	0.50
11050.40	23527.00	5626.60	4650.00	50000	0.95	70000	600	0.70	0.20	0.10	0.00	0.50	0.50
22719.20	36971.00	7601.60	4650.00	50000	0.95	110000	600	0.70	0.20	0.10	0.00	0.50	0.50
-3671.70	10083.00	5774.70	7980.00	60000	0.95	30000	300	0.70	0.20	0.10	0.00	0.50	0.50
6232.70	23527.00	2314.33	7980.00	60000	0.95	70000	300	0.70	0.20	0.10	0.00	0.50	0.50
16137.10	36971.00	12953.90	7980.00	60000	0.95	110000	300	0.70	0.20	0.10	0.00	0.50	0.50
-2789.50	10083.00	4802.50	7980.00	60000	0.95	30000	450	0.70	0.20	0.10	0.00	0.50	0.50
8291.17	23527.00	7255.83	7980.00	60000	0.95	70000	450	0.70	0.20	0.10	0.00	0.50	0.50
19371.83	36971.00	9649.17	7980.00	60000	0.95	110000	450	0.70	0.20	0.10	0.00	0.50	0.50
-2348.40	10083.00	4451.40	7980.00	60000	0.95	30000	600	0.70	0.20	0.10	0.00	0.50	0.50
9320.40	23527.00	6226.60	7980.00	60000	0.95	70000	600	0.70	0.20	0.10	0.00	0.50	0.50

Figure 2. A sample page of computer output from the computer analysis.

Results

The effect of individual variables on the annual net return can be studied by changing one factor and keeping all other factors constant.

Total bushels utilizing the system produces the greatest change in net return, as shown in Figures 3, 4, and 5. Throughout the entire analysis, net return was negative when operating with 30, 000 bushels. A linear relationship exists and net return increases as the volume through the system increases. Therefore, it is necessary to have large volumes available to effectively utilize this system.

The effects of gradeout percentages and cost of the system are shown in Figure 3. As the apples increase in quality (GOP1 increases), the net return decreases. This is an important factor to consider when the apples arrive at the storage plant. A quick check on quality should be made to determine whether the fruit should be hydrohandled. The cost of the system has a fixed effect on net return. As the cost increases, the net return decreases by a constant amount in each case.

Figure 4 shows the effects of machine efficiency and operating rates on net return. Higher efficiency indicates higher return. This is due to the increases in savings on storage costs and potential storage gains. Increased operating rates also increase net return, especially as the volume of the apples is increased.

The variety mix of the fruit utilizing the system has effects on net return as shown in Figure 5. Jonathan and McIntosh varieties are more desirable for CA storage since their increase in value is greater than that of Red Delicious (see Table 1).

Conclusions

The hypothetical analysis presented shows the possibilities of operating a hydrohandling system with substantial profits. An important factor to consider is that a large volume of fruit must be available to utilize the machine. Also, the size and quality of the fruit must justify the use of the system.

Other considerations are available labor for operation of the system, the additional time required for handling before the fruit is placed into storage, and the effects of the system on the quality of the fruit when it is removed from storage.

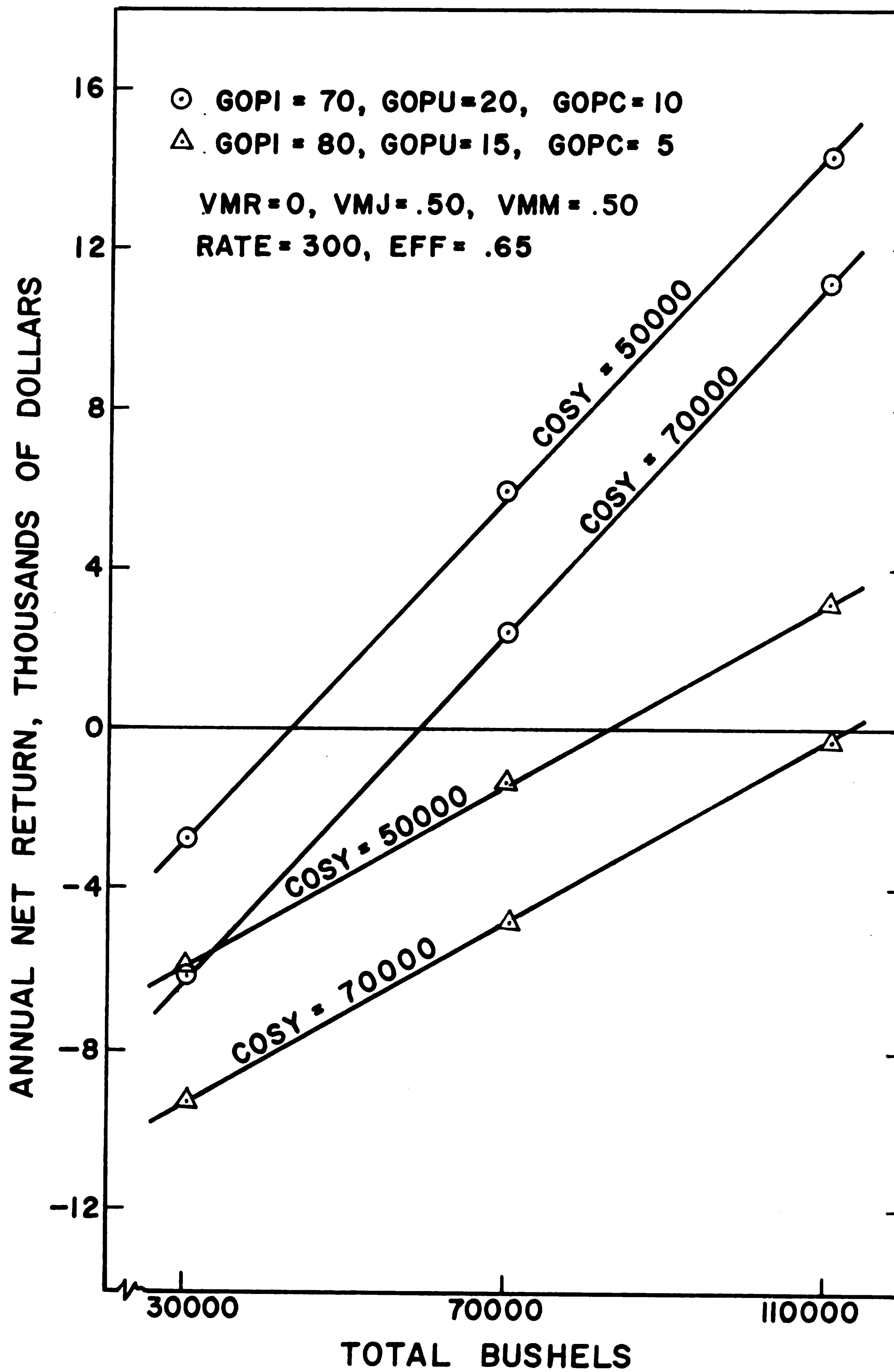

Figure 3. The effects of gradeout percentages, cost of system, and total bushels on annual net return.

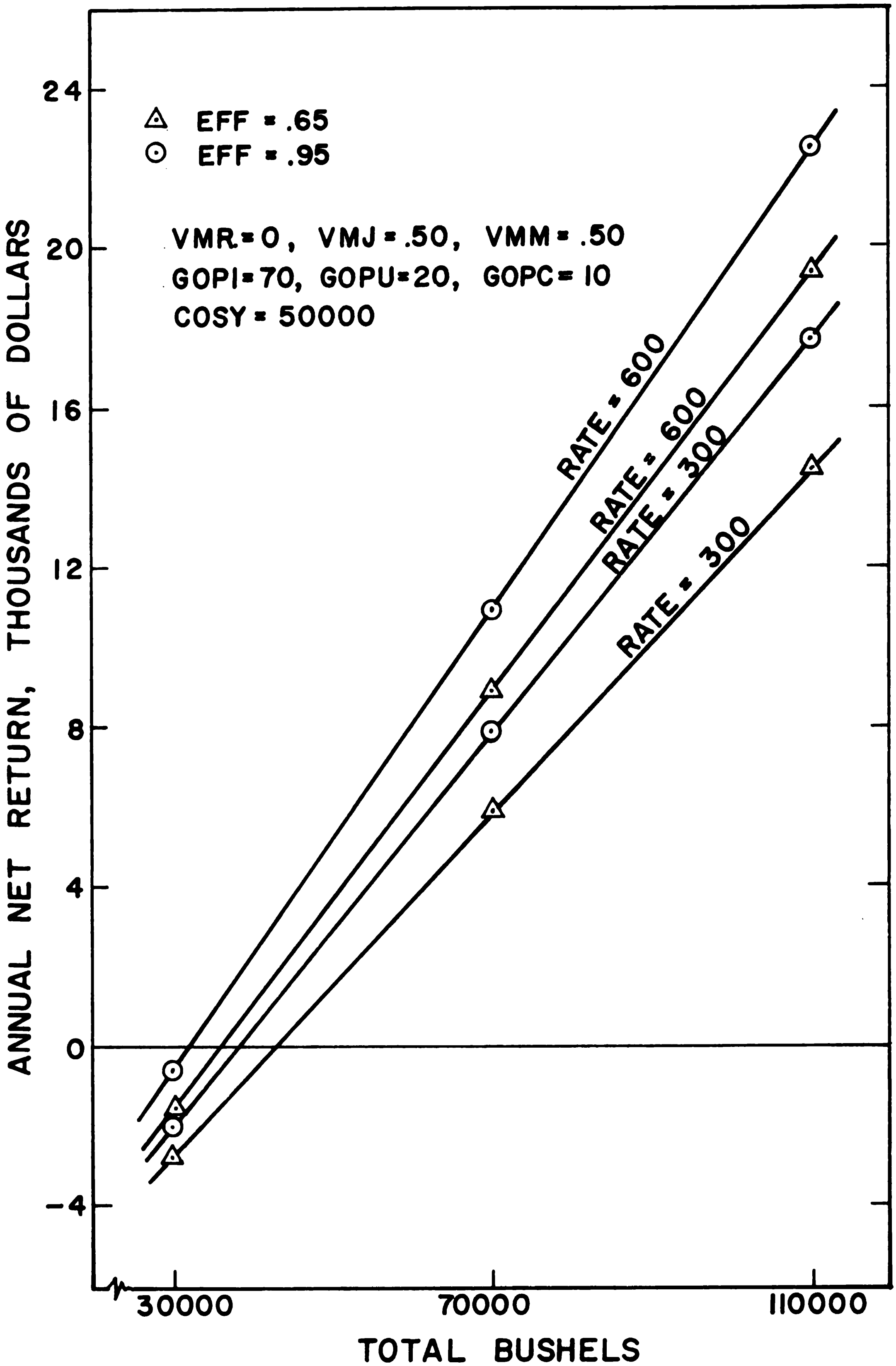

Figure 4. The effects of efficiency of operation, operating rate, and total bushels on annual net return.

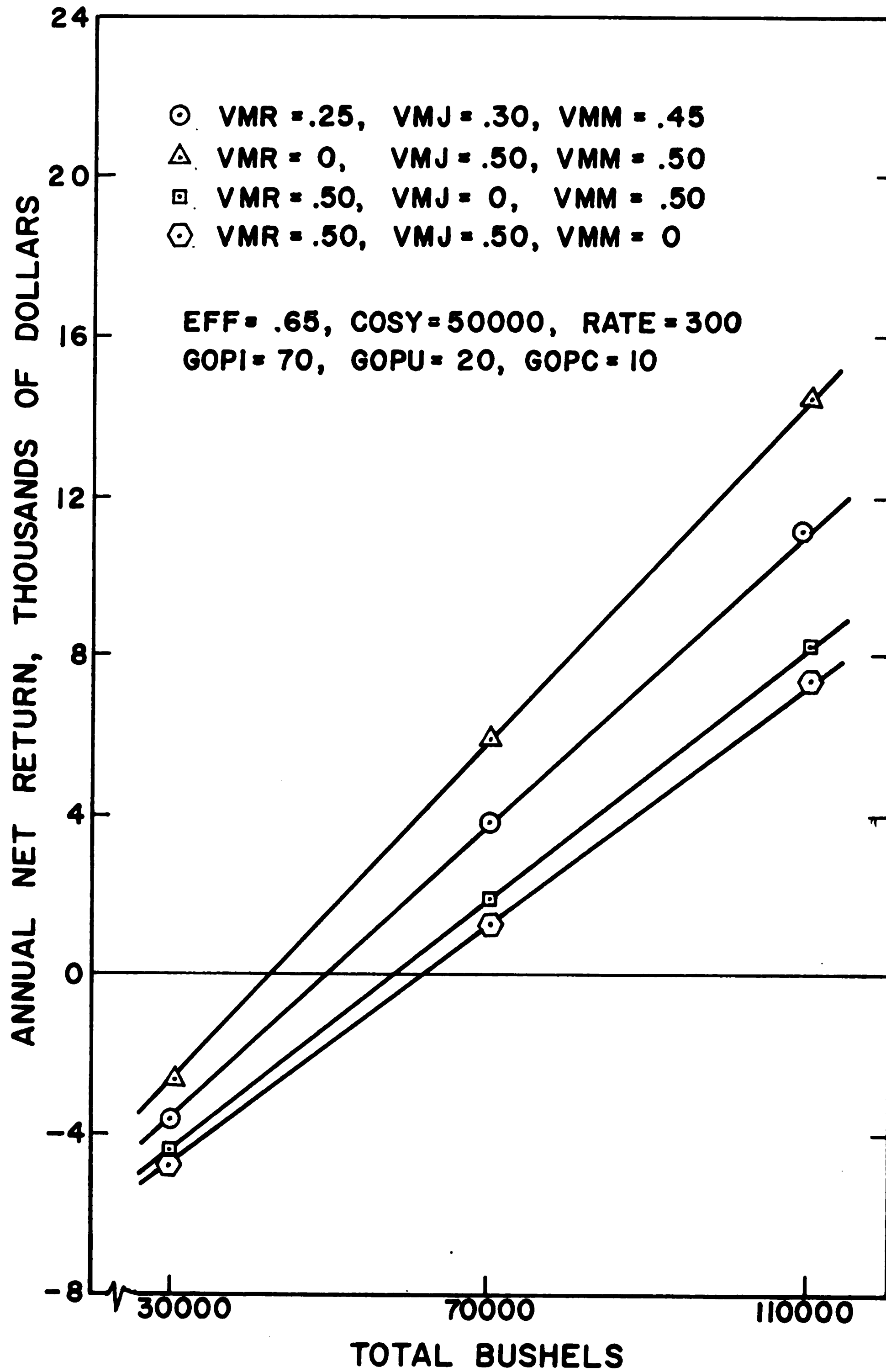

Figure 5. The effects of variety mix and total bushels on annual net return.

ACCUMULATOR STUDIES

The operation of the prototype hydrohandling system presented several difficulties which indicated a need for further study and research. One of the difficulties was a problem in measuring the fill of the accumulators. The result was a great inconsistency in the fill of the bulk boxes as they were removed from the machine. This is undesirable for several reasons. If the box is underfilled, apples must be added to fill it (a hand operation), or storage space will be wasted. If the box is overfilled, spillage in the accumulator tanks occurs, often causing severe bruises, and apples must be removed from the box to allow stacking without further bruising the apples at the top of the box. Several methods to reduce this problem were studied.

Measurement Principles Investigated

A basic principle which is used in this study is that of buoyant force. Specific gravities of apples, as determined by Cooper (1962), vary from 0.790 to 0.861 among several varieties. When apples are submerged in water, they provide a vertical force which may be related to the volume of the sample.

Two principles are used to measure the buoyant force of a sample of apples. The first utilizes a pressure sensing device attached to a manometer, which provides an indication of pressure changes in the device. The second principle uses a scale which is preloaded to a given deflection. As the buoyant force increases, the scale deflection decreases.

Apparatus

A model testing frame was constructed to accommodate an accumulator and approximately one bushel of apples, Figure 6. The frame was mounted in a tank large enough to allow the entire accumulator to be submerged. Three accumulators are used in the experiment.

The first accumulator was constructed of 1/4 inch plexiglass sheet and contains a wheelbarrow inner tube as a pressure sensing device, Figure 7. The tube is within the box and rests on a sheet of 1/8 inch plexiglass suspended by strings. The 1/8 inch sheet is free to move upward as apples float inside the accumulator. An angle iron frame restricts the upward motion of the box and keeps the tube from floating the accumulator. The tube is initially charged with a slight air pressure and is connected to the manometer with a plastic hose as shown in Figure 8.

A second accumulator is constructed of polyethylene material and an air pillow serves as a pressure sensing device. The air pillow is placed above the accumulator, Figure 9, and a plexiglass sheet mounted on angle iron supports provides a rigid top. The polyethylene box will float at water level when the testing frame is submerged. Its corners are linked to the plexiglass sheet with chains to provide stability when apples float inside the box. The air pillow is also initially charged with a slight air pressure and connected to the manometer with a plastic hose.

The polyethylene box is again used in the third measuring device. This consists of a 20 pound capacity scale, suspended from

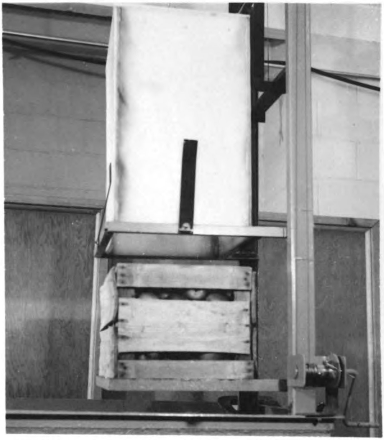

Figure 6. Accumulator testing frame with sample ready for submerging.

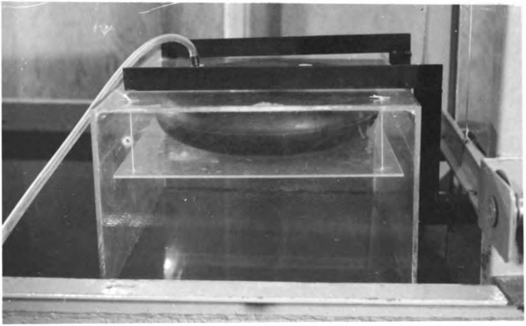

Figure 7. Tube sensing device mounted in accumulator.

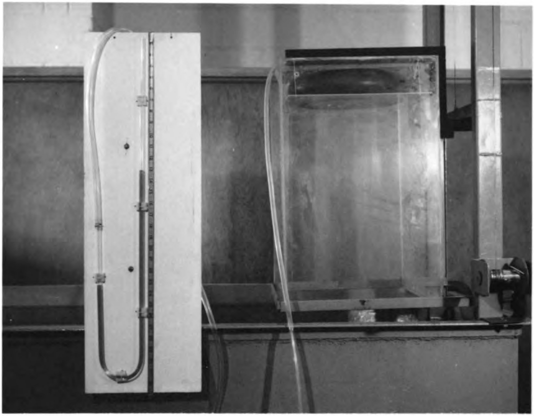

Figure 8. Accumulator with tube attached to manometer.

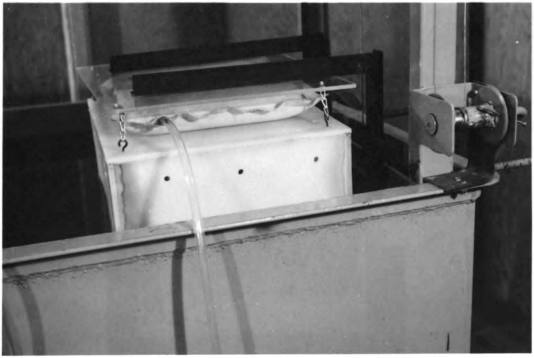

Figure 9. Air pillow sensing device mounted to accumulator.

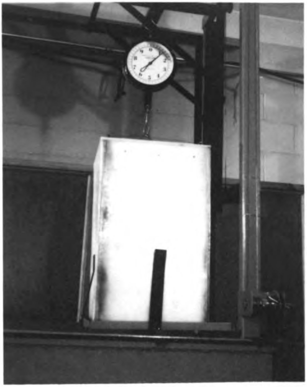

Figure 10. Scale mounted on accumulator.

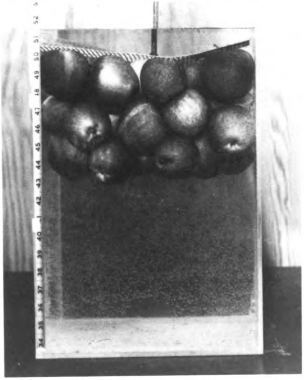

Figure 11. Measuring volume of sample by water displacement method.

an angle iron frame, and attached to the box with wires leading from the corners of the box, Figure 10. An initial deflection is provided by adding weights on the top of the box.

A method to measure absolute volumes of the apple samples, by means of water displacement, was devised. A 12 inch by 12 inch by 30 inch box was constructed of 1/4 inch plexiglass sheet. The apple samples were placed in this box and completely submerged by using a wire mesh fastened to a small rod as shown in Figure 11. The water displaced by the apples was measured with the use of a tape attached to the box.

A dynamometer scale, with a capacity of 100 pounds, was used to divide the apples, by weight, into ten samples.

Test Procedures

Three varieties of apples were used in the experiment, McIntosh, Golden Delicious, and Red Delicious. Each lot of apples was reduced to 10 samples by weight, ranging from 5 to 50 pounds.

The volume measurements were made utilizing the box described. An initial reading was taken prior to introducing the sample. The final reading was taken while the apples were submerged. The volume of the sample was calculated from the difference in readings, since the inside dimensions of the box were 12 inches by 12 inches. The volume of the wire mesh used for submerging the samples was negligible in comparison to the volume of the samples and was therefore neglected. Table 5 gives a comparison of weights and volumes measured for the three varieties.

Table 5. Comparisons of weights and volumes measured for three varieties of apples.

Weight, lbs.	McIntosh Volume, ft^3	Golden Delicious Volume, ft^3	Red Delicious Volume, ft^3
5	0.099	0.089	0.094
10	0.203	0.188	0.161
15	0.260	0.292	0.286
20	0.411	0.385	0.385
25	0.500	0.479	0.484
30	0.615	0.583	0.578
35	0.708	0.667	0.677
40	0.797	0.760	0.766
45	0.922	0.865	0.854
50	1.010	0.953	0.948

Each accumulator was tested with all the samples. A tape attached to the manometer mount, see Figure 8, was read before each sample was submerged. The fluid in the manometer is water. The final reading was taken with the accumulators completely submerged in the tank.

The plexiglass accumulator is restricted from floating and the force measured is that exerted on the interior plexiglass sheet depressing the tube. The friction of the apples on the walls may be a source of error. The polyethylene accumulator is light enough to float on the surface of the water. The force of the apples is dispersed in lifting the box and in depressing the air pillow. With the scale, the force of the apples is entirely measured by the negative deflection of the scale.

Results

The data from the experiment was analyzed by use of a statistical computer program titled Least square curve fitting with orthogonal polynomials (LSCFWOP). The program will compute the polynomial of degree K, ($K \leq 100$) which best fits M, ($M \leq 3000$), data points by the method of least squares. It will then evaluate the polynomial at the various abscissa points to obtain new ordinates. The computed ordinates are compared with the original ordinates to test the accuracy of fit. From this we obtain the standard error of estimate, SE, which is a measure of the amount of variation from the regression line. SE is defined by the expression:

$$SE = \left[\frac{1}{M} \sum_{i=1}^{M} (Y_i^{(c)} - Y_i)^2 \right]^{1/2}$$

where M = number of data points

$Y_i^{(c)}$ = computed ordinate

Y_i = original ordinate

The program is listed in Appendix II.

A second program was used to calculate the coefficient of correlation of the data. The coefficient of correlation, r, is given by the following expression:

$$r = \frac{n \Sigma XY - \Sigma X \Sigma Y}{\sqrt{[n \Sigma X^2 - (\Sigma X)^2][n \Sigma Y^2 - (\Sigma Y)^2]}}$$

where n = number of observations

X, Y = observed data

The coefficient of correlation is a measure of how closely the variables are related. With 8 degrees of freedom as in this experiment, the 99% significance level for r is 0.765 (Steel). The program for calculating r is given in Appendix III.

Figure 12 shows the manometer deflection versus volume for McIntosh apples using the tube and air pillow accumulators. The regression equation for the tube accumulator is $Y' = 1.793 + 50.15\,X$ (Y' is the estimated value of Y) and the data has a correlation coefficient $r = 0.9921$. The standard error of estimate is SE = 1.870. For the air pillow accumulator we have $Y' = 0.8367 + 39.39X$, $r = 0.9968$, and SE = 0.9337.

Figure 13 shows the results for Golden Delicious apples. For the tube accumulator, $Y' = -1.444 + 30.31\,X$, $r = 0.9950$, and SE = 0.8399. For the air pillow accumulator, $Y' = -1.901 + 20.53\,X$, $r = 0.9676$, and SE = 1.475.

Figure 14 shows the results for Red Delicious apples. For the tube accumulator, $Y' = -0.9788 + 44.87\,X$, $r = 0.9965$, and SE = 1.044. For the air pillow accumulator, $Y' = -0.7440 + 31.42\,X$, $r = 0.9948$, and SE = 0.8913.

Figure 15 shows the scale deflection versus volume for the three varieties, using the scale accumulator. The results for McIntosh are $Y' = 0.9296 + 139.2\,X$, $r = 0.9965$, and SE = 3.447. For Golden Delicious, the estimated value for Y is $Y' = 1.588 + 111.8X$, $r = 0.9943$, and SE = 3.285. The values for Red Delicious are $Y' = 9.453 + 108.0\,X$, $r = 0.9963$, and SE = 2.595.

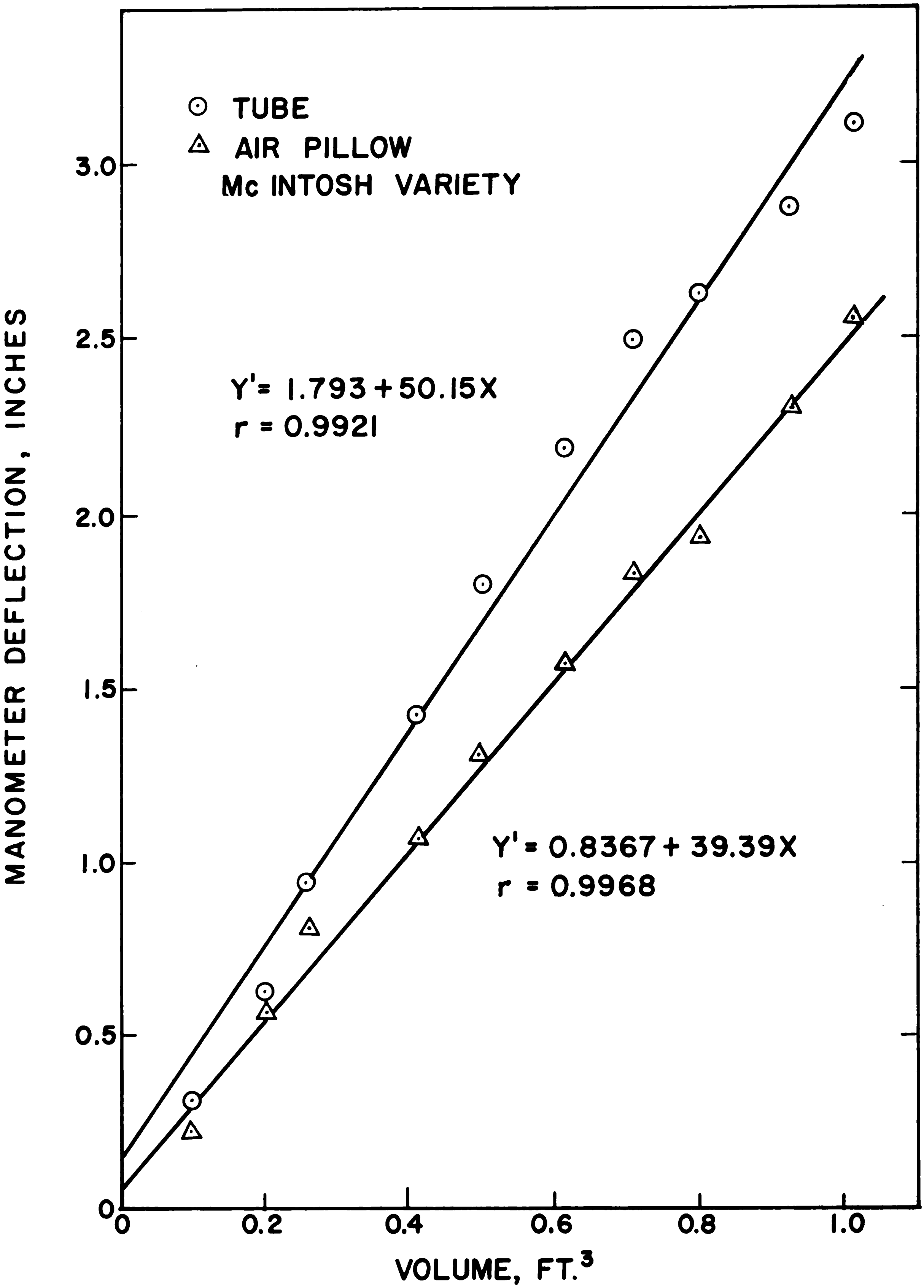

Figure 12. Manometer readings for McIntosh apples using the tube and air pillow accumulators.

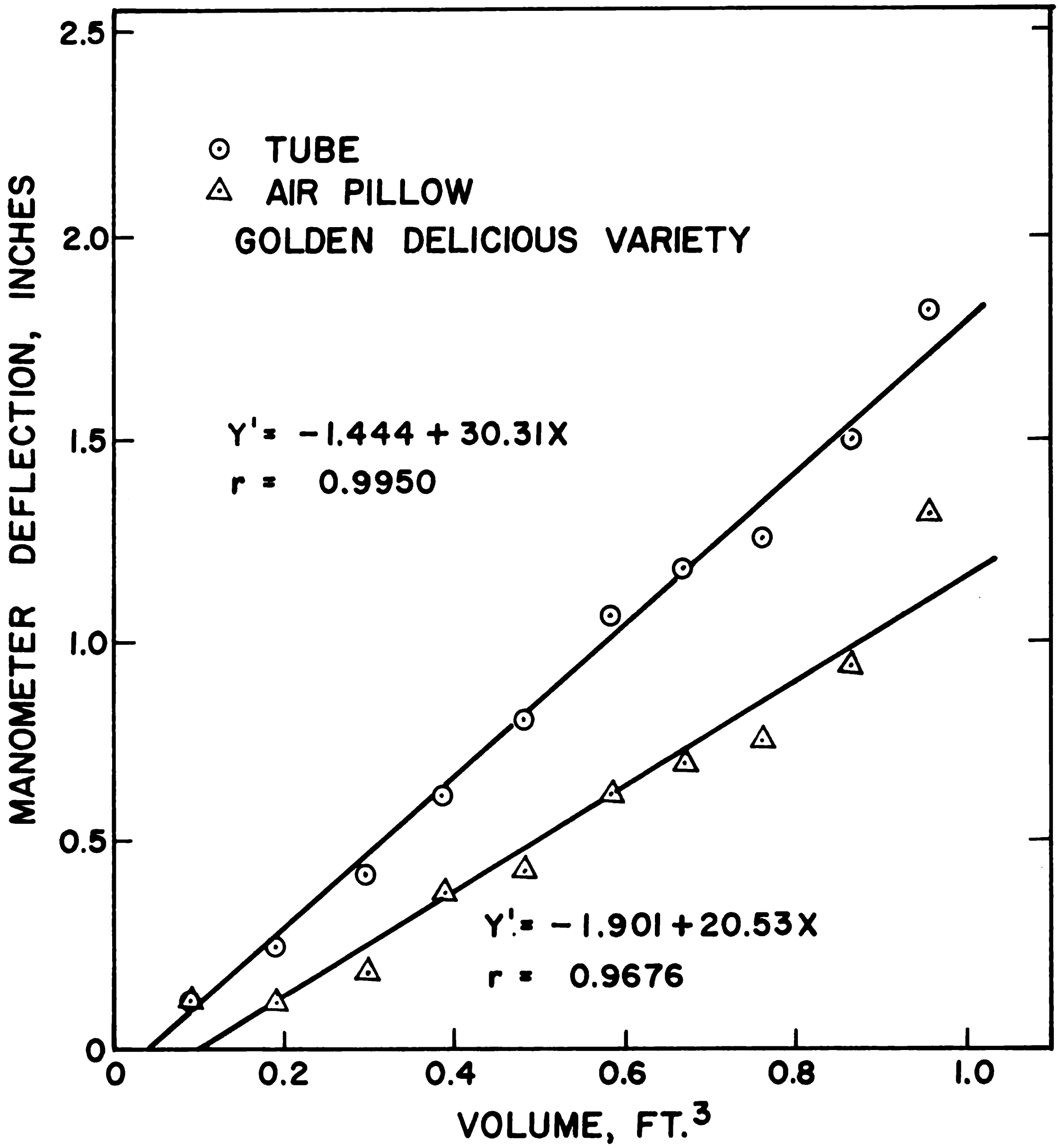

Figure 13. Manometer readings for Golden Delicious apples using the tube and air pillow accumulators.

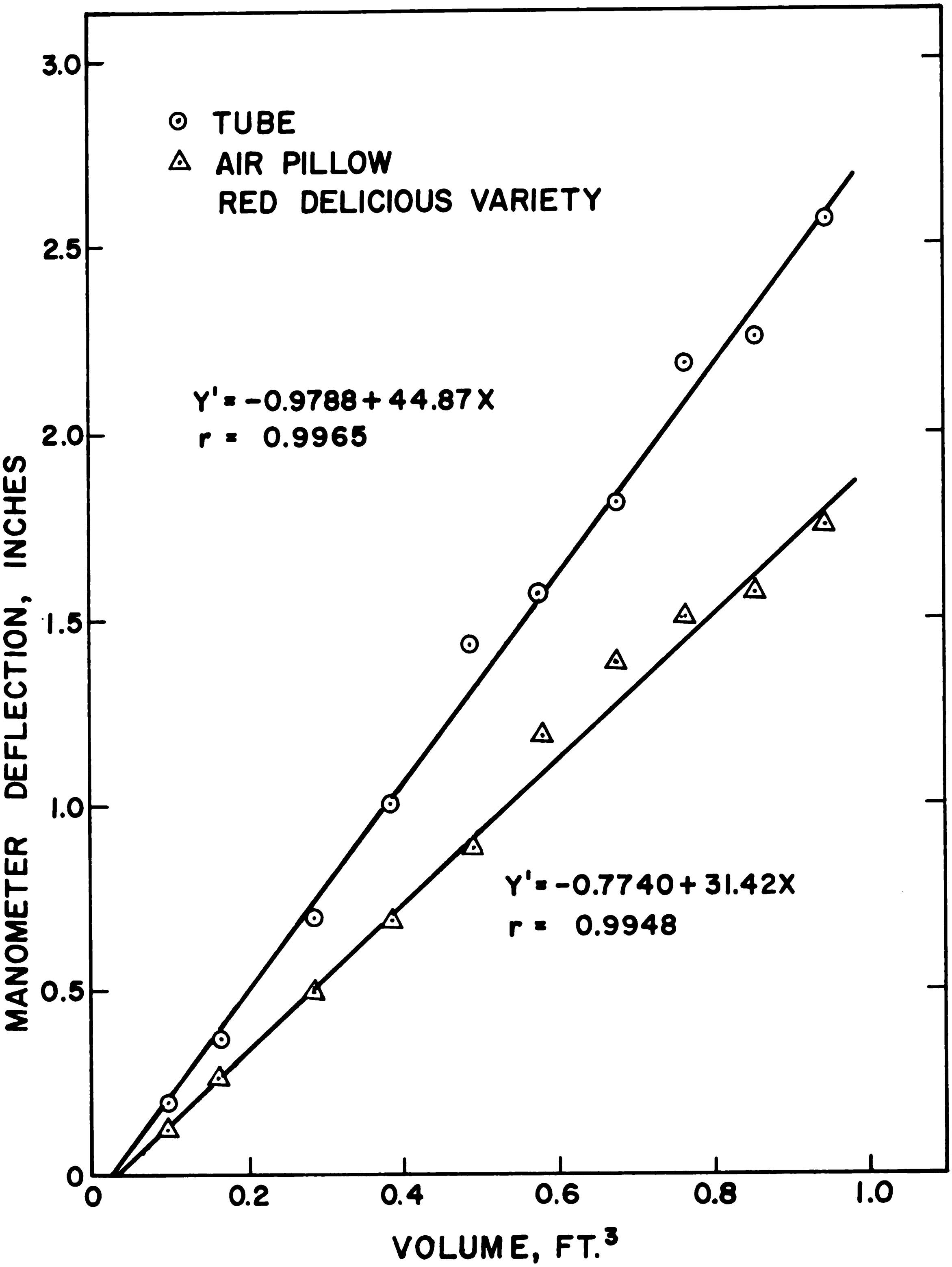

Figure 14. Manometer readings for Red Delicious apples using the tube and air pillow accumulators.

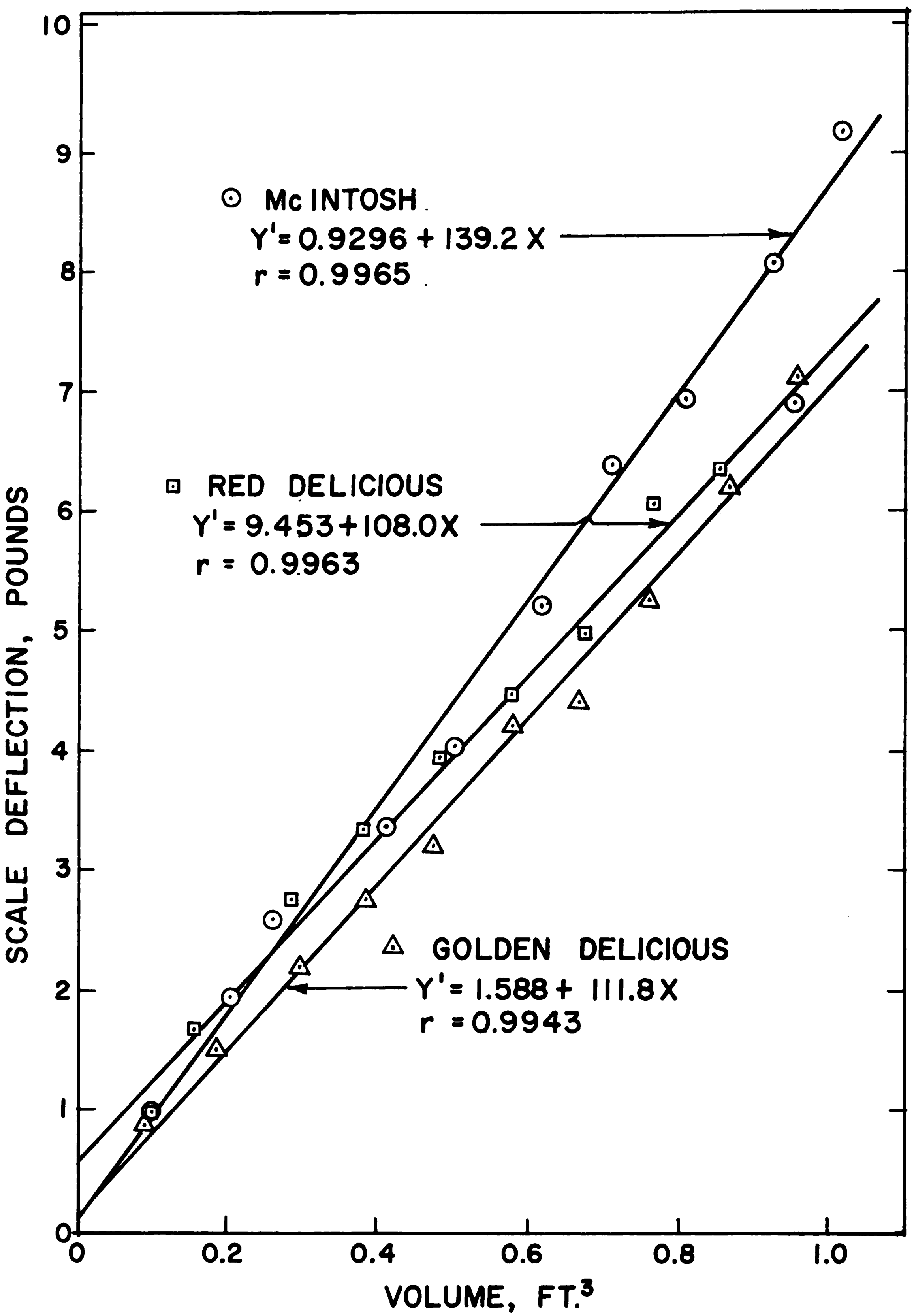

Figure 15. Scale readings obtained with the scale accumulator for McIntosh, Golden Delicious, and Red Delicious apple varieties.

Conclusions

The results of the experiment show linear relationships exist between the measuring devices tested and the volume of the sample. The high values for the correlation coefficients indicate that these relationships are highly significant. A value of $r = 1.0$ is a perfect correlation. The values for the standard error of estimate also show that the data fits very closely to the regression equations.

Comparisons of the tube and air pillow accumulators indicate slightly higher readings for the tube. This may be due to the fact that with the air pillow accumulator the force of the apples must lift the entire box to depress the pillow, while with the tube accumulator the apples lift only the 1/8 inch plexiglass sheet to depress the tube. It also seems that the stationary system of the tube accumulator is more desirable than the floating polyethylene box, which must be stabilized to maintain control. In a full scale application, the pressure measuring instruments would have to be quite accurate, since the force of 50 pounds of apples over an area of approximately 2 square feet is of the order of 0.01 psi.

The scale accumulator also shows good results. In this case, the total force exerted by the apples is measured, and sizeable changes (9 lbs. 2 oz.) were recorded for a 50 pound sample. The accuracy of the device can be more easily controlled for this accumulator.

All three types of accumulators showed some variations with the different varieties of apples tested. Calibrations would be necessary for each variety in an operating system. The scale accumulator would be best for a full scale application since it records a greater deflection and would require a less accurate measuring instrument. Changes in design would be necessary for adapting these methods to the present operational machine.

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APPENDIX I

```
      PROGRAM APLHPRO
      READ 20,SLIF,HELP,HLAB,AAE,PDR1,PDRU,PDJ1,PDJU,PDM1,PDMU,PDC,SCO
   20 FORMAT(4F6.2,8F5.2)
    1 READ 10, GOP1, GOPU, GOPC, VMR, VMJ, VMM
   10 FORMAT(6F10.2)
      IF(1.-GOP1) 26,26,4
    4 DO 25 KEFF = 65, 95, 10
      EFF = KEFF
      EFF = EFF/100.
      PRINT 2
    2 FORMAT(*0          ANR          GEG          OPCS          OWCS              COSY
     1  EFF     TOBU     RATE                    GOP1     GOPU     GOPC     VMR     VMJ     VMM*
     5)
      DO 25 KCOSY = 5, 7, 1
      COSY = KCOSY * 10000
      DO 25 KRATE = 300, 600, 150
      RATE = KRATE
      DO 25 KTOBU = 3, 11, 4
      TOBU = KTOBU * 10000
      NO = NO + 1
      SALV = .10*COSY
      DEP = (COSY-SALV)/SLIF
      AIN = .06*((COSY+SALV)/2)
      AIS = .0025*COSY
      ATAX = .0075*COSY
      OWCS = DEP + AIN + AIS + ATAX
      AMRL = .04*COSY
      AWAT=(TOBU/20000.)*5.40
      TIME = TOBU/RATE
      OPCS=TIME*(HELP+HLAB)+AMRL+AWAT+AAE
      SSCO=TOBU*EFF*(GOPU*VMR*(SCO-PDRU)+GOPU*VMJ*(SCO-PDJU)+GOPU*VMM*(S
     2CO-PDMU)+GOPC*(SCO-PDC))
      PSG1=TOBU*(GOPU+GOPC)*(VMR*(PDR1-SCO)+VMJ*(PDJ1-SCO)+VMM*(PDM1-SCO
     3))
      GEG = SSCO + PSG1
      ANR = GEG - OWCS - OPCS
      PRINT 3,ANR,GEG,OPCS,OWCS,COSY,EFF,TOBU,RATE,GOP1,GOPU,GOPC,VMR,VM
     4J,VMM
    3 FORMAT(*0*,4F10.2,10X,F5.0,F7.2,2F7.0,10X,6F6.2)
   25 CONTINUE
      GO TO 1
   26 END
'RUN,10,0,1400
   10.   .286 26.18   720.   .95   .27 1.38   .38 1.34   .17   .12   .55
        70        20        10        25        30        45
        70        20        10         0        50        50
        70        20        10        50         0        50
        70        20        10        50        50         0
        75        20         5        25        30        45
        75        20         5         0        50        50
        75        20         5        50         0        50
        75        20         5        50        50         0
        80        15         5        25        30        45
        80        15         5         0        50        50
        80        15         5        50         0        50
        80        15         5        50        50         0
     10000
```

APPENDIX II

```
      PROGRAM LSCFWOP
      DIMENSION VEC(3000,6),S(101),ALP(101),BETA(101),RHOSQ(101),XP(101
      DIMENSION INFMT(10),ID(10)
      COMMON VEC,S,ALP,BETA,XP
      IHLT=8H
 1327 READ 8000,ID
      DO 1337 I=1,10
      IF(ID(I)-IHLT) 1400,1337,1400
 1337 CONTINUE
      GO TO 411
 1400 PRINT 2
    2 FORMAT(1H1)
      PRINT 8000,ID
      READ 8000,INFMT
 8000 FORMAT(10A8)
      PRINT 1500,INFMT
 1500 FORMAT(//14H INPUT FORMAT 10A8/)
      READ 21,MM,KK,KOT,KIP,KAP,KOP,NOP,NIP,MTI
   21 FORMAT(10I5)
      READ INFMT,XBAR,GAMMA,TOL
      PRINT 4
    4 FORMAT(/44H  MM   KK  KOT  KIP  KAP  KOP  NOP  NIP  MTI)
      PRINT 21,MM,KK,KOT,KIP,KAP,KOP,NOP,NIP,MTI
      PRINT 1
    1 FORMAT(//23H XBAR     GAMMA     TOL)
      PRINT INFMT,XBAR,GAMMA,TOL
      READ INFMT,(VEC(J,1),VEC(J,2),J=1,MM)
      CALL SHIFT(XBAR,GAMMA,MM)
      S1 = MM
      DO 31 J = 1,MM
      VEC(J,3) = 0.0
   31 VEC(J,4) = 1.0
      BETA(1) = 0.0
      S3 = 0.0
      DO 32 L = 1,MM
   32 S3 = S3 + VEC(L,2)**2
      K2 = KK + 1
      DO 302 I = 1,K2
      S4 = 0.0
      DO 33 J = 1,MM
   33 S4 = S4 + VEC(J,2)*VEC(J,4)
      S(I) = S4/S1
      S5 = S3-S(I)**2*S1
      IF(MM-I-1)305,305,301
  301 RHOSQ(I) = S5/FLOATF(MM-I-1)
      GO TO 303
  305 RHOSQ(I) = S5
  303 K1 = I -1
      DO 34 K = 1,K1
      IF(ABSF(RHOSQ(K)-RHOSQ(I))-TOL) 71,71,34
   34 CONTINUE
      IF(I - K2)35,72,72
   35 DO 36 N = 1,MM
   36 VEC(N,5) = VEC(N,1)*VEC(N,4)
      T1 = 0.0
```

```
      DO 37 JJJ = 1,MM
   37 T1 = T1 + VEC(JJJ,5)*VEC(JJJ,4)
      ALP(I+1) = T1/S1
      T2 = 0.0
      DO 38 M = 1,MM
      VEC(M,5) = (VEC(M,1)-ALP(I+1))*VEC(M,4)-BETA(I)*VEC(M,3)
      T2 = T2+VEC(M,5)**2
      VEC(M,3) = VEC(M,4)
   38 VEC(M,4) = VEC(M,5)
      BETA(I+1) = T2/S1
      S3 = S5
      S1 = T2
  302 CONTINUE
   72 K3 = K2
      GO TO 40
   71 K3 = I
   40 CALL UNSHIFT(XBAR,GAMMA,MM)
      KGL= 2
      IF(KIP) 718,718,717
  717 CALL POLK(K3,KAP)
  718 IF(NOP) 420,719,719
  719 DO 7000 J=1,MM
 7000 VEC(J,5) = VEC(J,2)
      IF(NOP)420,405,407
  407 PRINT 1001
 1001 FORMAT(1H2/50H THE ORDINATE VALUES USING THE RECURRENCE FORMULAS)
      PRINT 2
      MC = MM
      GO TO 1002
  405 CALL SHIFT(XBAR,GAMMA,MM)
      DO 406 N =1,MM
      VEC(N,2) = XP(1)
      K4 = K3 - 1
      DO 406 K=1,K4
  406 VEC(N,2) = VEC(N,2)*VEC(N,1) + XP(K+1)
      CALL UNSHIFT(XBAR,GAMMA,MM)
      IF(MTI-K4) 4760,4760,420
 4760 PRINT 5,K4
    5 FORMAT(1H2/73H THE ORDINATE VALUES AS EVALUATED BY GENERATING THE
     1POLYNOMIAL OF DEGREE I4/1H1)
      CALL XPRINT(MM,KOP)
  420 IF(KOT) 1327,1327,402
  402 READ 21,MC
      PRINT 821
  821 FORMAT(1H2/61H THE FOLLOWING ORDINATES ARE CALCULATED FOR THE NEW
     1ABSCISSAS)
      KGL = 1
      KOT = KOT - 1
      READ INFMT,(VEC(J,1),J=1,MC)
 1002 K2 = K3 - 1
      NOP = 0
      CALL SHIFT(XBAR,GAMMA,MC)
      DO 51 J = 1,MC
      VEC(J,2) = 0.0
      VEC(J,3) = 0.0
```

```
   51 VEC(J,4) = 1.0
      DO 502 I = 1,K3
      DO 52 J = 1,MC
      VEC(J,2) = VEC(J,2) + S(I)*VEC(J,4)
      IF(I -K3)503,52,52
  503 P2 = (VEC(J,1)-ALP(I+1))*VEC(J,4) - BETA(I)*VEC(J,3)
      VEC(J,3) = VEC(J,4)
      VEC(J,4) = P2
   52 CONTINUE
      CALL UNSHIFT(XBAR,GAMMA,MC)
      JJ2 = I - 1
      IF(NIP)1003,1003,1004
 1004 IF(I-K3)502,1003,502
 1003 IF(MTI-JJ2) 5436,5436,502
 5436 PRINT 643,JJ2
  643 FORMAT(////66H THE FOLLOWING VALUES WERE CALCULATED USING A POLYN
     1MIAL OF DEGREE I4)
      GO TO (705,799), KGL
  799 CALL XPRINT(MC,KOP)
      GO TO 502
  705 PRINT 707
  707 FORMAT(/3(8X,29H ABSCISSA          ORDINATE    ))
      MC1 = MC - 2
      DO 701 K = 1,MC1,3
      L = K
  701 PRINT 23,VEC(K,1),VEC(K,2),VEC(K+1,1),VEC(K+1,2),VEC(K+2,1),
     1  VEC(K+2,2)
      IF(L+1-MC1)703,702,502
  702 PRINT 23,VEC(MC,1),VEC(MC,2)
      GO TO 502
  703 PRINT 23,VEC(MC-1,1),VEC(MC-1,2),VEC(MC,1),VEC(MC,2)
  502 CALL SHIFT(XBAR,GAMMA,MC)
 5002 CONTINUE
   23 FORMAT(3(5X,1PE14.4,3X,1PE14.4))
      IF(KOT) 1327,1327,402
  411 CONTINUE
      END
       SUBROUTINE POLK(KQ,KR)
      DIMENSION COEF(100,100),ALP(101),BETA(101),S(101),XP(101),
     1 DUM(7999)
      COMMON DUM,COEF,S,ALP,BETA,XP
      DO 31 I = 1,KQ
      COEF(I,1) = 1.0
   31 COEF(I,I+1) = 0.0
      DO 32 I = 2,KQ
   32 COEF(I,2) = COEF(I-1,2) - ALP(I)
       DO 33 J = 3,KQ
      DO 33 I = J,KQ
   33 COEF(I,J) = COEF(I-1,J) - ALP(I)*COEF(I-1,J-1) -
     1  BETA(I-1)*COEF(I-2,J-2)
      DO 34 I = 1,KQ
      DO 34 J = 1,I
   34 COEF(I,J) = COEF(I,J)*S(I)
   17 FORMAT(///46H THE COEFFICIENTS FOR THE POLYNOMIAL OF DEGREE I4/(/
     1 1PE20.10,1PE20.10,1PE20.10,1PE20.10,1PE20.10,1PE20.10))
```

```
      DO 26 N = 1,KQ
      MKM = N - 1
      XP(N) = 0.0
      DO 531 I=1,N
  531 XP(N) = COEF(I,I) + XP(N)
      IF(MKM) 400,350,400
  400 DO 35 J=1,MKM
      XP(N-J) = 0.0
      M = J + 1
      DO 35 I = M,N
   35 XP(N-J) = COEF(I,I-J) + XP(N-J)
  350 IF(KR) 21,26,23
   21 MN1 = N - 1
      PRINT 17,MN1,(XP(L),L=1,N)
      GO TO 26
   23 IF(N-KQ)26,21,26
   26 CONTINUE
      END
      SUBROUTINE SHIFT(X,Y,MQ)
      DIMENSION VEC(3000,6),S(101),ALP(101),BETA(101),XP(101)
      COMMON VEC,S,ALP,BETA,XP
      DO 31 I=1,MQ
   31 VEC(I,1)=(VEC(I,1)-X)/(1.0-Y)
      END
      SUBROUTINE UNSHIFT(X,Y,MQ)
      DIMENSION VEC(3000,6),S(101),ALP(101),BETA(101),XP(101)
      COMMON VEC,S,ALP,BETA,XP
      DO 31 I=1,MQ
   31 VEC(I,1)=VEC(I,1)*(1.0-Y) + X
      END
      SUBROUTINE XPRINT(NUM,KOP)
      DIMENSION VEC(3000,6),S(101),ALP(101),BETA(101),XP(101)
      COMMON VEC,S,ALP,BETA,XP
      YBAR = 0.0
      YAV  = 0.0
      YSQ = 0.0
      YMAX = 0.0
      DO 950 J=1,NUM
      VEC(J,6)= VEC(J,2)-VEC(J,5)
      T = ABSF(VEC(J,6))
      YBAR = YBAR + T
      YSQ = YSQ + T*T
      IF(YMAX-T) 970,950,950
  970 YMAX = T
  950 YAV = YAV + VEC(J,6)
      YBAR = YBAR/FLOATF(NUM)
      YSQ = SQRTF(YSQ/FLOATF(NUM))
      GO TO (900,902,904,905),KOP
  904 PRINT 966
  966 FORMAT(////9X,8HORIGINAL,11X,8HCOMPUTED,11X,8HORDINATE/9X,8HABSCI
     1SA,11X,8HORDINATE,10X,11HDIFFERENCES//)
      PRINT 965,(VEC(J,1),VEC(J,2),VEC(J,6),J=1,NUM)
  965 FORMAT(3(5X,1PE14.4))
      GO TO 900
  902 PRINT 964
```

```
 964 FORMAT(////9X,8HORIGINAL,11X,8HORIGINAL,11X,8HORDINATE/9X,8HABSCI
    1SA,11X,8HORDINATE,10X,11HDIFFERENCES//)
     PRINT 965,(VEC(J,1),VEC(J,5),VEC(J,6),J=1,NUM)
     GO TO 900
 905 PRINT 962
 962 FORMAT(////9X,8HORIGINAL,11X,8HORIGINAL,11X,8HCOMPUTED,11X,8HORDI
    1ATE/9X,8HABSCISSA,11X,8HORDINATE,11X,8HORDINATE,10X,11HDIFFERENCE
    2//)
     PRINT 961,(VEC(J,1),VEC(J,5),VEC(J,2),VEC(J,6),J=1,NUM)
 961 FORMAT( 2(5X,E14.2),5X,E14.3,5X,E14.4)
 900 PRINT 960, YAV, YBAR , YSQ , YMAX
 960 FORMAT(////53H SUM OF (COMPUTED ORDINATE MINUS ORIGINAL ORDINATE)
    1 1PE16.8//17H ERROR NORM L1 = 1PE16.8//17H ERROR NORM L2 = 1PE16.
    2 //25H ERROR NORM L-INFINITY = 1PE16.8)
     GO TO (1900,2000,2000,2000),KOP
1900 PRINT 4
   4 FORMAT(1H2)
     RETURN
2000 PRINT 5
   5 FORMAT(1H1)
     END
     DATA FOLLOWS
```

APPENDIX III

```
      PROGRAM CORRCOEF
      DO 35 K=1,9
      SX=0.0
      SY=0.0
      SX2=0.0
      SY2=0.0
      SXY=0.0
      DO 25 J=1,10
    1 READ 10, X,Y
   10 FORMAT (2F10.3)
      SX=SX+X
      SY=SY+Y
      SX2=SX2+X**2
      SY2=SY2+Y**2
      SXY=SXY+X*Y
   25 CONTINUE
      ANO=10.0
      XM=SX/ANO
      YM=SY/ANO
      XSD=SQRT((SX2-SX*SX/ANO)/(ANO-1.0))
      YSD=SQRT((SY2-SY*SY/ANO)/(ANO-1.0))
      R=(ANO*SXY-SX*SY)/SQRT((ANO*SX2-SX*SX)*(ANO*SY2-SY*SY))
      PRINT 20, XM, YM
   20 FORMAT(*0THE MEAN OF X = *,F10.4,*  THE MEAN OF Y = *,F10.4)
      PRINT 30, XSD, YSD, R
   30 FORMAT(*0THE STD DEV OF X = *,F10.4,*  THE STD DEV OF Y = *,F10.4,
     1*  THE CORRELATION COEFFICIENT = *,F10.4)
   35 CONTINUE
      END
      DATA FOLLOWS
```