LOW TEMPERATURE CONCENTRATION OF FRUIT AND VEGETABLE JUICES

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Thomas A. Curtis

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This is to certify that the

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Walter M. Carleton
Major professor

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THOMAS A. CURTIS

A THESIS

Submitted to the School of Graduate Studies of Michigan
State College of Agriculture and Applied Science
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The frozen concentrated fruit juice industry is relatively new. The reception of frozen concentrated orange juice and later such juices as lemon, lime, grapefruit, grape, tangerine and others were so well received that a whole new industry, both from a grower's standpoint and equipment manufacturer's standpoint, was born. Growers' prices swelled to ten times that which they received before the advent of this industry. This price leveled off at six times the original.

A whole new line of low temperature evaporators appeared. Six equipment manufacturers placed new types of evaporators on the market to handle the sudden demand for frozen concentrates. Basically, most of these evaporators use refrigeration systems either directly or indirectly for both heating the incoming juice and cooling the outgoing juice. Efficiencies of these new evaporators are much higher than the old standard types. Research on the development of concentration by freezing was stepped up with new gains made.

The three main factors responsible for the sudden success of frozen concentrates include: (a) the overall development of the frozen foods industry; (b) the development of the cut-back method for making orange concentrate, and; (c) the development of low temperature evaporators and facilities for hauling and storing the concentrates at $0^{\circ}F$ or lower.

It is felt that there would be a ready market for any new highly palatable juice concentrate. For this reason, juices that would conceivably make a highly palatable concentrate were investigated with the hope of developing one or more juices or juice blends into a highly palatable concentrate.

The main objectives of this investigation included:

1. To design and construct an improved apparatus for the concentration at low temperatures of fruit and vegetable juices; the treatment of the juice to be similar to that which it would receive on a commercial basis.
2. To develop or attempt to develop a fruit or vegetable juice or juices of high palatability that would, if placed on the market, be received with high consumer preference.
3. To determine which of these juices would warrant further investigation as a frozen concentrate.

A low temperature concentration unit was designed and built utilizing a refrigeration system and the inherent efficiencies of a refrigeration system. New design features included pulling the juice up a slope at a slow velocity, and a water bath for carrying heat from the condensing vapor to the low side of the refrigeration system.

Of the juices unknown to the market as concentrates plum, apple, celery and blueberry offered the most promise of being developed into a palatable concentrate. Italian Purple and Japanese Red prune plums, Grimes, Jonathan, Crab, Delicious and Spy apples, celery and blueberry juice was investigated.

The juices were all tasted and scored in preliminary testing and tasted and scored in final testing with the composition of the final tests depending upon the scores of the preliminary testing.

Because of the small volume of samples, limited facilities, limited number of trained testers, and the large number of samples, the results of these tests were necessarily limited to determining which juices warranted further investigation for beverage purposes.

A complete data log and heat transfer calculations as well as an analysis of the system were included in this investigation.

APPROVED:

Walter M. Carleton
Major Professor

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INTRODUCTION

The frozen concentrated fruit and vegetable juice industry is relatively new. Its start may be dated back to 1931 when cold orange concentrate first appeared on the market. The juice was delivered by milkmen and in cardboard containers. The test marketing ended in default as the juice failed to hold up in storage either with the processor or with the housewife. The first real gains of the industry started in 1944 when Dr. L. G. MacDowell, Director of Research for the Florida Citrus Commission, suggested that the commission overconcentrate orange juice under high vacuum and correspondingly low temperatures and add about 10 percent of the fresh juice to bring the concentrate to the desired percent solids. This became known as the cut-back method and was the real start of the frozen concentrate juice industry.

Orange juice is the standard by which all other juice concentrates will set their prices, production totals, etc. Orange juice is firmly entrenched in the housewife's menu. As orange juice is the yardstick for other products, madam housewife is the yardstick for orange juice. Her demand and the price she will pay, governs the production of all juice concentrates.

The cut-back method of producing the orange concentrate will not prove satisfactory with all concentrates. While the orange concentrate has started a whole host of other frozen concentrates, they are not all prepared in the same manner. A good rule of thumb for using the cut-back method could be to use the cut-back method with any juice having a tart, strong flavor, such that 10-20 percent when added to its concentrate will restore enough of the original flavor and aroma to favorably compare to the original.

This rule would immediately take in all of the citric juices and few of the other fruit juices, but practically none of the vegetable juices. For example, apple juice gives up much of its flavor, as do any of the juices, to the water vapor that is drawn off the juice. These volatile flavor compounds are in the form of esters and are easily recovered by fractional distillation. The process of recovering the flavor compounds by fractional distillation has only recently been practiced with considerable success with apple and grape juice concentrates.

Orange juice, like so many other juices, is sensitive to heat and the development of methods for concentration at low temperatures was necessary. Grape juice and tomato juice (7) are, however, not bothered by hot pack or pasteurization temperatures and therefore will probably never enjoy the success as a concentrate that orange juice has had. Grape juice has had more success, however, than that predicted by men in the field and will always have a small corner in the frozen concentrate industry, because of its simplicity in preparation and delightful flavor.

Since the advent of frozen concentrated orange juice, new frozen concentrates have appeared on the market, notably lemon, lime, grapefruit, prune, coffee, chocolate drink, tangerine, orange-grapefruit blend, and in limited quantities apple and cherry juice concentrate. Missing from the list of juice concentrates are fruit juices such as fresh plum, raspberry, blackberry, crab apple, currant, and blueberry, and vegetable juices such as celery and tomato. All of these mentioned have possibilities as a palatable frozen concentrate.

Reception of the Product: Needless to say, orange concentrate has been overwhelmingly received by the public. In its first test marketing, gratifying results were received. This occurred in a drugstore in Pittsburgh, Pennsylvania, where the concentrate was sold for the freshly squeezed juice (27). Out of 200 customers, feeling that they were drinking the freshly squeezed juice, only one suggested that it did not quite taste like the fresh juice. The dime was cheerfully refunded.

The growers in Florida were removed from certain disastrous losses due to surplus orange crops. In 1945 the grower was receiving thirty-five cents for a box of oranges, while in 1947 this price had jumped to $3.50 per box. Naturally the price leveled off, but not to anywhere near the thirty-five cent level. The leveling off occurred at around $2.00 per box with no danger of falling off. In 1947 through 1950 it was not surprising to hear about major juice processors buying out whole groves at what would formerly be termed fantastic prices. Growers were selling what they had, then developing swamp lands into more groves, selling those and so on. Anyone who owned large groves were suddenly wealthy, more so than they could have possibly dreamed.

If a palatable vegetable juice were to be exploited, a tremendous educational program would have to be carried on. The average person would have to be convinced that he or she should drink the vegetable juice as a beverage or as a breakfast juice. Nevertheless further investigation in this field is warranted by the fact that there are so many juices that would have a ready market if produced with a high palatable flavor. The advantages of having ready availability of vitamins in the concentrate cannot be over-emphasized.

REVIEW OF LITERATURE

It is interesting to note that there are three major factors responsible for the success of the frozen juice concentrate industry. First and foremost it must be conceded that any frozen product would not have a chance were it not for the over-all general development of the frozen foods industry. Second, the rapid development of equipment and manufacturing methods for low temperature concentration were of tremendous importance in allowing for the fast success of the juice concentrate industry. For example, production was increased from two million gallons in 1947 to twenty million in 1950 (estimated) for orange juice alone. The fact that in most all grocery stores of average size, there is a frozen foods cabinet for storing the orange juice for sale, plus the fact that modern methods of processing, handling and shipping at temperatures of zero or lower, made such production increases possible. Third, the development of the cut-back method did away with any flat, insipid juice that would result from concentration by boiling, regardless of temperatures used. Rector (22) mentions the frozen food stimulus, surplus raw material, demand for the concentrate from soft drink manufacturers, wartime demand for a concentrate for Europe, preliminary work on the freeze drying of blood plasma, and the advance nutritional knowledge, as being the six principal stimuli leading to the creation of this product.

The process of cutting the over-concentrated juice with single strength juice is covered by a public service patent. Neither the citrus commission nor the equipment engineers could claim exclusive rights to the process due to the part played by the United States Department of Agriculture in its development. There is free availability, therefore, to the patent which states in brief (10):

(1) A process of producing a citrus fruit juice concentrate capable of speedy reconstruction by addition of water to make a cold drink having a substantial portion of the original aroma, flavor, and palatibility of the citrus fruit, comprising concentrating whole juice of citrus fruit under vacuum to about five-fold to eight-fold, then diluting the concentrated juice with fresh, unconcentrated whole juice of the same citrus fruit to lower the concentration to three-fold to four-fold, sealing under vacuum and freezing.

(2) Applicable to all fruit juices.

(3) Free availability of the patent.

With each fruit or vegetable juice there is a different problem. In the case of orange juice only 10 percent of the fresh juice is necessary to restore enough of the original flavor and aroma to pass the most critical taste test. This means that the original juice is concentrated to 59° Brix then cut back to 42° Brix with fresh juice. Unfortunately this process will not work with all juices. Many contain most of their flavor and practically all of their color either in or next to the skin; another group such as apples must have their flavor compounds removed, clarified, and concentrated, and their esters or flavor compounds added to the concentrate; others such as blueberries must be heated to 180°, squeezed and allowed to settle for three months without clarification before processing, as clarification would ruin the flavor and remove the natural flavor and aroma (13) as well as most of the color; others such as grape and some apple varieties may have sugar added, then be concentrated in order to arrive at a high enough solids content without jelling or precipitation. The literature contains nothing on the low temperature concentration of celery, carrot, beet, currant, blueberry, raspberry, crab apple, apple blends nor as to the exact nature of their flavor compounds, the amount of heat that each will withstand without flavor damage, suggested processing methods in preparing for concentration. Perhaps most important of all, there is nothing in the literature as to their desirability, from a taste standpoint, as a fruit juice concentrate.

There is considerable research being conducted in an attempt to develop an economically feasible method for the recovery of the esters or flavor compounds which are lost during any concentration by boiling, regardless of the operating temperatures. Milleville and Eskew (17) have devised a satisfactory method of ester recovery. The juice distillate (containing the flavor compounds in the form of esters) is heated under pressure; the pressure is then suddenly released and the vapors fractionated and concentrated so that the flavor is about 150 times that in the fresh juice. Such a method is now used commercially; however, there is considerable room for improvement in this method.

The United States Regional Laboratory at Philadelphia (9) developed an ester distillation process for recovering the esters from grape juice, and earlier a process for the recovery of apple esters. Until recently, grape and apple concentrates were practically unknown to the market. They were previously concentrated and the esters fractionated and returned to the concentrate for the purpose of making fuller flavored preserves, jellies and candies. However, the field of ester recovery has spread to that of the concentrate with the resulting product difficult to differentiate from that of the original juice, even by the most critical taste buds.

EQUIPMENT NEW TO THE INDUSTRY

The equipment that has aided the development of the concentrate uses, for the most part, involves the use of both sides of a refrigeration system. The high side (hot gas) is used for heating the juice and the low side (cold boiling liquid) is used to condense the water that has been boiled off the juice. Mitchell (18) states that Joe Cross of Mojonnier Brothers Equipment Company, after a thorough study of the problem at hand, suggested using a refrigeration system for simultaneous heating and cooling the orange juice. It was immediately tried and with considerable success.

Using equipment that was originally intended to fill a huga army demand for orange juice powder, the Florida

Citrus Commission was able to get into mass production quickly, rather than wait for manufacture and delay in giving the orders for new equipment to a private concern. This all came about after the initial success of test marketed frozen concentrated orange juice.

Cross (6) states that this new system requires no steam or other sources of heat, operates at any temperature down to 40°F, gives multiple effect economy at single temperatures, and delivers all water vapor as condensate. In connection with low temperature concentration the following steps must be rigidly followed; rapid handling under sanitary conditions, thorough deaeration, hermetic sealing in gas tight containers, and the juice must be quickly frozen and stored at 0°F or less. This may be said about any unpasteurized food product which must be expected to hold up under storage. The total time from extraction to freezing in the can is now twenty minutes for orange juice.

For over a century, designers had been looking for a method of concentrating liquids in a closed vacuum cycle, the heat given off in the condenser to be used in boiling the incoming liquid. There is less than 2 percent more heat in a pound of steam at 100°F than 60°F, however, the volume at 60°F is 1203 cubic feet and any vapor pump handling such a volume would lose far more than 2 percent in friction; other losses combine to make it more economical to use live steam rather than the regenerative cycle. The high ratio of performance of a refrigerating system, from the standpoint of heat, adapts it perfectly to this service. It is easy for a refrigerating machine to handle from three to five times the heat-energy put into the motor driving it. Applied to a low temperature system (5) using ammonia means that two pounds of ammonia at 7.2 cubic feet is pumped instead of one pound of steam at 1208 cubic feet.

After the adoption of the Mojonnier system, several other equipment manufacturers brough out their version of low temperature concentration equipment. The most notable of these is the Kelly-Howard concentrator, which like most of the others, incorporates a refrigeration system either directly or indirectly. The Kelly-Howard concentrator (19) (now known as the Carrier-Howard) uses hot water to provide heat for initial boiling, the original heat being supplied by a hot well indirectly connected to a refrigeration system. The vapor from this boiling is pumped to the next effect and provides heat to continue boiling the juice from which it just left and in the next effect. In other words a step down vacuum system is used, with a vacuum of 29.14, 29.44 and 29.64 inches of mercury in each successive step.

Development of the Mojonnier system has also stimulated other manufacturers. Buflovak has now developed an evaporator heated with low pressure steam which produces a concentrate under practically the same temperature conditions as those obtained in the Mojonnier and the Kelly-Howard evaporator. Rector (22) states that as far as can be determined, the quality of the product produced in the evaporators is identical.

The Stokes Machinery Company has developed a process of drying by sublimation which still has only limited use in the field of low temperature concentration. The equipment is high priced, likewise the maintenance; also they have not developed a continuous system, although this is the ultimate goal.

The National Research Corporation is the only firm to switch from freeze drying orange juice to a powder to the frozen concentrate with any success. This Corporation placed their money on developing a powdered product for consumer use. This investment proved to be a failure. However, in the process they had developed a high capacity low temperature evaporator of unique design such that when the outstanding results of the first test marketing of orange concentrate (using the cut-back method as well as low temperature evaporation) reached Florida, the Corporation was able to start production in their evaporators on a large scale and get into the market quickly. The National Research Corporation must, therefore, be given credit as being instrumental in the development of the present concentrate industry.

All of the aforementioned companies making low temperature evaporators have applied for patents. Other than basic claims, these patents are still pending at this writing. It must be remembered that the rapid progress in this field is very new and that new developments continually turn up. Knowledge of these developments is not always immediately known.

Systems like the Mojonnier, Carrier-Howard and others have several advantages over other types or older steam type vacuum systems. These advantages (17) are: (a)higher economies; (b) less damage to flavors; (c) wide variation of operation temperatures; (d) flexibility of operation; (e) requires no source of heat, only electricity to operate compressors, and; (f) delivers all water vapor as condensate. By careful selection of refrigerants these systems may be used for any juice concentrating over any temperature range for any fruit or vegetable or sugar solution. Cross (6) states that if this system were to be compared to, say, a steam boiler multiple effect evaporator handling an equal amount of evaporation, the energy input to this system would be only a small part of energy required to produce steam in the boiler; further it would require a fifteen effect steam evaporator to acquire the same efficiency.

The fact that all water vapor drawn from the juice being processed is delivered as a condensate is important when the esters or flavor compounds must be extracted from this water and added to the concentrate. The condensate is also used when concentrating certain pharmaceuticals, and alcohol solutions or any solution that gives up important compounds in its distillate.

The one process of concentrating juices at low temperatures that does away with cut-back methods, flavor losses due to evaporation, etc., is concentration by freezing. A commercially economical system of this type is the dream of all processors. Many investigators and many companies have spent countless years and countless hundreds of thousands of dollars attempting to develop a system of this type that would be economically feasible. About the best systems to come out of all of this research are described briefly from what little information there is available.

> <u>Stahl Method (26):</u> The Stahl method (on which considerable current research is being conducted) consists of either freezing the deaerated juice to a slush and then centrifuging, or freezing to a solid cake and crushing the frozen mass in an ice crusher and then centrifuging. Several freezings and centrifugings are necessary to obtain the desired concentration.
>
> <u>Noyes Process (4):</u> The Noyes process like the Stahl method gives little indication as to the type of equipment that is used. The process is simply the freezing of the juice and then by adding carefully controlled heat uniformly, the water is removed either by draining or siphoning.

The development of a suitable freezing concentration system is important in that none of the flavor compounds are removed during the concentration process. With such a system, over-concentration, cut-back methods, ester recovery from fractional distillation, etc., would be eliminated.

Proponents of freezing concentration point out that the latent heat of freezing water is only 80 calories, while that of evaporation is 537 calories. This is true, but such efficiency is not obtained in commercial practice (23) because of the less direct use of energy in freezing caused by the development of mechanical energy.

Of the two systems discussed above, it is difficult to determine which will be fully developed on a commercial basis. Little is known about the Stahl process, other than a mention here and there in food engineering journals.

The author is more familiar with the Noyes process because of a personal visit to the Cherry Growers Co-op, Traverse City, Michigan, as well as perusal of the patents covered by this process. It is felt that eventually a commercially adaptable process will be developed and it is the author's opinion that the Co-op is close to the solution, if not already there.

Noyes' system is at present being used on a commercial basis by the Co-op at Traverse City. There, the Co-op is concentrating cherry and apple juice by freezing. This process formerly required ten days. By tedious and time consuming labor, they (the Co-op) have reduced this process for concentrating apple and cherry juice by freezing to two days.

The Co-op is not producing concentrates at full capacity; a little more data on production costs, further developments in equipment, and a hook-up with a national frozen foods firm such as Snow Crop, Minute Maid, Pasco, etc., is all that is preventing full capacity production of this juice. They (the Co-op) believe that they can operate on a commercial scale with this system and still undersell orange juice.

At this writing too much cannot be said about what is going on at Traverse City. The Co-op has spent the time and money required to develop this process and its secrets are guarded accordingly.

From the patents (28), it may be concluded that the juice is frozen into a solid mass. Carefully controlled heat is then uniformly added and the concentrate is drained off, leaving a practically pure ice crystal residue. This is one step farther than most investigators have carried the freezing process and may well be the main part of the Co-op's system.

Dr. Pauline Paul (3) and others in the Home Economics Department of Michigan State College received some interesting results from concentrating some Michigan fruit juices by freezing. The juices were slush frozen and centrifuged.

A few of the interesting results included the fact that the grape and raspberry concentrate was preferred over the original juice, and that cherry juice was too tart and that black raspberry was too flat for beverage purposes. Tomato juices turned out weak in color, texture, and flavor. .

PART II

STATEMENT OF THE PROBLEM

The definite objectives of this work were as follows:

1. To design and construct apparatus for the concentration at low temperatures of fruit and vegetable juices, such system to be different in design from any other known system. The treatment of the juice to be similar to that which it would receive on a commercial basis.
2. To develop or attempt to develop a fruit or vegetable juice or juices of high palatibility that would, if placed on the market, be received with high consumer preference.
3. To determine which of these juices would warrant further investigation as a cold beverage concentrate.

DISCUSSION OF OBJECTIVES

A discussion of the construction of the apparatus appears later in this work. It is sufficient to say here that it was important that the juices under investigation be treated in a manner similar to that which they would receive in a commercial plant. The results of the taste panels are, therefore, of direct use to those people in the juice processing industry. If the juices were to be treated in any other manner, there would be delays by commercial firms for the development of equipment to handle any special treatments. As will be seen, the juices were all processed in a manner similar to commercial packs of similar juices. The principle of concentration is nothing new in that the juice is subjected to a high vacuum, and a carefully controlled low heat input. The low heat treatment during concentration prevents any cooked flavor development, or excess loss of volatile flavor compounds in the condensate. In all cases the vapor drawn from the juice was delivered as a condensate with the thought that it could be fractionated for study as a flavor improvement when added to the concentrate.

The main opportunity confronting fruit and vegetable growers in non citrus growing areas is for an attempt to be made on the exploitation of juices from fruit and vegetables growing in their own back yards. Vegetable juices are known to contain certain essential vitamins and minerals. However, it is hard to believe that the housewife would purchase vegetable juices for her family to drink as a beverage. There would always be a small demand for a vegetable juice or a blend of vegetable juices for their health giving qualities but not as a beverage. From the standpoint of vitamins and minerals, beet root juices (23) are an almost perfect food, but the juice contains a very distasteful earthy flavor that so far has been impossible to remove.

A stock answer as to whether a person would drink carrot, pea, spinach, cabbage, turnip, etc., as a beverage is "only a vegetarian sadist would drink such stuff"; it is felt that the demand would be so slight that investigation in such juices is not warranted.

Celery juice, on the other hand, does have certain possibilities as a beverage, breakfast pickup or seasoner. Slight as it may seem, there is a definite number of people that would welcome a highly palatable, properly seasoned celery juice, preferably in the frozen concentrate form for convenience of handling and preservation of the highly volatile flavor compounds inherent in the juice. For this reason, celery juice was the only vegetable juice investigated in this work.

Tomato juice has possibilities as a cold concentrate, but, like grape juice, it is not damaged by the temperature of the hot pack. This juice separates on freezing (7) and offers a faded color and flat taste to the consumer. Concentration by freezing (3) offers approximately the same results. It is felt that exploitation of this juice as a frozen concentrate would not yield the desired results.

Apple concentrate will find a ready market as a frozen concentrate, although, a good canned single strength product has appeared recently on the market. It is felt by the author that crab apple offers immense possibilities as a booster for some of the more insipid juices inherent in certain apple varieties.

Fruit juices such as strawberry, blackberry, peach, pear, etc., were not investigated in that the inherent qualities of these juices do not lend themselves readily to desirable beverages. Juices with weak flat flavors that would not conceivably receive attention as a concentrate were not considered in this work. Other juices such as currant and raspberry were unobtainable at the time of operation.

THE JUICES INVESTIGATED

The juices investigated in this work included five varieties of apple, two varieties of plum, celery and blueberry. It was felt that of the juices unknown to the market as a concentrate, these offered the greatest possibilities.

The apple varieties included Northern Spy, Golden Delicious, Grimes Golden, Jonathan and Crab. From this work it was hoped that Crab Apple could be developed into a booster for normal cider and definitely proven to improve the flavor of juice from apples giving flat, watery, insipid juice.

Plum juice, having a natural tart acid taste, was investigated with the hope of developing it into a beverage, either by itself or in combination with other juices such as apple, blueberry, etc.

Celery juice was investigated with the thought that it could be developed into a beverage or at least a seasoner for dressings, soups, etc.

Blueberry was investigated with the thought that it might be developed into a beverage because of its immense popularity as a flavoring compound in cakes, cookies, pies, etc.

JUICE TREATMENT

Spy, Delicious, Grimes and Jonathan: These apple varieties were grated and pressed in a small 10 ton apple press. Immediately after pressing the juice, pectinol was added at a rate of 12 ounces per hundred gallons; this amounting to 3.36 grams per gallon. The juice was allowed to stand at room temperature for six hours, and then placed in a cooler at 36°F for 15 hours. At this time the clear juice was siphoned from the precipitated pectin and immediately concentrated. The juice was concentrated at 3 to 1, with 75 percent of the water removed. The juices were then stored at -20°F until ready for taste tests.

Crab Apple: The juice from this apple is known to contain high acid and an astringent taste. For this reason the apples were stored for approximately 45 days after picking. The temperature of storage was approximately 40°F. After 45 days, the texture of the Crab Apples was mealy and the acid content reduced. The Crab Apples were grated, pressed and depectinized in a manner similar to the other apple varieties. After concentration, precipitation occurred, and it was necessary to filter the juice through a filter pad with diatomaceous earth added to the juice. The juice was then stored at -20°F. This juice had a high acid flavor and had a tendency to pucker the mouth; nevertheless, it was a typical apple flavor.

Plum: Two varieties of prune plum were investigated; the processing before concentration being the same. The two plum varieties were an Italian Purple Prune Plum and a Japanese Red Plum. The plums were washed and pitted from the raw state. The halves were placed in an open steam jacketed kettle and quickly heated to 160°F. The plums were slowly stirred with as little mashing as possible. Four and one half ounces of rapid-flo filter aid (diatomaceous earth, type 1) was added to each peck of plums processed. The plums were then placed in a nylon bag and pressed at 500 p.s.i. on a horizonal hydraulic press. The resulting juice was clear, of deep color, and very astringent to the taste. Pectinol A was added at a rate of one pound per 100 gallons of juice, and allowed to set at 70°F for six hours, and for 15 hours at 36°F.

The clear juice was then siphoned off, concentrated and stored at -20°F.

Celery: Celery was washed and cut into six inch strips and steam blanched for five minutes. The celery was immediately immersed in cold water and passed through a screw impeller type of tomato juice extractor and filtered through a juice cloth. The juice was salted to .25 percent by weight (13). The color was light green and had a slight cooked, weak flavor.

Blueberry Juice: Tressler, et.al, (13) suggest the storing of blueberry juice for two months after heating to 180°F. At the time of this investigation, time did not permit the storage of the juice. Therefore, a quicker method of processing before concentration was attempted. The berries were heated to 180°F in an open steam jacketed kettle. They were then passed through a screw impeller type of tomato juice extractor. The juice was first stored at 36°F for seven days with no apparent settling. The juice was then frozen solid, thawed and again allowed to set for seven days, still with no apparent settling. The juice was again heated to 180°F and a cellulose mash was added. The juice was then hand squeezed through juice cloth. The resulting liquid was of high color and flavor yet thin enough for the concentration process; the cellulose mash absorbing most of the sludge and mucilaginous matter inherent in the juice. The soluble solids of the juice was doubled (from 14 to 28 percent) and the juice immediately became too thick for further concentration. The juice had a flat week flavor with high staining properties and had a thick undesirable texture. Storage of the juice may be the only answer in preparation for beverage purposes, as clarification removes some of the flavor.

The original solids and final solids of the juices investigated are listed as follows:

Juice	Original Solids	Final Solids
Spy Apples	11.2%	44.9%
Delicious Apples	11.1%	44.6%
Jonathan Apples	11.5%	45.8%
Grimes Apples	11.7%	46.8%
Purple Plum	15.9%	49.0%
Red Plum	10.2%	41.0%
Celery	4.1%	20.0%
Blueberry	14.0%	28.0%
Crab Apples	14.0%	42.0%

CONSTRUCTION OF APPARATUS

It was decided that a refrigeration cycle would be used as a heat source and in turn as a cooling source for delivering the vapor as a condensate. This type of system would offer high economy, easily controlled heat, flexibility for operation (any wall plug) and flexibility of construction, i.e., any temperature range, any pressures, by proper selection of refrigorant. The equipment, for experimental purposes, namely a compressor, expansion valve and copper tubing, was easily obtained. The previously mentioned factors were all considered in choosing and designing the equipment in order to hold down the cost.

The equipment for the juice cycle had to be either stainless steel or block tin tubing. A combination of both was used; stainless steel tubing in which to boil the juice and a coil of block tin tubing in which to condense the vapor. A sloping double tube effect was considered as the most economical both from cost and construction details. The sloping effect takes advantage of a natural pump, i.e., the vacuum pump pulls the juice up the tube at a much slower velocity than that of a downward slope. This fact results in less surface area (lower cost) for heat transfer and greater amount of water removed per effect or passage than a downward slope or vertical shell and tube effect. From the previous discussion, it can readily be seen that such a design would have definite commercial advantages.

A water bath was chosen as a carrier of heat between the cold boiling refrigerant and the condensing vapor. This removed the necessity and expense of using a material that would not effect the flavor of the condensate nor react unfavorably with the refrigerant. The construction of such an evaporator would also entail considerable cost and remove any flexibility of the system in that one could not be disassembled without dismantling the other. By keeping the two systems separate, separate metals (copper for the refrigerant, block tin tubing for the condensate) were used, construction details were relatively simple, and the cost comparatively low. One main advantage of such an evaporator is the large temperature differential that could be used. This large temperature differential allows for less equipment cost in that the same amount of heat may be transferred for less surface area than a system using a smaller temperature differential. This fact is highly desirable for experimental purposes. However, a commercial system would probably do away with the carrier, combine the two systems, use a smaller temperature differential and more heat transfer area and consequently more cost. The reader may ask why, and this is easily answered in that such commercial systems would obtain more efficiency with refrigeration equipment using smaller temperature differentials, which, in the long run, would counteract the extra expense involved in construction and use of greater transfer areas. By combining the two systems, a commercial system would also take advantage of a higher overall heat transfer coefficient due to the heat being transferred directly from a boiling liquid to a condensing vapor (16).

A Cenco-Hyvac vacuum pump was used. The pump uses a 115 volt one-eighth horsepower motor, V-Belt driven. The pump was protected against excess moisture by the subcooling of the condensate. This pump lowered the boiling point of water to 85°F during operation of refrigeration system. With the heat source shut off, the boiling point was lowered to 60°F. This phenomenon may be explained thus: The amount of water vapor coming out of the tube is such that at any given time the boiling point will not fall below 85°F, the water vapor is so thick that such lowering is impossible. When the heat is shut off and vapor ceases to pour out of the evaporator tube, the pump draws off the vapor immediately above the juice, thereby lowering the boiling point of that solution. The system is leakproof for all practical purposes, in that a vacuum of 27" of mercury is maintained 24 hours after the drawing of the vacuum. For this project this meant that the boiling point of the original juice was lowered to 90°F. As the juice became concentrated, the boiling point would rise,

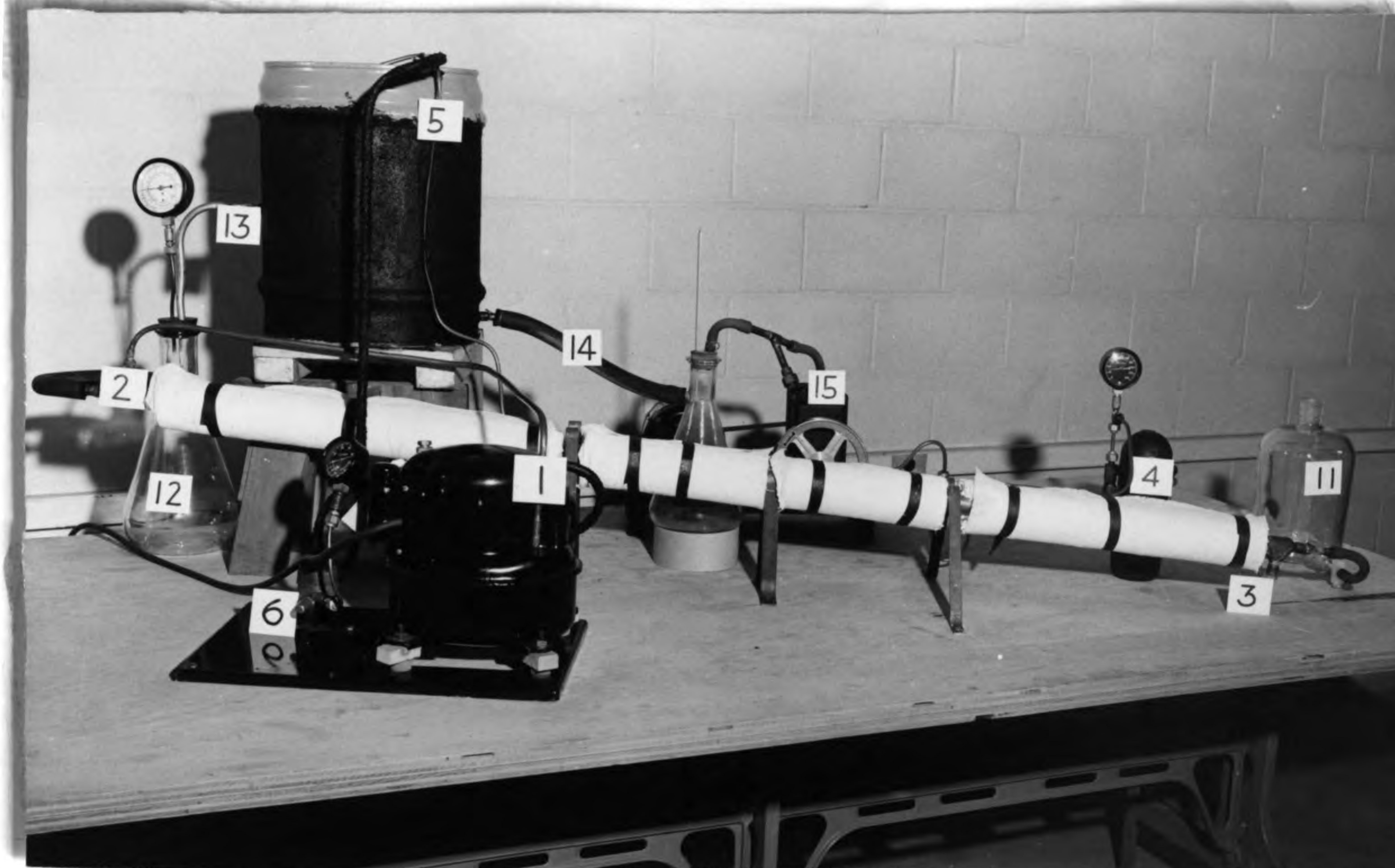


FIGURE 1

VIEW 1 OF APPARATUS USED IN LOW
TEMPERATURE CONCENTRATION WORK

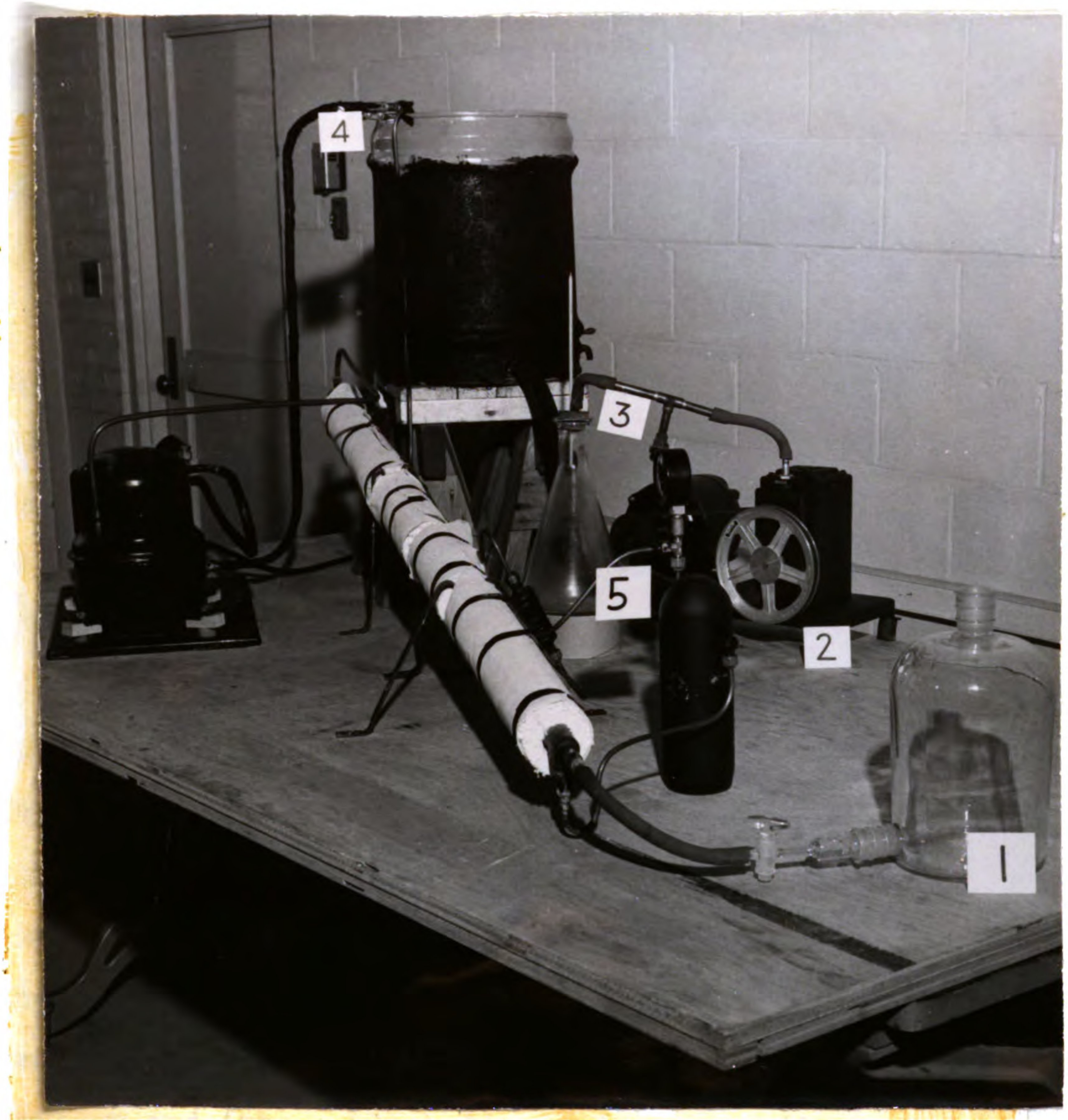


FIGURE 2

VIEW 2 OF APPARATUS USED IN LOW TEMPERATURE CONCENTRATION WORK (due to the increase in solids), although the vapor pressure above the juice would remain the same. For example, a juice containing 11 percent sugar would boil at approximately 90°F on its first pass through the system. On the last pass through the system and a final concentrate of 44 percent sugar, the boiling point would rise to 105°F. This amount of vacuum and correspondingly low boiling temperature was deemed low enough to prevent any development of a cooked flavor in the juices being investigated.

HOW THE SYSTEM WORKS

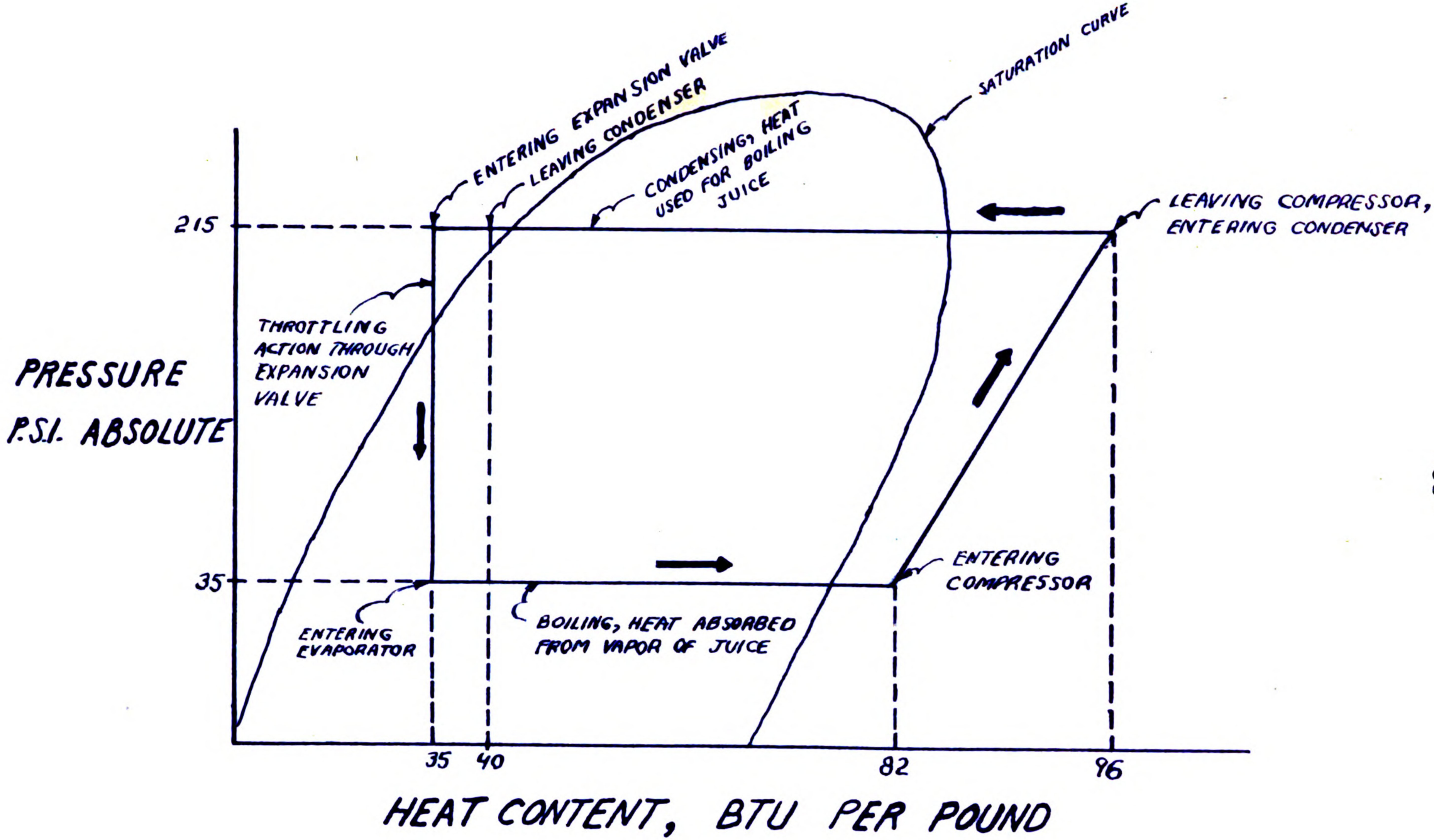
Juice Cycle: The original juice (point 1, fig. 2) (point 11, fig. 1) enters a long sloping tube (point 3, fig. 1) and picks up heat from condensing refrigerant gas. The boiling juice (under high vacuum) flows out of the tube (point 2, fig. 1) and spills over into a four liter suction flask (point 12, fig. 1). The vapor that has been driven off the juice is drawn through the rubber stopper and into a block tin condensing coil which is immersed in a cold water bath (point 13, fig. 1). The vapor condenses in this coil and flows out of the coil and into another suction flask (point 14, fig. 1). The vacuum is drawn off the top of this section flask (point 3, fig. 2) by the vacuum pump (point 15, fig. 1). The condensing vapor gives up its heat to the cold water bath which in turn gives up its heat to the cold boiling refrigerant.

Refrigeration Cycle: Hot high temperature freon gas leaves the compressor (point 1, fig. 1) and enters the double evaporator tube (point 2, fig. 1). This hot gas then condenses as it gives up its heat to the boiling juice within the tube. The hot high temperature liquid leaves the evaporator tube (point 3, fig. 1) and enters the liquid receiver (point 4, fig. 1). The hot liquid then passes through a small silica gel drier (point 5, fig. 2) and enters a thermostatic expansion valve (point 5, fig. 1) where it is throttled into a cold low pressure liquid before entering a copper coil immersed in the cold water bath, which serves as an evaporator for the refrigerant. The cold, low pressure boiling refrigerant picks up heat from the cold water (which is the same heat picked up from the condensing juice vapor). The cold, low pressure gas is then drawn off from the boiling refrigerant (point 4, fig. 2) and compressed into a hot high pressure gas. This completes the cycle.

The reader may follow the same cycles on the colored schematic view (fig. 3, page 34). This sketch should clearly illustrate some of the mechanics of the system, i.e., the juice flowing up the long sloping tube, picking up heat from the condensing gas. Also the form which the coils take for the condensing vapor and the boiling refrigerant has been drawn to approximate their shape and position in the water bath. The color scheme is illustrated by the key in the upper right hand corner of the sketch and the cycles are easily followed:

PERFORMANCE OF THE SYSTEM

Operating conditions for each juice is approximately the same. The only variance occurs when the temperature of the incoming juice ranges considerably below its boiling point. The initial temperature of the cold water bath for each operation was the same, giving the same average low pressure on the low side of the refrigeration system. The average pressure of the high side is governed by the boiling temperature and quantity of juice flowing up the evaporator tube. The boiling temperature of the juice is governed by the amount of vacuum drawn (constant) and total soluble solids content of the juices being concentrated (variable). For all practical purposes the boiling temperature of the juices in question may be considered the same as they varied only a few degrees. From the PH chart (page 33) it may be noticed that the amount of heat available for boiling the juice is more than the heat picked up in the low side. This fact sets up an inequality which would make this system unfeasible for long periods of operation without a supplementary condenser on the high

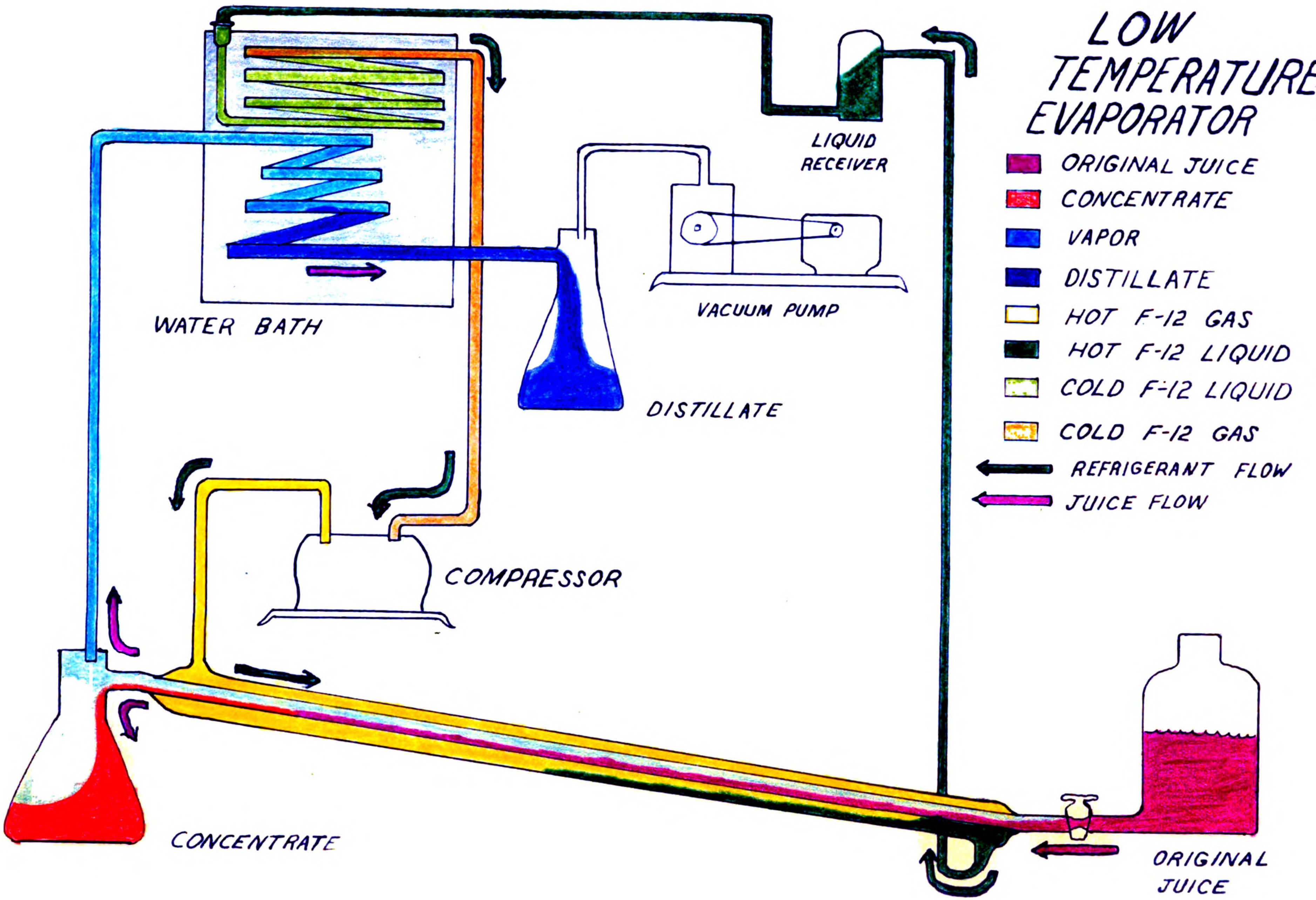


HEAT AVAILABLE FOR BOILING JUICE = 96 - 40 = 56 BTU'S/LB.

REFRIGERATION EFFECT = 82 - 35 = 47 BTU'S/LB.

COMPRESSOR WORK = 96 - 82 = 14 BTU'S/LB.

PH CHART - FREON 12


LOW
TEMPERATURE
EVAPORATOR
ORIGINAL JUICE
CONCENTRATE
VAPOR
DISTILLATE
HOT F-12 GAS
HOT F-12 LIQUID
COLD F-12 LIQUID
COLD F-12 GAS
REFRIGERANT FLOW
JUICE FLOW
LIQUID RECEIVER
VACUUM PUMP
WATER BATH
DISTILLATE
COMPRESSOR
CONCENTRATE
ORIGINAL JUICE

side. The difference would approach equality with smaller temperature and pressure differentials. For experimental purposes and short periods of operation (4 hours) this inequality does not interfere with the operation. The heat difference shows up in the water bath as it receives more heat from the condensing vapor than that which is picked up by the refrigerant, consequently, there is a slow rise in the temperature of the water bath. For short periods of operation this is considered negligible. The rise in temperature of the water bath means that the temperature of the subcooled water vapor is higher. In the calculation of heat transfer area (see Appendix, page 4) extra tube length provides for the heat inequality in that the distillate is subcooled 40 degrees. For four hours of operation the subcooling is reduced to 35 degrees which is still appreciably lower than the boiling point of the distillate and which still protects the vacuum pump from drawing excess water vapor.

The unit volume of juice concentrated in all cases was one gallon. To concentrate to 3 to 1 means that 75 percent of the total volume in the form of water must be removed. Three fourths of one gallon is three quarts or six pints which is six pounds. The rate of removal of water from the juice is one twentieth of a pound per minute or three pounds per hour. To concentrate one gallon to 3 to 1, theoretically, requires two hours of actual operating time. Total time of operation averaged two hours and forty minutes because of the time required to transfer the partially concentrated juice to the original flask for another pass through the system and because of the inefficiencies of the system. Total passes through the system for a concentrate of 3 to 1 averaged four, which compares with a quadruple effect continuous evaporator.

Following is a data log on operating temperatures, pressures, kilowatts used, pounds of vapor drawn off, etc. Thermometers were placed in the stream of partially concentrated juice flowing out of the evaporator tube and in the stream of distillate flowing out of the block tin tubing. The vacuum drawn is read from tables corresponding to the boiling point of the juice; far more accurate than reading the type of gage used. A low pressure gage is placed in the refrigeration cycle immediately before the low side gas enters the compressor and a high pressure gage at the liquid receiver. Temperatures of the refrigerant at these various spots in the system come from a PH chart or refrigerant tables. The kilowatts and pounds of vapor were measured directly with a watt meter and liquid measure respectively.

PERFORMANCE DATA

REFRIGERATION CYCLE:

1. Condensing Pressure: Average condensing pressure and temperature of freon gas = 215 psi abs. and 137°F.

2. Evaporator Pressure: Average pressure and temperature of boiling freon = 35 psi abs. and 18°F.

JUICE CYCLE:

1. Average initial temperature of incoming juice = 60°F.

2. Vacuum and boiling temperature of juice = .7392 inches of mercury and 95°F. (It must be remembered that the vacuum is constant but that the boiling temperature of the juice rises as it becomes concentrated; 95°F is the average boiling temperature.)

OPERATION PERFORMANCE:

1. Average pounds of vapor drawn off of juice per hour = .8 pounds.

2. Average kilowatt hours used per hour = .228.

3. Pounds of water removed per kilowatt hour = $\frac{.8}{.228}$ = 3.5 lb.

4. Cost per pound of water removed (at 3¢ per kilowatt hour) = $\frac{3}{3.5}$ = .86¢.

5. Evaporator area for juice = 1.075 sq. ft.

6. Square feet of surface per lb. vapor per hour = $\frac{1.075}{.8}$ = 1.34.

7. Evaporator performance (1 kilowatt = 3413 BTU)

$$\text{Performance} = \frac{\text{BTU Output}}{\text{BTU Input}} = \frac{.8 \times 1103}{.228 \times 3413} = 1.137.$$

RESULTS

The juices were stored in one half pint containers at -20°F until such time as they were ready for taste tests. The length of storage varied from two and one half months for the plum juice to three weeks for Spy and Jonathan apple juice. The minimum for any juice was three weeks with an average of seven weeks, which was considered sufficient for any off flavor development due to storage. Celery juice was the only juice to develop off flavors. The off flavor development may have been due to improper blanching, i.e., enough enzymes were active at the time of storage to cause flavor deterioation in storage. Proper blanching may prevent such off flavors.

There were some comments with regard to the celery in that it was suggested that California varieties would have produced a better juice. Remarks regarding the flavor of the reconstituted juice was "bitter", "salty", "metallic" and "completely unacceptable".

The general plan of attack was to conduct preliminary taste tests in order to determine which of the juices investigated would be preferred or which blends would give promise of being developed into a highly palatable beverage. From the preliminary results, two beverages were made up from the concentrates and single strength juices, their composition depending on earlier individual scores.

In accordance with the suggestion of Baten (1), crackers and water were provided for removing the effects of each sample before going on to the next sample. It must be remembered that a large part of the people available for scoring the samples were unfamiliar with the proper technique involved and that these people may have had a tendency to give a high score. For this reason, a majority of the testing was turned over to Dr. Pauline Paul of the Department of Home Economics. A highly critical score was virtually assured, as well as having trained personnel make the tests. Because of the large number of samples tested, the score sheet (see page 40) was made as elementary as practical. Concurrent with the testing in the Home Economics Department, the author conducted taste tests at the Department of Agricultural Engineering, using the same score sheets and samples with the same basic ingredients. The results are combined in this work.

The tests were set up in groups with no one person tasting more than nine samples on any given day. The groups, composition, preferences and typical remarks follow:

<u>Group 1</u>: Delicious, Jonathan, Crab, Grimes apple juice and purple plum were set up with three samples to each variety. Samples A, B, and C of each variety were straight reconstituted juice, original juice, and reconstituted juice plus 10 percent original

______________________________ Age ______________________________

Date ______________________________

(1) Rank samples in order of preference:

1. ____________

2. ____________

3. ____________

4. ____________

5. ____________

6. ____________

(2) Comments, especially on flavor:

(3) Which ones, if any, would you be willing to purchase for home use?

SAMPLE SCORE SHEET USED IN PRELIMINARY TESTING

1. Which do you prefer?

A.

B.

2. Which one, if any, would you care to drink as a beverage?

3. Which, if any, do you prefer over regular apple juice?

SAMPLE SCORE SHEET USED IN FINAL TEST

juice respectively. For the remainder of this work, the reconstituted plus 10 percent of the original juice will be known as the cutback method or cutback juice.

1. Jonathan and Grimes received high acceptability ratings for both the original juice and the cut-back juice. Typical comments included "typical apple flavor", "good taste", "lacks aroma but has good taste". In both cases the straight reconstituted rated last but received an acceptable flavor score. Typical comments were "slightly flat, lacks aroma", "would be very good were it not for the fact that the others were present for comparison".

2. The straight reconstituted crab and purple plum were preferred over the original juice and the cut-back juice. However, the plum was unacceptable as a beverage in that it was highly acid and astringent to the taste. Typical comments included "too tart", "too much twang", "too sour". The Crab Apple also received a high acceptability score in the original juice form.

3. Delicious apple juice gave a poor, weak tasting juice. The cut-back juice was preferred. Typical comments were: "too watery", "weak", "high aroma but flat taste".

Group 2: Three samples were set up with various apple blends. Sample A contained 20 percent Crab, Spy, Delicious, Jonathan, and Grimes. Sample B contained 50 percent Spy and 50 percent Delicious. Sample C contained 40 percent Spy, 40 percent Delicious and 20 percent Crab. Straight reconstituted juice was used throughout, lowering any flavor score.

Sample A: This sample received the highest preference score, but not as high overall score as compared to some of the other juices. Typical comments included "too much acid", "rather flat", "lacking aroma", "undesirable residual taste".

Sample C: This sample ranked second to sample A. Typical comments included "slightly acid", "lacks aroma but has a sharp taste", "rather flat in apple flavor", "needs something".

Sample B: This sample ranked very close to Sample C. The presence of Crab Apple in the other two was preferred. Typical comments were: "weak", "flat", and "some aroma".

Group 3: This group consisted of plum, apple blends made up from scores received previously on the individual varieties. All of the juices in these blends were made up from the concentrates. Sample A contained 40 percent each of Delicious and Grimes and 20 percent purple plum. Sample B contained 40 percent each of Spy, and Jonathan and 20 percent purple plum. Sample C contained 75 percent Spy and 15 percent each of plum and Crab Apple.

Sample B: This sample rated very high as compared to the other two. Out of twenty tests it received 12 firsts, 8 seconds and 0 lasts. Typical comments were: "could be stronger", "rather tart", "least sharp", "distinctly superior", "desirable plum flavor", "snappy apple and plum distinct".

Sample A: This sample rated second. It received 6 firsts, 8 seconds and 6 thirds out of twenty scores. Typical comments were: "distinct plum flavor", "a little sharp", "a most pleasing residual flavor", "most mellow".

Sample C: This sample rated last out of the three. Out of twenty tests it received 4 firsts, 4 seconds, and 14 thirds. Typical comments were: "too much whang", "much too sharp", "too much acid, not enough flavor", "watery flavor, but leaves tart residual taste".

Group 4: Each of the five apple varieties were blended with purple plum at a ratio of five apple and one plum.

Only one blend was outstanding and this was the Grimes-Plum blend. The score on this blend was the highest of all the juices tested, and indications are that this juice definitely warrants further investigation for beverage purposes, preferably in the frozen concentrate form for a year around beverage.

Group 5: Celery juice was tested in the three standard forms, that is, single strength, cutback and reconstituted. All were characterized as strong, bitter, salty and completely unacceptable. A small minority of the testers suggested that the juice may have possibilities as a seasoner in soups, dressings or in combination with tomato or other vegetable juices. Others suggested that varieties from California or other sections of the country may prove satisfactory for beverage or seasoning purposes.

Group 6: This group consisted of sweetened plum and blueberry concentrates, tested for possibilities as an ice cream sauce. The concentrates were made up as follows:

- #1 - 50 ml. purple plum concentrate plus 50 ml. sirup A.
- #2 - 50 ml. purple plum concentrate plus 50 ml. sirup B.
- #3 - 50 ml. red plum concentrate plus 50 ml. sirup B.
- #4 - 50 ml. single strength purple plum plus 50 ml. sirup B.

#5 - 100 ml. blueberry concentrate, 50 ml. sirup B, 5 ml. purple plum concentrate.

Sirup A - 1 cup sugar, 1 cup water
Sirup B - 3 cups sugar, 1 cup water

The testers preferred #4 and #5. The plum concentrates were all too tart. The blueberry concentrates were criticized by some as being rather flat. Perhaps a larger amount of plum concentrates or a higher concentrate of blueberry would improve it.

Group 7: This group consisted of two samples. They were made up primarily from those individual varieties receiving high scores and from those juices left in stock. The scores are considered to be as good a cross section of individual palates as practical. There was a total of three and one half pints of each sample. Total testers numbered fifty. They were staff members and graduate students from the Department of Agricultural Engineering, staff members and students from the Department of Home Economics, and staff members from the Department of Horticulture. This was the final attempt to further develop a highly palatable beverage of known composition and juice treatment. The results speak for themselves.

The two samples were labeled A and B (see sample score sheet, page 41). The composition of Sample A was 35 percent Grimes, 26.4 percent Spy, 24.1 percent Delicious, 9.3 percent Crab and 5.2 percent Jonathan. These percentages are of the total solids in the final sample represented by each variety. Of these percentages all of the Jonathan and 5 percent of Grimes were original juice, thus making each sample similar to a commercial cut-back juice. Sample B contained 32.3 percent Grimes, 24.7 percent Spy, 22.5 percent Delicious, 8.9 percent purple plum, 6.8 percent sugar sirup (testing 64 percent sugar), and 4.8 percent Jonathan. The total soluble solids of these samples tested was 12.8 percent. The PH of each was 3.54 giving an indication of rather high acid. Every attempt was made to make the samples alike with the exception of Crab Apple in one and plum in the other.

Examples of score sheets used in testing these juices are attached on pages 40 and 41. The questions on the preliminary score sheet were asked in an attempt to get the tester to think critically before scoring and to receive the comments and evaluations. The questions on the final sheet were for straight evaluation purposes. The information should be of interest to those in the juice processing industry.

The results of the testing are tabulated as follows:

1. Which do you prefer?
   A - 37
   B - 10
   No choice - 3

2. Which would you drink as a beverage?
   A - 22
   B - 6
   Neither - 2

3. Which do you prefer over regular apple juice?
A - 18
B - 6
Both - 9
Same preference - 8
Neither - 6

DISCUSSION OF RESULTS

In attempting to evaluate the results of the taste tests, it must be remembered that one type of reconstituted juice wasn't tried, i.e., a reconstituted juice with its recovered esters added. Every attempt was made to have the esters fractioned from the distillates. One possibility existed and that was to use the ester recovery apparatus owned by the Department of Horticulture at Michigan State College. However, due to circumstances beyond anyone's control, the successful erection and operation of the apparatus was not completed at the time of the taste testing. Therefore, this type of juice, i.e., one with the esters added back, was not scored with the others. The practice of adding back esters from apple distillate is being practiced commercially with candy, pastry manufacturers, makers of jams and jellies, etc.

The adding back of esters should generally raise the score of the juice under investigation. The scores of the juices in this work are, therefore, slightly lower than if the juices contained the esters. The various blends receiving high acceptability ratings would, therefore, receive a higher score yet if the ester impregnation system were used.

The volume of each variety of juice was not great, one gallon being the average. From the number of varieties, it can be seen that the possible combinations of blends, in addition to the testing of each individual variety, makes a large total number of samples. Thorough discussions with men in the field of juice beverages helped to narrow the total number of samples tested, thereby allowing a greater number to take each test. Because of the limited facilities, limited number of trained testers, small volume of samples and the large number of samples, the results of those tests must necessarily be limited to determining which juices warrant further investigation for beverage purposes.

In the preliminary taste tests it may be noted that the reconstituted juice received low scores all along the line. It is a well established fact that any beverage that contains volatile flavor and aroma compounds immediately loses these components of flavor with the vapor drawn off, the heaviest concentration being in the first 10-25 percent of the vapor. The resulting juice is always flat to the taste. The only juices that are actually preferred as a concentrate are those with high original acid and tartness. This was proven when both the Crab Apple and the Plum were favored in the reconstituted form and again in

Dr. Paul's (3) work. Comments all the way through the testing included "flatness", and "lacking aroma" whenever the straight concentrates were used. Those comments were missing in some of the cut-back juices and the original juices. This work clearly indicates that the cut-back method is successful with most of the apple and plum juice beverages.

Delicious apple juice should be used at a minimum with apple blends and plum-apple blends. This juice gives a desirable aroma and may be used in limited quantities (preferably not more than 10 percent) for that purpose. In larger quantities this juice leaves an undesirable residual taste in the mouth and adds practically nothing to the desirability of the body of the juice.

Grimes, Jonathan, Spy and Delicious are varieties normally used in making cider, depending on what is left over from the market, number of packing house culls, seconds, etc. There is no standard formula for making cider. It varies from year to year, depending on surpluses, culls, etc. Crab Apple is entirely new to the cider industry in this country. In Europe there are special varieties of this apple grown for cider purposes only. The results from this work indicate that this apple has definite possibilities for adding high flavor and aroma to apple blends either as a straight run juice or as a concentrate. Difficulty may be encountered as the juice precipitates upon concentration regardless of depectinizing treatment. Continued filtration or siphoning is required after concentration with this juice.

The two final beverages both show high promise of being adaptable for beverage purposes. The scores were much higher and the beverages were much more warmly received than those in the preliminary testing. This would, in part, be due to the fact that the final beverages contained at least 10 percent by solids of original juice, whereas the juice blends in the preliminary testing were made from straight run concentrates. Also, the final two beverages were made up from combinations and blends receiving high scores in the preliminary testing, which was the purpose of such preliminary tests. A large majority preferred Sample A over Sample B. It is felt that this is due, in part, to the confusion resulting from Question 3 on the score sheet. This question asked, "which if any, do you prefer over regular apple juice". Sample B had a definite plum flavor and may have been down-graded accordingly because of the lack of natural apple flavor. The fact, however, that such a large percentage (95 percent) deemed that they would at least drink one or the other as a beverage was gratifying. Eighty-five percent liked the beverage just as well as or better than regular apple juice. This clearly indicates that either of these beverages would be successful if placed on the consumer market as a concentrate, using the cut-back method. It must be remembered that these scores were given to juices two months old and with only 10 percent of the original juice present to give aroma and flavor.

Because of the large number of culls and seconds, in the Delicious variety of apples, a good method of making a palatable beverage using this juice would be highly received by the industry. Samples using Crab Apple in varying amounts with the Delicious are preferred over the same samples without the Crab Apple.

Fresh plum juice contains acid in amounts of 1.8 percent to 2.5 percent expressed as malic. This amount of acid makes the juice unacceptable as a straight juice, although the flavor and color of the juice lends itself favorably to beverage purposes. For this reason plum was blended with apple juice and the results indicate that a blend of Grimes and plum offers an excellent chance of becoming a beverage with high consumer preference. This beverage, along with several other blends, definitely warrants further investigation by juice processors.

It is regrettable that time did not permit the further concentration of blueberry juice. Storage of the juice for two to three months is probably the one successful method of removing the sludge and mucilaginous material inherent in the juice. The juice was concentrated from 14 percent to 28 percent solids when thickening occurred. Nevertheless, this concentrate when mixed with plum shows possibilities as an acceptable ice cream sauce. However, the cost of this juice will probably prohibit its successful exploitation as a beverage or ice cream sauce.

CONCLUSIONS

1. Jonathan, Spy and Grimes apple juice give an acceptable concentrate using the cut-back method.
2. Crab Apple juice is unstable in that the juice must be filtered or siphoned off after concentration.
3. Straight purple or red plum juices (prune variety) are unacceptable as beverages.
4. Cut-back apple juice of the Spy, Grimes, Jonathan and Delicious varieties gives acceptable concentrates for blending purposes.
5. Concentration removes practically all of the aroma commonly associated with apple juice.
6. Concentration improves the flavor of Crab Apple and purple plum for blending purposes.
7. The presence of Crab Apple in proportions of 10 to 20 percent improves the flavor of normal apple juice blends.
8. The following blends, on the basis of scores received in the taste tests of this work, definitely warrant further investigation for beverage purposes:

    1. 84% Grimes apple juice
       16% Purple Plum

2. 20% Crab Apple
   20% Grimes
   20% Jonathan
   20% Spy
   20% Delicious

3. 40% Spy
   40% Jonathan
   20% Purple Plum (sweetened to taste)

4. 35% Grimes
   26.4% Spy
   24.1% Delicious
   9.3% Crab Apple
   5.2% Jonathan

5. 32.3% Grimes
   24.7% Spy
   22.5% Delicious
   8.9% Purple Plum
   6.8% Sugar (testing 64%)
   4.8% Jonathan

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APPENDIX

DETERMINATION OF EQUIPMENT SIZE

Keeping in mind that low cost and simple construction was desirable, a system of small (as practical) capacity was selected. A compressor of approximately one-half horsepower figured to be satisfactory. The amount of water boiled off per hour is governed by the size of the compressor or heat input in the form of electrical power. This type of system could easily have ten times the capacity, but the cost and size would be approximately as large.

MOTOR HORSEPOWER OF COMPRESSOR

The size of the motor to operate the compressor was calculated in the following manner (29):

1. Desired to remove 1/20 of a pound of water per minute.

2. At 95°F, water requires (at a vacuum of 28.26" of Hg.) 1040.1 BTU's to change into steam. Total load therefore is:

   $$\frac{1040.1}{20} \times 60 = 3306 \text{ BTU's/hour or } 55.1 \text{ BTU's/minute.}$$

3. Condenser heat available per pound of refrigerant from the PH chart = 56 BTU's/lb.

   $$\text{pounds to circulate/min.} - \frac{56}{55.1} = .985 \text{ lb/min.}$$

4. Compressor work from PH chart = 14 BTU's/lb.
   Total Compressor Work = .985 x 14 = 13.8 BTU's/min.

5. Theoretical Indicated Horsepower = $\frac{13.8}{42.42} = .329$

6. Motor horsepower using a drive efficiency of 98 percent, a compression efficiency of 80 percent and a mechanical efficiency of 82 percent =

$$M.H.P. = \frac{T.I.H.P.}{M.E.xD.E.xC.E.} = \frac{.329}{.98x.80x.82} = .5125$$

One-half horsepower motor was used.

CALCULATION OF HEAT TRANSFER AREAS

1. The condensing surface for the high side of the refrigeration system consists of one-half inch welded, type 304, 18 gage stainless steel tubing. The juice flows up this tube and accepts heat as the hot refrigerant gas condenses. The length of tubing required may be calculated as follows:

$Q = UA(T_1-T_2)K$

Q = Overall transfer of heat which equals 3306 BTU's (see item 2, page 1 of appendix).

U = Overall heat transfer coefficient equals 110 for a condensing vapor and boiling liquid.

A = Total area required to transmit total heat for the given conditions = 3.1418xDL. Outside diameter of pipe equals .65 inches or .65/12 feet.

T_1 = Temperature of the condensing gas equals 137°F.

T_2 = Temperature of the boiling juice equals 95°F.

K = Fullness factor of pipe, estimated at 2/3 full.

$$L = \frac{3306 \times 12}{(137-95)(110)(3.1418)(.65)(2/3)} = 6.31 \text{ feet}$$

overall length used was 7 feet

2. The surface for the evaporator of the refrigeration system consists of one half inch copper tubing. After the proper length was calculated, the tubing was wound into a coil and placed in the upper part of the water bath assuring good natural convection currents since cold water will sink and warm water will rise (the condensing water vapor coil was placed in the bottom of the water bath). The length of tubing for the refrigeration evaporator surface was calculated as follows:

$Q = UA(T_1 - T_2)$

Q = Overall transfer of heat which equals 2820 (see PH chart, page 33).

U = Overall heat transfer coefficient which equals 40 for a boiling liquid to a liquid with non-agitation (16).

A = Total area required to transmit the total heat for the conditions given which equals 3.1418xDxL. Outside diameter of pipe equals one half inch or 1/24 of foot.

T_1 = Temperature of the water bath which equals $43^{o}F$.

T_2 = Temperature of the boiling refrigerant which equals $18^{o}F$.

$$Q = U \times 3.1418 \times D \times L(T_1 - T_2)$$

$$L = \frac{2820 \times 24}{40 \times 3.1418 \times 1 \times 25}$$ = 21.5 feet, overall length used was 22 feet.

3. The surface area required for the water vapor to condense consisted of one half inch block tin tubing. The tubing (after length required was calculated) was formed into a pyramidal shaped coil and was allowed to rest in the lower part of the water bath (see schematic drawing, page 34), thus assuring maximum natural convection currents. The heat is given up to the water bath by the vapor condensing in this tubing. The water is warmed and rises to the cold re-

frigerant coil above it which accepts this heat, the water simply being the carrier of the heat from the condensing water vapor to the boiling refrigerant. The length of tubing required is calculated in the following manner:

$Q = UA(T_1 - T_2)$

Q = Overall hourly transfer of heat which equals 3306.1 (see item 2, page 1 of appendix).

U = Overall heat transfer coefficient which equals 100 for a condensing vapor to a liquid with no agitation other than natural convection currents.

A = Total area required to transmit total heat for the given conditions which equals 3.1418xDxL. Outside diameter of tubing equals 1/24 of a foot.

T_1 = Temperature of condensing vapor which equals its boiling temperature of 95°F, however, 75° was used in the calculation because it was desired to subcool the condensate.

T_2 = Temperature of the water bath which equals 43°F.

$$Q = Ux3.1318xDxLx(75-43)$$

$$L = \frac{3306 \times 24}{100x1x3.1418x32} = 7.9 \text{ feet}$$

The total length used was 10 feet of effective length to assure protection for the vacuum pump. The subcooling maintained a minimum amount of vapor going into the pump. Total subcooling amounted to 45° as the condensate was delivered at 50°F.

4. The area used to boil the juice is the same area used as a condensing surface for the hot refrigerant gas. To assure a proper amount of heat trans-

fer, the juice need only be throttled such that the pressure of hot refirgerant gas remains constant. This means that the same amount of refrigerant is being condensed that is being compressed, which assures previously calculated heat transfer (see PH chart, page 33). By forcing the juice to flow up hill at a correspondingly slower velocity than that of a downhill slope, less area would be required to transfer the same amount of heat to a given quantity of juice. This means that for a given surface area, the same amount of water will be driven off a smaller quantity of juice which will deliver a higher concentrate. The amount of water driven off the juice remains constant as this is governed by the size of compressor used, the amount of juice accepting the heat from the hot gas is governed by its velocity over the given area, boiling temperature, etc; all other factors being constant, the velocity of the juice is the main factor governing the amount of heat it will accept for a given surface area.