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A MASS AND THERMAL ENERGY ANALYSIS
OF STEAM PEELING FOR POTATOES

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A MASS AND THERMAL ENERGY ANALYSIS OF STEAM PEELING FOR POTATOES

By

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ABSTRACT

A MASS AND THERMAL ENERGY ANALYSIS OF
STEAM PEELING FOR POTATOES

by

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The steam peeling process for potatoes is energy intensive and may have product losses of 15-25%; thus it offers an excellent opportunity for analysis in an effort to improve efficiency of both raw material and energy utilization.

Mass and thermal energy balances were conducted for a potato steam peeler under normal operating conditions. Material inputs and outputs were determined by direct measurement, heat contents of mass streams and heat losses from equipment surfaces were calculated, and appropriate raw material characteristics and process parameters were monitored. All mass streams were analyzed for total solids, starch, and ash contents.

Results indicate that for early autumn potatoes, peel losses ranged from 3.70% to 13.05%. Losses increased with longer exposure to steam and for lower specific gravity potatoes. Average solids, starch, and ash losses during peeling were 7.66%, 10.28%, and 14.12%, respectively. When lower peeling losses enabled the processor to achieve adequate peeled product quality, less heat was absorbed by

the product and waste streams but significant amounts of thermal energy were lost. Observations such as these yield useful information for a production facility in terms of planning for future raw material, energy, and waste disposal requirements. In addition, a mass and thermal energy analysis provides insight into opportunities for process modifications leading to increased mass recovery and thermal energy efficiency.

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NOMENCLATURE

General

A	surface area of peeling vessel shell, m
a	half-length, cm
b	half-width, cm
c	half-height, cm
c_p	specific heat, kJ/kgC
g	acceleration due to gravity, 9.81m/sec
G	geometric index, dimensionless
h	heat transfer coefficient, kJ/(hr m C)
h_f	enthalpy of saturated liquid, kJ/kg
h_{fg}	enthalpy of evaporation, kJ/kg
k	thermal conductivity, kJ/(hr m C)
L	length of peeling vessel, m
L_{ma}	location of mass average temperature, dimensionless
M	mass, kg
m	constant defined by equation (8)
N_{Gr}	Grashof number, dimensionless
N_{Nu}	Nusselt number, dimensionless
N_{Pr}	Prandtl number, dimensionless
Q	thermal energy content, kJ
R	correlation coefficient, dimensionless
T	temperature, C

V	volume, cm^3
X	steam quality, dimensionless
α	level of significance, dimensionless
β	coefficient of volumetric expansion, K^{-1}
ϵ	emissivity, dimensionless
θ	temperature, R
μ	viscosity, kg/(m sec)
ρ	density, kg/m^3
0	constant determined by equation (8)

Subscripts

c	convective
e	exiting (peeled) product
i	incoming (unpeeled) product
n	miscellaneous
p	peel
pc	peel and condensate
r	radiative
ref	reference
s	steam
sh	peeling vessel shell
sw	spray water
w	wash water
∞	surrounding air

INTRODUCTION

The quantity of potatoes processed in the United States has increased rapidly in the past few decades, from 1.8×10^9 kg in 1959, to 5.3×10^9 kg in 1969, to 7.0×10^9 kg in 1975. These figures represent an increased proportion in utilization for processing of all potatoes grown in this country from 16% to 37% to 48% for those respective years (USDA, 1973, 1977). Potato processing operations are responsible for extremely high volumes of waste production, as a result of peeling, trimming, and cutting losses. Based on average expected losses of yield for potato products of 20-50% (Shirazi, 1979), these wastes may exceed 4.2×10^9 kg per year and represent economic losses to the processor in the form of both product loss and waste disposal costs. Moon (1980) stresses that the most significant method of reducing waste and increasing overall material utilization at the processing plant level is to adopt practices and technologies which increase recovery of the salable product at each operation.

Energy costs for potato processing are high also, expecially for the peeling, blanching, frying, and canning or freezing operations. Singh (1978, 1977) discussed the importance of energy accounting of individual food processing operations in providing information about energy requirements, modes of energy losses and for developing energy conservation recommendations.

The peeling operation tends to have particularly high material losses, which may range up to 25% of raw product, depending on peeling method and final product requirements. Careful control of peeling is a necessity. With inadequate peeling, either extensive hand trimming is required or a low quality final product results. Overpeeling, on the other hand, causes unnecessary heat damage to the peeled potato, causes loss of edible tissue, causes increased waste disposal costs, and results in lost energy.

In general, a need exists for a method to account for mass and thermal energy losses during normal operation of a potato processing facility's peeling system. Such a method would yield useful information for the production facility in terms of planning for future raw material, energy, and waste disposal requirements. In addition, an in-depth mass and thermal energy analysis of potato steam peeling operations should provide insight into opportunities for process modifications leading to increased mass recovery and thermal energy efficiency.

The objectives of this study were: 1) to conduct a total and component mass balance on a steam peeling system for potatoes and quantify product losses for this system; 2) to conduct a thermal energy balance on a steam peeling system for potatoes and quantify energy losses for this system; 3) to develop relationships between product loss under various operating conditions with loss of potato components; 4) to develop relationships between product losses and thermal energy use; and 5) to develop recommendations for operation changes leading to increased utilization of product mass and thermal energy during the steam peeling of potatoes.

LITERATURE REVIEW

I. Material Utilization in Potato Processing Operations

A. Sources of Product Loss

For maximum yield and quality of finished potato products, potato processors desire potatoes with 1) high specific gravity (and high total solids content); 2) good texture and color; 3) low sugar content; 4) high maturity; 5) relative freedom from disease and bruising; and 6) low peeling requirements (Feustel et al., 1964). Potato breeding and improvement programs have been conducted for years to improve the suitability of potatoes for processing (Smith and Plaistad, 1968; East, 1908; Gilmore, 1905). Storage conditions are carefully controlled to minimize net necrosis, internal discoloration, mahogony browning, black spot, shrinkage due to dehydration and sprouting, and the accumulation of reducing sugars (Feustel et al., 1964). The three critical conditions of potato storage areas are the temperature, relative humidity, and uniform air circulation (Mazzola, 1946a). Even with the most suitable raw material, losses during processing of the various potato products are severe, as illustrated in Table 1.

Wastes which develop within a potato processing plant are of three types: 1) discrete particle size sufficient to permit their removal by coarse screen or air separation); 2) suspended material of very small or colloidal particle

Table 1. Summary of Losses During Potato Processing[1]

Processing Step or Product	Loss, %
Pre-processing	
Soil	1.5 - 3.0
Culls	0 - 60
Peel losses	0 - 50 (avg.=17)
Cutting, slicing	10 - 15
plus washing	15 - 40
Leaching	5 - 6.5
Blanching	1 - 2.0
Potato chips	74 - 80[2]
French fries	
raw cuts	25 - 50[2]
finished fried	55 - 70[2]
Canning	5 - 10
Dried, flakes	16 - 22[3]
Dried, slice & dice	30 - 40[3]

(1) Source: Leite and Uebersax (1979)

(2) Total losses including moisture

(3) Solids losses only; does not include moisture

size which requires sedimentation, centrifugation, or filter separation procedures, and 3) soluble materials which cannot be readily separated (Weckel et al., 1968).

Potatoes received at the plant are washed thoroughly to remove adhering soil and reduce the microbial load on the raw material. Stones, debris, and decayed tubers are also removed at this stage (Kueneman, 1975). Losses in yield due to soil and debris included with incoming raw material may be 3% and suggest some need for improved mechanical harvesting systems (Weckel et al., 1968).

Peeling losses for any product will vary widely with the peeling method, processing conditions, the raw product condition, and the quality standards of the processor (Huxsoll and Smith, 1975). Peeling losses will be discussed more extensively in Section II.

Inspection losses are due to three types of defects which would degrade product quality: 1) trimmable (surface bruise, scab, rot); 2) sortable (visible when the tuber is sliced, i.e., hollow heart or internal discoloration); or 3) discard (too severe to process economically). Because of such defects, yields of similar products may vary by 20 to 30% for different lots of potatoes (Miller, 1964). Trimming losses are also necessary for the removal of residual peel; therefore trimming requirements will depend on the efficiency of the peeling operation. Grieg and Manchester (1958) reported observed trimming labor times and costs for two different peeling methods.

Reeve (1971) discussed the reduction in yield due to the cutting and slicing operation and felt that Smith's (1975) estimation of .05-1.0% loss to be far too low. Reeve found that with "ideal slicing" at an average slice thickness of 1.4 mm, losses may range from 11.4% to over 17%. A 3 to 5% reduction in slicing losses could be achieved with slightly thicker slices, and further improvements in yield could result if potato varieties with smaller cell size were developed.

Discrete potato pieces lost in the cutting and slicing operation are due to (screened-out) undersized and broken pieces (slivers and nubbins) which would cause a product such as french fries to be under-grade. These losses may amount to about 10%, according to Weaver et al. (1975).

Most processed potato products are treated with water during blanching or to wash off surface starch or leach sugars that would otherwise cause browned products. Potato solids are lost in any of these processes, and Hautala et al. (1972) found that these losses increase with increased soaking or washing times, and with increased water temperature.

Moisture is removed from fries and chips before frying in order to decrease the load on the fryers. This also decreases product yield; however, losses of yield in dehydration processes for mashed potato flakes and granules manufacture are expected and desirable.

As an approach to the problem of high material losses in processing, research has been conducted in potato processing facilities in an attempt to characterize the sources, causes, and amounts of waste from individual processing operations. Weckel et al. (1968) found that the peeling operation accounts for 62% of one plant's discrete wastes, with sizing, grading, inspection, and spill losses accounting for most of the other discrete losses. Of the effluent production (waste types 2 and 3), 92.8% of the total solids in the effluent waste flow originated at the blanchers and tumble peelers. In a survey of a larger scale potato canning operation, Bough (1975) found that 93.6% of the effluent solids were from the lye peeler and reel washer. Shirazi (1979) quantified and characterized effluents from a french fry manufacturing plant and recommended measures to reduce water usage .

B. Recovery, Utilization, and Disposal of Potato Wastes

The environmental problems and the methods of treatment and disposal of potato processing effluents were outlined by Pailthorp et al. (1975). Moon (1980) discussed areas in which waste products from food processing might be accommodated: 1) application of processing or recovery technologies; 2) anaerobic or aerobic waste digestion methods prior to disposal; and 3) as animal feed. The latter method is often desirable because it is inexpensive and the waste is recycled in the food system, substituting for foodstuffs normally fed to humans. In addition, animals may often assimilate materials which humans cannot.

Several methods for the recovery of protein from potato processing effluents were explored by Meister and Thompson (1976). 30-40% of the crude protein currently discharged as waste was recoverable by any of the methods, with heating at pH of 4.0-4.5 being the most efficient, and economical when combined with starch recovery. Rosenau et al. (1978) developed a pilot plant process for separation of cull potates into starch, pulp, and a juice which may be further processed to a high quality protein powder and a molasses-like liquid for animal feed. Economically feasible application of the process would depend on a relatively constant supply of culls or similar material on the order of 500 tons per day. A processing method of concentrating starch effluent streams by evaporation and spray drying has been developed (Strolle et al., 1980). Profitable use of this method would be limited by properties of the effluent, the end use of the by-product, and the sharp rise in energy costs. Producing a poultry ration from the effluents is no longer economically feasible, whereas use as a fermentation medium is a realistic possibility. In their discussion of technical and environmental factors to consider in the utilization of waste from french fry manufacturing, Kamm et al. (1977) recommended the production of dextrose and recovery of starch as being high-profit, low risk operations. They cited uncertain technical experience as a problem in the production of single cell protein, and low return rate and sensitivity to commodity price fluctuations as risks in production of ethanol or molasses.

Options for treatment and disposal of a potato dehydration plant's effluents were discussed by Richter et al. (1973). The aerobic digestion treatment (producing activated sludge) in use reduced the food value of the bio-solids, a consideration if they were to be used as feed rather than for landfill. Alternate treatments studied included spray irrigation and a series of centrifugation, vacuum filtration, and drum drying stages.

Beauchat et al. (1978) and Sistrunk et al. (1979) studied fungal and bacterial fermentations, respectively, as procedures for pretreatment of the high-alkalinity lye-peeling effluents from potato processing plants. Beauchat et al. (1978) felt that positive future prospects existed for the sale of food waste protein products of single-cell protein recovered from such activated sludge treatments. Larkin et al. (1981) investigated the appropriateness of waste activated sludge biosolids from potato and corn snack food processing wastes as beef cattle feed. Results indicated that the biosolids are utilized in a manner similar to soybean meal and are suitable as a low-cost protein supplement. A successful program of land application of potato processing waste-activated solids was implemented by Mickelson et al. (1980).

The cost, marketing, and technological considerations needed to determine the advisability of waste product utilization measures for the food processing industry were outlined by Burch et al. (1963). Figure 1 illustrates some of the cost factors involved in a typical utilization route. They found little economic recovery value in potato chip processing wastes, since the moisture content is high and the food value for dairy cows is low, but centrifugation to remove starch from waste waters and having farmers haul away solid wastes for feed would each decrease municipal water treatment costs.

Potatoes have been used extensively for ethanol production and other purposes in Europe, but are underutilized in the United States. This is due to availability of raw material and costs of recovery of potato by-products have in the past exceeded expected returns (Leite and Uebersax, 1979). Knight (1969) and Treadway (1975) outlined the many applications of potato starch, including adhesives, paper milling, food additives, and textiles.

II. The Potato Peeling Operation

A. Peeling Requirements

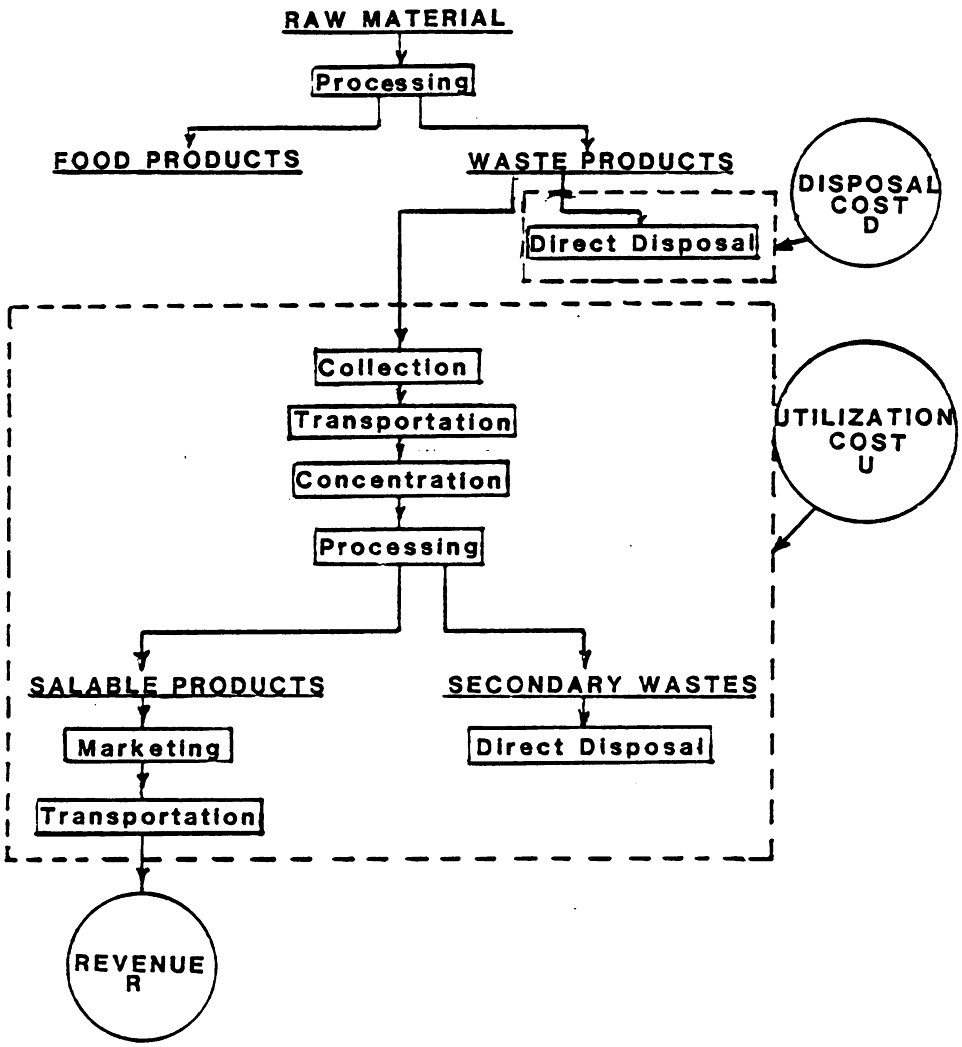

Figure 1: Steps contributing to the cost of waste product utilization

(Source: Burch et al., 1963)

The objectives of any peeling operation are to 1) remove a minimum amount of the potato's outer layer; 2) peel to the extent that the final product requires; 3) minimize the amount of hand trimming required to remove peel, eyes, or damaged tissue; 4) minimize heat or chemical damage to the product; 5) minimize energy, chemical, and water usage; and 6) minimize the pollution load for the process (Huxsoll and Smith, 1975; Feustel et al., 1964).

Peel losses will vary widely, however Huxsoll and Smith (1975) broadly classified losses for various products as:

Typical Peel Losses	
Canned small potatoes	40-50%
Prepeeled potatoes for restaurants	20-30%
French fries	10-20%
Dehydrated mashed potatoes	5-10%
Potato chips--early season	2-5%
Potato chips--late season	8-12%

The cut potato products do not require as complete peel removal as whole potatoes; with more surfaces created by slicing, defects such as flecks of peel or discoloration become less apparent (Harrington et al., 1956). In potato chip manufacture, the slices are so thin that a considerable amount of residual peel may be tolerated, or the potatoes may not be peeled at all. At the other extreme, whole prepeeled potatoes may be cleanly peeled and almost totally free of discoloration or defects. While french fries should be well peeled, some defects are tolerated for the highest grade of product. Thus, if the potatoes are overpeeled, the processor's yield is reduced and the product grade is not increased (Huxsoll and Smith, 1975).

Willard (1971a) standardized a seven-point visual grading scale for peeled potatoes with which the quality of a processor's peeled potatoes would be compared. The peeler operating conditions could subsequently be adjusted to obtain the desired peeling quality. Proper sampling for this type of test is critical: a wide range of peeling quality will be exhibited for a particular lot of tubers. For maximum efficiency, a small percentage of the potatoes must be underpeeled and require handtrimming; otherwise low yields would result (Harrington et al., 1956).

Feustel et al. (1964) indicate that if labor costs are high in comparison to raw material costs, then higher peel losses are allowable. However, any raw material saved by decreasing peel losses would show up as increased recovery, less of a waste disposal problem, and higher profits (Huxsoll and Smith, 1975).

B. Influence of Raw Material on Peeling Losses

For adequate peeling of potatoes, peel losses decrease with increasing size (mass) of the tuber since surface area

increases at a slower rate than volume (Adams et al., 1960; Dow, 1931). Harrington et al. (1956) and Dow (1931) report that sorting of potatoes before peeling is of value to the processor. Peeling potatoes of fairly uniform size decreases peel losses since small potatoes are not overpeeled in order to adequately peel the large potatoes.

Peel losses for adequate peeling will vary greatly depending on the variety of potato used. Desirable potato varieties are those with the following qualities: thin skin, few and shallow eyes, and regular shape, especially for mechanical peeling methods (Harrington et al., 1956). Wright and Whiteman (1949) reported that different varieties and different lots of the same variety possess textural characteristics that would render the underlying potato tissue more susceptible to abrasive action and thus increase peel losses. Mechanical peelers will wear down knobs and surface irregularities, tending to leave potatoes oval or oblong. Undesirable tuber shapes are therefore cylindrical, pancake, misshapen, or concave (Dow, 1931).

Reeve (1976) found that for chemical (caustic) peeling, varieties with russeted skin (such as Russet Burbanks) are most suitable. Reeve (1974, 1976) studied the periderm development of russeted varieties with histochemical tests. With suberization, the forming of corky layers of cells containing suberin, the skin acts like a sponge, holding the caustic and limiting further lye

penetration into the potato. Prematurely harvested potatoes do not have a mature skin layer; with flaking of peel during harvesting and handling, lye will penetrate quickly into those areas where the russeted layer is not fully developed, thus causing excessive peel losses.

With longer periods of storage of mature potatoes, thicker skins form and peeling losses required for adequate peeling greatly increase (Jeppsson and Robe, 1965; Mazzola, 1946a). If storage relative humidity is too low, potatoes tend to become rubbery and wrinkled, with decreased yields during peeling (Mazzola, 1946a). If potatoes are damaged during harvesting or handling, large moisture losses will occur through abrasions in the skin. Graham et al. (1969a) reported that surface blemishes and poor storage practices may double peeling losses.

The distribution of solids in the potato is an important factor in the amount of losses due to peeling. Figure 2 is an illustration of an idealized longitudinal tuber section, showing tissue zones. Table 2 illustrates the solids content of the potato zones, as well as the distribution of total material and total solids in the various zones, as determined by Reeve et al. (1970). As indicated, the cortical tissue has the highest total solids content, 23.47%. Also, the two exterior zones, the periderm and the cortical tissue, approximately 6mm deep, account for 45.88% and 47.5% of the total mass and total

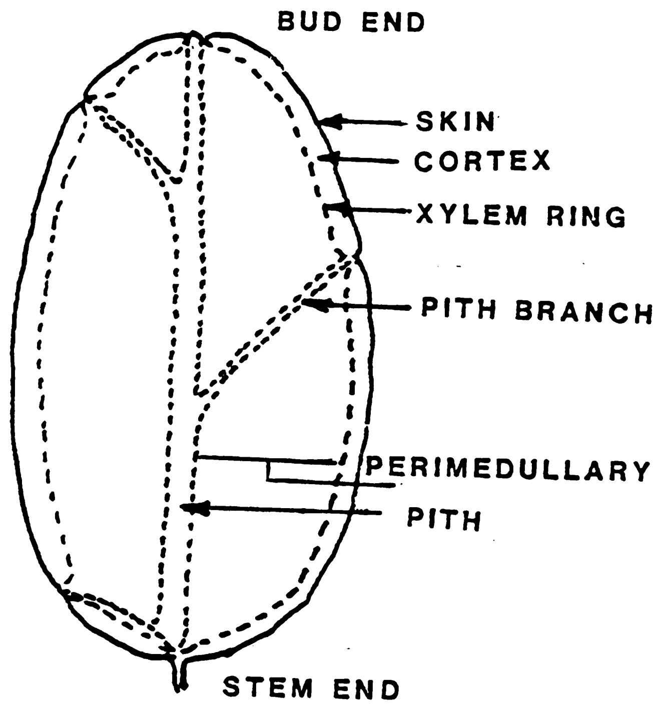

Figure 2. Idealized longitudinal section of tuber showing tissue zones

(Source: Reeve et al., 1970)

Table 2. Distribution of fresh weights and total solids in whole tubers[1],[2]

	Periderm	Cortex	Perimedullary tissue	Pith
Total solids in tissue zone, %	18.6	23.47	21.94	16.16
Fresh weight of whole tuber, %	3.88	42.0	50.5	3.6
Total solids of whole tuber, %	3.2	44.3	49.8	2.6

(1) Source: Reeve et al., 1970.

(2) Tubers were Russet Burbank, average weight = 241.5 g

solids, respectively, of the potato. By modeling a potato, Reeve (1971) estimated that if 3mm of cortical tissue (55% of the cortical tissue volume) were removed in peeling, 25-30% of the potato's solids would be lost.

C. Peeling Methods

1. Abrasion Peeling

Abrasion peeling is a mechanical method of peel removal in which abrasive surfaces grind away skin from the potatoes and water sprays flush away the loosened peel. The peeling system may be batch or continuous. For continuous peelers, the potatoes pass through a tunnel of revolving abrasive rollers. The rollers may be gritted or rubber rolls, or cylinder brushes, depending on the condition of the skin and the desired finished product texture (Huxsoll and Smith, 1975; Grieg and Manchester, 1958: Mazzola, 1946b).

The abrasive peeling method by nature grinds irregular surfaces toward a regular shape; the process will either tend to remove excess amounts of potato flesh or leave much unpeeled surface (Mazzola, 1946b). Therefore, abrasive peelers are best used for 1) relatively smooth potatoes; 2) canned potatoes, for which a final small, round product is desired; or 3) potato chips, for which thorough peel removal is not a requirement. An advantage of the abrasive method is that there is no heat or chemical damage to the product (Huxsoll and Smith, 1975).

Relatively high material losses can be expected for good peeled quality with abrasive peeling. 33-40% losses for quality abrasive peeling, depending on production rates, were reported by Mazzola (1946b). Wright and Whiteman (1949) indicated that peel losses could range from 11 to 37% depending on the variety and growing location of the potato. Harrington et al. (1956) found that thin- and thick-skinned potato varieties had 9 and 25% peel losses, respectively. Grieg and Manchester (1958) reported 30% and 40% peel and trim losses for thin- and thick-skined varieties. Abrasive peeling has low operating costs, 20% of the cost (for water, gas, chemicals and electricity) required to peel the same quantity of product by lye peeling methods (Grieg and Manchester, 1958). Depending on production rate, water use is only 33-40% of that for lye peeling, electrical use is 58-62%, and there is no chemical or gas use.

As discussed in an earlier section, abrasive peeling waste is high solids, high BOD effluent and thus presents a significant waste disposal cost to the processor.

2. Caustic Peeling

In conventional caustic (lye) peeling, chemical attack and thermal shock are used to loosen potato skin. Potatoes are immersed in a hot (54 to 104C) concentrated (15 to 25%) solution of sodium hydroxide. The peel is apparently loosened as a result of gelatinization, and the depth of

tissue affected is determined by the residence time in the caustic bath (3-8 min). The peel and lye-affected tissue is then removed with high pressure water sprays (Graham et al., 1969b; Feustel and Harrington, 1957; Harrington et. al., 1956).

With caustic peeling, peel losses are less influenced by the shape of the potato than with abrasive peeling. Skin is removed uniformly, even from the eyes, and less hand labor is required for trimming and inspection. Harrington et al. (1956) reported 14% and 25% peel losses with thin- and thick-skined varieties, respectively. Grieg and Manchester (1958) reported 21.5% and 26.3 % losses, including trimming..

At high temperatures (greater than 74C), the surface layer of the potato is gelatinized (forming a "heat ring"). This cooked layer may become tough during subsequent storage of the potatoes, and the probability of discoloration due to enzymatic activation and microbial spoilage during holding is high (Harrington et al., 1956). Dunlap (1944) recommended a precook stage in the peeling operation so that a 3/8 inch surface layer of tissue would be heated enough to inactivate enzymes and also facilitate peel removal. In order to minimize or eliminate discoloration and heat ring, lower temperature lye treatments have been recommended. In order to achieve adequate lye penetration at lower temperatures, Lankler and

Morgan (1944) suggested use of chemical wetting agents and Muneta and Jennings (1978) recommended two separate lye immersions, with a holding period between.

Since peelings from conventional caustic peeling systems are removed with water, the processors are faced with a large waste disposal problem. Primary waste treatment recovers about 50% of the peel as settleable solids. After neutralization from a pH of 10.5 to 7.0, the peel solids may be sold as livestock feed. The remaining effluent with its high organic solute level requires secondary waste treatment. Disposal of the final effluent (from secondary treatment) by spray irrigation or discharge into rivers may be limited due to the high sodium content (Muneta and Shen, 1972).

A "dry caustic" or infrared caustic peeling method has been developed to alleviate the disposal problem of lye peeling effluents: potatoes are immersed in a less concentrated lye solution (12-14%) at a lower temperature for a shorter period, and then exposed to infrared radiation (for about 1-3min at 870C) (Anon., 1970). The infrared heating accelerates caustic destruction of the peel, and the peel, dried from the heat, flakes and is easily removed mechanically (Smith, 1970). Low pressure water sprays or immersion remove final peel residues and residual heat.

Since the lye immersion stage may be at low temperature and if the potatoes are peeled quickly after infrared heating, no heat ring should develop with this peeling method (Graham, et al., 1969a; Willard, 1971b). The radiant heat is preferentially absorbed by the darker, defect areas of the potato's surface, facilitating lye penetration and peel removal in areas that would otherwise require hand trimming (Smith, 1970). Reeve (1974) estimated that 6-12% peel losses should provide adequate peeling for mature potatoes, with higher losses expected for tubers with immature and flaking peel.

Nearly all of the peel waste is in the form of a high solids paste that can be conditioned for use as an animal feed, burned or buried (Graham et al., 1969b). Only about 5% of the peel residue will require removal by the water sprays; this may be incorporated into the mass of peel, thus eliminating all peel waste from the plant effluent (Smith, 1970). Waste disposal costs are significantly decreased by eliminating the peel wastes from the plant effluent; Smith (1970) estimated that a typical potato processor can reduce solids in the plant effluent by 50-75%.

The water requirement for infrared caustic peeling is about 5% and 8-10% of that for conventional caustic and steam peeling, respectively. Caustic use is 20-30% of that for conventional lye peeling since more dilute solutions and shorter times are used (Smith, 1970). Cyr (1971) compared operating costs for the two methods of lye peeling. Grieg and Manchester (1958) illustrated how the lower peeling losses of caustic peeling methods are balanced by the higher capital and operating costs, as compared to abrasive peeling.

3. Steam Peeling

In steam peeling, potatoes are subjected to high pressure steam which rapidly heats and softens peel and underlying tissue. After adequate heat is applied, the pressure is quickly released, resulting in sudden evaporation of the moisture in the heated tissue, further loosening the peel. Water sprays or rubber rollers remove softened tissue from the potatoes (Talburt and Smith, 1975; Anon., 1944). Details of the operation of a rotating batch steam peeler have been published (Anon, 1980a).

Smith (1980) studied the effect of flash cooling with direct injection of cold water into a high pressure steam peeling chamber on the quality of sweet potato peeling. The flash cooling method decreased peel losses from 26% to 19%, decreased the heat absorption into the sweet potato, and slowed enzymatic discoloration significantly.

Willard (1971b) reported that steam peeling does not remove peel from eyes or defective areas efficiently. It has been recommended that steam penetration of 3/16 in. removes practically all skin and makes subsequent removal

of eyes and defects easier. Time of exposure to the high pressure steam must be carefully controlled to avoid cooking too deeply into the potato. Huxsoll and Smith (1975) indicated that the heat ring from steam peeling may be substantial. A nearly linear inverse relationship was found by Boyen (1950) between temperature of superheated steam and time of exposure necessary for good peeling. He reported that heat absorption, which should be avoided because of its malicious effect on the quality and physical appearance of the product, is minimized with higher steam temperatures. He reported that excellent results were obtained for new potatoes at 343C for 80 seconds and for old potatoes at 399C for 180 seconds.

Brown (1944) reported a range of peeling losses for steam peeling of 7.6-12.8%, depending on potato variety. Mazzola, (1946b) indicated that peel losses of 26% were average for potato processors using steam peeling, with greater losses resulting from unsorted or low grade lots. Higher peeling losses may be expected with steam peeling if potatoes have many defects or bruises (Muneta and Shen, 1972). However, steam peeling is advantageous in that no chemicals are used so that treated wastes can be spray irrigated. Also, if rollers rather than water sprays are used to remove peels from the potatoes, the waste disposal problem for a potato processor is further reduced (Huxsoll and Smith, 1975).

III. Energy Accounting

Rippen (1975) reported that the food system commands 12.8% of U.S. energy use, and that the ratio of energy input to energy consumed has risen, for 1940 to 1970, from 3:1 to 7:1. Unger (1975) observed that 3.6% of the country's energy in 1970 was used for food processing. A major component of energy usage in the food system, 28-36%, was for the processing stage

Due to the decreasing availability and increasing cost of fuel, there is a demonstrated need for energy-oriented research in the food industry. This research should quantify energy flow patterns and would be extremely useful in setting priorities regarding benefits from possible energy conservation measures (Singh, 1978).

Barton and Lutton (1979) found that food processing accounted for 7.6% of total manufacturing fuel usage and electricity consumption in the country in 1970. They emphasized the importance of the availability of complete profiles of energy use in food processing groups to government and business. This information is necessary for energy policy formulation for short-term and longer-term shortages.

Unger (1975) profiled energy use in selected industries, and discussed factors which would vary energy requirements, indicating potential energy saving measures. Food process energy requirements, areas of energy waste, and methods of recovery of waste energy were outlined by Doe (1977). Rippen (1975) and Rao et al. (1978) suggested general energy conservation measures including boiler maintenance, insulation and regenerative heating.

Energy analysis of food processing has been a subject of several recent studies. These include identification and measurement of energy use and measures for reducing energy consumption in spinach processing (Chhinnan et al., 1980) and in yogurt and sour cream manufacturing (Brusewitz and Singh, 1981). Romero et al. (1981) studied the energy intensive operations in apple processing and determined thermal energy efficiencies of an evaporator and appleauce cooker. Potential opportunities for energy conservation were suggested. Sources and magnitudes of thermal energy losses in sauerkraut manufacture were examined by Rao et. al. (1976). Fuels for thermal energy accounted for 86% to 90% of total plant energy costs; conservation measures were suggested which would reduce thermal energy use by 6-33%. Singh et al. (1980) identified the energy intensive operations in canning of tomato products, using energy accounting methods. Steam represented over 95% of the plant's total energy demand.

Bomben (1977) used material and thermal energy balances to calculate theoretical effluent generation and energy use in blanching and cooling operations, with this information being useful for judging the performance of blanchers.

Waste heat was used for regenerative heating at a potato chip manufacturing plant in Scotland. Recovered steam (evaporated from potatoes) was used to heat blancher water and for space heating, reducing by 25% the plant's energy use (Anon., 1980b).

Accounting of total energy required, from harvest to consumption, to produce a serving of mashed potatoes by ten different processing/marketing modes was conducted by Olabade, et al. (1977). Frozen and freeze-dried potatoes had the highest energy requirements. The wide difference in energy requirements suggests a need for energy accounting in the decision making for product development, processing, marketing and preparation.

Singh (1978) outlined procedures for conducting energy accounting and presented two case studies illustrating the usefulness of energy analysis. Singh (1977) conducted a thermal energy balance on a continuous atmosphere retort. Examples of thermal energy calculations required for an energy balance and methods for improving the thermal efficiency of the operation were presented. Experimental procedures for accurate measurement of steam flow using orifice meters and for determination of steam quality were presented by Singh (1980).

THEORETICAL CONSIDERATIONS

The mass and thermal energy analyses conducted in this investigation are based on fundamental concepts of mass conservation and energy conservation. By applying these concepts to a specific unit operation, such as potato peeling, observations related to the efficiency and effectiveness of the operation are possible.

The conservation of mass law indicates that:

$$\text{Mass of Inputs} - \text{Mass of Outputs} = 0 \qquad (1)$$

For a potato peeling operation, the basic equation for mass conservation requires that all mass inputs and outputs be defined. Based on observations of a steam peeling operation:

$$M_i + M_s + M_{sw} - M_e - M_p - M_{pc} - M_w - M_n = 0 \qquad (2)$$

By measurement of components in equation (2), the fate of various components of input streams is established and insight into the conversion efficiency for the process is provided. In addition to the conversion of raw product into primary product, a mass balance analysis will assist in identifying the output streams containing important product components.

The thermal energy balance is based on the concepts of energy conservation and the following general expression:

$$\text{Thermal Energy In} - \text{Thermal Energy Out} = 0 \qquad (3)$$

The application of the energy conservation law to potato peeling results in:

$$Q_i + Q_s + Q_{sw} - Q_e - Q_p - Q_{pc} - Q_w - Q_c - Q_r - Q_n = 0 \quad (4)$$

where input and output streams for thermal energy are identified with the same subscripts as equation (2). Two additional output streams for thermal energy include convective heat losses from the peeler surface (Q_c) and radiative heat transfer from the peeler surface (Q_r). Electrical energy inputs necessary for operating the potato peeling equipment will be considered to have negligible influence on the thermal energy balance. In addition, conduction losses through supporting equipment will be assumed to be minor due to the small conduction surface area.

For all streams containing product mass or water in liquid state, the following general equation describes the thermal energy content:

$$Q = M\, c_p\, (T - T_{ref}) \quad (5)$$

The mass (M) of the input or output stream will be the same as included in equation (2) and specific heat will be predicted. The temperature (T) of the stream must be measured and the reference temperature (T_{ref}) will be 0C in order to correspond to standard steam tables. The equation for the input steam will be:

$$Q_s = h_c\, A\, (T_{sh} - T_{\infty}) \quad (6)$$

where the quality (X) of steam utilized in the peeling process is incorporated.

The thermal energy losses from the surface of the peeling vessel due to convection and radiation required use of more involved expressions. The convective heat transfer from the vessel surface can be estimated by:

$$Q_c = h_c A (T_{sh} - T_{\infty}) \qquad (7)$$

where h_c is a convective heat transfer coefficient to be determined from the following correlations:

$$N_{Nu} = \phi (N_{Gr} N_{Pr})^m \qquad (8)$$

and:

$$N_{Gr}N_{Pr} = \frac{\rho^2 g \beta (T_{sh} - T_{\infty}) L^3 c_p}{k \mu} \qquad (9)$$

where the properties in equation (9) will be for air near the exterior surface of the vessel and at a mean temperature for the vessel surface (T_{sh}) and the surrounding air (T_{∞}) (Holman, 1976). The constants used in equation (8) will be for free convection from an isothermal vertical cylinder.

The heat transfer from the vessel surface due to radiation would be estimated from:

$$Q_r = h_r A (T_{sh} - T_{\infty}) \qquad (10)$$

with:

$$h_r = 0.0069\epsilon\left(\frac{\theta}{100}\right)^3 \qquad (11)$$

These expressions will apply when the vessel is small in comparison to the room containing the peeling operation (Earle, 1966).

EXPERIMENTAL PROCEDURES

I. Description of the Peeling Operation

All of the data and sample collection was conducted at a potato processing plant where the primary product is frozen french fries. All potatoes were peeled during processing, using a high pressure steam peeler. A schematic of the peeling system is shown in Figure 3.

The peeling system operates semi-continuously; during each cycle a pre-determined weight of potatoes which has accumulated in a weighhopper is transferred through the top of the vertical steam vessel. The vessel door closes, steam is introduced and the vessel rotates. At the end of a preset time, the steam valve closes, the exhaust valve opens, and the vessel stops rotating. After an exhaust period, the product is dumped from the steam vessel and is transported up a 2.1m inclined screw conveyor. (During each cycle of the peeling system, a small quantity of condensed steam mixed with peel flows out of the bottom of the screw conveyor.) The product then drops 1.5m through a stainless steel chute and is conveyed through a 2.4m inclined belt and brush peel removal apparatus. The peel, already loosened from the steam treatment, is rubbed away from the potatoes and conveyed down to the base of the equipment where it is discharged. After passing through this equipment, the potatoes are final-washed in a 3m spray

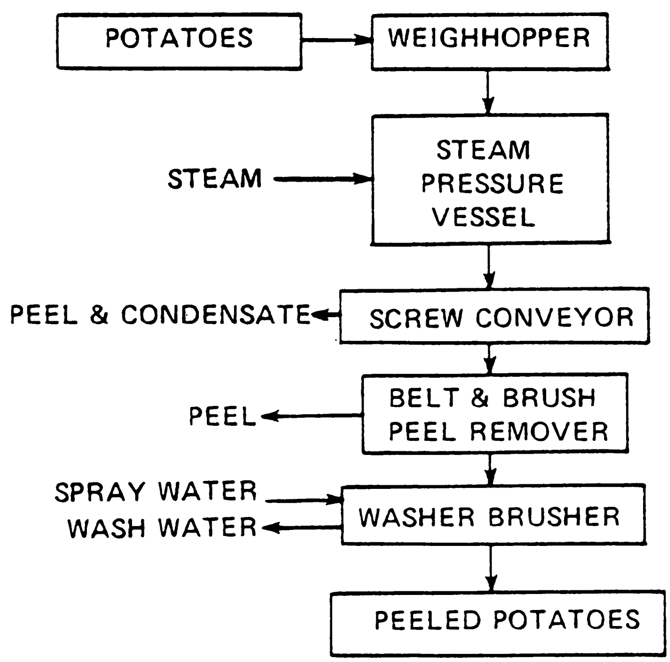

Figure 3. Schematic of the steam peeling operation for potatoes

washer/brusher apparatus, and emerge continuously as the final-peeled product.

Peeling is thus accomplished as a result of a number of actions on the potatoes during the peeling cycle: the thermal treatment (approximately 205C), the tumbling action of the steam vessel, the large pressure drop during exhausting, the abrasion and rubbing of belts, brushes, and rollers, and the water sprays.

II. Data Collection

Data collection took place over a period of 9 weeks (from 9/23/81 to 11/17/81) on 8 separate dates. On each day, either one or two data collection trials were conducted, with a separate material and thermal energy balance to be conducted for each of 14 trials. Appendix 1 shows a sample data collection sheet.

A. Determination of Raw Material Characteristics

For each lot of potatoes being processed during data collection periods, information was gathered about the condition of the raw material. The plant personnel made available the Michigan Department of Agriculture grading results for each lot, from which the following data was obtained:

1. Potato variety
2. Growing location
3. Percent of lot with serious external defects
4. Percent of lot graded #1 potatoes

In addition, the plant personnel indicated whether the potatoes had been stored before arriving at the plant, how long the potatoes had been held prior to processing, and whether the potatoes being run were "smalls" (undersize potatoes sorted out from normal operations).

Visual observations of the condition of the raw material were recorded, such as noticeable levels of "greening," bruising, damage, or suberization (development of a thicker, corky skin).

For each lot, fifteen consecutive unpeeled potatoes were collected before they entered the weighhopper. The average mass of those potatoes was determined. The average length, width, and height of the sampled potatoes were also determined. These determinations could be used to predict the volume of the potatoes, using an ellipsoid model for the potatoes' shape, where:

$$V = \frac{4}{3}\pi abc \qquad (12)$$

The length, width, and height were used to calculate the location where the mass average temperature of an average potato could be measured. Smith et al. (1967) developed a correlation to determine this location, based on the geometric index of the object:

$$G = .25 + .375/A^2 + .375/B^2 \qquad (13)$$

where A = a/c and B = b/c. The location of the mass average temperature,

$$L_{ma} = G^{.14} - .25 \qquad (14)$$

is the fractional distance along the half-height axis, measured from the outer edge of the object.

The specific gravity of the potatoes being processed was determined using the potato chip hydrometer developed by Smith (1975). Eight pounds of potatoes were placed in a wire basket and the basket was suspended from the bulb of the hydrometer. When the sample and apparatus were placed in a container of water, the specific gravity reading was obtained at the water level on the chart visible inside the tube.

B. Measurement of Mass

In order to obtain information required for a mass balance of the peeling system, measurements were obtained for flow of all inputs and outputs during one cycle of the peeling operation.

The total mass of potatoes into the system during one trial was indicated by the dial connected to the hydraulic load cell for the weighhopper. In all cases, the mass was 226.8 kg (500lb).

The mass of steam into the peeling vessel was determined from the volume of the vessel (from the manufacturer's information) and the specific volume of steam at the pressure and quality delivered by the plant's steam generation system. The steam pressure, read from a gage in the steam line, was the highest pressure reached during the cycle's steam time, and the steam quality was

based on information provided by plant personnel. Figures 4 and 5 represent the range of values of specific volume and enthalpy (used for thermal energy determination, part IV) that would be obtained from steam tables, depending on the actual quality of steam generated at the plant and the steam pressure.

A water meter was installed to determine the flow rate of water into the spray washer/brusher equipment. Since this equipment operates continuously, the mass of water into the system was converted to a per-cycle basis by multiplying the flow rate by the time for one complete cycle.

The mass of peeled potatoes leaving the peeling operation as product during one cycle was determined as:

$$M_e = \left(\frac{100 - \%\ \text{peel loss}}{100}\right) M_i \qquad (15)$$

The percentage of peel loss was established using a method standardized by Weaver et al. (1979). Twelve potatoes of the average mass of the lot (±15g) being processed were weighed, marked with vegetable dye, peeled under normal operating conditions, and reweighed. Potato tissue loss was calculated as:

$$\%\ \text{loss} = \frac{M_i - M_e}{M_i} \times 100\% \qquad (16)$$

Use of this test as an accurate method of accounting for potato tissue losses is based on the assumption that minimal water is absorbed by the potatoes during the steam

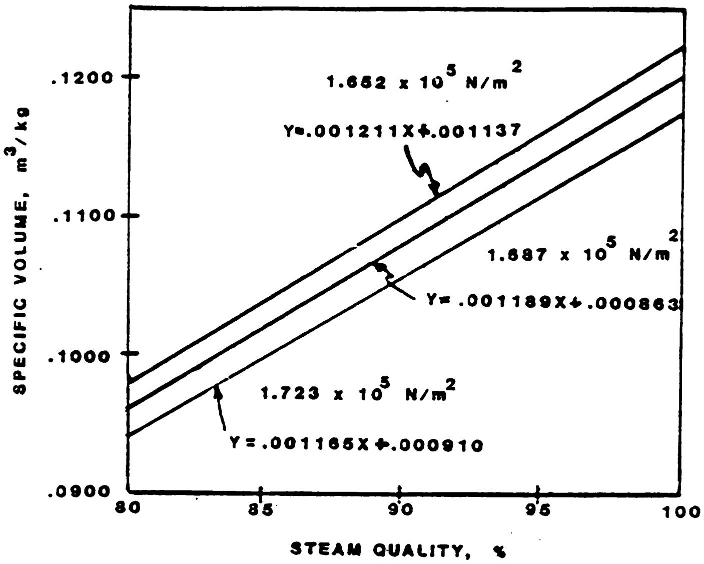

Figure 4. Range of values of steam specific volume for varying steam quality and pressure

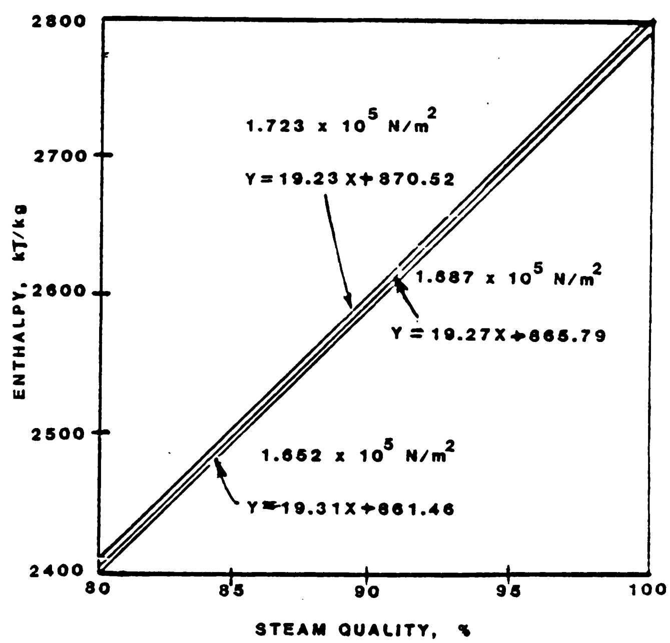

Figure 5. Range of values of steam enthalpy for varying steam quality and pressure

peeling cycle.

The mass of the peel waste stream was determined by collecting and weighing the peel discharged from the belt and brush peel removal equipment during a given period, and converting the peel flow rate to a per-cycle basis. However, quantitative collection of the peel waste was not possible for 10 of the trials, since a portion of the waste retrieval equipment was not operating. Therefore, the mass of peel lost during the cycle was estimated by difference after calculating a total material balance of the peeling system. Comparison of the measured and estimated peel mass values for the 4 trials where all the equipment was functioning properly indicated that the difference method was sufficient for the purposes of this experiment. All further calculations and discussion are based on the estimated, rather than measured, peel mass values, unless otherwise indicated.

Another source of waste from the system was the stream of peel and condensate leaving from the base of the screw conveyor. This material was collected and the mass per cycle was determined.

The wash water exiting from the washer/brusher equipment was also collected, measured, and expressed on a mass-per-cycle basis.

The loss of mass from the system as water vapor during exhausing and at other stages in the peeling operation was recognized but such losses could not be measured directly.

C. Temperature Measurements

In order to calculate a thermal energy balance for each trial, appropriate temperature measurements were taken during the the data collection periods. The temperature of the whole potatoes, both unpeeled and peeled, were determined using a dial thermometer inserted to a depth representing the mass average temperature of the object. The temperatures of the spray water, peel, peel and condensate, and wash water streams were measured using a dial thermometer inserted into a sample of the material that was collected. The temperature of the steam peeling vessel was determined with a contact pyrometer, a temperature measuring device for flat surfaces. Measurements were taken when the vessel had stopped rotating, both before and after the release of steam from the vessel. Fluctuations of the vessel temperature were not detectable during this time. The temperature was determined near the midsection of the vessel, the only area readily accessible for measurement. It was therefore necessary to assume that the vessel surface was isothermal.

D. Determination of Peeled Potato Characteristics

In order to interpret the quality of the peel removal during each trial, observations relating to the peeled product were recorded. The depth of the translucent, "cooked potato" layer was determined, as an indication of the extent of heat absorption into the peeled product. The specific gravity of the peeled potatoes was determined using the potato hydrometer. A subjective visual grading of the extent of peel removal was made, based on Willard's 7-point scale (see Appendix 2).

E. Sampling

Representative samples of the unpeeled and peeled potatoes, peel waste, peel and condensate, and starchy wash water were collected for each trial. Samples were put in labelled, heavy weight one gallon freezer bags, stored in styrofoam chests, transported from the plant to the laboratory, and frozen immediately at -20C.

III. Chemical Analysis

In order to compute component balances for each trial, all samples were analyzed for total solids, starch, and ash contents. Samples were thawed at room temperature for approximately 2 hours, and ground or blended thoroughly in a Waring blender. Approximately 1 kg of each sample was prepared; all analyses were conducted in triplicate.

A. Total Solids (Total Moisture)

Approximately 15 g of sample were dried in porcelain crucibles at 70C in a vacuum oven with a pressure of less than 50 mm Hg. (AOAC, 1980). The samples were dried until a decrease in weight of less than .5 mg was observed. The solids content was calculated as:

$$\%\ \text{Total Solids} = \left(\frac{\text{Final Sample Mass}}{\text{Original Sample Mass}}\right) \times 100\% \quad (17)$$

The moisture content was calculated as:

$$\% \text{ Moisture} = 100\% - \%\text{Total Solids} \qquad (18)$$

B. Ash

The dried samples (in their crucibles) from the total solids determination were placed in a muffle oven at 525C (AOAC, 1980) and left until a white ash was obtained, approximately 24 hours. The ash content was calculated as:

$$\% \text{ ash, dry basis} = \left(\frac{\text{Mass of ash}}{\text{Mass of solids prior to ashing}}\right) 100\% \qquad (19)$$

C. Starch

The starch content was determined using a polarimetric method developed by Dimmler (Joslyn, 1970). A sample of about 8g of ground potato was weighed into a test tube. Sample preparation proceeded as outlined by Joslyn, with the stannic chloride pentahydrate solution used in place of uranyl acetate solution. The optical rotation of the prepared sample solution was determined using a Perkin-Elmer Model 141 polarimeter. The starch content of the sample was calculated using the equation:

$$\% \text{ starch, dry basis} = \frac{a \times 10^6}{1 \times [\alpha]_D \times w \times \%TS} \qquad (20)$$

where: a = observed angular rotation
l = length of the optical cell, dm
$[\alpha]_D$ = specific rotation of starch (for potatoes, 203.0)
w = sample weight, g
% TS = Total Solids content, determined in Section A

IV. Calculation of Material and Thermal Energy Balances

Material balances were conducted for each trial of data collection using equations (1) and (2) (Theoretical Considerations). Material balances were conducted for total mass, total solids, starch, and ash, for each trial, and in all cases the basis was 226.8 kg (500 lb.) of incoming unpeeled potatoes. Appendix 3 shows a sample calculation of a mass balance.

Thermal energy balances were obtained by determining the flow of thermal energy in each of the mass input and output streams, and by calculating convective and radiative losses from the surface of the steam peeling vessel.

Thermal energy flow per cycle for steam (Q_s) was calculated from equation (6). Figures 4 and 5 indicate how the steam enthalpy and specific volume would vary, depending on what quality of steam was being used. Thermal energy flow for the unpeeled potatoes, peeled potatoes, potato peel, peel and condensate, spray water, and wash water streams was calculated from equation (5). The specific heat (c_p) for each material was determined from a relationship presented by Dickerson (1969):

$$c_p = .400 + .006(\text{Moisture Content,\%}) \qquad (21)$$

The radiative losses (Q_r) from the shell of the peeling vessel were calculated from equations (10) and (11), with the emissivity value, ϵ, taken from Holman (1976) for sheet steel with a strong, rough oxidized layer.

The convective losses (Q_c) from the peeling vessel were calculated from equations (7), (8), and (9). The empirical constants ϕ and m taken from Holman (1976) are for free convection from vertical cylinders with isothermal surfaces. Free convection was assumed since the vessel was stationary during the majority of the peeling cycle. When the vessel was in motion, the velocity of rotation was relatively low, and thus free convection effects were fairly important in comparison to forced convection effects.

Miscellaneous losses (Q_n) of thermal energy from the peeling system were determined by difference, using equation (4).

Appendix 4 shows a sample thermal energy balance calculation.

V. Statistical Methods

For instances when a relationship between two variables was desired, least squares linear regression was performed. Slopes and intercepts for a prediction equation were obtained and the significance level, α, of the slope was obtained using a T-test and a statistical program supplied by Texas Instruments. Standard errors of the estimate and also of the regression coefficient were calculated. The run test (Crow et al., 1960) for randomness of deviation ($y_i - y_i'$) of predicted values from the fitted regression line was used as a crude test of linearity of the relationships drawn between two variables.

RESULTS AND DISCUSSION

Mass balances (total and component), thermal energy balances, raw material characteristics, and processing conditions for each of the 14 trials of this investigation are summarized in Appendix V.

I. Raw Material Characteristics

Characteristics of the potatoes, as mean values and ranges, used during this investigation are shown in Table 3. The range of mass of an average potato was large since for two trials, potato "sortouts" were processed. These potatoes, graded out from several lots of potatoes because of their small size, were processed as a group. These sortouts had rather low specific gravities, as expected, since small potatoes tend to be more immature and thus lower in density (Smith, 1975).

Average potato volumes were calculated both by the ellipsoid model method and by dividing the average potato mass by the specific gravity. The ellipsoid method gave potato volumes 32%, on average, lower than for the specific gravity method, probably due to the lack of uniformity of the potato shapes. The volumes calculated by the specific gravity method were used in calculations where volume was required (i.e., for determining fill of the peeling vessel).

Table 3. Raw Material Characteristics of Potatoes Processed During this Investigation[1],[2],[3]

Parameter	Mean	Range
Mass, g	276	125 - 502
Volume, cm^3 [4]	255	116 - 463
Volume, cm^3 [5]	185	87 - 302
Sp. gr.$_{\text{raw potatoes}}$	1.0820	1.0775 - 1.0860
Sp. gr.$_{\text{peeled potatoes}}$	1.0840	1.0780 - 1.0870
Length, cm	10.0	7.2 - 12.0
Width, cm	6.8	5.6 - 8.5
Height, cm	5.1	4.1 - 6.0

(1) Mean and range values for 14 trials

(2) Two varieties were processed; 12 trials involved Kennebec, 2 trials involved Russet Burbank.

(3) 12 trials were for normal size potatoes, 2 trials were "sortouts."

(4) Volume determined by dividing average mass by average specific gravity.

(5) Volume determined by the ellipsoid model method.

The specific gravity of peeled potatoes was found to be greater than for unpeeled potatoes. This was as expected since the peeling process removes the lower density peel.

During this investigation, two different varietites of potatoes were processed: Kennebec and Russet Burbank. Both varieties are among the most desirable potatoes for processing due to their regular shape, high solids content (and corresponding high yield), and shallow eyes. Russet Burbanks have a thicker skin and undergo suberization with increasing maturity and time in storage, forming a thick, corky skin layer that requires more severe processing conditions for removal and reduces product yields (Thompson, 1975). Two trials in this investigation involved Russet Burbanks--these potatoes did have deeper skin and suberization was beginning to be apparent at the time of processing (11/10/81). The Kennebecs had a lighter skin layer, and as Thompson (1975) suggests, the early season potatoes of this variety were immature and had lost much of their skin in handling, prior to peeling.

Potato defects including bruises, rots, cracks, frozen areas, and greening were apparent. The freeze-injured potatoes were found in the later season raw material; other potato injuries did not seem to increase with lateness of the season.

II. Processing Conditions

Peeling processing conditions for this investigation are summarized in Table 4. The potato processor adjusted the time of steam exposure to the minimum time necessary to result in adequately peeled potatoes. Based on Willard's grading scale (Appendix II), all peeled potatoes were either well peeled or fairly well peeled (Grade 2 or 3). Steam times generally increased with time into the season and for sortouts.

All trials investigated were based on an input mass of 226.8 kg (500 lb) of unpeeled potatoes. The processor did not adjust the potato batch size as a means of controlling the peeling operation.

Steam pressure variations were relatively small in this investigation since the plant's boiler output remained steady and steam times were long enough for the pressure inside the peeling vessel to stabilize. Steam quality was estimated to be constant at 98%. As indicated in Figures 4 and 5, steam specific volume and enthalpy is more dependent on steam quality than pressure, and thus errors in steam quality estimation may have caused errors in both the mass and thermal energy balance.

For example, overestimating the steam quality by 9% or 15% (i.e., assuming it was 98% if it was actually 90% or 85%) would give steam mass values 8% and 13% low, respectively. The lower estimated steam mass would be offset by a higher estimated steam enthalpy, however. The

Table 4. Parameters of the Peeling Operation During this Investigation[1]

Parameter	Mean	Range
Steam exposure time, sec.		15 - 22
Raw potato load per cycle, kg.	226.8	226.8
Steam pressure, N/m^2 (psia)	168,000 (239)	165,200 - 172,300 (235 - 245)
Time per cycle, sec.	87.3	75 - 107
Visual peel grade[2]	2.3	2 - 3
Depth of cooked layer, mm	1.5	1.1 - 2.0
Peel loss, %	8.07	3.70 - 13.05

(1) Mean and range values for 14 trials.

(2) Based on Willard's (1971a) visual grading scale for peeled potatoes.

estimated values of total steam enthalpy per cycle would be only 3% and 5% low, respectively.

Another source of error in this investigation was due to the lack of information about the quantity of air in the steam vessel. Since air was not bled out of the vessel after the steam valve opened, air present in the vessel would cause the steam volume to be overestimated. This would cause errors in the steam mass and steam enthalpy values calculated for mass and thermal energy balances. If the vessel contents were assumed to be 20% potatoes and 80% air (at 66C) before the steam entered, the steam mass and enthalpy values would be approximately 9% lower than those values used in the material and thermal energy balances. For an error this great to occur, however, all steam would have to have been exhausted from the vessel prior to the vessel door closing for a new cycle.

An additional source of error in this investigation was the assumption that the steam mass per cycle was not dependent on the steam exposure time. With longer steam exposure times, more steam would be expected to condense. Thus, with increasing steam exposure times, both the total steam mass and enthalpy values should increase. Since steam flow rates were not measured directly, there was no means of estimating the error due to condensing steam.

The time for the peeling vessel to pass through one cycle of operation varied by up to 32 seconds. This would not affect the mass and thermal energy balances since they were calculated on a per-cycle basis, but shorter cycle times would increase plant production levels.

Losses of product in peeling, percent peel loss, ranged from 3.70% to 13.05% in this investigation. Generally, higher levels of losses were necessary to achieve adequate peeled quality for the later-autumn potatoes. These losses are lower than most of the literature values for losses expected in steam peeling, but it must be considered that: 1) these were early potatoes, from the field rather than from storage, and therefore had relatively thin skins; 2) mostly Kennebecs were processed, a light-skinned variety; and 3) earlier steam peeling tests did not use peelers operating at such high steam pressures. Higher pressures and shorter steam exposure times may give more efficient peeling results (Boyen, 1950). Depth of the cooked layer of potato tissue ranged from 1.1 to 2.0 mm.

The range and average of temperature values associated with the peeling system as determined during this investigation are summarized in Table 5. Little experimental error is felt to be associated with any of these temperature measurements.

III. Total and Component Mass Balances

Table 6 summarizes the magnitudes associated with the input and output streams of the peeling operation, with results expressed as the range of values and also the mean

Table 5. Temperatures Associated with the Steam Peeling System for Potatoes[1]

	Temperature, °C	
	Mean	Range
Ambient	20.8	18.9 - 22.8
Peeling Vessel	146.7	137.8 - 154.4
Raw Potatoes	16.7	14.4 - 18.9
Steam	202.7	202.0 - 204.0
Spray Water	17.9	13.3 - 20.0
Peeled Potatoes	27.7	23.9 - 31.1
Peel	36.6	28.9 - 43.3
Peel & Condensate	64.8	61.1 - 71.1
Wash Water	28.5	23.9 - 31.7

(1) Mean and range values for 14 trials

Table 6. Magnitudes of Input and Output Mass and Components (mean and range of values for 14 trials)

	Mass, kg				
	Total	Moisture	Solids	Starch	Ash
<u>Inputs</u>					
Raw Potatoes	226.80 (226.80)	172.05-180.49 (177.86)	46.31-54.75 (48.94)	18.98-32.65 (24.31)	1.67-2.40 (2.01)
Steam	6.59-6.86 (6.69)	6.59-6.86 (6.69)	---	---	---
Spray Water	27.66-43.85 (33.96)	27.66-43.85 (33.96)	---	---	---
Total Input	261.19-277.38 (267.45)	212.70-221.14 (218.51)	46.31-54.75 (48.94)	18.98-32.65 (24.31)	1.67-2.40 (2.01)
<u>Outputs</u>					
Peeled Potatoes	197.20-218.41 (208.50)	156.33-172.06 (163.34)	42.26-51.20 (45.16)	17.22-27.97 (21.74)	1.51-1.99 (1.72)
Peel	21.02-36.60 (26.88)	19.29-32.66 (24.20)	1.73-3.94 (2.68)	.15-1.16 (.59)	.17-.44 (.31)
Peel & Condensate	1.93-5.00 (3.81)	1.80-4.71 (3.61)	.09-.31 (.20)	.009-.05 (.04)	.02-.07 (.03)
Wash Water	16.87-39.44 (28.25)	16.47-38.99 (27.70)	.25-1.12 (.55)	.03-.30 (.16)	.02-.09 (.04)
Other Losses	---	-2.97-1.76 (-.34)	-1.76-2.97 (.34)	.65-5.26 (1.80)	-.35-.40 (-.09)
Total Output	261.19-277.38 (267.45)	212.70-221.14 (218.51)	46.31-54.75 (48.94)	18.98-32.65 (24.31)	1.67-2.40 (2.01)

values determined in this investigation of total and component mass during one peeling cycle. The combined mass of three input streams (raw unpeeled potatoes, steam, and spray water) is distributed among five output streams. The potato peel and wash water streams are the largest magnitudes in addition to the primary output of peeled potatoes. The total mass balance results averaged over all 14 trials are presented in Figure 6. The average composition of input and output mass streams is shown in Table 7.

This type of analysis furnishes several types of useful information to a food processor about the facility's peeling operation. Since this investigation covered a number of types of processing situations (i.e., a range of potato suppliers, specific gravities, defect levels, grades of potatoes, and sizes, and two varieties), the information would be generally applicable for a similar time period in a given processing season. Based on this investigation, the yield from the peeling process would be expected to average 91.9%, with approximately .03 kg of steam and .15 kg of spray water required to peel 1 kg of raw product. With an average cycle time of 87.3 seconds, and 226.8 kg of raw potatoes processed per cycle, this facility can peel approximately 224,500 kg of raw potatoes in 24 hours, using 6,000 kg steam and 33,600 kg water, yielding 206,300 kg of peeled product.

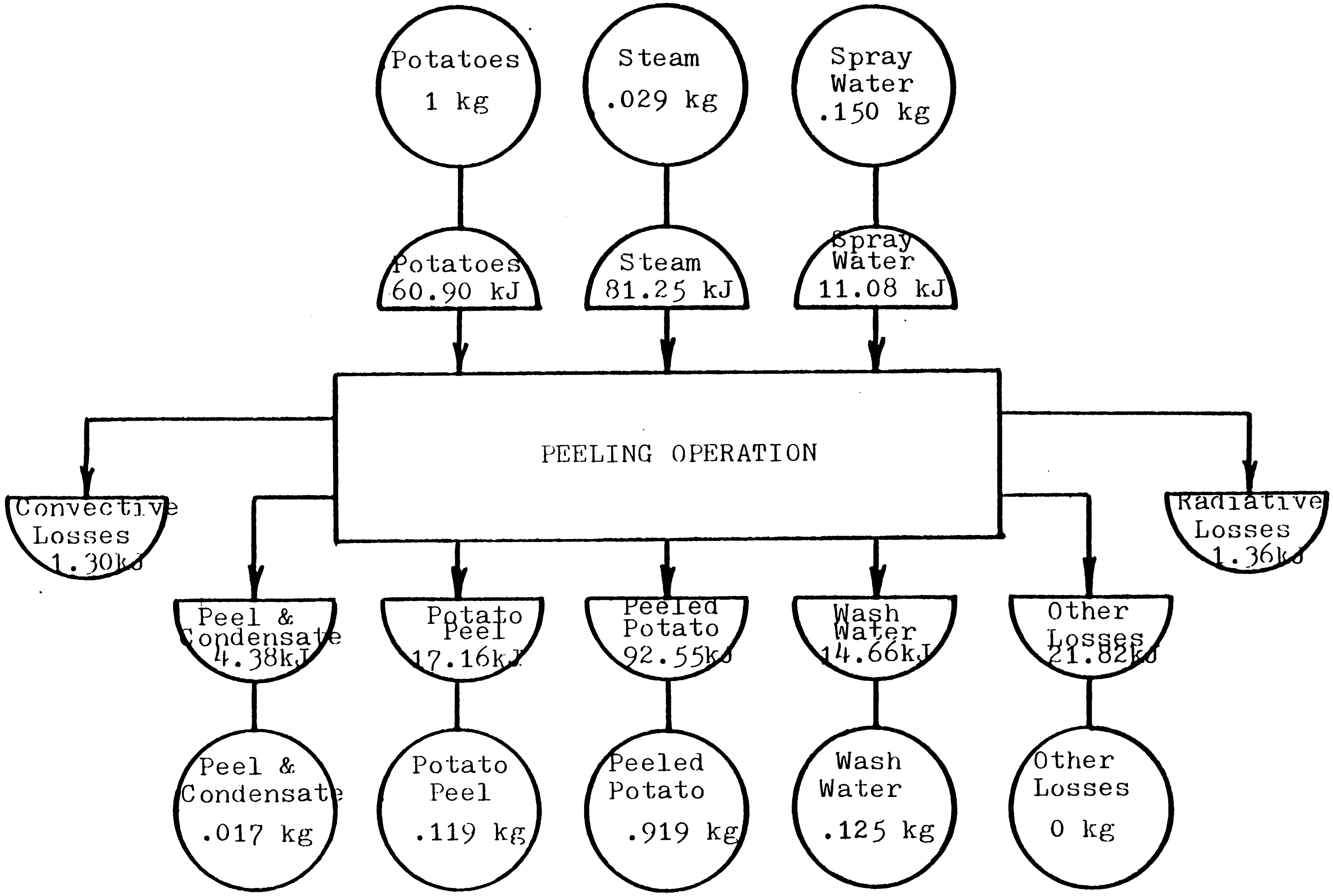

Figure 6. Total mass and thermal energy balance for the steam potato peeling operation, based on 1 kg unpeeled potatoes (average of 14 trials)

Table 7. Composition of Mass Streams Associated with the Steam Peeling Operation

	Moisture(1)	Solids(1)	Starch(2)	Ash(2)
Raw Potatoes	75.86-79.58(3) (78.42)(4)	20.42-24.14 (21.58)	36.44-67.30 (49.67)	3.41-5.03 (4.11)
Peeled Potatoes	75.79-79.68 (78.34)	20.32-24.21 (21.66)	34.80-64.70 (48.13)	3.19-4.52 (3.80)
Peel	89.23-91.81 (90.02)	8.19-10.77 (9.98)	8.51-32.17 (22.07)	7.62-19.08 (11.38)
Peel & Condensate	91.79-97.99 (94.67)	2.01-8.21 (5.33)	9.59-27.07 (17.37)	10.32-27.14 (16.81)
Wash Water	96.66-99.005 (98.05)	.995-3.34 (1.95)	8.61-47.47 (29.00)	4.68-9.62 (7.48)

(1) (kg/kg) x 100%

(2) (kg/kg solids) x 100%

(3) Range of values for 14 trials

(4) Mean of values for 14 trials

Important information about the nature and quantity of outputs from the peeling operation is also made available with this type of analysis. Large quantities of waste are generated as peel and as wash water, approximately 27 kg and 28 kg per cycle, respectively, or 26,600 kg and 28,000 kg per day. These quantities of waste represent a significant disposal problem for the potato processor.

The peel slurry, 9.98% solids, is suitably concentrated for removal from the processing facility as a solid waste. 22% of the peel solids is starch, 11% ash, and probably most of the remainder is fiber. Feasibility of utilizing the peel for livestock feed, as a fermentation medium, for starch recovery, or for other purposes may be investigated based on this or a more in-depth compositional analysis.

The wash water, 1.95% solids, must be treated either at the plant or by the municipal water treatment system. Feasibility of treatment methods to recover starch from the plant effluent would depend on consideration of the maximum yield of starch per day, 158 kg at this operation in addition to the amounts generated at other operations within the plant.

The total mass balance results for a typical trial are presented in Figure 7 where input and output magnitudes are expressed on the basis of 1 kg of unpeeled potatoes. As is evident, the peel and wash water streams are approximately

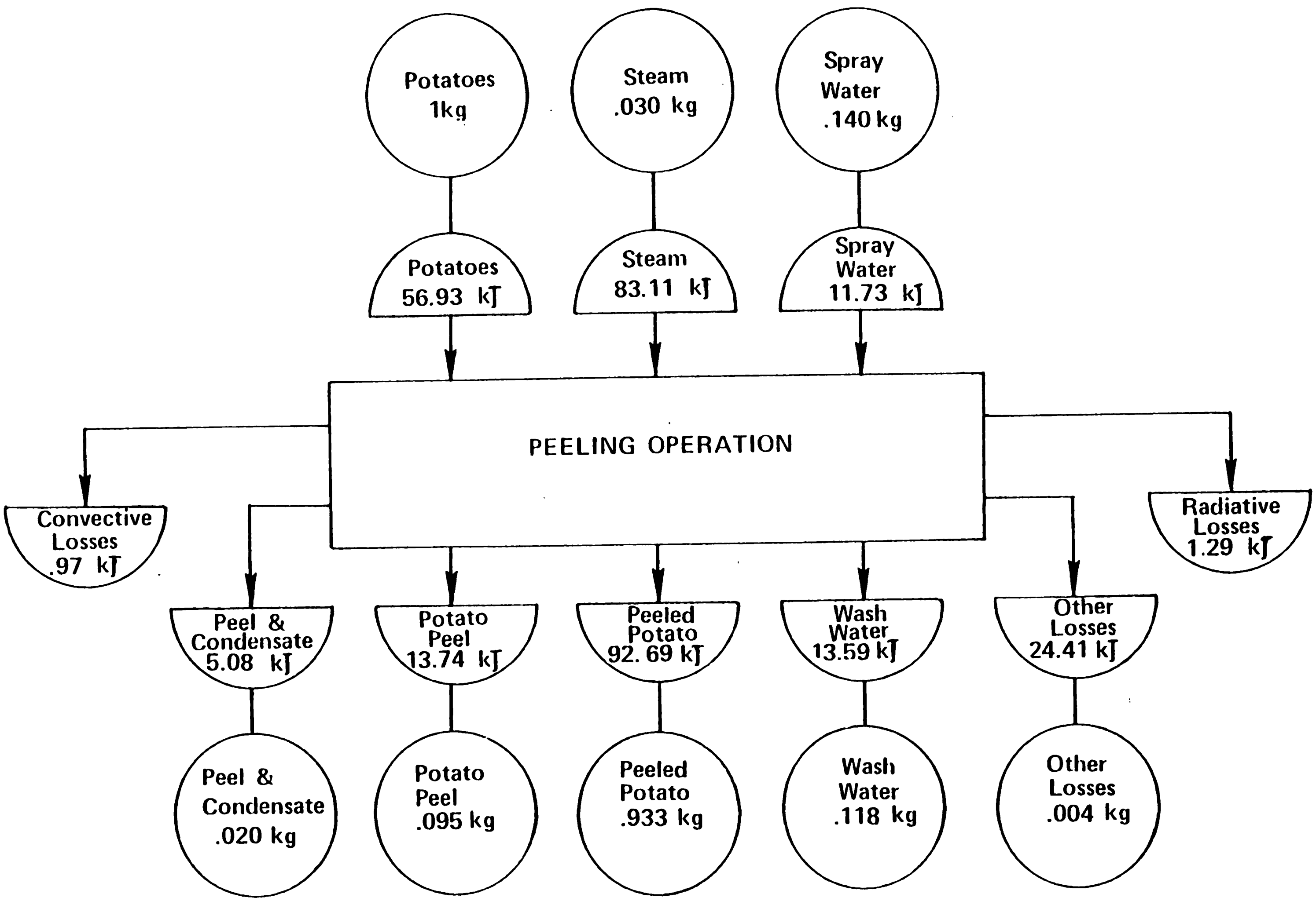

Figure 7. Total mass and thermal energy balance for the steam potato peeling operation, based on 1 kg unpeeled potatoes (Trial 3)

.1 kg per kg of unpeeled potato input. When the magnitudes of ouput streams are expressed as percentages of the total magnitudes of the input streams, the results can be indicated by the distribution in Figure 8. Based on this analysis, the peeled potato stream is about 80% of the total mass input, while the wash water is 10% and the potato peel is 8%.

Although the results of an individual mass balance may not reveal specific process modifications that would improve process efficiency, the approach presented should be useful in process analysis. For example, the results of changing steam or spray water magnitudes would be quite evident in the magnitudes of the various output streams shown in Figure 6. The potential for reductions in total magnitudes of the various waste streams while maintaining acceptable peeling effectiveness could be evaluated.

An in-depth mass and component analysis of a peeling system furnishes added information which can be used to monitor the efficiency of conversion of raw product into primary product. Mass balance data for all trials, shown in Appendix V, was used to calculate the percent recovery of raw potato components (solids, starch, and ash) into the various output streams: peeled potatoes, peel, peel and condensate, and wash water (Table 8). Recovery of ash is low in peeled potatoes in comparison to recovery of solids and starch; this is due to the disproportionately high ash

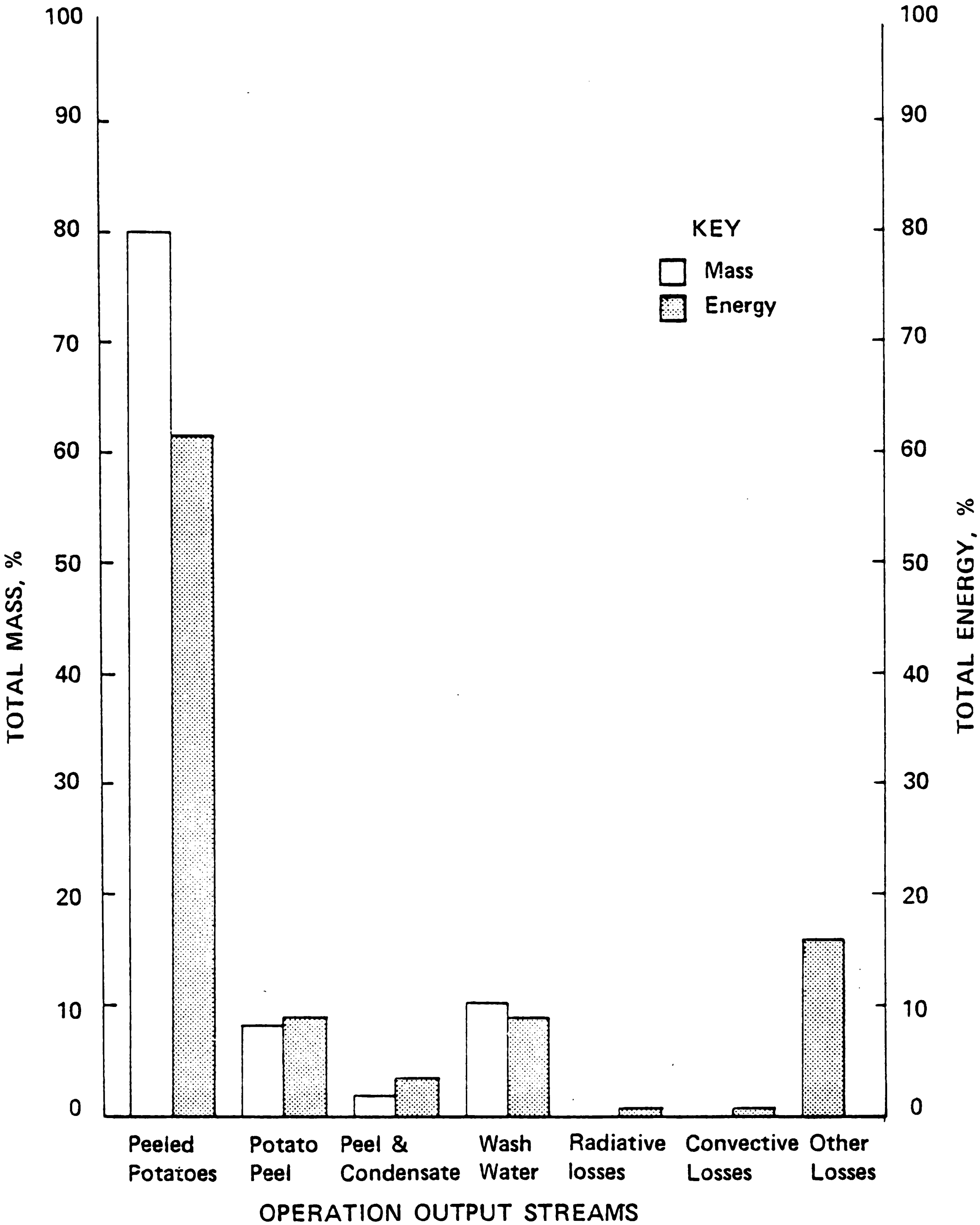

Figure 8. Magnitude of total mass and thermal energy in output streams, expressed as a percentage of the total magnitude of input streams (Trial 3)

Table 8. Recovery of Product Components in Output Streams

	Recovery, %		
	Solids	Starch	Ash
Peeled Potatoes	86.141-97.744[1] (92.399)[2]	78.865-94.982 (89.715)	69.545-95.480 (85.882)
Peel	3.648-7.196 (5.469)	.790-5.815 (2.531)	9.140-20.707 (15.120)
Peel & Condensate	.188-.566 (.387)	.039-.251 (.137)	.943-2.991 (1.641)
Wash Water	.633-2.319 (1.141)	.158-1.374 (.665)	.909-3.750 (2.036)

(1) Range of values for 14 trials

(2) Mean of values for 14 trials

content and low starch and solids content in the skin as compared to peeled potatoes. Recovery of the raw potato's starch and ash is relatively high in the peel and wash water output streams. When the mass of product components in various output streams is expressed as a percentage of the input mass, the distribution appears as presented in Figure 9 for a typical peeling trial.

By examining the peeling operation under various operating conditions it would seem that relationships might be predicted between product loss (as percent peel loss) and loss of product components (solids, starch, and ash). Such relationships, if statistically valid, would be useful to show how much of a product component such as starch will be recovered in the peeled potato at different levels of peeled quality (e.g., underpeeling because the final product may not require complete peel removal, or overpeeling, to avoid high trimming losses and labor costs). In addition, a prediction equation would indicate how much recoverable solids, starch or ash will be in the peel or wash water streams over a range of operating conditions.

Figures 10 and 11 show the linear regression prediction equations for the relationships between percent recovery of ash and solids in the peel and in the peeled potatoes, respectively, with increasing levels of peel loss required for adequate peeled product quality. As expected,

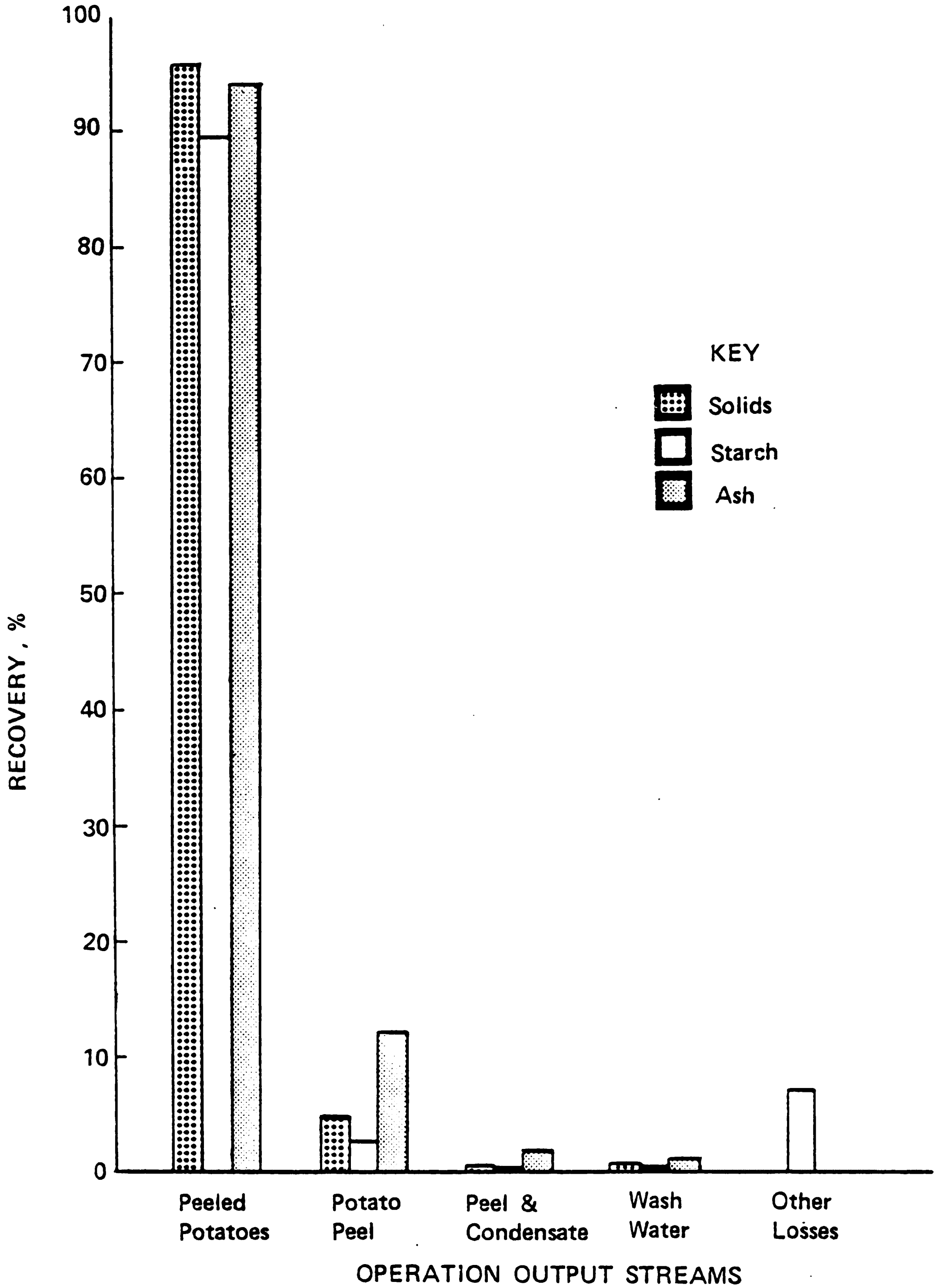

Figure 9. Mass of product components recovered in operation output streams, expressed as a percentage of total component input (Trial 3)

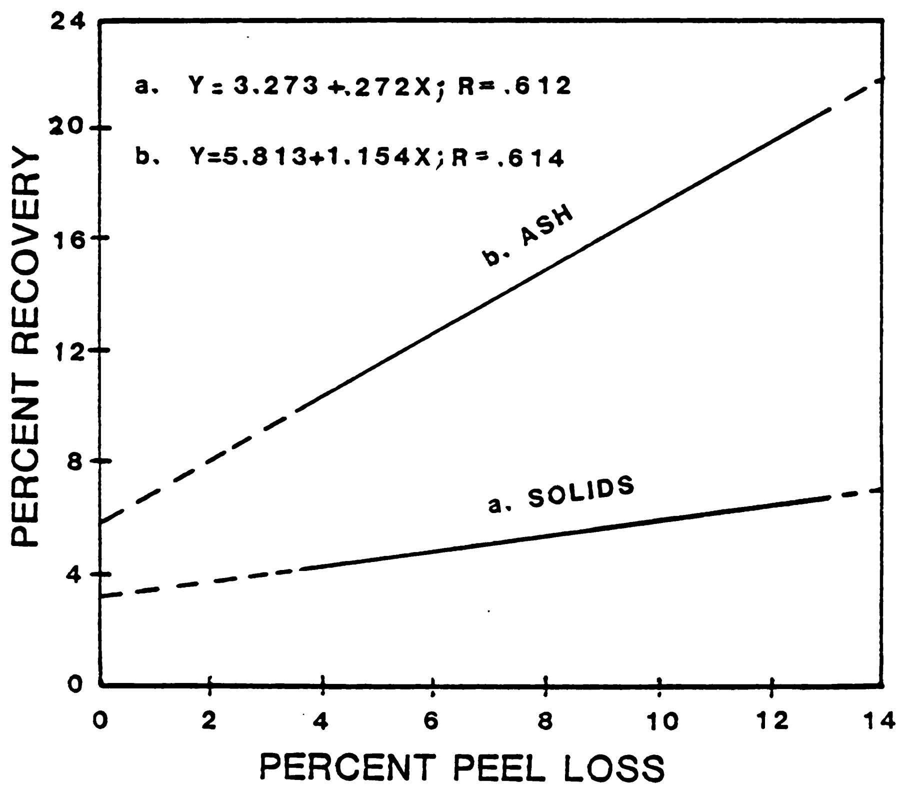

Figure 10. Correlation of percent recovery of product solids and ash in the potato peel with percent peel loss

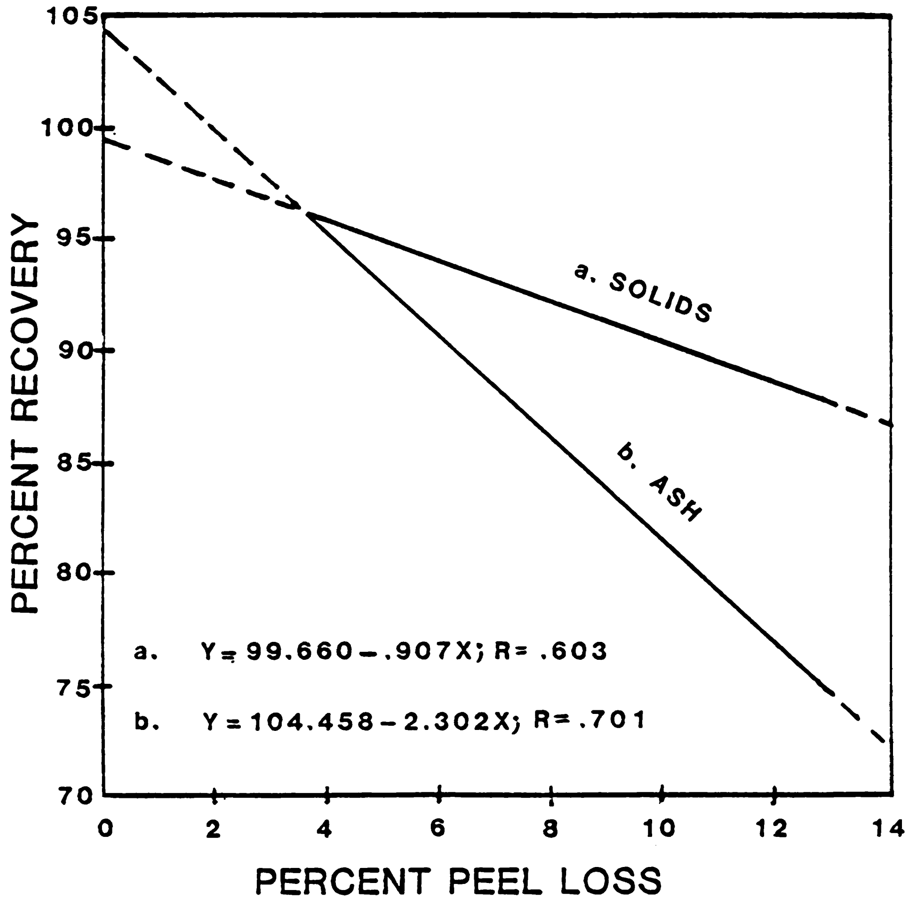

Figure 11. Correlation of percent recovery of product solids and ash in the peeled potatoes with percent peel loss

recovery of solids and ash in the peel increased with higher levels of peel removal (Figure 10), whereas recovery of these components decreased in the peeled potatoes (Figure 11). Also, ash recovery or loss increased for the peel and peeled potatoes at a faster rate than did solids recovery or loss, due to the high mineral content of the skin. The regression lines are dotted outside of the range of the experimental values since recovery of ash and solids most likely is not linear at extreme (low or high) levels of peel loss.

No statistically valid relationship could be drawn between recovery of solids or ash in either the wash water or the peel and condensate streams. For the wash water, quantities of starch, solids, and ash rinsed off would not be expected to be predictable since several factors--potato and water temperature, water pressure, and cell size--determine the extent of "sloughing" of starchy potato tissue (Hautala et al., 1972, Zaehringer et al., 1964). These factors are independent of the factors which determine the extent of peel loss. Even at high levels of peel loss, most of the peel material is removed before the potatoes enter the spray washer/brusher apparatus. Loss of potato components into the peel and condensate stream was also found to be independent of the percent peel loss. This is most likely because the condensate which flows out of the peeling vessel carries only a small amount of peel with it; the magnitude is not influenced in any predictable manner by the extent of peel removal.

Recovery of starch in the peeled potatoes was found to decrease with higher levels or amounts (%) of peel loss, but the level of significance of the correlation was very low. This is most likely because most of the peel removal occurs before the spray washer/brusher apparatus, whereas a significant level of starch loss occurs in that apparatus. Recovery of starch in the peel was not found to increase at a statistically significant rate with higher levels of peel loss. The reasons for this are not clear; possibly the peeling operation did not remove much of the potato tissue beneath the skin and thus levels of starch recovery in the peel were not very consistent.

Table 9 summarizes statistical parameters describing the relationships between peel loss and recovery of components in output streams.

The condition of the raw material used in peeling had been anticipated to affect the amount of peel loss required for adequate peeling and hence affect the mass balance of the peeling system. This investigation did not prove this to be true, however. While linear regression did show a positive correlation between potatoes with higher levels of external defects and greater losses of peel required to achieve adequate peeling, the significance level of the slopes was very low. In addition, the required level of

Table 9. Results of Regression Analysis for Recovery of Product Components vs. Peel Loss

Component Recovered	Regression Values(6) $S^{(1)}$	$I^{(2)}$	$R^{(3)}$	$\alpha_S^{(4)}$	$S_{Y/X}^{(5)}$
Solids in Peeled Potatoes	-.907	99.660	.603	.0221	3.060
Starch in Peeled Potatoes	-.600	94.556	.363	.2046	3.922
Ash in Peeled Potatoes	-2.302	104.458	.701	.0052	5.971
Solids in Peel	.272	3.273	.612	.0199	.897
Starch in Peel	.129	1.494	.253	.3887	1.251
Ash in Peel	1.154	5.813	.614	.0192	3.783
Solids in Peel & Condensate	-.004	.419	.071	.7573	.133
Starch in Peel & Condensate	-.003	.159	.100	.7573	.069
Ash in Peel & Condensate	-.031	1.887	.105	.7573	.743
Solids in Wash Water	.104	.300	.421	.1328	.574
Starch in Wash Water	.057	.205	.366	.7219	.370
Ash in Wash Water	.177	.605	.430	.4122	.950

(1) Slope of regression equation, using data from 14 trials
(2) Intercept of regression equation
(3) Correlation coefficient
(4) Significance level of slope
(5) Standard error of estimate
(6) All correlations found positive in linearity test (Crow et al., 1960).

peel loss was not found to be significantly dependent on the percent of potatoes graded Michigan # 1 (although the relationship was an inverse one, as anticipated). Average potato mass did not significantly affect peel loss requirements.

The level of peel loss was found to correlate fairly well (α = .047) with the specific gravity of the potatoes being processed (Figure 12). High specific gravity of potatoes has been correlated with high solids content (Thompson, 1975; Reeve et al., 1971), and thus high yields and better suitability of potatoes for processing. It is reasonable then to find that with higher specific gravities and therefore higher potato solids contents, less peel, as a percentage by weight of the whole tuber, must be removed for adequate peeled quality.

These relationships drawn between peel loss and raw material characteristics are summarized in Table 10.

IV. Thermal Energy Balance

Magnitudes of thermal energy contents of inputs and outputs of the peeling operation are shown in Table 11 with results expressed as the range of values and average values of enthalpy or heat loss determined in this investigation. The average enthalpy of the steam used in the process per cycle was 184,428 kJ. Based on the energy balance measurements, the thermal energy content of the potatoes increased, as a result of the steam exposure, by an average

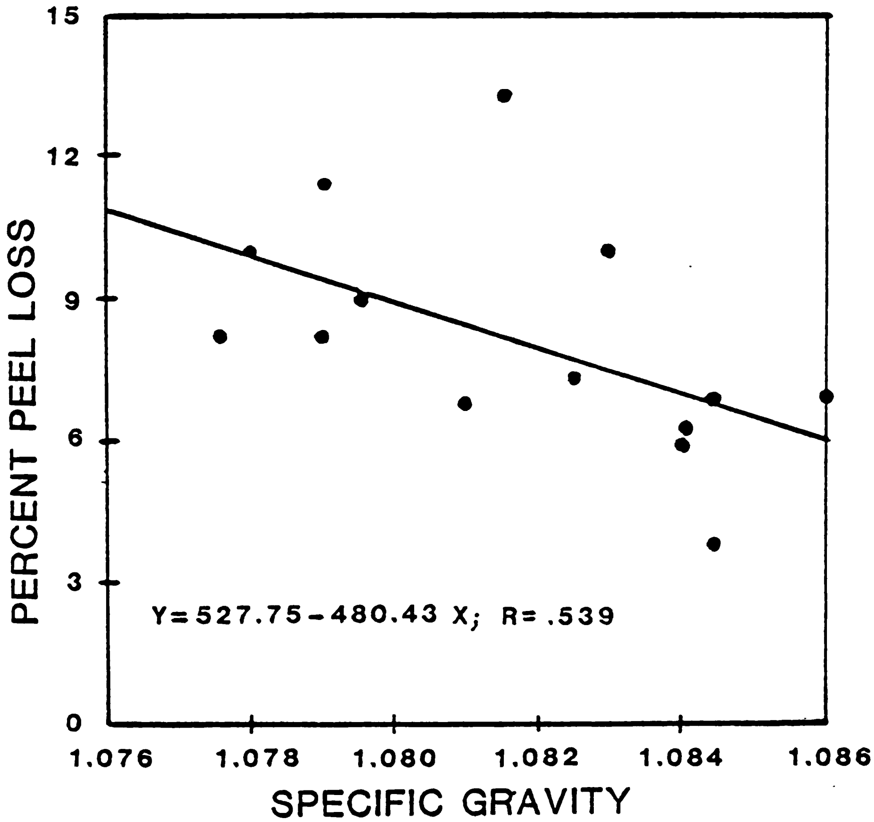

Figure 12. Correlation of percent peel loss required for adequate potato peeling vs. specific gravity

Table 10. Results of Regression Analysis for Peel Loss vs. Raw Material Characteristics

Parameter	Regression Values[(6)] $S^{(1)}$	$I^{(2)}$	$R^{(3)}$	$\alpha_S^{(4)}$	$S_{Y/X}^{(5)}$
Potato Mass	-.009	10.498	.367	.1932	2.372
Percent potatoes with extermal damage	.592	9.365	.261	.3615	2.462
Percent potatoes graded Michigan #1	-.883	82.694	.290	.3149	2.441
Specific gravity	-480.429	527.754	.539	.0470	2.147

(1) Slope of regression equation, using data from 14 trials
(2) Intercept of regression equation
(3) Correlation coefficient
(4) Significance level of slope
(5) Standard error of estimate
(6) All correlations found positive in linearity test (Crow, et al., 1960)

Table 11. Thermal Energy Balance for the Steam Peeling Operation for Potatoes[1]

	Heat Content per cycle, kJ	
	Mean	Range
Inputs		
Raw Potatoes	13,812	12,026 - 15,686
Steam	18,428	18,146 - 18,899
Spray Water	2,514	1,745 - 3,061
Total	34,754	32,637 - 36,488
Outputs		
Peeled Potatoes	20,991	18,603 - 22,971
Peel	3,892	2,838 - 5,517
Peel & Condensate	993	552 - 1,292
Wash Water	3,324	1,909 - 4,621
Radiative Losses	309	261 - 393
Convective Losses	294	257 - 370
Other Losses	4,951	1,361 - 9,902
Total	34,754	32,637 - 36,488

(1) Basis: 226.80 kg unpeeled potatoes. Thermal energy balance represents mean and range of values for 14 trials.

of 52%, from 13,812 kJ to 20,991 kJ per cycle. The energy content of the spray water increased by 32%, from 2514 kJ to 3324 kJ per cycle. A significant quantity (4951 kJ) of the thermal energy is not accounted for in output measurements.

The total thermal energy balance results averaged over all 14 trials of this investigation are presented in Figure 6, with the thermal energy associated with the various inputs and outputs of the peeling operation expressed in terms of 1 kg of unpeeled potatoes. As is evident, the majority of the thermal energy, 60.4%, leaves with the peeled potato, and "other losses" represents a significant magnitude, 14.2%, in comparison to the other output streams. The thermal energy losses due to radiation and convection from the surface of the peeling vessel are approximately equal, and appear to be negligible in comparison to the energy contents of the mass streams. Slight errors in temperature measurements would have a somewhat larger effect on radiative losses than on convective losses, but the effect on the overall thermal energy balance would not be very great.

The total thermal energy balance for a typical trial of this investigation is shown in Figure 7. By expressing the thermal energy in the various output streams as a percentage of the total input energy, the distribution shown in Figure 8 is obtained for a typical trial. Based on this analysis, over 60% of the input thermal energy leaves with the peeled potatoes and less than 1% is lost due to radiation and convection. Approximately 9% of the input thermal energy leaves with the potato peel and an additional 9% with the wash water. Approximately 16% of the thermal energy is not accounted for in any measurement and must be attributed to unidentified losses.

Steam peeling operations, in order to remove greater or lesser amounts of peel tissue, are typically adjusted by increasing or reducing time of exposure to steam. Linear regression for the 14 trials investigatd showed that a strong correlation (R = .85; significance level, , of the slope = .0001) existed between percent peel loss and time of steam exposure. Figure 13 illustrates this correlation.

There are two major implications of this correlation. First, adjusting the time of steam exposure is the only method currently used to change the amount of peel removed from potatoes when using this type of peeling operation. For potatoes with characteristics (large surface area or thicker skin) that require a higher percent peel loss, steam exposure times must be increased. In this investigation, steam exposure times tended to increase with time into the season (thicker-skinned potatoes) and for "sortouts" (large surface area).

Second, unnecessarily high peeling losses should be avoided, both to increase material utilization and decrease

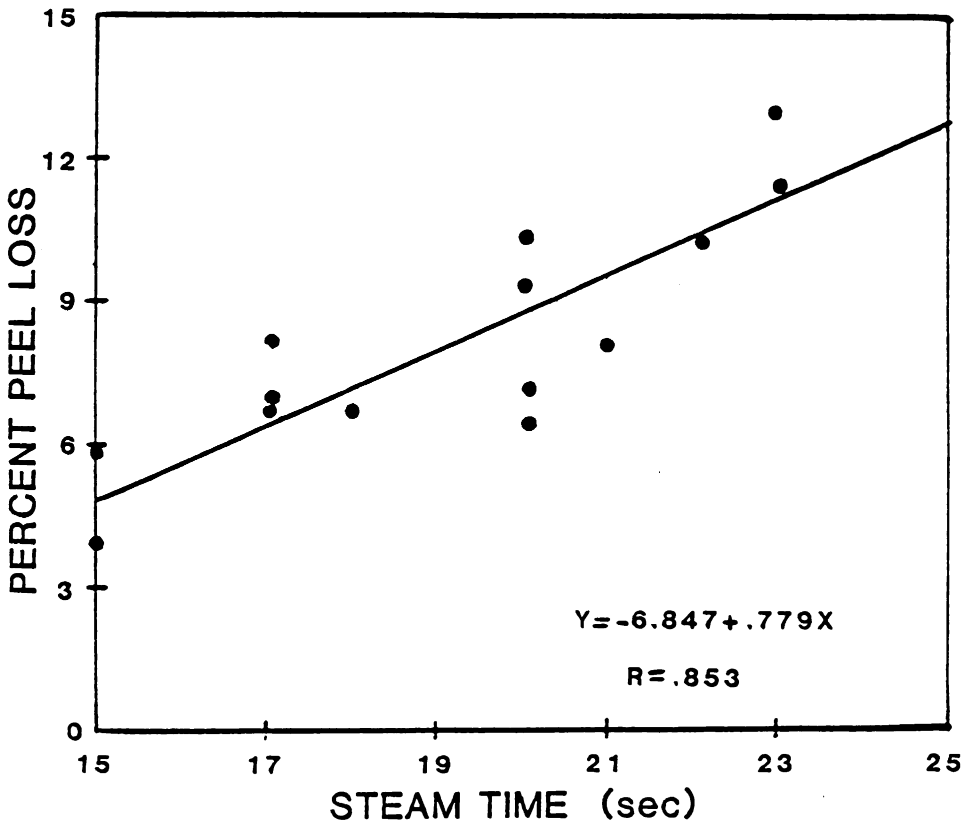

Figure 13. Correlation of percent peel loss with steam exposure time

thermal energy usage and heat damage to the potato. It would be desirable to decrease peel removal requirements by either processing potatoes with thinner skins (by choosing appropriate varieties or grades of potatoes, or improving storage practices) or aiming for a slightly lower peeled product quality.

Relationships between product loss under various operating conditions and thermal energy losses were investigated using least squares linear regression. These regression values and other statistical parameters for these relationships are summarized in Table 12. Loss of heat into the peeled product, determined as the increase in heat content of the potatoes during peeling, was not found to be significantly correlated with higher peeling losses. Losses of thermal energy into the spray water and losses of product as peel did show a predictable relationship (Figure 14). For higher peel losses, longer steam exposure time was required and more heat was absorbed by the potato. This heat was partially removed by the spray water.

Relationships were also found between the amount of peel loss and the thermal energy contents of the peel and the peel and condensate stream (Figure 15). For greater peel losses and longer steam exposure times, more heat was absorbed into the peel and this increase in the peel enthalpy was predicted at a .013 level of significance. It is reasonable that the peel and condensate stream's

Table 12. Results of Regression Analysis for Thermal Energy Losses vs. Percent Peel Loss

	Regression Values(6)				
Energy Losses	S(1)	I(2)	R(3)	α_S(4)	$S_{Y/X}$(5)
Peel	253.96	1843.95	.645	.0129	768.39
Peel and Condensate	-77.82	1620.67	.713	.0041	195.08
Increase in heat of spray water	272.65	-1390.19	.581	.0295	1528.95
Increase in heat of potatoes	165.35	5845.25	.224	.4536	1167.20
Unaccounted-for thermal energy losses	-562.06	9485.13	.597	.0237	1925.45

(1) Slope of regression equation, using data from 14 trials
(2) Intercept of regression equation
(3) Correlation coefficient
(4) Significance level of slope
(5) Standard error of estimate
(6) All correlations found positive in linearity test (Crow et al., 1960).

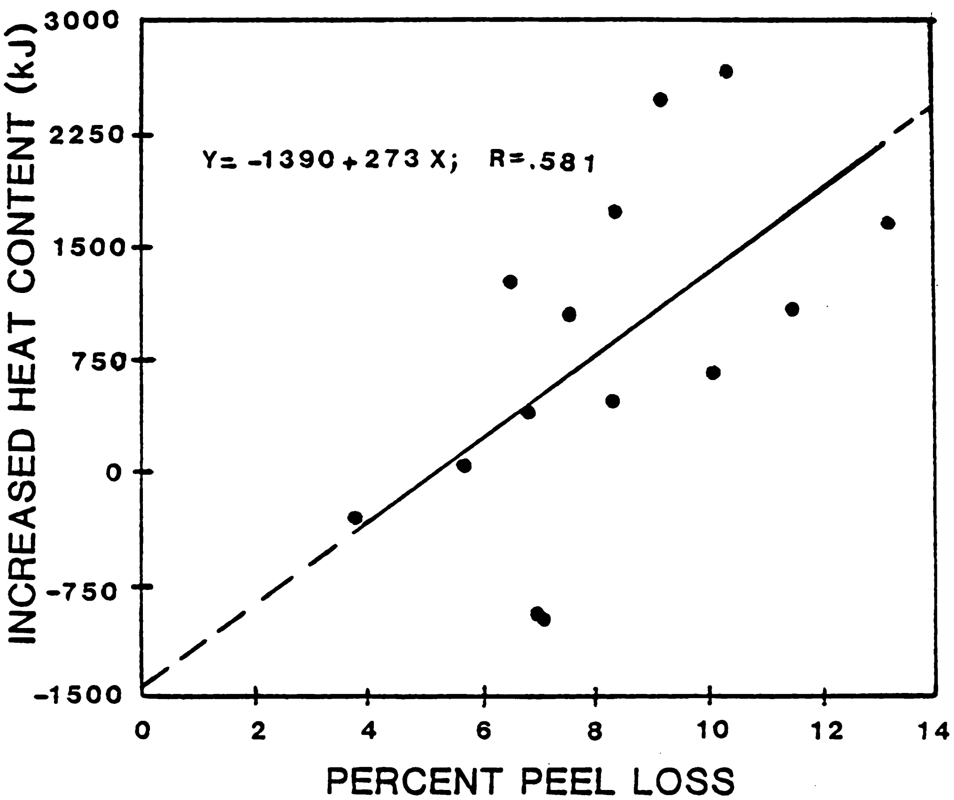

Figure 14. Correlation of increase in heat content of spray water with percent peel loss, based on 226.80 kg unpeeled potatoes

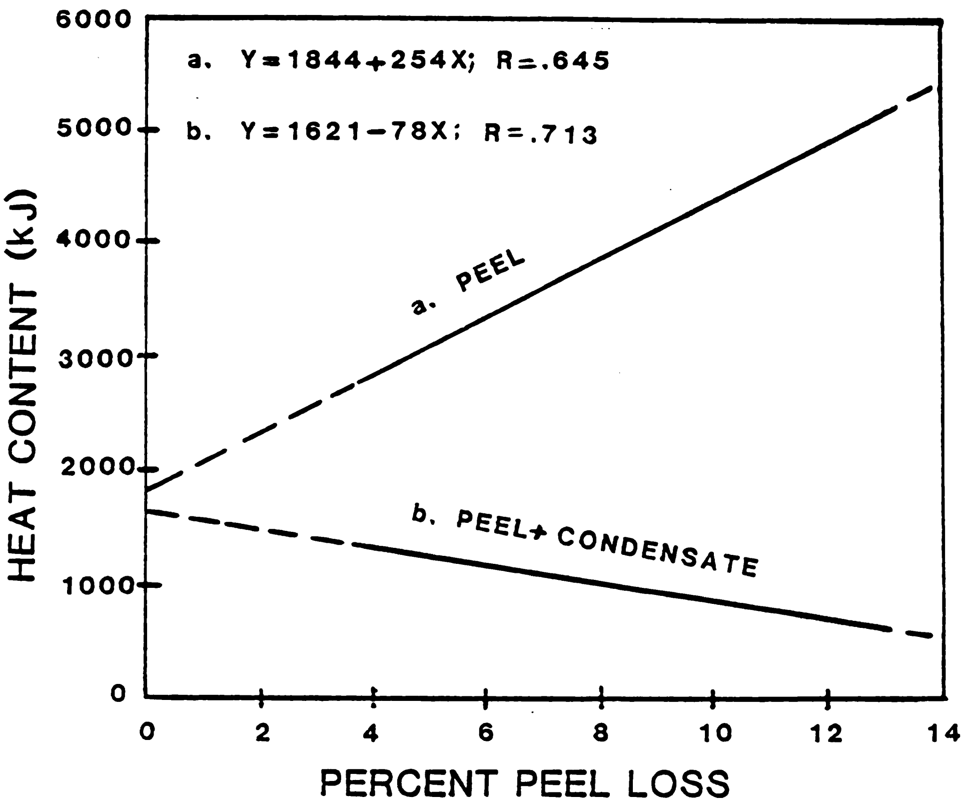

Figure 15. Correlation of heat content of peel and peel/condensate waste streams with percent peel loss, based on 226.80 kg unpeeled potatoes

enthalpy decreases with higher peel losses. With longer steam times, the steam's heat is more completely absorbed by the potato and peel, resulting in lower condensate enthalpy.

With longer steam times, more of the steam's heat content is absorbed by the potato and peel and the steam condenses fairly completely, resulting in less escaping steam. In this energy analysis, unaccounted-for heat losses were considered to be due (to some extent) to escaping steam. A correlation (Figure 16) was determined by least squares linear regression for the relationship between the miscellaneous heat losses and the percent peel loss for the 14 trials of this investigation. The indicated relationship is worth some consideration. If a potato processor uses potatoes that require only a small amount of peel removal, utilization of the raw material as raw product is increased. In addition, a lower steam exposure time is required (see Figure 13), decreasing heat absorption into the product. This is important because 1) energy requirements are lower; 2) less heat damage is inflicted on the potato product; and 3) a relatively large proportion of the steam used in the process is released, and potentially recoverable if the proper regenerative heating equipment is available.

Heat damage to the potato, as indicated by the depth of the cooked layer of tissue, would seem to be related to

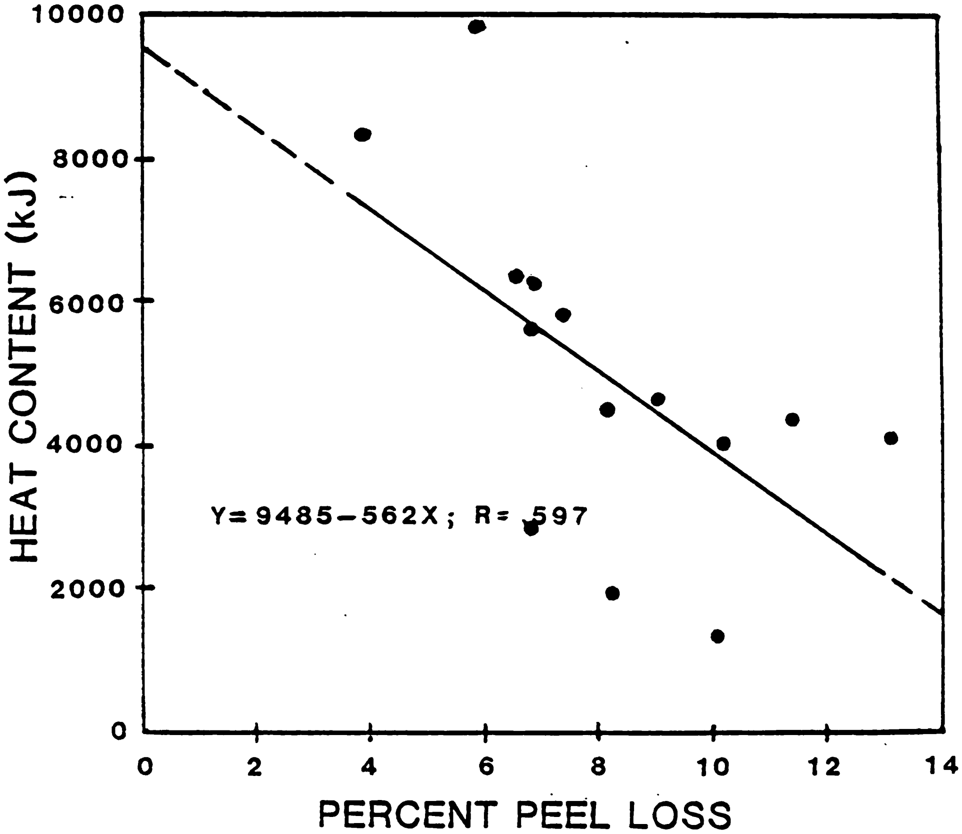

Figure 16. Correlation of unaccounted-for heat losses with percent peel loss, based on 226.80 kg unpeeled potatoes

the quantity of heat absorbed by the potato or removed from the spray water. While regression equations were calculated which predicted higher levels of heat absorption by the potatoes and spray water with deeper cooked layers, these correlations are not statistically valid (Table 13). In the same way, miscellaneous heat losses were predicted by regression to decrease with a deeper cooked layer, but the correlation coefficient was only .293. Also, depth of the cooked layer showed no sign of dependence on the time of steam exposure. The reason for these results is not clear; it would seem that the depth of the cooked layer would be somewhat indicative of the extent of the thermal treatment for the potatoes.

The results of a thermal energy analysis indicate at least three areas where improvement in thermal energy utilization might be achieved. First, a significant portion of the unidentified thermal energy losses may be due to uncondensed steam that escapes when the peeling vessel is opened to release the peeled potatoes. Large quantities of steam were observed to escape from the peeling vessel during each cycle. Modified operating procedures such as regenerative heating to make use of this escaping steam could result in a significant reduction in plant energy use.

A more specific energy analysis, in order to better quantify these steam losses, would be required to determine

Table 13. Results of Regression Analysis for Thermal Energy Losses vs. Depth of Cooked Layer

	Regression Values[6]				
Energy Losses	$S^{(1)}$	$I^{(2)}$	$R^{(3)}$	$\alpha_S{}^{(4)}$	$S_{Y/X}{}^{(5)}$
Increase in heat of spray water	383.32	218.09	.084	.7573	1193.40
Increase in heat of potatoes	2690.26	3028.60	.363	.2046	1750.17
Unaccounted-for thermal energy losses	-2773.78	9230.05	.293	.3149	2294.56

(1) Slope of regression equation, using data from 14 trials
(2) Intercept of regression equation
(3) Correlation coefficient
(4) Significance level of slope
(5) Standard error of estimate
(6) All correlations found positive in linearity test (Crow et al., 1960).

the feasibility of such modifications. For example, a large percentage of the unidentified thermal energy losses might actually be due to heat escaping from the potatoes as they travel through the peeling system.

One way to check whether steam losses account for much of the thermal energy losses from the peeling system would be to refer to the mass analyses and determine how much unaccounted moisture is lost from the system. In this investigation, the average water loss was negative (-.34 kg per cycle), i.e., more water entering the system was accounted for than water leaving the system. This seems to indicate errors in the determination of mass of some of the input or output streams. Possibly some assumptions made in order to determine the mass balance need to be reevaluated (i.e., calculating the peel mass by difference, or using the peel loss test to establish peeled potato mass).

If an individual trial is examined, for example, Trial 4 (10/13/81, Appendix V) with 5.72% loss, where measured peel mass was found to be very similar to the estimated peel mass, 1.21 kg of water was not accounted for. If this water was assumed to be lost as escaping steam, at 220 psig (168,700 N/m^2) the heat content of the escaping steam mass would be estimated as 3332 kg. In this case, 33.6% of miscellaneous heat loss could be attributable to escaping steam. For Trial 12, conducted a month later where required peel loss is high, 13.05%, loss of water from the system was only .33 kg. This could be interpreted to mean that 909 kJ of energy was lost as steam, or 22% of the miscellaneous thermal energy losses. Thus, a complete material balance is a prerequisite to obtaining an accurate thermal energy balance.

The second area deserving analysis is the loss of thermal energy with the peeled potatoes (the majority of the thermal energy). As shown in Figure 17, temperatures of potatoes were observed to decrease by about 5C from the time of leaving the screw conveyor until leaving the spray washer/brusher. Such a temperature change accounts for approximately 20% of the steam's enthalpy, or 74% of the unaccounted-for energy losses. Operation changes to reduce these losses may be desirable. Effective removal of the potatoes' heat with a water soak would be worth further investigation, both to decrease heat damage to the potato and to recover the heat from the water by regenerative heating. However, the importance of thermal energy recovery from the wash water must be balanced against increased losses of solids and starch which may result during extended soaking. Heat losses to the air and through equipment surfaces also occurred. This type of heat loss would probably not be directly recoverable, but proper equipment modifications might reduce such losses.

Finally, a more in-depth analysis of the peeling efficiency with reduced steam pressure or reduced exposure

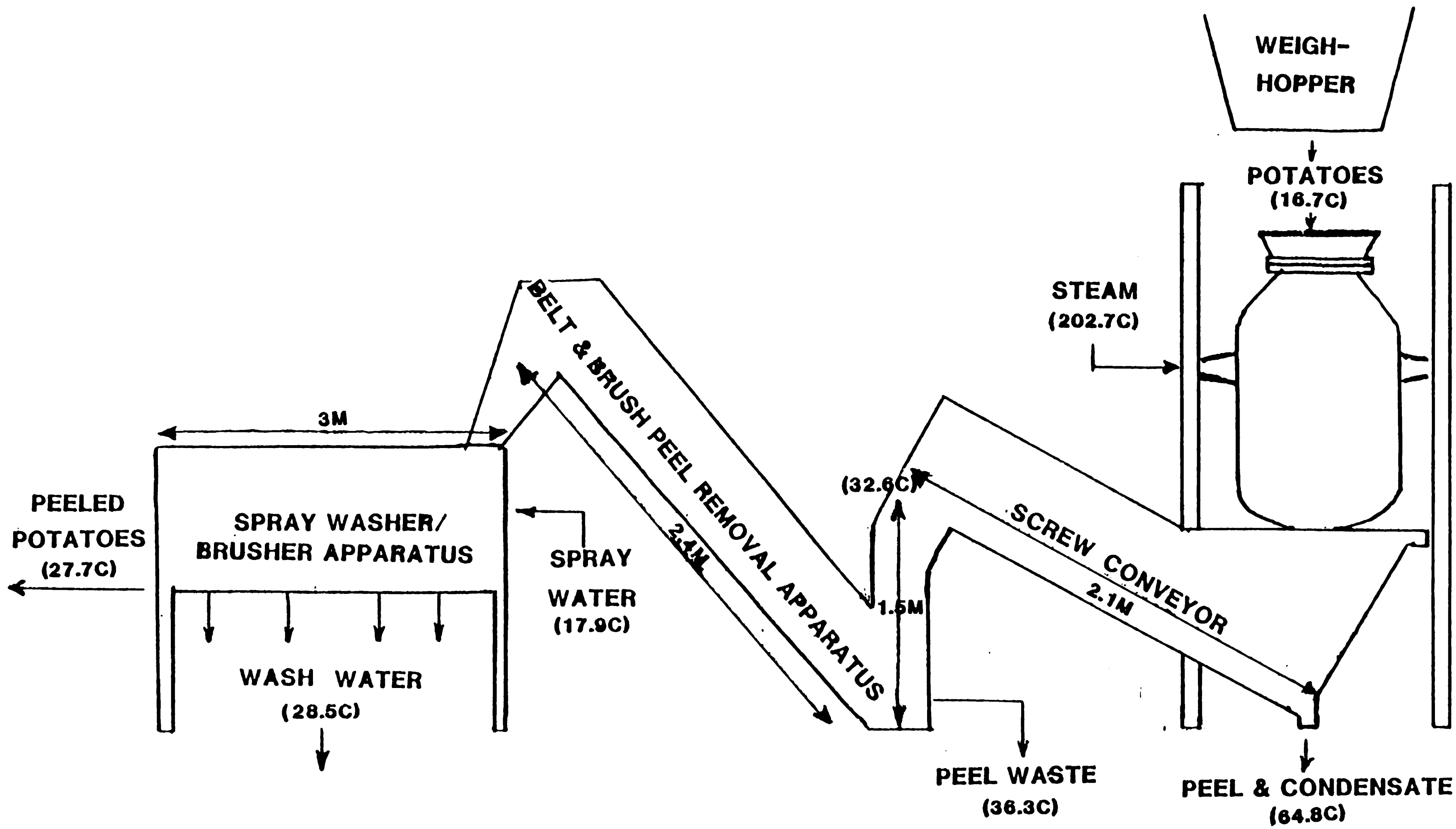

Figure 17. Diagram of the steam peeling operation, indicating equipment dimensions and average temperatures associated with the operation

time might lead to reduced thermal energy use. Boyen (1950) indicated that peeling at high steam pressures may result in more efficient peel removal (requiring less trimming) and lower steam exposure times. This would decrease heat damage to the potato as well.

CONCLUSIONS

The following conclusions and recommendations may be made about the steam peeling operation studied in this investigation.

1. In order to achieve a desirable peeled potato quality, losses in peeling ranged from 3.70% to 13.05% of raw, unpeeled potato weight.

2. Steam and water requirements averaged .03 kg and .15 kg, respectively, to peel 1 kg raw, unpeeled potatoes.

3. The major waste streams from steam peeling include the peel slurry (9.98% solids) and the wash water (1.95% solids), with quanitities of waste production averaging 11.8% and 12.5%, respectively, of the weight of incoming unpeeled potatoes.

4. Correlations of loss of raw potato solids and ash into the peel slurry with increasing levels of peel removal were both significant at the .02 level. Correlations of recovery of raw potato

solids and ash into the peeled potatoes with increasing levels of peel removal were significant at the .022 and .005 levels, respectively.

5. The level of peel loss required for adequate peeled potato quality was correlated with specific gravity at the .047 level of significance. Processing potato varieties with high specific gravities and relatively thin skins will result in the lowest product losses during peeling.

6. Use of undersized potatoes should be avoided since they have both large surface areas and low specific gravities, with resulting low yields from peeling.

7. The peeling operation should be carefully monitored to avoid peeling losses greater than the minimum required for an acceptable peeled product. Excessive peeling losses decrease material utilization, increase thermal energy requirements, and may result in damage to the final product.

8. A thermal energy balance conducted on the potato steam peeling operation indicated that approximately 60% of the input thermal energy

leaves with the peeled potato.

9. A significant magnitude of input thermal energy, 14.2%, is not accounted for in any output mass stream, suggesting that better thermal energy utilization might be obtained with operational changes.

10. The level of product loss during peeling was correlated (significance level = .0001) with time of steam exposure.

11. The heat content of the peel stream increased from 2929 kJ to 5517 kJ as peeling losses increased from 3.70% to 13.05%. Similarly, loss of heat into the spray water increased from -325 kJ to 1668 kJ for 3.70% and 13.05% peel loss, respectively.

12. As peeling losses decreased from 13.05% to 3.70%, more of the input thermal energy (4123 and 8263 kJ, respectively) was unaccounted for in output mass streams. Operational changes leading to recovery of this unabsorbed thermal energy would increase thermal energy utilization.

RECOMMENDATIONS FOR FUTURE INVESTIGATIONS

As a result of this investigation, a number of recommendations for future research that may lead to increased material and thermal energy utilization during steam peeling for potatoes are suggested.

1. Methods of utilizing the peel slurry waste should be investigated.

2. The feasibility of recovery of starch from the wash water as well as from other effluent-generating operations in the plant should be studied.

3. The potential for reduction of waste stream magnitudes by decreasing steam or spray water inputs while maintaining acceptable peeling effectiveness should be investigated.

4. Recovery of thermal energy of steam escaping from the peeling vessel during exhausting should be investigated.

5. The feasibility of recovery of heat from the

peeled potatoes by using a more thorough water spray or soak should be considered.

6. The effectiveness of peeling with decreased steam requirements should be investigated by modifying steam pressures and exposure times.

APPENDICES

Appendix I. Typical Data Collection Sheet for One Trial

Date: 11/3/81; Trial 9

Raw Material Characteristics

Tuber no.	Weight, g	Length, cm	Width, cm	Height, cm
1	258	9.5	7.0	5.4
2	428	13.0	7.6	5.8
3	207	9.7	5.8	4.2
4	296	8.9	8.4	5.9
5	187	7.8	6.3	4.5
6	309	9.6	7.8	5.5
7	145	8.1	4.6	4.2
8	232	10.1	6.5	4.6
9	181	9.2	5.8	4.8
10	252	9.8	7.2	5.0
11	210	9.5	5.5	4.8
12	99	6.3	5.4	3.4
13	96	6.8	4.5	4.3
14	102	5.8	5.4	4.2
15	99	7.2	4.5	4.3
Mean Values	207	8.8	6.2	4.7

Seclect 12 potatoes with mass = 207 $\pm$ 15 g.

Peel loss test:

Mass before peeling, g	Mass after peeling, g	Percent peel loss
209.5	190.5	9.07
220.0	196.6	10.64
194.5	176.0	9.51
222.5	197.5	11.24
203.5	180.0	11.55
207.5	189.5	8.67
186.5	166.0	10.99
188.0	168.0	10.64
208.5	189.5	9.11
191.5	170.0	11.23
213.5	193.0	9.60
203.0	183.5	9.61
		10.15% = mean peel loss

Sp. $gr._{raw}$ = 1.0830; sp. $gr._{peeled}$ = 1.0875

Michigan Dept. of Agr. inspection: Date rec'd at plant: 11/2
77% of lot graded Michigan #1 potatoes
18% of lot had serious external defects

Variety: Kennebec; Source: Minnesota;

Comments: field (not stored) potatoes; normal run (not sortouts); a significant number of tubers semmed bruised.

(Appendix I., cont'd.)

Processing parameters

Steam exposure time, sec.	20
Raw potato load per cycle, kg	226.8
Steam pressure, N/m^2	168,700 (225 psig)
Time per cycle, sec.	95
Visual peel grade	2
Depth of cooked layer, mm	1.5
Peel loss, %	10.15

Temperatures of inputs and outputs, °C

Ambient	20.0
Peeling Vessel	154.4
Raw Potatoes	16.7
Steam	203.0
Spray Water	13.3
Peeled Potatoes	27.8
Peel	35.6
Peel & Condensate	66.7
Wash Water	30.6

Flow rates of output streams (raw data)

Spray Water	5.95 gpm
Peel	could not determine
Wash Water	51.1 lb./min
Peel & Condensate	6.5 lb./cycle

Composition of mass streams

	Moisture	Solids	Starch	Ash
Raw, unpeeled potatoes	78.48	21.52	60.29	4.54
Peeled Potatoes	79.07	20.93	54.42	4.41
Peel	89.54	10.46	28.18	16.47
Peel & Condensate	91.79	8.21	20.70	22.90
Wash Water	97.38	2.62	15.64	8.61

(1) (kg/kg) x 100%

(2) (kg/kg solids) x 100%

Appendix II. Visual Grading Scale for Peeled Potatoes[1]

	Description
GRADE 1.	A perfect peeled potato: no skin remaining, all eyes and all defects peeled clean. The only exceptions would be defects such as deep bruise, penetrating into the potato, judged to be unpeelable. Normally this condition would be considered "overpeeled."
GRADE 2:	A well-peeled potato: one or two very small specks of skin left on the surface or in an eye cavity.
GRADE 3:	A fairly well-peeled potato: several very small spots of skin may be left or some of the cortical layer may remain in the deeper eyes. There may be one patch of skin or a defect which might be peeled off for french fries. This grade is fully acceptable for french-fry production, as the defects would be considered minor.
GRADE 4:	This grade does not appear well-peeled, having either multiple peel fragments or defects remaining. It could also have a very faint layer of outer cortical cells remaining. These potatoes would not be acceptable for production of french fries without trimming, but would be fully acceptable for dehydrated mashed potato manufacture.
GRADE 5:	This grade shows 5 to 50 percent of outer periderm or outer cortical cells remaining. These potatoes are generally unacceptable for use in dehydrated potato manufacture.
GRADE 6:	Some peel removed but anywhere from 50 to 90 percent of either the periderm or outer cortical layer remains. Completely unacceptable for processing. A very poor peeling effort, generally occurring during trials for minimum conditions.
GRADE 7:	A well scrubbed potato with less than 10 percent of outer peel removed resulting from extreme test conditions.

(1) Source: Willard (1971a)

Appendix III. Sample Material Balance Calculation (using data from Trial 9; see Appendix I)

Total Material Balance:

Inputs	Mass per cycle, kg	Method
Unpeeled Potatoes	226.80	On weighhopper dial: 500 lb$\left(\frac{.4536\ kg}{lb.}\right)$ = 226.8kg
Steam	6.73	225 psig, 98% quality steam vessel capacity 35.24 ft^3 = .9998 m^3 potato volume = (226.8kg) $\frac{cm^3}{1.083g}$ =.2094 m^3 steam volume = .7904 m^3 steam mass = $\frac{.7904m^3}{.1174m^3/kg}$=6.73kg
Spray Water	35.64	$\frac{5.95gal}{min.}\left(\frac{8.34lb}{gal}\right)\left(\frac{95sec}{cycle}\right)$ = 35.64 kg
Total Inputs	269.17	

Outputs		
Peeled Potatoes	203.78	226.8kg(1-.1015) = 203.78 kg
Peel & Condensate	2.95	$\frac{6.5\ lb}{cycle}\left(\frac{.4536kg}{lb}\right)$ =2.95kg
Wash Water	36.70	$\frac{51.1lb}{min.}\left(\frac{95sec}{cycle}\right)$= 36.70kg
Peel	25.74	269.17-(203.78+2.95+ 36.70)=25.74kg
Total Outputs	269.17	

(Appendix III., cont'd.)

Solids Balance:

Inputs	Mass per cycle, kg	Method
Unpeeled Potatoes	48.81	226.8kg$(\frac{.2152\text{kg solids}}{\text{kg}})$ =48.41kg
Steam	0.0	
Spray Water	0.0	
Total Inputs Solids	48.81	
Outputs		
Peeled Potatoes	42.65	203.78kg$(\frac{.2093\text{kg solids}}{\text{kg}})$ = 42.65 kg
Peel	2.69	25.74kg$(\frac{.1046\text{kg solids}}{\text{kg}})$ = 2.69kg
Peel & Condensate	.24	2.95 kg$(\frac{.0821\text{kg solids}}{\text{kg}})$ =.24 kg
Wash Water	.96	36.70kg$(\frac{.0262\text{kg solids}}{\text{kg}})$ =.96 kg
Total Output Solids	46.54	
Other Output Solids	= 2.27	

Starch Balance:

Inputs	Mass per cycle, kg	Method
Unpeeled Potatoes	29.43	48.81kg solids$(\frac{.6029\text{kg}}{\text{kg solids}})$ = 29.43 kg
Steam	0.0	
Spray Water	0.0	
Total Input Starch	29.43	
Outputs		
Peeled Potatoes	23.21	42.65kgsolids$(\frac{.5442\text{kg}}{\text{kg solids}})$ = 23.21 kg
Peel	.76	2.69kgsolids$(\frac{.2818\text{ kg}}{\text{kg solids}})$ = .76 kg

(Appendix III., cont'd.)

Peel & Condensate	.05	.24kg solids $\left(\frac{.2070\ kg}{kgsolids}\right)$ = .05 kg
Wash Water	.15	.96kg solids $\left(\frac{.1564\ kg}{kgsolids}\right)$ = .15 kg
Total Output Starch	24.17	
Other Output Starch	5.26	

Ash Balance:

Inputs	Mass per cycle, kg	Method
Unpeeled Potatoes	2.22	48.81kg solids $\left(\frac{.0454\ kg}{kgsolids}\right)$ = 2.22 kg
Steam	0.0	
Spray Water	0.0	
Total Input Ash	2.22	

Outputs		
Peeled Potatoes	1.88	42.65kgsolids $\left(\frac{.0441\ kg}{kgsolids}\right)$ = 1.88 kg
Peel	.44	2.69kgsolids $\left(\frac{.1647\ kg}{kgsolids}\right)$ = .44 kg
Peel & Condensate	.05	.24kg solids $\left(\frac{.2290\ kg}{kgsolids}\right)$ = .05 kg
Wash Water	.08	.96kg solids $\left(\frac{.0861\ kg}{kgsolids}\right)$ = .08 kg
Total Output Ash	2.45	
Other Output Ash	-.23	

Appendix IV. Sample Thermal Energy Balance Calculation

Specific heat calculations:

$$c_p = (.4 + .006(\text{Moisture Content,\%}))\frac{\text{BTU}}{\text{lbF}}\left(\frac{4.1869\text{kJ/kgC}}{(\text{BTU/lb F}}\right)$$

Mass Stream	c_p, kJ/kgC
Unpeeled Potatoes	3.646
Spray Water	4.187
Peeled Potatoes	3.661
Peel	3.924
Peel & Condensate	3.981
Wash Water	4.121

Heat content of mass streams:

$$Q = mc_p(T - T_{ref}); \qquad T_{ref} = 0^{\circ}C$$

Mass Stream	Heat content, kJ	Method
Unpeeled Potatoes	13,783	$226.80\text{kg}\left(\frac{3.646\text{kJ}}{\text{kg C}}\right)(16.67\text{C})$
Spray Water	1,990	$35.74\text{kg}\left(\frac{4.187\text{kJ}}{\text{kg C}}\right)(13.33\text{C})$
Peeled Potatoes	20,724	$203.78\text{kg}\left(\frac{3.661\text{kJ}}{\text{kg C}}\right)(27.78\text{C})$
Peel	3,591	$25.74\text{kg}\left(\frac{3.924\text{kJ}}{\text{kg C}}\right)(35.56\text{C})$
Peel & Condensate	783	$2.95\text{kg}\left(\frac{3.98\text{kJ}}{\text{kg C}}\right)(66.67\text{C})$
Wash Water	4,621	$36.70\text{kg}\left(\frac{4.121\text{kJ}}{\text{kg C}}\right)(30.56\text{C})$

Heat content of steam:

$$Q_s = m(h_{fg} + X\ h_{fg})$$

From Figure 5, at 225 psig = 1.687×10^5 N/m^2,

Enthalpy = 2754.2 kJ/kg at X = .98

Heat content of steam = 6.73 kg (2754.2 kJ/kg) = 18,536 kg

(Appendix IV., cont'd.)

Radiative Heat Losses:

$$Q_r = h_r A (T_{sh} - T_\infty), \text{ where } h_r = .0069\epsilon\left(\frac{\theta}{100}\right)^3$$

ϵ = .80 (Sheet steel with a strong, rough oxidized layer)

$$\theta = \left(\frac{T_{sh} + T_\infty}{2}\right) = \left(\frac{154.4 + 20.0}{2}\right) = 649^\circ R$$

$$h_r = .0069(.80)\left(\frac{649}{100}\right)^3 \left(\frac{5.6782W/(m^2C)}{BTU/hrft^2F}\right) = 8.5678 \text{ W/(m}^2 \text{ C)}$$

$$A = 2\pi rh + 2\pi r^2 = \left(\frac{2\pi(40in.)(46in.)}{144in^2/ft^2} + 2\pi\left(\frac{20}{12}\right)^2 ft^2\right)\left(\frac{.092m^2}{ft^2}\right)$$

$$A = 5.351 \text{ m}^2$$

$$Q_r = \frac{8.5678 \text{ W}}{m^2 \text{ C}}(5.351 \text{ m}^2)(154.44-20.00)^\circ C = 367 \text{ kJ}$$

Convective Heat Losses:

$$Q_c = h_c A (T_{sh} - T_\infty)$$

$$N_{Gr}N_{Pr} = \frac{\rho^2 g\beta(T_{sh} - T_\infty) L^3 c_p}{k \mu}$$

$$= (.975kg/m^3)^2(9.81m/sec^2)(.00278^\circ K^{-1})(134.4K)$$

$$\times \left(\frac{46ft}{12}\right)^3\left(\frac{.3048m}{ft}\right)^3\left(\frac{1.010kJ}{kg\ C}\right)$$

$$\div \left(\frac{.03075 \text{ W}}{m^\circ C}\right)\left(\frac{2.1171 \times 10^{-5}kg}{m \text{ sec}}\right)$$

$$N_{Gr}N_{Pr} = 7.506 \times 10^9$$

$$\phi = .021, \ m = 2/5$$

$$N_{Nu} = \phi (N_{Gr}N_{Pr})^m = 187.23$$

$$N_{Nu} = h_c L/k$$

$$h_c = \frac{187.23 \ (.03075 \ W/m^\circ C)}{\left(\frac{46ft}{12}\right)\left(\frac{.3048m}{ft}\right)} = 4.928 \text{ W/m}^{2\circ}C$$

$$Q_c = (4.928W/m^{2\circ}C)(5.351m^2)(154.44 - 20)^\circ C = 342 \text{ kJ}$$

(Appendix IV., Cont'd.)

Thermal Energy Balance:

Inputs	Heat Content, kJ
Unpeeled Potatoes	13,783
Steam	18,536
Spray Water	1,990
Total Input Thermal Energy	34,309
Outputs	
Peeled Potatoes	20,724
Peel	3,591
Peel & Condensate	783
Wash Water	4,621
Radiative Losses	367
Convective Losses	342
Other Losses	3,881
Total Output Thermal Energy	34,309

Appendix V. Mass and Thermal Energy Balances, Raw Material Characteristics, and Processing Conditions for the 14 trials of this investigation.

Trial 1 (9/23/81)

Material and Thermal Energy Balance

	Mass per cycle, kg				Enthalpy per cycle, kJ
	Total	Solids	Starch	Ash	
Inputs					
Unpeeled Potatoes	226.80	47.45	31.93	2.20	14,763
Steam	6.59	---	---	---	18,146
Spray Water	30.26	---	---	---	2,393
Total	263.65	47.45	31.93	2.20	35,302
Outputs					
Peeled Potatoes	208.45	42.39	27.42	1.53	22,563
Peel	25.98	2.55	.45	.22	3,583
Peel & Condensate	4.54	.20	.05	.03	1,245
Wash Water	24.68	.25	.12	.02	2,853
Radiative Losses	---	---	---	---	279
Convective Losses	---	---	---	---	266
Other Losses	---	2.07	3.89	.40	4,513

Peel loss 8.09%
Steam time 17 sec
Steam pressure 220 psig
Cycle time 80 sec
Peel grade 3
Cook depth 2.0

Average;
Mass 277 g
Length 10.0 cm
Width 7.0 cm
Height 5.5 cm

Sp. gr.$_{unpeeled}$ = 1.0790
Sp. gr.$_{peeled}$ = 1.0780
Variety; Kennebec
Source: Minnesota
% External Defects 20
% Michigan # 1 69
Normal size
Light skin layer

(Appendix V., cont'd.) Trial 2 (10/8/81)

Material and Thermal Energy Balance

	Mass per cycle, kg				Enthalpy per
	Total	Solids	Starch	Ash	cycle, kJ
Inputs					
Unpeeled Potatoes	226.80	50.76	32.65	2.30	12,788
Steam	6.86	---	---	---	18,899
Spray Water	31.80	---	---	---	2,515
Total	265.46	50.76	32.65	2.30	34,202
Outputs					
Peeled Potatoes	204.30	46.58	27.97	1.84	22,971
Peel	29.62	3.13	.96	.31	5.033
Peel & Condensate	4.54	.14	.03	.03	1,139
Wash Water	27.00	.38	.07	.03	3,176
Radiative Losses	---	---	---	---	263
Convective Losses	---	---	---	---	259
Other Losses	---	.53	3.62	.09	1,361

Peel loss 9.92 %
Steam time 22 sec
Steam Pressure 230 psig
Cycle time 84 sec
Peel grade 2
Cook depth 2.0

Measured peel rate: 34.2 kg/cycle

Average:
Mass 125 g
Length 7.2 cm
Width 5.6 cm
Height 4.1 cm

Sp. gr.$_{unpeeled}$ = 1.078
Sp. gr.$_{peeled}$ = 1.080
Variety: Kennebec
Source: Minnesota, North Dakota, Michigan
% External Defects 10
% Michigan # 1 79
Sortout size
Light skin, much already flaked off.

(Appendix V., cont'd.) Trial 3 (10/8/81)

Material and Thermal Energy Balance

	Mass per cycle, kg				Enthalpy per
	Total	Solids	Starch	Ash	cycle, kJ
Inputs					
Unpeeled Potatoes	226.80	46.83	24.67	1.68	12,941
Steam	6.86	---	---	---	18,899
Spray Water	31.80	---	---	---	2,663
Total	265.46	46.83	24.67	1.68	34,503
Outputs					
Peeled Potatoes	211.72	44.73	22.04	1.58	21,070
Peel	22.39	2.32	.64	.21	3,126
Peel & Condensate	4.54	.24	.04	.03	1,156
Wash Water	26.81	.41	.15	.02	3,089
Radiative Losses	---	---	---	---	261
Convective Losses	---	---	---	---	257
Other Losses	---	-.87	1.80	-.16	5,544

Peel loss 6.65%
Steam time 18 sec
Steam pressure 230 psig
Cycle time 83.5 sec
Peel grade 2.0
Cook depth 1.8

Measured peel rate: 21.5kg/cycle

Average:
Mass 345 g
Length 11.2 cm
Width 7.3 cm
Height 5.6 cm

Sp. gr.$_{unpeeled}$ = 1.0810
Sp. gr.$_{peeled}$ = 1.0850
Variety: Kennebec
Source: Minnesota, North Dakota
% External Defects 10
% Michigan # 1 81
Normal size
Fairly light skin

(Appendix V., cont'd.) Trial 4 (10/13/81)

Material and Thermal Energy Balance

	Mass per cycle, kg				Enthalpy per
	Total	Solids	Starch	Ash	cycle, kJ
Inputs					
Unpeeled Potatoes	226.80	47.88	22.72	1.92	15,204
Steam	6.60	---	---	---	18,173
Spray Water	34.88	---	---	---	2,921
Total	268.28	47.88	22.72	1.92	36,298
Outputs					
Peeled Potatoes	213.83	46.40	21.58	1.79	18,603
Peel	23.33	2.21	.19	.21	3,071
Peel & Condensate	4.54	.09	.009	.02	1,148
Wash Water	26.58	.39	.05	.03	2,941
Radiative Losses	---	---	---	---	324
Convective Losses	---	---	---	---	309
Other Losses	---	-1.21	.89	-.13	9,902

Peel loss 5.72%
Steam time 15 sec
Steam pressure 220 psig
Cycle time 93 sec
Peel grade 3
Cook Depth 1.5 mm

Measured Peel Rate 23.3kg/cycle

Average:
Mass 229g
length 10.1cm
width 6.4cm
height 4.5cm

Sp. $gr._{unpeeled}$ = 1.084
Sp. $gr._{peeled}$ = 1.0855
Variety: Kennebec
Source: North Dakota
% External Defects 14
% Michigan # 1 75
Normal size
Normal peel

(Appendix V., cont'd.) Trial 5 (10/13/81)

Material and Thermal Energy Balance

	Mass per cycle, kg				Enthalpy per cycle, kJ
	Total	Solids	Starch	Ash	
Inputs					
Unpeeled Potatoes	226.80	47.42	18.98	1.86	15,686
Steam	6.60	---	---	---	18,173
Spray Water	31.39	---	---	---	2,629
Total	264.79	47.42	18.98	1.86	36,488
Outputs					
Peeled Potatoes	218.41	46.35	17.45	1.75	21,281
Peel	21.02	1.73	.15	.17	2,929
Peel & Condensate	4.54	.11	.01	.02	1,145
Wash Water	20.82	.30	.03	.03	2,304
Radiative Losses	---	---	---	---	290
Convective Losses	---	---	---	---	276
Other Losses	---	-1.06	1.34	-.11	8,263

Peel loss 3.70%
Steam time 15 sec
Steam pressure 220 psig
Cycle time 83 sec
Peel grade 3
Cook Depth 1.5 mm

Measured Peel Rate 16.9kg/cycle

Average:
Mass 229g
length 9.8 cm
width 6.5 cm
height 4.9 cm

Sp. gr.$_{unpeeled}$ = 1.0845
Sp. gr.$_{peeled}$ = 1.0850
Variety: Kennebec
Source: North Dakota
% External Defects 9
% Michigan # 1 83
Normal size
Normal peel

(Appendix V., cont'd.) Trial 6 (10/20/81)

Material and Thermal Energy Balance

	Mass per cycle, kg				Enthalpy per
	Total	Solids	Starch	Ash	cycle, kJ
Inputs					
Unpeeled Potatoes	226.80	50.87	18.93	1.77	14,610
Steam	6.60	---	---	---	18,173
Spray Water	34.75	---	---	---	2,910
Total	268.15	50.87	18.93	1.77	35,693
Outputs					
Peeled Potatoes	211.51	43.82	17.22	1.69	21,110
Peel	34.81	3.42	.53	.35	4,876
Peel & Condensate	4.50	.28	.04	.05	1,179
Wash Water	17.33	.38	.18	.03	1,909
Radiative Losses	---	---	---	---	290
Convective Losses	---	---	---	---	270
Other Losses	---	2.97	.96	-.35	6,059

Peel loss	6.74%
Steam time	17 sec
Steam pressure	220 psig
Cycle time	81 sec
Peel grade	2
Cook depth	1.2 mm

Average:

Mass	434 g
Length	11.7 cm
Width	7.8 cm
Height	5.8 cm

Sp. gr.$_{unpeeled}$ = 1.0845
Sp. gr.$_{peeled}$ = 1.0870
Variety: Kennebec
Source: North Dakota
% External Defects 14
% Michigan # 1 74
Normal size
Fairly light skin

(Appendix V., cont'd.) Trial 7 (10/20/81)

Material and Thermal Energy Balance

	Mass per cycle, kg				Enthalpy per cycle, kJ
	Total	Solids	Starch	Ash	
Inputs					
Unpeeled Potatoes	226.80	54.75	19.95	1.98	13,083
Steam	6.60	---	---	---	18,173
Spray Water	36.56	---	---	---	3,061
Total	269.96	54.75	19.95	1.98	34,317
Outputs					
Peeled Potatoes	211,49	51.20	17.82	1.77	22,706
Peel	36.60	3.94	1.16	.41	5,017
Peel & Condensate	5.00	.31	.05	.05	1,265
Wash Water	16.87	.40	.15	.03	2,050
Radiative Losses	---	---	---	---	293
Convective Losses	---	---	---	---	279
Other Losses	---	-1.10	.77	-.28	2,707

Peel loss	6.75%
Steam time	17 sec
Steam pressure	220 psig
Cycle time	84 sec
Peel grade	2
Cook depth	1.7 mm

Average:

Mass	369 g
Length	10.6 cm
Width	7.6 cm
Height	5.8 cm

Sp. gr.$_{unpeeled}$ = 1.0860
Sp. gr.$_{peeled}$ = 1.0870
Variety: Kennebec
Source: Minnesota, North Dakota
% External Defects 15
% Michigan # 1 68
Normal size
A large proportion of the tubers appear damaged. Some suberization observed.

(Appendix V., cont'd.) Trial 8 (10/26/81)

Material and Thermal Energy Balance

	Mass per cycle, kg				Enthalpy per cycle, kJ
	Total	Solids	Starch	Ash	
Inputs					
Unpeeled Potatoes	226.80	46.58	20.91	2.34	12,026
Steam	6.59	---	---	---	18,146
Spray Water	33.11	---	---	---	2,465
Total	266.50	46.58	20.91	2.34	32,637
Outputs					
Peeled Potatoes	208.25	42.32	18.96	1.91	21,692
Peel	22.33	2.24	.42	.43	3,417
Peel & Condensate	3.13	.24	.03	.07	785
Wash Water	32.79	.47	.12	.05	4,234
Radiative Losses	---	---	---	---	313
Convective Losses	---	---	---	---	301
Other Losses	---	1.31	1.38	-.12	1,895

Peel loss	8.18%
Steam time	21 sec
Steam pressure	220 psig
Cycle time	89 sec
Peel grade	3
Cook depth	1.5

Average:

Mass	183 g
Length	8.9 cm
Width	5.8 cm
Height	4.6 cm

Sp. $gr._{unpeeled}$ = 1.0775
Sp. $gr._{peeled}$ = 1.080
Variety: Kennebec
Source: Minnesota
% External defects 28
% Michigan # 1 59
Sortout size
Some greening and suberization

(Appendix V., cont'd.) Trial 9 (11/3/81)

Material and Thermal Energy Balance

	Mass per cycle, kg				Enthalpy per cycle, kJ
	Total	Solids	Starch	Ash	
Inputs					
Unpeeled Potatoes	226.80	48.81	29.43	2.22	13,783
Steam	6.73	---	---	---	18,536
Spray Water	35.64	---	---	---	1,990
Total	269.17	48.81	29.43	2.22	34,309
Outputs					
Peeled Potatoes	203.78	42.65	23.21	1.88	20,724
Peel	25.74	2.69	.76	.44	3,591
Peel & Condensate	2.95	.24	.05	.05	783
Wash Water	36.70	.96	.15	.08	4,621
Radiative Losses	---	---	---	---	367
Convective Losses	---	---	---	---	342
Other Losses	---	2.27	5.26	-.23	3,881

Peel loss 10.15%
Steam time 20 sec
Steam pressure 225 psig
Cycle time 95 sec
Peel grade 2
Cook depth 1.5 mm

Average:
Mass 207 g
Length 8.8 cm
Width 6.2 cm
Height 4.7 cm

Sp. gr.$_{unpeeled}$ = 1.0830
Sp. gr.$_{peeled}$ = 1.0875
Variety: Kennebec
Source: Minnesota
% External defects 18
% Michigan # 1 77
Normal size
Small, signs of rotting, bruising, suberization and freezing

(Appendix V., cont'd.) Trial 10 (11/3/81)

Material and Thermal Energy Balance

	Mass per cycle, kg				Enthalpy per
	Total	Solids	Starch	Ash	cycle, kJ
Inputs					
Unpeeled Potatoes	226.80	48.29	20.83	2.40	15,185
Steam	6.73	---	---	---	18,536
Spray Water	31.25	---	---	---	1,745
Total	264.78	48.29	20.83	2.40	35,466
Outputs					
Peeled Potatoes	206.46	44.86	18.91	1.99	21,716
Peel	22.28	2.36	.76	.37	3,494
Peel & Condensate	2.45	.19	.04	.04	642
Wash Water	33.59	1.12	.25	.09	4,288
Radiative Losses	---	---	---	---	325
Convective Losses	---	---	---	---	302
Other Losses	---	-.24	.87	-.09	4,699

Peel loss	8.97%
Steam time	20 sec
Steam pressure	225 psig
Cycle time	84 sec
Peel grade	2
Cook depth	1.5

Average:

Mass	266 g
Length	9.1 cm
Width	8.5 cm
Height	5.3 cm

$Sp.\ gr._{unpeeled} = 1.0795$

$Sp.\ gr._{peeled} = 1.0845$

Variety:	Kennebec	
Source:	Minnesota	
% External	Defects	17
% Michigan # 1		80
Normal size		

(Appendix V., cont'd.) Trial 11 (11/10/81)

Material and Thermal Energy Balance

	Mass per cycle, kg				Enthalpy per
	Total	Solids	Starch	Ash	cycle, kJ
Inputs					
Unpeeled Potatoes	226.80	50.49	25.49	2.12	12,799
Steam	6.73	---	---	---	18,536
Spray Water	27.66	---	---	---	2,059
Total	261.19	50.49	25.49	2.12	33,394
Outputs					
Peeled Potatoes	200.97	44.64	23.54	1.60	19,853
Peel	33.62	3.16	.56	.42	5,017
Peel & Condensate	1.93	.13	.01	.02	552
Wash Water	24.67	.41	.14	.03	3,124
Radiative Losses	---	---	---	---	263
Convective Losses	---	---	---	---	254
Other Losses	---	2.15	1.24	.05	4,331

Peel loss 11.39%
Steam time 23 sec
Steam pressure 225 psig
Cycle time 75 sec
Peel grade 3
Cook depth 1.7

Average:
Mass 241 g
Length 10.3 cm
Width 6.1 cm
Height 4.8 cm

Sp. $gr._{unpeeled}$ = 1.0790
Sp. $gr._{Peeled}$ = 1.0820
Variety: Russet Burbank
Source: Michigan
% External Defects 14
% Michigan # 1 71
Normal size
Good quality Russet Burbank,
Heavy skin compared to Kennebec
Peel left in crevices

(Appendix V., cont'd.) Trial 12 (11/10/81)

Material and Thermal Energy Balance

	Mass per cycle, kg				Enthalpy per
	Total	Solids	Starch	Ash	cycle, kJ
Inputs					
Unpeeled Potatoes	226.80	46.31	21.83	1.91	13,887
Steam	6.73	---	---	---	18,536
Spray Water	29.39	---	---	---	2,188
Total	262.92	46.31	21.83	1.91	34,611
Ouputs					
Peeled Potatoes	197.20	42.26	19.78	1.51	19,986
Peel	34.06	3.35	.65	.40	5,517
Peel & Condensate	2.04	.13	.02	.02	584
Wash Water	29.62	.90	.30	.07	3,856
Radiative Losses	---	---	---	---	278
Convective Losses	---	---	---	---	267
Other Losses	---	-.33	1.08	-.11	4,123

Peel loss 13.05%
Steam time 23 sec
Steam Pressure 225 psig
Cycle time 79 sec
Peel grade 2.5
Cook depth 1.5 mm

Average:
Mass 241 g
Length 10.4 cm
Width 6.1 cm
Height 4.8 cm

Sp. $gr._{unpeeled}$ = 1.0815
Sp. $gr._{peeled}$ = 1.0815
Variety: Russet Burbank
Source: Michigan
% External Defects 14
% Michigan # 1 72
Normal size
Thicker skins than Kennebec
Peel left in crevices
Good quality Russet Burbank

(Appendix V., cont'd.) Trial 13 (11/17/81)

Material and Thermal Energy Balance

	Mass per cycle, kg				Enthalpy per cycle, kJ
	Total	Solids	Starch	Ash	
Inputs					
Peeled Potatoes	226.8	48.94	25.16	1.67	13,777
Steam	6.73	---	---	---	18,536
Spray Water	43.85	---	---	---	2,856
Total	277.38	48.94	25.16	1.67	35,169
Outputs					
Peeled Potatoes	210.22	46.12	22.86	1.55	20,381
Peel	22.82	2.32	.62	.18	2,991
Peel & Condensate	4.90	.19	.05	.02	1,292
Wash Water	39.44	.45	.17	.02	3,918
Radiative Losses	---	---	---	---	388
Convective Losses	---	---	---	---	370
Other Losses	---	-.14	1.46	-.10	5,829

Peel loss	7.31%
Steam time	20 sec
Steam pressure	225 psig
Cycle time	107 sec
Peel grade	2
Cook depth	1.3

Average:

Mass	218g
Length	9.1 cm
Width	6.2 cm
Height	4.7 cm

Sp. gr.$_{unpeeled}$ = 1.0825
Sp. gr.$_{peeled}$ = 1.0840
Variety: Kennebec
Source: North Dakota
% External Defects 6
% Michigan # 1 88
Normal size
Fairly light skin, good over-all quality

(Appendix V., cont'd.) Trial 14 (11/17/81)

Material and Thermal Energy Balance

	Mass per cycle, kg				Enthalpy per
	Total	Solids	Starch	Ash	cycle, kJ
Inputs					
Unpeeled Potatoes	226.80	49.69	26.16	1.70	12,830
Steam	6.73	---	---	---	18,536
Spray Water	43.03	---	---	---	2,803
Total	276.56	49.69	26.16	1.70	34,169
Outputs					
Peeled Potatoes	212.44	48.10	24.56	1.53	19,216
Peel	21.66	2.21	.62	.17	2,838
Peel & Condensate	3.76	.18	.03	.02	985
Wash Water	38.70	.96	.30	.05	4,168
Radiative Losses	---	---	---	---	393
Convective Losses	---	---	---	---	369
Other Losses	---	-1.76	.65	-.07	6,200

Peel loss 6.33%
Steam time 20 sec
Steam pressure 225 psig
Cycle time 105 sec
Peel grade 2
Cook Depth 1.8

Average:
Mass 502 g
Length 12 cm
Width 8 cm
Height 6 cm

$Sp.\ gr._{unpeeled}$ = 1.0840
$Sp.\ gr._{peeled}$ = 1.0840
Variety: Kennebec
Source: North Dakota
% External Defects: 9
% Michigan #1 82
Normal size
Fairly light skin

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